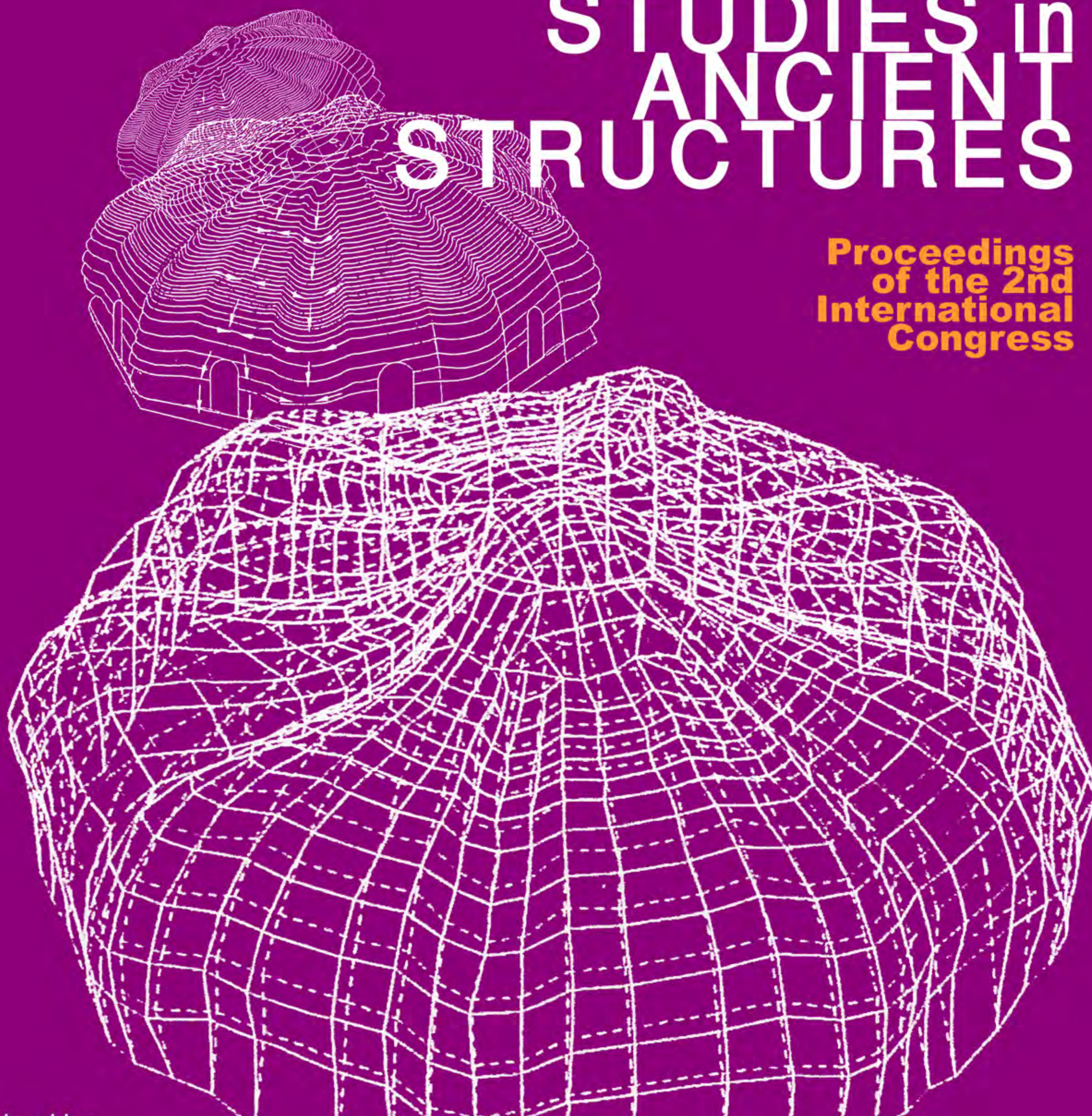
STUDIES in ANCIENT STRUCTURES

Proceedings of the 2nd International Congress



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July 9-13, 2001
Istanbul-Turkey

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Dr. Nadide SEÇKİN

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80750, Yıldız, İstanbul, Turkey
Tel : + 90 212 259 70 70
Fax : +90 212 261 05 49

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PREFACE

Ancient Structures referring to the historical buildings are the structures that symbolize the cultural identity and continuity of a land with its architectural, aesthetic, social, political, spiritual and symbolic values. Its age, technological significance with its design, materials and workmanship, association with a prominent designer, being the oldest example of a type or location in a historical setting and representing a period are all notable features to call a structure to be historical. Conservation of historical constructions requires a harmonious work of multidisciplinary team of specialists dealing with history, architecture and different fields of engineering.

The 2nd International Congress on “Studies in Ancient Structures-SAS2001” organized by the Faculty of Architecture of Yıldız Technical University, İstanbul, with the support of ICOMOS-Turkey is held in İstanbul on July 9-13, 2001. İstanbul, the only city in the world built on two continents and served as capital of three empires namely East Roman, Byzantine and Ottoman Empire is one of the most suitable places to communicate the rapid advances made in theoretical approaches, applied aspects and new materials and technologies for studies in preservation of the historical heritage. The Congress aimed at providing an international and interdisciplinary forum for discussion of the studies on ancient structures and to give researchers and practitioners an opportunity to exchange experiences and knowledge on preservation of the historical heritage.

These Proceedings containing papers sent by the specialists of different fields to the SAS2001 Congress is grouped according to their content, rather than according to their presentation, inorder to make it more useful as a reference text. Volume 1 contains Chapters on: Historical and Architectural Aspects of Ancient Structures and Historical Sites; Documentation of Ancient Structures Historical Environment; and Structural Concepts and Analysis of Historical Structures and Sites; Volume II contains Chapters on Experimental Methods and Test Results in Building Materials of Ancient Structures and Historical Sites; Restoration and Preservation Techniques in Ancient Structures and Historical Sites; and Environmental Aspects and Future of Historical Structures and Sites. The author index at the end of each Volume covers all papers in both Volumes.

Each of the papers included in these Proceedings was selected from a much larger group of submittals. Selection was made by the members of the Scientific Committee listed in both Volumes. Deep gratitudes to them for their effort during this hard work. Also many thanks to Prof. T.P.Tassios, Prof. M.Kawaguchi, Prof. S.Kelly, Prof. D.Kuban, Prof. S.Akman and Prof. Z.Ahunbay for their significant contribution as keynote speakers to the success of the Congress. Some of these speaches are also included in the Proceedings.

The Congress is supported by many organizations. Gratefull thanks to our University and Faculty authorities, to UNESCO Cultural Division, TUBİTAK- The Scientific Technical Research Council of Turkey, and other Institutions for sponsoring the Congress. Special thanks to Mr. Ersu Pekin and Mr. Çağatay Bilsel for preparing the illustrations on the covers of the two Volumes and CD, and Arch. Dilek Ekşi, Arch. B.Selcan Yalçın and Eng. Sevcan Yurtsever for their help in preparing the Proceedings and Arch.Olcay Çetiner for preparing the Proceedings on CD. Many thanks to Eng.Timurhan Timur and Eng.S.Emre Pusat of the Organizing Committee for their high performance in every step of the organization. Finally warm thanks to all the authors who undertook the effort of preparing their contribution. It is hoped that these contributions may be useful for professionals engaged in the problems of preservation and for those who have interest in the Studies on Ancient Structures.

Dr. Görün Arun
Chairman of the
Organizing Committee
June, 2001

CONTENTS

CHAPTER I Historical and Architectural Aspects of Ancient Structures and Historical Sites

CHAPTER III Structural Concepts and Analysis in Historical Structures and Sites

CHAPTER IV Experimental Methods and Test Results in Building Materials of Ancient Structures and Historical Sites

CHAPTER V Restoration and Preservation Techniques in Ancient Structures and Historical Sites

AUTHOR INDEX

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CHAPTER IV

EXPERIMENTAL METHODS
and
TEST RESULTS in BUILDING MATERIALS
of
ANCIENT STRUCTURES
and
HISTORICAL SITES

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
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EXPERIMENTAL RESEARCHES AND METHODS CARRIED OUT ON ANCIENT STRUCTURES

M. Süheyl Akman
Istanbul Technical University, Istanbul, Turkey

ABSTRACT

A great deal of experimental tests is continuously being applied on ancient structures for preservation and rehabilitation. These studies have been realized or conducted by scientists of different disciplines such as archeologists, structural engineers, architects, material scientists, geologists and microbiologists. In this paper, these tests and researches have been classified and briefly reviewed according to their technological and scientific areas.

1. INTRODUCTION

Since the beginning of the nineteenth century, interest towards ancient edifices and the desire to restore them have inclined the mankind to sustain large experimental studies. This delightful task naturally creates new research areas to architects, structural engineers and material scientists.

These experimental researches can be classified according to their actual states. Protohistoric or prehistoric buildings or settlements discovered during archeological excavation need careful geodetic, photogrammetric and geotechnical studies besides visual inspection. Construction materials and their production techniques used in those times are experimentally investigated by material scientists.

The buildings constructed in relatively recent past and which are still in use have rehabilitation and restoration problems. For structural engineers, this problem is to determine the carrying capacity by experimental methods and to strengthen the building without impairing its authenticity by using modern structural elements. In this field, the first approach is to use non-destructive tests on materials and then apply static or dynamic loading tests on the building. Another common problem encountered on these edifices is the deterioration of the materials due to atmospheric or other physico-chemical impacts. The researches consist of finding the essential cause of the damage and producing new replacement materials that are durable and also suitable to replace the old ones. Many chemical, mineralogical, bacteriological analyses and physical, mechanical, chemical durability tests are performed for these purposes.

In this paper, the experimental studies have been classified according to their technological scientific areas in the following five items: geodetic and photogrammetric studies, geotechnical tests, geophysical tests, tests on materials and structural tests.

2. GEODETIC AND PHOTOGRAMMETRIC STUDIES

Geodetic and photogrammetric surveys are especially necessary when new buildings or urban settlements are discovered in archeological excavations. Displacements of the objects or structural elements in excavations may greatly disturb further research, therefore the geodetic and photogrammetric surveys are continuously carried out during excavation.

The artificial models of the damaged edifices can be drawn by CAD techniques using the data of the photogrammetric surveys [1,2].

The digital photogrammetry enables us to obtain the three coordinates of each point with great accuracy, therefore displacements, settlements and tilting of the buildings and structural elements can be followed and reliable solutions for the soil consolidation are realized.

The distribution of the contact loads of a historic monument on soils constructed with different elements and materials cannot be easily determined. Photogrammetric studies also help the solution of this difficult problem [3].

Photogrammetric surveys are also a necessity for controlling the success of the rehabilitation or soil-consolidation achieved. These control processes may also be realized with conventional geodetic instruments such as electronic theodolites established in geodetic stations and completed with reflectors, stadias and poles [1].

3. GEOTECHNICAL STUDIES

It is obvious that the movements of the soil occupy great place among the causes of damages observed on ancient structures. In cases of damages of the buildings due to the settlement or loss of stability of the soil, the repair work begins with the improvement of the soil.

Investigations of the soil structure, determination of the old foundation system and the interaction of the building and the soil are the primary studies. It is generally necessary to undertake long-term studies and observations and their evaluations for obtaining concrete solutions. The method of drilling bore holes, placing extensometers into these holes, measuring the deformation of the soil layers, determining the oscillations of the ground water with level gauges are the most preferred processes for long-term monitoring [4]. To investigate the interaction between soil and building, the deformations and displacements of the building should be simultaneously recorded with the gauges mounted on different points of the building. Index properties and petrographic analysis of the soils are, of course, made on undisturbed specimen obtained from the boreholes.

During piling, electrographical discharge or grouting, real time monitoring should be kept up, and the change occurred in the carrying capacity of the strengthened building and the neighboring soil should be observed and controlled [5].

4. GEOPHYSICAL STUDIES

Geophysics that investigates the constitution and the dynamics of the earth has many branches. Basically, the techniques of the geophysical exploration rest on the fact that mineral deposits and geological strata possess distinctive physical properties. Formations that differ from their surroundings in density or magnetism produce anomalies in the earth's gravitational or magnetic fields; they may be detected and located by the gravimetric or magnetic geophysical methods. There are other methods based on the measurement of reactions of the subsurface bodies to impressed fields of force obtained by the use of explosives, shocks or acoustic emissions. The seismic waves produced by shocks are received by geophones and their velocities are computed. This seismic method has been used in archeological investigation to find out the place of tombs in tumuluses [6]. It has also been applied for tomographical analysis of large masonry [7]. Electrical methods of the geophysics which are especially designed for searching mineral ores or oils can also help in investigating the water content of the subsoil layers.

5. EXPERIMENTAL STUDIES ON MATERIALS

The historic monuments are generally masonry constructions. Atmospheric or aggressive environmental factors, climatic effects and natural disasters destroy the stones, bricks and mortars of these edifices. Their reparations without impairing their authenticity constitute a great part of the studies on ancient structures. The repair principles to pursue can be summarized as follows: 1- Find out the principal factor of the damage, 2- The material chosen for the reparation should be resistant against the principal damage factor, 3- This material must comply with the old one, 4- This material and the structural element repaired should not impair the authenticity of the edifice.

The determination of the main cause of the damage requires the examination of the environmental conditions in the first place and compiling events in historical duration. Of course, these studies do not need experimental intervention.

The studies on materials can be combined into two main groups: essays on ancient materials and production of the convenient repair materials.

5.1 Experimental Studies on Ancient Materials

The tests are generally performed on specimens taken from the structures. These specimens must be as small as possible for not damaging the buildings. The probability of test results to represent the properties of the initial material used can not be too high due to the deterioration occurred in the long span of time, but they may give valuable information on the damage process.

The test methods used for the chemical and mineralogical analysis generally consist of X-ray diffraction analysis (XRD) and/or X-ray fluorescence analysis (XRF) that are suitable for crystallized materials. These tests are qualitative, combining them with differential thermal analysis (DTA) and thermal gravimetric analysis (TGH) may help to obtain quantitative results and also these tests may detect the presence of amorphous components. These analysis are visually supported by optical polarized microscope, electron dispersing scanning electron microscope (SEM – EDX), stereoscopy and computer aided image analysis [8,9,10]. Inductive coupled plasma (ICP) method is also used for the chemical analysis [11]. Petrographical investigations are also accomplished together with these analyses.

Aggregate gradation, density, size and distribution of the porosity are primary studies undertaken in the physical and mechanical investigation of the old mortars. The sizes of the aggregates are determined by optical analysis, streomicroscopy or imaging systems. The gradation is obtained by laser diffraction particle size analyzer like sieving technique. For determining the sizes and the distribution of the voids, mercury intrusion system is generally used [10,12,13].

Some of the mechanical properties of mortars are compressive strength and elasticity modulus. To find out these properties, non-destructive tests such as ultrasonic pulse velocity and rarely rebound hammer tests are preferred. Some of the research is aimed at establishing correlation between color parameters and mechanical properties [14]. Acoustical properties of the materials and acoustical criteria of the buildings are also investigated for ancient basilicas that will be used as auditorium [15].

Among the causes of the deterioration of the old stones used in caves, biological effects are important. Many ancient historic structures suffered from deterioration due to the existence of fungi and bacteria, thus microbiological studies are executed in this field [16].

5.2 Tests Carried out on Repair Materials

It is impossible to produce new materials identical to the old ones today. On the other hand, the repair material should be stronger and more durable from the old one. Therefore, we have to use new materials in reparation projects, nevertheless the similarity of these new materials with the ancient ones should be realized because the value of the historic edifices can only be preserved in this manner.

Experimental repair works pursued on historical masonry buildings are concentrated on mortars which are generally produced with sand, hydrated lime and brick powder. In some cases, natural pozzolans were added in the mortar mixes. Therefore, the first attempt to solve the problem of the repair mortar is to prepare it with those ingredients. Quality control tests are executed on these mortars with modern advanced technologies shows that their porosity durability and mechanical strength are not satisfactory. Thus addition of chemical admixtures like superplasticizers and cements or hydraulic lime becomes necessary [13,17]. These experiments carried out in laboratories but also controlled in-situ.

Another restoration problem is to reuse the old structural damaged elements. It is possible to bond crushed building stones with glue such as epoxy resine, to cover deteriorated surface with synthetic solutions like acrylates.

The success of the reparation can be controlled by physical or mechanical tests but the aesthetic and authenticity problems are also of primary importance [18,19].

6. STRUCTURAL EXPERIMENTS

The carrying capacity and strengthening of the historic buildings that continue to be used nowadays should be investigated experimentally. Their strengthening is a delicate work due to the preservation of their authenticity.

The first stages of these works are the determination of the actual carrying capacity, enumeration of the damaged structural elements and evaluation of their damage levels. The tests carried out for these purposes should not evidently cause any damage to the building.

All these buildings are masonry constructions. Therefore, for computing their carrying capacity, it is necessary to investigate the soundness and damage level of the structural masonry elements. Some mechanical strength tests or creep tests can be carried out on specimens cut from the walls. This solution may be detrimental for the building, for this reason the nondestructive tests like ultrasonic pulse velocity measurement or thermography are preferred. But their results are not sufficiently reliable because the estimation errors will be large if the previous calibration tests for each material are not realized beforehand.

Detailed investigation of the masonry elements in order to detect crack patterns, porosity dispersion and mechanical diversity, video endoscopic studies are carried out. It is also possible to examine the inner structure of the masonry elements with seismic or gravimetric geophysical tests [7,20,21].

The compressive strengths, deformation capacities and elasticity modulus of the whole masonry elements can not be determined by laboratory tests on small specimens reliably. The flat jack tests conducted in-situ on building walls give accurate information for these properties [22,23,24].

The examination of the structure behavior under static and dynamic changes procures the necessary data and criteria for the structural design. Static investigation needs long term monitoring which combines with geotechnical tests. Horizontal and vertical displacements of the buildings, increase of the inclinations, crack patterns and their progress are observed and recorded. Many advanced apparatus are designed and constructed for these purposes like autoplomb technique, electrolytic inclinometers, telecoordinamometers, and etc. [25].

Dynamic measurements are obtained with high sensitivity accelerometers mounted on critical points of the buildings and strong motion accelerometers placed on the ground near the building. Vibrations are generated by impulse or ambient vibrations are used for this purpose. These tests help in determining the proper frequency, general modal shapes and damping capacity of the building which are necessary to make the earthquake risk analysis [21].

7. CONCLUDING REMARKS

A very large and important area of research is developed for recognizing, restoring and strengthening our historic heritage of great value. All the experimental methods and advanced apparatus of chemistry, physics, metallurgy, geophysics, photogrammetry are used continuously for these purposes. Many interesting and large experimental researches are carried out. It has not been possible to explain and describe all of these valuable studies in detail in this paper, however these can be found in the references given. Two general and strict principles for experimental investigations on ancient structures should be kept in mind:

1. Ancient structures and the materials used on those structures should be strictly preserved and protected during experimental tests.
2. Repaired edifices or structural elements should be more durable and stronger than the ancient structure but they must have the same view, character, function and aesthetics of the ancient structure.

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DIAGNOSIS AS A BASIS FOR PLANNING THE CONSERVATION OF ARCHITECTURAL MATERIALS : THE IMPORTANCE OF TECHNICAL STANDARDS, CODES OF PRACTICE AND GUIDELINES TO REGULATE CONTRACTS.

G. Alessandrini (1), M. Laurenzi Tabasso (2)
(1) CNR, Centro “G. Bozza”, Milan, Italy
(2) Conservation Scientist, former Assistant to the Director General of ICCROM, Rome, Italy

ABSTRACT

The paper briefly discusses the theoretical links between diagnostic studies and conservation options, with special reference to porous building materials (natural stones, mortars, bricks, etc.). The aim of such studies and their different aspects and steps are illustrated and the type of information that is more relevant to the understanding of the decay mechanisms and factors is stressed.
The use of standard approach and of standard analytical methods adds value to the results of any diagnostic study, making them better understandable by all those who want to study similar problems. Considering the peculiarities of ancient building structures and the values they express, the standard methods defined in the field of material and environmental sciences are not always suitable or applicable to materials that are part of historical structures and monuments. While the need for specific standards is rather frequently stressed also in international meetings, not many of such specific standards have been defined so far.
The Italian experience in this field, namely the results achieved by the UNI NORMAL Commission, is illustrated and some of the most important published documents are briefly discussed.
Finally, the *Guidelines to Regulate Contracts* (a sort of “special model tender”) for diagnostic studies on materials conservation is illustrated. The latter is an initiative, undertaken by the Normal Commission on the request of the Italian Ministry of Cultural Properties, to define the conditions and the technical-scientific aspects of contracts between public authorities (such as Superintendencies, regional or local Bodies) and scientific laboratories or private

specialists to carry out diagnostic studies on specific monuments or archaeological remains.

1. INTRODUCTION

The science of conservation today demands that, with respect to the historic-artistic and cultural "values" of an item of Cultural Property, a project for its conservation must be based on the results of a diagnostic study, aimed at understanding the original features and the state of decay of the item to conserve. "Conserving means knowing" and “diagnosis is the prerequisite of conservation planning” are axioms which could be proposed as a basis for the science of conservation.

The law in force at present in Italy (Law N. 109, 11 February 1994 and the “Rules for its Enforcement”, D.P.R. N.554, 21 December 1999) adopts the above principle as far as conservation works on cultural properties are concerned. It provides that the designing process of any conservation work develops through different temporal steps, from the preliminary project, to the definitive and the feasible one. The preliminary project and, to a lesser extent, the definitive project must include the collection of historical, documentary and technical-scientific information, necessary to the good “knowledge” of the property to conserve. In other words, diagnosis is provided by law.

Treating an artefact therefore means providing the specialist in charge of the treatment with exhaustive information on the material nature of the object, the production technique, and on the causes, mechanisms and entity of the deterioration. It means as well having extensive, specific scientific knowledge of the products and methodologies to use during the course of conservation treatment, especially in what concerns their compatibility respect to the original materials, their durability and their weathering characteristics. Correct and reliable diagnosis will therefore enable the conservator/restorer to carry out correct and reliable conservation treatments from both a technical and financial point of view.

In the case of architectural materials, the main objectives of the diagnosis can be listed as follows:

- to describe the characteristics (chemical, physical, mineralogical, petrographical etc.) of each single composing material and of the “whole” system, in case of architectural structures and composite items,
- to identify the causes and mechanisms of deterioration, possibly including those active in the past,
- to evaluate the interaction between the surfaces of the materials and their environmental parameters,
- to collect information on the conservation treatments applied in the past, to assess their performance,
- to collect information on the past use and misuse of the artefact, that could have had an influence on its present conditions,

- to evaluate the compatibility, effectiveness and potential noxiousness of the products and methodologies to be employed in the treatment.

The problem arises of establishing how deep the diagnostic investigation should be and of selecting the most suitable and cost effective scientific analysis to arrive at a significant understanding of the state and conservation of the artefact. The variety of methodologies today available to researchers and the proliferation of new, more and more sophisticated analytical technology has made it necessary to propose guidelines for planning the diagnostic studies and to standardize analysis procedures. Standardization represents, also for the conservation of historical artefacts, as in any other scientific and industrial contexts, a focal point and the only possibility of achieving results which are unequivocal, comparable with those obtained by other authors and therefore of more general use.

Considering the peculiarities of ancient building structures and the values they express, the standard methods defined in the field of material and environmental sciences are not always suitable or applicable to materials that are part of historical structures and monuments. While the need for specific standards is rather frequently stressed also in international meetings, not many of such specific standards have been defined so far.

In Italy, since the late 1970s, the task of standardization within the Cultural Property sector has been entrusted to the NORMAL Commission established in accordance with the Ministry of Cultural Property and the National Research Council (CNR). **NORMAL** is the acronym of the Italian words "**NOR**mativa **MA**teriali **L**apidei" (standards for stone materials). The Commission originally had the task of *"defining standard methods for the study of the deterioration of stone materials and their conservation,"* considering both natural stone materials (marble, stone) and artificial ones (mortar, brick, terra-cotta and ceramics, stucco, glass). Only in recent years has the Commission extended its competence to include metals, wood and "Museum Technologies (lighting systems, air conditioning, etc.)".

In 1997 the NORMAL Commission stipulated a convention with the Italian National Board of Unification (UNI). UNI is the only Italian organism entrusted with the responsibility of promulgating national standards as provisions of law and of representing the country in intergovernmental standardization bodies (e.g. at European Community level). UNI ratified the NORMAL papers as national standards to be circulated and known as "UNI-NORMAL Cultural Property standards" and are to be considered "provisions of law".

2. THE ACTIVITY OF THE UNI-NORMAL COMMISSION

The Commission is structured into Work Groups, each one dealing with a specific discipline (chemistry, physics, petrography, biology), or with specific technological processes (e.g. survey/recording and graphic documentation), specific materials (metals, mortars, ceramics, glass, wood), or with particular conservation aspects or technologies (e.g. humidity of masonry, technical installations and systems in museums) (See Appendix). Currently, about 330 specialists participate, on a voluntary basis, in the activities of the UNI-NORMAL Commission. The majority of the members are researchers and architects from the public sector (Ministry of Cultural Property), from national research institutes (CNR), from universities and from private research laboratories. Also present in specific groups are free-lance architects, professional consultants and restorers/conservators selected for their proven experience within the sector as well as technical experts from private industry who for years have been involved in the formulation of products or in the setting up of methodologies suitable for conservation treatments.

Up until now 49 NORMAL Papers have been published. The first 44 are copyrighted by the Central Institute of Restoration (ICR) and the CNR. They have a double set of numbers in order to make reference easy and rapid. The first number is progressive and refers both to the paper and to successive modified and/or updated editions of the same; the second number refers to the year of publication. The last five papers, published after the convention stipulated with UNI, are numbered according the general system of this Board (See Appendix).

The NORMAL Commission has also been instructed by the Ministry of Cultural Property to draw up *Guidelines to Regulate Contracts for Conservation Works, as provided by Rules for the enforcement of the above mentioned Law.* For the Italian public sector, this represents an invaluable instrument, able to profoundly influence the quality of treatment. The *Guidelines* include criteria for the selection of suitable procedures, for both the diagnosis and the conservation treatments, and descriptions of the latter. Following to this “code of practice”, is the description of the conditions to give out diagnosis and conservation works by contract. The existence of such a document which assembles and illustrates rules and precepts that represent the material culture of the restoration and conservation work site, describing each single operation (from the diagnosis to the different conservation treatments) and underlining its specific aims, could also serve as a stimulus to the world of business and commerce. The subject matter of the *Guidelines*, which are not yet completed, has been divided into volumes dedicated respectively to:

- Diagnosis and Controls
- Restoration of Architectural Property
- Restoration of Archaeological Property
- Restoration of Historical-artistic Property

The relevant NORMAL Work Groups are cooperating on each volume.

The *Guidelines* can be seen as an operative instrument with a dual function: as a guide to the choice of methodologies and products to adopt for treatment and as a tool to monitor their correct application. In fact, when they will be in force as an official document of the Ministry of Cultural Property the technical clarity of contracts will be enhanced and the administrative conditions for carrying out diagnosis, preventive tests, monitoring and maintenance works will be easier.

The parts of the *Guidelines* already compiled by the NORMAL Commission (Diagnosis for porous building materials; Diagnosis and Conservation treatments for paintings on wood and canvas) were recently tested by a group of 10 Superintendencies which applied them to draw some of the projects included in their programme of activity. The results of the test were recently discussed during a Seminar organised by the Ministry of Cultural Property and were considered very satisfactory.

3. THE NORMAL PAPERS

The papers published up until now can be grouped together according to the type of material, the analytical typology or to the treatment typology described in the paper itself. The papers can be grouped together as follows:

1. Knowledge of natural stone materials
1.1 Description of macroscopic alterations
1.2 Sampling and the conservation of samples
1.3 Mineralogical-petrographic, chemical and morphological description of the materials and of their decay products
1.4 Physical description of the materials
1.5 Biological agents of deterioration
2. Knowledge of artificial stone materials
2.1 Terminology
2.2 Description
2.3 Mineralogical-petrographic, chemical and morphological description of the materials and of their decay products
2.4 Physical description of the material
2.5 Biological agents of deterioration
3. Environmental study (parameters, measuring techniques and criteria for planning monitoring campaigns)
4. Conservation methods (aims, limits, advantages, drawbacks)
5. Selection of conservation products and treatments (testing methods, evaluation criteria)
6. Elements of knowledge regarding the artefact (survey, recording, graphic documentation, archival research)

The preparation of the papers has been based on either the bibliographical data or on regulations and standards, even international, already existing in material science and building trade, but suitably adapted to meet the particular requirements of conservation or, for the majority of the papers, on collective ad hoc experimentation carried out in the different laboratories which collaborate within the NORMAL Commission. In this last case, specific procedures are proposed and tested in common, before defining a standard method.

The Papers published up to now are listed in the Appendix.

They are distributed on request by UNI, via Battistotti Sassi n.11, 20129 Milano (Italy), http://www.unicei.it.

4. DEVELOPMENTS FOR THE FUTURE

After about 20 years of activity it can be stated that the NORMAL Commission played a very positive role within the Italian conservation world. The definition and diffusion of technical papers served, and still serve, as a guideline for scientific and conservation laboratories and contribute to raise the quality level of the diagnostic studies. The influence of these documents goes far beyond the national boundary, as demonstrated by the bibliographic references of papers published by authors from other European and Latin American countries who adopted the NORMAL methods in their experimental studies. As an example the NORMAL 1/80 "Macroscopic Alterations of Stone Materials: Lexicon" (published in 1980, revised in 1988 and published as 1/88) can be mentioned. The paper served as a model for similar papers proposed in Spanish, English and German and recently translated into Hebrew.

Beyond this direct effect, it is worth mentioning a side effect, very useful at national level: the participation to the Work Groups strongly facilitates contacts among the experts, creating new collaboration opportunities and stimulating the reciprocal understanding among specialists of different cultural background.

The UNI-NORMAL Cultural Property Commission will pursue its activity of standardization to embrace other categories of material (such as paper and its derivatives, textiles) and other specific technologies, in the hope that the work of standardization carried out in Italy in the field of conservation, as a result of its special nature, will also find a corresponding response in other European Union countries to whom all the UNI regulations are currently oriented.

APPENDIX

PUBLISHED PAPERS

NORMAL-1/80	MACROSCOPIC ALTERATIONS OF STONE MATERIALS: LEXICON
NORMAL-1/88	MACROSCOPIC ALTERATIONS OF STONE MATERIALS: LEXICON
NORMAL-2/80	RECORDING DATA OF STONE MATERIALS: CARD SYSTEM
NORMAL-3/80	STONE MATERIALS: SAMPLING
NORMAL-4/80	POROSIMETRY AND PORE SIZE DISTRIBUTION
NORMAL-5/82	MEASUREMENT OF ENVIRONMENTAL PARAMETERS
NORMAL-5/83	MEASUREMENT OF ENVIRONMENTAL PARAMETERS
NORMAL-5/86	MEASUREMENT OF ENVIRONMENTAL PARAMETERS

NORMAL-5/87	MEASUREMENT OF ENVIRONMENTAL PARAMETERS
NORMAL-6/81	DESCRIPTION OF LITHIC QUARRY MATERIALS: CARD SYSTEM
NORMAL-7/87	WATER ABSORPTION BY TOTAL IMMERSION - IMBIBITION CAPACITY
NORMAL-8/81	STUDY OF MORPHOLOGICAL CHARACTERISTICS WITH SCANNING ELECTRON MICROSCOPE
NORMAL-9/82	AUTOTROPHIC AND HETEROTROPHIC MICROFLORA: CULTURE ISOLATION TECHNIQUES
NORMAL-9/88	AUTOTROPHIC AND HETEROTROPHIC MICROFLORA: CULTURE ISOLATION TECHNIQUES
NORMAL-10/82	PETROGRAPHICAL DESCRIPTION OF NATURAL STONE MATERIALS
NORMAL-11/82	WATER ABSORPTION BY CAPILLARITY - COEFFICIENT OF CAPILLARY ABSORPTION
NORMAL-11/85	WATER ABSORPTION BY CAPILLARITY - COEFFICIENT OF CAPILLARY ABSORPTION
NORMAL-12/83	ARTIFICIAL AGGREGATES OF CLASTS AND NON-ARGILLACEOUS MATRIX BINDERS: DESCRIPTION SYSTEM
NORMAL-13/83	QUANTITATIVE ANALYSIS OF WATER SOLUBLE SALTS
NORMAL-14/83	THIN AND POLISHED CROSS-SECTIONS OF STONE MATERIALS: PREPARATION TECHNIQUE
NORMAL-15/85	ARTIFACTS AND AGGREGATES WITH ARGILLACEOUS MATRICES: DESCRIPTION SYSTEM
NORMAL-16/84	CHARACTERIZATION OF BUILDING STONE MATERIALS AND THEIR STATE OF CONSERVATION: ANALYTICAL SEQUENCE
NORMAL-17/84	METROLOGICAL ELEMENTS AND DIMENSIONAL CHARACTERISTICS: GRAPHIC DEFINITION
NORMAL-18/84	SURVEY OF THE FUNCTIONALITY OF TECHNICAL INSTALLATIONS: CARD SYSTEM
NORMAL-19/85	AUTOTROPHIC AND HETEROTROPHIC MICROFLORA: VISUAL SURVEY TECHNIQUES
NORMAL-20/85	CONSERVATION TREATMENTS: PLANNING, EXECUTION AND PREVENTIVE EVALUATION
NORMAL-21/85	PERMEABILITY TO WATER VAPOUR
NORMAL-22/86	MEASUREMENT OF THE SPEED OF SOUND PROPAGATION
NORMAL-23/86	TECHNICAL TERMINOLOGY: DEFINITION AND DESCRIPTION OF MORTARS
NORMAL-23/87	TECHNICAL TERMINOLOGY: DEFINITION AND DESCRIPTION OF MORTARS
NORMAL-24/86	SURVEY AND ANALYSIS METHODOLOGY FOR VEGETATION
NORMAL-25/87	AUTOTROPHIC AND HETEROTROPHIC MICROFLORA: TECHNIQUES OF ISOLATION AND MAINTENANCE IN PURE CULTURE
NORMAL-26/87	DESCRIPTION OF MORTARS FOR RESTORATION
NORMAL-27/88	CHARACTERISATION OF MORTARS
NORMAL-28/88	CHEMICAL COMPOSITION OF STONE MATERIALS

NORMAL-29/88	MEASUREMENT OF DRYING INDEX
NORMAL-30/89	METHODS OF CONTROL OF BIODETERIORATION
NORMAL-31/89	ANALYSIS OF RESIDUAL CALCIUM AND MAGNESIUM HYDROXIDES IN LIME MORTARS
NORMAL-32/89	GAS-VOLUMETRIC ANALYSIS OF CO_2
NORMAL-33/89	MEASUREMENT OF THE CONTACT ANGLE
NORMAL-34/91	ANALYSIS OF CLAY MATERIALS BY XRD
NORMAL-35/91	CHARACTERIZATION OF BIOCIDES: CARD SYSTEM
NORMAL-36/92	GLOSSARY FOR HISTORIC BUILDINGS IN TREATISES FROM 15th.-16th. CENTURY
NORMAL-37/92	BIOCIDE TREATMENTS: CARD SYSTEM FOR RECORDING DATA
NORMAL-38/93	EXPERIMENTAL EVALUATION OF THE EFFECTIVENESS OF BIOCIDES
NORMAL-39/93	SURVEY OF MICROBIC COUNT IN ATMOSPHERE
NORMAL-40/93	PONDERAL MEASUREMENT OF HUMIDITY IN MASONRY
NORMAL-41/93	PONDERAL MEASUREMENT OF HUMIDITY IN WALL PAINTED SURFACES
NORMAL-42/93	GENERAL CRITERIA FOR THE APPLICATION OF NON-DESTRUCTIVE TESTS
NORMAL-43/93	COLORIMETRIC MEASUREMENTS OF OPAQUE SURFACES
NORMAL-44/93	WATER ABSORPTION AT LOW PRESSURE

UNI 10739	CERAMIC TECHNOLOGY: TERMS AND DEFINITIONS (July 1998)
UNI 10813	NATURAL AND ARTIFICIAL STONES:CHECK OF PRESENCE OF PHOTOAUTOTROPHIC MICRO-ORGANISMS ON STONE MATERIALS BY UV/VIS SPECTROPHOTOMETRIC DETERMINATION OF CHLOROPHIL A, B, AND C (April 1999)
UNI 10859	NATURAL AND ARTIFICIAL STONES: DETERMINATION OF WATER ABSORPTION BY CAPILLARITY (replaces NORMAL 11/85) (January 2000)
UNI 10923	AUTOTROPHIC AND HETEROTROPHIC MICROFLORA: VISUAL SURVEY TECHNIQUES (replaces NORMAL 19/85) (in press)
UNI 10924	TECHNICAL TERMINOLOGY: DEFINITION AND DESCRIPTION OF MORTARS (replaces NORMAL 23/86 and 23/87) (in press)

WORK GROUPS OF THE UNI-NORMAL COMMISSION

1 - Biological methodologies
2 - Testing methods to control biological agents
3 - Chemical methodologies
4 - Air Pollution

5 - Methodologies to test surface conservation treatments
6 - Methodologies to characterize ceramic and glass materials
7 – Laboratory physical methodologies
8 – Environmental physics
9 – Methodologies for survey/recording
10 - Methodologies for documentation
11 - Methodologies to characterize ancient mortars and mortars for restoration
12 - Metals
13 – Petrographic methodologies
14 – Non-destructive test and mechanical tests
15 – Conservation of architectural properties
16 – Conservation of architectural properties - Technical installations and systems
17 – Conservation of archaeological properties
18 – Conservation of historical and artistic properties
19 – Humidity in masonry: diagnosis and interventions
20 – Wood and wooden materials
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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

POROSITY AND STRUCTURE OF OLD MORTARS

I.Papayianni (1), M Stefanidou, (2)
(1) Professor AUTH, Thessaloniki, Greece
(2) Dr Geologist, Thessaloniki, Greece

ABSTRACT

The structure of a great number of old mortars covering long historical period (from Roman to modern times) was studied by using direct and indirect methods of analysis in the frame of NATO SfS GR-Restoration project [3]. Different types of binders as well as aggregates of different gradation and type were found. Stereoscope, polarized microscope, SEM, image analysis and mercury porosimeter techniques were used.
A considerable amount of knowledge was revealed concerning the shape, the size, the distribution and the geometric characteristics of pores and cracks. Moreover some characteristics of the binder crystals and of the aggregate-paste interface were found.
In the paper, correlations are made between the microscopic features and the quality features of these mortars.

1. INTRODUCTION

The role of microstructure in understanding and ameliorating the behaviour of building materials has been widely recognized. As *Pratt* states ‘’ the links between direct observation of pore structure and indirect measurements remain tantalizingly obscure’’[1]. However, it seems that the combination of testing methodologies could result in more reliable description of microstructure.

The mortar is one of the ancient building materials used with stones, bricks, wood, metals in construction. Its quality influences the bearing capacity and longevity of masonry structures.

Old mortars are characterized by high porosity values due to their nature (their constituents and the proportions in which they are used) and to the deterioration they have suffered through time. Unfortunately in most of the cases it is impossible to distinguish the origin of the porosity or even to find out in what extent the porosity is attributed to one or to the other agent. Independently of the origin of the porosity, its value provides a criterion for evaluation the material. The old mortars are usually made with lime, hydraulic lime or lime+pozzolana. Many efforts have been made to correlate porosity with strength in traditional mortars [2] [4] [5]. Although, Powers relation (1) seems to be in valid, there is still lack of experimental work in order to produce a mathematic model.

$$\sigma = \sigma_0 (1-P)^3 \qquad (1)$$

σ=strength

σ_0=strength of material with zero porosity (90-130Mpa)

P= porosity

2. MEASURING TECHNIQUES

The study of old mortar structure was made by applying direct and indirect methods.

The direct methods used at the present study were:

1. Stereoscopic observation of mortar sample
2. Observation with polarized microscope by using thin section of treated mortar sample

In both cases computer aided image analysis was practiced so that a statistic evaluation of findings was possible

3. Scanning electron microscopy (SEM) was used in order to investigate the mineralogy of the mortar sample

The indirect methods applied were:

1. Water absorption under vacuum according to RILEM CPC 11.3
2. Pore size distribution of old mortars by using the mercury porosimetry technique

3. THE CHARACTERISTICS OF THE OLD MORTARS

The structure of old mortars is not uniform, since it consists of three phases [6] those of the aggregates, of the paste and of the aggregate-paste interface. It is common to find both dense and loose binder spots with different degree of crystallization in the same sample [fig. 1]. The type of binder seems to play an important role in the structure. Mortars which are characterized as pure lime ones have looser structure [fig.2] than the mortars with hydraulic binder[fig.3]. That is because different crystals are developed in each case and these crystals are bound together in different ways. In the first case SEM analysis reveals the calcitic plate -like ($CaCO_3$) crystals and the way they are connected [fig.4]. The structure is characterized by large spherical pores (d>100μ) and open cracks (width>50μm and length >500μm) which contribute to high open porosity (30-35%).

On the other hand,in mortars with hydraulic binder, needle like crystals are developed [fig. 5] in parallel to the plate-like ones which present strong cohesion. The porosity measured is lower (20-28%) and it is attributed to the micropores (d<50μm) and to the microcracks (d<50μm and length 200-300μm).

Mainly natural aggregates emanating from the near rivers and streams are used in old mortars. Part of their grains are often substituted by crushed bricks or calcite grains in different size and proportions. In many cases crushed bricks have reacted with the binder and the formation of reaction zones on the circumference of them is observed. This reaction enhances the interface of aggregate-paste reinforcing the mortar structure[fig.6]. The reaction between aggregate-binder seems to prevent the crack development since the rim acts as ‘ barrier ‘ to crack propagation [fig. 8].

In the case of calcite grains, they often react with the binder [fig.7] and they tend to be embodied with it.

The binder/ aggregate (b/a) ratio plays important role in the porosity and the shape of the pores. Low b/a ratio may result in many spherical pores, the size and the position of which depends on the workmanship of the mixture. Voids in contact with the aggregates are typical in this case [fig. 9] while shrinkage cracks are limited.

The measurements of pore size distribution of a number of old mortars which were taken from monuments dated from Roman up to 19th century, showed that the main volume of their pores are in the area of 1-0,1μm [2]. It also seems that in stronger mortars such as those with hydraulic components, a transfer of pore size distribution curve to the finer pores is observed (table 1).

4. **CONCLUSIONS**

The study of the microstructure could be a reliable criterion for interpreting the behaviour of old mortars which may have similar chemical or physical characteristics. The main parameters that affect the physiognomy of it are:

- the paste of binding agent
- the aggregates (type, gradation, shape)
- the b/a ratio

The porosity of old mortars is mostly attributed to spherical pores and cracks which usually coexist. The open porosity is usually of high value (20-40%)

in comparison with that of modern cement mortars. The main volume of pores ranges between the sizes of 1-0,1μm. The stronger mortars present finer pore size distribution curve. The geometric characteristics are very important as large cracks (> 500x50μm) result in the loosening of the structure while large pores (especially when they are isolated in the structure) are ‘’ weak’’ points but they do not participate in the deterioration process

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Fig. 1 Loose and dense structure in the binder (x65)

Fig. 2 Lime mortar structure of 5th century. Open cracks and large pores (x65)

Fig. 3 Structure of pozzolanic mortar from 7[th] century.
Good cohesion between the crystal units (x65)

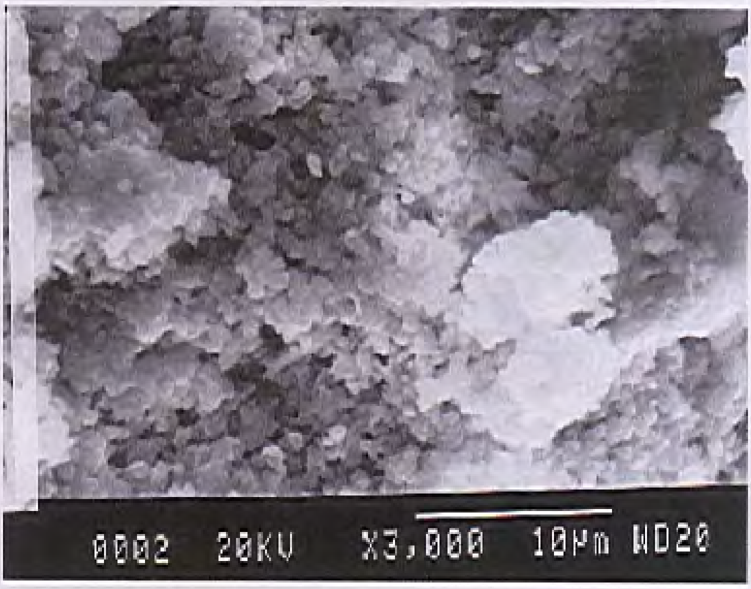

Fig. 4 Microstructure of a pure lime-mortar.
Plates of $CaCO_3$ with loose cohesion (SEM x3000)

Fig. 5 Microstructure of hydraulic mortar. Needle-like crystals are formed in the structure (SEM x3000)

Fig. 6 Crushed brick as aggregate reacting with the binder and forming a reaction rim with thickness 50µm. (Galerius Palace, Polarized microscope x65)

Fig. 7 Reaction of calcitic aggregate with the binder (x65)

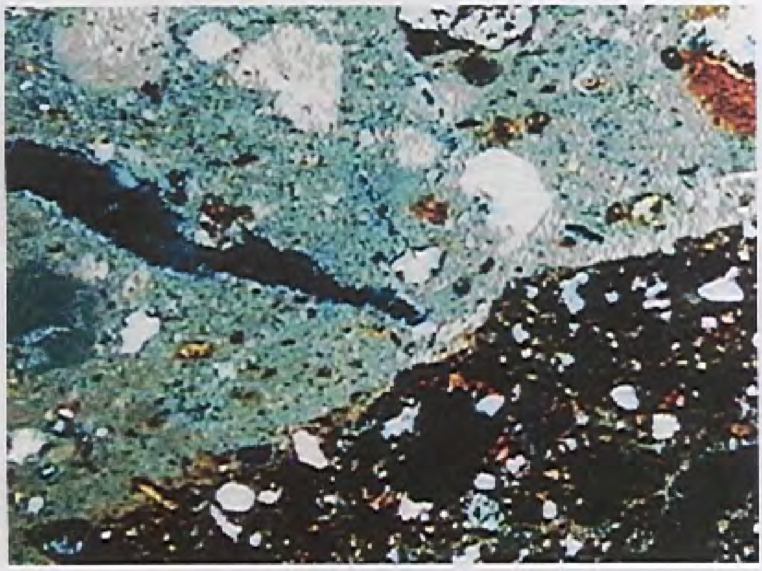

Fig. 8 Brick aggregate blocking the development of the crack (x65)

Fig. 9 Void in contact with an aggregate due to loose compaction (Stereoscope, x15)

Table 1. Pore size distribution on old mortars from different historic periods [2]

Monument	>2μm (%)	2-1μm (%)	1-0,5μm (%)	0,5-0,1μm (%)	0,1-0,01μm (%)
Roman Forum 2nd century		6,8	24,1	45	19
Hagia Sophia 7th century		2,3	3,6	64,7	25
Acheropiitos 7th century		3,6	13,5	49	19,4
Pazar Hamam 15th century	>6,4	19,5	20,3	33,8	11,6

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 e-mail:sas2001@yildiz.edu.tr http://www.yildiz.edu.tr/mim/sas2001

OPTIMIZATION OF COMPATIBLE RESTORATION MORTARS FOR THE PROTECTION OF HAGIA SOPHIA

A. Moropoulou, A. Bakolas, P. Moundoulas, E. Aggelakopoulou,
S. Anagnostopoulou
National Technical University of Athens, Department of Chemical Engineering, Section of Materials Science and Engineering, 9, Iroon Polytechniou St., 15773 Zografou, Athens, Greece.

ABSTRACT

In the present work optimization of restoration mortars was performed on the basis of reverse engineering approach. The examination and selection of raw materials and the production of a number of mixtures with different ratios of binder / additives / aggregates and gradations were carried out. The selection of these materials was based on the examination of the historic mortars of the monument. In order to evaluate mortar mixes during setting and hardening, thermal analysis (DTA-TG), mercury porosimetry analysis and mechanical tests (compressive, flexural) were performed. The results indicate that mortars with hydraulic lime as binding material being admixed with crushed brick, present better behaviour than those with aerial lime, or lime-cement, or lime-pozzolanic additives. The results are in accordance with the acceptability limits defined by the investigation of the historic ones. The results obtained from two-phase production permitted the selection of proper mortar mixtures and their pilot application on a historic masonry of Hagia Sophia, which is going to be evaluated on time as far as compatibility and mortars good performance on the masonry are concerned.

1. INTRODUCTION

The present work focuses on the preparation and evaluation of optimized restoration mortar mixtures which will be able to respond to intensive environmental loads, to continuous mechanical stresses and be compatible to the original structural units of the masonry. Structural studies to determine the earthquake worthiness of Hagia Sophia have proved that the monument's static and dymamic behavior depends strongly on the properties of masonry materials (stones, bricks, mortars etc.). Previous works led to the classification of the characteristic crushed brick-lime mortars of Hagia-Sophia to the category of hydraulic composites, explaining the good performance of structural units [4]. Investigations on crushed brick-lime mortars of Hagia Sophia led to the conclusion that the examined mortars present various production technologies with binder/aggregate ratios varying from ¼ to ½ per volume [10]. Low ratios (¼) are probably attributed to the washing out of calcite due to weathering [3] and not to specific Byzantine process technologies. Binder, that comprises the mortar matrix, presents hydraulic character partially attributed to the binding materials and partially to the lime-crushed brick interactions at the interface [9]. Moreover, crushed brick grain size influences directly its hydraulic reactivity, as well as its physico-mechanical properties [1]. In previous work, Transmission Electron Microscopy provided valuable information concerning the development between the crystalline phases of calcite and the dispersed ceramic fragments of an amorphous sheet structure calcium alumino-silicate gel formation. The presence of these amorphous phases comprises a matrix of hydraulic nature, which allows energy absorption [2]. The durability of the examined historic composites and their compatibility to the structural units are attributed to the quality of raw materials, their physicochemical and mechanical properties and the production technologies.

Consequently, a reverse engineering approach has to be adopted for the reproduction of historic mortars [12]. Moreover, an integrated investigation should be attempted [3], concerning structural and materials aspects, in order to develop and evaluate proper conservation materials.

2. REVERSE ENGINEERING AS A METHODOLOGY FOR THE PRODUCTION OF COMPATIBLE RESTORATION MORTARS

The first step of the above methodology is the characterization of historic mortars, the selection of raw materials and finally the general mortar mixture directives. With these directives preparation of restoration mortars with different binder/additives/aggregates ratios, are tested. The evaluation of restoration mortars properties is required for the specification of the technical characteristics of the mortars pastes and during the setting and hardening. The following step is the optimization of restoration mortar mixes based on the data provided as mentioned above and selection of the proper production process. The final but most important step is the pilot application for the evaluation of restoration mortars on masonry scale by non-destructive techniques. [5]

2.1. Experimental procedure for the evaluation of restoration mortars mixtures during setting and hardening – First phase production

In order to evaluate the various mortars mixtures during setting and hardening the following measurements were performed: Differential Thermal and ThermoGravimetric Analysis (DTA - TG) (Netzsch, STA 409 EP) in order to estimate the hardening rate and the development of chemical phases, Mercury Porosimetry (Posimeter 2000, Fisons Instruments) in order to evaluate microstructural characteristics during hardening and Mechanical Strength Tests (DIN 18555 September 1982) in order to estimate mortars strength acquired during hardening [7].

2.1.1 Microstructural and Mechanical evaluation

Mixtures with natural hydraulic lime and lime putty / pozzolanic additives presented high mechanical strengths either with sand aggregate or mixed aggregates of sand and crushed brick at the time of 9 months of curing.

As far as microstructure is concerned, a correlation between microstructural parameters and mechanical strength was detected. During hardening there is an increase in specific surface area along with a decrease to the average pore radius that leads to increased mechanical strength values. Total porosity ranges between 30-48% with hydraulic lime mortars presenting the lower values, which leads to more cohesive materials. Bulk density values are relatively low, especially for mixtures with mixed aggregates due to the presence of crushed brick [8].

2.1.2 Thermal Analysis Evaluation

Mixtures with natural hydraulic lime as binder showed high rate of chemical phases evolution, which is almost completed after 3 months. Structurally bound water is detected even from the first 15 days of hardening. The development of hydraulic phases contributes to the mechanical strengths that mortars acquire.

Lime mortars presented the slowest rate of chemical phases evolution, which is not completed even after 9 months. The rate of hardening is very slow until the third month, and becomes faster until 9 months.

The examination of mortars with pozzolanic additives showed that the evolution of chemical phases is slower than that of hydraulic lime mortars. The structurally bound water (~ 1,00%) indicates the presence of ceramic powder and earth of Milos due to the hydraulic phases.

Cement mortars of this category, due to the low content of cement, perform similar results as lime putty mortars. The significant difference is that in the evaluation of lime putty – cement mortars structurally bound water is detected. Low percentage of cement leads to the separation of binders [13] while high cement content has to be avoided given the incompatible microstructure of the material to the original units [6].

2.2 Optimization – Second phase production

Based on the results obtained from the first phase production of restoration mortars, an optimization phase followed, concerning a thorough investigation of the parameters controlling mechanical strengths along with microstructural characteristics. At this point of research different mortar mixtures were studied, according to the typical mortar categories declosed from the investigation of historic ones (typical lime, hydraulic lime, lime – pozzolana mortars).

2.2.1 Optimization of raw materials

A number of raw materials (lime putty, lime powder, NHL-2, Earth of Milos, Brick Powder, Sand, Crushed Brick) were tested using the following techniques (DTA-TG, XRD, XRF, Mercury Intrusion Porosimetry, pozzolanicity test, active silica test, chemical analysis). The final selection of raw materials is based on the specific requirements that the materials should fulfill [7].

The materials selected for the production of mortar mixtures at the second phase and their basic characteristics are presented below:

Lime putty presented high percentage of $Ca(OH)_2$ and its colloid nature considered being a desired characteristic. The free water content of lime putty and its bulk density were approximately 58% and 0,825 g/cm^3, respectively.

Lime powder was also tested for reproducibility reasons. Lime powder presents a higher percentage of $Ca(OH)_2$ (88%) than lime putty and low percentage of $CaCO_3$ (~5,5%).

For the production of hydraulic mortars, natural hydraulic lime (NHL-2 according to CEN-prEN 459-1) was used.

Earth of Milos was examined as a pozzolanic additive. The percentage finer than 64μm is about 88%. From the pozzolanicity test compressive strength was about 6 N/mm^2. The total percentage of silica is about 65%, and the relative percentage of active silica is 20%, while XRD analysis reveals the high content of amorphous glassy phases.

Being an artificial pozzolana, brick powder was produced by crushing and grinding compact bricks. Pozzolanicity test showed compressive strength values up to 6,2 N/mm^2, while it is finer than Earth of Milos (percentage finer than 64μm is about 94%). The total percentage of silica is about 58%, and the relative percentage of active silica is 20%.

Washed river-sand, yellow-colored was used from the river Strimonas. Chemical analysis reveals its silicate nature. It presents a wide grain size distribution ranging between 0/1mm.

The crushed brick comes from Thessaloniki-Macedonia. It presents a grain size distribution ranging from 1/6mm. The microstructural characteristics of the brick were examined showing values of total porosity ~28% and bulk density 1.89 g/cm^3.

2.2.2 Optimization of mortar mixture directives

The most important parameter is the content of the binder in the mixture and the binder/pozzolanic additive ratio. Generally an increase of 5–10% of the added binding material was followed aiming to augmented mechanical strengths and to the plasticity of mortar pastes. Furthermore, investigations on the optimum lime/pozzolanic additive ratio led to a proportion of 1:1 augmenting at the same time the hydraulic nature of the mortar.

In all the mixtures studied at the optimization phase a standard mixture of aggregates (sand and crushed brick) was used, in order to produce lightweight and elastic mortars simulating the historic ones. The proportions of sand and crushed brick used in the mixture were determined in a way that the obtained gradation curve would be wide and sigmoid with a percentage of voids relevant to the percentage of the binding material added. The above mentioned criteria led to an aggregate mix of 65% sand (0/1mm) and 35% crushed brick (1/6 mm).

According to the results from the previous work the following mortar mixtures were proposed:

Lime Putty – Aggregates (1/1,8 b.w.):	LP.A.
Lime Powder – Aggregates (1/1,5 b.w.):	LPo.A.
Hydraulic Lime – Aggregates (1/2,3 b.w.):	NHL.A.
Lime Putty – Earth of Milos – Aggregates (1/1/2 b.w.):	LP.M.A.
Lime Putty – Ceramic Powder – Aggregates (1/1/2 b.w.):	LP.CP.A.
Lime Powder – Ceramic Powder – Aggregates (1/1/2 b.w):	LPo.CP.A.

Preparation of the pastes took place at the laboratory by the use of a mixer. Binding material along with pozzolanic additive (according to the mixture prepared) are being admixed with the appropriate content of water, as it has been previously determined by the testing of pastes (flow test). Aggregate materials (sand and crushed brick) are being premixed and then gradually added to the mixture.

The pastes are being moulded immediately after their preparation to appropriately prepared moulds according to the DIN 1164. Immediately after the preparation of the specimens, moulds are covered with glass sheets and kept at 20 ^{0}C and 100% relative humidity for one day. From the second day the specimens are stored under controlled conditions of 20 ^{0}C and 55% relative humidity.

In order to evaluate the mortar synthesis, the experimental procedure of the first phase was followed.

2.2.3 Results

Evaluation of Microstructural Characteristics

The microstructural characteristics of all mortars tested are shown on Table 5.The microstructural investigation shows improvement in all parameters tested, and especially on the Total Porosity, where the results are in absolute agreement with the acceptability limits defined by the investigation of the historic mortars [5], although the microstructural distribution is controlled by the crushed brick (aggregate). The values for density show lower values from those of the first syntheses.

Table 5: Microstructural characteristics of mortars (1st and 2nd phase) after 3 months

Mortar Category	Code	Production phase	A_s	d	P (%)
Hydraulic Lime	NHL.A	1st	4.01	1.6	42.5
		2nd	4,62	1,8	33.9
Lime	LP.A	1st	2.40	1.7	42.7
		2nd	3.30	1,6	43.7
	LPo.A	2nd	5,30	1,6	38,9
Lime-Pozzolanic Additive	LP.M.A	1st	0.62	1.7	42.7
		2nd	3.04	1,6	40.7
	LP.CP.A	1st	0.36	1.8	42.5
		2nd	3,60	1,6	41,0
	LPo.CP.A	2nd	4,20	1,5	37,3

As: Specific surface area (m^2/g) – d: Bulk density (g/cm^3) – P %: Total porosity (%).

Evaluation of Mechanical Characteristics

The results from the mechanical strength tests are shown on the Table below:

Table 6: Mechanical Strength Tests Results of Mortars (1st and 2nd phase) after 3 months

Mortar Category	Code	Production phase	$f_{m,f}$	$f_{m,c}$	$f_{m,t}$
Hydraulic Lime	NHL.A	1st	0.7	3.3	0.4
		2nd	0.7	3.5	0.4
Lime	LP.A	1st	0.3	0.5	0.2
		2nd	0.5	1.0	0.3
	LPo.A	2nd	0.5	1.2	0.3
Lime-Pozzolanic Additive	LP.M.A	1st	0.2	0.5	0.1
		2nd	0.4	1.1	0.2
	LP.CP.A	1st	0.3	1.6	0.2
		2nd	0.4	1.2	0.2
	LPo.CP.A	2nd	0.6	2.4	0.4

$f_{m,f}$: Flexural Strength, $f_{m,c}$: Compressive Strength, $f_{m,t}$: Tensile Strength

The results indicate improvement in all mixtures tested in comparison to the mixtures of the first phase production. Mortars with lime powder as binder presented better behavior than those with lime putty. From mixtures with pozzolanic additives those with ceramic powder showed better results. Hydraulic lime mortars presented the best behavior among all. The results need to be confirmed by the tests of 6 and 9 months of curing.

2.3 Conclusions

Combined evaluation of the data obtained from the first and second phase production of restoration mortars ameliorates the proper optimized mortar mixtures.

Mortars with hydraulic lime and lime powder - ceramic additive showed the best behavior among all mixtures tested as far as microstructural characteristics and mechanical strengths are concern.

The use of lime powder in mixtures provided better reproducibility. Furthermore results after 3 months indicate that mortars with lime powder exhibit better microstructural and mechanical characteristics than lime putty mortars.

Mixtures with natural hydraulic lime and lime powder along with ceramic powder as pozzolanic additive present the best mechanical strength of all, as well as satisfactory workability and rates of setting.

The presence of crushed brick to all mixtures led to the production of lightweight mortars simulated the historic ones.

Mortars with hydraulic lime mixed with crushed-brick presented the highest mechanical strengths than those with aerial binder that presented the lowest values. Furthermore, comparisons between first phase production restoration mortars and optimized mixtures showed that the critical factor for the improvement of mechanical strengths was the increase of the binder to the mixtures, along with the gradation of the aggregates.

Experimental results at the time of 6 and 9 months need to be deduced for the thorough evaluation of the mixtures. Nevertheless, the three months results indicate that the optimization of mixtures is successful.

Combined evaluation of all results obtained from both phases of production led to the selection of proper restoration mortars that applied on pilot scale at the Hagia-Sophia monument.

3. PILOT APPLICATION

Selected mixtures were applied on a historic masonry of Hagia Sophia monument. The authorities of Hagia-Sophia chose the location and wideness of the masonry. Applied materials concerned repair joint mortars. The aim of this application was the evaluation of restoration mortars performance on a masonry scale, regarding their compatibility with historic structural units. Monitoring of their performance will take place in situ by means of non-destructive techniques, indicating the modifications of microstructure, their mechanical properties and their behavior under actual environmental loads.

3.1 Application Area

According to the architectural imprint of the monument, as shown in Fig.3, the application area is located on the perimetric arcade of the atrium, at the North/West section of the outer narthex of Hagia Sophia, which was built on the 6^{th} century, according to the authorities of the monument. The main characteristic of the structure is the different conservation interventions that have taken place through the coarse of time. Incompatible restoration materials (i.e. cement) have caused decay problems on the masonry, which were also detected.

The presence of rising dump was obvious from the macroscopic observations on the masonry, along with the extended decay of old mortars surface due to the polluted atmosphere.

An extended vertical crack was observed along bricks and joint mortars, on the level of the application area.

Figures 1, 2 present the state of masonry before the pilot application.

Fig. 1:Aspect of the work field before the application

Fig.2: Extended vertical crack on the masonry (decayed joint mortars)

Before the pilot application Fibre Optics Microscopy applied in order to evaluate the state of the surface as shown in Figure 3.

Fig.3 Total loss of binding material. Weathered mortar surface

Joints were cleaned by mechanical means and washed out before the pilot application.

3.2 Mortar Mixtures and Application Technique

The mortar mixtures that were applied on the pilot masonry surface are given above:

a) Hydrated lime powder mortar with ceramic powder as pozzolanic additive and mixed aggregates of sand and crushed brick.
b) Hydraulic lime mortar with ceramic powder as pozzolanic additive and mixed aggregates of sand and crushed brick.
c) Hydrated lime powder mortar with artificial pozzolanic additive and mixed aggregates of sand and crushed brick.

Mortar components were mixed carefully at the University of Bogazici. For the in situ application the given surface of the pilot masonry was divided in three vertical zones, at each one of them a different mortar mixture was applied.

The depth of the applied mortars was approximately 5cm, while the distance from the exterior surface of the bricks was 1-2cm. Consequently, the thickness of the mortar was approximately 3-4cm and its height 5-6cm. During the application, restoration mortars were compacted in two layers and each of them was allowed to harden for approximately half an hour before the next layer was applied, so as to minimize the overall shrinkage crack of the paste. Moreover, after the application the joint mortars were tooled to match, at some extent, to the texture of masonry traditional mortars. Figures 4, 5 show the application area, as well as, the apllicated mortars.

Fig. 4: Application of hydrated lime mortar

Fig. 5: Application of pozzolanic mortar

In order to prevent the shrinkage cracking of the applied restoration mortars, the application was followed by continuous rinsed of joints during the first days after the application.

4 CONCLUSIONS AND PERSPECTIVES

The in situ application of restoration mortars at the pilot masonry of Hagia Sophia presented satisfactory results. The mortars on the masonry exhibited the desired workability, they were easily applied and performed quite fast rates of setting.

Although the mortar mixes were of different chemical composition, none of them was cracked during the first days after application.

The future behaviour of the mortars on masonry will be evaluated by non destructive and other instrumental techniques in order to examine the compatibility of the applied mortars with the structural units of the masonry (bricks, mortars) and their long time physicochemical behaviour.

The following non-destructive techniques will be performed in situ: a) Infrared Thermography for the detection of the compatibility between the restoration mortars and the historic masonry, b) Ultra Sonic Technique for the evaluation of mechanical properties and the detection of possible cracks and decay width and c) Fibre Optics Microscopy for the investigation of the microstructure of the restoration mortars during hardening.

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

SYNTHESIS OF MORTARS FOR USE IN THE REPAIR AND MAINTENANCE OF HISTORIC BUILDINGS AND MONUMENTS IN THE ISLAND OF CRETE, GREECE

E. Mistakidou, Th. Markopoulos and G. Alevizos
Technical University of Crete, Dept. of Mineral Resources Engineering,
University Campus, 73100 Chania, Greece

ABSTRACT

For the needs of restoration in historic buildings and monuments on the island of Crete, local materials were used in order to produce hydraulic lime and mortars with suitable properties. The raw materials used for the preparation of the mortars were hydrated lime (produced in the laboratory), fine grained brick powder (a waste product of a local brick producer), sea sand and Portland cement.

The raw materials and the produced mortars were studied with optical microscopy, X-ray diffraction analysis (XRD), X-ray fluorescence analysis (XRF) and laser diffraction particle size analyzer (as wet sieving) in order to determine their mineralogical composition and physical characteristics.

Mixtures of the materials, properly grounded and mixed in various proportions have been prepared and added to small pieces of bioclastic limestone and bricks. In certain mixtures Portland cement was added. Bioclastic limestones and bricks were preferred because they are used in the construction of ancient buildings and till nowadays have shown good weathering resistance.

All mortars showed good durability and compatibility with the bioclastic lime-stone, under natural weathering conditions for a period of six months, while the mortar adhesion with the bricks varies.

1. INTRODUCTION

Modern buildings are made of hard, impermeable materials, cement mortars, renders and plasters. It is often difficult to force the problems, which appear when these materials and techniques are applied to old and ancient buildings because it takes many years for the disadvantages of using modern materials on old buildings to become apparent.

Moisture and soluble salts unable to evaporate build up behind impermeable surfaces, speeding up the decay of built-in timbers, providing ideal conditions for decay.

Since the 1970's, based on the pioneering work of Prof. Baker at Wells Cathedral at the West Front, various mortars based on lime-pozzolana reactivity have been used as alternatives for restoration operation.

One obvious disadvantage of lime-pozzolana pastes is their long setting time and slow strength development. In practice, it is important for the mortar to reach satisfactory strengths within in short period under certain climatic conditions. But a soft lime absorbs a certain amount of moisture, which subsequently evaporates, so a balance is maintained. A cement render on the same wall will become microscopically cracked as the wall responds to atmospheric changes-moisture will be sucked in, through these fine cracks, but since it is unable to evaporate the wall becomes more and more damp [Schofield J. 1985].

In the case of high lime mortars rainwater it absorbed into the mortar dissolving minute amounts of uncombined lime (calcium hydroxide) which penetrates in voids. Soon carbonates precipitate in the cracks, filling or plugging the interstices [Tougelidis G. et al, 1995].

The purpose of this study is to examine the potential reactivity (hydraulic-pozzolanic character) of brick powder mixed with raw materials, hydrated lime, seasand and with small amounts of Portland cement.

2. MATERIALS AND METHODS

The experimental procedure was aimed to evaluate the properties of the hardened, after a period of six months. For the investigation the following methods were used:

- Grain size analysis (wet sieving as laser diffraction) to estimate the grain size distribution in the samples,
- X-ray diffraction analysis to identify the crystalline phases of the primary materials of the mortars,
- X-ray fluorescence analysis for chemical analysis,
- Differential Thermal Analysis (DTA) and thermogravimetric analysis,
- Optical microscopy for the petrological characterization of the mortars,
- Dietrich-Früling method (determination of free lime content)

2.1. Raw materials

Aggregates

Seasand from the Akrotiri area (near to the city of Chania) was used. The sand was washed out to remove the soluble substances (salts, etc.). The grain size (by wet sieving), the mineralogical (XRD) and chemical analysis (XRF) are presented in Fig. 1a and Tables 1 and 2.

Brick powder was produced from grinding of burned bricks, which fall out in the final stage of the production of a local producer. The mineralogical and chemical composition and particle size distribution of the brick powder is given in Fig. 1a and Tables 1 and 2.

Binding materials

Lime putty was produced in the laboratory and was used to prepare the mortar mixtures. Limestone was collected from a local quarry and has been used as raw material. The pure hydrated high calcium lime (CH) for the preparation of the lime putty, meets the ASTM C141 specifications and has been produced in laboratory. The grain size distribution (laser particle size analyzer), the chemical and the mineralogical analysis are presented in Fig. 1b and Tables 1 and 2. Portland cement was also added in one mortar mixture.

Table 1: The X-ray diffraction analysis results of the examined raw materials

Raw materials	Minerals
Seasand	Calcite, aragonite [$CaCO_3$], hornblende [$(Fe, Mg, Ca)_6Al[(OH)_2/AlSi_7 O_{22}]$], quartz [$SiO_2$]
Brickpowder	Quartz, wollastonite [$CaSiO_3$], hematite [Fe_2O_3], anorthite [$CaAl_2Si_2O_8$], akermanite [$Ca_2MgSi_2O_7$], anhydrite* [$CaSO_4$]
Hydrated lime	Portlandite [$Ca(OH)_2$]

* very small amount

Table 2: Chemical analysis results

	Raw materials		
	Seasand	Brickpowder	Hydrated lime
Fe_2O_3	0,27	9,57	0,04
MnO	0,01	0,11	<0,01
CaO	41,1	15,56	53,1
K2O	0,04	2,27	0,02
SiO_2	14,01	49,71	0,49
Al_2O_3	3,1	11,71	0,14
MgO	5,12	8,59	1,06
Na_2O	0,03	0,67	0,01
TiO_2	n.a.[1]	0,70	<0,01
P_2O_5	n.a.	0,09	<0,01
L.o.i.[2]	35,69	0,89	43,23
Sum	99,37	99,85	98,09

[1] not available
[2] by 1050°C for 1hr

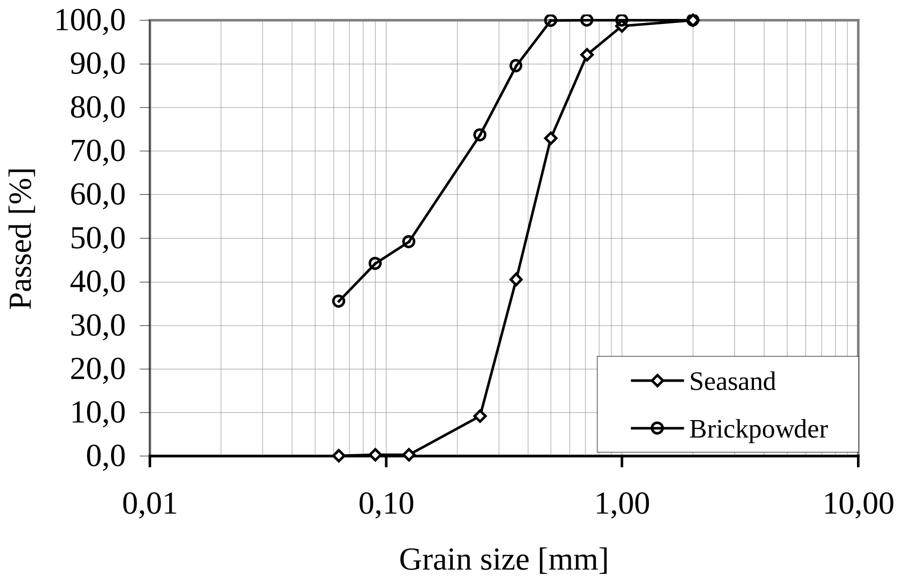

Fig. 1a: Grain size distribution of mortar aggregates.

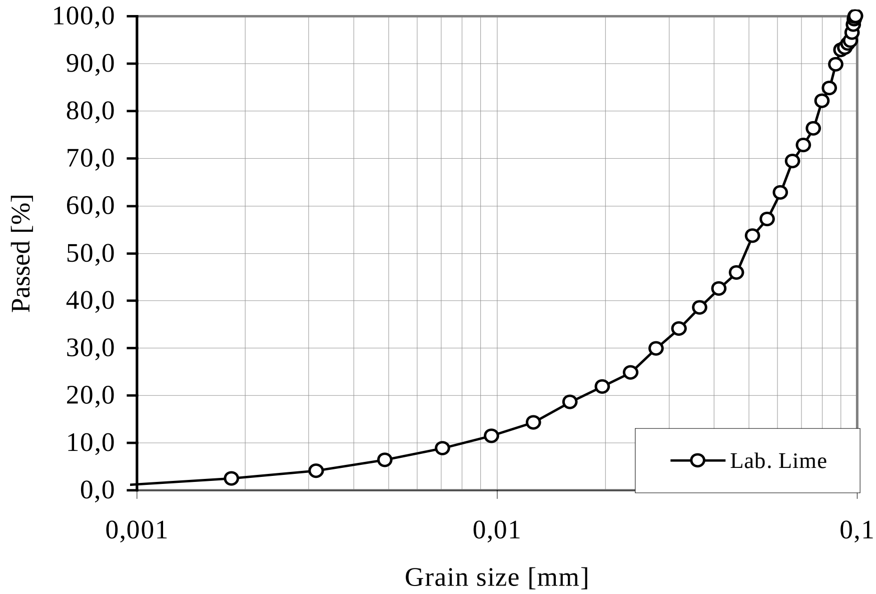

Fig. 1b: Grain size distribution of the hydrated lime binder, a laboratory product.

2.2. Preparation of the mortars

The preparation of mortars was carried out at room temperatures. The materials, which have been used, were mixed[3] by weight percentages (Table 3) and adequate amount of tap water (25 up to 33%wt).

The compatibility of the mortars with bioclastic limestone and brick was examined. Small pieces (~5cm) of the building materials were fully covered by the prepared mortars and after a period of six months, the covered specimens were cut transversally. Polished sections were prepared and studied via optical microscopy. The mortars were examined by X-ray diffraction, thermal analysis and by the Dietrich-Früling method in order to estimate the maturity of the created mortars. The final, on dry stage colour of mortars, varies from subwhite, reddish to pale red-brown which, from aesthetic point of view seams to be similar to the colour of most ancient mortars used on Crete.

Table 3: Mixing proportions (by weight) of the constituents of the mortars

Mortars Specimen	Seasand	Brickpowder	Hydrated lime	Portland Cement
	Percentages [%] by weight			
K. 2	-	2	1	-
K. 3	1	1	1	-
K. 4	2,13	1,75	1	-
K. 5	2,06	1	1,11	-
K. 6	1,8	1	1,05	-
K. 7	1	-	1	1
K.9	3	3	1	-

3. EXPERIMENTAL RESULTS AND DISCUSSION

The presence of portlandite (CH) in cured mortars indicates that the reaction was not completed. Generally there are two possibilities for the CH to react: The first is with the reactive silica in the pozzolanic material, i.e. brick powder to form calciumsilicate, calciumaluminate hydrate (CSH, CAH) phases and the second is with the CO_2 from the air to form $CaCO_3$. In all examined samples CH is present even after the period of 6 months. The intensity of the CH (XRD peak) correlates with the hydrated lime content of the mortars (Table 3). This observation of the X-ray diffraction combined with those from DTA data has been estimated through the thermogravimetric (weight losses in the range of temperatures from 360 to 550^oC) analysis (Table 4).

[3]the present study will be focused in seven from the fourteen samples

Weight loss beyond 360°C is due to the dehydroxylization of CSH as CAH phases while those between 550 up to 1050°C were caused mainly by the decomposition of $CaCO_3$ (Table 4). The whole calcitic content of the samples (Table 5) measured volumetrically (Dietrich-Früling method) showed a very good correla-tion with the total loss of ignition amounts (summarized values from table 4) of the samples.

Calcium silicate hydrate as calcium aluminate hydrate crystalline phases have been observed in very small amounts and variable compositions (from $Ca_2SiO_4 \cdot H_2O$ to $Ca_3Si_3O_9 \cdot H_2O$ and $Ca\ Al_2Si_4O_{12} \cdot 2H_2O$ to $Ca_5Si_6O_{17} \cdot 5H_2O$) as reaction product between silica and CH. The CAH phases have been identified in the K.4, K.5, K.6 and K.7 mortars, which are richer in $CaCO_3$ while the CSH phases were indentified in all other samples. Although CSH and CAH are present in small amounts (calculating as difference from thermogravimetric analysis data, Table 4) are showed a good correlation with the hydrated lime and brick powder added into the mortars [Borino G. et al., 1997, Tougelidis G. et al., 1999]. The small abundance of the hydrated phases seems to be controlled by the storage conditions, i.e. highest diffusion degree of the mortars. The samples had been prepared in early summer and were kept at room temperatures (>26°C). There is not much information available on the nature of the reactions [Chiari G. et al, 1992] forming the CSH and CAH phases but seems to be highly dependent on reaction time and temperature. In other words the CSH and CAH formation for the prepared hydraulic lime mortars seams strongly to be influenced by:

a) The degree of diffusion degree of the moisture content of the samples caused by the climatic conditions as well as from

b) grain size and grain morphology of the seasand.

The above suggestion has been confirmed by simple dehydration of the mortars. The dehydrated mortars have been again examined by X-ray diffraction and DTA. The portlandite (CH) peak was negiglible to absent while the peak height of the identified variable CSH phases was greater.

Table 4: Weight loss of the examined mortar samples.

Samples	105°C/ 2hrs	360°C/ 1hr	550°C/1hr	1050°C/1hr
	Weight loss (%)			
K2	1,14	1,55	2,87	14,06
K3	0,73	1,00	3,78	25,22
K4	0,72	0,98	2,06	23,55
K5	0,45	0,65	2,73	27,34
K6	0,60	0,85	3,03	26,53
K7	2,72	3,17	5,83	30,01
K9	0,41	0,64	1,54	21,85

Table 5: $CaCO_3$ content (%wt) estimated by the Dietrich-Früling method.

	Mortar samples						
	K2	K3	K4	K5	K6	K7	K9
$CaCO_3$ (%wt)	31,60	56,06	51,44	61,47	60,17	56,02	45,30

The compatibility of the mortars was excellent for the mortars which covered the bioclastic limestone (Fig. 2 a, b) while for those covered the commercial brick fragments were of inferior (Fig. 2 d, e, f). An exception to that was the excellent compatibility of mortar K.2 (Tab. 3) with the brick (Fig. 2 c). The microscopic examination for the samples have characterized by excellent compatibility showed an interface reaction zone between the mortar and the bioclastic limestone, or the pieces of brick, in the case of the mortar K.2.

For all other mortars characterized by a good to fairly good compatibility a distinguished (more or less) reaction layer of few (2 to 3) millimeters was observed. This can be distinguished from the whole mortar and displays very gut adhesion with the brick material and consists mainly of lime and brickpowder, the finest part of the specific fixed mortar. The remained coarser part, above this thin layer tends to show -diverse in directions- dry cracks (Fig. 2 f). This kind of adhesion has been observed mostly for the mortars K.4, K.5 and K.6, which contained the highest amount of seasand (Fig. 2 f). Obviously this optical observation is associated with the coarse grain size and the morphology of the mixed seasand, with the water's diffusion rate and with those parameters concerning the brick materials [Tougelidis G. et al., 1999], i.e. its high water absorption (≥25%W.A). The contrary mortar K.2 displayed excellent compatibility with the brick fragments (Fig. 2 c). This mortar have been prepared without seasand (Table 3) and showed (in addition to its higher compatibility), high shrinkage. Finally mortar K.7 which contains Portland cement displayed excellent compatibility with the building materials. However the use of Portland cement is avoided during restoration works [Schofield, J. 1985, Moropoulou, A. et al., 2000].

4. CONCLUSIONS

a) All the prepared mortars show good compatibility with bioclastic limestone while the compatibility with the brick varied was from gut to fairly good. An exception to that was showed by the mortar K.2 with an excellent compati-bility although higher shrinkage with the brick.

b) Full maturity of the cured mortars has not been obtained even after of six months, because portlandite (CH) is still present in certain amounts in the mortars.

c) The presence of various CSH and CAH phases has been estimated in restricted amounts. Although the mechanism of their formation is not well understood it seems to be influenced by the nature and consistence of the samples, as well as from the climatic conditions during and after their preparation.

d) The presence of Portland cement in mortars enhances the cohesion and compatibility of the obtained mixture.

e) From an aesthetic point of view the colour of the produced mortars approaches that of most mortars used in ancient days on Crete.

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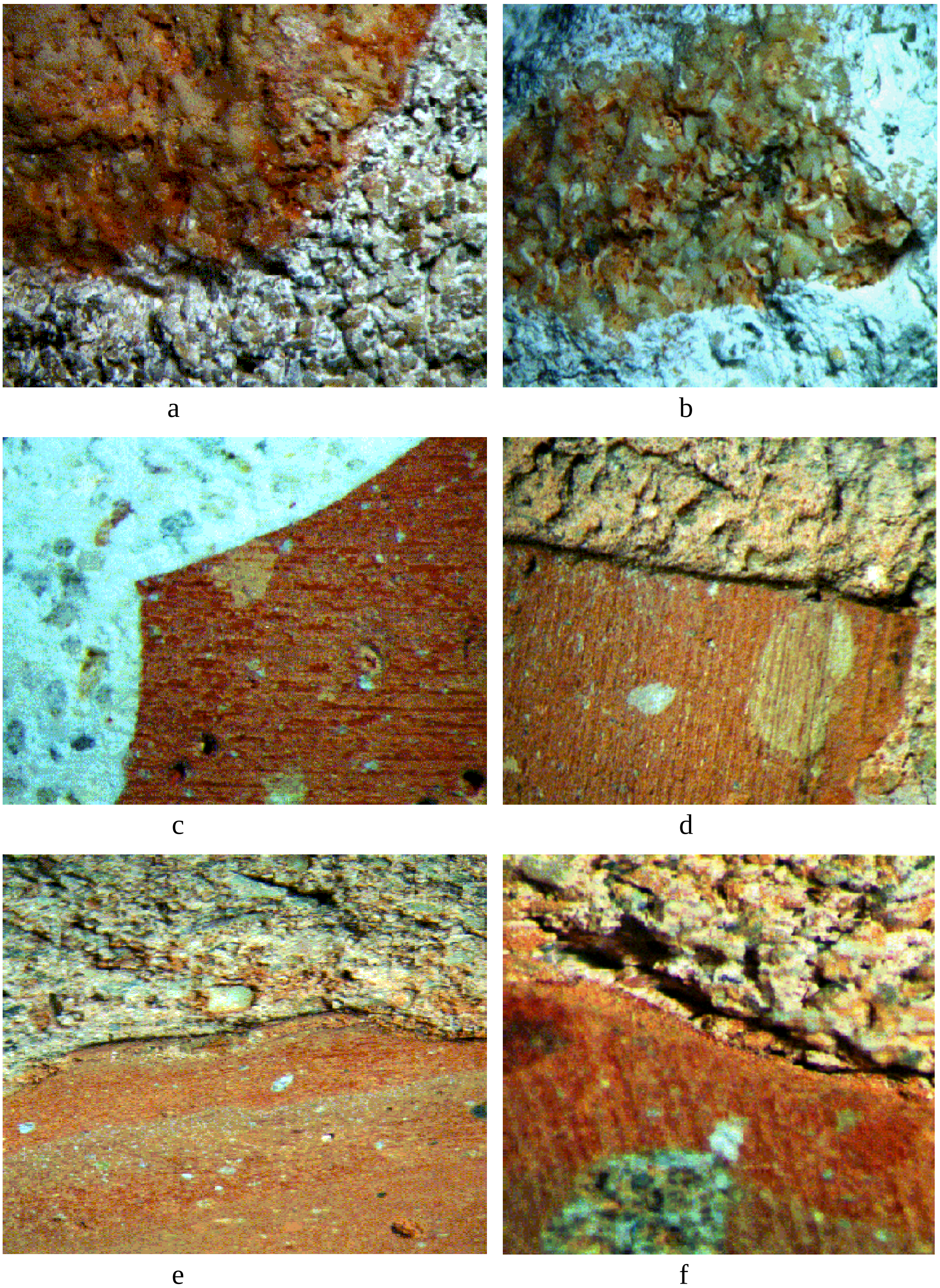

Fig. 2: Microphotographs from prepared mortars. Compatibility between bio-clastic limestone and brick with the mortar; (a, b, c) excellent, (d, e, f) of inferior.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

A FUNDAMENTAL STUDY ON RELATIONSHIP BETWEEN COLOR AND MECHANICAL CHARACTERISTICS OF SLAKED LIME MORTAR USED FOR HISTORICAL MASONRY STRUCTURES

T. Aoki (1), N. Ito (2), A. Miyamura (1), T. Kadoya (3), A. De Stefano (4)
(1) SDA, Nagoya City University, Nagoya, Japan
(2) Miyagi National College of Technology, Miyagi, Japan
(3) Gifu National College of Technology, Gifu, Japan
(4) Politecnico di Torino, Turin, Italy

ABSTRACT

In the present paper, in order to establish a non-destructive testing method by color analysis for slaked lime mortar commonly used for historical masonry structures, the relationships between surface color, and water content of mortar, mix proportions, age, mechanical characteristics such as static and dynamic moduli of elasticity and compressive strength are investigated. Experimental checks show a good correlation between surface color and mechanical characteristics, and it is possible to predict the mix proportions and mechanical characteristics by color measurement under ideal condition.

1. INTRODUCTION

The stability of many of historical masonry structures is now threatened by aging fractures due to many reasons including chemical degradation. The repair and maintenance of these structures require a reliable evaluation of their structural behavior and current fundamental mechanical characteristics of their materials. However, the higher the historical value of a structure, the more prohibitive a core test becomes.

The purpose of this paper is 1) to grasp how the influence of surface color is related to mix proportions, 2) to investigate the relationship between surface color and mechanical characteristics, 3) to derive the practical expressions for mix proportions as well as for mechanical characteristics of the mortar by using surface color, and 4) to establish a non-destructive test by color for slaked lime mortar commonly used for historical masonry structures.

2. MEASUREMENTS OF WATER CONTENT, COLOR AND ITS VALUE

2.1. Measurement of water content

Water content of slaked lime mortar is measured by means of a high frequency capacity (pF) instrument. Automatic correction for temperature can be realized during its measurement.

2.2. Surface color measurement

The surface color of slaked lime mortar is measured by means of a spectrophotometer. The illuminating/viewing system is d/8 (diffuse illumination, 8° viewing, specular component exclude; SCE) geometry which conforms to condition C defined by Japan industrial standard (JIS) Z 8722. The measurement range of wavelength is 400-700nm, the step of wavelength is 10nm, its half-width is about 15nm, the measurement range of reflectivity is 0-175%, and the limit of resolution is 0.01%. Measurement conditions are as follows; Commission Internationale de l'Eclairage (CIE) standard illuminants D_{65}, CIE 2° standard observer, colorimetric value $L^*a^*b^*$.

2.3. $L^*a^*b^*$ color space

The $L^*a^*b^*$ color space is one of the uniform color spaces defined by CIE in 1976. It is adopted into JIS Z 8729 as the specification of color of materials according to the CIE 1976 ($L^*a^*b^*$) space and the CIE 1976 ($L^*u^*v^*$) space. In $L^*a^*b^*$ color space, L^* indicates lightness and a^* and b^* are the chromaticity coordinates which represent hue and chroma (C^* :$(C^*)^2=(a^*)^2+(b^*)^2)$. The a^* and b^* indicate color directions; $+a^*$ is the red, $-a^*$, the green, $+b^*$, the yellow, and $-b^*$, the blue directions, respectively. As the a^* and b^* values increase and the point moves out from the center (dull), the saturation of the color increases [1].

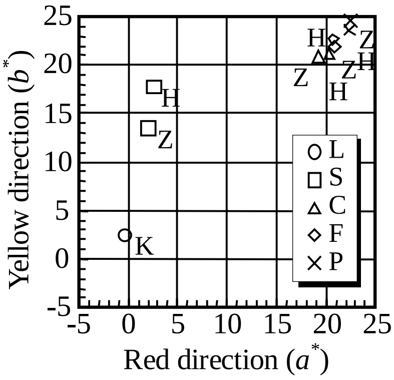
3. EXPERIMENTAL DETAILS

3.1. Materials of mortar

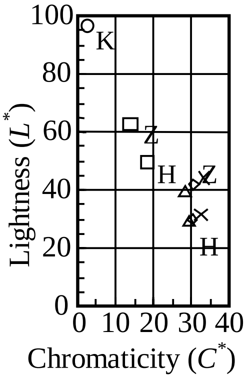
Slaked lime (L, specific gravity of air-dried condition 2.34) from Ogaki, Gifu Prefecture, Japan, fine aggregate (S, pit sand, fineness modulus 2.79, specific gravity of saturated and surface-dried condition 2.55, absorption as a percentage of dry mass 1.29%) from Toyota, Aichi Prefecture, and tap water are used. According to the grading of the fine aggregates for ordinary Portland cement defined by JASS5 [2], crushed brick is provided as the same as its lower limit (C, fineness modulus 3.43, specific gravity of saturated and surface-dried condition 2.35, absorption 9.88%), and as its upper limit (F, fineness modulus 2.00, specific gravity of saturated and surface-dried condition 2.51, absorption 4.91%), as parallel with its upper limit (P, maximum particle size 0.6 mm, fineness modulus

0.85, specific gravity of air-dried condition 2.63), respectively.

The a^*, b^* chromaticity diagram (hue and saturation) and the relationship between chromaticity and lightness are shown in Figure 1(a) and (b), respectively. Where, L, S, C, F, P, H, K, and Z are slaked lime, fine aggregate, crushed brick (fineness modulus 3.43, 2.00, 0.85), saturated and surface-dried condition, air-dried condition, and absolute dry condition, respectively. The lightness value becomes smaller in presence of slaked lime, fine aggregate, and crushed brick. The color of fine aggregate and crushed brick are yellow and yellow-red, respectively. As the grain diameter of crushed brick becomes smaller, its chroma value increases. As the water content increases, color becomes more vivid and dark.



(a) a^*, b^* chromaticity diagram



(b) Chromaticity and lightness

Figure 1 Color of the constitutive materials of the mortar

3.2. Mix proportions of mortar

In order to evaluate the influence of mass, specific gravity, water content, surface color, static and dynamic moduli of elasticity, and compressive strength on the mix proportions, the mix design is determined by the volumetric ratio of slaked lime: fine aggregate of 1 : 2 estimated using the reference data [3-5, Vitruvius's description (BC 1st century) is confirmed in Alberti's (15th century)]. According to the mix design, the ten kinds of specimens are made as listed in Table 1. In other words, the specimens are as follows;

1) slaked lime (L),
2) variations of the mixing ratio by volume of crushed brick having a grading equivalent to the lower limit (C, fineness modulus 3.43) of fine aggregates for ordinary Portland cement defined by JASS5 in a mixture with slaked lime and fine aggregate,
3) variations of the mixing ratio by volume of crushed brick having a grading equivalent to the upper limit (F, fineness modulus 2.00) in a mixture with slaked lime and fine aggregate,
4) variations of the mixing ratio by volume of crushed brick having a grading parallel with the upper limit (P, maximum particle size 0.6 mm, fineness

modulus 0.85) in a mixture with slaked lime and fine aggregate.

Fine aggregate and crushed brick more than 0.6 mm in grain diameter are used in absolute dry condition, but slaked lime and crushed brick less than 0.6 mm in grain diameter, in air-dried condition.

Table 1 Mix proportions per liter

Spec.	Slaked lime (g/L)	Fine aggregate (g/L)	Crushed brick (g/L)	Water (cc/L)	Flow (mm)	Water/ slaked lime (%)	Slaked lime rate (%)	Slaked lime : fine aggregate	Fine aggregate: crushed brick	Brick grain size (mm)	Brick fineness modulus
L1	845.4	0.0	0.0	634.0	154	75.0	100.0	1.0:0.0	1.0:0.0	-	0.00
C1	618.9	506.4	141.7	464.2	135	75.0	48.8	1.0:1.0	1.0:3.0	<10	3.43
C2	465.4	761.6	213.1	395.6	145	85.0	32.3	1.0:2.0	1.0:3.0	<10	3.43
C3	380.0	932.7	261.0	342.0	138	90.0	24.1	1.0:3.0	1.0:3.0	<10	3.43
F1	618.9	506.4	160.1	464.2	143	75.0	48.2	1.0:1.0	1.0:3.0	<2.5	2.00
F2	465.4	761.6	240.8	395.6	155	85.0	31.7	1.0:2.0	1.0:3.0	<2.5	2.00
F3	380.0	932.7	294.9	342.0	133	90.0	23.6	1.0:3.0	1.0:3.0	<2.5	2.00
P1	618.9	506.4	176.4	464.2	158	75.0	47.5	1.0:1.0	1.0:3.0	<0.6	0.85
P2	465.4	761.6	265.2	395.6	155	85.0	31.2	1.0:2.0	1.0:3.0	<0.6	0.85
P3	380.0	932.7	324.8	342.0	135	90.0	23.2	1.0:3.0	1.0:3.0	<0.6	0.85

3.3. Specimens and their curing conditions

The slaked lime mortar specimen is a cube measuring 4cm × 4cm × 8cm. As slaked lime possesses an air hardening property (the chemical reaction of carbon dioxide in air and calcium hydroxide in slaked lime generates calcium carbonate; $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$), specimens initially made as 4cm × 4cm × 16cm according to JIS R 5201 are demolded at 3 days after air curing, cut into equal parts at the age of 14 days and then additionally air cured. The number of specimens is three for each measurement.

3.4. Measurement items and experimental method

Measurement items are mass, specific gravity, water content, colorimetric value, static and dynamic moduli of elasticity, and compressive strength of the mortar. Material tests are carried out for each measurement item of the age of 4, 13, 26, (39), 52, and (78) weeks. Water content is measured on the side surface of each specimen. With respect to color measuring points, 5 points of the side surface, 5 points of the placing surface of the mortar, and 5 points of the cutting plane, for a total number of color measuring points of 15. The side surface without uneven represents an ideal condition. On the other hand, both the placing surface and cutting plane are close to the actual state of historical masonry structures.

The compressive strength and dynamic modulus of elasticity tests are carried out according to JIS A 1108 and JIS A 1127, respectively. The specific gravity test of slaked lime is followed by the density test in JIS R 5201. Water is used instead of mineral oil so that slaked lime does not cause a chemical reaction with water due to air hardening. The specific gravity test and absorption test of crushed brick are carried out according to JIS A 1109.

4. RESULTS AND DISCUSSION

4.1. Specific gravity, water content and mechanical characteristics

Figure 2 shows the development of specific gravity. As carbon dioxide in air and slaked lime react in all kinds of specimens as curing progresses, specific gravity increases and its rate is almost the same in each specimen. As the relative amount of slaked lime increases, water content (high frequency capacity) becomes smaller.

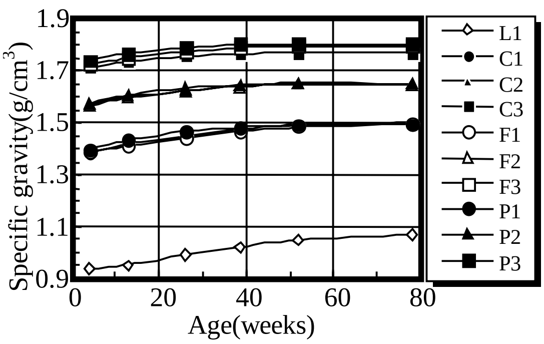


Figure 2 Development of specific gravity

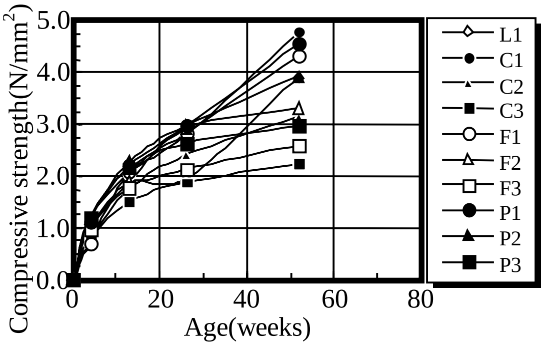


Figure 3 Development of compressive strength

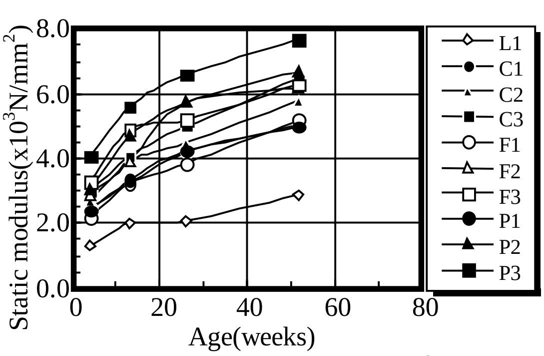


Figure 4 Development of static modulus of elasticity

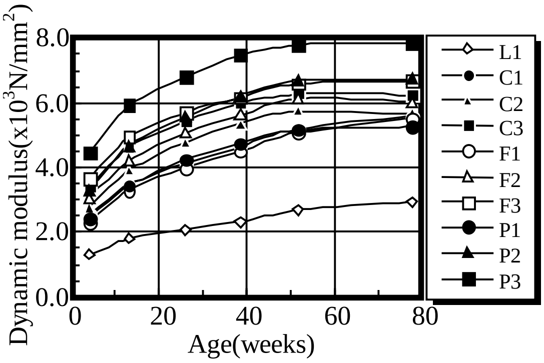
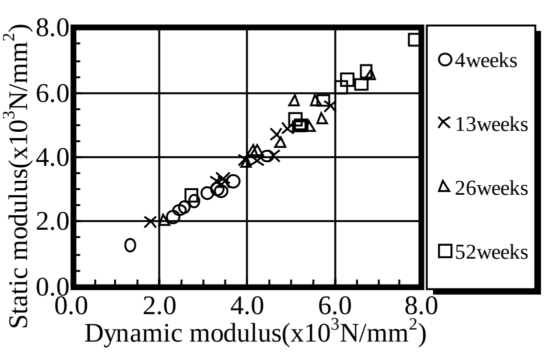


Figure 5 Development of dynamic modulus of elasticity



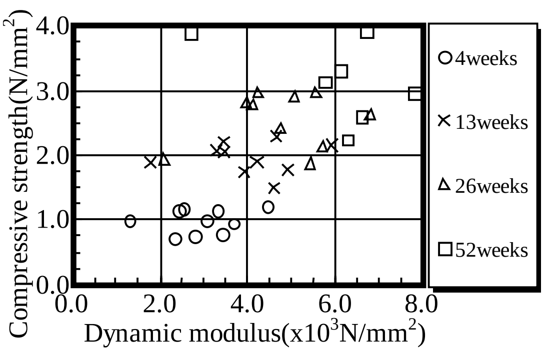


Figure 6 Relationship between static and dynamic moduli of elasticity

Figure 7 Relationship between compressive strength and dynamic modulus of elasticity

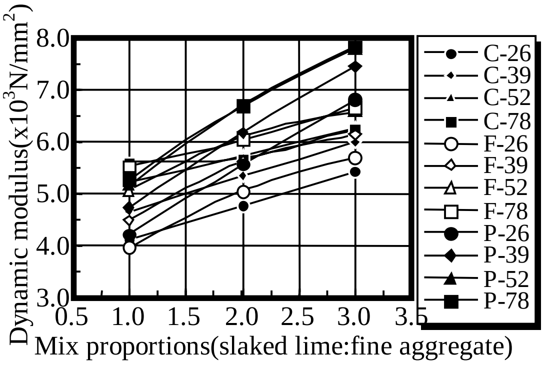


Figure 8 Relationship between dynamic modulus of elasticity and mix proportions

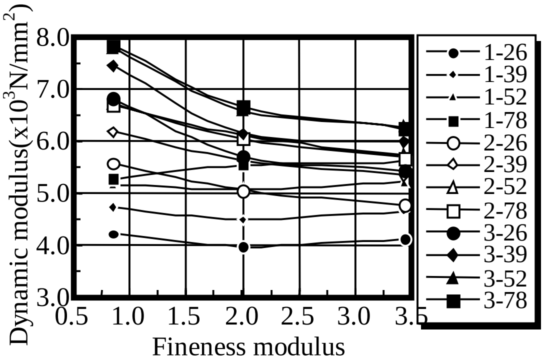


Figure 9 Relationship between dynamic modulus of elasticity and fineness modulus

The development of compressive strength, static and dynamic moduli of elasticity of the mortar are shown in Figures 3 to 5. These figures show that compressive strength, static and dynamic moduli of elasticity become larger as the number of days increases with few variations to each specimen.

Figures 6 and 7 show relationships between static modulus of elasticity, compressive strength and dynamic modulus of elasticity, respectively. As dynamic modulus of elasticity becomes higher, compressive strength and static modulus of elasticity also increase proportionally.

Figures 8 and 9 show relationships between dynamic modulus of elasticity and mix proportions and fineness modulus of crushed brick. In these figures, number after mark "-" represents the age of weeks. Obviously, the dynamic modulus of elasticity with brick powder (P) is higher than that without it since specimens become dense by filling the voids between the particles of aggregates. As the mixing ratios of fine aggregate and crushed brick increase, dynamic modulus of elasticity becomes higher. The same behavior is obtainable for mass, specific gravity, and compressive strength.

4.2. Surface color and mix proportions

Figures 10 and 11 show the development of lightness and chromaticity of the side surface, respectively. The results of experiments show that chroma value C^* increases as the number of days progresses for all the specimens. This implies that yellow-red becomes vivid and lightness value L^* becomes small. Relationships between lightness, chromaticity of the side surface and mix proportions, fineness modulus are shown in Figures 12 to 15. Regardless of the mixing ratio by volume, specimens with brick powder (P) are more vivid and darker than those without it. As the ratio of fine aggregate and crushed brick per slaked lime increases, it becomes confirmative that chroma value increases and lightness becomes smaller. The same tendency is obtained for both the placing surface and the cutting plane.

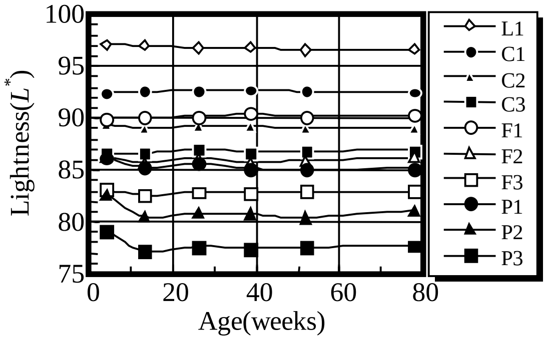


Figure 10 Development of lightness

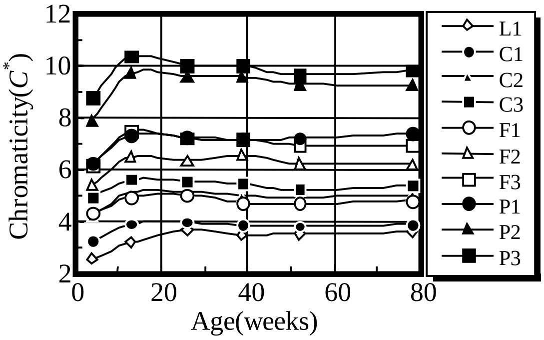


Figure 11 Development of chromaticity

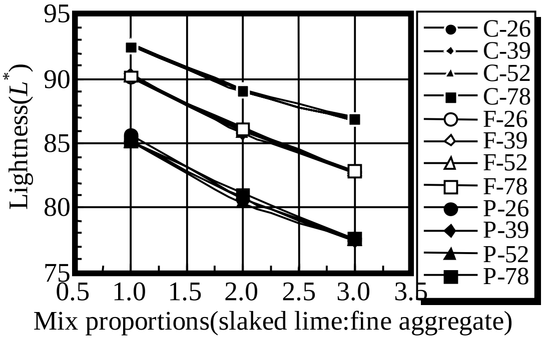


Figure 12 Relationship between lightness and mix proportions

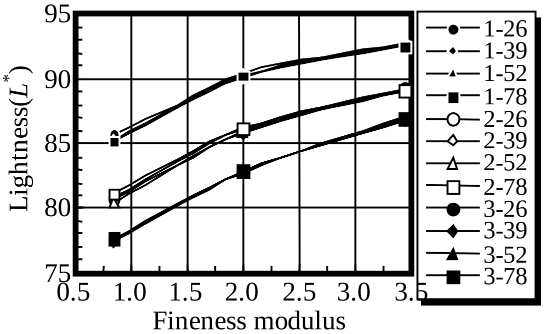


Figure 13 Relationship between lightness and fineness modulus

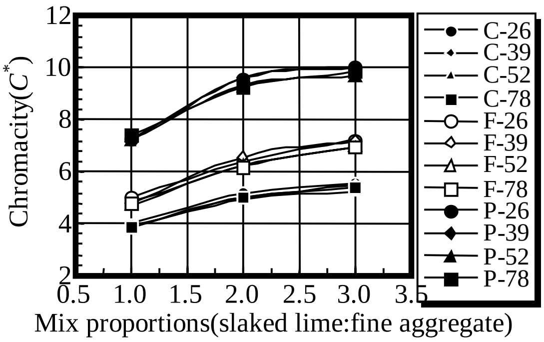


Figure 14 Relationship between chromaticity and mix proportions

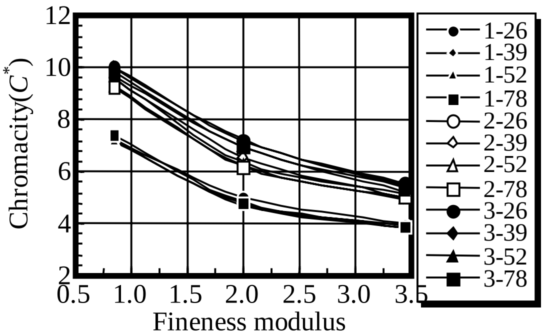


Figure 15 Relationship between chromaticity and fineness modulus

Table 2 shows the influence of mix proportions on colorimetric value of the side surface. This table shows that lightness value L^* becomes higher and red

(a^*) and yellow (b^*) values become smaller according to the amount of slaked lime. On the other hand, as the amount of fine aggregate and crushed brick increase, a^* and b^* values become larger and L^* value becomes smaller. Since multi-correlation coefficients are more than 0.95 in each case, there appears a high correlation between surface color and mix proportions.

The influence of colorimetric value of the side surface on mix proportions are listed in Table 3. As lightness L^* value becomes higher, the amount of slaked lime increases, but the amount of fine aggregate and crushed brick decrease. On the other hand, as red (a^*) and yellow (b^*) values become larger, the amount of slaked lime decreases and of fine aggregate and crushed brick increase. Since multi-correlation coefficients are more than 0.95 in each term, there is a high correlation between mix proportions and surface color. This means that it is possible to predict the mix proportions by color measurement.

Table 2 Influence of mix proportions on colorimetric value

Corr. coef.	Slaked Lime L	Fine aggregate S	Crushed brick B	Fineness modulus F	Multi-corr. coef.
L^*	0.7939	-0.7936	-0.9070	0.1733	0.9928
a^*	-0.6906	0.7013	0.8399	-0.2628	0.9924
b^*	-0.6269	0.6192	0.7648	-0.3671	0.9523
C^*	-0.6132	0.6089	0.7649	-0.3986	0.9768

Table 3 Influence of colorimetric value on mix proportions

Corr. coef.	L^*	a^*	b^*	C^*	Multi-corr. coef.
L	0.7939	-0.6906	-0.6269	-0.6132	0.9783
S	-0.7936	0.7013	0.6192	0.6089	0.9825
B	-0.9070	0.8399	0.7648	0.7649	0.9882
F	0.1733	-0.2628	-0.3671	-0.3986	0.9546

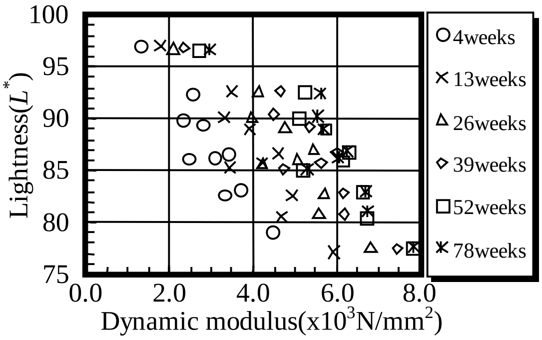


Figure 16 Relationship between lightness and dynamic modulus of elasticity

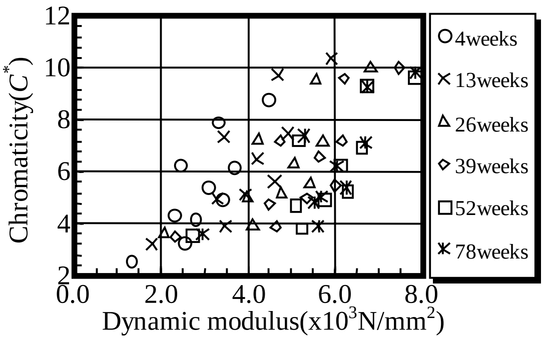
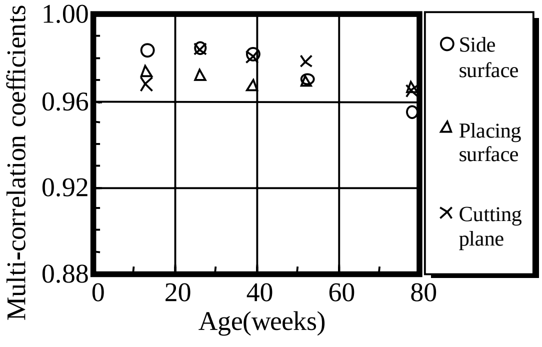


Figure 17 Relationship between chromaticity and dynamic modulus of elasticity



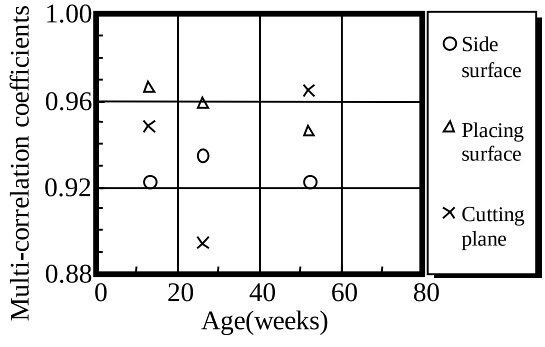


Figure 18 Development of multi-correlation coefficients relating to dynamic modulus of elasticity

Figure 19 Development of multi-correlation coefficients relating to compressive strength

4.3. Expressions for mix proportions

Within the limits of experiments at the age of 13 to 78 weeks, expressions for mix proportions determined by multi-regression analysis are given by

$$L = 94.0L^* + 7.19a^* - 305b^* + 330C^* - 8095 \quad (1)$$

$$S = -156L^* + 91.0a^* + 651b^* - 721C^* + 15407 \quad (2)$$

$$B = -41.5L^* + 23.6a^* + 121b^* - 149C^* + 4129 \quad (3)$$

$$F = -0.310L^* + 1.34a^* + 4.90b^* - 4.96C^* + 31.0 \quad (4)$$

where, L, slaked lime (g), S, fine aggregate (g), B, crushed brick (g), F, fineness modulus, respectively. $L^*a^*b^*C^*$ represent colorimetric values ($L^*a^*b^*$ color space) defined by equations (1) to (4). Mix proportions can be predicted by substituting the values of the colorimetric value of the side surface into equations (1) to (4). The contribution percentages of equations (1) to (4) are 95.7%, 96.5%, 97.7% and 91.1%, respectively. The same tendency is obtained for both the placing surface and the cutting plane.

4.4. Expressions for dynamic modulus of elasticity and compressive strength

Within the limits of experiments at the age of 78 (52) weeks, expressions for dynamic modulus of elasticity and compressive strength determined by multi-regression analysis are given by

$$E_D = -0.403L^* + 0.252a^* + 0.395b^* - 1.03C^* + 44.5 \quad (5)$$

$$\sigma_c = 0.712L^* + 1.68a^* + 0.412b^* - 0.286C^* - 64.5 \quad (6)$$

where, E_D, dynamic modulus of elasticity ($\times 10^3 N/mm^2$), σ_c, compressive strength (N/mm^2), respectively. The estimation of dynamic modulus of elasticity and compressive strength can be made by substituting values of colorimetric value of the side surface into equations (5) and (6). As red and yellow become more vivid, that is a^* and b^* increases, dynamic modulus of elasticity and compressive strength become higher. The contribution percentages of equations (5) and (6) are 91.3% and 85.1%, respectively. The estimation of tensile strength and static modulus of elasticity can be given elsewhere [6]. Figures 18 and 19 show the development of multi-correlation relating to dynamic modulus of elasticity and compressive strength, respectively. Where, purpose variable is dynamic modulus of elasticity or compressive strength and explanation variable is colorimetric values $L^*a^*b^*C^*$. As seen in these Figures, the same tendency is obtained for both the placing surface and the cutting plane.

5. CONCLUSIONS

The following concluding remarks are obtained:

1) As the ratio of slaked lime increases, water content (high frequency capacity) becomes smaller as the number of day progresses.
2) As the fineness modulus of crushed brick becomes smaller and the amount of fine aggregate and crushed brick against slaked lime increases, the mass, specific gravity, compressive strength, static and dynamic moduli of elasticity of mortar become large.
3) The influence of mix proportions on surface color is investigated and the relationship between surface color and mechanical characteristics is obtained. Expressions for mix proportions as well as for mechanical characteristics of the mortar are proposed based on the experiments.
4) There is large correlation between surface color and mechanical characteristics, and it is possible to predict the mix proportions and mechanical characteristics by color measurement under ideal condition.

The present research is undertaken with the goal of conserving historical masonry structures. Hereafter, experiments for statistical evaluation for mix proportions and mechanical characteristics over the long-term are to be studied and the realization of a non-destructive test by color discussed.

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COMPARISON BETWEEN THERMAL ANALYSES AND X-RAY DIFFRACTOMETRY FOR THE CHARACTERISATION OF ANCIENT MAGNESIUM LIME MORTARS

M. Macchiarola (1), B. Fabbri (1), C. Fiori (2)
(1) C.N.R., Istituto di Ricerche Tecnologiche per la Ceramica, Faenza and Ravenna, Italy
(2) Università di Bologna, Dip. di Storie e Metodi per la Conservazione dei Beni Culturali, sede di Ravenna, Italy

ABSTRACT

Magnesium lime mortars, produced through the calcination of dolomitic limestones, can be recognised by the identification of magnesian phases such as: magnesite, hydromagnesite, brucite and nesquehonite.

A study was performed using differential thermal (DTA) and thermal gravimetric (TGA) analyses, conducted simultaneously, and X-ray diffractometry (XRD) on a large sampling of magnesium lime mortars of various ages, taken from monuments and historic buildings in three Italian cities.

The comparison between the two analytical methods employed confirms the validity of thermal analyses in the study of magnesium lime mortars, in that they are able to detect and quantify the magnesian phases indicative of a mortar produced by calcination of dolomitic limestones.

The identification of these same phases by diffractometry is more difficult, and their quantification is unreliable.

1. INTRODUCTION

The careful study of the composition of ancient mortars, for what concerns both the aggregate and binder, makes it possible to obtain precise information about the raw materials used, their provenance and the preparation methods employed in the past.

The characterisation of ancient mortars, combined with the analytical study of the degradation products, is clearly of fundamental importance for the planning and implementation of a correct conservation programme.

In recent years, the study of ancient and traditional mortars by differential and gravimetric thermal analyses (DTA-TGA) conducted simultaneously has proven particularly interesting [1, 2, 3 and 4]. In fact, this method of analysis makes it possible to identify and quantify, generally with a good level of precision, the principal components of the ancient mortars. In addition, DTA-TGA thermal analyses provide further qualitative-quantitative information about the principal degradation products of the mortars, such as gypsum and calcium oxalates, detecting the presence of organic compounds associated with atmospheric depositions of natural or anthropic origin, or with treatments (protective and/or consolidating of an organic base) applied in the past [5 and 6]. Finally, DTA-TGA analyses are particularly suitable for studying mortars of architectural and archaeological interest, because despite being destructive in character they only require a few milligrams of material for each test.

Among the different types of ancient mortars, those less studied are very probably magnesium lime mortars, due to their low frequency of finding. These are mortars prepared with lime produced by the calcination of dolomitic limestones. They can be recognised through the detection of magnesian phases such as: magnesite, brucite, hydromagnesite and nesquehonite produced during the setting phase by the carbonation and/or hydration of the magnesian fraction of the binder. The structure of the magnesian phases is microcrystalline or even amorphous; in this case, their identification by analytical methods such as X-ray diffractometry (XRD) and optical microscope observations (OM) is generally problematic and in some cases impossible.

The aim of this work was to evaluate the suitability of differential and gravimetric thermal analyses for the study of ancient magnesium lime mortars. In particular, we assessed the ease of using DTA-TGA analyses for identifying and quantifying the magnesian phases, as compared with X-ray diffractometry (XRD).

The validity of thermal analyses for the study of magnesium lime mortars was tested on different mortar samples of various ages, taken from three Italian cities (Palermo, Salerno and Milan).

2. EXPERIMENTAL SECTION

The study was conducted on mortars believed to be magnesian, taken from three different historical, architectural and geographical contexts. In fact, we examined:

- nineteen samples of plaster taken from buildings in the historic centre of Palermo (3 decorations, 7 finishes and 9 bedding mortar) ranging in age from the 17th to the 19th century;
- five samples of 8th century mosaic mortars belonging to the wall mosaics of Church of S. Pietro a Corte in Salerno (3 setting mortars and 2 plasters);

- six samples of original and restoration mosaic mortars, ranging in age from the 9th to the 20th century, from the wall mosaics of the Church of S. Ambrogio in Milan (2 setting mortars dated between the 9th and 12th century, 2 restoration setting mortars from the 19th century, 1 restoration setting mortar from the 20th century and 1 restoration plaster from the 19th century).

The Palermo mortars were identified by the prefix PA, followed by a number and an additional code indicating the neighbourhood in which the sampled historic building is situated, and the stratigraphic position of the sample. The Salerno mortars were identified by the prefix SA, and the Milan mortars by the prefix MI.

All the mortars (30 samples) were ground into powder and examined by differential and gravimetric thermal analyses (DTA-TGA) conducted simultaneously in air, using a STANTON STA 1500 apparatus and platinum crucibles. The tests were carried out between 20 °C and 1000 °C, with a constant heating rate of 10 °C per minute. The quantity of material used for each individual test was between 6 and 17 milligrams approximately.

The mineralogical phases in the samples were investigated by means of X-ray diffraction analysis (XRD), using a Rigaku Dmax IIIC diffractometer with $CuK\alpha_1$ radiation, a current intensity of 30 mA and a potential difference of 35 KV. The investigated angle interval 2θ was between 4° and 64°, with a scanning rate of 2° per minute.

3. RESULTS AND DISCUSSION

3.1. Thermal analyses (DTA-TGA)

The results obtained by the DTA-TGA thermal analyses are given in Table 1 as weight percentages, calculated stoichiometrically from the loss of weight measured by TGA, after having attributed the various thermal effects to a specific compound.

The DTA-TGA analyses indicate the presence of one or more magnesian phases in nearly all the samples examined. In fact, out of thirty samples investigated, only four (PA6MAII, PA6MAI, PA5MAI and MI4) did not contain at least trace levels of magnesian phases. We can therefore assume that these four samples were prepared using non-magnesian lime.

The magnesian phase most commonly observed is magnesite ($MgCO_3$), which appears in 21 samples. The calculated quantities of this compound are exceedingly variable (maximum concentration approximately 27%), and obviously depend on the dolomite content in the carbonate raw material. In the experimental phase, the endothermic peak corresponding to the decarbonation of magnesite was found to occur between 420 and 500 °C approximately. This strong variability of the decarbonation reaction temperature can be explained by the varying degrees of crystallisation of the magnesite in the different samples examined. In those samples where the magnesite occurs as larger sized crystals, the decarbonation reaction takes place at higher temperatures, and vice versa.

Some manuals for the recognition of inorganic compounds by DTA analysis [7] place the endothermic peak due to the decarbonation of magnesite at considerably higher temperatures. The significantly lower temperatures observed for magnesite in this work can be attributed to the fact that we operated in different experimental conditions. In particular, this study used considerably smaller quantities of materials for testing, and a much lower heating gradient, which shifts all the reactions to a lower temperature. In any case, its certain identification as magnesite is confirmed by the XRD analyses.

Table 1. Concentrations (%) obtained by DTA-TGA analyses

Sample	**calcite + dolomite**	**magne_ site**	**hydroma_ gnesite**	**bru_ cite**	**nesque_ honite**	**gypsum**	**quartz**
PA2MAII	65	3				tr.	*
PA6MAII	34						**
PA11VUII	45	7	2				**
PA21ALII	36	7	2				***
PA32CAII	36	8				3	***
PA35CAII	70		3				*
PA38VUII	63	tr.	tr.			tr.	*
PA40ROIII	46	10				tr.	**
PA7LUII	57			3		tr.	**
PA2MAI	54		2			1	*
PA6MAI	72						-
PA11VUI	30	8	3			tr.	***
PA24CAIII	38	9				tr.	**
PA32CAI	41	20				11	*
PA35CAI	82	5	4				-
PA40ROI	38	11					***
PA5MAI	44						***
PA31CAI	51	5				7	***
PA34CAI	34	7				2	***
SA3	15	tr.			tr.		*
SA7	33	10			tr.		*
SA8	68				tr.	tr.	-
SA10	88				tr.		-
SA11	74	6	7				-
MI1	51	27					-
MI3	69	7	8			tr.	-
MI4	36					tr.	-
MI5	66	3	12			2	-
MI6	57	14				tr.	*
MI8	48	5		16			-

tr. = traces
*** = abundant, ** = scarce, * = traces, - = not detected

A less frequent and on the whole less plentiful phase is hydromagnesite ($Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$), which appears in 10 samples with a maximum content of 12% approximately (MI5). Hydromagnesite is recognised by the presence, on the DTA curve, of three endothermic peaks. The first appears at a temperature between 250 and 270 °C approximately, and corresponds to the loss of the four unbound water molecules; the second occurs at a temperature between 365 and 400 °C and corresponds to the loss of the hydroxyl group; the third, corresponding to the decarbonation reaction (420–450 °C), is generally weak and, in the presence of magnesite, often not distinguishable from the endothermic decarbonation peak of this compound [1 and 8].

A decidedly rarer phase is brucite ($Mg(OH)_2$), which appears in only two samples (PA7LUIIC, 3% and MI8, 16%). When heated, this phase is dehydrated (endothermic reaction) at a temperature equal to or slightly below 400 °C (390–400 °C).

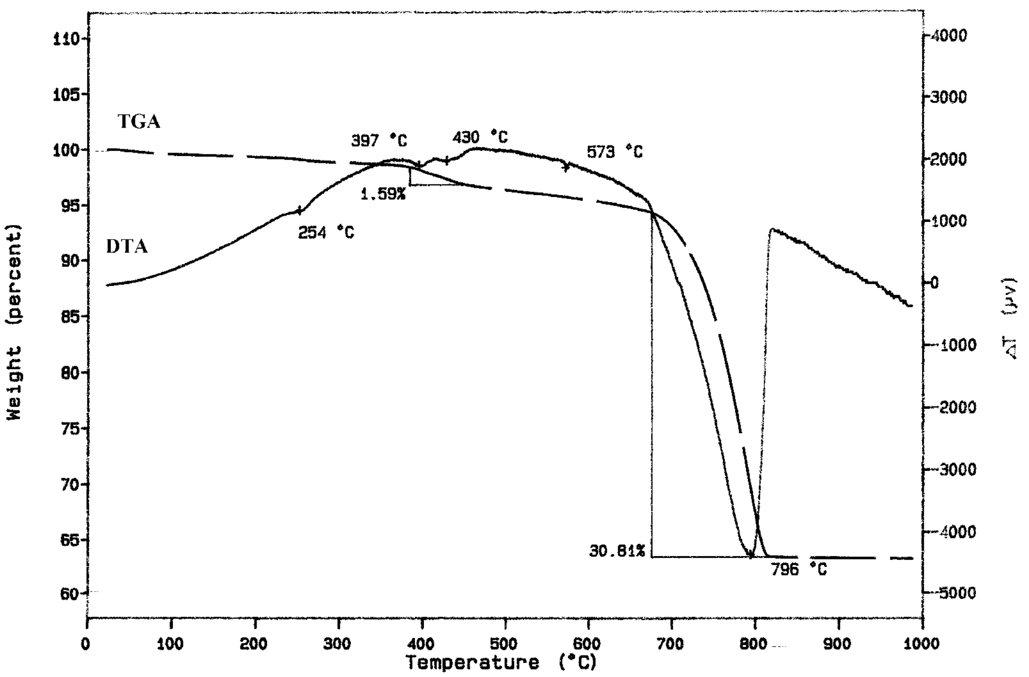

Figure 1. DTA-TGA thermogram of sample PA35CAII. The three endothermic peaks on the DTA curve at the temperatures of 254, 397 and 430 °C identify the presence of hydromagnesite.

Nesquehonite ($MgCO_3 \cdot 3H_2O$) instead appears at trace levels in only four of the Salerno samples. The decomposition takes place in two phases at the temperatures of approximately 350 °C and 430–460 °C respectively.

Because the DTA-TGA thermal analyses do not always precisely distinguish dolomite from calcite, Table 1 shows the sum of the two minerals, calculated as if it was only calcite.

From the data in Table 1 we note the presence of gypsum in many of the analysed samples. The detected gypsum is the result of sulphation phenomena (transformation of calcite into gypsum), due to the dry and wet deposition of sulphur, released into the atmosphere by the combustion of fossil fuels (oil and coal) which contain this element in varying amounts [9 and 10].

For what concerns the quartz content, only an estimate is given. In fact, quartz is identified by thermal analyses through the endothermic reaction in which it changes from the α to the β structural form. Under the experimental conditions used in this study, this reaction takes place at 573 °C and is not accompanied by any change in the weight of the sample. The concentration of quartz in the samples analysed was therefore estimated based on the amount of heat produced by the above mentioned reaction.

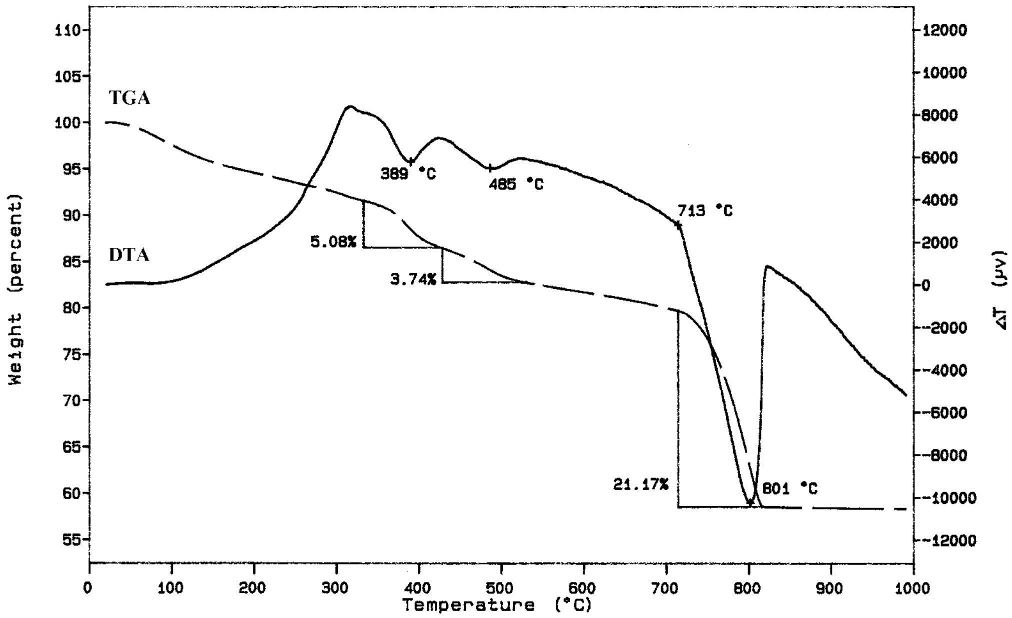

Figure 2. DTA-TGA thermogram of sample MI8. The two endothermic peaks at 389 and 485 °C identify the presence of brucite and magnesite respectively.

3.2 X-ray diffractometry (XRD)

The crystalline phases identified by XRD analysis are shown in Table 2. The diffraction analyses detected the presence of magnesian phases (magnesite, hydromagnesite and brucite), but not in all the samples in which they were detected by thermal analysis, and the quantities detected are generally traces. In agreement with the results of the DTA-TGA analyses, the magnesian phase most commonly found by XRD analysis was magnesite (17 samples); followed by traces of hydromagnesite (5 samples) and brucite in only one sample (MI8). The presence of nesquehonite was never detected. In particular, no magnesian phases were detected in the four samples which did not have thermal effects associated with those phases (PA6MAII, PA6MAI, PA5MAI and MI4).

Table 2. Crystalline phases identified by X-ray diffractometry analyses

Sample	**Ca**	**Do**	**Ma**	**Hy**	**Br**	**Qz**	**Pl**	**Mi**	**Gy**	**Cm**	**Py**
PA2MAII	°°°°	°°				°°			tr.	tr.	
PA6MAII	°°	tr.				°°°°				tr.	
PA11VUII	°°°	°				°°°°	tr.			tr.	
PA21ALII	°°	tr.	tr.			°°°°				tr.	
PA32CAII	°	tr.	tr.			°°°°	tr.			tr.	
PA35CAII	°	°°°°		tr.		°°	tr.			tr.	
PA38VUII	°	tr.	tr.	tr.		°°°°			tr.		
PA40ROIII	°°	°	tr.			°°°°			tr.	tr.	
PA7LUII	°°	°				°°°°					
PA2MAI	°°°°	°				°°°			tr.	tr.	
PA6MAI	°°°°	tr.				°					
PA11VUI	°°°	tr.	tr.			°°°°	tr.		tr.	tr.	
PA24CAIII	°	tr.	tr.			°°°°					
PA32CAI	°°°°	tr.	tr.			°°°°			tr.		
PA35CAI	°	°°°°	tr.	tr.		°					
PA40ROI	°°	°	tr.			°°°°				tr.	
PA5MAI	°°°°	°°°				°°°°					
PA31CAI	°	tr.	tr.			°°°°	tr.			tr.	
PA34CAI	°°	tr.	tr.			°°°°				tr.	
SA3	°°°	°°	tr.			°°°	°°°°	°			°
SA7	°°°	°°	°			°°	°°	°			°°
SA8	°°	°°°°				tr.					
SA10	°°°	°°°°				tr.					
SA11	°°°°	°°	tr.	tr.							
MI1	°°°°		°°								
MI3	°°°°	tr.	tr.			°					
MI4	°°°°					°°					
MI5	°°°°	°		tr.		tr.					
MI6	°°°°		tr.			tr.			tr.		
MI8	°°°°	°			°	°°					

Ca = calcite, Do = dolomite, Ma = magnesite, Hy = hydromagnesite, Br = brucite, Qz = quartz, Pl = plagioclases, Mi = micas, Gy = gypsum, Cm = clay minerals, Py = pyroxenes
°°°° = very abundant, °°° = abundant, °° = discrete, ° = scarce, tr. = traces

Looking at the most frequently detected magnesian phase (magnesite), we note that there is no correspondence between the quantities of this component determined by thermal analysis and those determined by XRD analysis. In fact, in many cases concentrations much higher than 5% are detected as traces by diffractometry, without distinguishing them from other cases where the magnesite concentrations are approximately equal to or less than 5%. It therefore appears that the amount of magnesite detected by XRD analysis is influenced more by the degree of crystallinity of the compound than by its effective abundance in the mortar under study. This is probably true for all the magnesian phases, because often it is only the principal reflex of each compound that appears on the diffractogram.

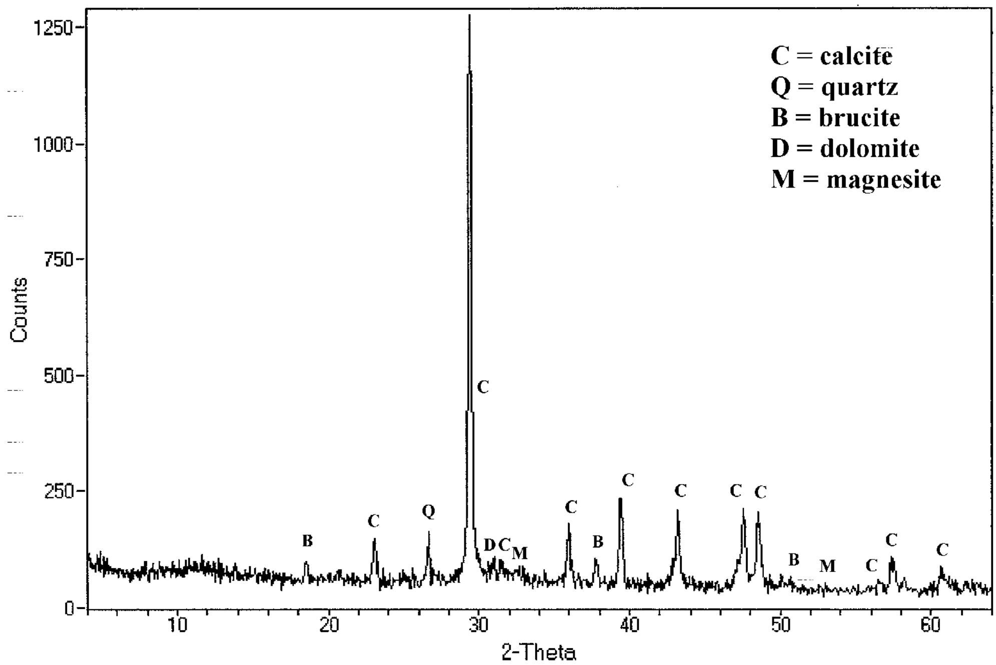

Figure 3. X-ray diffractogram of sample MI8 (the thermogram is shown in Figure 2). The reflections corresponding to brucite (B) and magnesite (M) appear especially weak. In particular, the two reflections attributable to magnesite are barely distinguishable from the background radiation.

Table 2 shows the presence of dolomite in varying amounts in nearly all the samples examined. This mineral is obviously attributable to the presence of dolomitic granules within the aggregate. This indicates that a part of the aggregate used to prepare the mortars was obtained from the same lithostratigraphic units used for producing the magnesian limes, or from natural sands originating from these units.

Calcite was found in varying concentrations in all the analysed samples, because it always constitutes the binder (lime), and in many cases also constitutes a significant part of the aggregate.

Clearly attributable to the aggregate is the presence of quartz, followed by much lower concentrations of plagioclases, pyroxenes, micas and clay minerals.

The traces of gypsum found in some samples are attributable, as already stated in the preceding paragraph, to the sulphation of the carbonate binder.

4. CONCLUSIONS

The comparison between thermal (DTA-TGA) and diffractometry (XRD) analyses performed on a sizeable number of ancient magnesium lime mortars from three Italian localities (Palermo, Salerno and Milan) has underlined:

- The possibility of using thermal analysis to identify and quantify magnesian phases such as: magnesite, hydromagnesite, brucite and nesquehonite, which can be considered indicative of lime obtained from the calcination of dolomitic limestones. Naturally the quantities of magnesian phases identified can provide useful information for reconstructing the composition of the calcinated dolomitic limestone and hence determining its provenance.
- The identification of the same magnesian phases is not always possible by XRD analysis, due to their microcrystalline structure. Magnesian phases present in the mortars in considerable amounts are often only detected based on the presence of their principal reflex with weak intensity. Therefore the estimated concentrations for any magnesian phases identified are highly unreliable.
- The decomposition of the magnesian phases during thermal analysis takes place at temperatures which can vary considerably from one sample to the next, thereby casting doubt, at times, on the attribution of the observed reactions. This is especially true for brucite and magnesite. The latter had decomposition temperatures which varied from just over 400 °C to approximately 500 °C, which is still well below the value most frequently given in the literature.

It is in any case important to underline that the complete characterisation of a mortar, independently of its type, is only possible by combining the results of thermal and diffraction analysis, and perhaps using other types of analysis as well.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

Effects of Migrating Corrosion Inhibitors on Reinforced Lightweight and Common Mortars

G. Batis, E. Rakanta
Section of Materials Science and Engineering
Dept. of Chemical Engineering, National Technical University, Athens, Greece

ABSTRACT

In reinforced landmark, historical buildings, a series of mortars are commonly used for rendering of horizontal elements or filling of vertical ones. Corrosion of reinforcing steel represents the most important cause of concrete structure deterioration. This paper studies the protective effect of the reinforcement mortars, against rebars corrosion in mortar specimens containing corrosion inhibitors as admixture or as impregnation agent.

The migrating corrosion effectiveness was assessed in lightweight concrete with Greek pumice stone and in common mortar specimens. The inhibiting behavior of organic aminobased migrating corrosion inhibitors against steel corrosion was evaluated by specimens' immersion into 3,5%w.t. sodium chloride corrosive solution and by exposure to the atmosphere. The corrosion activity and inhibiting efficiencies (IE) were tested by measuring the rebars weight loss, their half - cell potential, carbonation depth and electrochemical measurements of chronicles corrosion rate of rebars in concrete specimens.

The results of our experiments have shown that the presence of the inhibiting protection increases in the mortars systems with the usage of migrating corrosion inhibitor compared to the reference specimens without corrosion inhibitor. Furthermore, common mortar specimens exhibited lower rebar corrosion rate than the lightweight concrete specimens. Finally, specimens with corrosion inhibitor exhibited the best corrosion protection results in corrosive conditions without chloride ions.

1. INTRODUCTION

Corrosion of reinforcing steel embedded in concrete is becoming a significant structural and financial problem. As it is known, in Greece, many historical buildings and structures are located in coastal regions (islands) where the weather is characterized by pollutants such as part particles Cl^- and carbon dioxide, CO_2. This leads to an increased incidence of spalls, delimination and as a consequence the deterioration of concrete in reinforced structures.

In restorations, a series of traditional construction materials such as mortars, steel and grouts are commonly used for repairing and filling elements of structures. They are generally composed of cement, sand, lime and water or cement, sand, superplastisizer, and water **[1]**. Due to the fact, that the rest of the construction and the repair mortar have high porosity, the durability of these mortars is questionable as far as the corrosion of the reinforcement steel. This results in an attack from probably all sides as the water can penetrate either from the foundation and leakages in the roof or from porous walls **[2]**. As a result to a all above mentioned, many times the use of chemical admixture is essential due to blocking the ingress of chloride ions and oxygen, increasing the resistance of the passive film on the steel to breakdown by chloride ions.**[3-4]**

The use of chemical admixtures, which acts as corrosion inhibitors, is a method for preventing and delaying the onset of rebar corrosion. An ideal corrosion inhibitor has been defined as "a chemical compound, which, when added in adequate amounts to concrete, can prevent corrosion of embedded steel and has no adverse effect on the properties of concrete" **[5]**. Nowadays chemical corrosion inhibitors present an easily implemented solution to the growing problem of corrosion of reinforcing steel in concrete. However, to be considered viable, these additives should not only prevent or delay the onset of corrosion, they must not have any detrimental effect on the properties of the concrete itself, such as strength, setting time, workability and durability **[6]**. It must be clarified, that corrosion inhibitors do not totally stop corrosion, but rather increase the time to the onset of corrosion and reduce its eventual rate. Drawbacks of corrosion inhibiting admixtures are that they may not remain in the repair area, potentially reducing the concentration of the inhibitor bellowing necessary values and secondly, when used in a limited area long a continuous reinforcing bar, there is the potential for micro cell corrosion development **[7]**.

The aim of this study is the examination of the performance, in chloride environment of two different sets of steel reinforced mortar specimens (lightweight and common mortar) together with corrosion inhibitor in an effort to lower the corrosion rate of steel reinforcement. Corrosion parameters such as corrosion rates, I_{corr}, R_p of reinforcing steel in mortar specimens from two differences types of mortar have been evaluated by electrochemical measurements and compared with that obtained from metal loss determination. Electrochemical corrosion measurements gives a snapshot of how the system mortar – steel behaved under corrosive environments versus time. Linear polarization, as well as

Tafel technique are not destructive methods for assessing the instantaneous corrosion current density. It has been widely used in monitoring corrosion of laboratory measurements and allowed to compare the performance of inhibitors in mortars specimens **[8]**.

2. MATERIALS AND EVALUATION METHODS

2.1. Materials

Greek Portlant cement was used for whole mortar specimens in this study. The chemical composition is given in Table 1.

Half of the test specimens were constructed with lightweight aggregate and the rest of them were with Greek sand. The use of the porous lightweight aggregates results in porosity increase, which could negatively affect the corrosion rate if steel rebars.

The lightweight aggregate used was a Greek porous pumice of 0 to 8mm diameter. The mean value of the sand grains diameter was 250μm < d < 4mm.

Round deform med reinforcing steel, nominally 12mm in diameter (Φ12) was used for all test specimens. Fabrication of the steel for the test specimens simply involved cutting to the consistent length of 100mm. Their chemical composition is given in Table 1.

Drinking water from Athens water supply network and INHIB-M, corrosion inhibitor alkanolamines based on, were used for the specimens' construction. The corrosion-inhibiting admixture was used according to the manufactures instructions regarding dose rate and mixing into the concrete. INHIB-M protects both the anodic and cathodic parts of the corrosion all. It's claimed to work by depositing a physical barrier in the form of the surface film that inhibits corrosion of the steel by preventing contact between moisture and oxygen. The inhibitor is able to diffuse through the concrete through either a vapor or liquid phase.

Table1: chemical composition % of OPC cement.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	$CaO_{(f)}$	LOI
20.67	4.99	3.18	63.60	2.73	0.37	0.29	2.414	2.41	2.52

Table2: chemical composition % of steel rebars.

C	Mn	S	P	Si	Ni	Cr	Cu	V	Mo
0.18	0.99	0.047	0.023	0.15	0.09	0.09	0.21	0.002	0.021

2.2. Specimens Casting

The test specimens considered for the present study were 80mm long, 80mm wide and 100mm high. They contained four identical steel rebars in the position shown in figure 1. Copper wire cables were connected to each steel bar for electrochemical measurements. Prior to the preparation, the surface of the steel bars were washed with water, then immersed for 15 min in strong solution of HCl with organic corrosion inhibitor washed thoroughly with distilled water to eliminate traces of the corrosion inhibitor and chloride ions. Following that, they were cleaned with alcohol and with acetone and then weighed to 0,1mg accuracy.

Thereafter, the bars were placed in moulds, as shown in figure 1, where the mortars was cast and stored at ambient conditions in the laboratory for 24 hours. After being demolded, were cured in tap water at 25 ^{o}C for 24 hours.

The specimens were stored for an additional 24h at ambient temperature and thereafter the part shown in Figure 1 was insulated with epoxy resin.

Finally half of them were partially immersed in 3.5% w.t NaCl solution up to 20mm from the bottom of the mortar specimens and the rest of them were exposed to the atmospheric conditions.

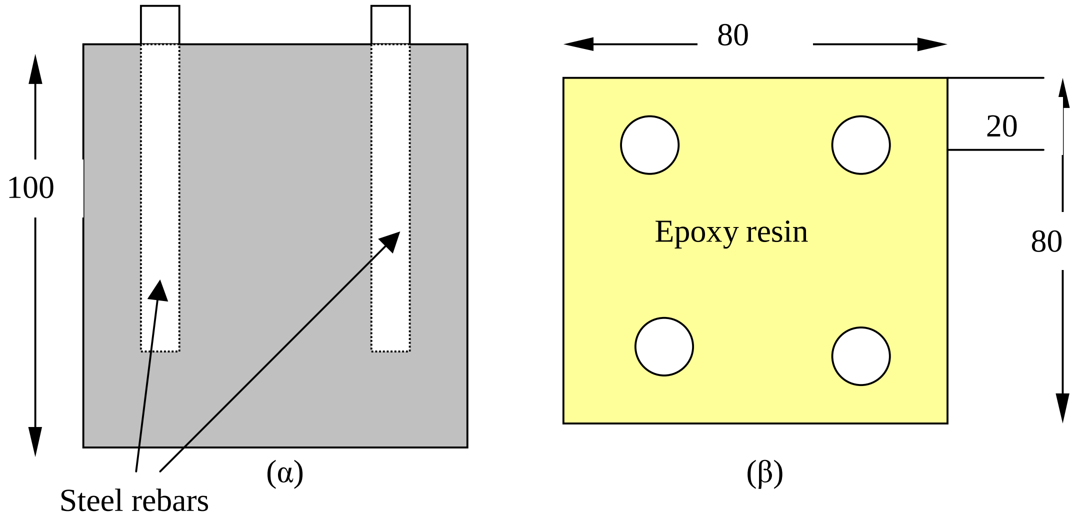

Figure 1: Schematic representation of reinforced mortar specimen (a) upper, (b) latter view. Dimensions of specimens in mm

2.3. Evaluation Methods

The objective of these experiments was to investigate mortar with corrosion inhibitor as corrosion protection system and evaluate its performance in reference to specimens without any addition of admixtures.

The migrating corrosion effectiveness was assessed in lightweight concrete with Greek pumice stone and in common mortar specimens. The inhibiting behavior of organic alkanolamines based migrating corrosion inhibitors against steel corrosion was evaluated by specimens' immersion into 3,5%w.t NaCl corrosive solution and by exposure to the atmosphere. The code numbers and the composition for the different sets of specimens used in this study are shown in Table 3. The experimental duration of this study was 1year. Whole experimental procedure will be discontinued at the conclusion of two full years of testing.

Methods used to assess specimens' performance included the corrosion potential, carbonation depth, corrosion rate, and mass loss time dependence of the rebars measurements.

Specimens with all categories were immersed in 3.5%w.t NaCl solution and their electro chemicals values were examined in order to evaluate the reinforcement corrosion in mortars. The test setup for both the Tafel plot as well as the linear polarization resistance techniques included a potensiostat / galvanostat, E.G & Model 263. Additionally, a computer program, Softcorr III developed by E.G & G Princeton Research was used for applying the potential scan, analyzing the parameters I_{corr}, R_p.

Half – cell potential measurements for each of the test specimens were recorded at regular intervals versus a saturated calomel reference electrode (SCE), for the duration of this experiment. Initially, these measurements were taken every day, until equilibrium conditions were established. Following, half – cell measurements were recorded every week. Twelve months after the start of this experiment the specimens were removed from the corrosive environment and broken in order to measure the carbonation depth and weight loss of steel rebars.

Table 3: Type and Composition of specimens

Specimens						
	Composition ratio					
Code name	**Cement**	**Pumice**	**Sand**	**Water**	**Corrosion inhibitor (lt/m³)**	**Remarks**
K-I	1	3	-	1	-	***Category I:*** *Immersed in 3,5%w.t NaCl*
KM-I	1	3	-	1	1.24	
S-I	1	-	3	0.6	-	
SM-I	1	-	3	0.6	1.24	
K-II	1	3	-	1	-	***Category II:*** *Exposed in Atmosphere*
KM-II	1	3	-	1	1.24	
S-II	1	-	3	0.6	-	
SM-II	1	-	3	0.6	1.24	

The steel rebars were cleaned from rust according to above mention procedure, the metal loss was determined and the corrosion rates were calculated by the following equation.

*Corrosion rate (μm/y) = 8.76x10⁷ W/ (A*T*D)* (1)

$$\text{Corrosion rate } (\mu m/y) = 8.76\times10^{7}\, W/(A*T*D) \quad (1)$$

W: metal loss in [g], *A*: area of steel in [cm^2], ***T***: time of exposure in [h], ***D***: density of steel in [g/cm^3]

The carbonation of the specimens was determined by the method recommended by RILEM CPC-18, on broken mortar pieces. The carbonation depth of mortar was calculated in the interval section of the specimen using phenolophalein and by measuring the area where the colour did not change to red.

3. MEASUREMENTS AND RESULTS

3.1. Category-I: Specimens immersed in 3.5%w.t NaCl

Half-cell potential measurements given in figure 2 came out from the first category of specimens that were immersed in 3.5%w.t NaCl solution. According to the standard test method ASTM C 876, Standard test method for Half Cell Potentials of reinforcing Steel in Concrete, the more negative the voltometer reading, the greater the probability of active corrosion. Values less than –350mV, have as a result 90% probability of active corrosion. It is obvious that for all the specimens there is a tendency for the reduction of their potential value from the range of –300mV to –650mV.these measurements suggests a high probability of an active stage of corrosion throughout the test period.

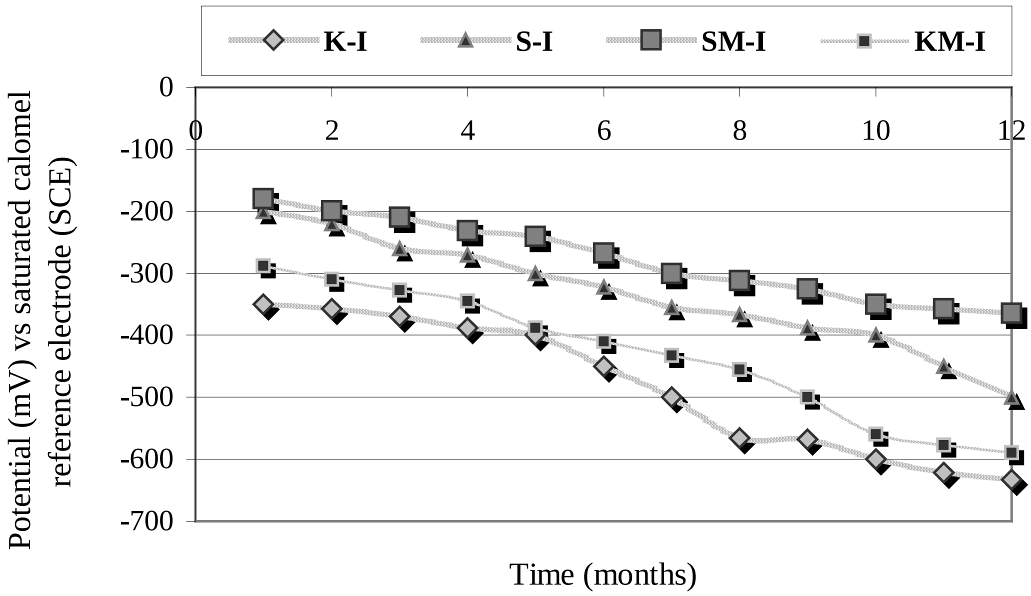

Figure 2: Half- cell potential measurements vs immersion time.

The results of mass loss measurements of reinforcing steel, after twelve months of exposure in chlorides solution are given in figure 3. It is obvious that mass loss differences are higher when lightweight mortars are compared to common mortars that contain as aggregate sand. From these results, the improvement of the mortars properties and consequently of the corrosion performance of steel rebars when the aminobased corrosion inhibitor added is evident. The INHIB-M, lowering the steel rebar mass loss after twelve months of exposured by about 45% in lightweight mortar and 50% in common mortar specimens.

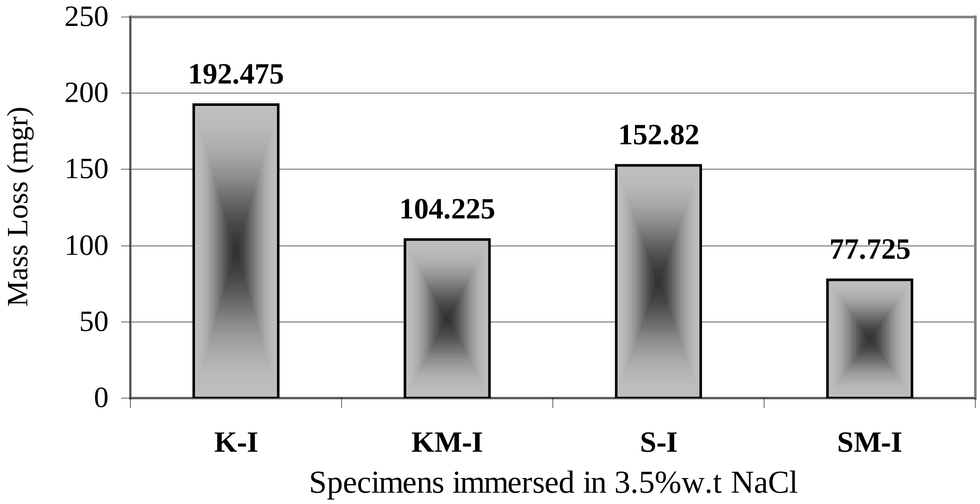

Figure 3: Mass loss measurements of lightweight and common mortars after 12 months of partially immerse to NaCl 3.5%w.t.

Carbonation of specimens versus time is shown in figure 4. Between mortars with sand and mortars with Greek pumice as an aggregate, it is observed that the specimens, which exhibit carbonation, were the latter mortars. Lightweight specimens without corrosion inhibitor, exhibit 3.5 times higher carbonation depth values than those with corrosion inhibitor. From these results, it seemed that the corrosion inhibitor addition in the lightweight mortars protect steel by a mechanism that seem to influence to carbon dioxide access.

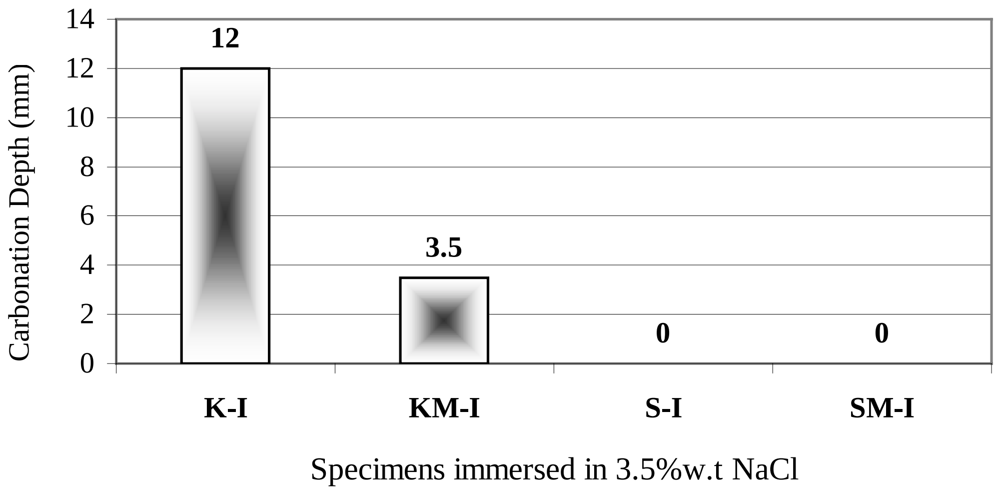

Figure 4: Carbonation depth of lightweight and common mortars after 12 months of exposure to NaCl 3.5%w.t.

In Tafel plot technique, a potential scan was applied to the specimens starting from E_{corr} and extending to 250mV either in the cathodic or anodic direction. The current measurements in this case were the difference between anodic and cathodic currents. Figure 5 gives the Tafel curves generated at chloride level of 3.5% w.t.in solution that specimens were been immerse. In linear polarization technique, a controlled potential scan was applied to the specimens in a range much smaller than that used in the Tafel plot. It was from E_{corr}-25mV to E_{corr}+25mV. The R_p polarization resistance, which is the slope of the potential current curve at E_{corr} is related to I_{corr}. Table 4 is a comparison of the corrosion rate values from electrochemical techniques with those from the mass loss determination technique.

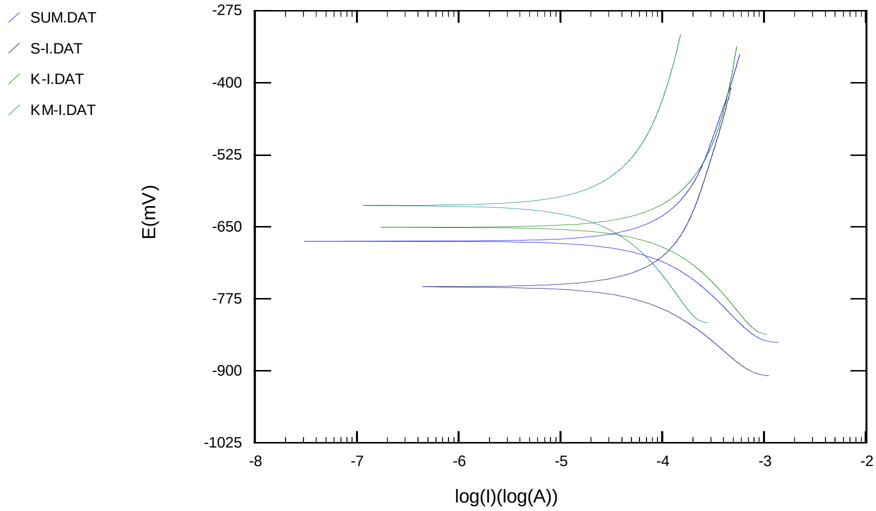

Figure 5: Tafel plots curves for reinforcing steel in common mortar and lightweight specimens immersed in 3.5%w.t. NaCl

Table 4: Corrosion rates of reinforcing steel in mortars with and without corrosion inhibitor, calculated by different techniques.

Code name	**Tafel plot technique**			**Linear polarization technique**			**Weight loss determination**	
	Rp (Ohms)	Icorr (μA)	Corrosion rate (mpy)	Rp (Ohms)	Icorr (μA)	Corrosion rate (mpy)	Mass loss (mg)	Corrosion rate (mpy)
K-I	371.6	58.44	1.715	386.1	56.24	1.650	192.475	0.71193
KM-I	538.5	40.32	1.183	438.5	49.52	1.453	104.225	0.3855
S-I	460	47.20	1.384	480	45.15	1.325	152.82	0.5652
SM-I	1379	15.75	0.4617	1481	14.66	0.4298	77.725	0.2874

3.2. Category-II: Specimens exposed in atmosphere.

The results of mass loss measurements of reinforcing steel, after twelve months of exposure in atmosphere are given in figure 6. The INHIB-M, lowering the steel rebar mass loss after twelve months of exposured by about 44% in lightweight mortar and 45% in common mortar specimens.

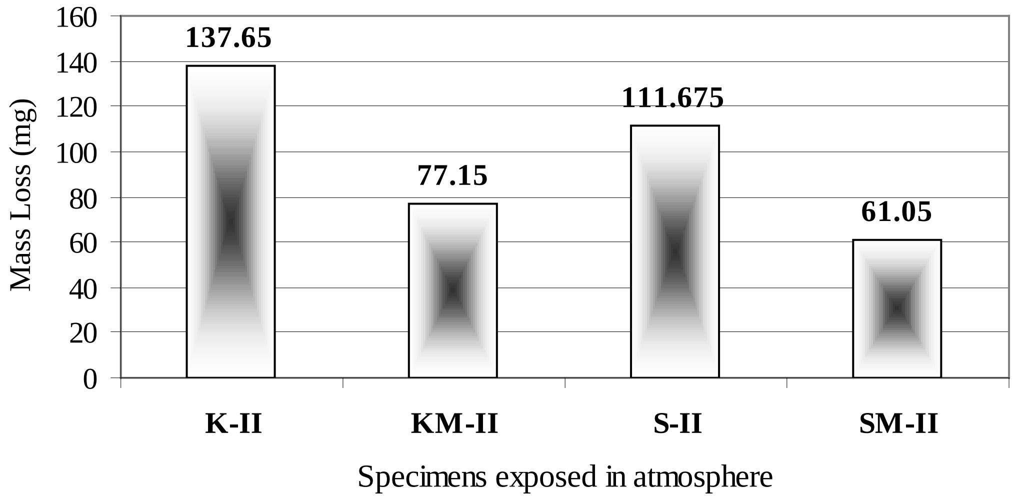

Figure 6: Mass loss measurements of lightweight and common mortars after 12 months of exposure to atmosphere.

Carbonation of specimens versus time is shown in figure 7. From these results, it seemed that the corrosion inhibitor addition in mortars protect steel by a mechanism that does not seem to influence to carbon dioxide access. The carbonation depth in lightweight mortars is definitely higher than those in mortars with sand as aggregates.

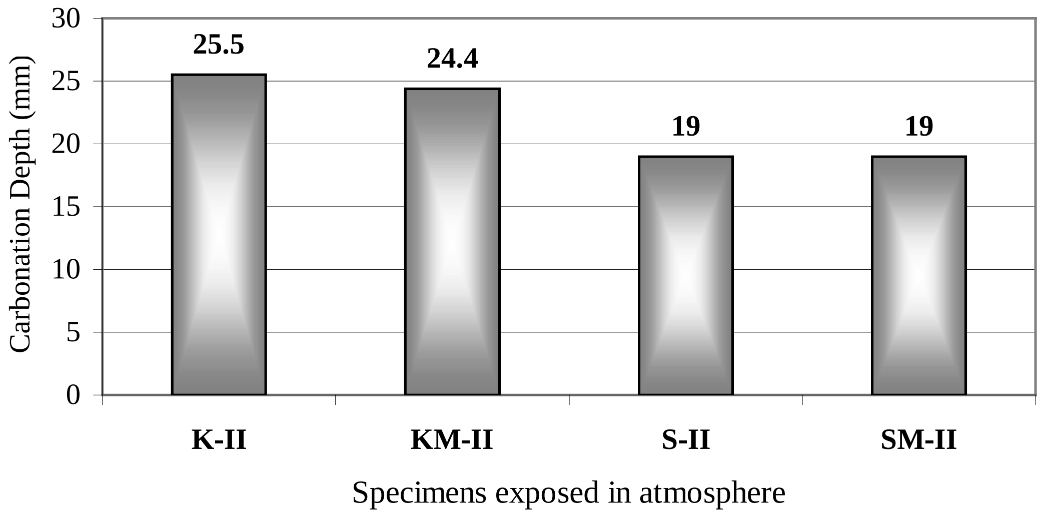

Figure 7: Carbonation depth of lightweight and common mortars after 12 months of exposure to atmosphere.

4. CONCLUSIONS

The usage of corrosion inhibitors has decreased corrosion both in the specimens that were partially immersed in 3.5%w.t NaCl as well as in those that were exposed in atmospheric conditions exposed for about 45% and 50% respectively.

The results of the electrochemical measurements for calculating the corrosion rate in order to have a first estimation of the corrosion of the mortar specimens that were partially immersed in 3.5%w.t NaCl solution are certified and confirmed by the results of the calculations of the reinforcements mass loss in the mortars for a twelve month corrosion period.

The carbonisation with a high porosity aggregates is by far larger when compared with the one in the specimens that were mortars made with common sand. The corrosion in the lightweight mortars has reached the surface of the reinforcements in a about a year's time and in that case the corrosion inhibitor has decreased the reinforcements corrosion for about 45%. As a result the conclusions of this study are in line with the confession that the usage of corrosion inhibitors is doubling the lifetime of the constructions.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

MECHANICAL RESPONSE OF DRY JOINT MASONRY

P. Roca[1] , D. Oliveira[2], P. Lourenço[2], I. Carol[1],
[1]Universitat Politècnica de Catalunya, Barcelona, Spain
[2]Universidade do Minho, Portugal

ABSTRACT

The paper describes an experimental study aimed at the characterisation of the mechanical response of dry joint masonry elements subject to vertical and horizontal loading. Reference is made to the difficulty encountered in the numerical simulation of the experimental results obtained, showing the large complexity of the phenomena involved in the mechanical behaviour and strength of this type of masonry.

1. INTRODUCTION

Almost nothing is known about the mechanical behaviour and strength of walls made of masonry with dry joints. In fact, research on masonry has been almost exclusively devoted to the characterisation of the response of brick masonry and, in some cases, stone block masonry, with mortar joints.

Although not so abundant as mortar joint masonry, there are important ancient constructions originally built with dry joint masonry. In other cases, the loss of the original mortar due to environmental erosion has produced a dry joint-like construction. The analysis of these cases requires more experimental evidence, combined with additional modelling effort, aimed at a better understanding of constructions showing this particular kind of fabric.

In order to contribute to improve the knowledge of dry joint masonry, a set of experiments have been carried out in the Laboratory of Construction Technology of Universitat Politècnica de Catalunya on a set of dry joint masonry walls subject to combined vertical and horizontal load. The experiments allowed to characterise –at least for a specific type of stone and geometry- the combination of loads leading to failure and the ultimate mechanisms developed.

Two different numerical techniques of analysis are currently used in order to simulate the experiments (section 4). In spite of the ability of these techniques to deal with frictional problems, the accurate simulation of the experimental results is encountering significant difficulties. These difficulties suggest that the phenomenological complexity of the problem –dry joint masonry mechanics- might not be adequately comprehended even by the up-to-date models utilised.

2. PRELIMINARY TESTS

Some preliminary experiments were carried out in order to obtain basic information on the mechanical parameters of the sandstone used and the fabrics built with them. For that purpose, individual blocks as well as some prismatic specimens built either with dry or mortar joints were tested in compression. The obtained results are summarised in table 1.

Table 1- Experimental results in uniaxial compression (average values)

Description	Compressive strength (MPa)
Individual stone blocks (horizontal position)	
20×10×10 cm	80
20×20×10 cm	76
40×20×20 cm	62.5
4 stacked blocks with 1cm mortar joints	50
4 stacked blocks with dry joints	34

Two main conclusions can be drawn from these preliminary tests: (1) dry joints specimens show a compressive strength lower to those built with mortar joints; (2) significant scale effects can be detected which strongly influence the compressive strength of the block specimens.

Complementary experiments allowed to measure an angle of friction ϕ of 33º between block surfaces. It must be mentioned that the stone blocks were cut mechanically and showed a very smooth surface.

3. TEST OF WALLS SUBJECT TO HORIZONTAL LOADING

The experiments were carried out on seven dry stone walls arranged as shown in figure 1. The dimension of the sandstone blocks used were 20×20×10cm. Taking into account that historical structures are usually submitted to low compressive stress states, the walls were tested for vertical loads of 30, 100, 200, and 250 kN, resulting compressive stresses of 0.15, 0.50, 1.00 and 1.25 MPa, respectively. In fact, it was observed that larger vertical load produced lateral buckling of the walls for combined, very small horizontal loads.

The main steps of the testing procedure were: (1) the application of a vertical load (compression) by means of a hydraulic actuator; during the following steps, the hydraulic actuator was kept under force control, resulting in a constant vertical load; (2) the gradual application of small displacement increments by means of a second hydraulic actuator; The load was applied against the reinforced concrete beam built over the stone walls. More information about the test procedure and the results can be obtained in Oliveira [1].

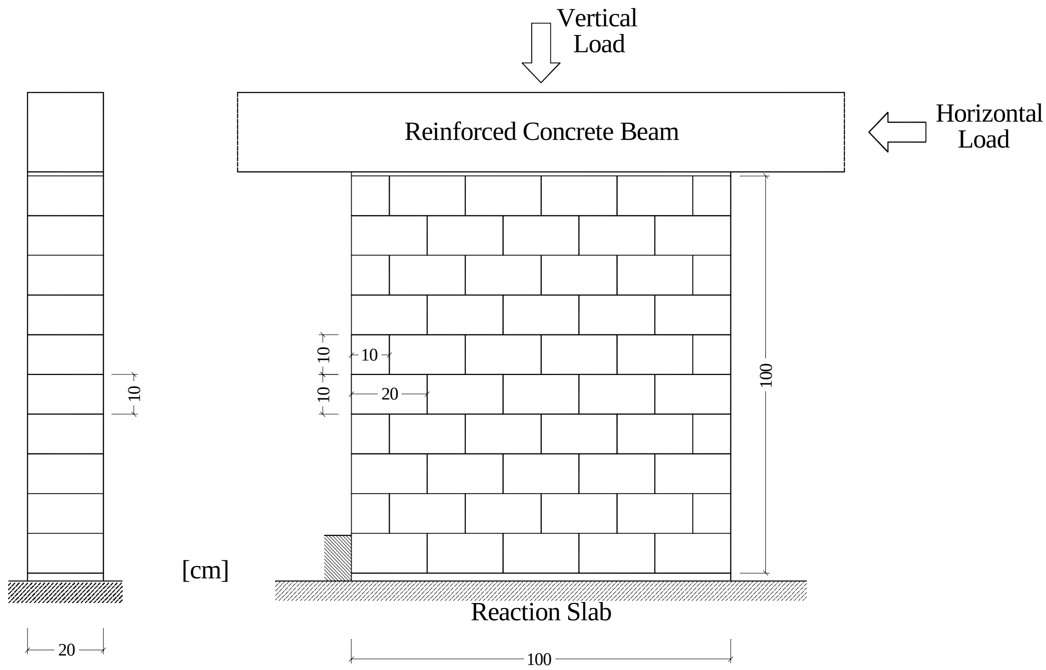


Figure 1 -Adopted geometry and loading arrangement.

The experimental load-displacement diagrams obtained for the walls are shown in figure 2. The load-displacement diagrams are characterised by two main distinct behaviours. During a first branch, while no sliding between blocks occurs, the curves exhibit great stiffness up to 30% of the peak load (figure 2). The second part of the diagrams is characterised by a gradual, punctuated loss of stiffness due to the occurrence of relative movements between blocks. Large post-failure branches were obtained for all cases (except for the ones experiencing lateral buckling).

The lack of an interlayer material promoted stress concentration in some contact points, leading to vertical cracking of the stones. As expectable, this cracking process took more importance for higher vertical loads. For lower stress levels, failure happened by rotation of part of the wall, following the stone joints (stepped line), without visible cracking (figure 3,A).

For higher vertical loads, cracking started to become noticeable, being the stepped line partially replaced by a diagonal band, where visible damage was localised. Rotation was substituted by horizontal displacements along the diagonal band (figure 3, B-D). For the highest vertical loads applied (250 kN), the danger of lateral buckling was real. In fact, a test not described in this paper failed prematurely by lateral buckling.

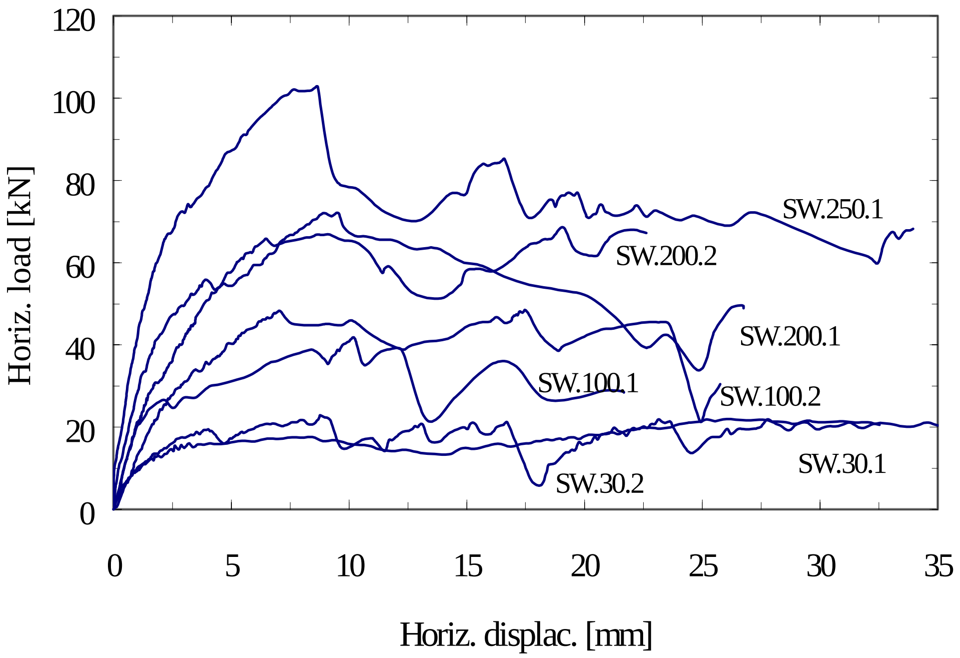
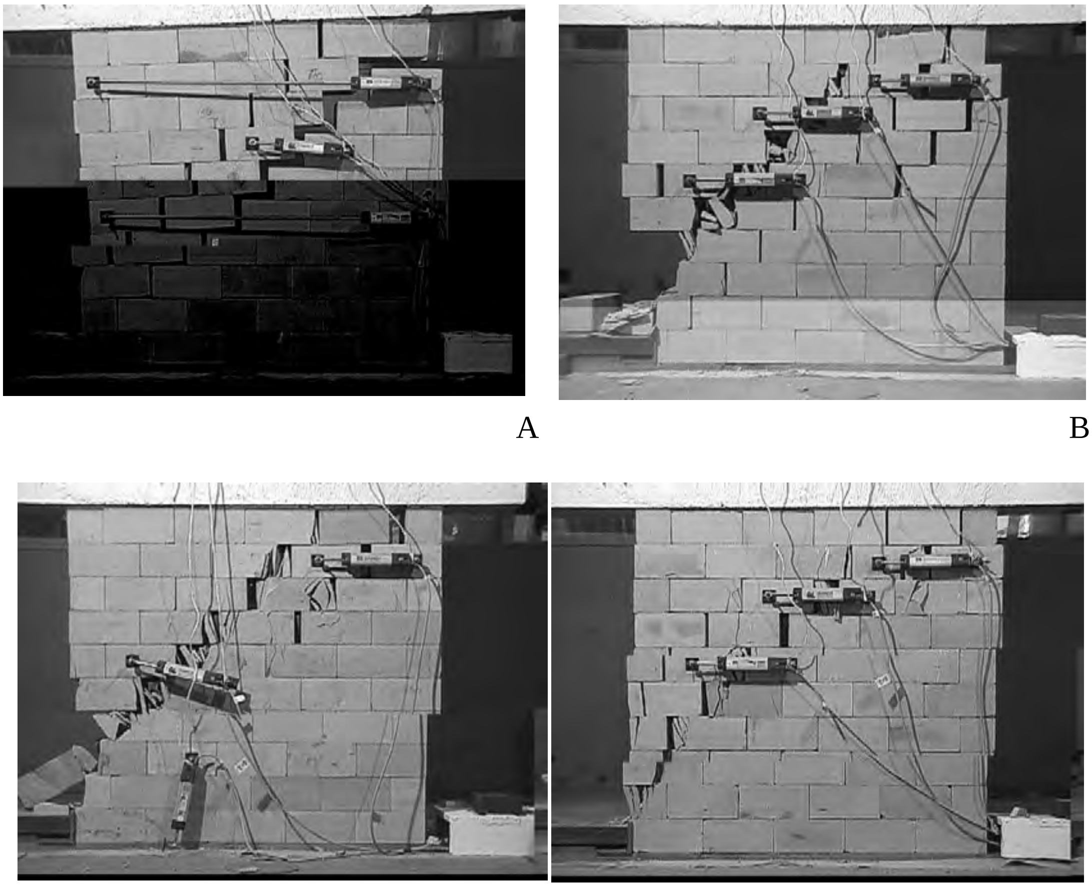


Figure 2 – Experimental diagrams showing the relationship between the applied horizontal force and the maximum horizontal displacement. The walls are designated as SW.*n.m* where *m* is the number of wall subject to equal vertical load *n* (in *kN*).



A B

C D

Figure 3 – Aspect of walls at failure (A-SW30.1, B-SW100.1, C-SW200.1, D-SW250.1).

The linear regression computed for the seven walls showed a good approximation to the experimental data (with regression coefficient $r = 0.98$, figure 4). However, this approximation implied cohesion different from zero. For a linear regression with zero cohesion, a slightly greater coefficient was obtained, but the first two points (SW30.1 and SW30.2) were less approached ($r = 0.95$). On the other hand, if those two points are not considered, the relation between the average shear (τ) and compression (σ) stresses is expressed as $\tau = 45.3 + 0.34\sigma$ for a regression coefficient equal to 0.96. As can be observed, the value obtained as ratio between the horizontal and vertical values does not correspond to the angle of friction measured in the preliminary tests (section 2.)

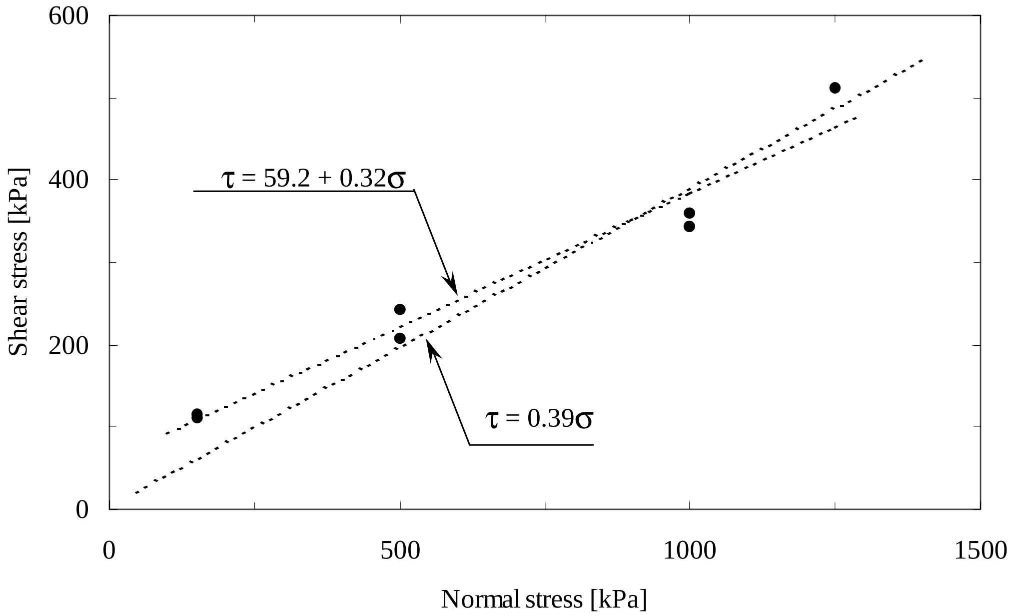


Figure 4 -Relation between normal and tangential stresses: Experimental data and linear regression

4. ANALYTICAL SIMULATION

The response of the experimental walls is now being analysed by means of two different numerical models. First, the joint model proposed by Carol and López for the study of cracking phenomena in quasi-brittle material [2]. Second, Lourenço and Rots' multi-surface interface model for the analysis of masonry constructions [3].

The attempt to simulate the experimental response of the walls is encountering significant difficulties due to the inherent complexity of the mechanics of dry-joint masonry, which involves fracture, contact and friction problems.

It has been observed that both the ultimate load or the overall stiffness of the wall are not easily predicted based on the knowledge of the main mechanical characteristics of the material (i.e., the angle of friction and the initial stiffnesses previously measured). In fact, the maximum horizontal displacement and the geometry of the ultimate mechanism developed (characterised by the distribution of sliding between blocks and the location of the main diagonal crack, figure 5) shows much dependency with the values given to most of the parameters required by the model. Obtaining a satisfactory agreement between the experimental and numerical load-displacement curves has been possible but at the cost of adjusting some of the basic parameters used in the models, as the angle of friction.

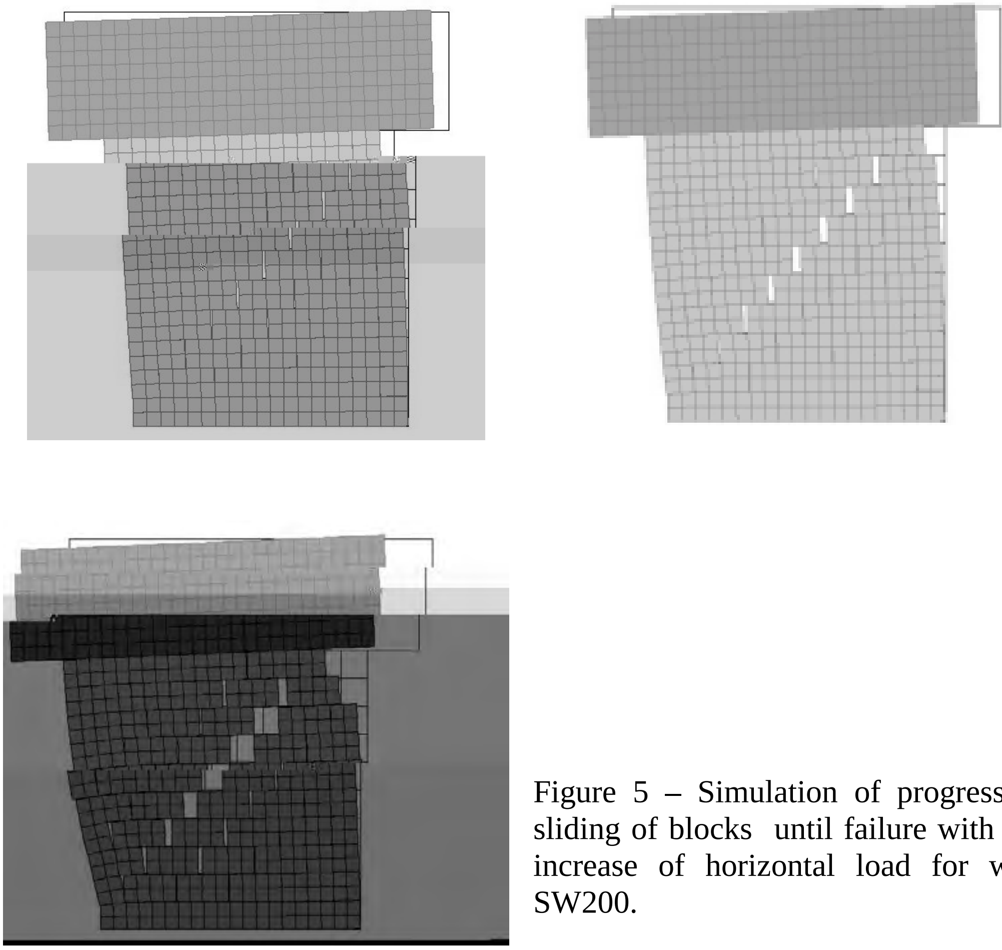


Figure 5 – Simulation of progressive sliding of blocks until failure with the increase of horizontal load for wall SW200.

5. FINAL REMARKS

The experiments carried out on a set of dry-joint masonry walls subject to vertical and horizontal loading permitted some preliminary conclusions about the mechanical behaviour of this type of masonry. It was observed that, for moderate average compression stresses, the failure is governed by a linear relation between horizontal and vertical load.

The accurate numerical simulation of the response shown by the experimental walls is encountering, at the moment, significant difficulties even if up-to-date numerical approaches (including frictional joint elements and other sophisticate devices) are used. However, the authors expect to obtain better approaches after further numerical and experimental study now being undertaken.

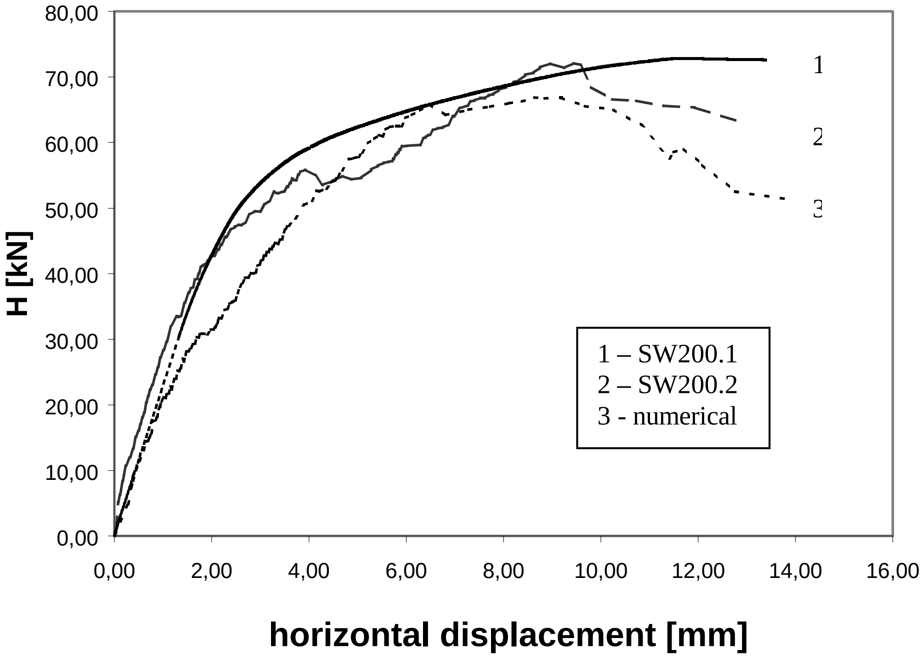


Figure 6 – Comparison of curves relating the horizontal force (H) with the horizontal displacement for walls SW200.1 and SW200.2.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

PRODUCTION AND TESTING OF BRICKS FOR REPAIR WORK

A. Radivojevic (1), D. Dervissis (2)
(1) Faculty of Architecture, University of Belgrade, Yugoslavia
(2) Individual architect, Thessaloniki, Greece

ABSTRACT

Having in mind the importance that the achievement of compatibility between modern and original materials has for a nowadays conservation praxis of historical buildings, there is a constant effort among the experts to establish the most suitable way for the production of suitable materials for repair work. The problem is especially interesting when building materials produced by the man's hand are concerned, such as mortars and bricks, offering in this way a possibility to influence their properties. This requires a prior investigation of properties of original materials, giving a clue of desired characteristics of repair ones, as well as a control of a production itself, including an establishment of methodology for testing a final product before its use.

Focussed to problems of bricks for repair work, this paper presents results and conclusions of one brick-testing procedure that was carried out during the conservation course, CAMBA-98, in Thessaloniki. The methodology that was used for this purpose was previously developed in the Laboratory of the Division of Science and Technology of Structures of AUTH, Greece.

1. INTRODUCTION

In nowadays conservation praxis of historical masonry buildings, the compatibility between the modern, repair work materials, and the original ones should be considered as a priority. Being materials produced by the man's hand and offering in this way a real possibility to influence their characteristics, mortars and bricks are materials where the compatibility problem, crucial for repair work, is especially present.

Evident changes in production and building technology from the ancient times up to nowadays, impose that achievement of required properties of repair materials meant for conservation work, often requires differences from the presently used procedures of their composition and application. This also requires a more severe control of the obtained properties.

Due to this fact, certain methods of laboratory tests have been established, one of which, developed in the Laboratory of the Division of Science and Technology of Structures of AUTH, would be presented in this paper. The paper presents a part of a research, which was carried out as a part of training program of the joint ICCROM and AUTH conservation course, CAMBA-98, organized in Thessaloniki, Greece in 1998.

Since bricks were one of the main building materials of masonry buildings of ancient times, the work was focused on a problem of bricks used for repair work. Its objective was to test properties of a type of bricks, manufactured to be used in conservation works of a Late Roman Galerious Palace in Thessaloniki. For this purpose, ten samples of bricks were chosen for the testing. The bricks were supposed to be of the size of 15x31x5cm. Their format was not typical Roman one, but represented half size of the square brick 31x31x5cm. The demanded format was ordered in this way by conservators of the Palace, in order to facilitate their work. The brick samples were marked with different numbers, from 1 to 10 before been put under different tests.

The applied tests for their suitability in repair work included the following examinations:

- dimensional stability and curvature
- visual observation - optical and microscopical
- homogeneity by sonic meter
- content in soluble salts
- porosity and specific gravity
- water absorption in short time
- rate of hair elevation
- mechanical characteristics.

2. ANCIENT BRICKS

The crucial fact in a process of production and use of manufactured bricks for repair work is awareness of properties that we attend to achieve. Having this in mind, it should be mentioned that, in this particular case, original bricks dated from the Late Roman period, which could be considered as a transitional phase between the Roman and the Byzantine time. Therefore, there were some particularities concerning size and other physical properties of the bricks.

As an obvious example, one of the characteristics was that in the region of Ilyric prefecture, with Thessaloniki as its capital, both, square and rectangular shapes of bricks were used in masonry, although the rectangular one was prevailing. This fact could be explained as a reflection of a distant local tradition, dating from ancient Greece. According to Vitruvius and his *Ten Books of Architecture*, at that time and in the mentioned region, there was only one rectangular shape of bricks (adobes) that was in use, while all other formats were square in shape [6].

The researchers of Galerious Palace in Thessaloniki have established that different sizes and shapes of bricks were used for its construction [10]. Although the use of square bricks of the sizes 30-31x30-31x4,5cm was recorded in Galerious Palace, the sizes of bricks used the most often were 40x30x3-3,5cm and 40x30,4.5cm.

These two predominant formats of original bricks were previously examined in the Laboratory of the Division of Science and Technology of Structures of AUTH [5]. The measured values and descriptions of their properties of interest will be taken into a consideration further on as properties that new manufactured bricks should achieve.

Table 1. Characteristics of ancient bricks from Galerious Palace in Thessaloniki

Type	Dimensions			Apparent Specific gravity	Absorption %	Strength kg/cm^2	Colour
	Length [cm]	Width [cm]	Thick. [cm]				
1	40	30	4,5	1,70 - 1,80	16 - 18	235 - 315	Red Brown Yellow
Microscopical observations: Grooves on the upper surface of bricks - bulges - concentrations of calcite - pores max. size <2 mm - cracks < 1 mm - fine aggregates - rich in clay powder - good bond with mortar							
Type	Dimensions			Apparent Specific gravity	Absorption %	Strength kg/cm^2	Colour
	Length [cm]	Width [cm]	Thick. [cm]				
2	40	30	3-3,5	1,67 - 1,85	12,5 – 14,5	85-110	Light red Brown
Microscopical observations: Grooves of different shapes on the upper brick surface -- coarse aggregates - pores max. size <2 mm - cracks < 1 mm -salts in pores - good bond with mortar							

3. MANUFACTURING OF BRICKS

No matter of our awareness of the ancient brick properties, it is not always easy to achieve that the new bricks, manufactured for the conservation purpose, obtain similar characteristics in all aspects as the old ones. The differences that still exist could be explained as a consequence of their different manufacturing process, especially when burning of bricks is considered.

Burning temperatures in ancient and contemporary brick production technology vary to the extent that different technological changes happen in each production process, becoming in this way the cause of the existence of their different properties. It is a common knowledge that ancient bricks were burnt on the temperatures that were not higher than 800^oC. Unlike them, burning process of the contemporary brick production understands much higher temperatures, provoking in this way melting of the brick mass that results with significant porosity reduction of a brick. Consequently, this becomes the cause of other differences in physical properties between ancient and contemporary bricks, creating in this way certain problems when bricks for conservation work are considered.

One of the solutions for overcoming this inconvenience, is brick production in small, semi-manual factories, that offers acceptable results of brick properties, but their high cost, as well. According to this, the tested brick samples were made by one of the local manufacturers who has already been engaged in the production of bricks for the repair work, using a semi-manual production process.

3.1. Main characteristics of applied brick-production

There is a great resemblance between the applied production process and the traditional one. Some phases are based on traditional principles and therefore are more or less like in the ancient times, but there are some necessary modifications and adjustments as well that enable more efficient manufacturing process.

The choice of the clay used for the brick production is based on the tradition of using local raw clay material. Therefore, the clay comes from two places in the wider area of Thessaloniki, from Kilkis, as well as from the West of the lake Yianitsa. Although the manufacturer does not do any kind of laboratory testing of the clay material, the long term family tradition and experience in this field of work, has proved to be sufficient in the process of choosing a good clay.

To achieve good qualities of a brick product, clay is left outside to season for about one year, which is a necessary step, well known since the Roman times. Exposure to the rain and sun leads to the extraction of the impurities from the clay, which helps later in avoiding possible cracks and other irregularities of the bricks.

The following step of brick production requires manufacturer’s experience as well, and concerns achievement of a good clay mixture. This could be easily achieved by recognizing the possible need for adding other ingredients, in case the clay material was “greasy” or “fat”. The added material could be sand, or clay containing the sand, in which case the appropriate mixture should be:

50% of strong clay + 50% of clay with sand.

Afterwards, by adding some water into the mixture and mixing it then in a special mixer, material becomes more workable and ready to be put into a traditional wooden frame mold of a required size of the brick. The next step after molding considers placing raw bricks in a storeroom, where they are left to dry for at least one month, moving gradually from the lower level to the upper and upper shelves.

The final step in a process of brick-production is their burning, which in this particular case happens in a small modern oven designed to enable the separation from one brick to another on their thickness distance. The burning process itself is controlled in a way which proves achievement of required properties of bricks, but which is efficient enough at the same time. This means that the starting temperature of the oven is about 300^{o}C, reached in several steps of 50^{o}C and raised slowly up to 1100^{o}C. Depending on the quality of the clay used for their preparation, as well as on their size, bricks remain in the oven 9 to 10 hours.

4. CHARACTERISTICS OF TESTED BRICKS

The suitability of bricks for their use in conservation repair work was confirmed by applying certain laboratory tests and measurements on the samples. These tests not only prove the suitability of individual bricks and their compatibility with ancient ones, but also present the quality and uniformity or their production itself.

4.1. Dimensional stability – size and deviations

Concerning the dimensional stability, the tested bricks showed some deviations of their average sizes from the required ones:

- the length (required 30cm): from 29,5 to 31,75cm,
- the width (required 15cm): from 14,57 to 14,9cm,
- the thickness (required 5cm): from 4,93 to 5,16cm,
- the weight: from 3730 to 4130g.

The expressed differences could be tolerated, meaning that all the brick samples fulfilled the necessary requirements for their dimensional stability.

It should be also mentioned that curvature of tested bricks was always present in some way, especially in the longitudinal cross section, in which the deviation from the vertical plan was up to 2,5cm. This could be explained by the large size of bricks, shaped according to the proportion of 1:2:0,3, as well as by the way of their burning. These two facts together probably provoked the described kind of non-convenient curvature for this kind of building material.

4.2. Visual observations

Concerning visual characteristics of bricks, based on their optical and microscopical observation, it could be concluded that all of them had similar properties.

There were no big variations concerning their colour, varying from red to brown-red, and apart from two samples that showed some differences in colour in a middle area, their colour was uniform on the whole brick surface.

The surface of bricks was always rough, with a presence of scaling. Corners of the bricks were often irregular, due to the molding.

Microscopical observation of bricks showed that all of them were made from the same kind of clay material, containing quartz and lime grains, and many philosilicates. Some of them had some pieces of dryad clay in a matrix, which indicated that some parts of clay material had already been dried on sun before the mixture was ready to be used. One brick sample unique in this way due to the presence of an isolated brick grain inside a matrix.

Compaction of a clay material used for the brick production was un-uniform. The half of the samples were made from clay material that was not well compacted, what resulted with a presence of certain amount of small pores and microcracks. On the other hand, the other five brick samples, whose compaction was good, did not show this problem.

4.3. Homogeneity of the bricks

Results obtained by measuring whole bricks by sono-meter showed that there was a great divergation of measured values of each brick, from 5,97 to even 34,79. This means that texture of bricks was not homogeneous through all their mass. It should be mentioned that the day after testing, one of the samples that demonstrated great variations of measured values, was found broken.

When these results were statistically estimated, it was proven that there was a variation of average velocity values of bricks of 10,75%. This data indicates that this particular brick production does not offer a standardized quality of bricks.

4.4. Content in soluble salts

The ion chromatography test proved that none of tested bricks had a problem with salts, so they could be used for a repair work without any problem of this kind.

4.5. Porosity and specific gravity

When achieved values of percentage of porosity, as well as of specific gravity are concerned, all brick-samples reached the qualities compatible to the required values of the ancient bricks. The porosity percentage varied from 16,79 to 18,11, while the values of the specific gravity are between 1,636 and 1,655, closely relating to the values of original ancient building materials (1,67-1,85).

4.6. Water absorption in short time

Measurements of water absorption of bricks showed that all tested bricks had acceptable values of this property. The behavior of bricks was uniform and bricks absorbed water in the following rates:
after 15 minutes, from 9,59% to 12,86%, and
after 24 hours, from 12,90% to 13,53%.

This percentage of absorbed water was a little bit lower then one that ancient bricks of a same thickness had (16-18%), but it was still acceptable. The good property of these bricks was that almost whole quantity of water was absorbed after first 15 minutes, what is a very good quality for a building process.

4.7. Water elevation by the suction

Concerning water elevation by suction, all of tested bricks showed the similar behavior. Results were almost uniform after 24h: from 0,961% to 2,57%. Even the highest registered value of one of the samples, which was significantly higher from the values of the others, was still between the tolerated values.

4.8. Mechanical characteristics

Results of tested mechanical characteristics of bricks could be evaluated in this way:

Flexural strength of tested bricks varied from 11,98 kc/cm^2 to 56,672 kg/cm^2. The lowest strength value was measured on the sample that had cracks present in a brick structure, for which the cracking pattern of this brick was irregular.

Compressive strength also showed certain varieties in average values, from 109,32 kg/cm^2 to 139,27 kg/cm^2.

The measured values were in correlation with values of ancient bricks of 3-3,5cm thickness (85-110 kg/cm^2), but they did not reach those of original thicker bricks of 4,5 cm thickness (235-315 kg/cm^2). However, it should be taken into account that sizes of corresponding ancient bricks were not the same as those of tested bricks.

5. CONCLUSIONS

According to the results of the applied tests, in spite of certain divergations from the required brick properties that were found out in some tests, it could be concluded that tested bricks could be accepted as suitable for repair work.

However, it should be mentioned that presented type of evaluation is related only to the final product (brick), but not to the material used for its production. The manufacturing technology was neither tested in any way. For these reasons, response given to the conservators and manufacturers after the test results can be understood just as an affirmative, or a negative one. It can not give a precise answer about eventual needs for changes of clay material or production process, nor indicate the necessary directions of those changes. Therefore, it should be stressed that better control and testing of these two factors could anticipate even better quality of repair brick material.

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RELATIONSHIP BETWEEN SOME PHYSICO-TECHNICAL CHARACTERISTICS OF STONE

D. Hoffmann, K. Niesel
Federal Institute for Materials Research and Testing (BAM),
12205 Berlin, Germany

ABSTRACT

The first promising steps directed to a more quantitative conception of an expected material's weathering behaviour have been proven as fruitful and could furthermore be expanded by measuring data on pore structure, moisture transport and mechanical strength of natural building stone. This was carried out with the aid of relevant correlations. Collecting values of this type has meanwhile led to a multitude of results with whose elaboration the meaningfulness of single relationships could be considerably increased. In this connection a wide spectrum of characteristics and properties was investigated. From the value triplet of three differing weathering-related dependent variables one can calculate a useful weatherability index.

1. INTRODUCTION

It belongs to hardly avoidable fallacies to ascribe alteration damages occurring on a building material always unambiguously to the effect of one certain weathering factor. Because it seems never easy to satisfactorily accurately define a deterioration process of any kind with respect to heterogeneity, pore-space geometry and anisotropic behaviour of various material-typical parameters [1], [2], [3], [4]. Equally different, however, is also the expectation of those who are involved in measures on building sites or in substitutive monument protection. Considering the pretentious thinking being typical for nowadays and as well as the permanent urge to immediate solutions close to practice, sometimes it seems once more suitable to refer back to the source of all activities in monument protection to be taken in earnest: the assured scientific-technical experiment. This is especially valid for vehicle for a material's decay being therefore an inevitable weathering event. Even inveterate „modellers“ cannot help but orienting their constructions on corresponding measuring results.

First tests with regard to a correlation of characteristic data concerning weathering behaviour were carried out earlier on sandstone and limestone [5]. So with the aim to create a better survey in the last decades, an extensive amount of data material assisted by experiments was collected. There is up to date, however, a fundamental lack in a genuine direct experimental access to porous building material's weathering behaviour; a prior cost-benefit analysis, lamenting on the irresistible decay of free-standing stone monuments, and so-called assured time indexes for increasing or decreasing material-layer thickness may be less useful [6]. But in order to also be able to give future competent advice for substitution of stone, materials testers orientated in natural science should however attempt to listen to „Mother Nature" with all modesty of one of her disciples, what a stone characterises which withstands, without any respect to its exposure on a building or outdoors, longer than another towards such a complex attack, so that research yielding any results can be performed above all.

2. POSING THE PROBLEM

Former bibliographic data have for the most part mechanical characteristics as its subject, and possibly water absorption served as a necessary partial result for determining apparent density or porosity respectively, whereas on the contrary practically capillary behaviour and even pore-size distribution scarcely were of relevance. Unsatisfactory remain also the characterising of abrasion behaviour of materials less hard, as lime mortar or rendering, as well as results of capillary liquid rise, and that mostly because of insufficient consideration of test duration or absorption height.

The relationship between compressive strength and water absorption or open porosity respectively, already known for brick since the thirties of the last century [7] has meanwhile been confirmed by our own test results on different sedimentary rocks [8]. In the same sense one can find on refractory brick a reverse tendency of gas permeability and dynamic modulus of elasticity [9]. Via the aforementioned characteristics and also pore volume <5 µm radius there consequently exists a connection to capillary liquid rise too as one can reveal towards water absorption and penetration coefficients. This finally means that not only as the sum of existing pore space but also size distribution of pores have an influence upon a material's strength. Therefore no ones may claim that any mechanical feature does not vary if others, e.g. pore-related features within one and the same production or quarry batch have experienced change. For this P. Duffaut et al. [10] gave hints by the title of their paper "Pore spaces as the main factor of rocks' mechanical behaviour". Consequently in the present case the interest is principally less in dynamics of weathering. Rather it deals with judgement standards observed from a material still to be studied better, which – roughly spoken – allow to estimate its sensitivity against the sum of all possible kinds of stress. A comprehensive insight into such material parameters determining weathering therefore promises only some success when enhancing sufficiently the spectrum of test methods and after including modern media of data administration and statistics. Therefore the beginning with our own endeavour [5], [8] has also required necessarily an improvement [11].

Here a word still should to be mentioned on quantifying properties or characteristics respectively. The striving of most authors is increasingly addressed not only to classify these by the aid of parameters but also to establish universal evaluation criteria able to involve all possible cases. However, since as a rule one thing depends on the cost of another, here a kind of conflict of interests is programmed beforehand, over which great systematists in the field of weathering as was J. Hirschwald [12] must regularly stumble. Because it should be cautioned about an unsuspecting combination of petrographic aspects to be determined, e.g. with pore-related parameters or even features of weathering. With all critical reservation, such experiences nevertheless lead to placing the emphasis upon characterising of features in any sense relevant to weathering. But not only mechanical properties as they find expression in the nature of the scaffold structure of a solid matter are requested. For also parameters which may be deduced from moisture transport [13], [14] display although in most cases indirectly - the negative of it, namely the pore structure.

3. TEST METHODS

In principle the weathering process leads thereto that a natural stone or another porous mineral building material grows closer together with physico–chemical conditions of its surroundings and during this weakens its strength. That is why the task first consists thereof to establish relationships between its mechanical, pore-related and other physico-technical features obtained by experiment, and to compare with its specific characteristics and properties. As far as liaisons between distinguishable features exist after all, conclusions on parameters more or less exactly to be determined will be a final aim of such efforts.

As an example it should be mentioned here the strength tested at wet (after water saturation) and dry stages. In this connection a corresponding quotient of both values was already stated by J. Tetmajer in 1884 as a "durability coefficient" [15] and is later on also applied in the modified form of a "softening coefficient" [16]. Such an indirect action belongs to the few practicable ways, which enable at all an access to those intricate relationships, namely to erect a bridge between the structure of a porous stone and its intrinsic characteristics or properties respectively. A threshold value in its nature between "frost-sensitive" and "frost-insensitive" materials frequently attacked but an absolutely useful quotient represents the saturation coefficient (s value) already proposed by J.Hirschwald in 1908 [12], which corresponds to the ratio of water absorption at atmospheric pressure and at 15 MPa. Because its theoretical demarcation at 0.9

shall take into account that the volume of freezing water increases to about 9% within the pores of stone still finds enough space to yield which should actually be valid for idealised conditions (cf. [8], expanded version, pp. 10-14). Another also generally applicable non-linear function for quantifying mass loss during sodium sulphate crystallization test [17], [18], e.g. then though loses its validity, if stone shows mechanical anisotropy or even layer-wise decay. Nevertheless the scale parameter p_1 obtained from the respective formula itself shows fair suitability for correlations as far as one sets $p_1 = x$ in the corresponding function. For correlation attempts it seems advisable to use different pore-size ranges. With the aim of characterising pore structure, the medium pore radius or the pore radius at 50% fractile (median) is therefore employed, both obtained by mercury intrusion porosimetry . Furthermore ultrasound measurements (delay and velocity), dynamic modulus of elasticity as well as grinding abrasion are fruitful. Also gas permeability and water vapour diffusion resistance index µ are suitable. Determination of cited parameters are carried out according to generally introduced standards or guidelines.

Since a reduced reliability of results obtained comes from differing test conditions, for the purpose of multiple regression analysis finally suits only a **great number of measuring values determined on many samples**. Therefore here progress is to be expected at an elevated expenditure which cannot, however, be done other than by institutes having the strength which exists in continuity of their tasks. So it seems necessary to work with **as many parameters as possible from a great materials palette,** wherefore data material being satisfactorily usable should be available. To the few systematic works on the basis of sufficiently large measuring value collectives herefore belong the representative corresponding investigations of J. W. Mc Burney and C. E. Lovewell [19], D. B. Honeyborne and P. B. Harris [20], M. Mamillan [21], P. Bousquié [22], S. Grunert [23], C. Félix [24] and our own results obtained as well [25] since practically each feature – whether directly or indirectly – is connected with the others, one should perform a correlation of all possible data experimentally assured.

4. RESULTS

According to experience up to now the quotient compressive strength in wet stage divided by that in dry one decreases with an increasing pore volume in the size of smaller than 5 µm radius (Fig. 1).

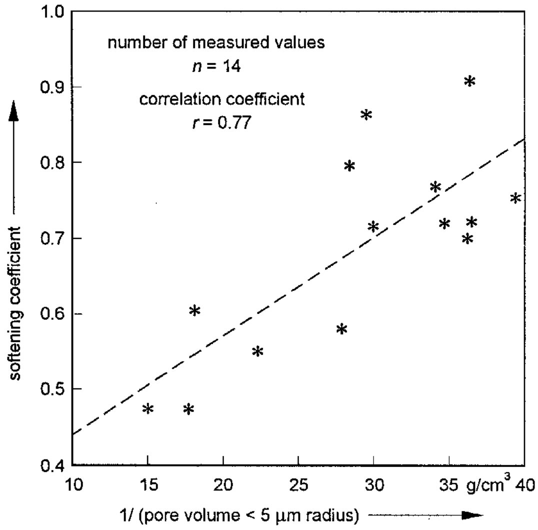


Figure 1. Softening coefficient as a function of pore volume <5 µm radius of sandstone

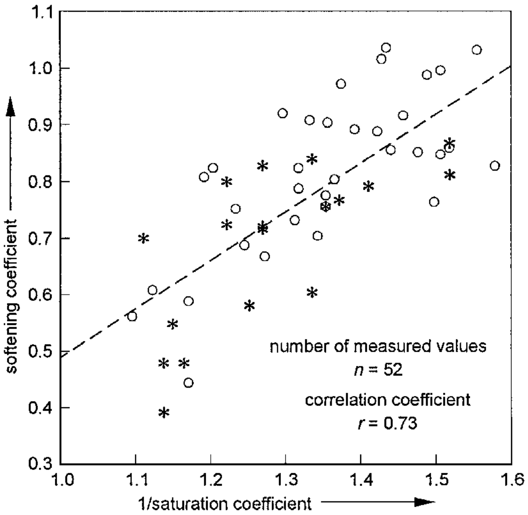


Figure 2. Relationship between softening and saturation coefficients of sandstone (literature data marked by circles [23])

This is analogously also valid for medium pore radius (median) and hydraulic diameter both of which grow i.e. shift pore spectrum to coarser pores whereof follows that respective sandstones are less sensitive to atmospherical attack: consequently so-called critical diameter $d_{10\ m}$ changes to coarse pores, when that quotient increases. But also other confirmed relationships are to be found, so e.g. with ultrasonic delay furnishing an indirect measure for mechanical strength, which decreases when that quotient increases. Finally in case of sandstone one can analogously correlate softening coefficient with another weathering-relevant factor: the s value (Fig. 2) where its increase compulsorily causes a lowering of that (also limestone). Apart from the relationship with apparent density or open porosity respectively [11], an increase of the fine pores' portion between 100 nm and 5 µm radius here also leads to a growth of s value as ultrasonic delay also does, and therefore in reverse sense to a decrease of dynamic elasticity modulus (Fig. 3).

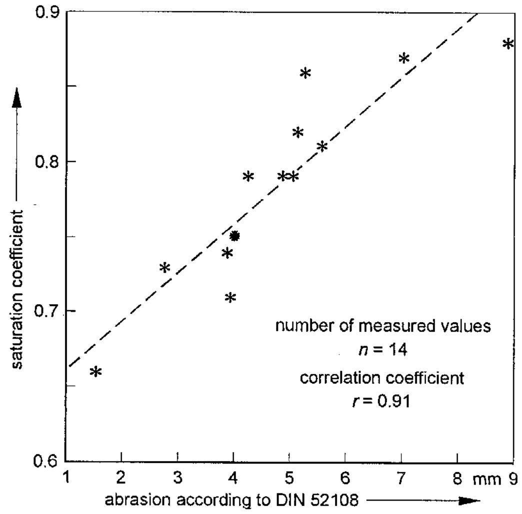


Figure 3. Relationship between saturation coefficient and abrasion according to DIN 52108 of sandstone

reveals a corresponding relationship to abrasion resistance according to DIN 52 108:1988-08 being valid as a measure for grain-bonding strength, which is correspondingly small when that quotient is great.

Between softening coefficient and that distinguishing material-specific point, scale factor p_1, on the non-linear mass-loss curve during a sodium sulphate crystallization test, such way can bring about a connection to the third crucial weathering-related parameter. Both increase analogously (Fig. 4).

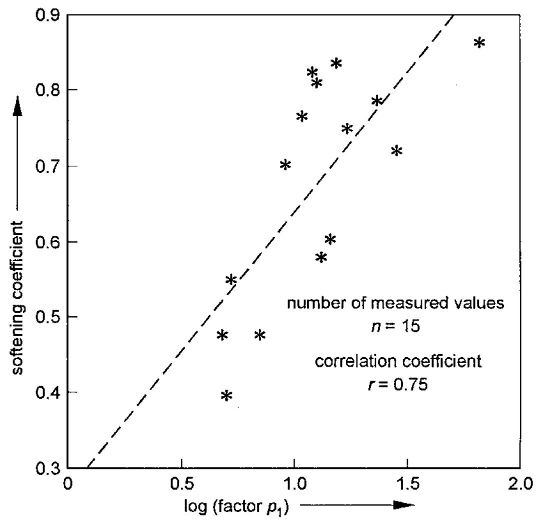
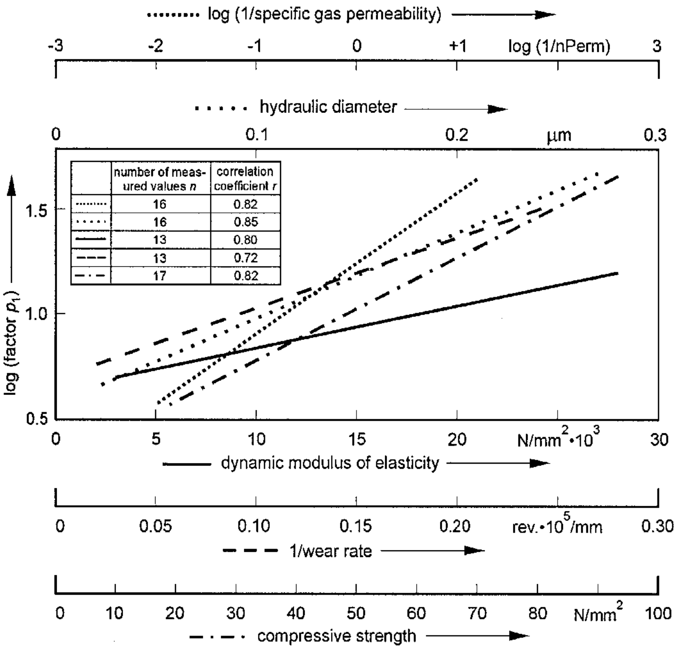


Figure 4. Relationship between softening coefficient and sodium sulphate crystallization test-factor p_1 of sandstone

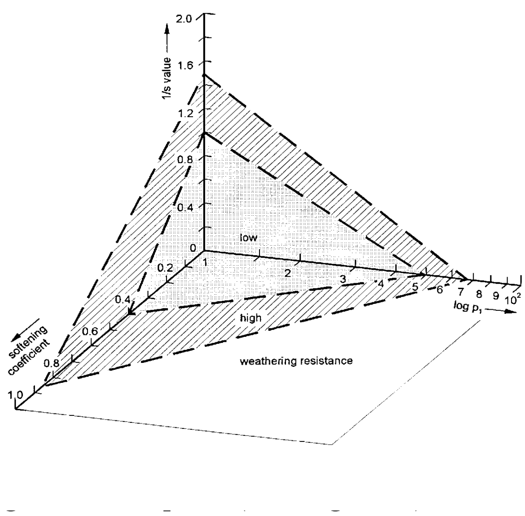
Figure 5. Sodium sulphate crystallization test-factor p_1 as a function of various pore-related and mechanical characteristics of sandstone



This finding coincides with former experiences [8] and works also in the case of limestone which on the other hand points out a relation to volumina in the fine-pores' range. Besides corresponding connections to density or open porosity (small p_1 values correlate with large porosity), there are also marked relations to diverse strength parameters as e.g. to abrasion (test description cf. [14], [25]), flexural and compressive strengths, modulus of elasticity, and finally to gas permeability also (Fig. 5).

By diminishing of p_1 the delay of ultrasound rises, whereas its velocity consequently drops. So in the case of correlation attempts with most of physico-technical characteristics considered as independent variables in the sense of multiple regression analysis, plausible relationships emerge.

Figure 6. Three-fold combination of parameters for calculating the weatherability index



With the assumption tl ... ameters on the other hand designated ... the value triplet was plotted as a tri ... (x100 =

weatherability index as a summarizing parameter of properties) was elevated if resistance increases so that here probably is the key for a threshold value always required by practitioners. Hereto in table 1 are quoted corresponding data, wherefrom results a critical value of 94 – according to demarcation in DIN V 52106:1994-08 by an arbitrarily given saturation coefficient of 0.75 and by corresponding values of the other parameters– which one should raise to 100 because of a better managing.

Table 1: Calculated weatherability index for 14 sandstone samples

sandstone samples	area	weatherability index (area x100)	
19 s (cf.Fig.6)	0.480	48	
15 s	0.498	50	
18 s	0.557	56	
7 s	0.592	59	
21 s	0.734	73	
33 s	0.853	85	
5 s	0.936	94	" critical" point 94 at a s value of 0.75
9 s	0.973	97	
5 s	0.975	97	
3 s	1.076	108	adopted threshold value = 100
4 s	1.090	109	
36 s	1.146	115	
35 s	1.239	124	
47 s (cf.Fig.6)	1.709	171	

5. CONCLUSIONS

From results obtained one can derive a system of correlations without any contradiction in which are enclosed all three dependent variables to be considered in the sense of a multiple regression analysis and portraying weathering behaviour. Also pore-related as well as those other physico-technical properties and characteristics (altogether = independent variables) in correlation attempts always react logically consistent. In general it is to be ascertained that one material is then more resistant than another if having a higher apparent density and therefore lower porosity, at the same time a smaller fine pores' portion, and if it shows lower elasticity modulus or ultrasonic delay at a higher strength or lower abrasion respectively. There is also the fact of lower water absorption including water absorption coefficient and a modified evaporation behaviour. Anyway it should consequently be possible to clarify such a problem by consulting those three parameters determining weathering behaviour by summing them up into one value, the magnitude of which runs parallel to weathering resistance.

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DURABILITY AND DECAY TYPE OF SANDSTONE FROM THE FACADE OF THE ST.MARCO CHURCH IN BELGRADE (SERBIA)

V. Matovic (1), D. Milovanovic (1)
(1) Faculty of Mining and Geology, Belgrade, Yugoslavia

ABSTRACT

The St. Marco church has been built on the model of the our most beautiful middle age monument, the Gracanica monastery. Although made of ferro-concrete, it represents the monument of the Ancient Byzantine free style. Stone panel of its facade was made as a combination of the Bele Vode Sandstone and the Red Permian Sandstone. In order to determine the causes of the sandstone decay, a detailed observation of the state and the degree of blocks degradation of has been performed. This paper deals with causes of the decay and existence of different types of damages.

1. INTRODUCTION

The most important place within mediaeval cultural heritage of Serbia belongs to sacral architecture. Church buildings are witnesses of Serbian culture and its Orthodox tradition. The church and cultural treasure of old Serbian State, creative imagination of craftsmen and their ability to realise various architectural ideas have been preserved in stones until today.

Since the Middle Age, stone has been the best natural building material. Due to its durability, the greatest built attainments still represent materialized witnesses of history. Some types of stone have marked the important periods of old Serbian architecture [1]. Monumental church objects from the XIII century were built of soft materials such as marble, marble breccia, onyx, etc. Because of the strong influence of Apulian Romanesque on the Zeta and Raska architecture, craftsmen started to use travertine, stone, which do not look so precious, but has a proper workability.

Limitation to local quarries, as well as an eternal ambition for easily engraved material made sandstones the constructional symbol of the Serbo-Byzantine and especially the Morava, architectural school during the XIV century. Various types of sandstone in brick frames gave gentle look and specific coloring to the facades in numerous Serbian monasteries (fig.1). Sandstones enabled not only the traditional construction by alternated stone and bricks but they were also a proper material for carving or plastic decoration in famous geometric motifs of Morava architecture.

The sandstones used for most churches originated from two localities: Bele Vode (20 km NW of Krusevac), known as “Belovodski" and sandstone from the river Grza (20 km east of Paracin), known as “the Red Permian Sandstone”.

Figure 1. Geographic position of some church that were built of sandstone in Serbia

Aiming to keep the mediaeval tradition, facades of new temples were also built of the Bele Vode Sandstone, while the Red Sandstone was used instead of bricks. Craftsmen, however, did not know much about textural properties and durability of sandstone. Sometimes they did not use these rocks properly, which resulted in their rapid disintegration after a short time. Such an example is the St Marco’s church in Belgrade, with the facade made of the Bele Vode Sandstone and of Red Permian Sandstone. After 60 years of its existence, different types of decay could be observed on its facade. The Bele Vode sandstone is of better durability or degraded to a lesser extent, while the different types of decay were recognized on the Red Permian Sandstone. This paper deals with causes of the decay and existence of different types of damages.

2. HISTORY AND ARCHITECTURE OF St. MARCO’S CHURCH

The church was built from 1931. to 1939. and it represents the first ferro-concrete building of Byzantine style in our country [2]. It has ferro-concrete copper-covered roofs and cement-mortar walls. Stone paneling of the church facade was made of the sandstone from Bele Vode and of the Red Permian sandstones. Plinth with projecting parts, out of walls is paneled with granitic rocks (fig. 2.).

During the Second World War, central doma was damaged and northern colonna of the church was destroyed. The sacramental rites started in 1941., but the church was not sanctified until 1948. Its stepped mass covers 1900 m^2, being 60 m long, with the central dome of 10 m in diameter and 52 m high, as the most dominant elements above four small cupolas. It's interior is in the Byzantine style, while the monotony of bilateral symmetry was avoided by locating the bell-tower above nartex [3]. Such lightsome frontal look and elongated monumental mass gave the basilic look to the St Marco's church.

Figure 2. The St. Marco church

Elegant forefront is rising above the high three-stepped plinth, dominated by the monumental portal. A shallow niche overhanged by an archivolt and roof cornice is situated above the massive wooden door. Within the niche, there is the fresco with the frame of the Red Permian Sandstone (fig.3). On both sides of the portal, the arcades with the massive columns and composite stone capitol are situated (fig. 3a). Arcades have mosaic floors made of Italian limestones and serpentine and carbonaceous breccias, which are intensively destructed today (fig. 3b).

Facades are without sculptural, plastic decoration, typical for church architecture. Picturesque facades achieved by colorific red sandstone combined with gray or yellow coloured sandstone from the Bele Vode, produced perfect polychromatic effect. Sandstone elements are polytonally shaped, or trapesoid on archivolts. They are of different size, 15 cm thick, connected with mortar joints up to 1 cm thick. The Bele Vode sandstone surfaces are striated, while surfaces of red sandstone are flat, without traces of any kind of treatment.

Lateral facades are more decorated than the frontal part of the church, and gave the impression of more complete composition. Arcades with niche, colonnades and decorative capitals make flat facades more picturesque. Arcades connect angular towers with octagonal domes whose edges are emphasized by colonnades.

Pilasters and sightless, often coupled arcade's niche decorate interior parts of lateral porches. Single, biforium or triforium windows with curved vaults separated with colonnades are located inside arcade's niche. Archivolts on the niches are semicircular, except on the central part of the lateral facades storey where they are broken in the top above triforium. Picturesque "dance" of colours is intensified with panels located around the single windows inside niches. The panels have fishbone decorations, obtained by alternation of white and red sandstones.

A polygonal altar apse with sightless niches and edges marked with colonnades, dominants the east facade.

Facades end with saw-tooth roof cornices which follow niche and doma archivolt curves.

Figure 3.The portal of the St. Marco church; a-capital; b-very damaged floor slab of carbonaceous breccia

3. PETROGRAPHICAL AND PHYSICAL FEATURES OF SANDSTONE

The sandstone from the Bele Vode village represents a shallow-water, lacustrine sediment of the Lower Miocene age. It is exposed in two localities in the vicinity of Krusevac: in Kukljina and Bele Vode villages, covering the area of about 5 km^2. The outcrop of the Bele Vode sandstone is cut by the small gravitational faults. Sandstone mass is massive in its lower part, whereas in its upper part is banked, platy or well bedded. The sandstone is gray or yellow-brown in color, shading from pink to red. Their structure is massive or layered, but due to well-oriented laths of micas it could be defined as internally layered/laminated, which is a common feature of sandstone. Sandstone has coarse-grained or fine-grained psammitic texture and easily visible cavities up to 5 mm in diameter.

According to mineral composition (clasts of quartz, alkali feldspar-orthoclase and microcline, plagioclase, muscovite and fragments of rocks) the sandstone corresponds to arcose. Clasts vary from 0.2 to 1 mm in size, angular and weakly sorted (gray varieties) or sub-rounded and rounded, well sorted (yellow varieties). Porous contact cement is ranging in composition from siliceous-clayey material (in gray sandstone) to ferruginous-carbonaceous material (in pink sandstone).

According to their physical properties [4], bulk density (1880-2420 kg/m^3), density (1940-2720 kg/m^3), absolute porosity (7.4 – 27.9 %) and water absorption ability (2.43 – 9.16%), the Bele Vode sandstone is medium heavy rock of high porosity and with average to high water absorption.

Long-lasting studies of its durability under frost and freezing and thawing cycles revealed the Bele Vode sandstone as stable rock, whereas crystallization experiment estimated it as partly unstable.

Numerous studies from the different localities and the different levels in the rock mass show remarkable heterogeneity concerning the way of its appearance as well as its technical properties. Unequal sandstone durability to weathering is caused by the differences in porosity and water absorption ability of the pore cavities.

The Red Permian Sandstone also represents arcose, rarely quartz sandstone. Intercalations of conglomerates, coarse-grained arcose, shales or siltstones appear within sets of the red sandstone. The sandstone is well stratified, sometimes massive, while horizontal and cross lamination is rare. Frequent concentration of micas along bedding planes implies the existence of internal lamination. The red color is a characteristic feature of this sandstone, but traces of decolorisation and local occurrences of gray sandstone is also observed. The Red Permian Sandstone is composed of clasts of quartz, feldspars, fragments of rocks (volcanic rocks, cherts, quartzites and schists) and matrix. Concerning the grain/clast size, roundness and sorting, these rocks could be divided into two groups: fine-grained (0.05-0.25 mm), well-sorted sandstone, and medium grained to coarse-grained (0.25 – 1 mm), weakly sorted sandstone. Clasts are cemented with contact-porous ferruginous-calcite cement, while siliceous cement is rare. Ferruginous-clayey cement could also be present, but only among the fine-grained varieties.

Physical properties of the Red Permian Sandstone are uniform[5]. Due to the presence of ferric oxides, their color varies from red to violet, and its intensity depends on the amount and distribution of ferric-hydroxide, i.e. oxide. Presence of hematite, magnetite and limonite as color-bearers in these rocks, implied permanence of their color. The Red Permian Sandstone is medium heavy (2630-2690 kg/m^3), exceptionally to average porous rock (4.9-11.2%), with considerable to average water absorption ability (1.53-3.06%) and is unstable if exposed to frost.

Correlation of petrographical and physical properties revealed that coarse- and medium-grained, weakly sorted sandstone has lower porosity and lower waters absorption ability than fine-grained, well-sorted arcose.

Well-exposed internal lamination, as a structural feature of sandstone as well as the presence of clayey components, resulted in their poor durability and more intense degradation if compared with the coarse-grained varieties, which has been proven by the observation of the facades.

4. SANDSTONE DECAY TYPES

Intensity and type of decay of sandstone depend on its mineral composition, fabric (texture and structure), physical-mechanical properties, way of building and position of stony elements. Characteristic reachable parts of the facade show that stone panel made from the Bele Vode sandstone do not show signs of remarkable destruction, i.e. extremely small number of elements indicate that weathering has already started. However, certain parts of the facade made of Red Permian Sandstone is intensively destructed and they require adequate protection, thus they will be thoroughly discussed in further text.

Sixty years after construction, the Red Sandstone shows various types of destruction, caused mainly by physical factors. Certain elements are intensively destructed, especially on the western and northern facade. Deep destruction grasped elements in the lower part of facade, especially the first row above the plinth, where there is no single element with preserved primary plate (western facade). The intensity of destruction mostly depends on the way of cutting and the position of open surfaces in relation to the position of the bedding surfaces. The elements with open surfaces parallel to bedded planes are intensively distracted, while those with perpendicularly placed visible surfaces, are almost without signs of physical destruction.

The following types of decay could be recognized among sandstone elements: granular decay, exfoliation, and spaling, while efflorescence and subflorescency are the most characteristic ones. Development of microflora was not recognized, but it can be expected possible in higher facade parts, especially on the south (close to gutter).

In the lowest layer of the western church facade, the Red Permian Sandstone elements are subjected to intense weathering, either granular, or breaking into pieces. The first layer of these elements is situated on the plinth with projecting part of few meters wide (entrance stairways and floors of the arcade). These projecting parts retain rainwater or snow during wintertime, which resulted in the presence of moisture/humidity, i.e. the main cause of destruction. Marginal elements of the main church entrance are subjected to deep granular disintegration and breaking into pieces (up to 10 cm) (fig. 4a). Rarely preserved primary sandstone surfaces in the lowest layer are coated with a black crust, due to deposited solid particles of aerosol within pores (fig. 4 b). Sandstone elements in the first row above the plinth of the arcades, (western facade), are intensively disintegrated. Because of weak ventilation and longer retaining of water, their primarily flat surfaces are completely distracted. At the same time new-opened surfaces are affected with granular and spalling disintegration (fig. 4 c), with numerous blisters that could easily be broken and disintegrated (fig. 5 a).

Capillary ascent of moisture provoked breaking of the elements of the Red Sandstone in the vertical columns, as well as in the elements made of the Bele Vode Sandstone, within the second layer above the plinth. A few elements of the Bele Vode Sandstone, already weakened by striating treatment, are detached up to 5 mm in depth, whereas the Red Permian Sandstone is broken into parts up to the depth of few cm. This strong and deep disintegration does not affect more resistant cement mortar (fig. 5b). Elements of red sandstones whose open surfaces are perpendicular to bedding planes remain better preserved. Thin fractures and

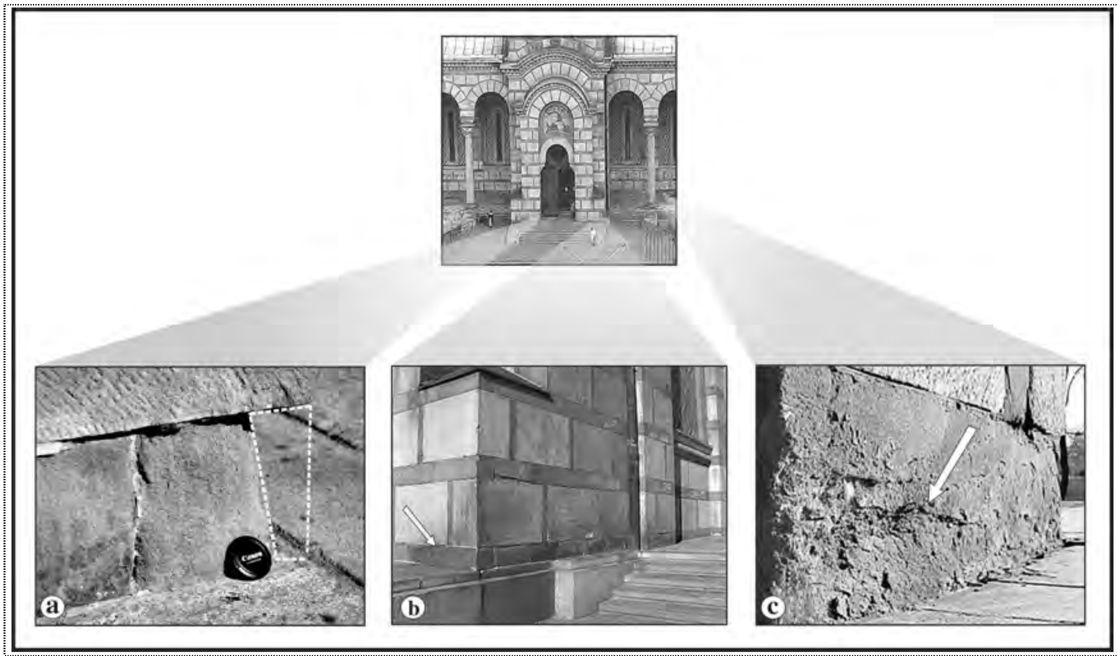

Figure 4. Decay types of sandstone elements of western facade of the church: a-erosion and deep granular disintegration; b-"black crust"; c-flaking and scaling.

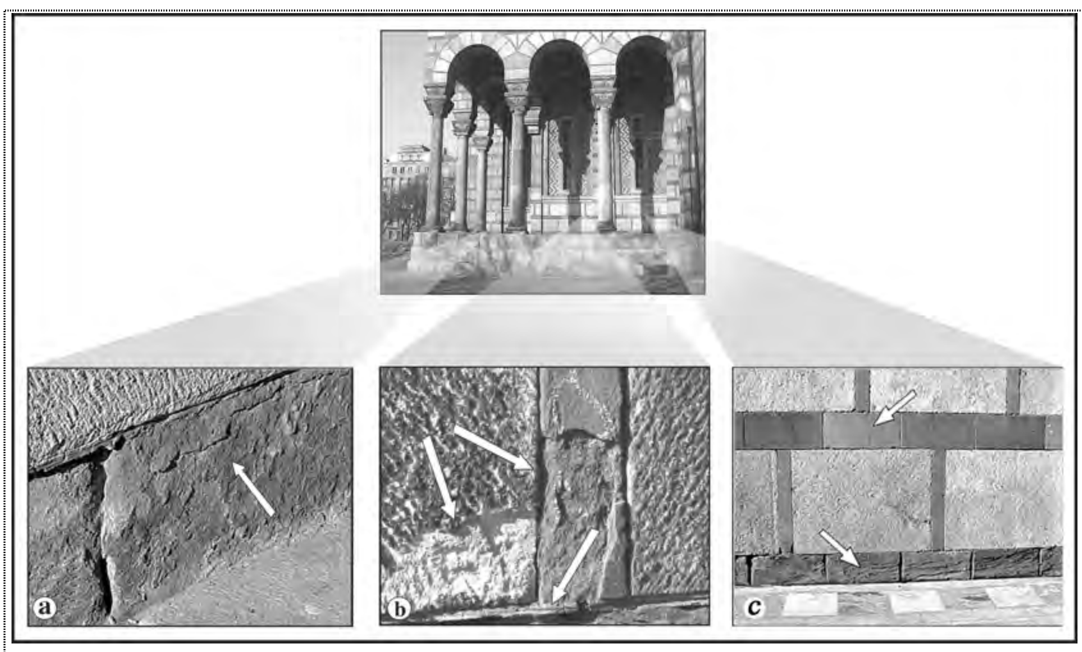

Figure 5. Decay types on southern facade of the church; a-blistering and chipping; b-breaking into pieces and more resistant mortar joint; c-sandstone elements with surfaces perpendicularly to bedded plane are without signs of damages (upon) and those with parallel surfaces are intensively damaged (down).

beginning of disintegration could be seen on them, but further disintegration is not possible, while elements with open surfaces parallel to the bedding plane are intensively destroyed (fig. 5c). Exfoliation is the main type of decay on the southern and eastern side of the facade. About 20 cm the projecting part of the plinth on lateral facades enables longer circulation of moisture and snow, which caused disintegration of the first layer of the Red Sandstone. Original surfaces of numerous elements are almost completely destroyed, and further disintegration is going on along the bedding surfaces (fig. 6 a). The results of efflorescence in the shape of white borders in higher parts of the southern facade, which marks the level of water circulation. The exfoliation and blistering of their primary surfaces is caused by subflorescency in the pore space (fig. 6 b).

On the northern facade, especially on higher parts of the arcade, decay in a form of exfoliation and flaking is well-expressed (fig. 6 c). Coupled frames of windows, built of the Red Permian Sandstone, are exposed to weaker ventilation and longer moisture circulation; thus their surfaces are rarely preserved. About 3-mm thick convex crust has been formed during the first phase of disintegration. Moisture, captured under the crust disintegrates the stone interior, until a complete separation of crust, when further granular, flaking and spalling degradation continue. On lower sandstone elements, efflorescence develops as white borders, which marks the deepest level of penetration. XRF analysis of the salt from the Red Permian Sandstone surface showed the presence of thenardite and mirabilite. Even their crystallization is unfavorable from aesthetic point of view, their destructive influence is also possible.

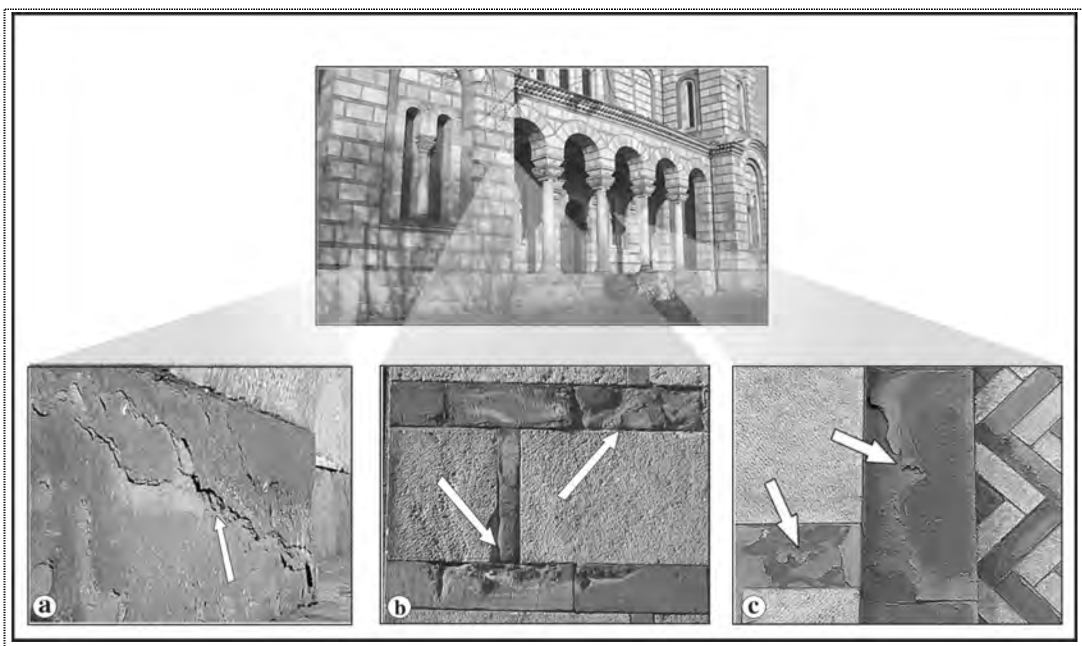

Figure 6. Decay types of northern facade: a-exfoliation; b-subflorescences; c-exfoliation and granular disintegration

5. CONCLUSION

Intensive physical destruction has been recorded on some elements of the stone paneling of the facade of the St. Marco’s church (made of the Bele Vode sandstone and of the Red Permian Sandstone) six decades after its construction. Form, intensity and velocity of the decay depend on mineral composition, texture and physical properties of sandstones. This is strongly influenced by weathering conditions, i. e water and snow, but the position of stone elements and the way of building are also important. The Bele Vode Sandstone was estimated as high porous rock of moderate-to-high water absorption ability. Their condition within the facade of the St. Marco’s church revealed that types of higher quality were used as a building material. Red Permian Sandstone is, according to its mineral composition and texture, fine- to medium-grained or coarse-grained arcose. Considering their physical properties, they are moderate-to-extremely porous rocks, with notable or moderate water absorption ability, unstable if exposed to frost. Their weak durability is verified and obvious on the St Marco’s church today, but it should be noted that fine-grained varieties are more distracted than medium or coarse-grained.

Rainwater and frost are the main causes of the Red Permian Sandstone destruction. The form and intensity of sandstone decay also depend on the height of stone elements above the plinth and by the position of their surfaces in relation to the stratification. Intense breaking and granular disintegration of sandstones occur in the lowest parts of the facade, where projecting part of the plinth enables accumulation and retaining of rainwater and frost, permanent moisturizing and exposing of sandstone to alternate influence of freezing and thawing during winter. Sandstone porosity enables circulation of water up to considerable depth. Consequently, pressure caused by water freezing resulted in mechanical disintegration of cement and destruction of stone surfaces (breaking into pieces, granular disintegration and flaking) up to the mentioned depth.

Mechanical destruction is also obvious on the elements in higher parts of the facade, where water can not be retained. But exfoliation and flaking is produced by humidity (rain, fog, and moisture). Penetration of water and moisture into sandstone enables destruction of stone texture and formation of exterior crust.

Such crust represents temporary preservation coating that enables retaining of humidity and its destructive influence on the stone. At the beginning, it was hard resistant crust, which, gradually, looses connection with “healthy part”, blisters and breaks out, i.e. exfoliation and flaking parallel to stratification occur. After it’s separation, a new-opened surface is fragile and more susceptible to further decay.

According to the petrographic analysis, physical properties and condition of sandstones, more and more intense further distruction could be expected.

In order to preserve the integrity of facades and slow down the already started decay, preservation of stone elements is necessary.

Circulation of water (humidity) and its destructive influence could be prevented by surface hydrophobisation, during lower temperatures in the first place. Deep penetration of hydrophobic substance and constant observation and protection would enable long-lasting protection of the facade, and preservation of architectural value of the temple in the Serbian capital.

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A POZZOLANIC PLASTER FOR CONSERVATION OF HISTORICAL EARTHEN WALLS

N. Değirmenci (1),B. Baradan (2)
(1) Balıkesir University, Balıkesir, Turkey
(2) Dokuz Eylül University, İzmir, Turkey

ABSTRACT

Earth as a construction material has been used for thousands years not only in rural housing but also in monuments and historical structures. Earthen architecture that has survived in archaeological sites is a heritage must be handed over to the next generations. Experience showed that exposed historical adobe or it is called in Turkey “Kerpiç” do not survive for a long period after excavations due to environmental hazards. Various conservation and preservation methods have been developed to protect historical earthen structures. However, most of these methods did not solve the problem due to different nature of adobe.

In Anatolia , a historical binder used throughout the ages by Seljuk Turks and Ottomans. The binder was called as “Horasan” and composed of fired brick powder, lime and water. Some researchers claim that the composition also incorporates egg-white, ash, some fibers like straw, goat hair.

The present research has been inspired by this historical binder the developed composition incorporates fired brick powder, hydrated lime, fly ash and water. The mechanical and physical properties of the multipurpose pozzolanic plaster were investigated within the scope of the research.

The test results proved that the developed plaster seems to be a suitable material for preservation of adobe walls since it has properties in conformity with soil. Also it is a durable material against the hazardous effects of water.

In addition to the use of preservation and amendment of adobe walls, this pozzolanic mixture may be used in brick forming, repairing jobs as a binder or stabilizer.

1.INTRODUCTION

Earth is one of the oldest construction materials known to man. A Large percentage of the world's population today live in earthen houses. Especially in developing countries, adobe has been used widely in rural regions due to the economic shortcomings and financial problems. Besides the great need for earth as a building material in under-developed countries; preservation of existing monumental or historical earthen buildings is one of the world-wide concern [1].

The best known advantages of adobe are; its low cost, good thermal and acoustical properties, high resistance against fire and easiness in its production and its use in construction. Adobe is available almost everywhere, production of blocks and construction of adobe masonry houses require almost no energy and equipment. It could be performed even by the least skilled people and adobe house construction methods suits local, social and economic life styles very well [2].

However, adobe has some disadvantages such as; low mechanical properties and poor resistance to wind and rain.

In many parts of the world, various conservation and preservation methods have been used to protect contemporary and historical earthen structures. The aim of the present work is to search for the right protective materials and methodology for improving the engineering properties of adobe.

In Anatolia, a historical binder used throughout the centuries by Seljuk Turks and Ottomans. The binder was called as "Horasan" and composed of fired brick powder, lime and water. In some references ash and egg-white were also added to this composition but there is no evidence about the certain ratios of these materials [3].

The research has been inspired by "Horasan" and a multipurpose binder composed of fired brick powder, hydrated lime, fly ash and water has been developed.

2.MATERIALS

The class "C" fly ash used in this study was procured from Soma-B Power Plant. As it is known, fly ash is a by-product material obtained by burning pulverized coal in thermal power plants. Considering the high cost of Portland cement, fly ash as a stabilization material may be very beneficial. Fly ash as a pozzolanic material reacts chemically with lime to a cementitious component that improves the strength and hardness of plaster material and reduces shrinkage.

Lime has been procured in the paper sacks from local suppliers. Lime starts pozzolanic reaction and increases workability of mixture. Lime also gives sufficient water retention qualities that will help to improve the durability of adobe surfaces.

One of the most widely used building materials in Turkey is fired brick. About 10 % of a-year's production of fired brick is discarded. This by - product is not utilized in any way. These wastes were crushed and reduced to fine powder.

The chemical and physical properties of fly ash is presented in Table 1. The grain size distribution of fly ash, lime and powdered brick used in pozzolanic plaster is also presented in Figure 1.

Table 1. The Physical and Chemical Properties of Fly Ash

Physical Properties	**Value**
Fineness, Retained, %	
On sieve # 30	0,00
On sieve # 200	16,00
On sieve # 325	31,20
Specific Gravity	2,24
Moisture Content %	0,63
Chemical Analysis	**Percentage by weight %**
SiO_2	45,98
Al_2O_3	23,75
Fe_2O_3	4,59
Mgo	2,10
CaO	15,34
K_2O	1,19
Na_2O	0,21
SO_3	0,99
Loss on Ignition	1,62
Insoluble Residue	0,57

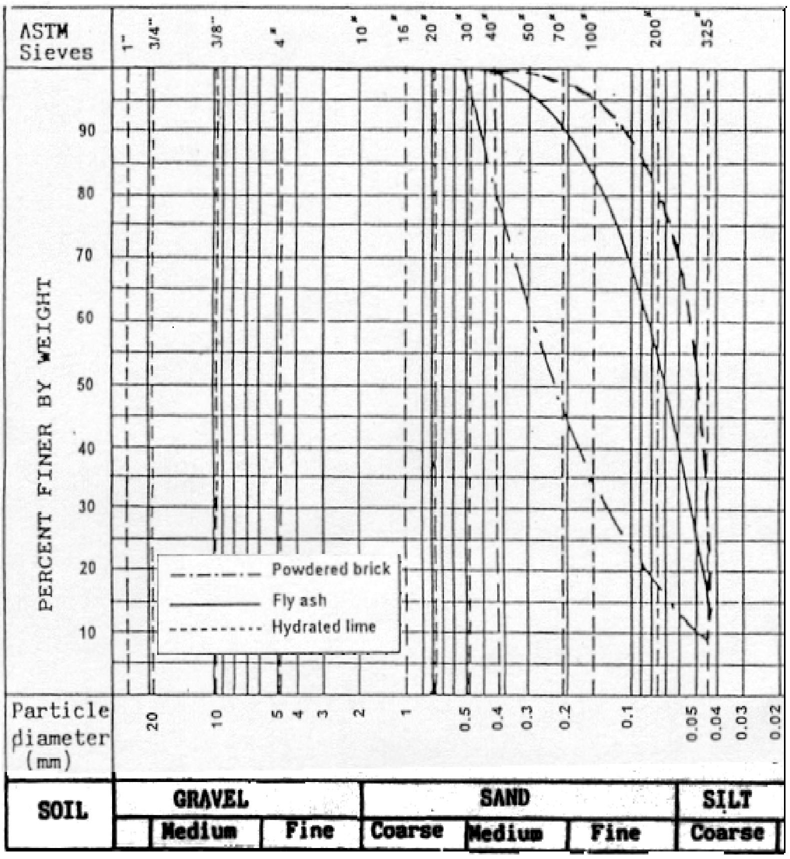

Figure 1. Grain Size Distribution of Fly Ash Hydrated Lime and Powdered Brick

3. EXPERIMENTAL STUDIES

First step was to determine the optimum hydrated lime content to improve workability of the mixture and to activate the pozzolanic reaction. Hydrated lime was incorporated 10, 20, 30, 40 and 50 percent of the total weight of the mixture. Reasonable results were obtained with 10% of hydrated lime. Then various fly ash/powdered brick ratios (FA/PB) were investigated while hydrated lime (HL) ratio kept constant as 10% to obtain compressive strength values comparable to adobe's mechanical properties. The amount of mixing water was found by flow table to provide optimum workability. FA/PB ratios varied between 0,50 and 3,00 in the mixtures. A compressive strength in the range of 7,04 MPa at 28 days was selected for the type of pozzolanic plaster and FA/PB ratio was 1,5 in this mixture.

The composition of this mixture and the results of compressive strength at 28 days are given in Table 2 and in Figure 2. respectively.

Table 2. Mix Proportions of Pozzolanic Plaster Mixture with Versus Fly Ash/Powdered Brick Ratio.

Mixture Number	FA/PB	Materials %				Unit Weight (g/cm^3)	Comprs. Strength (MPa) At 28 days
		HL	FA	PB	W		
1.1	0,50	10	60	30	29	2587	3,90
1.2	0,75	10	51	39	30	2590	5,77
1.3	1,00	10	45	45	29	2587	6,28
1.4	1,25	10	50	40	30	2590	6,94
1.5	1,50	10	54	36	30	2587	7,04
1.6	1,75	10	57	33	30	2590	7,49
1.7	2,00	10	60	30	30	2590	8,22
1.8	2,25	10	62	28	30	2593	8,38
1.9	2,50	10	64	26	30	2600	8,72
1.10	2,75	10	66	24	31	2610	8,30
1.11	3,00	10	68	22	31	2610	8,31

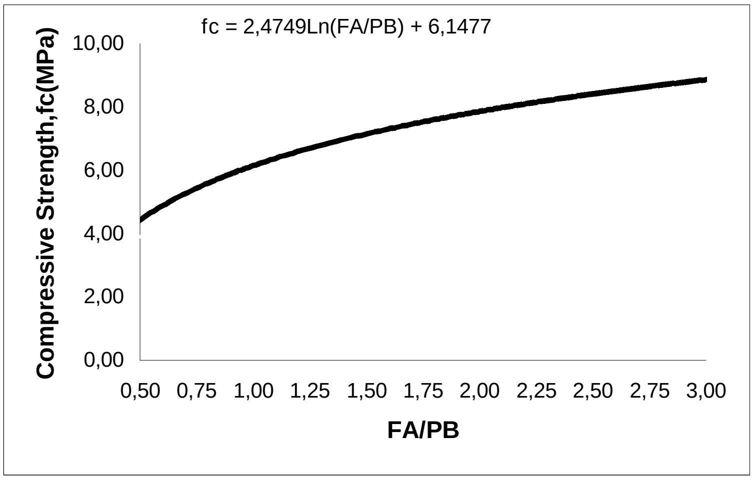

Figure 2. Compressive Strength 28-Day and FA/PB Ratio Relation

The basic ingredients were dry mixed manually until obtaining a homogeneous appearance. The dry compositions were then mixed in a Hobard mixer with addition of water. After mixing wet mixtures were cast into cube and prismatic molds in two layers and each layer were compacted by rodding and placing on a vibration table with a period of 30 sec. The specimens were kept in molds for three days in a humid environment. After demolding, the specimens were covered with wet burlaps until the testing period. The specimens could not be demolded after 24 hours since the hydration process and strength development of pozzolanic mixtures containing high fly ash develops very slowly.

The compressive strength of selected type of pozzolanic plaster was determined as 7,04 Mpa at 28 days and fly ash/powdered brick ratio was 1,5 in this mixture. The compressive strength tests for this selected type of pozzolanic plaster mixture were employed on the 50 mm cubes at 7, 14, 21, 28, 56, 90 and 120 days. A 3000 KN press was used in the test with a loading rate of 0,9 KN/sec. Before testing smooth metal sheets were placed to the bottom and top of the specimens during the test to minimize the end effects. The results of this test are shown in Figure 3.

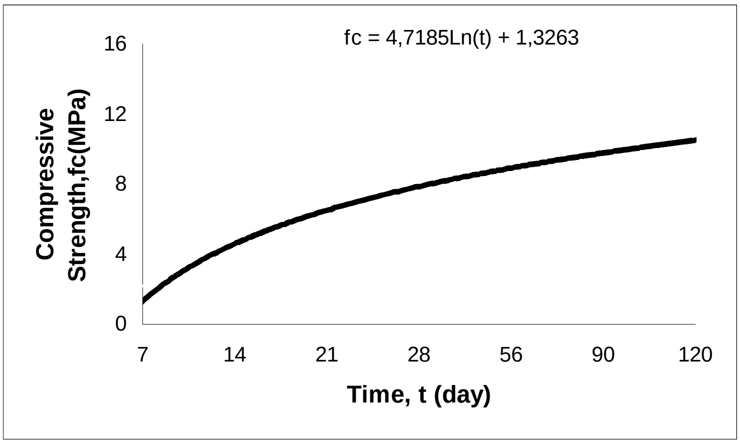

Figure 3. Compressive Strength for The Selected Type of Pozzolanic Plaster Versus Time

Also a series of test were performed on similar water soaked specimens in order to control the durability of the mixture against water. The test results of 24 hours water soaked specimens are presented in Figure 4.

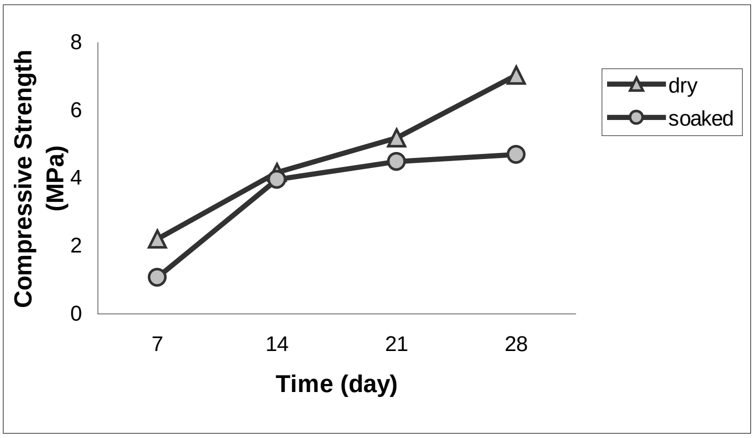

Figure 4.Compressive Strength of Dry and Soaked Specimens

Prismatic specimens were prepared for determining the flexural strength using Rilem Cembureau mortar molds. The tests were performed on a span of 100 mm with a center point loading according to Turkish Standard for Physical Testing Method of Cement (TS 24) [4]. The relationship between compressive strength and flexural strength is given in Figure 5.

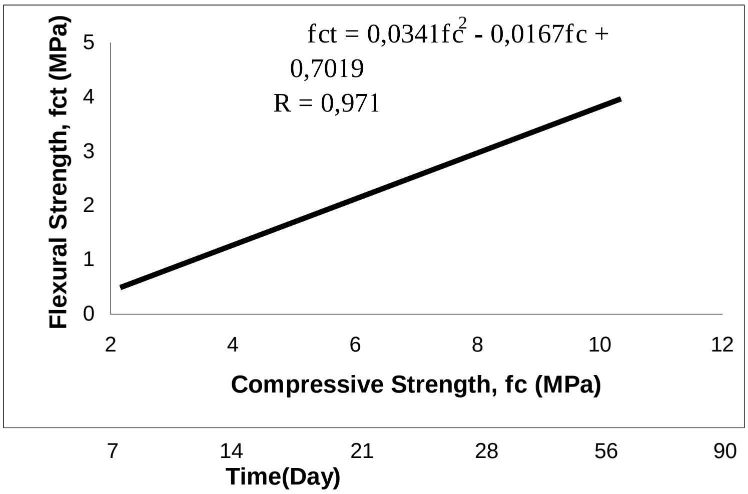

Figure 5. The Relationship between Compressive Strength and Flexural Strength

Finally ,the end of the research, three types of plasters were applied on adobe walls;

- Traditional Cement-Lime Plaster,
- Traditional Mud Plaster,
- Developed Pozzolanic Plaster.

The plastered model walls were then subjected to simulation of rain by application of wetting and drying cycles. Damage due to simulated rain was visually rated as in Table3. Figure 6.1 through 6.8 show the result of simulated rain test. The test results indicate that mud plaster was the poorest all. Very little erosion was rated on cement-lime plaster but a few cracks were observed along the walls. The Pozzolanic Plaster was perfectly resistant for intrusion of water and a very few cracks were observed.

Table 3. The Results of Simulated Rain Test

Treatment	Erosion Rating
Pozzolanic Plaster	Very Little
Mud Plaster	Very Serious
Cement-Lime Plast.	Very Little
Without Plaster	Very Serious

4.CONCLUSIONS

The rate of compressive strength development was very low between 7 and 28 days however after 28 days the strength of pozzolanic plaster mixtures increased rapidly due to the late hydration process of pozzolanic reaction. In this research a pozzolanic mixture with a 28-day compressive strength of 7,04 MPa had been selected for further studies. The generally required compressive strength for adobe brick is about 1,0 MPa [5]. The values of 1,0 Mpa can be achieved at 3 days for the selected pozzolanic plaster mixture.

Flexural strength to compressive strength ratio of the pozzolanic plaster was approximately 30%. This value is greater than the average value required for adobe brick.

The main deficiency of adobe is its susceptibility to water-damage. The mechanical properties of specimens did not decrease meaningfully even after 24 hours of soaking in water. This can be attributed to the pozzolanic properties of fly ash and lime.

Very few cracks observed on test walls that are plastered with the pozzolanic mixture since the physical properties of the soil and plaster are in conformity.

Pozzolanic plaster requires less energy and can be manufactured at a cost considerably less than cement and than many other construction materials since two main ingredients, fly ash and powdered brick are discarded by-products. Utilization of these wastes also provides technical, economical and environmental benefits. This durable pozzolanic plaster mixture may be prepared in site but the main problems are procurement, transportation and uniform mixing of fly ash, powdered brick and lime. In addition to the use of preservation and amendment of adobe walls, the developed mixture may be used in manufacture of construction blocks.

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Figure 6.1 Adobe Wall with Pozzolanic Plaster before Rain Test

Figure 6.2 Adobe Wall with PozzolanicPlaster after Rain Test

Figure 6.3 Adobe Wall with Cement - Lime Plaster before Rain

Figure 6.4 Adobe Wall with Cement –Lime Plaster after Rain Test

Figure 6.5 Adobe Wall with Mud Plaster before Rain Test

Figure 6.6 Adobe Wall with Mud Plaster after Rain Test

Figure 6.7 Adobe Wall without Plaster before Rain Test

Figure 6.8 Adobe Wall without Plaster after Rain Test

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80750 YILDIZ, İSTANBUL, TURKEY
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RENDERING AND PLASTERS OF OTTOMAN MONUMENTS IN THESSALONIKI

I.Papayianni (1), M.Stefanidou (2)
(1) Professor AUTH, Thessaloniki, Greece
(2) Dr Geologist, Thessaloniki, Greece

ABSTRACT

In Ottoman monuments plasters and renderings were widely used to cover both interior and exterior of the masonry elements in order to protect the structure and decorate the facades and the cupolas. They were based on lime and applied in successive layers so as to form a thick cover 2-5cm or architectural projections. They suffer from deterioration due to moisture and biological attack and they are often pulverized easily or detached in great parts.

The stratigraphy and the technological characteristics of them were found by chemical and microscopic analysis while some physical properties were also tested in order to conclude about their quality.

The quality of the old renderings could be attributed both to their constituents and to the technique that was used during the application. This knowledge about their characteristics could also much help the design of the new repair renderings for the restoration of the monuments.

1. INTRODUCTION

Covering the structure with renderings is a well-known technique in buildings since pre-historic period where adobe masonry was covered with mud or lime based mortar. In Roman and Byzantine period, special renderings were used in structures where water-tightness was required such as the aqueducts and the interior of baths [1].

During Ottoman period it seems that there is continuity in plastering/ rendering technique. Mortars were used to cover as a protective skin for the structure or to decorate it by adding a sense of luxury to the users.

The constituents of renderings of that period are:

- mud
- lime (of different chemical composition)
- pozzolana

and sand of various gradation

Special trained masons applied thick renderings in successive layers and worked very carefully finishing surfaces by creating as much as possible a hard and durable skin of the structure. The thickness varies from 2-5cm (figure 1). This technique was followed up to the end of 19^{th} century or even up to early decades of 20^{th} century in Greece[4].

2. TECHNOLOGY AND STRUCTURE

The renderings of Ottoman period usually consist of 2 or 3 layers differing in the grain gradation and the binder to aggregate ratio. They are mostly based on lime. The quality of the constituents is usually the same in all the layers. The internal layer (attached to the structure) usually consists of sand up to 4mm and the binder to aggregate ratio is usually 2/1 [1]. The aggregates are sometimes crushed ceramic material of the size 2-4mm. Microcracks are observed in the structure (length 200-300μm and width 10-15μm) as a result of the shrinkage. The main binder is lime of good quality or lime+pozzolanic material, that is in some cases brick dust.

Finer sand 0-2mm or 0-1mm is used in the external layer. The binder /aggregate ratio is 1/1 or 2/1. The percentage of fine contents is 80-90%.

These renderings are distinguished by a very high lime content (40-50%)[2]. Calcitic lumps and carbon grains are also observed. The percentage of siliceous material is small (8-17%) but when water tightness is required (in baths or aqueducts) an amorphous active silicate material is added in higher percent (20-40%)[3] (Table 1).

When a third layer was applied, it is a thin layer (0,2-0,3cm) of lime having a protective and rather scarifying role. The absence of aggregates is typical but in some cases fine chopped wooden fibers (length up to 3mm and width <1mm) are added in 0.5-1% b.w. in order to increase the resistance to weathering (figure 2). All the layers are characterized by high cohesiveness making their detachment relatively difficult (figure 3).

The microscopic study of the renderings showed that the external layers are more compact than the internal ones. This is achieved with the use of finer aggregates in combination with reactive lime and with very good compaction. In this way, masons could make impervious surfaces which saved the structures up to nowadays.

The measurement of the porosity by using image analysis technique, shows that the porosity of the external layer is 2-3% and is characterized by pores of 100-150μm while the internal layer is characterized by higher porosity of about 5% and the size of the pores is between 300-400μm.

The colour of the rendering is usually white- gray but when the brick dust was added, a characteristic beautiful pink hue is produced (figure 4).

3. PATHOLOGY

Renderings are surfaces exposed directly to different deteriorating agents. Open fissures create a net in the rendering layer and as a result large parts can be detached leaving the structure open or pulverization is occured (figure 5). The decorative schemes or painting are destroyed. It seems that moisture problem is the main pathology. Swelling and stains are the common symptoms of their pathology (figure 6). In addition, biological deterioration could be seen on the surface creating aesthetic (colour change) and mechanical/chemical damage. The rich in lime substratum of plasters and renderings is ideal for the colonization of micro organisms.

4. CONCLUSIONS

The quality of the renderings of Ottoman period could be attributed both to the constituents and the application technique. The longevity of the buildings of that period could partly attributed to the good quality of the renderings. The study of the old plasters/ renderings reveals many elements of old building technology. In order to proceed to the restoration of the monuments, new repair renderings are required. Based on the results of the characteristics of the old plasters/renderings the design and the manufacture of new mortars compatible with the old ones is possible.

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Figure 1. Rendering from Pazar Hamam. The thickness is 3cm

Figure 2. Wooden fibres inside the rendering reinforcing the structure. (Stereoscope x10)

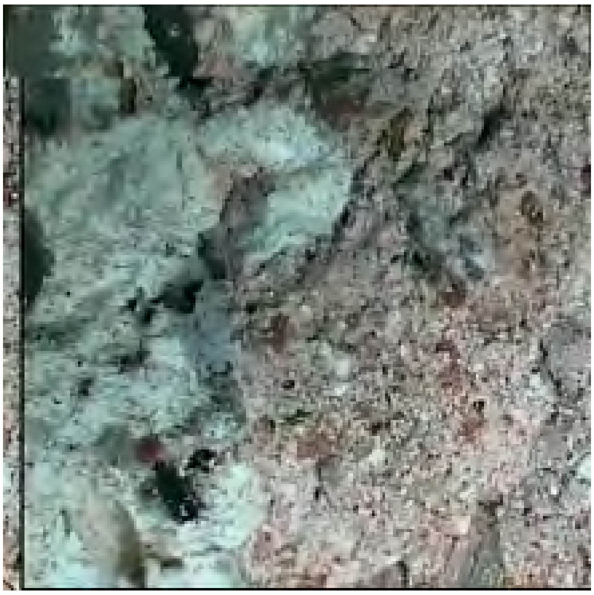

Figure 3. Cohesiveness between different layers of renderings (Stereoscope x10)

Figure 4. Pink rendering from Pazar Hamam.


Figure 5. Detachment of the rendering due to moisture at Alkazar


Figure 6. Discoloration due to moisture at Pazar Hamam

Table 1. Characteristics of Ottoman renderings

Monument	**Features of plasters/ renderings**					
	Colour	Chemical composition % **CaO**	**(Fe2O3+Al2O3+SiO2)**	Porosity %	App. Sp. Gravity	Stereoscopic observation
Pazar Hamam 15th century	Pink	30-35	2,5-3,0	25-28	1,5-1,6	Fine brick aggregates, lime lumps, cracks
Alkazar 16th century	White-grey	50-55	0,6-1,0	20-25	1,54-1,56	Wooden chips, lime lumps,
Geni Hamam 15th century	pink	32-35	1,5-2,5	30-32	1,35-1,37	Open cracks, fine crushed bricks, straw, wooden chips, lime lumps

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

DETERIORATION AND CONSOLIDATION OF THE ŞIRINÇAVUŞ VOLCANIC TUFF

E. Gürdal (1), A. Ersen (1), A. Güleç (2), N. Baturayoğlu (1)
(1) Istanbul Technical University, Istanbul, Turkey
(2) Istanbul University, Istanbul, Turkey

ABSTRACT

The deterioration of Şirinçavuş tuffs was researched by means of chemical and petrographic analysis, ICP and SEM-EDXA. It was seen that the deterioration of the tuffs in industrially air polluted environments was due to the decomposition of the feldspars and their transformation into clay minerals. Şirinçavuş tuffs include small amounts of calcite in their mineral composition, which is transformed into calcium sulphate in the polluted atmosphere. Clay minerals which are the by-products of the decomposition of the feldspars migrate into the pores of the stone in the wetting-and-drying cycles and are consequently washed away with rain water, leading to a heterogenous microstructure and surface erosion.

The deteriorated Şirinçavuş tuff samples were impregnated with Paraloid B72, 5% in toluene (methyl acrilate, ethyl metacrylate copolymer, Röhm and Haas) and a silane-siloxane combination was applied to their surfaces with the help of a brush. The research on the consolidation of the Şirinçavuş tuff was carried out based on the results of the tests for determining the efficacy of these consolidants by evaluating the change in the physical properties of the untreated and treated samples. The results were unsuccessful due to a limited and heterogenous penetration and consolidation depth. Results of the ageing tests also proved that consolidation treatments were harmful, as freeze-thaw cycles and crystallization of the water soluble salts resulted in extensive flaking and consecutively rapid surface erosion.

1. INTRODUCTION

Conservation studies and in-situ applications for the volcanic stonework especially for the tuffs have been carried out for the last three decades. The volcanic rocks which were used for monuments or sculpture are basalt, andesite, dacite, rhyolite and trachyte. However, the papers and articles on the weathering and conservation of igneous rocks consist only a small percentage of the total stone conservation research work [1]. Nevertheless, tuff building or sculpture stones have been studied most extensively, because they are widely present around the volcanic regions. Tuffs are consolidated pyroclastic rocks which were expelled through air or water. Their compositions vary according to the nature of the droplets of lava and fragments of the conduit, crater walls. Crystals or fragments of feldspars can be seen in the glassy matrix, also zeolites (hydrous aluminosilicates) as well as other minerals can be detected. Zeolites enhance the deterioration and the conservation of tuffs with their ion exchanging character. Tuffs are very porous, sometimes have almost 50% porosity owing to the vesicles left from the gases which had ejected the pyroclasts. It was concluded that these large amounts of open porosity not only cause the rapid deterioration of the volcanic tuffs but also enhance the impregnation of the consolidants.

Volcanic rocks contain different silicate minerals, usually one or more of the feldspars, olivines, pyroxenes, amphiboles, quartz and micas. Volcanic rocks are also classified as silalic and mafic rocks depending on the amount of the silicon they contain where the decreasing amounts of silicone turns the scale from acidic to basic.

Volcanic rocks which were formed in high temperatures are not chemically stable at atmospheric medium. The calcium, magnesium, sodium and potassium are gradually solubilized and consecutively [2, 3] zeolites, clay minerals and other hydreous minerals are formed.

Also crystallization cycles of the water soluble salts, the frost heave and biodeterioration processes are favoured in aqueus medium and high ambient temperatures. The high and chaotic pore structure of the tuffs increase the water retaining capacity, and thus accelerate the decay mechanisms [4, 5, 6, 7 and 8]. Generally the glassy matrix is deteriorated more rapidly than the crystalline parts. Also thermal expansion and contraction cycles of the different minerals in the composition of the tuffs lead to disintegration and exfoliation [9].

It was also stated that the hydrolitic process of deterioration of a basaltic tuff resulted in the alteration of the plagioclases into clays and olivines into serpentine minerals after long periods of water retention [10, 11].

The deterioration of the tuffs is also dependent on the porosimetry, thus higher percentages of the smallest radius class is subjected to higher pressure during water absorption and salt crystallizations. Generally the physical and mechanical deterioration processes are more rapid than the chemical alterations [11, 12, 14 and 15]. Fissuring, exfoliation, lifting and detachment of the scales are the typical surface erosion types of the mechanical deteriorations.

The crystalline phases which seldom exhibit signs of alteration are sometimes altered by the localized de-vitrification phenomena where chlorite and kaolinite are formed. [16]

Most of the scientific research which was conducted for the conservation of the volcanic tuffs stated the necessity of the consolidation treatments. Alkoxysilane solutions which deposit silica in the pores of the deteriorated stones were favoured and recommended. The consolidated stones were usually protected with water repellent surface sealings. [17, 18, 19 and 20] Paraloid B72 (Röhm and Haas) usually protected with silicone resin solutions or other water repellents performed well in the laboratory treatments. [21, 22 and 23]

Water repellents on their own were widely used for decreasing the water absorption of the tuffs as to slow down the rate of deterioration caused by the infiltration of water. Further it is claimed that the water repellent impregnations were more efficient to prevent the decay than the consolidant+water repellent impregnations because the consolidant hinders the deep penetration of the water repellent. [24]

It was also seen that the result of the in-situ impregnations after 5 years was unsatisfactory although the laboratory investigations had concluded that the consolidation treatments were very promising. [25]

Epoxy resin treatments which are rarely efficient for the consolidation of the limestones and sandstones are found to be fairly satisfactory for the tuffs. [25, 27 and 28] However some of the conclusions do not include the ageing tests.

In this research, paraloid B72 (Röhm and Haas, methyl acrylate and ethylmethacrylate copolymer) 5% in toluene and a siloxane combination (STT-Simge Antigraff-Tiefengrund) was impregnated to the weathered samples of Şirinçavuş tuff.

2. EXPERIMENTAL WORK

Minerological and chemical properties of the sound and the decayed parts of the samples were detected with petrographical, Inductively Coupled Plasma (ICP) and Scanning Electron Microscope coupled with Electron Dispersive X-Ray Diffraction (SEM-EDX) analysis. The water soluble salts were analyzed qualitatively and semi-quantitavely by spot test methods. The wall mortar and the pointing mortars of the ashlar blocks were sampled, and the core drilled samples were also visually observed to detect the kind of the binder.

3. CHARACTERIZATION OF THE ŞİRİNÇAVUŞ VOLCANIC TUFF

3.1. Petrographical Analysis

Şirinçavuş volcanic tuff had a pinkish-white colour and it contained mainly coarse minerals with heterogenous sizes and irregular shapes. The irregular shaped large grains were the main constituents while the fine minerals (mafic minerals) were in minority in the porous texture. The petrographic analysis showed that the minerals of Şirinçavuş volcanic tuff contained over 70% plagioclase as andesine and oligioclase and other minerals including biotite, alkaline feldspar, quartz, pyroxene and hornblende in the order of decreasing abundancy. The texture of the stone was composed of these minerals 35-40% in brown cement.

3.2. The Deterioration Procedure

Although most of the minerals of the Şirinçavuş tuff do not decompose, the plagioclases were chemically decomposed (sericitation). 0.5-1.0 mm wide cracks should have been formed either during the geological formation of these stones or had developed later on.

Clay sized secondary minerals were the chemical decomposition products of the feldspar (orthoclase), quartz, magnesium, silicate and chlorite minerals and they were detected in the SEM-EDX analysis. These minerals and especially plagioclases were decomposed by reacting with the H_2SO_4 in the polluted air and produced K_2SO_4 and Na_2SO_4 salts and some clay minerals and secondary quartz.

Besides the aforementioned minerals Şirinçavuş volcanic tuff contained small amount of $CaCO_3$ (2-3%) which had also reacted with the H_2SO_4 in the polluted air and produced gypsum crystals.

Altough there is some deterioration indications as flaking and powdering, the only soluble salt detected was a little amount of SO_4^{-2}. The other soluble salts such as Cl^-, NO_3^- and CO_3^{-2}, which came from the repair mortar must be washed away by rain.

The results of the ICP analysis of the sound (T1) and the deteriorated (T2) samples, which are given in Table 1, support the data gained from the petrographical and SEM-EDX analysis. The amount of the SiO_2 was decreased due to its decomposition and conversion into clay minerals. Also it was detected that the amounts of the $CaSO_4$, Na_2O, K_2O which were the by-products of the decomposition were increased. In the case of the rainwater contact and washing away with its mechanical effect, there is no serious damage for the stone object. But if these by-products were accumulated in the pores, they would result as efflorescence or swelling and heterogenous migration of the clay minerals after the wetting–drying cycles of the stone, causing blistering, flaking, powdering and deep alveolar surface erosions. Also the soft pockets formed by clay depositions during the geological formation of the Şirinçavuş tuff was weathered out after the wetting-drying cycles of the ashlar blocks.

The gypsum accumulation on the dark coloured biotite and decomposition and alteration into clay particles clearly show the deterioration procedure and the morphology of the Şirinçavuş tuff (Table 2, Samples 5 and 5a). Also the decomposition of quartz and feldspar were detected in SEM photographs (Table 2, Samples 3 and 4). The same chemical reactions, which were the causes of the chemical decomposition were also continued on the rain washed surfaces. But in this case the decomposition by-products were washed away and the surface erosion resulted as the disintegration of the eroded crystals, and this process took a longer period. The soft pockets were more rapidly eroded according to the migration of the clay minerals and cavities were formed on the stone surfaces.

The accumulation of the clay sized particles around the decomposed feldspars (orthose), quartz and magnesium silicate minerals could not be detected on the petrographic slides, but they were clearly seen on the SEM photographs.

Table 1. Results of the ICP analyses of the sound and the deteriorated Şirinçavuş volcanic tuff (T_1 and T_2 respectively)

Sample No→ Constituents ↓	**T1**	**T2**
SiO_2 %	68.27	67.22
Al_2O_3 "	14.88	14.94
Fe_2O_3 "	3.07	2.35
MgO_2 "	0.61	0.57
CaO "	2.26	3.01
Na_2O "	3.35	3.43
K_2O "	4.53	4.55
TiO_2 "	0.33	0.33
P_2O_5 "	0.60	0.03
MnO "	0.30	0.03
Cr_2O_3 "	0.004	0.003
Ba ppm	1080	1139
Ni "	37	39
Sr "	462	485
Zr "	190	190
Y "	13	13
Nb "	17	18
Sc "	3	3
LOI %	2.4	3.3
Tot/C "	0.14	0.20
Tot/S "	0.06	0.40

LOI Loss of ignition
Tot/C Total percent of carbon
Tot/S Total percent of sulphur

Table 2. Results of the SEM-EDX analysis of Şirinçavuş tuff from different points.

Constituents	**1**	**2**	**3**	**4**	**5**	**5a***	**6**	**6a***
SiO_2	66.39	64.38	75.15	74.86	43.43	58.67	51.16	66.27
Al_2O_3	18.48	22.39	13.22	13.92	15.22	16.15	20.05	18.61
FeO	1.66	0.53	1.76	1.95	17.72	6.54	2.53	1.36
CaO	4.99	5.82	2.10	1.71	2.32	2.54	11.94	1.19
MnO	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00
MgO	0.28	0.24	0.94	0.54	6.93	3.60	0.50	0.62
Na_2O	4.23	5.30	1.59	2.76	1.24	2.02	4.52	2.53
K_2O	2.27	0.82	2.95	2.23	7.14	6.17	1.30	7.58
SO_3	1.03	0.39	1.28	0.89	1.11	2.09	7.01	0.57
BaO	0.19	0.05	0.09	0.05	0.30	0.12	0.12	0.07
TiO_2	0.17	0.00	0.60	0.96	0.14	0.00	0.00	0.29
EDX Magn.	x2000	x2000	x2000	x3000	x2000	x100	x2000	x100

* EDX analysis from the same point taken with a different scale of magnification.

4. CONSOLIDATION TREATMENT

4.1. Experimental Work

Test programme aimed to conduct tests to determine and compare the physical properties of the untreated and treated Şirinçavuş volcanic tuff samples and evaluate the efficacy of the consolidants. Viability of the consolidation treatment was controlled by means of the ageing tests.

4.2. Preparation of the Samples and Application of the Consolidants

Deteriorated Şirinçavuş tuff facework blocks was taken from the facade of Dolmabahçe Palace (Istanbul, Turkey) and were core-drilled into 5.28x10.56 cm cylindrical sample blocks. All of the samples were dried at 105^{o}C and conditioned at 20 ± 2^oC and 60 ± 5% RH until constant weight was obtained. Three of these samples were called untreated and their physical properties were determined. Afterwards they were dried and conditioned again before the impregnation of the consolidants.

Paraloid B72 (Röhm and Haas, acrylic co-polymer) 5% in toluene was applied by brush to the vertical surfaces of the cylindrical samples to simulate the application of the consolidants in-situ. Impregnation applications were composed of 2 cycles each lasting 60 minutes with an interval of 240 minutes. The consolidant absorption rate was 0.967 l/m^2. After 24 hours a silane-siloxane solution was brushed to the surfaces of the same samples for an hour. The consumption rate was 0.400 l/m^2. Coefficient of capillarity for the impregnation by means of capillary suction was was 0.02592 cm.$\sqrt{\text{min}}$ when the consolidants were mixed in the ratio of 1:1.

Two 5.28 cm diametered and 1 cm thick untreated samples were conducted to water vapour permeability test. Afterwards they were impregnated with the consolidants, by means of 24 hours of total immersion. All of the treated samples were allowed to cure for 30 days.

3 untreated samples were kept for the ageing tests.

4.3. Parameters Measured

- Depth of penetration, depth of impregnation
- Change in unit weight, specific gravity
- Weight increase
- Change in water absorption (by weight %)
- Total porosity
- Change in water vapour permeability
- Change in coefficient of capillarity
- Artificial ageing of the untreated and the treated samples

6. RESULTS

6.1. Depth of Penetration and Impregnation

The penetration depths were homogenous and 5-6 mm. The penetration depth can be increased by prolonged impregnation or by means of capillary suction.

The impregnation depth was 1-2 mm, which is superficial and insufficient.

6.2. Weight Increase, Change of Unit Weight and Spcific Gravity

The weight increase after the polymerization of the consolidants was 1.59%. The unit weight of the untreated Şirinçavuş volcanic tuff was 1.87 g/cm^3, after the consolidation treatment it was calculated as 1.38 g/cm^3. The specific gravity of the treated samples did not change and this was 2.53 g/cm^3.

6.3. Change in the Water Absorption (by Weight %) and Total Porosity

The water absorption (by weight %) was 0.84% reduced and it was 11.8% after the treatment. This shows that the impregnation was superficial and a film forming impregnation was not achieved. The total porosity was not affected by the treatment.

6.4. Change in the Coefficient of Cappilarity

The coefficient of capillarity was reduced to 0.00185 g/cm^2.$\sqrt{\text{min}}$ from 0.023 g/cm^3.$\sqrt{\text{min}}$. The result should be evaluated together with those of the change in water absorption (by weight %) and it can be seen that the samples were surface sealed.

6.5. Change in the Water Vapour Permeability

The decrease of the water vapour permeability after the consolidation or hydrofobization means the retarding of the drying period and cryptoflorescence in the presence of the water soluble salts. Consecutively this phenomena leads to acute surface erosion. In this case hindering of the water vapour permeablitiy was detected according to the result of the experimental work. The coefficient of water vapour permeability was increased 250%, which is above the acceptable limits of 50-100%.

7. AGEING TESTS

7.1. Freeze-Thaw Cycles

There was no surface erosion after the 25th cycle but this superficial water repellency did not mean a total protection from ageing as the results of the crytallization cycles of the super-saturated sodium sulphate decahydrate solution was very destructive.

7.2. Crystallization Cycles of $Na_2SO_4.10H_2O$

Table 3 Results of the salt crystallization test

Cycle Number	Initial Weights		Erosion Morphology	
	441.66	445.72	○	○
1	443.8	449.1	○	■
2	457.3	451.6	■	■
3	477.4	477.3	■	■
4	477.1	476.8	■	■
5	475.7	475.1	■	■
6	468.8	466.9	■	■
7	459.5	461.8	■	■
8	442.0	449.0	□	□
9	449.6	445.2	□	□
10	–	444.0	–	□
Extensive exfoliation and chipping.				

○ Sound
■ Surface Erosion
□ Fissuring and Exfoliation

8. CONCLUSIONS

- It can be clearly stated that the consolidation and surface protection of Şirinçavuş volcanic tuff is detrimental and lead to a rapid surface erosion in the presence of water soluble salts, especially sulphates.
- The impregnation depths and their homogeneity did not mean much as the microstructure of the Şirinçavuş volcanic tuff was very heterogenous and this was due to the mineralogic composition and the alteration process of the feldspars to kaolinite which lead to a more complicated phenomena.
- In-situ consolidation treatments will accelerate the deterioration processes.

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Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

PRELIMINARY INVESTIGATIONS ON CONSTRUCTION MATERIALS AND CONSERVATION STATE OF A HISTORICAL BUILDING IN RURAL AREA NEAR FAENZA (ITALY)

V. Bonora (1), B. Fabbri (2), R. Negrotti (3), A. Proni (4)
(1) Department of Applied Chemistry and Material Science, Bologna, Italy
(2) C.N.R., Research Institute for Ceramics Technology, Faenza, Italy
(3) C.N.R., Centre "Gino Bozza", Milan, Italy
(4) Engineer, Faenza, Italy

ABSTRACT

Bricks and mortars from a building dated back to the 16th century, located in rural area, were investigated. The aim was to evidence the different stages of construction and to define composition and source of the soluble salts in the building materials. Both bricks and mortars show variable composition and/or microstructure, but it is impossible to put into evidence any significant scheme of distribution in the four facades of the building. That is caused by the large number of interventions in the time and to the reuse of old bricks. The salts are mainly constituted by sulphate, nitrate, chloride, fluoride, calcium, sodium and potassium, but the total amount of cations is half of the anions on average. That means that unusual cations are present, which were not determined, probably connected with the rural environment where the building is located.

1. INTRODUCTION

In the countryside that leads from Faenza to Ravenna, not far away from the old Parish of Cesato, there is the villa which is called *Castellina dei Manfredi*, since it was property of the masters of Faenza, as its name suggests, between the 13th century and the end of the 15th century. The current building has been partially built upon the foundations of the castle which is known for having been, in 1285, the place where *the slaughter of Cesato* occurred, as Dante Alighieri describes in *The Divine Comedy*, Inferno, Canto 33°, vv. 109-157. The original building was demolished in 1350 to avoid that the cardinal legate's army took possession of it; the place kept on being mentioned however, in several historical papers under the name of *Villa de la Carise*.

The present main body of the building dates back to the XVI century and it is characterised by an essentially cubic shape with a perfectly square plan (figure 1). Examining the structure it is possible to notice how the building underwent some rearrangements, beginning from the south-western area which was initially even lower than it is now, as you may observe from the oval-shaped openings of the garret which have been partially walled up to make room for the current ones.

The ground floor is characterised by a big entrance way that passes through, makes independent various service rooms and opens onto the little staircase with a double flight. The first floor gets into the square plan of the building with a spatial composition which is based on the diagonal symmetry axes. In this way cross spaces are created, which converge without interruption into the central octagonal room thanks to some bevels in the inside angular walls.

The building is made of a masonry structure of bricks; in the north-western front, which is not plastered, is clearly evident the connection between the oldest and the lowest part in the building (towards Southwest) and the most recent part (towards Northeast). This building is described in the town-plan as “building of monumental architectural value in agricultural area”. The first binding obligation which the building was subject to, was notified to the then owner on the 30th of August in 1911. It was restricted to the staircase, to the upper cross room and to the memorial tablet of the 16th century. The following binding obligations, the last of which dates back to the 3rd of April in 1987, concern instead the whole building.

The object of this research is the study of the main features of the materials that have been used during the construction of the masonry (bricks and mortars). In this way it will be also possible to obtain information about the damage due to rural environment, that has a quite low degree of atmospheric pollution, with the exception of extremely localised incidental phenomenology that is linked to the agricultural use for which the building has been intended for a lot of time. A possible intervention of restoration, which might be functional as well, will have to take into consideration that information, adjusting both the interventions and the use of the materials.

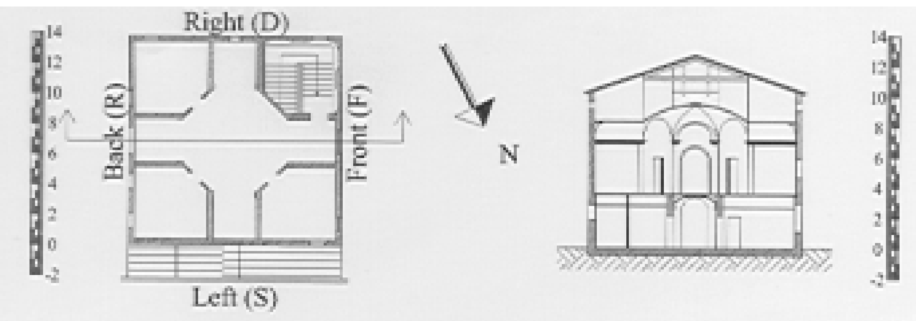

Figure 1 – Plan of the 1st floor (on the left) and section (on the right).

2. EXPERIMENTAL PART

2.1. Materials

Bricks and mortars were sampled on all four of the walls of the building at various heights, more frequently on the front because it is the only wall whose masonry is completely visible. The right side and the back are covered with plaster, while a recently built structure leans against the left side. The material was scraped away and marked respectively with the letters F (front), R (back), D (right, towards Southwest), S (left, towards Northeast). Thirty sampling points were chosen: three samples were often collected from each of these points, i.e. two bricks, that are close to each other, and one mortar that is between the two bricks (figure 2).

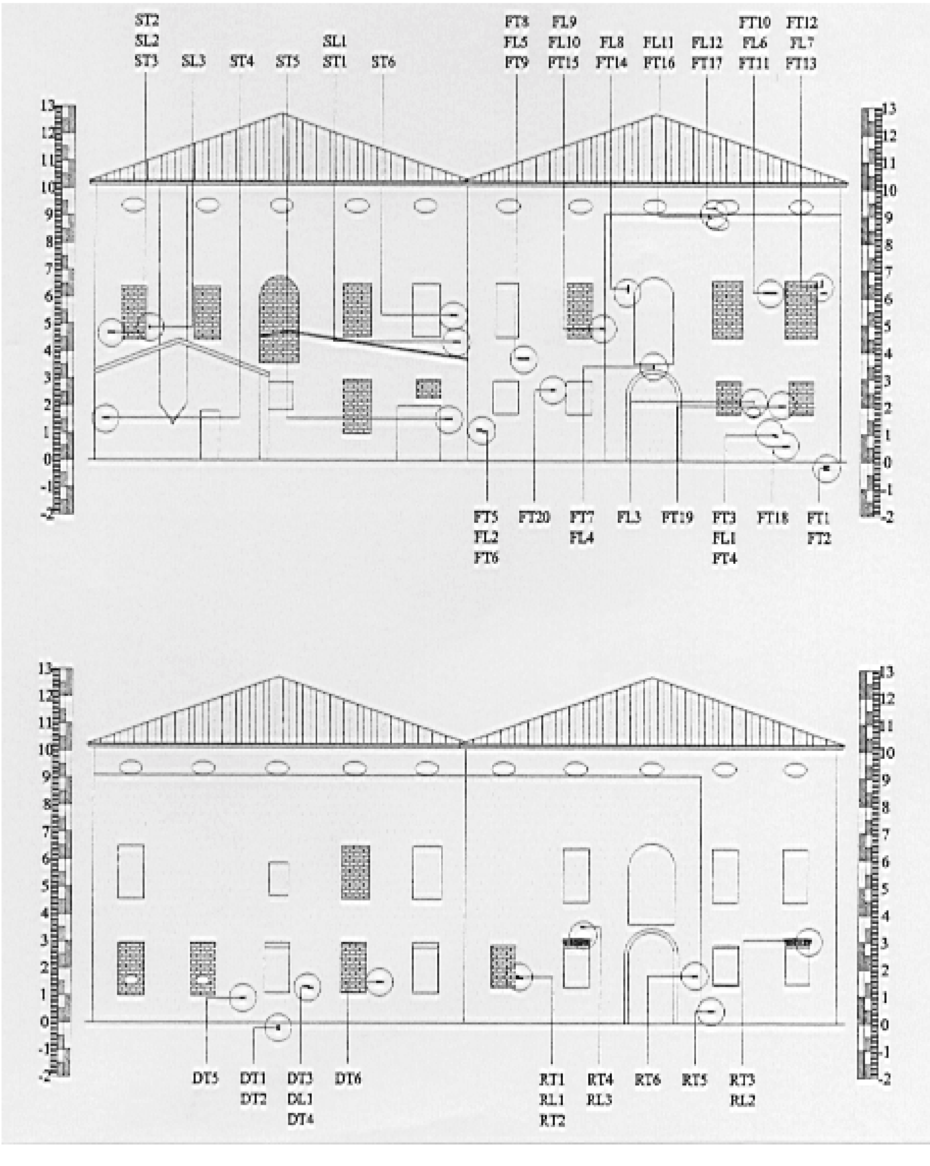

Figure 2 – Location of the sampling points on the four facades of the building.

2.2. Characterisation

The characterisation was performed on a selection of samples collected: 25 bricks and 11 mortars (table 1).

- *X-Ray Diffraction (XRD),* by Philips PW 1840 with a copper anticathode, was employed for the identification of the main crystalline phases in bricks and mortars. The characterisation has been carried out at room temperature, on an interval 2θ from 4° to 64° and a scanning speed of 2° per minute;

- *X-Ray Fluorescence (XRF)*, by Philips PW 1480 with an anticathode of scandium, was employed for the determination of the chemical composition of the bricks. The analysis was carried out on tablets of 2.5 cm diameter and 5 mm thick. This tablet was prepared by pressing 0.5 g of the powdered sample on a bearing of boric acid at about 2000 kg/cm^2; the ignition loss (I.L.) was performed by calcining at a temperature of 1000 °C, for about two hours, 1 g of dried sample. The samples rich in soluble salts were previously washed five times in distilled water. With the exception of I.L. and P_2O_5, the data were normalised to 100.

Table 1 – Sampling position and conductivity of the samples analysed

BRICKS										MORTARS				
Facade	**Sampling point**	**Sample**	**Height (cm)**	**Conductivity µS.cm^{-1}**	**Facade**	**Sampling point**	**Sample**	**Height (cm)**	**Conductivity µS.cm^{-1}**	**Facade**	**Sampling point**	**Sample**	**Height (cm)**	**Conductivity µS.cm^{-1}**
Front	1	FT1	-20	25	Right	2	DT1	-20	36	Front	3	FL1	105	n.d.
		FT2	-20	33		11	DT4	120	144		4	FL2	65	167
	3	FT3	95	80		24	DT5	90	98		5	FL3	150	26
		FT4	95	36		25	DT6	140	119		12	FL6	610	n.d.
	4	FT5	65	140	Left	16	ST1	430	42		15	FL10	480	n.d.
	12	FT10	610	36		17	ST3	460	71		19	FL11	880	n.d.
	13	FT12	612	27		28	ST4	150	126	Right	11	DL1	120	57
	15	FT15	480	41		29	ST5	150	108					
	19	FT16	880	31		30	ST6	530	28					
	21	FT18	60	180	Back	8	RT1	165	175	Left	16	SL1	430	33
	22	FT19	150	71		9	RT3	300	32		17	SL2	460	n.d.
	23	FT20	260	110		26	RT5	45	106	Back	8	RL1	165	68
	---	---	---	---		27	RT6	175	86		9	RL2	300	n.d.

- *Mineral-petrographic analysis* was performed on thin section of bricks with transmitted light [1]. This analysis allows to identify the skeleton and to classify dimensionally the skeleton itself: silty (<63μm), very thin sandy (63-125μm), thin sandy (125-250μm), average sandy (250-500μm), coarse sandy (>500μm);

- *Evaluation of the soluble salts* was performed by electrical conductivity (Analytical Control Instrument 101) and ion chromatography (IC, Dionex DX 100) on both bricks and mortars. The conductivity was measured in the solution that had been obtained from 100 mg of sample kept in 100 ml of bidistilled water, for 72 hours, at room temperature, and modified by subtracting the conductivity of the bidistilled water [2]. The soluble ions, seven anions and five cations, were measured by IC with conductometric detector, chromatographic column and electrosmotic suppressor, which are specific for anions and cations, after water dissolution of 100 mg of powder for 2 hours;

- *Binder/aggregate ratio*: the binder/aggregate ratio of the mortars was determined by weighing the quantities of both the binder and the aggregate which were obtained from 2 g of sample after a few consecutive treatments of 5-10 minutes each in water in ultrasonic bath and decantation;

- *Granulometry of the aggregate*: the aggregate, which is the result of the treatments that were carried out to determine the binder/aggregate ratio, was divided into particle size fractions by using the following series of sieves: 1 – 0.5 – 0.25 – 0.125 – 0.063 mm.

3. RESULTS

3.1. Bricks

A part some irregularities, the chemical compositions of the bricks result very homogeneous (table 2). Silica shows values around 54%, alumina and calcium around 15%. Iron is generally comprised between 5 and 6%, magnesium is around 4% and potassium between 2.5 and 3%. Sodium (about 1%), titanium (about 0.7%) and manganese (about 0.13%) complete the normalised composition.

I.L. values are different and they underline a different level of rehydration and carbonation of the body, probably as a consequence of different firing temperatures of the various bricks.

The XRD diffraction patterns show that the principal minerals present are quartz and calcite. In addition, plagioclase and mica are quite always detectable, while dolomite and pyroxene only in a few samples. The presence of pyroxene and the contemporary absence of micas allow to individuate a group of samples (FT1, FT5, FT12, RT3) which were fired at a fairly high temperature, assessable at 900-950°C. The samples without pyroxene were fired at lower temperature and they can be further subdivided into two groups, one with low amounts of calcite and illite (FT10, FT15, RT1, DT1, DT4) and the other with a higher quantity of calcite and illite (FT2, FT16, ST1, ST3). A firing temperature around 850-900°C can be attributed to the group with low calcite content, while a firing temperature around 800-850°C can be hypothesised for the samples with high calcite content.

Table 2 – Chemical composition of the bricks (wt. %)

	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	I.L.	P_2O_5
FT1	54.91	15.15	0.66	5.40	0.12	3.97	15.49	1.36	2.92	3.36	0.26
FT2	53.77	16.07	0.70	5.47	0.12	3.71	16.18	0.91	3.06	12.00	0.23
FT5	52.61	15.83	0.69	5.69	0.13	4.71	16.27	1.24	2.83	5.17	0.18
FT10	53.52	16.27	0.73	5.91	0.13	3.98	15.40	1.00	3.06	7.24	0.24
FT12	53.91	15.21	0.66	5.35	0.12	3.92	16.62	1.39	2.81	3.16	0.17
FT15	53.96	15.11	0.65	5.26	0.12	3.94	16.84	1.25	2.70	7.00	0.15
FT16	53.62	16.35	0.70	5.69	0.13	3.66	16.01	0.93	2.89	13.24	0.22
DT1	51.89	15.74	0.69	6.02	0.13	5.10	16.53	0.79	3.11	6.31	0.23
DT4	54.67	14.00	0.60	4.80	0.12	4.65	17.15	1.22	2.79	9.39	0.17
ST1	51.89	16.55	0.76	6.40	0.14	3.84	16.37	1.04	3.01	13.76	0.17
ST3	55.22	15.00	0.65	5.23	0.12	3.74	16.21	1.12	2.72	12.29	0.16
RT1	57.13	16.83	0.78	6.40	0.15	3.65	10.77	1.16	3.12	6.31	0.19
RT3	54.23	14.84	0.66	5.39	0.12	4.00	16.85	1.25	2.65	3.75	0.16

From the thin section observation the bodies of the bricks appear very fine and porous, with evident differences in colour and quantity of skeleton from one point to another of the same sample. The ground-mass is sometimes anisotropic and sometimes isotropic, depending on the firing degree of the material. A clear connection can be noted between the anisotropy/isotropy of the ground-mass and the amount of pyroxene detected by XRD. The quantity of skeleton is highly variable, ranging from 5 to 20% approximately, but this variability is mainly due to the above-mentioned non-homogeneity of the bodies.

The results pertaining to the soluble salts in the bricks are reported in table 3. It can be noted that the concentrations of nitrate, sulphate, chloride and calcium ions are the highest ones, but their values show a very wide variation range.

Nitrate ion values are distributed in the range 0.7-4.5% and chloride ions in the range 0-1.2%, but they both individuate two groups of samples:

a) samples FT4, FT5, FT18, FT19, DT1, ST3, ST6, RT5 = 0.7-1.8% nitrates and 0-0.4% chlorides;
b) samples FT3, FT20, DT5, DT6, ST4, ST5, RT6 = 3.5-4.5% nitrates and 0.7-1.2% chlorides.

Sulphate and calcium values are fairly homogeneously distributed in the range 0.4-5.4% and 0.4-1.6% respectively, with the exception of sample FT18, which contains more than 9% sulphates and 2.5% calcium approximately.

Among the anions, fluoride, nitride, phosphate and oxalate concentrations were also measured. Fluoride ions resulted always present with low concentrations, around 0.2%. Nitride ions resulted always absent, as well as phosphate and oxalate ions, with two small exceptions: sample FT20 (0.28% phosphate) and sample DT6 (0.04% oxalate).

Table 3 – Content of soluble ions (wt. %) for the bricks

Sample	Fluoride	Chloride	Nitrate	Sulfate	Potassium	Sodium	Magnesium	Calcium
FT3	0.23	0.75	4.20	2.00	0.25	0.09	0.04	0.75
FT4	0.17	0.13	1.18	0.45	0.06	0.04	0.02	0.58
FT5	0.20	0.05	0.70	1.35	0.04	0.03	0.01	1.60
FT18	0.21	0.25	1.58	9.19	0.13	0.04	0.02	2.59
FT19	0.19	0.35	1.76	1.93	0.10	0.07	0.03	0.92
FT20	0.22	0.73	4.21	3.39	0.08	0.09	0.04	1.26
DT1	0.21	0.08	0.74	0.64	0.04	0.02	0.02	0.50
DT5	0.18	0.77	3.64	0.53	0.34	0.23	0.06	0.56
DT6	0.19	1.21	4.55	1.85	0.23	0.20	0.04	1.10
ST3	0.24	0.06	0.88	3.60	0.05	0.05	0.02	1.01
ST4	0.20	0.87	4.06	2.94	0.27	0.14	0.03	1.20
ST5	0.23	0.99	3.58	2.03	0.19	0.10	0.02	1.01
ST6	0.18	0.20	1.11	1.02	0.01	0.02	0.01	0.40
RT5	0.20	0.36	1.67	5.42	0.10	0.08	0.03	1.32
RT6	0.25	1.21	4.04	0.74	0.11	0.16	0.02	0.84

Among the cations, potassium (<0.4%), sodium (<0.3%) and magnesium (<0.1%) resulted always present. Also ammonium was always detected, but it can be neglected because its concentrations never exceeded 0.02%.

Except the sample FT5, the total amount of anions appears always very larger than that of cations, as evidenced by the correlation diagram reported in figure 3a, where the data are correctly expressed in “micro-equivalents”.

Conductivity values (table 1) vary from about 25 up to 180 $\mu S.cm^{-1}$, and are good correlated with the total anion contents (figure 3b), sample FT5 excluded:

$$\text{conductivity } (\mu S.cm^{-1}) \cong 0.7 \cdot \text{anions } (\mu eq)$$

What above-mentioned means that a significant quantity of cations is lacking, practically in all the samples analysed, probably coming from some complex salts used in agricultural practice, for example fertilizers or fungicides.

3.2. Mortars

The x-ray diffractometric analysis of the selected mortars evidenced two principal components: calcite and quartz. Significant amounts of plagioclase and illite/muscovite are often present, while k-feldspar and dolomite show a high quantity only in a few cases.

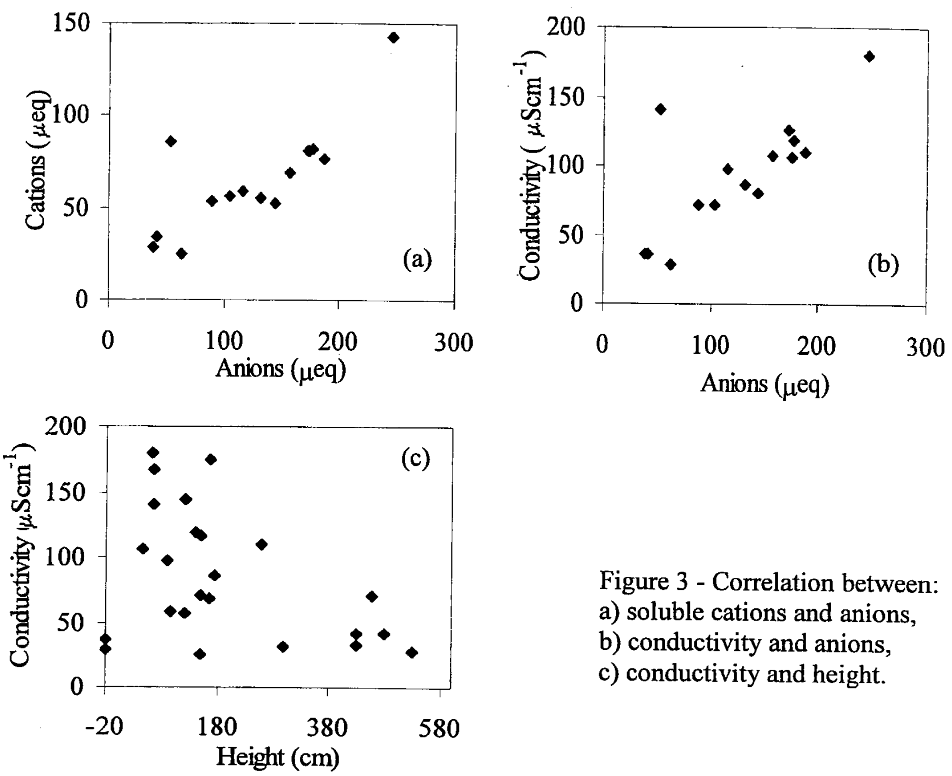

Figure 3 - Correlation between:
a) soluble cations and anions,
b) conductivity and anions,
c) conductivity and height.

Gypsum and graphite were detected in relevant amount only in one sample each; another sample shows small amounts of cristobalite. That means that the binder is calcium carbonate (calcite), which is mixed with gypsum in the sample RL2. Quartz is the principal component of the aggregate, often accompanied by feldspars (plagioclase and k-feldspar) and micas (illite/muscovite).

Because calcite is very abundant, probably a significant amount of calcite grains is present as aggregate together with quartz. The sample containing graphite was collected near a fireplace, so its presence is due to fire pollution. The presence of dolomite could be explained in two ways: component of the aggregate or of the binder. In the latter case it would indicate an uncompleted decomposition of the dolomitic limestones used for the production of lime. Anyway, the presence of dolomite could distinguish mortars of different origin or construction period, as well as the presence of variable quantities of feldspars and micas do, but there is no evident connection with the position of the mortars in the various parts of the building.

The seven samples analysed show different binder/aggregate ratios, ranging from 0.30 up to a maximum of 0.93 (table 4). In spite of the limited number of samples, three groups of mortars can be distinguished:

- RL2 and SL2 = practically equal amounts of binder and aggregate (B/A about 1:1);

Table 4 – Binder/aggregate ratio and grain size distribution (wt. %) of the aggregate of the mortars

Sample	**B/A ratio**	**Grain size (mm)**			
		< 0,125	**0.125-0,25**	**0,25-0,50**	**> 0,50**
FL1	0.45	31.1	45.3	21.5	2.1
FL2	0.51	15.7	25.6	44.8	13.9
FL10	0.56	32.6	50.0	16.7	0.7
SL1	0.44	38.5	55.1	5.9	0.5
SL2	0.77	44.5	44.3	10.2	1.0
RL1	0.30	21.0	49.9	20.4	8.7
RL2	0.93	35.6	47.7	12.2	4.5

- FL1, FL2, FL10 and SL1 = binder about half of the aggregate (B/A ≅ 1:2);
- RL1 = binder/aggregate ratio about 1:3.

This variability confirms that the building is the result of different interventions, as already said speaking about the mineralogical composition.

Table 4 shows that the mortar FL2 contains the coarser aggregate with a median diameter (Φ_{50}) is 0.28 mm against 0.19-0.14 mm of the other ones.

Five mortars were analysed by determining their conductivity. The data obtained (table 1) range from 26 (sample FL3) to 168 $\mu S.cm^{-1}$ (sample FL2). This means that the content of soluble salts varies depending on the collecting point of the sample, but there is no clear evidence of a connection between the conductivity data of mortars and bricks coming from the same points. The conductivity value for the mortar FL2 (168 $\mu S.cm^{-1}$), for example, is very similar to that of the near brick (FT5 = 140 $\mu S.cm^{-1}$), but the value found for the mortar RL1 (68 $\mu S.cm^{-1}$) is very different from its near brick (RT1 = 175 $\mu S.cm^{-1}$).

3.3. Soil

Four soil samples were analysed in order to determine their soluble salt content and to verify if the soil can be the source of the salts found in the masonry. Their conductivity resulted low, ranging from 14 to 19 $\mu S.cm^{-1}$. Accordingly to this, also the content of soluble salts is low, of the same order of that resulting for the bricks DT1, FT4 and ST6. The most important ions are sulphate, nitrate and fluoride among the anions, and calcium among the cations. Nitride, phosphate and oxalate are always absent, while sodium, potassium, magnesium and ammonium are present in traces. As it occurs in the bricks, the total amount of anions in the soil samples is more o less two times the total amount of cations.

4. DISCUSSION AND CONCLUSION

4.1. Construction materials

The chemical composition of the bricks is very homogeneous. It deals with a calcium-rich body obtained by employing local raw materials. In addition, it is likely that the subsequent reconstruction phases were carried out by reusing at least part of the still suitable old bricks, recovered from the building remains.

The non-homogeneity of the body inside a same brick, revealed by the optical observations in thin section, means that the raw materials were badly mixed during the manufacture. This characteristic inhibits the possibility of distinguishing the pieces produced in different times on the basis of the mineral-petrographic investigation. In fact, what we observe in thin section strongly depends on the area we are observing and not only on the real average composition of the bricks.

The firing of the shaped bricks was performed in variable conditions of temperature and oxidation level inside the furnace, so that the bricks show a firing grade corresponding to temperatures as high as 800-900°C and colour shades ranging from red to yellow. Unfortunately the described situation is not favourable in order to distinguish the parts of the building constructed in different times, by comparing the characteristics of the bricks. But the choice of new materials to be utilised in the possible reconstruction or repairing of parts of the building is easy and there are not many alternatives.

The binder composition of all the analysed samples resulted to be carbonatic, except only one sample characterised by a binder constituted by a mix of lime and gypsum. So, the variability shown by the mineralogical composition of the mortars is mainly referred to the aggregate. As a matter of fact, variable quantities of feldspars, dolomite and micas are found together with abundant quartz, but these variations do not appear in any way connected with the position of the collecting point of the samples, neither considering the heights nor the facade. In addition, the mortars show different binder/aggregate ratios, that varies from 1:1 to 1:3.

As a consequence, we can say that there were different stages of construction of the building, when different mortars were used, but it is impossible to say where they are, due to the masking effect of various minor maintenance interventions.

4.2. Conservation state

The aspects referred to the conservation state of the materials are very interesting, and in particular the composition and distribution of the soluble salts. As it can be seen in figure 3c, accordingly to what reported in literature [3], the higher values of conductivity were detected in brick or mortar samples collected at heights around one meter from the ground (FT18: 60 cm, 180 $\mu S.cm^{-1}$; RT1:165 cm, 175 $\mu S.cm^{-1}$; FT5: 65 cm, 140 $\mu S.cm^{-1}$; FL2:65 cm, 167 $\mu S.cm^{-1}$). The main soluble ions are sulphate, nitrate, chloride, fluoride and calcium. At the same eight, the samples characterised by higher conductivity contain high amounts of sulphate and calcium, while the samples containing high quantities of nitrate and chloride never show conductivity values higher than 130 $\mu S.cm^{-1}$. In addition, it should be noted that nitrate and chloride contents are strictly connected between them, as well as both they are quite well correlated with sodium and potassium. Probably this can be interpreted in terms of provenance of the soluble salts, taking also into account that chloride and nitrate ions are lighter and smaller than SO_4^{--} ion. The formation of calcium sulphates would mainly occur directly in the brick by reaction of calcium from the mortars and sulphate from the atmosphere. On the opposite, sodium and potassium nitrates and chlorides would be transported by capillary rising in solutions coming from the soil. The concentration of soluble salts in the soil is very lower than that measured in bricks and mortars, but the soil represents a practically inexhaustible source.

The concentration of soluble salts in the mortars resulted always lower than in the bricks at the same height. In addition there not a constant ratio between the concentration of the various ions in the bricks and in the adjacent mortars. Probably that is due to the different microstructure of the two materials, in the sense that capillary rising of water is easier in the bricks than in the mortars.

The last subject to be pointed out is the noticeable difference of total amount of anions and cations when they are expressed in chemical "equivalents", and that anions are higher than cations. On the average the ratio between anions and cations is about 2:1, and such a situation was never encountered in other case studies [4]. That means that some ion was not determined because it was not included in the usual list of the ions determined when natural or artificial stones like bricks and mortars are investigated. So, it is necessary to imagine the presence of some uncommon ion probably deriving from the dissolution of complex fertilizers or pesticides. That will be the matter for further investigations.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

STRUCTURAL EVALUATION BY USE OF DYNAMIC TESTS

V. Sigmund, T. Ivanković, P. Brana
University J.J.Strossmayer, Faculty of Civil Engineering, Osijek, Croatia

ABSTRACT:

Detecting structural state of historical monuments and their adequate strengthening is a complex problem that requires cooperation among various specialists. The only way to do that is by non-destructive experiments that are simple and reliable enough. Dynamic tests are the one that fulfill these requirements. The examples of various dynamic tests (ambient vibrations, impulse excitation and transfer function tests) applied on historic structures are presented in this paper. They were used for determination of dynamic characteristics, evaluation of the real structural state, modification of the mathematical model and behavior analysis under extreme events. The modified model, that represents the real structure, was used to investigate the structural response to extreme loadings, to check the influence of various strengthening methods and to choose the best method strengthening for particular structure (if needed).

1. INTRODUCTION:

Old historical monuments are a living witness of the previous folk achievements, their tradition and culture. Their value is enormous and it is very important to preserve them for the next generations. Visible and invisible structural damages, whether caused by natural phenomena or by human actions can make structure unable to withstand the next extreme events or to collapse from itself. The fact that the monuments survived many catastrophic events, does not guarantee their survival in the next one.

The problems in understanding the true structural behavior arise from, sometimes, unknown building methods, various materials used, structural degradation, complex structural history, unknown strengthening methods and modifications and from their extreme value. Each monument's structure is unique and there are no standard or usual methods that could guide the engineer to perform the optimal structural strengthening method. Estimation of the structure's present state is very important and invaluable first step.

Experimental methods, that could reveal the structural state and its true behavior that are inexpensive and non-destructive are preferable. Structure's dynamic characteristics (frequencies, mode shapes and damping values) reveal the most important structural data and represent the "personal" card of the structure. By knowing the dynamic characteristics we are able to determine: (a) structural state and interaction with the neighboring structures and ground; (b) detection of the horizontal and vertical stiffness and mass distribution; (c) contribution evaluation of particular elements; (d) detection of the elements homogeneity; (e) verification of the mathematical design model and its calibration so that it represents the real structural state and behavior; (f) evaluation of the structural behavior under extreme events; (g) choice of the best strengthening method by checking various methods on the calibrated model; (h)verification of the performed strengthening quality by subsequently measuring dynamic characteristics.

The methods used to determine structural dynamic characteristics are: ambient vibration measurements, impulse excitation and transfer function tests. All of them are non-destructive and use some sort of statistical averaging in order to derive the important data from which dynamic structural characteristics are obtained.

Several examples of the applied dynamic tests on historical monuments are presented. Dynamic tests served as a useful tool to reveal the overall structural behavior, vertical and horizontal force transfer mechanisms and the structural state. Experimental results were used to calibrate a mathematical model, which otherwise significantly deviated from the reality, and additional studies on it were made.

By measuring the dynamic characteristics at certain time intervals, structural degradation can be detected and adequate measures undertaken at the right time. Changes in mode shapes indicate changes in strength distribution, changes in damping characteristics indicate change in the homogeneity, and changes in natural frequencies indicate change in the overall structural state.

2. FERHAD-PASHA MOSQUE FROM THE XVI CENTURY

Ferhad-Pasha's mosque in Banja Luka, Bosnia and Herzegovina, was one of the most famous historic monuments of Islamic architecture from the XVI century. The latest photo is given on Fig. 1. Its structure had been several times damaged and repaired. Each repair held until the next event when the same damage re-appeared or the previous repair caused damage to another part. The mosque was severely damaged during the 1969. earthquake (IX degrees MCS), was repaired and damaged again by the next earthquake in the 1981. Repeated damage showed that by strengthening only certain structural parts did not provide satisfactory results. The structure had to be considered and analyzed as a complex system.

Investigation of material and structural characteristics was necessary in order to define the best strengthening method. Following steps were undertaken: (a) evaluation of material characteristics; (b) vertical check of the walls and praying tower; (c) check of the walls homogeneity; (d) ambient vibration measurement of the main structure and praying tower. Measuring instruments were placed on the main mosque building horizontally and vertically and on the minaret vertically so that all oscillation forms could be measured.

Fig.1 Ferhad-Pasha Mosque

The structural walls were made from formed lime stones placed on the inner and outer side and with a space between. The space was filled with mortar and crushed stones. The brick dome rested on the walls and the horizontal connection among different wall sections was provided by cast iron ties. Measured dynamic characteristics revealed predominant structural response as a unique system. That indicated good and compact overall structural behavior. Some wall sections had tendencies of uncontrolled behavior that was concluded from different frequencies they had and their connection with the rest of the structure had to be restated.

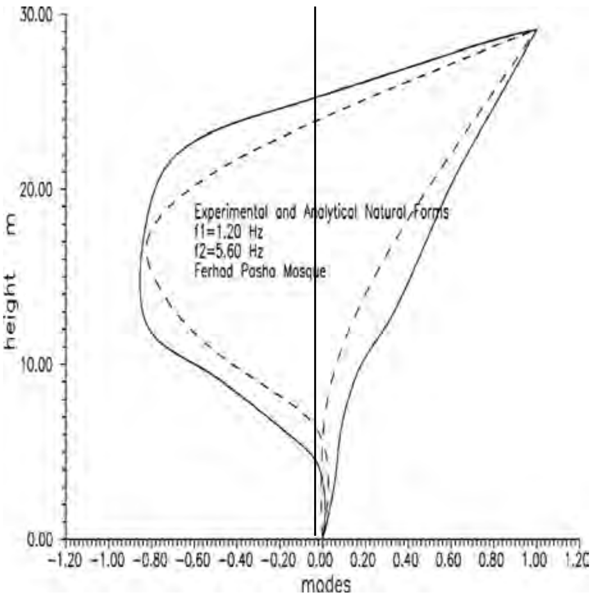
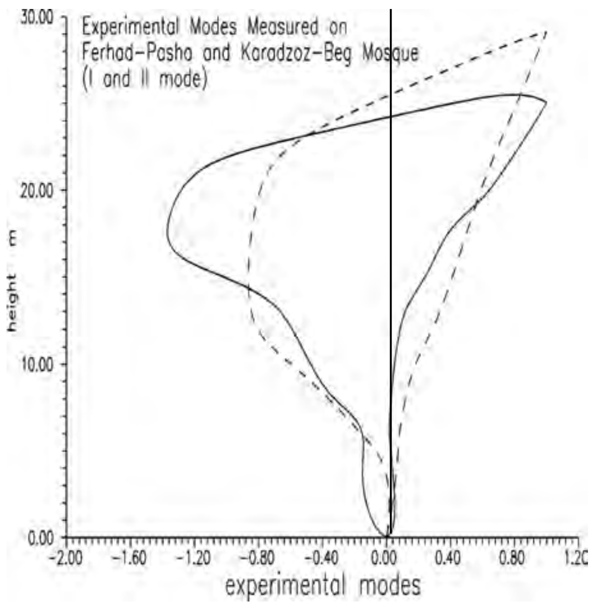


Figure 2 Measured mode forms

The natural frequencies of minaret contained two separate values: the frequencies of minaret itself and the frequencies of the mosque. Thus, the tower beside its own natural forms, had forms caused by its interaction with the mosque which had significant influence on the tower's overall response. Measured high values of the damping coefficient, irregular natural forms and low natural frequencies indicated poor structural state and existence of many poorly connected zones which could endanger overall structural stability. The mode shapes (measured-continuous line and calculated ones-dashed line) are presented on Fig. 2. The presented analytical values were obtained from geometric and material data. They deviated from the experimental ones. That meant that horizontal force distribution based on uncorrected analytical model did not represent the real state (stiffness and mass distribution along the height).

Experimental results indicated poor structural state and they were used to establish a real distribution of mass and stiffness along the height, and to attribute earthquake forces distributed according to the measured values. By knowing the measured results, reliable mathematical model of the structure could be established. Such a model really represented structural behavior and on it further analytical studies were made. It was found that seismic strengthening was necessary. The chosen strengthening method did not disturb the mosque's historic value and was simple enough for execution. After the strengthening was finished, its effectiveness was checked again by the ambient vibration test of the whole structure.

3. EXPERIMENTAL RESULTS OF THE XVI CENTURY MOSQUES



Several significant mosques from the XVI century in Bosnia and Herzegovina (Ferhad Pasha Mosque and Arnaudia Mosque in Banja Luka, Karadzoz Bey Mosque in Mostar and Gazi-Husrev Bey mosque in Sarajevo were dynamically tested using ambient vibrations in order to determine their state and to suggest the most adequate strengthening method.

Experimental results of the measured natural forms for Ferhad-Pasha (dashed line) and Karadzoz-Bey (continuous line)

Figure 3. Measured mode forms on Karadzoz-Beg and Ferhad-Pasha Mosque

minarets are presented in Fig. 3. It is obvious from the form shapes that structural stiffness of Karadzoz-Bey minaret had poor values between 13 and 22m of height. That indicated poor structural state and structural elements stones in that area.

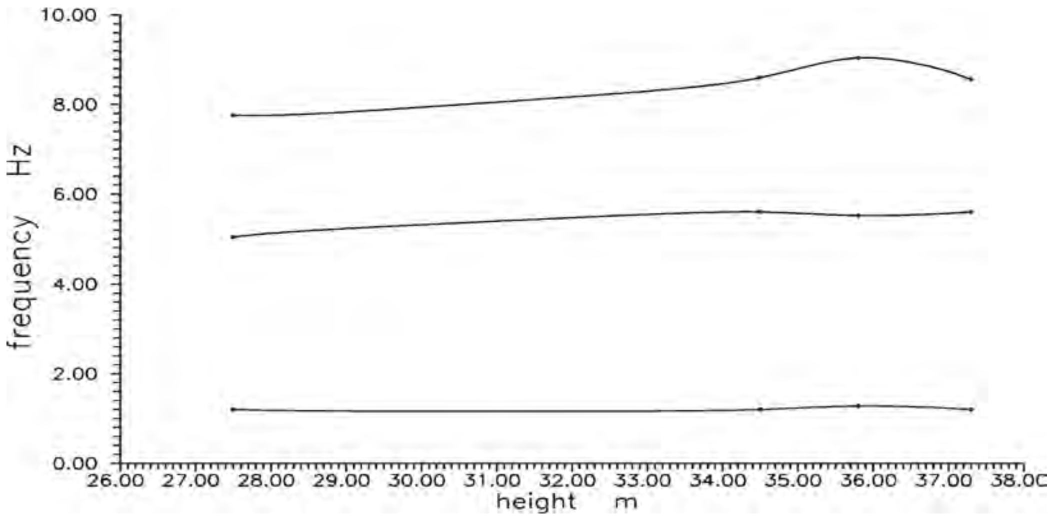


Figure 4. Measured 1.,2. and 3. natural frequencies vs. height of the praying tower

The structural dimensions of the minarets are presented in Table 1. Experimentally determined natural frequencies are presented in Table 2. and a presentation of the dependence among the first three natural frequencies and structural height is given in Fig. 4. Some interesting facts could be observed:

1. Natural frequencies were very close for all mosques, irrespective of the fact that various materials, heights and wall cross-sections were used;
2. Value of the damping coefficient was well correlated with the structural state of minaret (higher damping values indicated less compact sections);
3. The builders seemingly had some predefined (experimental) structural dimensions as a blueprint for building.

Table 1. Geometry data of the minarets

Mosque	Height [m]	D-outer [m]	D-inside [m]	Connect. [m]	Serefa [m]	Roof [m]
Ferhadija	37.3	2.56	1.5	9.8	29.1	43.3
Arnaudija	27.5	1.7	1.2	7.4	22.2	31.8
Karadzoz	34.5	2.18	1.3	8.9	25.1	34.5
GaziHusrev	35.8	3.2	1.4	8.52	28	44.5

Table 2. Measured fundamental frequencies

Mosque	Height [m]	Pe-I [Hz]	Pe-II [Hz]	Pe-III [Hz]	Pa-I [Hz]	Pa-II [Hz]	Pa-III [Hz]
Ferhadia	37.3	1.2	5.6	8.56	1.24	5.2	8.48
Arnaudia	27.5	1.2	5.04	8.72	1.04	4.72	9.2
Karadzoz	34.5	1.2	5.6	8.6	1.2	5.4	8.6
GaziHusrev	35.8	1.28	5.52	10.1	1.28	4.96	9.04

where: Pe = perpendicular and Pa = parallel to the mosque walls

4. OLD MASONRY RETAINING WALL STRUCTURE

Modern road that connects Rijeka and Karlovac is still using some parts of the old Maria Luisa road that is over 200 years old. Due to higher traffic loads and erosion some retaining wall sections were showing significant decay, and it was necessary to establish structural state, to distinguish among the safe and unsafe regions based on the measured quality and finally to suggest the strengthening method and sequence of strengthening. Because of a continuous heavy traffic the wall sections could not have been strengthened at once.

The retaining walls were erected from stone blocks set in place with no mortar connection. Their height varied from 3 to 12m. Filling behind the walls was somewhere interconnected with the wall and somewhere just placed like an infill. As the sections' geometry, material and foundation characteristics were unknown the static analysis was very difficult or impossible.

Because of its age, unknown building method and its carrying ability, some measure of its stability and carrying ability was necessary to be established. It was necessary to distinguish among various wall sections on the basis of some measured quantity. As the only applicable method, dynamic testing of the wall sections was performed. Two methods were applied: (a) impulse tests (impulse was caused by a truck passing over an obstacle) and (b) transfer function test (measured were force input and the wall response). Wall was dynamically excited and its response was measured along the height. Accelerators were placed on various points along the wall height and their response was registered, stochastically analyzed and filtered. Based on both methods, wall response to dynamic excitation along the height at various locations was obtained, and the mode shapes of vibration were established. Some superimposed characteristic results are shown on Fig. 5

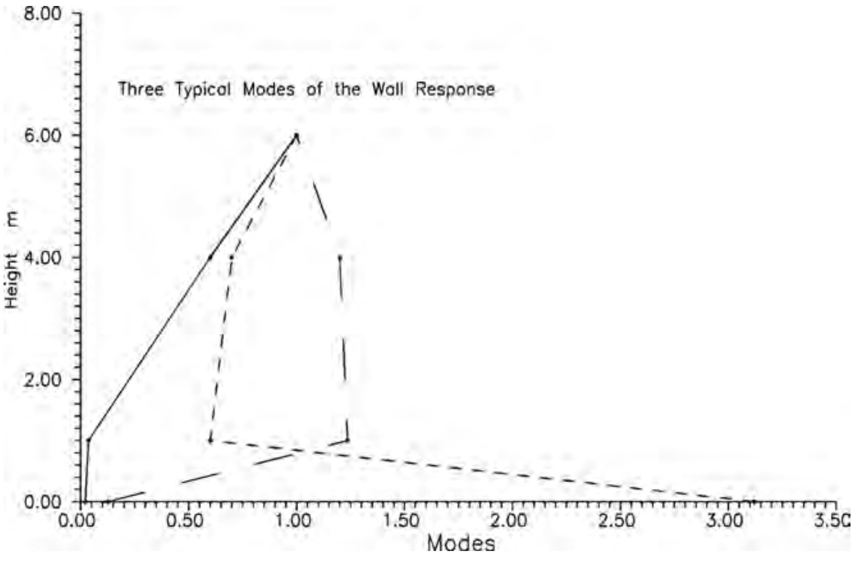


Figure 5 Measured wall-response mode shapes

From the measured results it was possible to draw conclusions about: the structural state of walls, interaction among the wall foundations and the ground, critical wall sections that needed immediate actions, choice of the best strengthening method from the various methods available (the one that suits the measured wall behavior), and subsequently, after strengthening, to check the quality of the strengthening works.

We knew that distribution of the horizontal ground pressure on the wall depends from the wall displacement. From the measured mode shapes, three main cases of the wall displacements could have been established:

a. The wall was immovable and horizontal pressure on the wall depended only on the ground elastic characteristics.

b. The wall had translation displacements like:

b.1. Displacements were smaller than 0.02 mm and horizontal ground pressure on the wall was close to the numerical one according to the Coulomb law;

b.2. Displacements were bigger than 0.02 mm and horizontal ground pressure on the wall decayed.

c. Wall was rotating around the axis on the top or bottom of the wall section.

From the wall stability point of view categories (a) and (b1) were considered stable and categories (b2) and (c) unstable. On the basis of measured results the wall sections were distinguished accordingly. The measurement proved to be very successful and the results were used for devising adequate and the cheapest strengthening method without traffic disturbances.

5. THE OLD BRIDGE IN MOSTAR

The Old Bridge in Mostar was one of the most famous structural advances and as such was part of various investigations during its existence. Detecting its true structural behavior and the true mathematical model that fully represented its behavior and state was of the prime importance before any other undertakings.

Figure 6 The Old Bridge in Mostar

Ambient vibrations of the bridge structure were measured for horizontal and vertical direction along the span. The initial mathematical model had been made based on geometry and material data. Although geometry, modulus of elasticity and mass data were precise calculated natural forms and frequencies significantly deviated from the measured structural behavior. The main difficulty proved to be a measure of contribution of the pier and parapet walls to overall structural behavior. The measured mode shapes indicated that for vertical loading bridge behaved as an arch of a smaller span. The pier parts of the bridge were practically immovable. In the horizontal direction the bridge behaved as a beam with fixed supports. Based on the experimental results, analytical model was modified until a satisfactory correlation among measured and analytical results (natural frequencies and forms) was achieved.

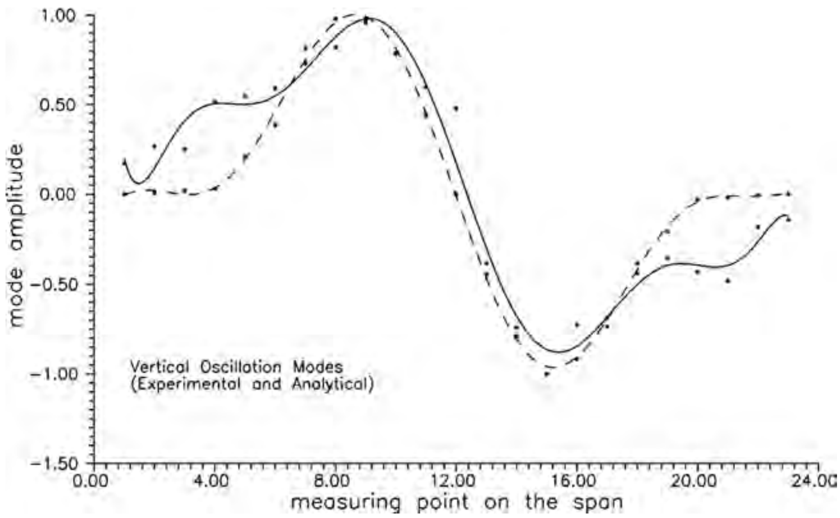


Figure 7. Vertical mode shape

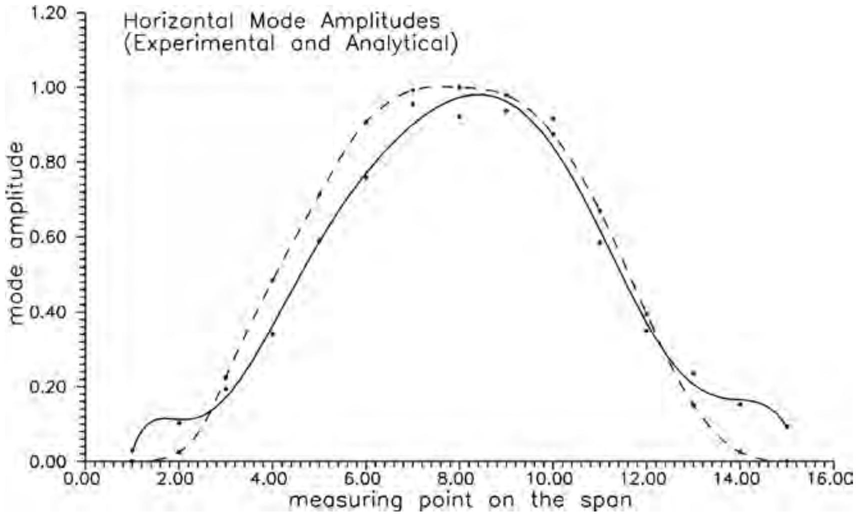


Figure 8. Horizontal mode shape

The piers were taken into account by a change in boundary conditions on both sides. That caused reduction of span for vertical direction, while leaving the same span width for the horizontal direction. Contribution of the parapet walls was taken into account through the increase of the bridge cross-sectional stiffness. The measured natural forms (continuous line) and the ones calculated with a modified analytical model are shown on Fig. 7. and 8.

Good correlation was obvious and the modified mathematical model was then used for structural analysis and structural stability evaluation under extreme events. Measured results could always be used for a comparative analysis of future measurements.

6. CONCLUSIONS

Dynamic characteristics represent the structure's personal card. All changes in structural state (cracks, corrosion, loosening of the connection among the elements, etc) reveal itself through the change of particular dynamic characteristics (natural frequencies, forms and damping coefficient). Dynamic tests reveal the true structural behavior and state. They can be used to formulate the precise mathematical model on which simulations of the extreme actions can be done. The best, cheapest and the most eloquent strengthening methods can thus be investigated and applied. Also, after the strengthening is finished comparing dynamic characteristics before and after the strengthening measures have been done can test its quality. By collecting and statistically analyzing the measured data more knowledge about the previous building methods can be gained and many times learned from the revealed knowledge of the old builders.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

INVESTIGATION OF MATERIAL PROPERTIES OF DOLMABAHCE PALACE RECEPTION (MUAYEDE) HALL'S DOME AND VAULTS

F. Aköz, N. Yüzer, Ö. Çakır, N. Kabay
Yıldız Technical University, İstanbul, Turkey

ABSTRACT

Dolmabahce Palace was built by Sultan Abdulmecit between the years 1844 and 1853 that consists of 285 rooms and 46 halls. This Palace is an impressive building facing the sea with very high walls on the side facing inland. Some deep and wide cracks have been occurred on the dome, vaults and the joint areas of vaults and walls of Dolmabahçe Palace Reception (Muayede) Hall. For this reason, experimental studies were carried out to research the crack state and determine the material properties. The tests and the measurements were repeated after the strengthening. According to these results, in the masonary structures, it is possible to determine the improvement in the structure before and after the strengthening by applying non-destructive tests.

1. INTRODUCTION

Investigation of material properties of a monument by using non-destructive methods usually includes rebound test, sonic test, radiographic tests, surface hardness test, permeability test and bonding test [1]. Before the experimental studies the areas that will be tested were coded and the cracks zone were marked according to the statistical survey project of Reception (Muayede) Hall. Non-destructive tests were applied in-situ with ultrasonic test apparatus and Schmidt hammer, the surface temperature and relative humidity of the elements were also measured. Physical and mechanical tests were performed on the samples, which were taken from the areas, that non-destructive tests were performed. Crack depth and direction was investigated by applying ultrasonic tests around the cracks zone before and after the strengthening. By applying the corresponding tests on the samples, which were prepared from the materials that were used in strengthening, the mechanical properties were determined.

2. INVESTIGATIONS, DETERMINATIONS AND MEASUREMENTS

The locations, measured points, surface and relative humidity of material and environmental conditions of Dolmabahçe Palace Muayede Hall's Dome, Vaults and Walls is given in Table 1. Before starting the measurements, a general investigation in Muayede Hall's dome and vaults was performed, experimental study opportunities were investigated and the elements were coded as shown in Figure 1. The fissures and the crack areas were marked on a sketch. The investigations, determinations and the measurements are repeated on the construction before and after the strengthening. Moreover, in order to perform the necessary tests in the laboratory, sample pieces were taken from brick and mortar.

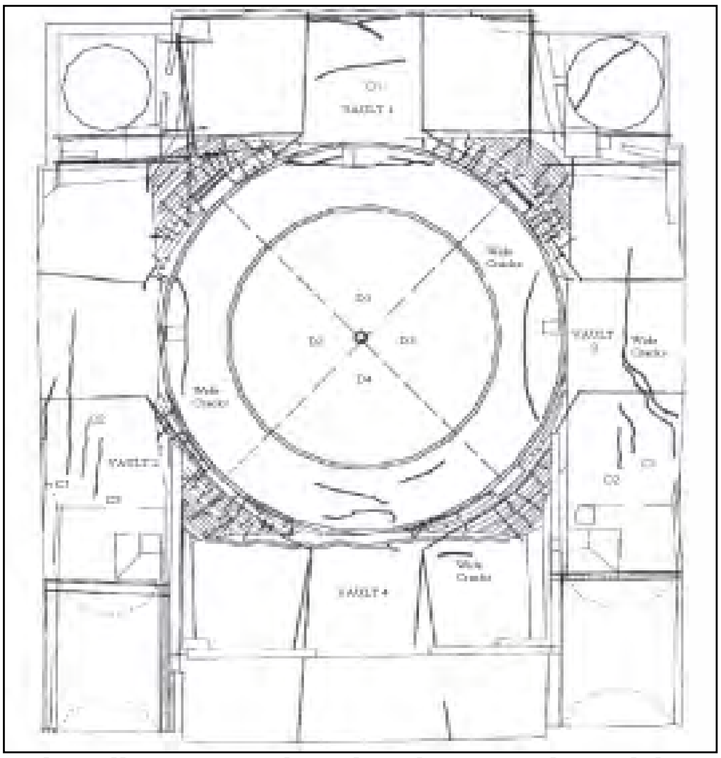

Figure 1 Muayede Hall's Dome and Vaults' element codes and the crack areas

a) In order to determine the properties of brick and mortar, the surface temperature (T_s, ^oC) and relative humidity of surface were measured three times in each point by using protimeter survey master apparatus. The results obtained are given in Table 1.
b) At the same points, surface hardness (R) was determined by a pendulum type Schmidt hammer.

Table 1 Some measurements performed on Dome and Vaults before and after strengthening

	Location	Measured Points	Number of Measured Points	Material		Environmental Conditions	
				Surface Temp. (°C)	Relative Humidity (%)	Temp. (°C)	Relative Humidity (%)
Before Strengthening	Vault 1 (V1)	Brick, Mortar, Crack	41, 30, 21	29,5-30	14-18	30	57
	Vault 2 (V2)	Brick, 1st Crack, Mortar, 2nd and 3rd Cracks	57, 20, 30,18	27-30	14-100	25-27	65-74,5
	Vault 4 (V4)	Brick, Mortar	32, 32	29-32	14-22	30,5	60
	T1 Side of the Dome (D1)	Brick, Mortar	19, 19	27	14-28	26	51
	T2 Side of the Dome (D2)	Brick, Mortar	31, 31	25,5-27	14-18	29	72
	T3 Side of the Dome (D3)	Brick, Mortar	23, 23	25,5-27	14-40	23,5-29	71-72
	T4 Side of the Dome (D4)	Brick, Mortar	28, 28	26-27	14-18	-	-
After Strengthening	Vault 1 (V1)	Brick, Mortar, Crack	30, 30, 9	22,5-23	14-16	20	76,5
	Vault 2 (V2)	Mortar, 1st Crack, 2nd and 3rd Cracks, Brick	29, 7, 8, 37	25-27	14-20	22,5-23	64-68
	Vault 3 (V3)	Brick, Mortar, 1st and 2nd Cracks	31, 24, 12	29-30	14-20	28	68
	Vault 4 (V4)	Brick, Mortar	32	23-24	14-24	22	72
	T1 Side of the dome (D1)	Brick, Mortar	19,19	23	14	20	62
	T2 Side of the dome (D2)	Brick, Mortar	31, 31	23	14	20	61
	T3 Side of the dome (D3)	Brick, Mortar	23, 23	-	-	-	-
	T4 Side of the dome (D4)	Brick, Mortar	28, 28	23	14-18	20	61

c) In the same areas, the sound transition time (t, μs) was measured by applying the indirect method as shown in Figure 2.b by using a Pundit type ultrasonic test apparatus of 55 kHz frequency which is appropriate to ASTM C5970-BS 1881 on the determined length (l, mm) [2,3].

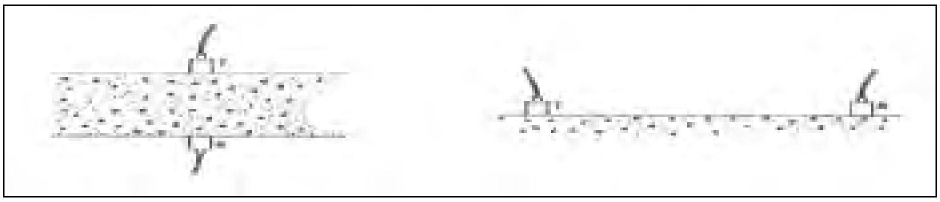

Figure 2.a Direct Method Figure 2.b Indirect Method

d) In order to determine the crack depth and direction in the crack areas marked in Figure 1, according to BS1881:Part 203:1986, the sound transition times t_1, t_2, t_3 and t_4 (μs) are measured by changing the probe positions (Figure 3) [3].

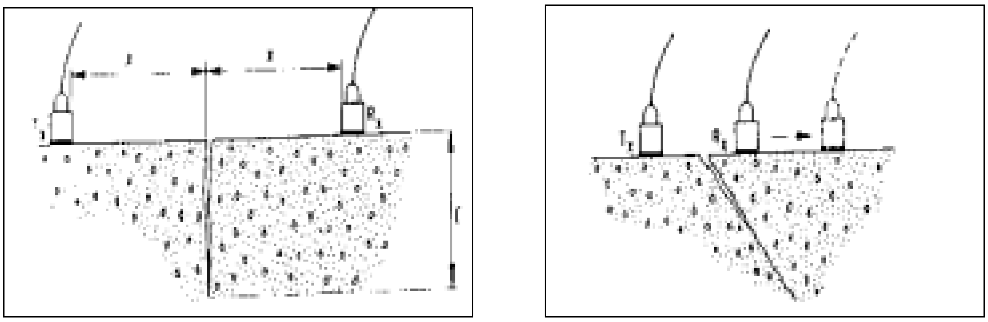

Figure 3.a Investigation of crack depth. Figure 3.b Investigation of crack direction

As seen in the work schedule, in the 1^{st} and 2^{nd} measurements in dome and vaults non-destructive measurements were performed in 997 points. Because of the fact that the material resistance in these elements are too low, it was impossible to cut core samples in-situ, so brick and mortar samples were cut out to establish the required tests in laboratory.

3. LABORATORY STUDIES

To represent the in-situ tests, on brick and mortar samples, which are taken to the laboratory, sound transition times were measured on the same surfaces and to check these results, the same measurements were performed in the opposite directions as shown in Figure 2.a and 2.b and samples were prepared to apply physical and mechanical tests.

In these samples, volume density (β, gr/cm^3), specific density (γ, gr/cm^3), porosity (p, %), volumetric water absorption (v_a, %), water absorption (w_a, %) and degree of saturation (S_d, %) were determined by using Archimedes Principle. Mean values of the test results that were performed at least in 3 samples are given in Table 2.

Table 2. Physical Test Results of Brick and Mortar

Material	β gr/cm^3	γ gr/cm^3	v_a %	w_a %	p %	S_d %
Brick	1,49	2,63	36	67	43	83
Mortar	1,34	2,50	42	72	46	91

a) To perform the mechanical tests, 9 pieces of samples of 44 mm and 53 mm average diameters were taken by a core apparatus and the compressive strength test was performed.
b) The dimensions and the resistance of the mortar specimens were unsuitable to cut out core samples so the test was performed on 40mm by 53mm dimensioned steel plates on 5 samples as shown in Figure 4.

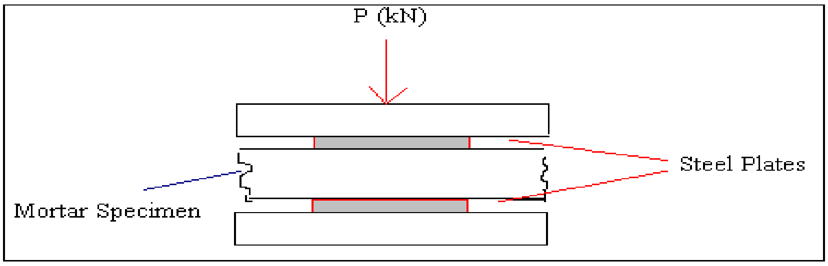

Figure 4. Compressive strength test on mortar specimens

c) Compressive Strength test was performed in a 20 kN capacity test apparatus in 0.5 mm/min pace rate and the change in length (Δl, mm) was determined by a comparator.
d) 40x40x160 mm dimensioned prism and 70x70x70 mm dimensioned cube specimens were prepared from the materials that were used in strengthening. Compressive strength and flexural strength tests were performed on these samples at the 14th and 28th days.

4. EVALUATIONS

Non-destructive test results and the laboratory test results are evaluated together and the procedures are explained below.
a) Compressive strength ($f_c=P_k/A$, MPa) is determined by dividing the ultimate load (P_k) by the area that the load is applied. In the experimental studies, it is tried to obtain the h/d=λ ratio near to 1. The dimension effect is omitted and the mean values of compressive strength are given in Table 3.
b) Flexural and compressive strength of the materials used in strengthening works are determined and the mean values are given in Table 4.

Table 3 Mechanical Test Results of Brick and Mortar.

Laboratory Test Results			Limit values given in TS 704 [4]	
Material	Compressive Strength (f_c, MPa)	Static Modulus of Elasticity (E_d, MPa)	Compressive Strength ($f_{c,mean}$, MPa)	Compressive Strength ($f_{c,min}$, MPa)
Brick	6,13	428	5,0	4,0
Mortar	1,54	51	-	-

Table 4 Mechanical Test Results of the Materials Used in Strengthening

Place of Production	Test Period (day)	Flexural Strength (MPa)	Compressive Strength (MPa)	Explanation
Samples produced in laboratory	14	-	0,59	A: Weak Hydraulic Lime[1] + Tile Particle+ Tile Brass
	28	-	0,67	
	14	1,33	4,03	B: KL4 Added Weak Hydraulic Lime + Tile Particle+ Tile Brass
	28	2,93	6,62	
Samples produced in-situ	28	10,86	38,92	D: Epoxy Combiner[3] + Tile Particle + Tile Brass

- : The samples are scattered while demoulding so the flexural strength test couldn't be performed.
[1] : Weak hydraulic lime: Calx-Romano
[2] : Strong water lime: Inızıone 50
[3] : Epoxy: AV 32

The pulse velocity (V=l/t, mm/µs) was determined by the measurements performed in-situ and in the laboratory. The in-situ rebound test measurements are revised (R_r) by taking the curves in the dome and vaults into consideration. By using the compressive strength (f_c), which was determined by applying the corresponding test on the samples that are prepared from brick and mortar pieces taken from the structure, the pulse velocity and the surface hardness measured on the areas that the samples are taken, the Equations 1 and 2 for brick and mortar were obtained respectively. Theoretical compressive strength values (f_{teo}, MPa) are calculated by using these equations and the results obtained are given in Table 5.

$$f_{teo,brick} = -1,665 + 0,006xR_c^2 + 0,214xV^2 \qquad \text{(r=0,990)} \qquad (1)$$

$$f_{teo,mortar} = 1,300 + 0,001xR_c^2 - 0,155xe^{0,01xR_cxV} \qquad \text{(r=0,980)} \qquad (2)$$

Table 5 The Non-Destructive Test Results of Masonary Element's Brick and Mortar Components.

Location		Brick								Mortar							
		Mean values of 1st Measurements				Mean values of 2nd Measurements				Mean values of 1st Measurements				Mean values of 2nd Measurements			
		R_r	V km/sn	f_{teo} MPa	E_d MPa	R_r	V km/sn	f_{teo} MPa	E_d MPa	R_r	V km/sn	f_{teo} MPa	E_d MPa	R_r	V km/sn	f_{teo} MPa	E_d MPa
VAULT	V1	37	0,817	7,4	1294,3	38	1,059	7,9	1927,2	25	0,127	1,6	22,9	24	0,140	1,6	27,4
	V2	40	0,839	9,1	1295,4	42	1,058	10,1	1776,8	27	0,132	1,7	25,2	29	0,158	1,8	35,8
	V3	-	-	-	-	41	0,851	9,3	1395,9	-	-	-	-	27	0,152	1,7	36,9
	V4	39	0,833	8,4	1515,0	40	1,172	9,1	2419,1	26	0,169	1,7	57,9	26	0,166	1,7	40,9
DOME	D1	48	1,027	13,2	1747,2	45	1,205	11,9	2359,4	29	0,136	1,8	26,9	29	0,131	1,8	24,7
	D2	47	0,916	12,6	1458,9	47	1,068	12,8	1856,8	28	0,145	1,8	31,8	31	0,159	1,9	42,0
	D3	45	1,000	11,4	1647,4	47	1,270	12,7	2769,6	29	0,136	1,8	35,7	32	0,135	1,9	29,6
	D4	49	1,014	13,8	1680,6	47	1,040	12,5	1768,1	33	0,126	2,0	23,1	33	0,163	2,0	46,1
Mean Values		42	0,921	10,2	1519,8	43	1,090	10,8	2034,1	28	0,139	1,7	31,9	29	0,151	1,8	35,4

c) The stress (σ=P/A) and the strain ($\varepsilon=\Delta l/l$) values are obtained from the compressive strength test results performed on brick and mortar samples. According to these results, σ-ε relation is developed and given in Figure 5. The Modulus of elasticity (E_s, MPa) was determined by the tangent of the initial point of the curve and the mean values are given in Table 3.

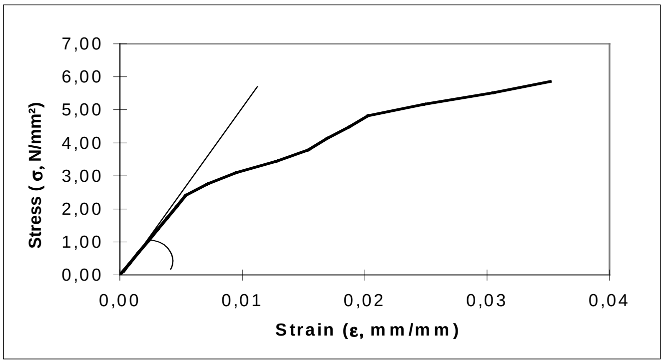

Figure 5 Stress-strain relation of brick and mortar samples of the structure

d) The dynamic modulus of elasticity of brick and mortar were calculated by equation 3 [5] and the mean values are given in Table 5.

$$E_d = \frac{10^4 x V^2 x \beta}{g} \qquad (3)$$

In this equation, V (mm/μs) is pulse velocity, g (m/sec^2) is acceleration of gravity and β (kg/dm^3) is the sample's volume density.

e) The ultrasonic pulse measurements were performed in each sides of the cracks by the ultrasonic test apparatus according to BS 1881:Part 203:1986 by changing the probes and applying the measurements in the lengths as l_1=15+15 cm and l_2=30+30 cm as shown in Figures 3a and 3b. In these measurements, sound transition time occasionally was too low and unstable. Unstable and low readings of pulse velocity confirm that the masonry elements are not homogeneous, the cracks seen on the surface continue in the interfaces and the cross sections. Reaching uniform values in brick and mortar samples in laboratory and the increase in the pulse velocity shows that the cracks are scattered and continue in the interfaces.

f) The calculations made by using the mathematical equation given in BS1881:Part 203:1986 in order to research the crack direction also showed that the crack is scattered. Sound transition time measurements, which are performed after the injection, reached uniform values in shorter times. By taking these results into consideration, the measurements before and after the strengthening are compared, the measurements performed around the crack areas are summarized in Table 6.

Table 6 Evaluation of the pulse velocity measurements performed around the crack zone

Location	Crack Code	Number of Point	Sound Transition Time		Difference (%)
			*1st (µs)	**2nd (µs)	
Vault 1 (V1)	C1	1	1310	708	46,0
		2	1399	1307	6,6
		3	1542	1378	10,6
		4	1615	1050	35,0
		5	1627	1527	6,1
		6	1668	1306	21,7
		7	1388	1278	7,9
		8	1799	1181	34,4
		9	1666	1112	33,3
Vault 2 (V2)	C1	1	1768	1019	42,4
		2	1841	780	57,6
		3	1340	1043	22,2
		4	1594	651	59,2
		5	1760	1098	37,6
		6	1784	1060	40,6
		7	1821	1014	44,3
	C2	1	1733	1018	41,3
		2	1839	1058	42,5
		3	1741	1048	39,8
		4	1555	1001	35,6
	C3	1	1493	1016	31,9
		2	1774	1121	36,8
		3	1993	1079	45,9
		4	1842	1071	41,9
Vault 3 (V3)	C1	1	1650	396	76,0
		2	1829	1076	41,2
		3	1531	1123	26,6
		4	1888	225	88,1
	C2	1	1457	330	77,4
		2	1915	255	86,7
		3	1954	223	88,6

* : Measurements before the strengthening
** : Measurements after the strengthening

5. CONCLUSION

The non-destructive tests and the laboratory tests are evaluated together and the results obtained are given below.

a) According to the tests, which are performed after the strengthening to determine the surface hardness on brick, it is seen that there is an increase in surface hardness and compressive strength of brick in the amounts of %2,8 and %6,0 respectively. The increase in surface hardness and compressive strength of mortar's are %3,2 and %2,3 respectively. This increase is not related with the compressive strength of brick and mortar individually. It is the result of the increase in the element's rigidity as a result of the covering process of the cracks in the masonry structure.

c) According to these results, in the masonry structures, it is possible to determine the improvement in the structure before and after the strengthening by applying non-destructive tests.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

ASSESSMENT OF THE STABILITY CONDITIONS OF A CISTERCIAN CLOISTER

P.B. Lourenço, G. Vasconcelos, L. Ramos
University of Minho, Department of Civil Engineering, Guimarães, Portugal

ABSTRACT

This paper describes the evaluation followed to define the stability conditions of a Cistercian cloister in Portugal. The adopted methodology of diagnosis results in clear advantages in terms of safeguard of the authenticity of the construction and, consequently, of its heritage and historical value.

1. INTRODUCTION

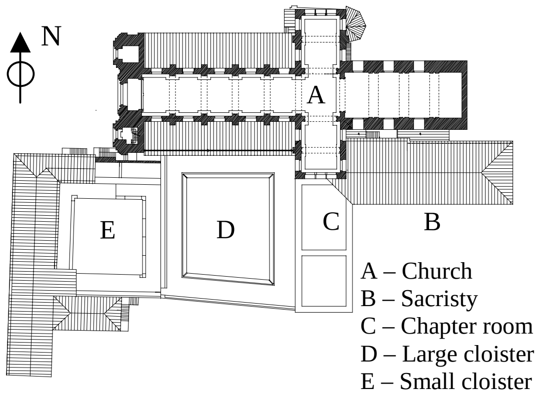
Preservation of the architectural heritage is considered a fundamental issue in the cultural life of modern societies. In recent years, large investments have been concentrated in this area, leading to developments in the areas of inspection, non-destructive testing, monitoring and structural analysis of monuments. Nevertheless, understanding, analyzing and repairing historical constructions remains one of the most significant challenges to the modern technicians.

Up to recently, it was normal to carry out any intervention without spending proper resources (time and money) in studying the reasons why the intervention was required. This lead often to either heavy interventions, which result in a decrease of the historical value of the construction, or inadequate interventions, which did not solve the problem that require the intervention. Fortunately, this attitude has changed as more and more attention is being devoted to the tasks of inspection and diagnosis. Indeed, the costs involved in the inspections and diagnoses are easily recovered in the intervention itself.

In this paper, an example of a comprehensive diagnosis of a historical construction is presented. The survey and characterization of the damage, together with in situ and laboratory testing, allowed to gather the information necessary to establish the need of an intervention and to bound this intervention. Additionally, the obtained information allowed to analyze the construction in a computer, which resulted in clear information on its structural behavior.

2. HISTORICAL FRAMEWORK

The Monastery and Church of Salzedas are located in Salzedas, Tarouca and the church was recently classified as National Monument of Portugal. The church is essentially set in a urban environment, whereas the monastery is set in a more rural environment, see Figure 1a. The plan dimensions are very considerable, 75×101 m^2, making it the second largest monastery in Portugal, after the World Heritage Monument – Monastery of Alcobaça. The monastery and church possess a longitudinal irregular plan with different volumes, typical of a Cistercian Abbey, see Figure 1b. The present study focus exclusively in the cloister dated from the 17th century (D – Large cloister, in the picture).



(a) (b)

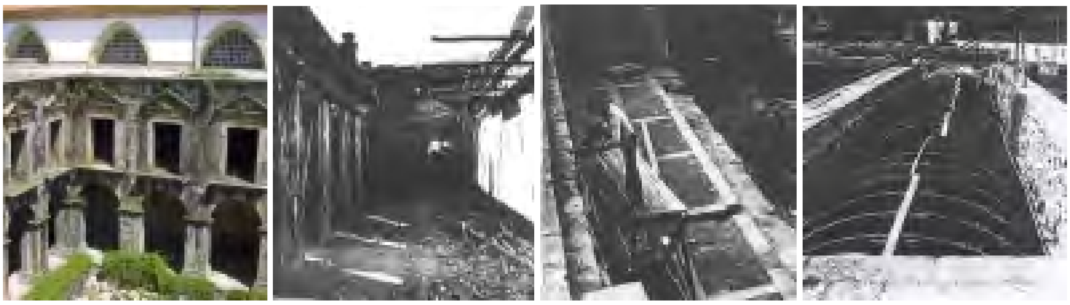
Figure 1 – Monastery and Church of Salzedas: (a) aerial view and (b) plan

The large cloister is regular and substitutes part of the primitive cloisters, see Figure 2a. It possesses crossed vaults in the 1st level and canon vaults in the 2nd level. The walls, brackets and ribs are made of granite and the vaults are made of brick masonry with clay filling. The Monastery is not own by the state and, therefore, only limited interventions were carried out.

After repeated statements of the pre-collapse status of the cloister [1,2], the General Directorate for National Buildings and Monuments (DGEMN) started a restoration plan that was carried out in 1980/1981 and 1983, including the following works, see Figure 2b-d:

- The vault of the 2nd level of the West wing was demolished, being replaced by a reinforced concrete vault;
- The wall separating the large and small cloisters, between the 1st and the 2nd levels was, dismounted and remounted plumb.

These interventions must be valued as, in their absence, it is likely that collapse would prevail with a larger loss of the architectural heritage. However, it is noted that the works do not comply with modern theories of intervention in historical structures and, today, would be very debatable.



(a) (b) (c) (d)

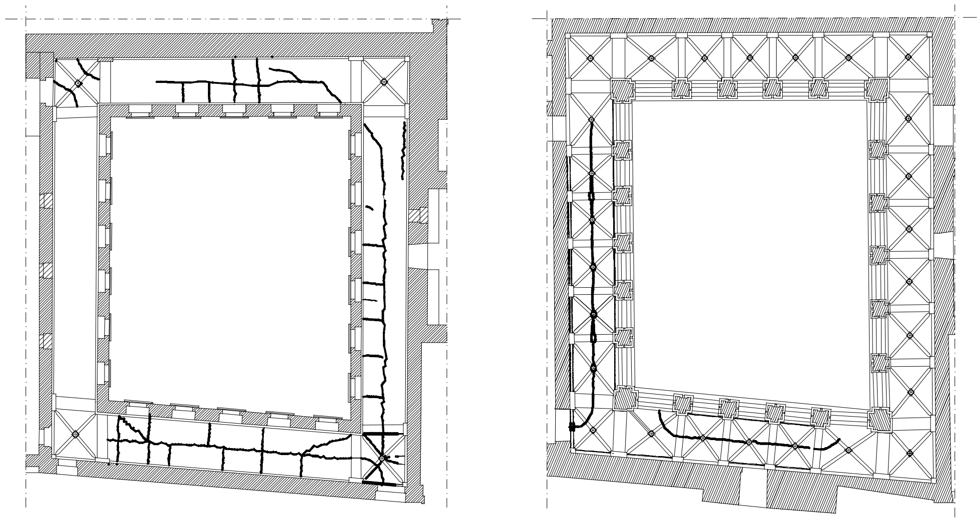
Figure 2 – Aspects of the cloister: (a) present view, (b) demolition of the canon vault, (c) dismounting of the external wall between the large cloister and the small cloister and (d) reconstruction of a reinforced concrete vault

3. SIGNS OF DAMAGE

The condition of the cloister is quite poor, including biological colonization sometimes associated with moisture stains, deterioration of the bricks in the vaults, cracks with variable thickness, crushing of stones and excessive movements in walls and vaults.

3.1. Observed Cracks

The largest and widest set of cracks occurs in the canon vaults of the South and East wings of the 2nd level, as well as the SE and NW corners, see Figure 3a. The cracks occurs mostly in the longitudinal direction, even if some transversal cracks also occur, up to a crack opening of 40 mm. The vaults of the first level exhibit also cracks, in the South and West wings, up to a crack opening of 15 mm, see Figure 3b. The West wing is supported on temporary wooden poles.



(a) (b)

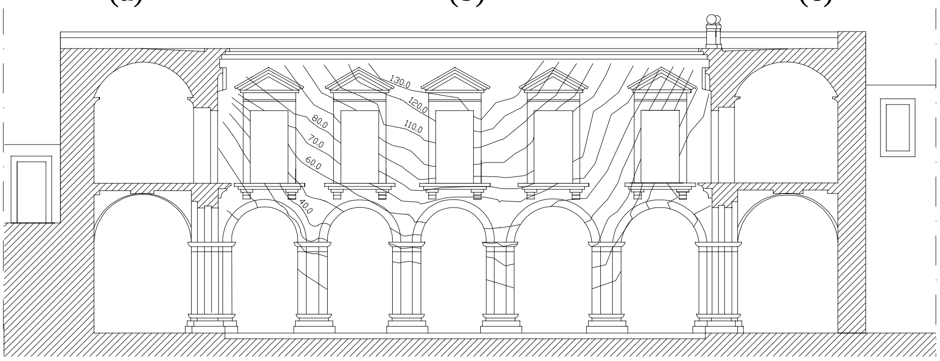
Figure 3 – Mapping of cracks for the (a) 2nd level and (b) 1st level

The walls exhibit widespread cracking at the 2nd level and almost no cracking at the 1st level. With the exception of a few localized areas, cracking is minor (crack openings in the range of 1 to 5 mm).

3.2. Observed Displacements

Vertical displacements up to 35 mm were measured at the key of the crossed vaults of the 1st level. But all the walls of the cloisters exhibit large horizontal movements that lead to the separation between the vaults and the walls, in a clear lack of verticality, see Figure 4. The out-of-plumb displacement of the internal walls reaches values of 0.18 m, 0.14 m, 0.09 m and 0.07 m in the wings West, South, East and North, respectively.

(a) (b) (c)



(d)

Figure 4 – Aspects of the wall movements: (a) separation between wall and vault (intrados of 1st level), (b) detail, (c) separation between wall and vault (extrados of 2nd level) and (d) horizontal movements in the direction of the court

3.3. Other Damage

The brackets supporting the crossed vaults of the first level show signs of compressive crushing, particularly in the West wing, see Figure 5a. This can be explained by the tilting movement of the walls. The absence of connection between the infill of the crossed vaults and the walls resulted in a very localized area to transfer the load, i.e. only the brackets. Also, a significant number of bricks show deterioration, particularly around the cracked areas, see Figure 5b. This occurs in both levels and can be explained by frost-thaw cycles and water infiltration, as the amount of rainfall per year in the region is high and the temperatures in the winter are excellent for ice formation (daily cycles with ±0º).

(a) (b) (c)

Figure 5 – Aspects of the mechanical deterioration: (a) crushing of the stone brackets of the 1st level and (b,c) decohesion of the bricks

Other perturbing signs, less relevant from the structural point of view, include damage of the stone due to freeze-thaw cycles and overall biological colonization, see Figure 6.

(a) (b) (c)

Figure 6 – Other aspects of the materials deterioration: (a) degradation of stone carving and (b,c) biological colonization

4. IN-SITU SURVEY AND LABORATORY INVESTIGATION

In order to characterize the construction, to justify the observed damage and to define corrective measures, an experimental in-situ and laboratory testing program was carried out.

4.1. Soil and Foundation Survey

This survey consisted of seven borings and three pits to allow the mechanical and physical characterization of the soil and foundations. It was possible to define a layered soil consisting of embankment of clayey nature (1.1 m), organic soil (0.30 m), alluvial soil with medium large stones, naturally wounded and worn by the action of water (0.60), alluvial soil with pebble (0.50 m). Between 2.5 and 2.7 m depth, the soil is granular with some clay and below 2.7 m depth large stones with 0.30 m to 0.40 m are found, see Figure 7.

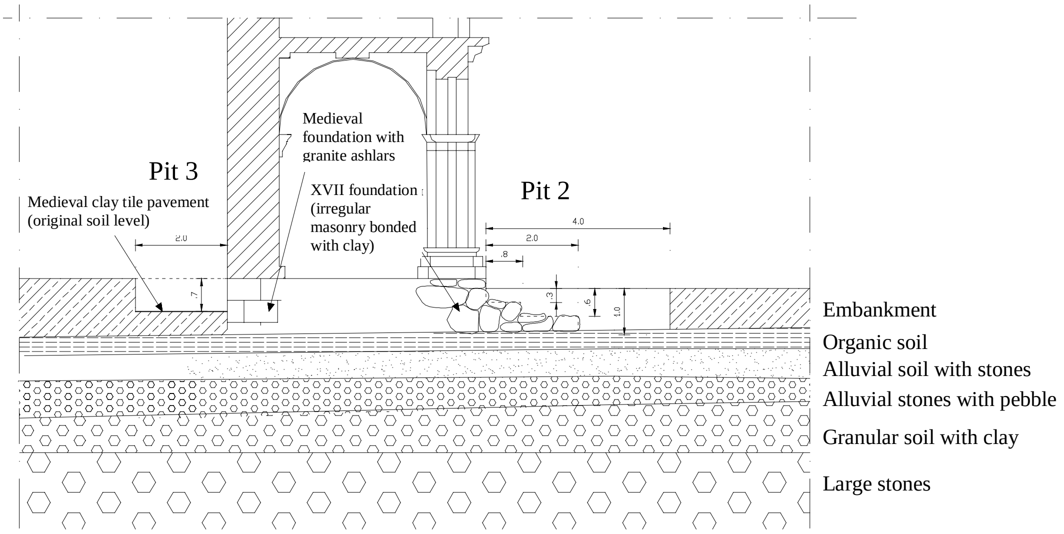


Figure 7 – Detail of the soil survey

The foundation soil exhibits moderated resistance and large heterogeneity for depths between 1.0 and 1.8 m, were supposedly all the cloister foundations are set. The foundations for the walls seem to be medieval and of good quality, but the foundations of the cloister columns are inadequate. These irregular masonry foundations are unable to distribute the loads over a significant soil area and the foundations depth around 1.0 m seems to indicate that the foundations were built on top of the original pavement level, directly on organic soil.

4.2. Visual Inspection with Rigid Endoscope

In order to characterize the inner constitution of vaults and walls, a few bore holes and several cracks were inspected with a rigid endoscope, see Figure 8. The inspection allowed several conclusions, among which:

- The vaults are made with clay brick masonry with 0.22 m thickness and clay filling. Separation between the two materials was not found;
- The walls are made with large granite stones, with dry joints or a thin clay joint. Clay seems to be washed out in most cases due to weathering. An internal core of weaker mechanical characteristics was not found;
- Internal longitudinal cracks that would compromise the stability of the walls under vertical loading were not found.

As a result of the inspection with the rigid endoscope, it was concluded that the granite walls of the cloister are adequate and there is no danger of collapse due to decohesion under vertical loading. Coring and other techniques to estimate the strength of the walls were considered not necessary and it was decided to carry out a simple flat-jack stress control.

(a) (b) (c)

Figure 8 – Aspects of the inspection with rigid endoscope: (a) drilling machine (b) visual inspection and (c) photograph

4.3. Flat-jack Testing

Flat-jack testing was carried out in the spirit of the norms ASTM C1196 and C1197, even if the selection of a place to execute the test was difficult due to the irregular nature of masonry. To open the slot, both a sawing machine and a drilling machine were used, see Figure 9a,b. A rectangular flat-jack with $406 \times 102 \times 4.2$ mm^3 and shims were adjusted with a pressure of 3.0 MPa. Afterwards, two tests to measure the in situ vertical stress were carried out, utilizing the three pairs of marks illustrated in Figure 9c and denoted as row 1, row 2 and row 3.

(a) (b)

Figure 9 – Flat-jack testing: (a) Sawing the slot, (b) stitch-drilling the slot and (c) measuring operation

The results of one of the tests is represented in Figure 10 but the two tests results were very similar. It can be observed that the row 2 and row 3 are more adjusted with the slot, whereas row 1 shows a clear lower stiffness. The average in-situ stress obtained with the latter rows is 1.2 MPa. The value expected with a simple numerical analysis, is around 0.6 MPa. The 50% difference between these values might be due to the irregular shape of the masonry blocks, indicating that only half of the stone block is inactive. It is stressed that the value of 1.2 MPa obtained can be considered as relatively low for the particular type of masonry.

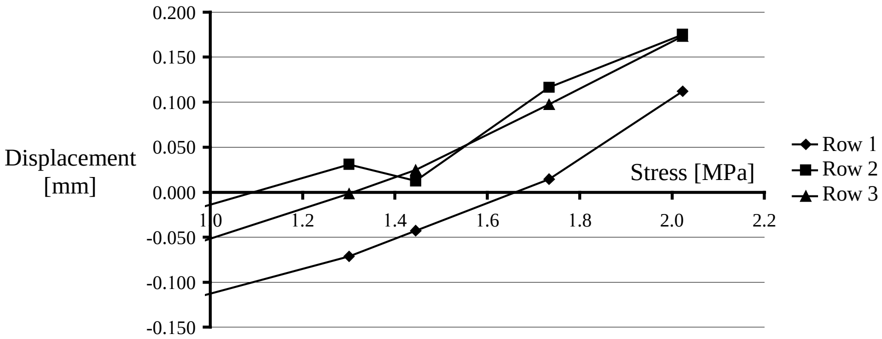


Figure 10 – Stress-relative displacements results of flat-jack testing

4.4. Coring

In order to confirm the internal constitution of the vaults and to characterize the mechanical behavior of the brick masonry, three ϕ75 mm cores were extracted from the vault, see Figure 11. The cores confirmed the borehole observation.

(a) (b)

Figure 11 – Samples for mechanical testing: (a) coring and (b) sample

4.5. Chemical, physical and mechanical characterization

The plaster, vault infill and mortar from the brick masonry of the vaults were characterized with X-ray diffraction, non-soluble residual and burn loss tests, see Figure 12a. The bricks were characterized with absorption tests and uniaxial compression tests, see Figure 12b,c,d. The mortar from the brick masonry was also characterized with uniaxial compression tests, see Figure 12e. The representative samples were extracted from the construction or the cored samples.

The tests indicated the composition of the plaster and mortar (1:3 in volume) and the composition of the vault infill (clay). The bricks are of low quality and non-durable, with an absorption in cold water around 20% and a volume mass of 1560 kN/m^3.

The uniaxial compression tests were carried out in samples of 45×45×45 mm^3, tested with greased Teflon layers to avoid the plate confining effect. The obtained Young's modulus and strength for the bricks were E_b = 7.3 GPa and f_b = 5.2 MPa, respectively. These values are quite low and confirm the poor quality of the bricks. The obtained Young's modulus and strength for the mortar were

E_m = 8.6 MPa and f_m = 3.8 MPa, respectively. This strength value can be considered normal for the mortar composition.

With these results it is possible to estimate the strength of the brick masonry as

$$f_k = K \times f_b^{0.65} \times f_m^{0.25} = 0.60 \times 5.2^{0.65} \times 3.8^{0.25} = 2.4 \text{ MPa}, \tag{2}$$

according to Eurocode 6. The Young's modulus of the composite might be obtained from homogenization procedures as

$$E = \frac{t_m + t_u}{\dfrac{t_m}{E_m} + \dfrac{t_u}{E_u}} \times \rho = \frac{0.02 + 0.04}{\dfrac{0.02}{8.6} + \dfrac{0.04}{7.3}} \times 0.5 = 3.8 \text{ GPa}, \tag{3}$$

where t_m represents the thickness of the mortar, t_u represents the height of the brick and ρ represents an efficiency factor associated with the deficient bond between the two materials (assumed equal to 0.5).

The above values allowed to perform a numerical analysis of the structure [3].

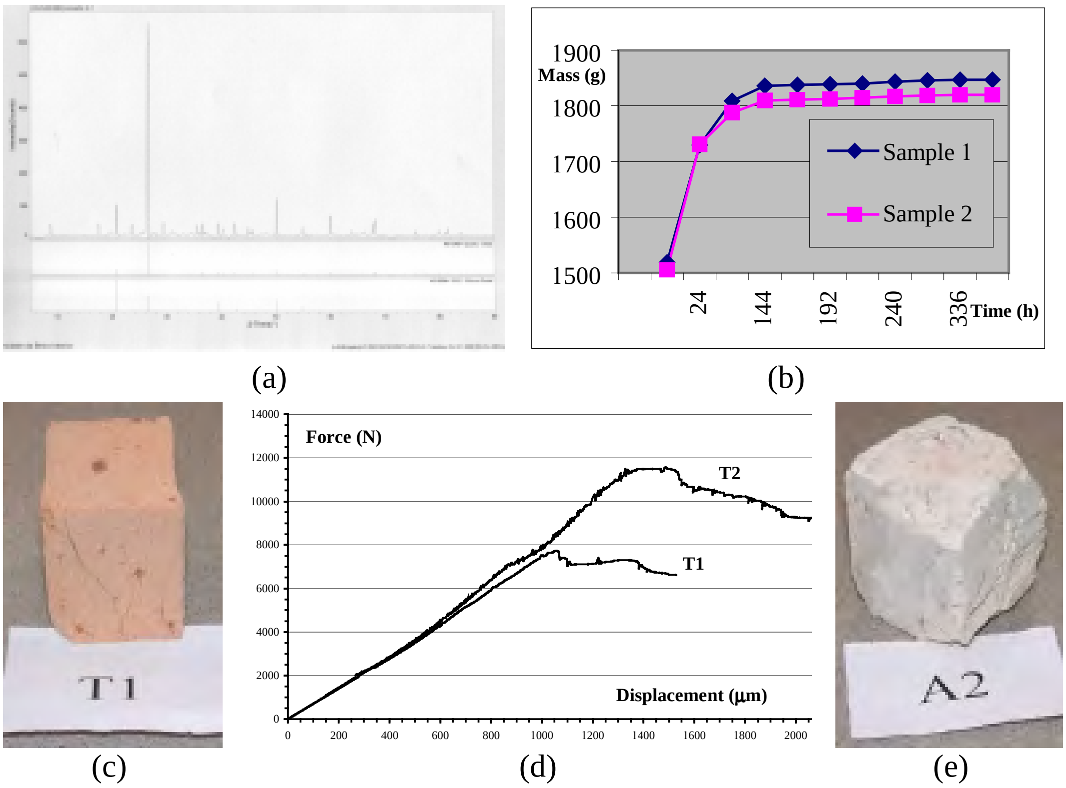


Figure 12 – Examples of chemical, physical and mechanical testing: (a) X-ray diffraction test on vault infill material, (b) absorption test on brick, (c) compressive failure of brick, (d) uniaxial compression test on brick (two samples) and (e) compressive failure of mortar

5. RECOMMENDATIONS

The conclusions of the numerical analyses of [3] together with the inspection described in the previous section allowed to conclude that: (a) the non-symmetry between the internal and external walls of the cloister result in movements in the direction of the court, as observed in the construction; (b) a linear elastic analysis of the construction results in very limited displacements (in the order of the millimeter) and moderate stress values (maximum tensile stress of +0.25 MPa and maximum compressive stress of –0.6 MPa). The large displacements observed in the construction require a geometrical and physical non-linear analysis; (c) in order to obtain horizontal displacements in the order of the observed in the structure, it is necessary to consider the soil-structure interaction. It seems therefore that the foundations play a key-role in the observed damage; (d) the high movements recorded in the construction and the deterioration of the brick vaults indicate that the safety level of the structure is not compatible with any use and immediate intervention is necessary.

With the study described it was possible to recommend the following intervention, see details in [3]: (a) Immediate (Winter of 2000) – Covering of the roof to stop water infiltration and further damage in the brick vaults; temporary shoring of the SE corner and the vaults in the South wing; (b) Short Term – Strengthen vaults in the 2^{nd} level (all wings) and vaults in the first level (South wing); strengthen foundations of the columns in the internal walls of the cloister.

6. CONCLUSIONS

A comprehensive program of inspection and diagnosis of a Cistercian cloister is presented. The results of the inspection, together of a numerical simulation of the construction, allowed to understand the damage of the construction, to assess its safety and to propose a set of corrective measures.

It was possible to demonstrate the value of the study to define a strengthening project that minimizes the intervention itself and maximizes the performance of the intervention. This strengthening project is currently under execution.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

PRELIMINARY RESULTS OF STRUCTURAL AND MATERIAL INVESTIGATIONS IN THE GREAT PALACE IN ISTANBUL (TURKEY): THE BOUKOLEON AREA

E. Bolognesi (1), B. Fabbri (2)
(1) Associazione Palatina Istanbul, Rome, Italy
(2) CNR, Research Institute for Ceramics Technology, Faenza, Italy

ABSTRACT

The area we focus on lies in the districts of Sultanahmet, Can Kurtaran and Kucuk Aya Sofya in Istanbul, on the slopes of the hill. In the days of Byzantium, the area was dominated by the Great Palace of the Byzantine Emperors. Modelled on the Palace of the Caesars on the Palatine in Rome, the Palace was founded by Constantine the Great (306-337) and it was enlarged under Justinian in the first half of the sixth century, taking in the western area of the three lower terraces as far as the shore (the Lower Palace). The main buildings of this new sector were located on its upper terrace, above the harbour later known as the Boukoleon.

Upon the basis of structural analyses of the masonry and of analyses of mortars, we try to define a correlation between them. The mortars were characterised by determining the binder/aggregate ratio, the grain size distribution of the aggregate and the composition of the aggregate granules. The binder/aggregate ratio of the mortars is fairly constant. On the contrary, we pointed out at specific grain size distribution of the aggregate in mortars belonging to structures possibly dating to the ninth (big size grain) and to the tenth centuries (medium size grain). Probably the composition of the aggregate might be just as useful as the grain size distribution.

1. INTRODUCTION

The Great Palace of Costantinople was founded by Constantine the Great (306-337) in the first half of the fourth century in the area of today Sultanahmet, Can Kurtaran and Küçük Aya Sofya. Modelled on the Palace of the Caesars on the Palatine in Rome, the Constantinian Palace (the Upper Palace) was built on the three upper terraces of the complex, on top of the hill, with the major buildings situated on the highest terrace, on a level with the Hippodrome and St. Sophia.

The Great Palace was enlarged under Justinian in the first half of the sixth century, taking in the western area of the three lower terraces as far as the shore (the Lower Palace). The main buildings of this new sector were located on its upper terrace, above the harbour later known as the Boukoleon. The church of St. Sergius and Bacchus (founded by Justinian between 519 and 536, and today the mosque of Küçük Aya Sofya) was transformed into a monastery by the middle of the sixth century, marking the western boundaries of the Palace.

Between the seventh and the ninth century, the Palace complex was further extended to include the north-eastern zone of the three lower terraces. By the tenth century, the Imperial Palace occupied the area between St. Sergius and Bacchus to the south-west, and the Palace of the Manganae and the monastery of the Hodegetria to the north-east. Now the Great Palace was at the height of its splendour, and four times the size of the Palace of the Caesars on the Palatine. From this time on it became the standard model of most Palatine architecture, from Charlemagne to the Fatimids of Egypt. Constantinus Porphyrogenitus (913-59) describes in the Book of Ceremonies the many halls, churches and gardens, placed along the ceremonial routes internal to the Palace complex.

Soon after, the Palace begun to decline. Nicephorus Phokas (963-69) reduced it to its central nucleus around the harbour of the Boukoleon, allowing the rest of the complex to fall into ruin. The complex continued to be used on State occasions, even after the imperial court had moved to the Palace of the Blachernae on the Golden Horn at the end of the eleventh century. The Great Palace was the official residence of the Latin Emperors of Constantinople. But the rapid decay of the grand buildings finally caused the total abandonment[1].

The ruins of the Boukoleon harbour, along the sea-walls near Çatladî Kapî, are today perhaps the most impressing among the few monumental remains. We have thus chosen to start from here our research about the possibility of dating structural remains on the basis of mortars analyses. The results we present here are in no way definitive. But we would like to present them as a point of departure.

2. MATERIALS AND METHODS

In order to identify and characterise the walls of the Boukoleon's various construction periods, many mortar samples were analysed.
In particular, 31 mortar samples were taken into consideration.

As regarding the structural investigations the areas of provenance and the kind of wall structure involved were also taken into consideration.

The mortar samples were collected coming from west to east, in the Landing Staircase area (A), from the south (a) and east (b) sea-walls, from the Parallel Structures (c), and from the Cistern (d) below the Staircase, at the sea-level of the Great Palace terracing; in the Loggia area (B), the so-called Palace of Justinian

[1] R. Guilland, La Disparition du Grand Palais, BSL 31 (1970), 189-91.

from the south sea-wall (a), the Loggia itself (b), and the single arch between loggia and lighthouse tower (c); in the Lighthouse Tower (C), both at the sea-level and on the middle terrace of the Lower Palace; and in the north-south passage (D). In these areas, the analysed samples were part of different kinds of wall structures. The following figure 1 and table 1 list and describe the location of the sample and their relative wall structure.

As regarding material investigations, the mortar samples were subjected to the following analyses:

- *Binder/aggregate ratio*. To this purpose, about 100 g of mortar were treated with a 5% (by volume) hydrochloric solution, in order to obtain the dissolution of the binder;
  the binder/aggregate ratio was then calculated with the formula: B/A = (P-A)/A, where B/A is the binder/aggregate ratio (by weight), P the initial weight of mortar and A the weight of undissolved aggregate;
- *Grain size distribution* of the aggregate, determined by sieving the undissolved material by diluted hydrochloric acid. The following series of sieves was used: 5, 2, 1 and 0.5 mm. In addition the size of the biggest grain in each sample was also identified.
- Evaluation of the *composition of the aggregate* granules by observation and hand separation under the optical microscope.

After such material and structural analyses, it was possible to observe that particular kind of mortar was usually associated with a particular kind of wall structures. If that wall structures could be dated to a definite period of time by the combination of archaeological observations and sources analyses, the kind of mortar could be a hint at the dating of a less identifiable kind of masonry.

3. ANALYTICAL RESULTS

In performing the various analyses, we found them to be of varying aspects of usefulness.

We analysed the ratio between the binder and the aggregate. This ratio showed very small variations among the different mortars, ranging from a minimum of 0.22 (sample ML14) to a maximum of 0.37 (samples ML53 and ML57). The average value is 0.31. That means that the amount of binder is comprised in the range 18-27% and the aggregate 73-82%, with an average of 24% of binder and 76% of aggregate. In other words, all the mortars we analysed were made by mixing three parts of aggregate and one part of binder approximately.

This conclusion is very useful from a restoration point of view, when it is necessary to reproduce the mortar for repairing the remains or rebuilding the walls. But it is clear that it is impossible to distinguish walls of different age on the basis of such technological parameter.

A second type of analyses focused on the grain-size within the aggregate. Here more interesting characteristics turned out (table 2), because important variations are evidenced from one to another sample.

Figure 1 – The Boukoleon area: A = Landing staircase; B = Loggia;
C = Lighthouse tower; D = North-south passage.

Table 1 – Locations of mortar samples in the Boukoleon area and wall structures

A. Landing staircase	
a. South wall	
Exterior wall	17 (east of the sea-gate) *ashlars with re-employed marbles*
	18 (east of the sea-gate) *bricks*
Internal wall	5 (west of the sea-gate) *ashlars with re-employed marbles*
	6 (east of the sea-gate) *ashlars with re-employed marbles*
	7 (A_1) and 10 (A_2) *ashlars with re-employed marbles*
Interior covering	8 (A_1), 11 (A_2) and 13 (A_3) *small stones*
	9 (fallen arch in A_1) *bricks*
b. East wall	
Exterior wall	1 (near cistern gate) *stone and brick courses*
	4 (lower filling of big arch) *small stones*
	44 (filling of middle window, base of columns) and
	45 (around column shafts) *small stones*
	46 (base of single column, north window) *small stones*
	67 (upper filling of big arch) *small stones*
c. Parallel structures	
	14 (arch between A_1- A_2) *bricks*
	25 (north pier A_3- A_4) *bricks with single stone course*
	12 (east wall between Parallel structures and Cistern: internal filling) *ashlars with bricks above*
d. Cistern	2 (internal masonry) *stone and brick courses*
	3 (plaster)
B. Loggia	
a. South wall	
Exterior wall	42 (west of the Loggia) *ashlars with re-employed marbles*
Exterior covering	43 (west of the Loggia) *small stones*
b. Loggia	53 (the second northern arch from the east) *bricks*
	54 (lower filling of the arch as above) *small stones*
	57 (three-mullioned window) *stone and brick courses*
c. Single arch	58 (arch between Loggia and Lighthouse) *stone and brick courses*
C. Lighthouse Tower	
	51 (main wall, near the gate) *stone and brick courses*
	52 (exterior covering) *small stones*
	64 (upper floor: pier between arches) *bricks*
D. North-south passage	
	66 (main wall) *stone and brick courses*

For all the samples, most grains are concentrated in the 0.5-20 mm dimension range, but the amount of grains (% by weight) in the various intervals within that range varies greatly from one to another sample. The amount of grains with dimensions less than 1 mm varies from about 1% up to 45%, while the aggregate in the 1-2 mm range is generally less than 10%. The grains in the 2-5 mm interval vary from about 2% to 36% and the quantity of aggregate bigger than 5 mm from 23% to 96%.

Table 2 – Grain size distribution of the aggregate in the mortar samples

Sample	Grain size distribution (mm)					
	<0.5	0.5-1	1-2	2-5	>5	maximum
1	2.8	1.9	4.8	16.9	73.6	20
2	6.5	9.0	18.5	40.5	25.5	10
3	1.4	2.0	5.2	12.7	78.7	15
4	18.1	13.3	14.0	26.3	28.3	10
5	0.9	1.5	4.1	7.4	86.1	20
6	6.3	6.9	10.3	22.2	54.3	10
7	1.6	3.0	17.7	21.7	56.0	15
8	2.1	3.5	4.2	12.1	78.1	15
9	2.4	2.8	10.7	21.9	62.2	15
10	1.9	2.9	7.9	11.3	76.0	25
11	4.7	10.7	13.4	22.6	48.6	25
12	2.5	3.7	9.7	19.8	64.3	15
13	4.5	8.2	14.2	27.7	45.4	25
14	3.1	10.8	6.2	13.2	66.7	25
17	1.7	2.8	2.8	11.1	81.6	15
18	0.1	0.6	1.2	2.0	96.1	15
25	14.6	30.8	10.8	20.2	23.6	15
42	0.8	2.6	3.0	9.2	84.4	25
43	3.6	6.0	2.3	2.6	85.5	15
44	3.9	7.2	14.0	20.1	54.8	15
45	6.4	9.2	11.2	19.1	54.1	25
46	3.9	5.4	11.1	21.1	58.5	15
51	1.5	3.5	4.0	10.4	80.6	20
52	2.1	15.3	10.2	23.0	49.4	15
53	4.2	4.4	5.5	24.9	61.0	10
54	4.4	6.4	6.4	21.7	61.1	15
57	1.5	2.9	2.3	6.5	86.8	25
58	3.1	4.0	4.0	19.2	69.7	20
64	1.6	13.9	9.5	35.8	39.2	12
66	2.1	5.6	4.6	3.7	84.0	30
67	4.1	6.3	12.4	17.3	59.9	10

In order to individuate the possible existence of different groups, a statistical procedure was adopted. The percentages of the fractions coarser than 5 mm were used for obtaining a frequency histogram. In this way two main groups were identified. They correspond to as many peaks of frequency in the histogram: the first group has the fraction >5 mm approximately comprised between 70% and 87% (twelve samples) and the second one between 45% and 64% (fifteen samples).

Group M1. This group includes twelve mortar samples: 1, 3, 5, 8, 10, 17, 42, 43, 51, 57, 58 and 66; the mortar n.57 shows the biggest amount of aggregate coarser than 5 mm (86,8% approximately), while the finest aggregate is that of mortar n. 58 (69,7% of aggregate coarser than 5 mm). The maximum size of the aggregate was found to be in the range 15-25 mm with an average value as high as 20.4 mm.

Group M2. This group includes fifteen mortar samples: 6, 7, 9, 11, 12, 13, 14, 44, 45, 46, 52, 53, 54, 64 and 67. The finest sample of the group is the mortar n.64, while n.14 is the biggest one. The maximum dimension of the single grains of the aggregate in each sample is in the range 10-25 mm with an average value as high as 16.5 mm.

The average cumulative frequency distribution curves of the two groups are shown in Figure 2 and 3, together with the variation range defined by the standard deviation, as reported in table 3.

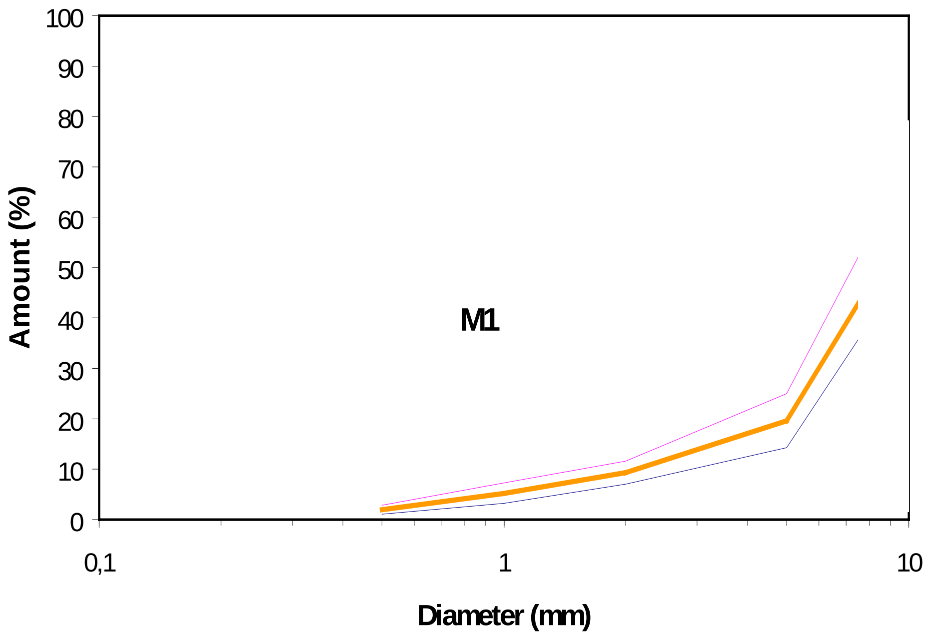

Figure 2 – Average and standard deviation of the grain-size distribution of the mortars in the group M1.

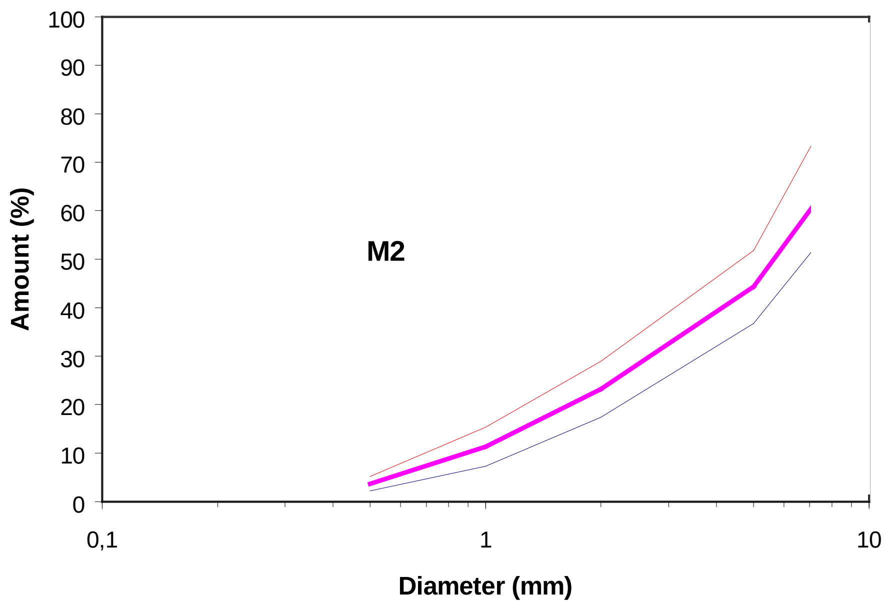

Figure 3 - Average and standard deviation of the grain-size distribution of the mortars in the group M2.

Table 3 – Average grain size distribution (wt %) of the groups of mortars

Frequency distribution	Group		Sample			
	M1 (n=12)	M2 (n=15)	n. 2	n. 4	n. 18	n. 25
< 0,5 mm	2.0 ± 0.8	3.7 ± 1.5	6.5	18.1	0.1	14.6
< 1 mm	5.2 ± 2.0	11.3 ± 4.0	15.5	31.4	0.7	45.4
< 2 mm	9.3 ± 2.3	23.2 ± 5.8	34.0	45.4	1.9	56.2
< 5 mm	19.6 ± 5.4	44.3 ± 7.5	74.5	71.7	3.9	76.4
> 5 mm	80.4 ± 5.4	55.7 ± 7.5	25.5	28.3	96.1	23.6
Maximum size (mm)	20.4 ± 5.0	16.5 ± 5.7	10	10	15	15

Four mortar samples are not included in the two mentioned groups, but they do not form another group, because they are different from each other (table 3 and figure 4). The sample n.18 is the coarsest one among all the analysed mortars. In addition, it has a singular aggregate composition, because the quantity of cocciopesto is very small and the main part is constituted by calcareous rock fragments. The samples n. 2, 4 and 25 show the finest grain size; in fact the amount of grains coarser than 5 mm does not reach 30%. In addition, figure 4 shows that the cumulative frequency distribution of the mortar 25 is characterised by an inversion of slope in correspondence of the 1-2 mm granulometric fraction, that indicates a bimodal distribution, with maximum in the ranges 0.5-1 mm and over 5 mm. Some other sample shows a similar state, but never with the evidence of sample 25.

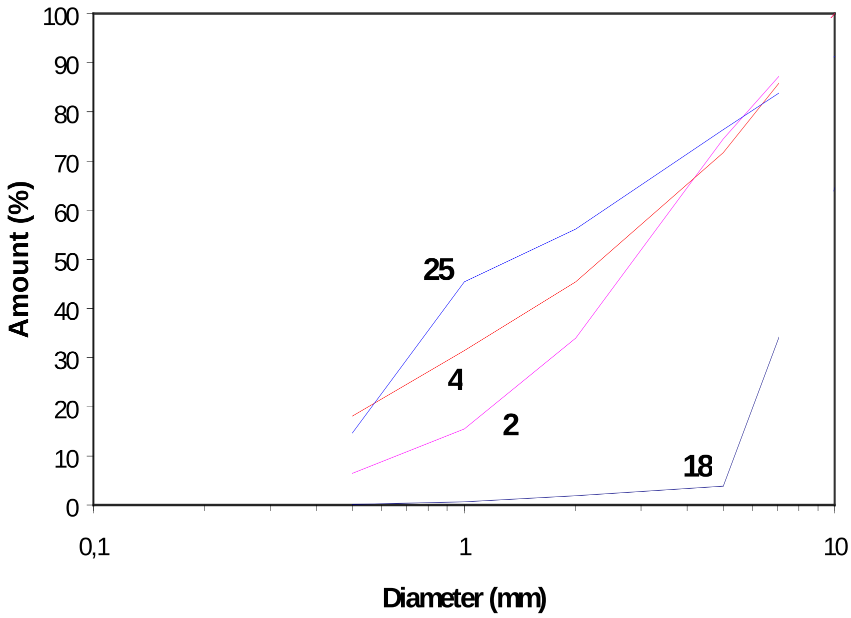

Figure 4 – Grain size distribution of the mortars not included in the groups M1 and M2.

The composition of the aggregate is typically represented by cocciopesto, and in the case of many mortars (9 out of 31) only cocciopesto can be found. On the contrary, various mortar samples show a significant amount of grains with a different composition, mainly fragments of calcareous rocks, quartz grains and basalt fragments, but they never constitute the majority. The only exception is given by sample n. 18, whose aggregate is made of almost 80% of rock fragments and only 20% of cocciopesto grains. The grains of aggregate different from cocciopesto are more frequently encountered in the finer fractions, especially <2 mm. But it is difficult to find out precise rules and to understand if this aspect of the samples could be useful for distinguishing mortars of different building periods, because some samples of this type are present in both the groups M1 and M2. A more detailed investigation would be from this point of view highly desirable.

4. DISCUSSION OF RESULTS

As above mentioned, the archaeological observations and the sources analyses allow for defining the approximate construction time of most of the architectonic structures. As a consequence, also the dating of the artificial materials employed (i.e. mortars and bricks) can be thus hypothesised. Naturally these materials may also be not contemporary with the original structures, because of subsequent restoration and consolidation.

We will now focus on the kind of masonry where the analysed kind of mortars happen to be.

In table 4, the mortars analysed are subdivided following the kind of wall structures and grain size of the aggregate. It can be seen that:

I) Mortars n. 1, 3, 51, 57, 58, and 66 are part of stone and brick alternating courses, dating probably to the IX century. All these mortars belong to the granulometric group M1. Only three samples of the same kind of masonry (n. 2, 18, 64) are not included in the group M1, but show a finer grain size distribution. From the above it is possible to hypothesise that the grain size distribution of the group M1 is characteristic of the IX century.

II) The mortars n. 9, 11, 13, 44, 45, 46, 52, 53, 54, and 67 come from structures made of small stones and probably dating to the X century. They belong to the granulometric group M2. The grain size distribution of the group M2 may thus be considered typical of the X century. Here we have two exceptions, given by the samples n. 43, which results coarser, and n.4, which results finer than that may be considered to be the typical mortar of the same century.

III) Many samples of the VI century were analysed. But they show different grain size distribution: two of them are included in the group M1 (n. 5 and 10), three in the group M2 (n. 6, 7 and 14) and the last is much finer (n. 25). This situation inhibits the possibility of defining a mortar typical of the VI century and requires further investigations in order to explain why.

Table 4 – Subdivision of the mortars as a function of the wall structure and grain size of the aggregate

Wall structure	Mortars		
	M1 (n = 12)	M2 (n = 15)	Others samples (n = 4)
Ashlars with re-employed marbles (VI century)	5 - 10	6 - 7	
Single stone courses and brick masonry (VI century)		14	25
Ashlars with re-employed marbles (VIII century)	17 - 42	12	
Brick and stone alternating courses (IX century)	1 - 3* - 51 57 - 58 - 66	64	2 - 18
Small stones (X century)	8 - 43	9 - 11 - 13 - 44 - 45 46 - 52 - 53 - 54 - 67	4

*Plaster in the cistern

In many cases there are difficulties of interpretation of the architectonic structures starting from the present situation. In certain cases it is not clear which is the real kind of the wall structure and consequently the time of construction until drillings will be possible. These conditions can be produced in order to explain the various exceptions given by mortars, coming from comparable wall structures, which are not included in the same granulometric group.

In addition, there is the possibility that the analytical procedure (from the collection of the sample up to the separation of the aggregate) can influence the results modifying the true grain size distribution. From this point of view, the main probability is that the determined grain size distribution is finer than the real one, as it might be occurred for some of the above mentioned samples, for example n. 2 and 64. Finally, we should not forget that the grain size distribution can vary due to degradation processes, becoming finer.

Other than the grain size distribution, we noted that the composition of the aggregate can give further information. In fact, the aggregate of the sample n.18 is mainly made of rock fragments and not by cocciopesto fragments. This sample is one of those not fitting the granulometric group M1 as the majority of the mortars of the IX century do.

5. CONCLUSIONS

The binder/aggregate ratio of the mortars is fairly constant. It is unfortunately of no use in order to dating the different wall structures under examination. From this point of view the grain size distribution of the mortars seems to be a more promising criterion of analysis.

In the present work we pointed out at specific grain size distribution of the aggregate in mortars belonging to structures possibly dating to the ninth (big size grain) and to the tenth centuries (medium size grain), when indeed this area of the Palace lived most intensive new developments. On the contrary it was not possible to identify in a similar way specific grain size distribution of the aggregate in the probable sixth century mortar samples.

Further research will need to better explore the possible associations between mortar analyses and the relevant structural remains: a promising way to gain better knowledge of difficult monuments. Probably the composition of the aggregate might be just as useful as the grain size distribution.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

ESTIMATION OF THE IN-SITU MECHANICAL PROPERTIES OF THE CONSTRUCTION MATERIALS IN A MEDIEVAL ANATOLIAN BUILDING, SAHİP ATA HANİKAH IN KONYA

Ö. Kırca (1), T. K. Erdem (2), B. H. Uslu (3), Ö. Bakırer (4)
(1) ÇimSa Çimento Sanayi A.Ş., Mersin Turkey
(2) Middle East Technical University, Dept. of Civil Engineering, Ankara, Turkey
(3) Astaldi Co., Bolu, Turkey
(4) Middle East Technical University, Faculty of Architecture, Ankara, Turkey

ABSTRACT

In Anatolian architecture of the Seljuk period, cut stone and handmade clay brick were the main construction materials. Traditional construction techniques and materials such as Khurasan mortar, rubblestone and glazed bricks were also common for this period.

The historical building Sahip Ata Hanikah, which was built outside the Larende Gate in Konya in the second half of the 13th century, was examined in this study. The building group, founded by Sahip Ata Fahreddin Ali, the famous grand vizier of the Seljuk court during this period, consists of four major parts, Mosque, Türbe, Hanikah and Hamam which were not planned as a complex at the time of construction but added one after the other.

This paper includes the information about the mechanical properties of the construction materials used in this structure, and the estimated in-situ strength and modulus of elasticity values. In order to evaluate these values, statistical methods were used on the data obtained both in the laboratory and at the site. As a result, in-situ strength and in-situ modulus of elasticity values were calculated in a relatively accurate manner.

1. INTRODUCTION

The building group Sahip Ata Hanikah was founded outside the Larende Gate in Konya by Sahip Ata Fahreddin Ali, the famous grand vizier of the Seljuk court during the second half of the 13th century. This building group consists of four major parts, Mosque, Türbe, Hanikah and Hamam, which are not planned as a complex at the time of the construction.

Khurasan mortar and lime were the two traditional binding materials during this era. Khurasan mortar is a composite material that is produced by mixing the lime with pulverised and calcined clays. Such binding materials have been used for more than 2000 years. As a result of the investigations conducted on the Anatolian Architecture, it can be claimed that construction of many ancient structures that still exist in Anatolia was accomplished by using mixtures of lime and natural pozzolan, such as volcanic materials, crushed bricks, etc [6].

As it is seen from the structures constructed during the Great Seljuks in Iran and Anatolia, cut stone has been widely used as a construction material besides the hand-made clay bricks. Due to the easiness of shaping the bricks and due to their high strengths at the hardened state, bricks were used as a construction as a decorative material [2].

This paper deals with the construction materials of the Sahip Ata Hanikah in Konya and their mechanical properties in civil engineering point of view, by examining them both at site by non-destructive test methods and in laboratory by non-destructive and destructive test methods. The most important objective of this study is to estimate the in-situ compressive strength and modulus of elasticity values at site in a relatively high reliability and accuracy so that these estimated results can easily be used and they will be very beneficial for the repair, rehabilitation, and restoration works of this structure.

2. EXPERIMENTAL PROGRAM

In this study, both a field work, mainly based on non-destructive tests at site, and a laboratory work consisting of not only non-destructive but also some destructive tests were performed on cut stone, clay brick and the binding material. Table 1 and Table 2 show all of the test methods performed on these materials.

Table 1 Tests Performed on Cut Stone

Tests	Relevant Standards [1], [4]
Compressive Strength	ASTM C 170
Absorption and Density	ASTM C 97
Ultrasound Pulse Velocity	ASTM C 597
Modulus of Elasticity	ISRM, Test Methods
Rebound Hammer	ISRM, Test Methods
Brazil Indirect Tension	ISRM, Test Methods

Table 2 Tests Performed on Brick and Binding Material

Tests	Relevant Standards [1]
Flexural Strength	ASTM C 67
Compressive Strength	ASTM C 67
Absorption and Density	ASTM C 67
X-Ray Diffraction	-

2.1 Tests Performed at Site

Since the stone walls are the load-carrying system, estimation of in-situ strength and modulus of elasticity is necessary for cut stone only. Therefore, two non-destructive test methods, rebound Schmidt Hammer and ultrasound pulse velocity tests, were applied on the cut stones at different locations of the building.

The results are shown in Table 3.

Table 3 Rebound Hammer and Ultrasonic Pulse Velocity Test Results Performed at Site

Test Loc.	Aver. Schmidt Hammer Values	Schmidt Hammer Comp. Str. σ_{sch} (MPa)	Aver. Pulse Time (10^{-6}*s)	Length (cm)	Pulse Vel. V_{pulse}(m/s)	Calibrated Pulse Vel. V_{pulse}(m/s)
L1	36	28,5	x	x	x	x
L2	36	28,5	x	x	x	x
L3	36	28,5	x	x	x	x
L4	36	28,5	x	x	x	x
L5	36	28,5	x	x	x	x
L6	36	28,5	x	x	x	x
L7	35	27,0	128,9	38	2948	2788
L8	36	28,5	124,1	38	3062	2896
L9	37	30,0	x	x	x	x
L10	36	28,5	x	x	x	x
L11	38	31,4	127,4	36	2826	2673
L12	38	31,4	127,1	36	2832	2679
L13	37	30,0	x	x	x	x
L14	38	31,4	x	x	x	x
L15	36	28,5	116,2	36	3098	2932
L16	37	30,0	117,2	36	3072	2906
L17	37	30,0	127,4	36	2826	2673
L18	36	28,5	130,7	36	2754	2605
L19	38	31,4	x	x	x	x
L20	35	27,0	x	x	x	x
L21	39	33,0	x	x	x	x

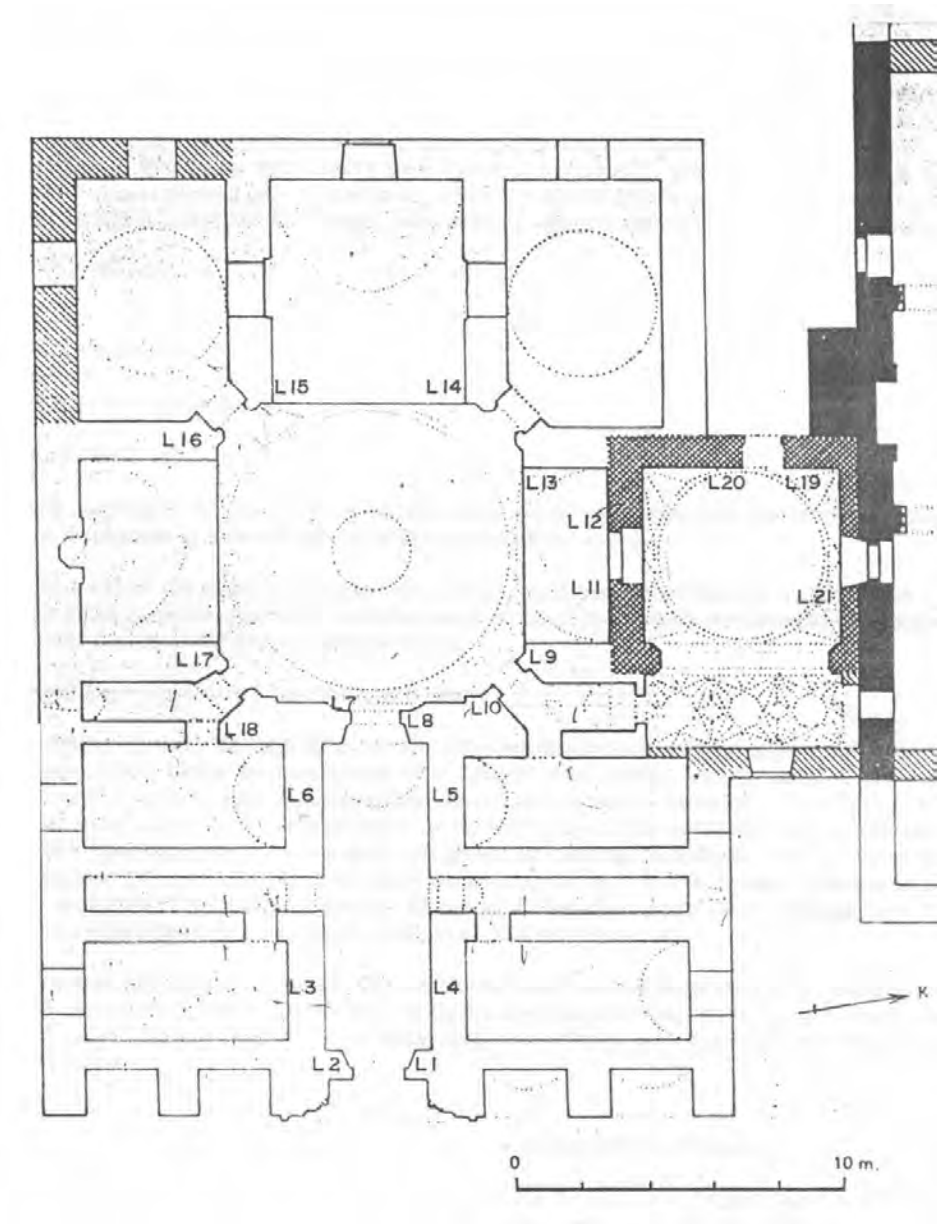

Figure 1 Plan view of the Hanikah

2.1.1 Rebound Schmidt Hammer Test Method

This test was applied on the stone walls of the building approximately at a height of between one to two meters throughout the field work by using a Type N hammer. Six rebound values were taken at each location shown in Figure 1 such that the distance between two data points is not less than 2 cm which is equal to two times the diameter of the impact plunger of the hammer. Then, an average value was calculated for each location and this value was used in the related chart, given on the hammer, to obtain approximate compressive strength (see Table 3).

2.1.2 Ultrasonic Pulse Velocity Method

Ultrasonic pulse velocity method was applied on the stone walls approximately at a height of between one to two meters throughout the field work. This procedure is applicable in both field and laboratory testing regardless of size or shape of the specimen within the limitations of avaliable pulse-generating sources. Due to this shortcoming, this test method was applied on 8 out of 21 locations where rebound hammer test was conducted (Figure 1). Four pulse time values were taken at 8 locations. After an average value was calculated, it was multiplied with a calibration factor of 402/425 which was obtained by using the standard calibration metal bar. Thereafter, pulse velocity values were calculated from the formula:

$$V = (L / T) \times 10^6 \text{, m/s} \quad (1)$$

where,
L = Length, m,
T = Calibrated average pulse time, μs.

2.3 Laboratory Work

The tests at the laboratory were performed on the samples of cut stone, clay brick and the binding material brought to the laboratory from the ruin of the structure.

In order to perform the tests, core specimens (all having 5,44cm diameter) were taken from the dimension stone samples, and clay brick samples were reduced to prismatic specimens. Binding material was powdered for X-Ray Diffraction test.

2.3.1 Tests Performed on Cut Stone

In order to determine the modulus of elasticity of the specimens, strain gauges were attached to the core specimens before the application of a uniaxial compression load by using a universal testing machine. Thereafter, core specimens were subjected to compression until failure. Loads and corresponding strain values were recorded. Stress vs strain diagrams were plotted for each specimen. Modulus of elasticity values were obtained from the slopes of the lines plotted by using secant method at 50% of failure load.

Moreover, water absorption, density, and ultrasonic pulse velocity tests were also conducted to these core specimens before performing the destructive test methods on them. Test results are all pointed out in Table 4.

As an additional work, indirect tensile strength Brazil test were conducted to four specimens prepared according to the standard specification [4]. Tensile strength values were calculated from the formula (2) and these are tabulated in Table 5.

$$\sigma_{tens} = (2 \times P) / (\pi \times L \times d) \text{, (MPa)} \quad (2)$$

where,
P = Compressive load on the core specimen, (kgf)
L = Length of the specimen, (mm)
d = Diameter of the specimen, (mm)

Table 4 Tests Results for the Cut Stone Core Specimens in Laboratory

No:	Height (cm)	Density (g/cm^3)	$Water_{abs.}$ (%)	T_{pulse} (10^{-6}*s)	V_{pulse} (m/s)	σ_u (MPa)	E (GPa)
C1	11,59	2,20	4,69	38,9	2979	25,8	21,1
C2	11,09	2,20	4,70	39,9	2779	22,4	19,7
C3	11,39	2,20	4,66	38,8	2936	24,3	20,9
C4	11,44	2,20	4,83	41,8	2737	20,9	18,5
C5	10,84	2,20	4,81	39,2	2765	21,8	18,6
C6	11,84	2,14	4,78	40,6	2916	23,2	20,7
C7	10,69	2,31	4,84	40,1	2666	18,4	17,8
C8	11,29	2,21	4,59	39,9	2830	22,9	20,5

Table 5 Tensile Strength Test Results Performed on Stone Core Specimens

No:	Diameter (mm)	Height (mm)	$P_{tension}$(kgf)	$\sigma_{tens.}$(MPa)
C9	54,4	25,6	7000	3,1
C10	54,4	25,8	6750	3,0
C11	54,4	26,8	6500	2,8
C12	54,4	26,0	6800	3,0

2.3.2 Tests Performed on Hand-made Clay Brick

Flexural strength test was conducted to the prismatic brick specimens and flexural strength values were evaluated by using the formula (3) taken from the related standard [1].

$$\sigma_f = 1{,}5\ (P_f \times l) / (b \times d^2)\ ,\ (MPa) \qquad (3)$$

where, P_f is the maximum load on the prismatic brick in kgf and l, b, d are span length, width, and depth in mm, respectively.

Thereafter, half bricks obtained from flexure tests were subjected to compression until failure by using universal testing machine, in order to obtain their compressive strengths.

Moreover, water absorption and density tests were also conducted to these specimens before performing the destructive test methods on them. Test results are all pointed out in Table 6.

Table 6 Tests Results for Prismatic Brick Specimens

No	d (cm)	b (cm)	l (cm)	$Water_{abs.}$ (%)	D (g/cm^3)	P_c (kgf)	σ_c (MPa)	P_f (kgf)	σ_f (MPa)
B1	5,1	9,3	19,0	20,50	1,83	13650	15,2	280	3,0
B2	5,0	8,9	19,0	21,38	1,89	13500	15,7	285	3,3
B3	4,7	9,0	18,7	23,05	1,99	8650	10,1	270	3,5
B4	4,7	8,6	19,0	22,75	1,99	9650	11,6	275	3,7
B5	4,3	9,3	19,9	13,52	2,05	17650	18,7	315	4,7
B6	4,6	9,3	19,7	14,90	1,93	14650	15,7	290	3,8
B7	4,5	9,2	19,5	14,62	1,85	15900	17,4	300	4,1

2.3.3 X-Ray Diffraction Method on Binding Material

Binding material brought from the site were powdered for performing the X-Ray diffraction test. The values observed from the X-Ray diffractogram were compared with the catalogue values. It was seen that there was only CaCO3 in chemical composition of the binding material.

Table 7 Catalogue Values (5-586) [3] and Values Obtained from X-Ray Diffractogram

Catalogue Value	3,86	3,04	2,50	2,29	2,10	1,91	1,88	1,60
Diffractogram Value	3,88	3,04	2,50	2,28	2,10	1,91	1,88	1,61

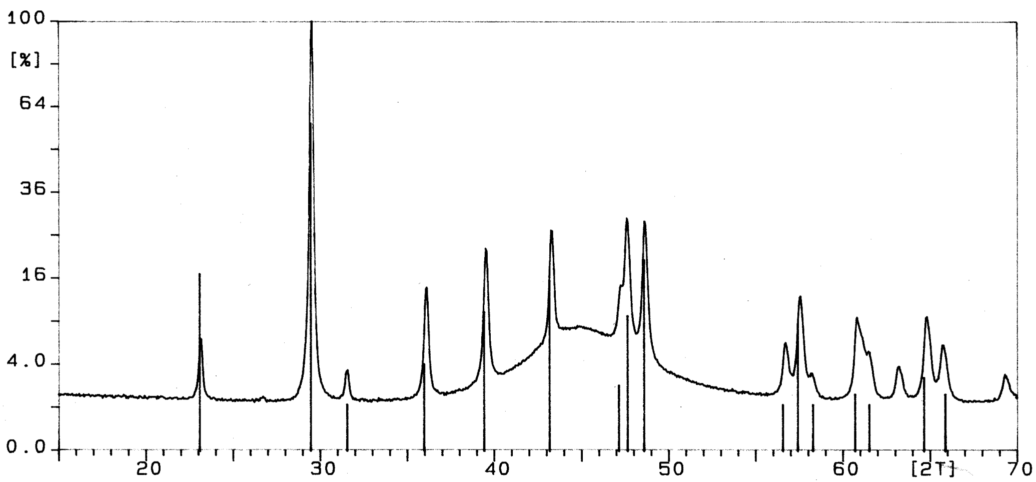

Figure 2 X-Ray Diffractogram of Binding Material

3. ESTIMATION OF IN-SITU STRENGTH AND MODULUS OF ELASTICITY

Compressive strength (σ) - pulse velocity (V) and modulus of elasticity (E) - compressive strength (σ) relationships for the cut stone specimens were tried to be obtained by a statistical study on the data obtained in the laboratory. These emprical formulas were decided to be in the form of Power functions as:

$$\sigma_{lab} = A \text{ x } V_{lab}^{B} \quad (4)$$

$$E_{lab} = C \text{ x } \sigma_{lab}^{D} \quad (5)$$

where,

σ_{lab} = compressive strength value found in laboratory, MPa,
V_{lab} = ultrasonic pulse velocity value found in laboratory, m/s, and
E_{lab} = modulus of elasticity value found in laboratory, GPa, and
A, B, C and D = constant numerical coefficients.

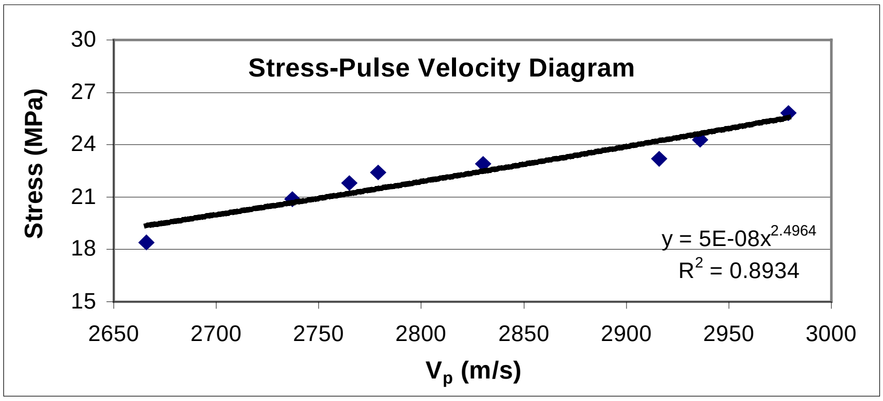

Figure 3 Relationship between Compressive Strength and Pulse Velocities

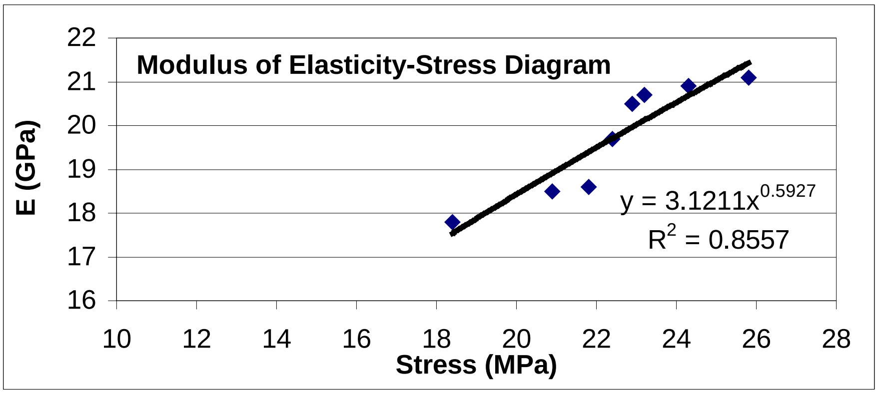

Figure 4 Relationship between Modulus of Elasticity and Compressive Strength

A, B, C and D vales were evaluated by Microsoft Excel software, as shown in Figures 3 and 4. The emprical formulas, then, were originated as:

$$\sigma = 5x10^{-8} \text{ x } V^{2.4964} \quad (6)$$
$$E = 3{,}1211 \text{ x } \sigma^{0{,}5927} \quad (7)$$

Thereafter, ultrasonic pulse velocity values obtained from different locations at site were used in formula (6) and σ_{site1} values, estimated compressive strength by using (6), were calculated for all locations. Similarly, Estimated σ_{site1} values obtained from different locations at site were put into the formula (7) and E_{site1} values, estimated modulus of elasticity by using (7), were evaluated at all points of applications at site (Table 9).

Finally, as the third step of the work, another method was applied to be able to estimate in-situ compressive strength and modulus of elasticity values. Formula (8a), in ASTM C 597 [1], was used to evaluate a constant K value for each core specimen tested in laboratory. Then, a representative K_{ave} value was calculated by taking the average of these values (Table 8). The formula is given as

$$V_{lab}^2 = K \text{ x } E_{lab} / D_{lab} \quad (8a)$$

where,
K = a constant value,
V_{lab} = ultrasonic pulse velocity value found in laboratory, m/s,
E_{lab} = modulus of elasticity value found in laboratory, kgf/m^2,
D_{lab} = density of cut stone core specimen found in laboratory, kg/m^3.

Table 8 Calculated “K” values from Laboratory Data

No	D(kg/m^3)	V(m/s)	E(10^8*kgf/m^2)	K_{value}
C1	2200	2979	21,1	9,25
C2	2200	2779	19,7	8,62
C3	2200	2936	20,9	9,07
C4	2200	2737	18,5	8,91
C5	2200	2765	18,6	9,04
C6	2140	2916	20,7	8,79
C7	2310	2666	17,8	9,22
C8	2210	2830	20,5	8,63
D_{ave} = 2207 (kg/m^3)			K_{ave} = 8,94	

After the determination of D_{ave} and K_{ave} values, they were put into the formula (8a), and the formula was originated as;

$$V_{site}^2 = 8{,}94 \text{ x } E_{site2} / 2207 \quad (8b)$$

$E_{site2} = 246,87 \times V_{site}^{2}$ (8c)

Thereafter, V_{site} values obtained from different locations at site were put into the formula and E_{site2} values, estimated modulus of elasticity by using (8c), were evaluated at all points of applications at site. Finally, σ_{site2} values, estimated compressive strength by using (7) and E_{site2}, were evaluated at all points of applications at site.

All of the estimated in-situ strength and modulus of elasticity values by using the methods mentioned are given in Table 9.

Table 9 Estimated In-situ Strength and Modulus of Elasticity Values

Loc.No:	V_{pulse}(m/s)	σ_{site1}(MPa)	E_{site1}(GPa)	σ_{site2}(MPa)	E_{site2}(Gpa)
L7	2788	19,9	18,4	21,4	19,2
L8	2896	21,9	19,5	24,3	20,7
L11	2673	17,9	17,3	18,6	17,6
L12	2679	18,0	17,3	18,7	17,7
L15	2932	22,6	19,8	25,4	21,2
L16	2906	22,1	19,6	24,6	20,8
L17	2673	17,9	17,3	18,6	17,6
L18	2605	16,8	16,6	17,0	16,7

4. DISCUSSION of RESULTS and CONCLUSION

Mechanical properties of materials of construction of the Sahip Ata Hanikah in Konya were investigated with both at site (by non-destructive test methods) and in laboratory (by destructive and non-destructive test methods).

In the site by eye-inspection it was concluded that the stone was andesite. When compared with ultrasound pulse velocity test, the results of the rebound hammer were less reliable as it is expected since they are affected by smoothness, carbonation, and moisture condition of material surface, size and age of specimens [5]. So, it is a rough method for estimating the in-situ strength of a construction material and the estimated values can differ between 10% and 15% from the actual values. In the site, strength values found by rebound hammer test lies between 27 and 33 MPa which was higher than those found in the laboratory as 18.4-25.8 MPa. The pulse velocity values obtained in the lab were used to estimate in-situ compressive strength and modulus of elasticity values by applying some statistical approaches.

As a result of laboratory tests, the water absorption capacities of cut stone were within the range of 4.59% and 4.84%, whereas, those of bricks were between 13.52%and 23.05%. They were relatively high which was normal because of the excessive amount of abrassion occurred in the long-run due to the environmental effects. Moreover, during the compression test, it was observed that the stone showed differential settlements proving its non-homogenious structure.

While the modulus of elasticity values of the cut stones were found between 17.8 MPa and 23.5 MPa, their compressive strength values lied between 18.4 MPa and 25.8 MPa. In addition tensile strength was approximately 3.0 MPa. As a result, the stone might be considered as an andesite with average characteristics.

The compressive strength values of the brick were between 10.1 MPa and 18.7 MPa. On the other hand, the minimum and maximum flexural strength values were 3.0 MPa and 4.7 MPa, respectively.

Binding material was found to be composed of only $CaCO_3$ according to the values obtained from the X-Ray diffractogram which was an expected result due to the wide-range of its use in similar structures in the same region and centuries.

First site estimations of modulus of elasticity values ranged within 16.6 MPa and 19.8 MPa, on the other hand, compressive strength values varied between 16.8 MPa and 22.6 MPa. Therefore, it can be concluded that the first site estimations are perfectly in accordance with the values in the laboratory. The results of second method that was used for site estimations were almost the same with those obtained in the laboratory. Second estimation results were as follows: Modulus of elasticity values were within the16.7 MPa and 21.2 MPa. Compressive strength values ranged between 17.0 MPa and 25.4 MPa.

Finally, it can easily be concluded that the results of two estimation procedures support each other and the in-situ strength and modulus of elasticity values were estimated with a high reliability and accuracy. So that, these estimated results can be used and they will be very benefical for the repair, rehabilitation and restoration work of this construction without any doubt.

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A SURVEY OF THE SITUATION OF THREE BASILICAS SITUATED IN NORTH ITALY

A. Dei Svaldi (1), A. Mazzucato (1), M. Soranzo (2)
(1) University of Padova, Italy.
(2) University of Udine, Italy.

ABSTRACT

The paper deals with three ancient monuments located on the Padana plain (North Italy): the basilica of Aquileia, in province of Udine, built toward the end of the IV century; the basilica of St.Vitale, near the city of Ravenna, constructed by Giuliano Argentario and consecrated in the VI century; the basilica of St.Marco, built in Venice since the X century.
The three monuments, founded on normalconsolidated alluvial strata, during the centuries suffered various damages and were subjected to structural modifications and restoration works. In order to restore anomalous situations they have been always examined by specialists and since last years, this work was supported by a constant monitoring realized with the installation of instruments inside the masonry and in the soil strata.
After a detailed picture of the history, the environment and the building technique of these monuments, the paper deals with the aspects concerning the evolution of the damage due to the deformation of the subsoil and the structure, emphasizing the importance of the monitoring instrumentation, which have made possible to identify the causes of damage and consequently allows an accurate planning and management of the maintenance works with a glimpse to the future history.

1. INTRODUCTION

The present situation of historical monuments is usually greatly affected by subsoil characteristics, by foundation types and by soil-structure interaction. In other words, geotechnical problems usually play an important role in the past life of historical buildings and in the design of preservation works.
The study of the soil-structure interaction of ancient monuments consist in the

analysis of the behaviour of the structures and the soil subjected to the stress changes due to loads and other factors as demolitions, constructions, excavations, groundwater level variations, subsidence etc.
The problem of the interaction is then of notable complexity because usually the pass behaviour is not known at all and it is not so simple to foresee the future behaviour with regard to restoration works and interventions of safeguard.
The study requires the collection of numerous data to determine the physical-mechanical characteristics of the various structural components and of the foundation soil, to appraise the stress history of the subsoil and to represent the existing condition of structures. It is necessary to consider the evolution of the damage in particular with regard to those factors as the dampness, the temperature, the vibrations and the excursions of groundwater level.
An analysis of all the factors over listed consents to appraise the influence that each of them have in the respect of the deterioration of the structures. Acquires then particular importance the monitoring of the monuments, that should be performed for a meaningful time.
Across the structural modeling that follows the detailed analysis of the collected data it may appraise the safety order of the structures and of the foundations with regard to the current stress state and to that consequent to possible interventions.
The paper deals with three ancient monuments that are different for construction age, for structural typology and for foundation soils.

2. THE BASILICA OF S.VITALE

The basilica of St.Vitale, erected from Giuliano Argentario and consecrated in the 547 d.C., is a building with octagonal plan and the sides of about 15 m (fig. 1), it may be divided in two bodies: one internal, more tall, that contains the dome and one exterior, that contains the ambulacrum, at the ground floor, and the women's gallery to the first floor. On the outside perimeter are admitted two chapels sideways to the apse, the narthex and the bell tower [5].
Common destinies to a lot of monuments is that, in the course of the centuries, they was subjected to changes (restructurings, partial demolitions, etc.) more or less substantial and such to alter more or less deeply the original structure; also the basilica of St.Vitale, was subjected, in the centuries, to substantial works relating to the construction of chapels, to the connections with outside buildings and to the raising of the bell tower.
As well as the structural changes it is necessary to consider also the effects of the natural subsidence, about 2-3 mm/year, that has induced from the time of the construction to today a total settlement of about 250 cm. Such circumstances have created considerable problems and already from the 1930 it was necessary to implement a wide net of drains under the basilica to remove the groundwater that invaded the floor.

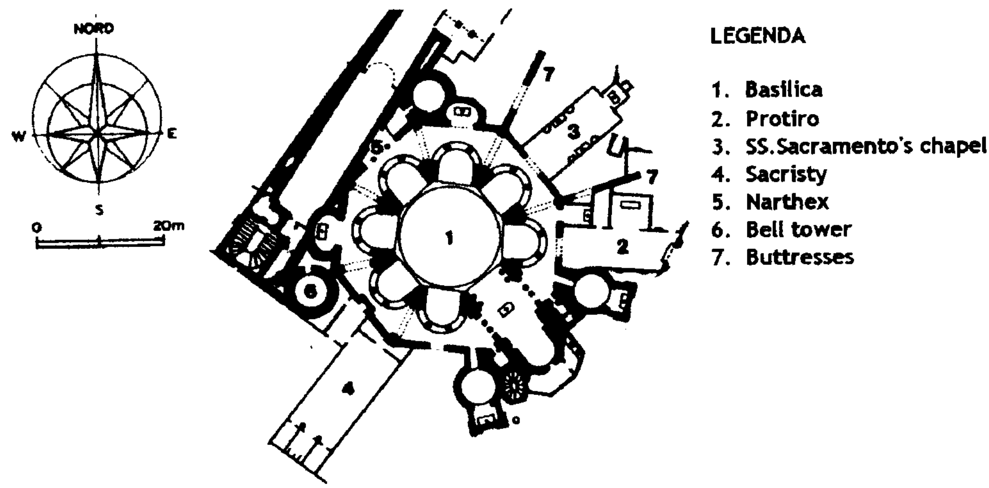

Figure 1 – Plan view of the St.Vitale's basilica (XVIII sec.).

After the 1950 the subsidence was subsequently increased for the effect of the extraction of gas and water from the subsoil in the area of Ravenna, witch has given place to a settlement of the order of 100 cm.

The stratigraphy in the area of St.Vitale, till depth of 40 m, is reported in figure 2. It is possible to recognize four formation: the first, that is of the order of the 4-6 m, is constituted from sand and silty sand, the second and the fourth are constituted from silty clay of consistence from media to compact, slightly over-consolidate and the third is constituted from sands.

The study of the foundation typology has required the execution of numerous bore-hole surveys in proximity, across and in the supporting structure of the monument.

The foundations of the perimetric masonries and of the internal structural elements are constituted from a limestone and trachyte conglomerate (fig. 3), this structural element rest on piles of oak that have the toe to -3.00 m from the ground floor; the piles are set up on the silty sand that is met to such depth.

The analysis of the stress state in the structure (holding account of the historical evolution of the interventions) has underlined that originally the stress in the materials, in particular on the masonries and on the archs, reached the maximum values of 0.2-0.5 MPa.

Due to the structural changes in correspondence of some of the space pillars to the edge of the octagon, elevated stresses and displacements were generated for effect of the thrust of the cross vault and so, before the installation of chains and connecting rods, the vaults of women's gallery, the roof and the transversal archs suffered damages as illustrated in figure 4.

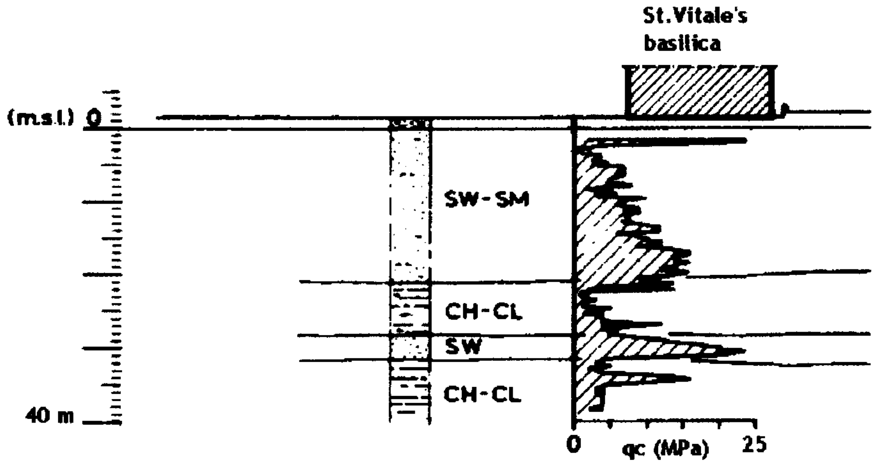

Figure 2 – Sub-soil profile under the St.Vitale's basilica.

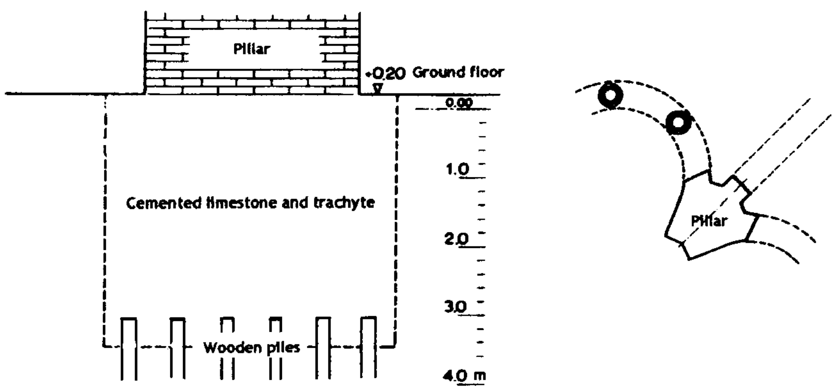

Figure 3 – Section view of the foundation of the central pillars.

The foundations of the perimetric masonries and the foundations that sustain the columns of the ambulacrum transmitt to the ground a mean pressures of about 0.23 MPa, the foundations of the eight central pillars, that sustain the drum and the dome, transmitt a mean pressures of about 0.40 MPa; the characteristics of the soil make acceptable the transmitted pressures.

The oscillations of the groundwater level in the first aquiferous, with regard to the necessary pumping to hold dry the floor of the basilica, have recommended the installation of numerous strain gauges in correspondence of the lesion to follow the evolution of the cracks. Moreover in correspondence of the edges of the matroneo were installed eight level gauges and inside and outside two hygrothermograph.

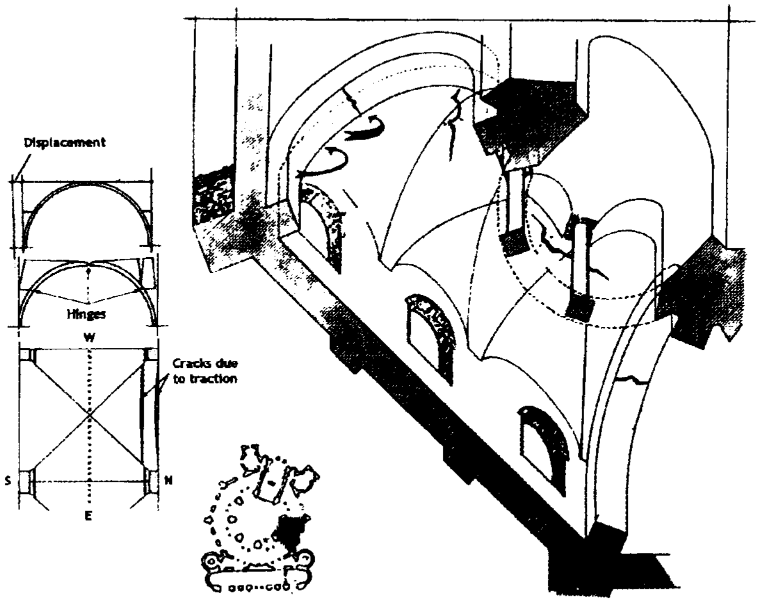

Figure 4 – Distribution of cracks on vaults and archs.

The relief of the pore water pressure highlighted the existence of two aquiferous located in the first and in the third formation. The deep granular formation doesn't show traces of the effects of the superficial drains that influence instead the first aquiferous with excursions varying among 30 and 80 cm, moreover the records of the differential settlements of the structures show extremely contained values, within a maximum less than a millimeter, so that at the moment doesn't arouse worries for the state of health of the monument.

3. THE BASILICA OF ST.MARCO

Venetian buildings are usually affected by various kinds of static problems, mainly connected to subsoil characteristics and foundation types. In this context, the basilica of St.Marco is the most significant and important example.
The history of St.Marco's basilica began more than a thousand years ago, in 832, when the first church was consecrated. Erection of the present basilica started in 1063 and it was consecrated in 1094. The old church was probably partly demolished; in fact, the new church was erected mainly on the foundations of the first old church and some of the old masonry walls (especially those of the apse and nave) became part of the present building.
After the construction, the load distribution was significantly altered by various events such as restoration work and construction of adjacent buildings and nowadays it can be considered a monument that need continuous monitoring.
The main problems of the basilica are connected to the poor characteristics of the subsoil. Further problems are also connected to the poor quality of the cement in the masonry structures.
The monument is a cruciform building composed of 3 naves crossed by a transept

(fig. 5). In the area of the apse, there is the presbytery and the underlying crypt. The basilica is roofed with 5 large brick domes connected by vaults. The diameter of the domes is about 13 m and the total height is about 30 m.
The state of stress in the masonry varies between 0.10 and 1.06 MPa [4].
The foundations (fig.6) were found to consist of short wooden piles (1.00-1.50 m long), supporting a wooden slab (10 cm thick), then several beds of large stones (with an overall thickness of about 2 m) and finally the masonry structure.
Like Ravenna, Venice also experienced natural and man-induced subsidence: the latter was very important in the 1950-70 period during which a man-induced decrease in pore water pressure of about 12 m of water column led to a subsidence of 12 cm, followed by a rebound of 2 cm [2], nowadays there is only natural subsidence, which rate is about 0.4 mm/year.
The subsoil of St. Marco's basilica (fig.7) is constituted by a first stratum, 1-2 m thick, of backfilled soil; a second stratum, 3-6 m thick, of soft silty clay; a third stratum, 10 m thick, of silty sand and fine sand and a fourth stratum of soft clayey silt which was investigated to a depth of 30 m.
The cohesive soil can be considered as normally consolidated. For the second layer the compression, Cc, and recompression, Cr, indices are about Cc=0.30-0.35 and Cr=0.05-0.08, while for the deep layer they are Cc=0.28 and Cr=0.05.

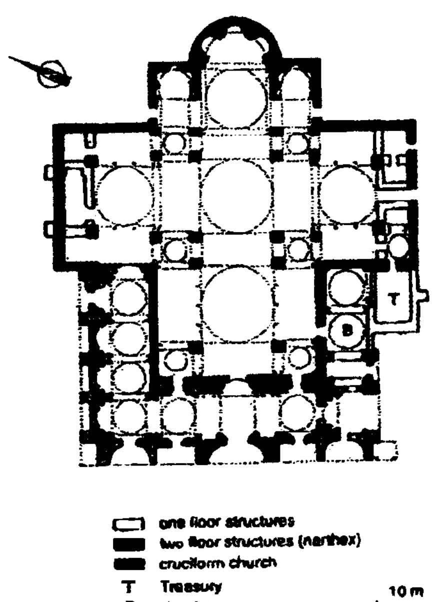

Figure 5 - Plan view of St. Marco's basilica.

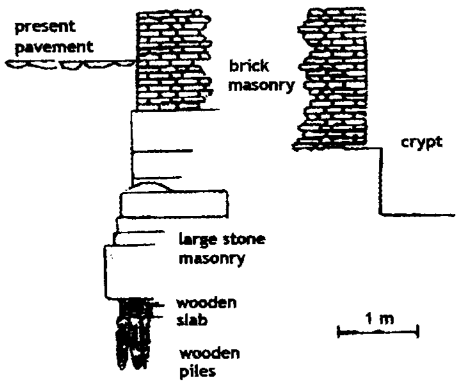

Figure 6 - Section view of the foundation structure in the apse [3].

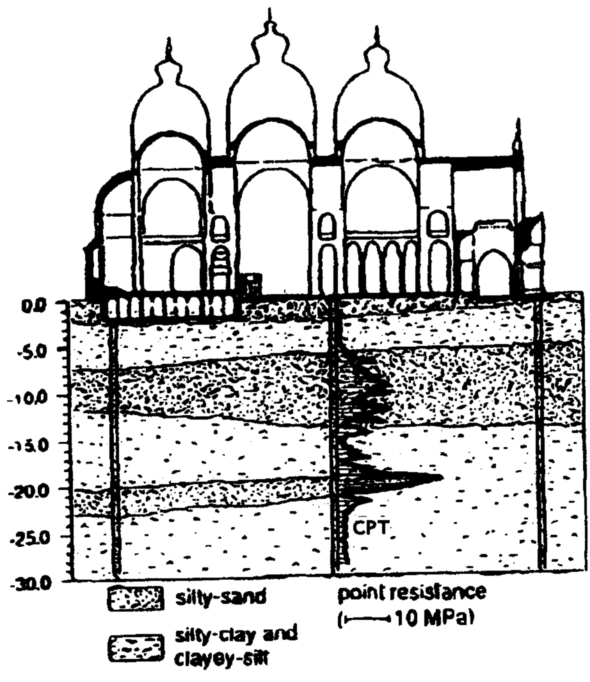

Figure 7 - Sub-soil profile of the St.Marco's basilica.

Due to the properties of the underlying soil and the load transmitted from the foundation, that is about 500-1000 kN/m as for a great number of the venetian buildings, the consolidation settlement of the basilica was about 40-60 cm.

The first survey of St. Marco's basilica was done at the beginning of this century, but it was only recently that precision surveys were performed regularly and continuously for a period of about 10 years, form 1983 until 1994 [4].

Referring to this later survey, figure 8 shows the evolution of the differential settlement of some points with respect to the reference point R placed in the

presbytery (fig.8a). The rate of differential movement is high in the first two years (1983-85), probably connected to the settling of the measurement gauges, and then becomes very small in the following eight years (1986-94).
Moreover, a small seasonal dependence of the rate of settlement can be seen in some of the years following 1986. It is worth noting that the differential settlements observed in 1989-94 are very small and further observations would be necessary to confirm this trend.

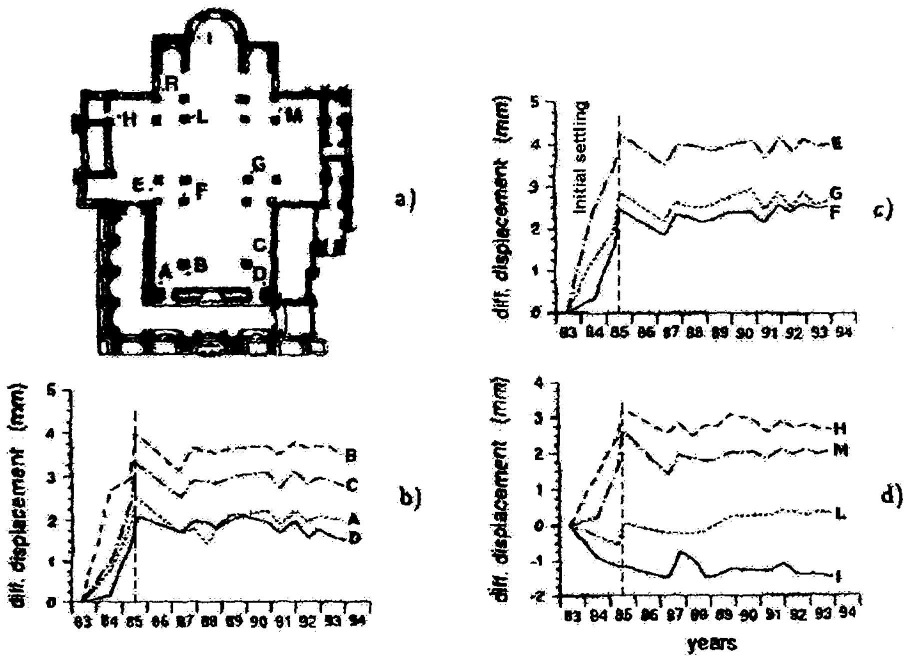

Figure 8 - Evolution of differential displacements in the period 1983-94. a) position of points; b) points in main nave; c) points in cross-arm; d) points in presbytery (the positive value refers to a displacement upwards in relation to the reference point R).

4. THE BASILICA OF AQUILEIA

The town of Aquileia, located at the extreme northern tip of the Adriatic Sea, was founded in 181 BC as a military garrison of the Roman Republic, whose purpose was to hold back barbaric invasions. The city was destroyed in 452 AD by the Huns and the only majestic monument that Aquileia inherited from antiquity is the patriarchal basilica, with its cross-shaped plan (65 m x 29 m) and its severe romanesque-gothic lines, and the impressive bell tower. The basilica (fig.9) was built in 5th century then Patriarch Massenzio (9th century) built the crypt and the transept; at the beginning of the 11th century the church was transformed by Patriarch Poppone (1019-1042), by building the apse, the bell tower and transforming the crypt (around 1030) [7].

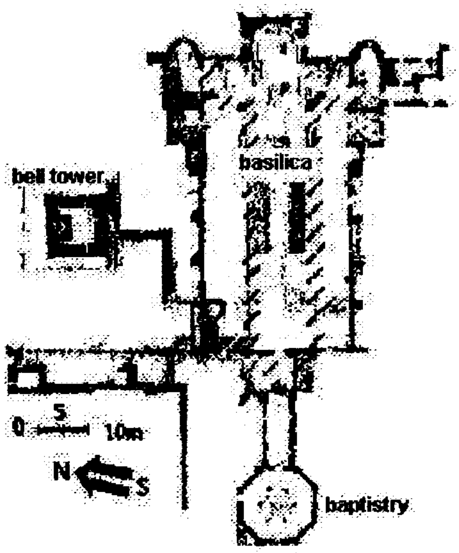

Figure 9 – Plan view of the basilica.

The foundation soil in the central site of Aquileia can be identified considering the data deduced from borings and laboratory tests, performed on soil samples [6]. The soil consist mainly of clay and silt in the upper layers (4-9 m in depth), whilst the lower layers are composed of silt and sand. Oedometric compression tests performed on samples taken from a depth of up to 9 meters from the top soil level yielded compressibility index values Cc ranging from 0.13 to 0.27, increasing proportionally with the plasticity indexes of the samples, and a recompression index value Cr ranging from 0.007 to 0.07.
Dealing with the settlement phenomena, is interesting to take as reference the bell tower of the basilica.
From the examination of written documents (i.e. manuscripts and stone engravings), as well as from some logical interpretation of the construction works, it is possible to outline the evolution that the bell tower has undergone. Furthermore, the history of the tower can be deduced from architectonic and historical changes, architectonic shapes and the materials employed in the construction works.
The tower was erected at the beginning of the XI century, it was 43 m high and it seems it was not a bell tower, at the beginning of the XIV century it became a real

bell tower and in the XV century it was completed up to a total high of 73 m.
Since that time restoration works are reported, often associated to earthquake phenomena and after the quake of 1348 the basement of the bell tower was enlarged. The sides of the square base, which originally measured 11.80 m, were enlarged to 19.30 m [1].
The heavy load, weighing on the tower foundations (fig.10) has caused the tower to settle considerably; consequently, there has been a lowering of the mosaic flooring around the basement of the bell tower by approximately 50 cm compared to the original level, moreover the Theodoric mosaic inside the bell tower is at an even lower level, another 50 cm, hence the settlement of the tower seems to be about 100 cm.
Although in terms of its general structure the whole monument reflects the characteristics conceived by Poppone it is the result of an exquisite combination of pre-existing architectural portions, modifications and subsequent attachments, such as those that became necessary after the 1348 earthquake and those brought about by the radical restoration requested by Patriarch Marquardo of Randeek (1365 - 1381), moreover archeological excavations have given evidence of layers of paleo-Christian chambers on which lays today's romanesque-gothic building.

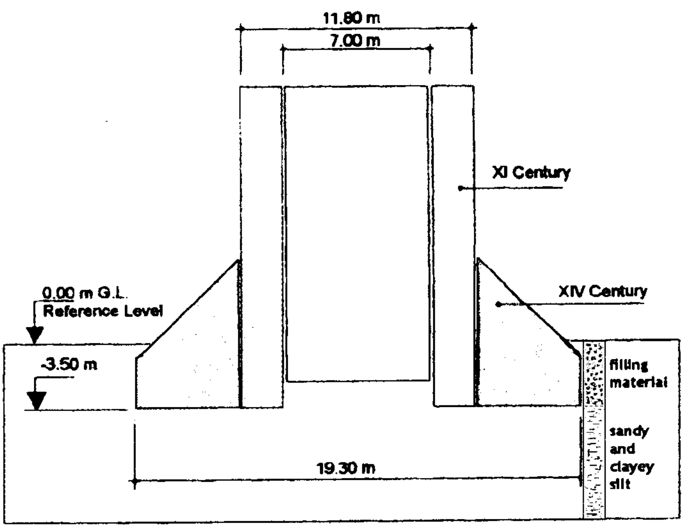

Figure 10 - Foundation structure of the bell tower and sub-soil profile.

5. MAIN CONCLUSIONS

The paper has analysed the situation of the ancient basilicas of St.Vitale, St.Marco and Aquileia, pointing out the presence of restoration works.
These works have to be performed keeping in mind the original structure, for this reason several interventions have been carried out with the main purpose of cleaning the monuments, eliminating the superimposed structures builded during their life.
Other works were carried out in order to reduce the effects due to natural phenomena, like subsidence, consolidation settlements and earthquake, or to arrest the deterioration of the mechanical properties of the materials.
A very important aid was given from the structural and geotechnical survey and from the monitoring service installed directly on the basilicas or in the nearby side.
Future restoration works have to consider the following points:

1. the recorded measurements may be very helpful to choose the possible design of the intervention works;
2. the inteventions have to be performed when the movements have exeeded the judged limits;
3. the efficiency of the interventions has to be prooved both with the previous measurements and with the movement recorded during and after the restoration works.

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THE OLD BRIDGE IN MOSTAR — THE EVALUATION OF THE ABUTMENTS' STATE BY NON-DESTRUCTIVE METHODS

T. Ivanković (1), V. Sigmund (1), V. Ivanković (2)
(1) University J. J. Strossmayer, Faculty of Civil Engineering, Osijek, Croatia
(2) University Zagreb, Faculty of Architecture, Zageb, Croatia

ABSTRACT

The Old Bridge in Mostar, with its elegant arch of a span of 28.6 m, was built in the XVIth century, and was on the UNESCO cultural heritage list. During the war in Bosnia and Herzegovina the crown of the Old Bridge in Mostar was torn down. The measures for its reconstruction have been started in an effort to use most of the old remnants. The abutments on both sides have withstood and the bridge reconstruction started by analysing their present state. Several non-destructive methods (seismic refraction with tomographic analysis, seismic refraction inside the infill, ultrasonic tests on the stone and mortar structure, and video-endoscopy) have been tried in order to ascertain their present state. Especially good results were obtained by combining seismic refraction with tomographic analysis, ultrasound and video-endoscopy. Ultrasonic tests on the masonry structure helped to establish the importance of mortar to the results of seismic tomography. The combined results gave a very good overview of the state of each of the support walls, which made possible a selective approach to the wall rehabilitation according to their particular state. Video-endoscopy and seismic refraction indicated a poor bond between the stones in the support walls.

Key words: non-destructive methods, ultrasonic test, video-endoscopy, seismic tomography, sclerometry, oolotic limestone

1. INTRODUCTION

Projects of reconstruction of valuable cultural and historical buildings call for a precise and detailed diagnostics of the condition of all the parts of the respective structure; for this reason it is necessary to carry out certain investigations. Investigative works must not have a negative effect on the existing condition and aspect of the building, so the use of non-destructive methods comes in useful. The choice of investigation methods is especially influenced by the type and the condition of the respective structure; the kind, position and degree of damage; and by local technical conditions of the execution of investigative works. The best results are expected when using the results comparison model of different destructive and non-destructive investigation methods. As an example of a successful application of some non-destructive investigation methods we present a part of the investigation results regarding the remains of the destroyed Old Bridge in Mostar (Fig. 1).

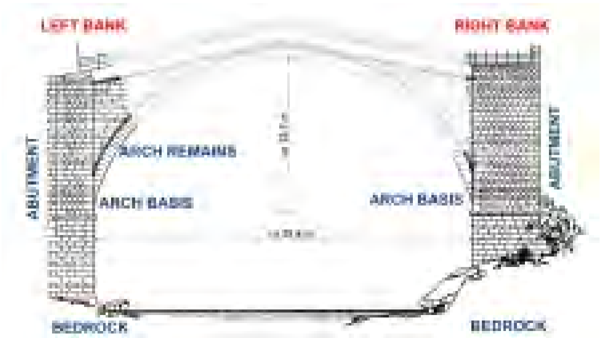

Figure 1: Main investigated disposition of the bridge

The Old Bridge in Mostar is treated as an architectonic masterpiece of the 16th century. This monumental edifice is on the UNESCO list of the world's cultural heritage. According to an inscription in the Turkish language, the construction of the Bridge ended in the year 974 according to Hidjra, that is, in 1566-1567. A letter found among the copies of the books of an imperial state councillor (Mhimme Defter) from early April 1568 says that "the bridge has been built recently" and that its builder was "architect Hajrudin, a disciple of the great builder Sinan". The stabilisation of the stones in the vault by joining up the massive stone blocks in three dimensions is an inventive constructional design. The ingenuity of this construction lies in the fact that the bridge structure is lighted exactly in the zones of the highest stresses. At the time of the high water level of the Neretva River, the wing walls of the bridge are in the water, and their bond with the littoral rock is realised through the abutments constructed of stone blocks, as a substitute for foundations.

In the region of the foundations and on the structure of the bridge various kinds of damage occurred in the course of time. The Osmanli inscription on the bridge makes mention of major repairs in the year 1150 according to Hidjra, which corresponds to the year 1737-1739. The Osmanli document from 1738, preserved in Istanbul, specifies the costs of the repair of this damage caused by the explosion of a powder storehouse (Cabe.hane). After that, major remedy works were undertaken in the 1954-1982 period, in the region of the foundations and on the bridge arch, but these works were not completed.

The Old Bridge in Mostar was destroyed in the war, on 9 November 1993. The reconstruction started on 29 September 1997, when the first stone block of the destroyed arch was retrieved from the bed of the Neretva River. The works are being executed under the auspices of UNESCO, and with the financial support of the World Bank and several European countries. It is not possible to reconstruct the bridge from the original parts, so that the facsimile method will be applied, i. e. an identical copy will be made on the basis of the preserved documentation.

The first stage of the Bridge reconstruction includes the investigative works in the region of the foundations, the walls, and the remains of the arch and the arch base. The purpose of these works was to make a diagnosis of the present condition and to define the causes of damage in the region of the foundation rock, the walls, and of the remains of the arch and the arch base.

2. TYPES AND DESCRIPTION OF STONE

The wider area of the City of Mostar lies for the most part on solid limestones, which are often used as architectonic stone. Among several types of limestone the builder chose the geologically youngest type, white oolitic limestone, which, due to specific genetic conditions, differs from other types. The stone deposits have no major exploitation reserves but they are sufficient for the needs of the planned reconstruction of the bridge. This means that the Designer's request to use the same stone type and from the same quarry can be met. Owing to its porosity and mineralogical/petrographic composition this stone, locally called "tanelija", is considerably lighter than other limestone types and is suitable for fashioning. As a result of a change in the sedimentation conditions and of diagenetic processes another limestone type appears in the same quarry, locally called "miljevina". It is a fine-grained limestone type without oolite, white-yellow in colour, of the same mineralogical/petrographic composition, but of essentially different structure and texture. The porosity of this stone type is substantially lower, so that its weight is higher.

The microscopic inspection of "tanelija" stone shows that the oolite percentage is related to the processes of the creation of concentric calcite shells round the central quartz grains. The spaces between the oolite are only partly filled with cement binder, so that this is the main reason for the high porosity of this stone. Water penetrates into the pores, which in freezing may cause surface damage to the stone. However, just on the surface the calcification process is intensive because the stone structure and the mineral composition facilitate re-crystallisation of calcite in the form of thin surface deposits. These surface calcite deposits prevent the penetration of water and gases deeper into the stone, increase the surface strength, and the resistance to impacts and wearing. The mild climate of this area, too, offsets the destructive effects of ice so that this problem is not pronounced. Destructive and non-destructive investigation methods of the stone in the Bridge remains disclosed the presence of secondary macro and micro cracks. Through these cracks water penetrates into deeper parts of the stone, but with the time these defects are remedied by re-crystallised calcite that acts as a cement binder, which means that in this stone type a process of natural repair occurs. The same process occurs at the joints of stone blocks, and it is especially pronounced in the zone of water level oscillations, so that it may be concluded that the bond between the stones in lower sections of the walls, foundations and the arch base has considerably grown stronger during these 400 years of the existence of the Old Bridge. This finding, in addition to the results of other investigation methods, points to a good prediction of the usability of the remains of the Bridge for future reconstruction.

The fine-grained stone type, "miljevina", has higher volume weight, breaks conchoidally on the surface, shows no presence of calcite re-crystallisation process, retains moisture for long, and is very sensitive to freezing. Owing to these features the "miljevina" stone is not suitable for bridge construction, which the builder knew only too well, for he made the proper selection of stone from the quarry. Only 0.5% of "miljevina" stone and 8% of the mixture of oolitic and fine-grained limestone were built into the bridge.

The whole arch structure, the foundations and the main part of the abutment wall, that is, all the vital parts of the bridge, were made of fashioned blocks of oolitic limestone. A large part of the side walls was made of manually shaped blocks of conglomerate, which is found in large quantities on the river banks. The inside of the walls is filled with undressed stone (conglomerate, solid dark and light limestone, oolitic limestone and breccia) bound with "Turkish" binder. As the type of stone is not important for the wall filling, the builder used different stone types taking into account transport and labour costs. The red breccia is to be found only in the fill of the left abutment wall, since the deposits of this stone type can be found only on the left bank of the river.

The "Turkish" binder is a lime binder with some additions, which have not been known with certainty yet. Mineralogical and petrographic analyses have demonstrated the composition of the basic components of this binder. The basic matter is lime powder with fine pores of unknown origin. Inside the lime powder there are grains of quartz, quartzite, schist and limonite. This binder is not resistant to a prolonged effect of water, so that in some parts of the wall filling it has been washed out. The strength of the binder is considerably lower than the strength of modern cements but it approaches the strength value of oolitic limestone, which is important in terms of construction.

3. NON-DESTRUCTIVE INVESTIGATION METHODS

Numerous destructive and non-destructive investigation methods have been applied on the remains of the Old Bridge and in the region of the bedrock. As a whole within the investigation model on the walls and the arch base a set of four non-destructive methods could be singled out: seismic sounding, ultrasonic test, sclerometry and video-endoscopy.

Each of these methods has a limited range of applicability, but the applicability of methods is considerably increased by a joint analysis of all investigation methods.

3.1. The method of seismic sounding with tomographic data processing

The basic principle of seismic sounding is the measurement of seismic wave velocities between the transmitter and the receiver. The velocity of the passage of seismic and ultrasonic waves is the basic indicator of the quality of the material being examined.

Spreading time of a seismic wave is the integral of the slowness function along the trajectory of the wave ray from a seismic source to a geophone. If we take *P* to mark an arbitrary path which connects a certain source with the geophone within the model of slowness *s*, then it is possible to define the functional τ^P which describes the spreading time of a seismic wave along the trajectory. Assuming the continuous distribution of slowness function *s(x)* we obtain:

$$\tau^P(s) = \int_P s(x)dl^P \qquad (1)$$

Here dl^P determines the infinitesimal distance along trajectory *P*.

If we have a set of registered times of seismic wave spreading: (t_1, t_2, t_3,…, t_m) for *m* source-geophone pairs within a medium characterised by slowness *s(x)*, then the following equation defines the wave ray P_i, which connects the i^{th} source-geophone pair (neglecting measurement errors):

$$\int_{Pi} s(x)dl^{Pi} = t_i \qquad \text{i = 1, 2, 3,…, m} \qquad (2)$$

Since the space between two boreholes is rectangularly divided, the length of the i^{th} ray in the j^{th} cell will be designated by $l_{i,j}$, hence:

$$l_{i,j} = \int_{Pi \cap Cell\ j} dl^{Pi} \qquad (3)$$

For the model with *n* cells we can write that:

$$\sum_{j=1}^{n} l_{i,j} \cdot s_j = t_i \qquad \text{i = 1, 2, 3,…, m} \qquad (4)$$

If we write the given equation in a matrix from, then:

$$s = \begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ . \\ . \\ . \\ s_n \end{pmatrix}; \quad t = \begin{pmatrix} t_1 \\ t_2 \\ t_3 \\ . \\ . \\ . \\ t_m \end{pmatrix} \quad M = \begin{pmatrix} l_{1,1} & l_{1,2} & l_{1,3} & . & . & . & . & l_{1,n} \\ l_{2,1} & l_{2,2} & l_{2,3} & . & . & . & . & l_{2,n} \\ l_{3,1} & l_{3,2} & l_{3,3} & . & . & . & . & l_{3,n} \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ l_{m,1} & l_{m,2} & l_{m,3} & . & . & . & . & l_{m,n} \end{pmatrix}. \tag{5}$$

Equation (4) represents the basic equation of a direct modelling within the analysis of wave rays equations, and we have in short:

$$M \cdot s = t \tag{6}$$

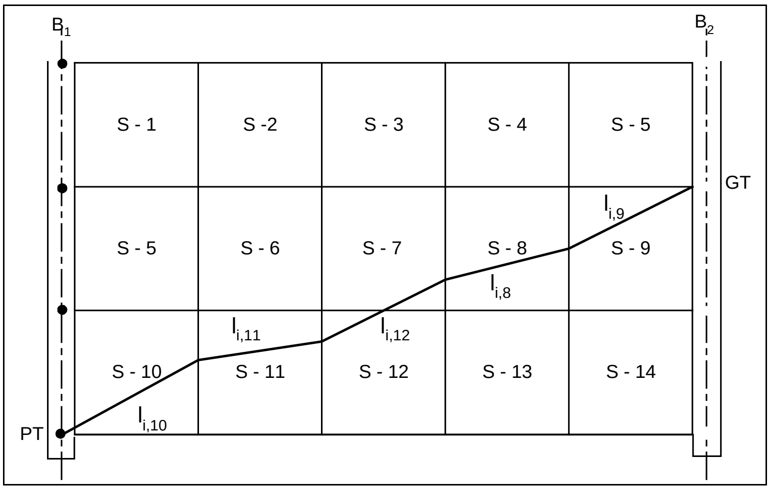

Figure 2: Schematic diagram of the ray passing through cells of slowness model

In *linear tomography*, or inversion, *M* and *t* are known, but vector *s* should be determined. It is assumed that the trajectories of wave rays are known in advance, which is acceptable in case of linear approximation, which neglects the dependence of a wave ray on space distribution of the slowness function. The usual assumption is that wave rays are straight lines connecting sources and detectors (geophones).

When solving the problems of linear inversion, it is necessary to solve the system of linear equations, where in the *M*-type $m \times n$ is a known matrix of wave rays, *s* is the unknown *n*-vector of slowness value components, and *t* is the known *m*-vector of seismic waves arrival times.

Seismic sounding of the surface of the abutment walls was carried out by placing a vertical series of seismic receivers (geophones) spaced at 1.0 m along one edge of the wall, while shoot points were situated along the opposite wall edge with the same vertical spacing. The same measuring manner was applied for the arch remains. In masonry the velocities of seismic waves are reduced due to the joints between individual stone blocks. According to an experimental investigation the joints filled with "Turkish" binder reduce the velocities of seismic waves by 12%, and these relations should be taken into consideration when evaluating the quality of a piece of masonry. A tomographic presentation of the velocities of seismic waves through the central wall of the right abutment determines the zones of different quality (Fig. 3).

Figure 3: Right bank – seismic sounding – central wall

The highest velocities of seismic waves, and the best condition of masonry as well, are in the middle of the wall between elevations 48 and 51 m.a.s. The evaluation of the wall condition is satisfactory because the tomographic survey represents the reduced velocities of seismic waves.

A tomograhic presentation of the velocities of seismic waves of the central wall on the left bank shows that the wall has no major damage, but that the distribution of velocities here is essentially different because the lowest seismic wave velocities are located in the middle of the wall, while the velocities at the bottom and on the top of the wall are twice as high. (Fig. 4).

The seismic sounding of the arch base was carried out between the vertical wall axis and the vertical borehole drilled through the fill of the wall. At the lowest section of the arch base on the left bank the velocities of seismic waves have the values ranging from 1000 to 1500 m/s. Such low velocities of seismic waves point to weak spots in the structure of that section of the arch base. The same results were obtained for the upper and central section of the arch base on the right bank.

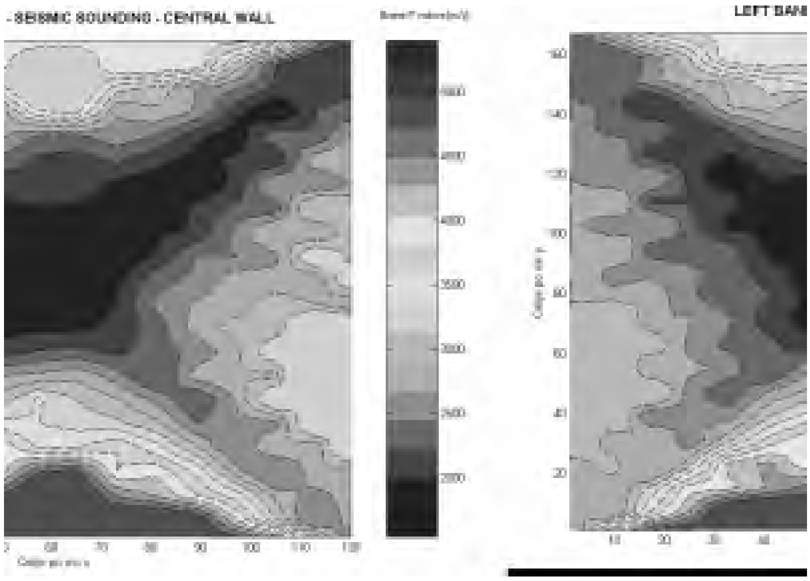

Figure 4: Left bank – seismic sounding – central wall

Tomograhic presentations of the velocities of seismic waves (Fig. 5 and Fig. 6) locate quite well the weak spots in the structure of the arch base.

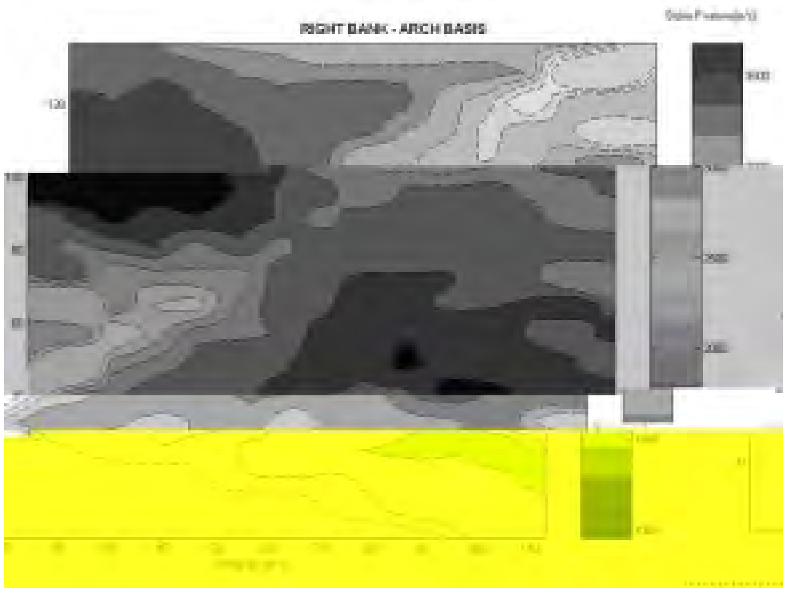

Figure 5: Right bank - Arch basis

These findings are very important for the bridge reconstruction project, for they warn of the need to repair the vital parts of the bridge remains.

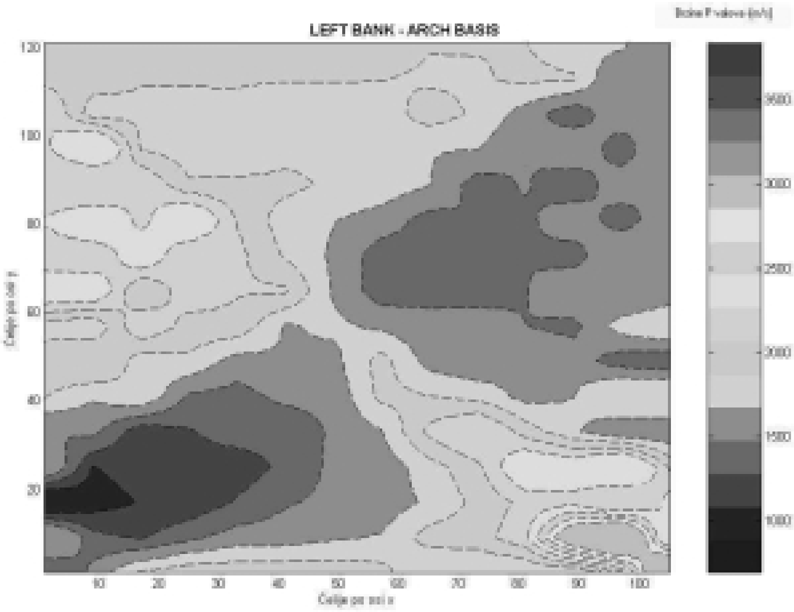

Figure 6: Left bank - Arch basis

3.2. Ultrasonic investigations

The base of the ultrasonic investigation method is the measurement of the velocities of the propagation of ultrasonic waves through stone. This method is suitable for the assessment of elasticity parameters, identification of defects and determination of crack sizes in stone. By initiating ultrasonic waves particles of matter are set in motion and mechanic waves of longitudinal and transversal form are created. The velocity of an ultrasonic wave depends on physical properties of material; it is a constant of material. The departure of velocity from reference values means a change in physical values of a material. The velocity of a longitudinal wave (v_p) is obtained by means of the measured values of the distance between the transmitter and the receiver (l) and the time of the wave passage through the material (t) (Fig. 7). For practical application we use a simplified relation of the velocity (v_p), material density (ρ) and the dynamic modulus of elasticity (E_{dyn}):

$$v_p = \sqrt{\frac{E_{dyn}}{\rho}} \qquad \text{from where follows} \qquad E_{dyn} = v_p^2 \cdot \rho \qquad (6)$$

The relation between the static and dynamic value of the modulus of elasticity is rather complex so it is desirable to carry out experimental measurements for every type of material. The relation for the "tanelija" stone was determined in that way:

$$E_{st} = 5 \cdot 10^2 E_{dyn} \qquad (7)$$

The results of ultrasonic tests of manually fashioned "tanelija" stone on the remains of the Old Bridge walls are presented in Table 1.

Table 1: Statistical data processing of stone block ultrasonic examination

STATISTICAL INPUT DATA		STATISTICAL OUTPUT DATA	
Range of ultrasonic velocities [m/s]	No. of entities	Statistical property	Value
0 - 500	0	Number of data	330
500 - 1000	4	Mean	2398
1000 - 1500	35	Median	2367
1500 - 2000	18	Minimum	877
2000 - 2500	163	Maximum	5333
2500 - 3000	65	Range	4456
3000 - 3500	17	Lower quartile	2198
3500 - 4000	21	Upper quartile	2667
4000 - 4500	5	Quartile range	469
4500 - 5000	1	Standard deviation	710
5000 - 5500	1	Variance	505444

Mostly represented are the values of the velocities of ultrasonic waves of about 2.500 m/s, which indicates a stone of medium quality. The results of these tests were considerably influenced by the presence of micro-cracks, which, in terms of construction, do not reduce the usability of the walls for the reconstruction of the Bridge.

Table 2: Statistical data processing of inter - stone block block joints ultrasonic examination

STATISTICAL INPUT DATA		STATISTICAL OUTPUT DATA	
Range of ultrasonic velocities [m/s]	No. of entities	Statistical property	Value
0 - 500	0	Number of data	261
500 - 1000	19	Mean	2104
1000 - 1500	42	Median	2260
1500 - 2000	32	Minimum	517
2000 – 2500	100	Maximum	4878
2500 - 3000	50	Range	4361
3000 - 3500	13	Lower quartile	1619
3500 - 4000	2	Upper quartile	2548
4000 - 4500	1	Quartile range	929
4500 - 5000	2	Standard deviation	733
		Variance	537709

The quality of the bond between the stone blocks was examined by measuring the velocities of ultrasonic waves through the blocks and between the blocks.

In this way the effect of the joints between the stone blocks on the seismic tests of the walls was also assessed. The test results show that the joints between the stone blocks (Table 2) slow down the velocities of ultrasonic waves by about 12% on the average.

The small deceleration factor may be explained by the builder's skill, the strong effect of the "Turkish" binder and the natural calcification in the joints.

3.3. Sclerometric tests

By measuring the recoil of an iron point after an impact of constant energy, information about the stone surface hardness is obtained. Sclerometric tests have a spot character, so the mineralogical-petrographic composition of stone has the greatest effect on the measuring results. This method fails to give good results if the stone of grained structure is made of minerals of different hardness. The homogeneous texture and the oolitic structure of the "tanelija" stone render it suitable for sclerometric tests. However, the calcified layer on the surface increases the surface hardness of stone, and for that reason the recoil values of 30-40 have the greatest frequency (Table 3). The tests on stone without the calcified layer show the recoil values of about 20.

Tablica 3: Statistical data processing of inter - stone block block joints ultrasonic examination

STATISTICAL INPUT DATA		*STATISTICAL OUTPUT DATA*	
Range of sclerometric rebound	**No. of entities**	**Statistical property**	**Value**
20 - 25	2	Number of data	225
25 – 30	12	Mean	34,9
30 - 35	95	Median	35
35 – 40	90	Minimum	23
40 – 45	19	Maximum	50
45 –50	7	Range	27
		Lower quartile	32
		Upper quartile	38
		Quartile range	6
		Standard deviation	4,4
		Variance	18,8

3.4. Video-endoscopic tests

This method uses miniature video cameras equipped with control, orientation and illumination devices. It is suitable for determining the position, size and frequency of cracks and other defects inside the walls, and for determining the structure, texture and type of stone. The frequency of all defects is expressed by damage percentage K whose value ranges from 0 for monolith to 100 for empty space.

For the walls with stone infill on the banks of the Old Bridge the following results were obtained:

- The contact between the wall and the stone filling constitutes a visible discontinuity in the larger part of the structure.
- The filling inside the walls contains unshaped stone blocks of different type and size. Stone pieces are bound by lime mortar.
- The binding properties of lime mortar vary from place to place, and in many places the binder is completely missing or has no binding properties at all.
- The damage coefficient *K* for a wall with a fill of up to 3.0 m in depth amounts to K=15.1. The upstream and central wall wings have approximately the same *K* value, while the downstream wings have a considerably higher degree of damage.
- In the upstream section of the wall on the left bank after 2.0 m there is an empty space with a volume of more than 100 m^3. The walls of this room are made of shaped conglomerate blocks, and they show the evidence of construction repairs using mortar on the basis of silicate binders, which means that these works were carried out after the construction of the Bridge. Full information about this finding will be available after archaeological investigations.

4. CONCLUSION

The application of non-destructive investigation methods is useful for the diagnostics of the state of ancient cultural and historical structures. By seismic tomography of the walls and the arch base of the Old Bridge in Mostar the zones of different damage degree were spatially determined. Certain parts of the arch base were marked as very weak zones, which means that, before continuing the construction of the destroyed part of the arch, it is necessary to carry out appropriate constructional repairs.

The present quality of shaped blocks of "tanelija" oolitic limestone was assessed by an ultrasonic test on the walls of the Old Bridge. The examination of the joints between the stone blocks made possible an assessment of their effect on the results of seismic tomography. The deceleration of elastic wave velocities due to the presence of these discontinuities amounts only to 12%, which indicates a good quality of the bond between stone blocks.

Sclerometric measurements give the information about the surface hardness of stone. They confirmed that the calcite surface layer, which had deposited on the stone surface in the course of time, greatly increases the surface hardness of stone. A comparison with the results of seismic tomography and ultrasonic tests is not possible due to a different character of these methods.

Video-endoscopy gave precise data about the degree of damage to the stone fill of the walls, the size and position of defects, and about a large room inside the wall on the left bank.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 e-mail:sas2001@yildiz.edu.tr http://www.yildiz.edu.tr/mim/sas2001
ICOMOS TURKEY

GEOTECHNICAL STABILIZATION PROBLEMS OF SOME MEDIEVAL CASTLES IN SLOVAKIA

F. Baliak, J. Malgot
STU, Dept. of Geotechnics, Bratislava, Slovakia

ABSTRACT

There are many historical monuments in Slovakia. They are very valuable from the point of view of their history and architecture. The most interesting are medieval castles (more than 200) which are at the present time in the very bad conditions.
The paper deals with the analyses of the engineering geological causes of the failures of the bodies of these castles. The suggestion of remedial works are analyzed, too.

1. INTRODUCTION

There are many cultural and valuable monuments in Slovakia, important with regard to history, urban development and architecture. The most attractive are castles and mansions, amouting to about 200 structures. However, the majority of them are ruins doomed to destruction.

Within the scope of the governmental task „Engineering geological passportization of selected historic monuments on the Slovak territory“, aimed at preservation of the cultural heritage, we paricipated in the solution of this project. From selected 53 historic structures (Fig. 1) we have realized passportization of 15 castles in Slovakia (Beckov, Bojnice, Bzovík, Devín, Divín, Fiľakovo, Halič, Hajnačka, Hričov, Kamenica, Krásna Hôrka, Liptovský Hrádok, Modrý Kameň, Považský hrad, Súľovský hrad). Important historic structures in Slovakia, where detailed engineering geological investigation had already been realized in the past, as well as subsequent reconstruction, sanation or preservation had been performed, are not included in this pasportization, as for instance castles Strečno, Orava, Spiš and others [4].

Factors, creating engineering geological causes of failures and deformations of the historic structures, analysis of the physical condition measures, providing elimination of negative phenomena causing failures, have been dealt with in this contribution.

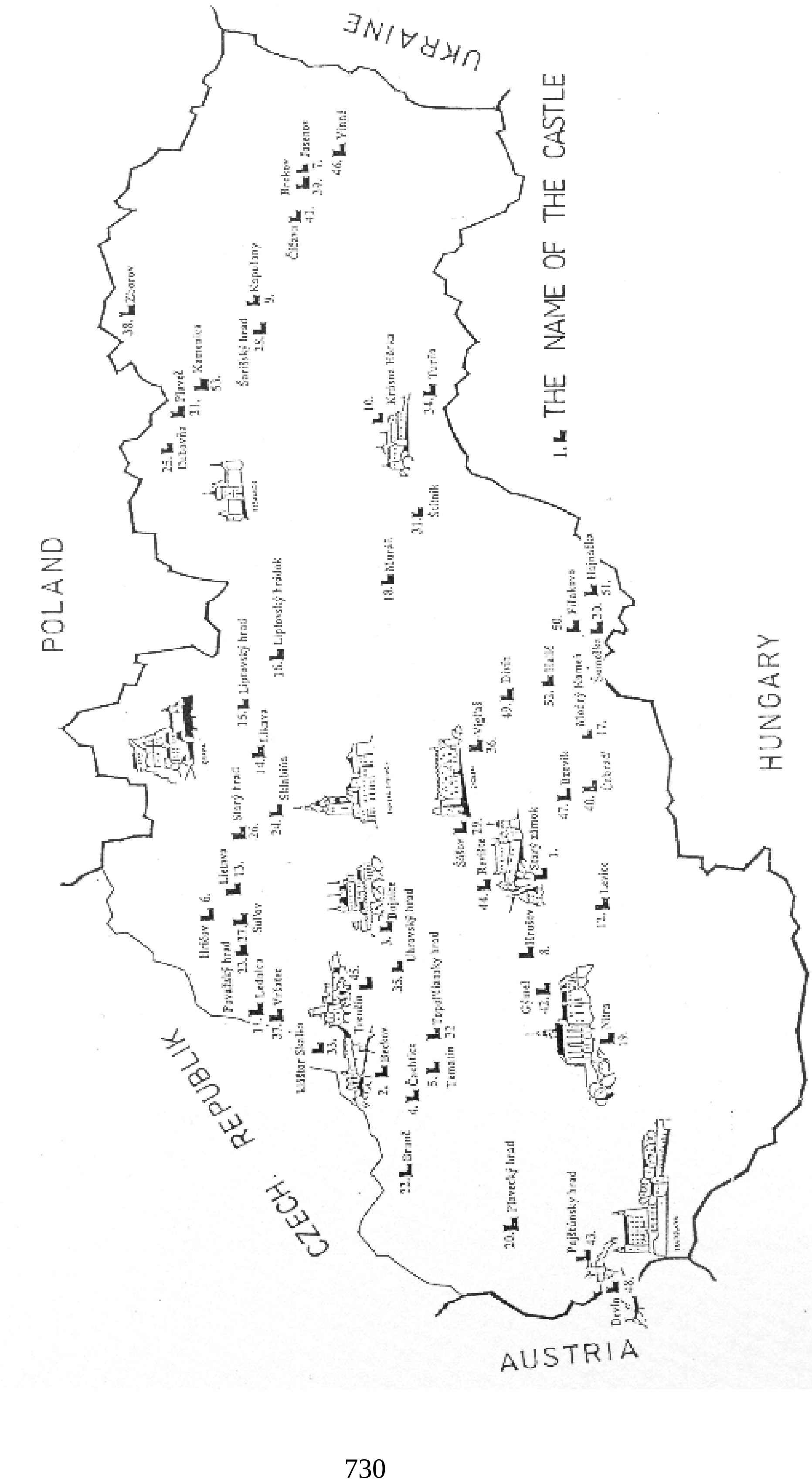

FIG. 1. THE SITES OF STUDYED CASTLES IN SLOVAKIA

2. ENGINEERING GEOLOGICAL CAUSES OF FAILURES

The majority of engineering geological causes of failures occuring on historical structures consists chiefly in changes of geological medium, resulting in negative interaction with historic structures. Many changes evidence negative long-term antorpogenous activity, influencing their character and intensity.

Detailed classification of engineering geological causes of failure occurece is described in the works by Baliak and Malgot [2], and Vlček [5].

On the basis of results obtained during the task solution it was concluded that the most frequent engineering-geological causes of failures in historic structures are geodynamic processes, above all slope movements and deformations, as well as weathering processes, erosion and carst development, or eventually simultaneous effect of several phenomena.

Slope movements (slides) result in failures of castle structures built on slopes with sensitive stability regime. The most frequent causes of failures are slope movement, of the type of gravitational loosening of the rock massif, rock falls and less frequent landslides.

Gravitational loosening of slopes affects chiefly structures, built on steep hills slopes or close to rock clifs. It is usually combined with intensive processes of mechanic weathering, in carbonaceous rock formations resulting in carts formation. Due to this gravitational loosening the networks of wide expansion joints occur in structures. In extreme cases transformations of creep motion into a falling movement may take place, which can break and pull down also a part of the structure. All castles in Slovakia, built on steep hills, are affected by gravitational loosening.

As to be able to identify the above mentioned of the bedrock of structures, a detailed evaluation of the bedrock of structures, a detailed of the bedrock of structures, a detailed description of structural parameters, aimed at the documentation of rock discontinuities, as well as of the decisive factor of stability. For solution of these tasks [3]. In evaluation of the castle rock massives we have interpreted altogether the geologic-tectonic structure of 26 transversal and 3 contour profiles. As example we present briefly the most disturbed rock massives of castles Súľov and Beckov.

The area of the Súľov castle extends on a rocky broken ridge in the N-S direction, created by Paleogene conglomerates, situated on Cretaceous flysch layers. In the E and W direction are rocky walls 60 m high with a $70\text{-}80^0$ dips, in some places even a 90^0 dip occurs. Intensive gravitational disturbance of the massif is presented in 3 detailed cross sections with data of the slope and discontinuities directions. An example of the profile DP-3 is presented in Fig. 2.

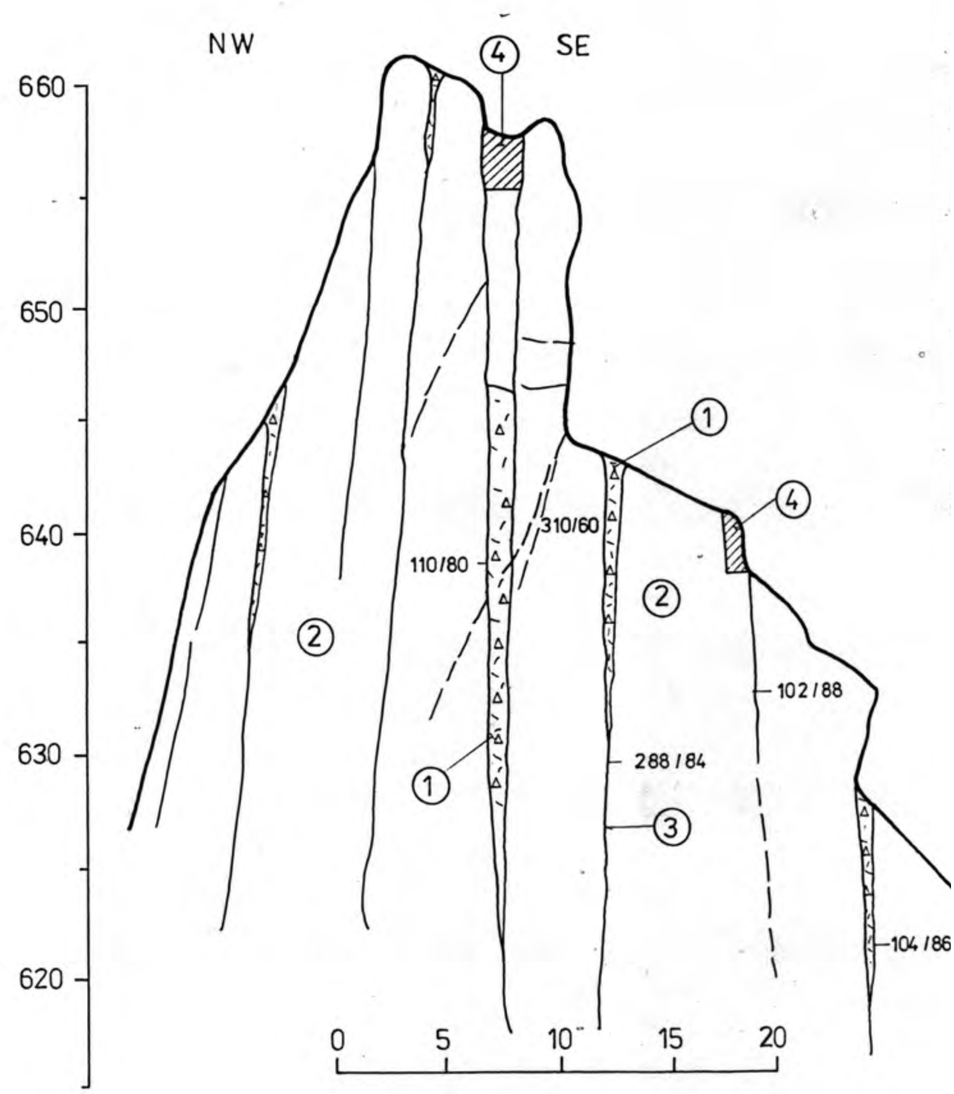

Fig. 2 Detail cross – section (DP-3) of the failrured massif of conglomerates
1- loamy-stony debris (Quartenary), 2 – Sulov conglomerates and breccias (Paleogene), 3 – tectonic lines and discontinuities with angles of dipping (a-approved, b-assumed), 4 – remnars of castle walls

The Beckov castle is situated on a prominent rocky cliff surrounded form N, NW, W and SE by rocky walls 20 to 60 m high, the average dips of slope being 70^0 to 80^0.The bedrock of the castle is composed by carbonaceous Triassic formations belonging to the Choč overlying nappe. These are tectonically disturbed thus creating favourable conditions for development of gravitational deformations, i.e. loosening and toppling. These processes jeopardize in several places the stability of the castle and a part of the eastern wall of the Northern palace falled down in the past.

Nine detailed profiles have been developed for detailed estimation of the rock massif. Examples of failures of the castle rock with parameters of the slope direction and discontinuities direction are presented in Fig. 3. Rock toppling, falling and slides are generally considered as catastrophic geological phenomena. They often induce crucial, failures on structures and even their destruction, though their occurence is rather rare. Rock falling happened, or has been jeopardizing parts of the castles Devín, Súľov, Považský hrad, Hričov, Beckov, Modrý Kameň and Kamenica (Fig. 4). Castle failures caused by sliding have not been recorded.

Weathering has been taking place in bedrocks of all Slovak castles. It is occuring mainly along the discontinuities surfaces, gradually causing their extension, thus contributing to intensive discruption of massifs, often with outstanding relief (i.g. Súľov, Hričov). With regard to deformation of structures the weathering processes influence negatively the contacts of walls with the bedrock due to various thermal dilatancy, bringing about changes of composition and characteristics of foundation rocks, thus causing development of failures. Frequently construction and sealing materials suffer from weathering processes.

Carst processes have negative impacts on extending failure lines of tectonic and gravitation origin. Carst development contributes to the total weakening of rock massifs. It occurs practically in all carbonaceous cliff on which castles were constructed, (investigated localities Beckov, Devín, Krásna Hôrka). The most pronounced failure of the rocky cliff may be seen in case of the castle Liptovský Hrádok, where due to carst processes the tectonic line had been extended into a cave and is passing from the massif also into the bedrock of the Tower, the walls of which are fractured.

Other geodynamic processes contributing to failures of rocky cliffs are erosion and transformation of rock. In addition to geodynamic phenomena an important role play groundwaters, dynamic effects, overloading and releasing [5].

3. ESTIMATION OF THE PHYSICAL CONDITION OF STRUCTURES AND RECOMMENDED CORRECTION MEASURES

Estimation of the present physical state of structures has been aimed - on the basis of failures character - at suggestion of restoration measures, which would provide timely protection and preservation of structures, prevent their proceeding destruction. The deformations were caused by damaging the static function of bearing elements of the structures. The failures are due to engineering-geological,

constructional, and antropogenous factors. Constructional deformations were induced by following factors:
- incorrect constructional solution,
- unsuitable quality of used constructional material,
- incompetent reconstruction interventions,
- low quality of handicraft works.

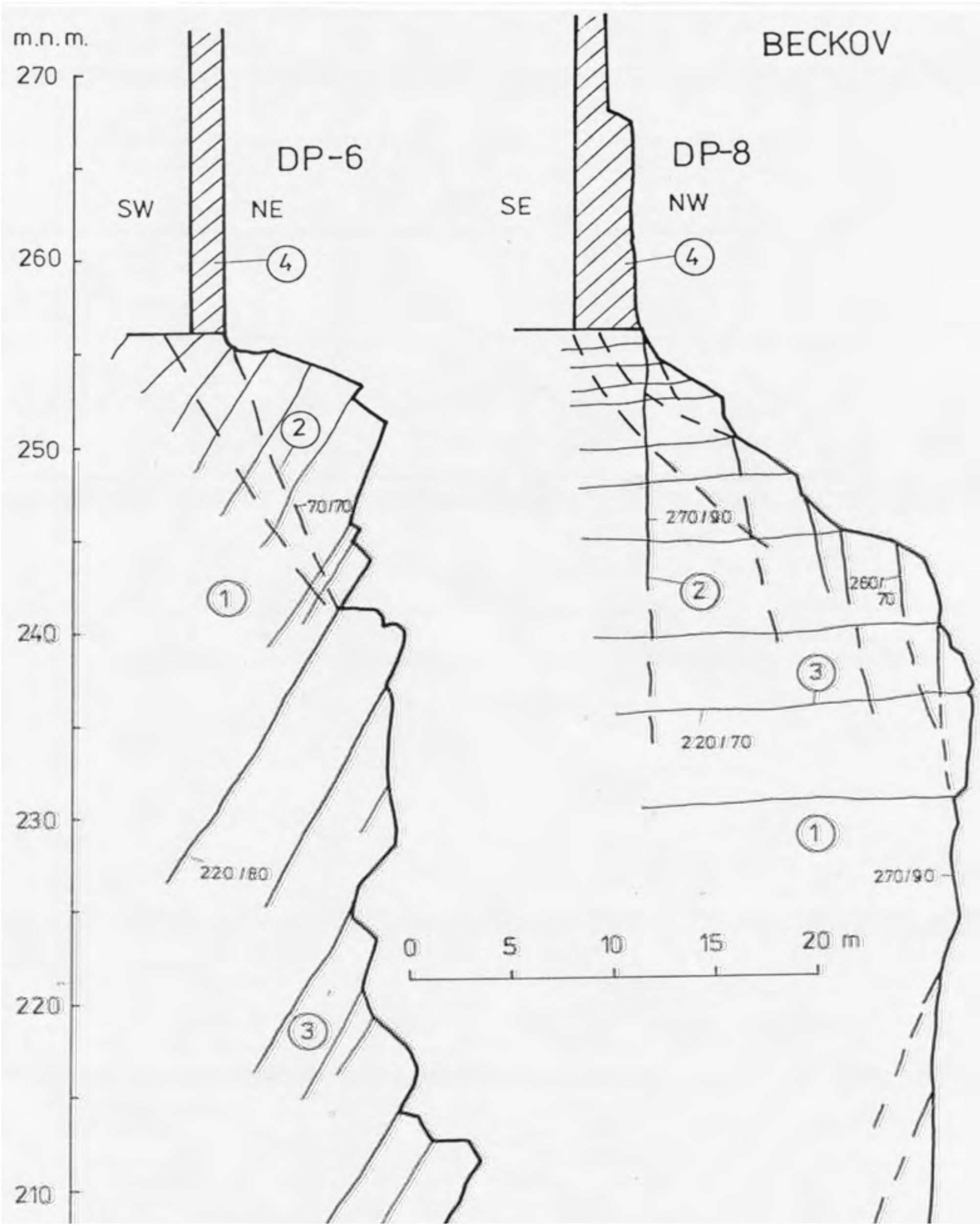

Fig. 3 Detail cross-sections (DP-6,8) throught the broken Beckov castle rock massif
1-masive limestones with dolomite interbeds (Upper Triassic), 2-important tectonic lines and discontinuities with data of dips, 3- bedding planes, 4- the castle walls

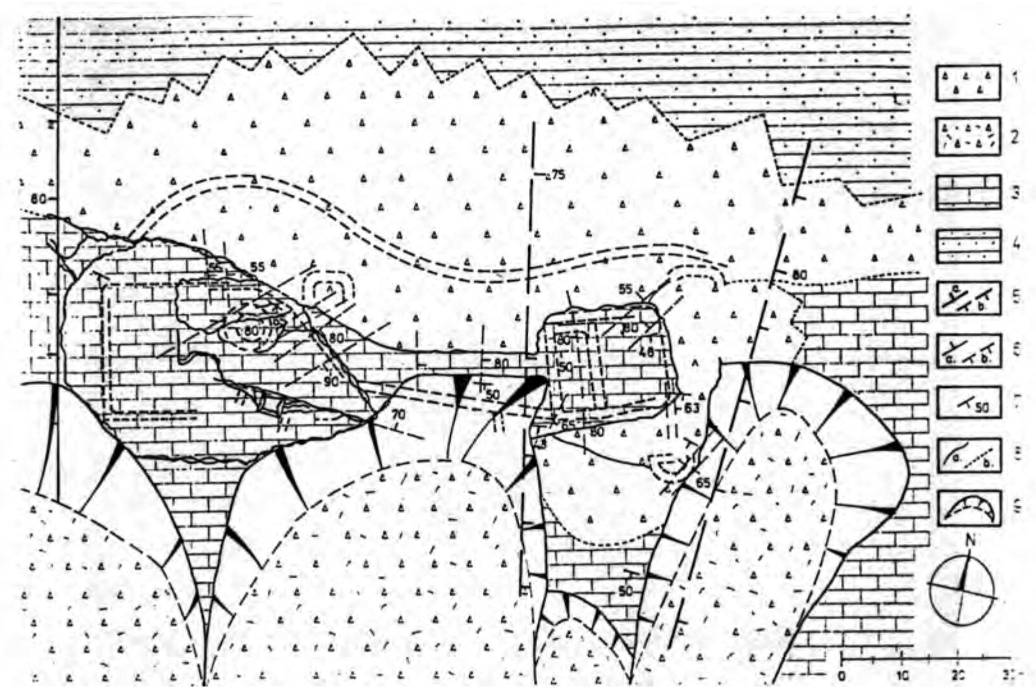

Fig. 4 A special engineering map of the Kamenica castle surrounding

1- loamy-stony debris, 2- debris of rock-falls (1-2 Quaternary), 3- crinoide limestones (Jurassic), 4- limy sandstones, sandy limestones, claystones (Paleogene), 5- important faults with angle of dip (a-approved, b-assumed), 6- important cracks with angle of dip (a-approved, b-assumed), 7- strike and dip of stratas, 8- geological bondaries (a-approved, b-assumed), 9- main scars of rock falls

Unambiguous specification of the "diagnosis" of structural deformations is extremely complex, sometimes even impossible. The castles have a rich history of constructional development, experiencing many rebuildings, reconstructions, additional building and adaptations, with consequent intervention into the static functions of respective parts of the structure.

Present physical state of studied castles may be considered as follows:

- good technical state, the complex of structures is used as museums, galleries, etc. - Bojnice, Krásna Hôrka,
- structures in a relative good condition, provided with roofs, with some unrestored parts: abandoned, without custod - Bzovík, Halič,

– partially in ruins without restoration - Liptovský hrádok, Modrý Kameň, Hričov, Považský hrad,
– completely in ruins - Súľovský hrad, Hajnáčka, Kamenica.

The essence of restoration measures is the geotechnical sphere. It consists of restoration of the bedrock of structures, foundation constructions, supporting walls and underground structures. It was recommended strenghtening of the bedrock by means of grouting, cementing, and sealing according to the foundation conditions may be thoroughly investigated with the aim to complete the survey and accomplish the static analyses (Fiľakovo, Hričov, Považský hrad), as to be able to draw up a complex, detailed project of restoration works, or to complete the proposal of restoration measures.

Emphasis is to be placed on geotechnical restoration of rocky walls of cliffs (Beckov, Devín, Liptovský Hrádok, Fiľakovo). Anchors have been recommended in this case. For determination of anchorage forces application of the theory of solid rock blocks is recommended, considering the parallel discontinuity surfaces of general direction (especially in case of the Beckov castle). For holding of separate blocks anchorings (bar anchors) are recommended combined with stabilization treshold. Breakings in rock walls must be sealed.

As an example of restoration and preservation of the structures of a castle and geotechnical restoration of rocky walls of rock massifs may be considered the Devín castle [1].

Devin castle ruins belongs to the national cultural heritage and protected natural produce. Protective measures on Slavic castle complex Devin means safeguard of the castle ruins as well as a remedy of the castle rock as a technical unit.

The most strenuous remedy works have required protection of the renaissance tower Mníška (Fig. 5). Weathering and technical intervention have shaped very complex from of the rock tower on which a keep is built up. It is restricted from all sides by tectonic planes. The open continuous discontinuity dividing the rock into two parts was the most dangerous. The rock was threatened by falling down along discontinuities. Rock blocks were pinned together into a monolith by the set of pre stressed anchors arranged into a fan [4].

Among the other remedy works it was performed strengthening of the rock under SE walls of the Upper castle (Citadel) buildings. In this section it was not protected distinctively separated rock block. It is supposed stabilization of the rock block by anchors fastened to the fresch rock. In respect to separation of the rock block anchors position must be considered to avoid a lateral movement. Attention needs also a part of the rock on the E-SE under the Polygonal bastion as there is evidence of slight movements along two distinctive tectonic discontinuities. Its stabilization by anchoring should be made.

The other parts of the castle rock are considered to be stable with no indication of deformation. The wall foundation on contact with rock is necessary to unite into one monolith (cracks fill out, injection) to impede weathering and rock loosening under the foundation. It is inevitable for long lasting stability. The rock walls are to be cleaned up of small loosened block, ledges and loosened rock pa

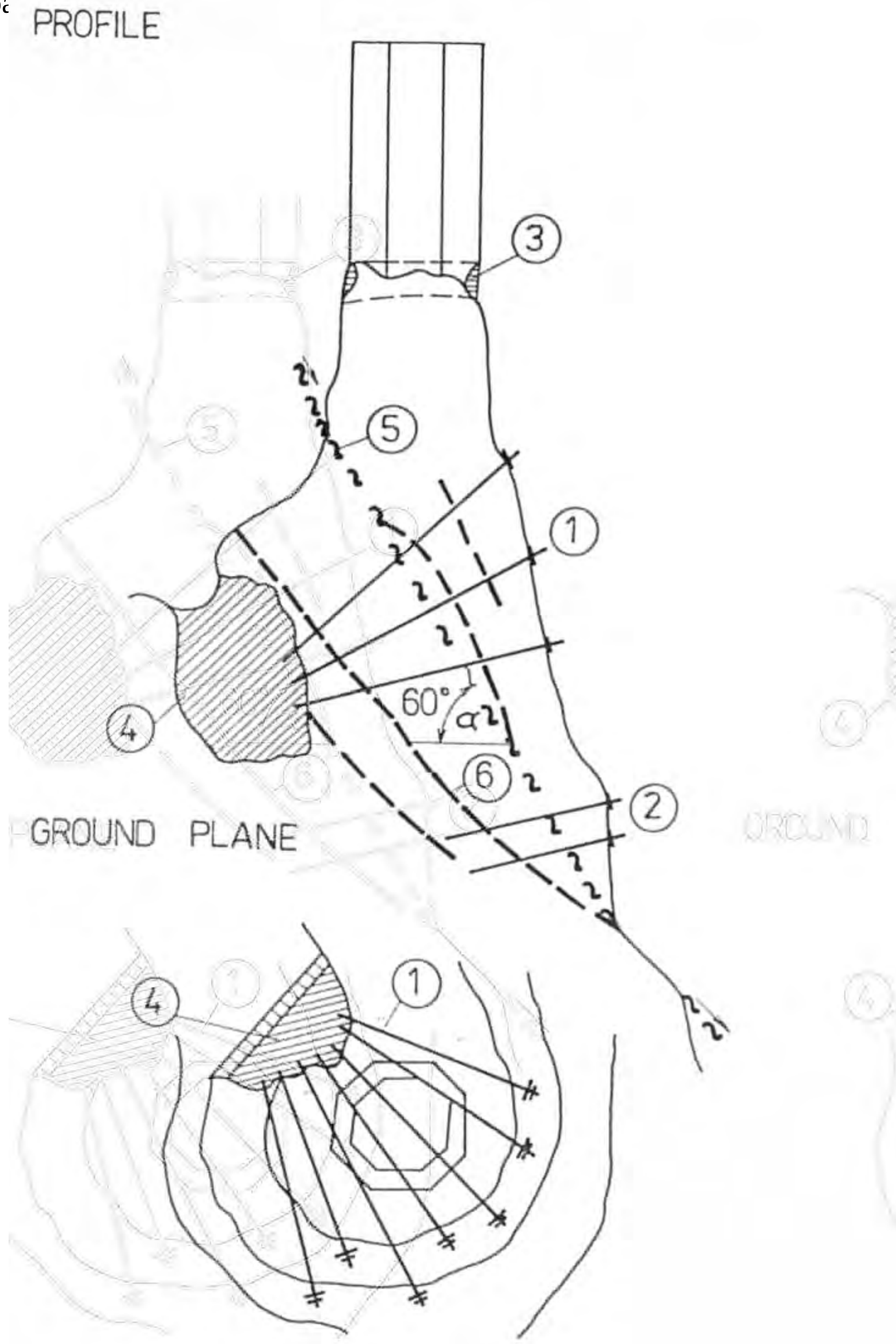

Fig. 5 Remedial works on the rock tower Mníška

1- press – strained bar anchors with a doubled binders, 2- support anchors,
3- armed concrete rings, 4- filling of the caverne, 5- most danger discontinuities,
6- other discontinuities

The castle buildings are reclaimed and preserved. Their physical condition is considered to be rather well. However, distinctive failures occur on some wall parts due to low quality of craftsman works.

4. CONCLUSION

The study of the engineering geological reasons of the failures of medieval castles has an important influence for solving of reconstruction works. For complete restauration of the castles is very important a team work of engineering geologists, archeologists, architects, historics a.s.o.

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CHAPTER V

RESTORATION
and
PRESERVATION TECHNIQUES
in
ANCIENT STRUCTURES
and
HISTORICAL SITES

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80750 YILDIZ, İSTANBUL, TURKEY
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CONSERVATION OF THE YESIL TURBE IN BURSA

Z. Ahunbay , B. Altınsay, F. Çılı, A. Ersen, E. Gürdal, K. Kuzucular, G. Tanyeli
Istanbul Technical University

ABSTRACT

The tomb of the Ottoman Sultan Çelebi Mehmed Han is known as Yesil Turbe, “the green tomb”, due to the colour of the faience tiles decorating its exterior and interior surfaces. The mausoleum is a landmark for Bursa, the capital of the Ottoman state between 1326-1365. Built in 1421, the tomb was maintained well and was in a good state of preservation until a strong earthquake damaged it in 1855. A Frenchman, Léon Parvillée was invited in 1863 to overcome the difficult situation. The restoration in 1864 was followed by other repairs in the twentieth century, because the glazed tiles used for repairs were not as good as the originals. The deterioration of the new facing as well as the lack of maintenance of the roof have caused serious problems. To save this significant monument from further damage and guarantee its future, the General Directorate of Waqfs initiated a conservation project. A multidisciplinary team was formed at Istanbul Technical University, Faculty of Architecture to study the structure and its problems. In 2000, the monument was inspected thorougly and appropriate measures for its conservation were proposed .

1. INTRODUCTION

Surrounded by tall cypress trees, Yesil Turbe stands majestically on a hilltop and is visible from many points of Bursa. It is part of an early Ottoman architectural complex which is significant for its artistic and historic value. The tomb is octagonal in plan; a dome with a diameter of approximately 15.20 meters covers the interior space. Under the floor of the mausoleum, there is a crypt where the sultan and his family are buried. Haci Ivaz bin Ahi Bayez t was the minister in charge of the construction which was completed in 1421. The tomb with its splendid ceramic decoration is similar to the contemporary Timurid tombs in Samarkand. The surviving original ceramics in the mosque, madrasa and tomb of the Yesil Complex have major significance for fifteenth century Turkish art. The

Fig. 1 Yesil Turbe and the surrounding area in the 19 th century
(Photo: Sebah and Jouaillier. Courtesy of DAI Istanbul)

glazed bricks which covered the exterior surfaces were shorn off by the earthquake in 1855. Photographs from the second half of the ninetenth century show the state of the tomb after the earthquake (Figure 1) and give an idea about the extent of the losses to the exterior surfaces. The north façade and the entrance to the tomb suffered severely from the tremors (Figure 2). Only the northeast façade of the tomb survived the earthquake with relatively minor damage.

2. RESTORATION OF Y E S I L TURBE IN THE NINETEENTH CENTURY

The big cracks in the dome and the major losses to the decorated surfaces discouraged the Ottomans. Some thought that the monument was beyond restoration; they proposed to demolish the tomb and build it anew. For some years the monument was left desolate. In 1862 Ahmed Vefik Pasha, a man of letters was appointed the mayor of Bursa. During his search to find the experts to save the damaged monuments, he was advised by M. Ritter, a French engineer to call on architect Léon Parvillée. Thus Léon Parvillée came to Bursa in 1863 and restored several monuments, among them the mosque and tomb of Yesil Complex [3]. He made a survey of the mausoleum and its decorative features. He ordered copies of the missing tiles to be made at Kütahya workshops. He

Fig. 2 Yesil Turbe during restoration in the nineteenth century
(Photo: G. Berggren. Courtesy of DAI Istanbul)

restored the entrance façade which had lost much of its tile decoration, covering the surfaces facing the north with plaster and put up a small canopy over the entrance. Within the entrance niche, surfaces which had lost their original tile decoration were plastered and painted over with the patterns of the missing tiles. Although Wilde describes the paintwork as of inferior quality [4], the approach

Fig. 3 Yesil Türbe after Léon Parvillée's restoration
(Photo: Abdullah Frères. Courtesy of DAI Istanbul)

of Parvillée to solve the problem seems practical and suitable for the time. In his work [3], he does not explain how far the work extended, whether he was able to complete the restoration of all the exterior surfaces. We know that his restoration was not long lasting; in 1904, the monument underwent another repair under supervision of architect A. Kömürcüoglu. The use of thin ceramics to cover the areas which had lost their original revetment created a discordance when the original glazed tiles were partially preserved on the same façade [2]. Although very rational from the point of view of conservation of original elements, aesthetically this was a solution not appreciated by all.

3. RESTORATIONS IN THE TWENTIETH CENTURY

Further repairs were carried out between 1941-1943 ; architect Macit Kural was in charge of this restoration. He has a long article [2] about this restoration but unfortunately he did not publish all the documents related to this intervention. He claims that the purpose of the restoration was to revise the mistakes of previous restorations; especially problems arising from the foreign patches on the façades. He removed the damaged tiles from the exterior surfaces, exposing the masonry walls. Photographs which show the masonry during restoration give an idea about the construction technique of the load bearing walls. It is unfortunate that he did not prepare a detailed survey of the monument before restoration . We do not know about the extent of damage at the time and there is not enough information about the interventions which took place. During this restoration some of the details installed by Parvillée were removed. Kural removed the canopy, and replaced the splayed corner of the entrance niche with an attached column. All the plastered surfaces on the north elevation of the entrance block were painted with a light green color. On the other elevations, the surfaces missing their glazed tiled surfaces were covered with tiles produced in Kütahya. To compensate for the difference in the thickness of the ceramics, the new tiles were backed with a thick cement mortar filling, without considering about the problems it would cause it the future.

In recent years, the tomb has been neglected and a lot of damage is caused by lack of maintenance. Some of the twentieth century ceramics have fallen out; it is possible to see the cement mortar backing in areas which have lost their tile covering. The latest repairs have not been very careful about the architectural integrity of the monument. On the west façade, the surface is covered with modern tiles; without paying attention to the presence of decorative features like the window pediment. Inside the tomb, the twentieth century repairs with Kütahya tiles have deteriorated in areas where there rising damp or penetration of water through the masonry have damaged them. It is possible to differentiate between the old and the modern tiles by the colour of the clay, the thickness of the tiles and the texture of their backs. The clay used in the original tiles is red ,

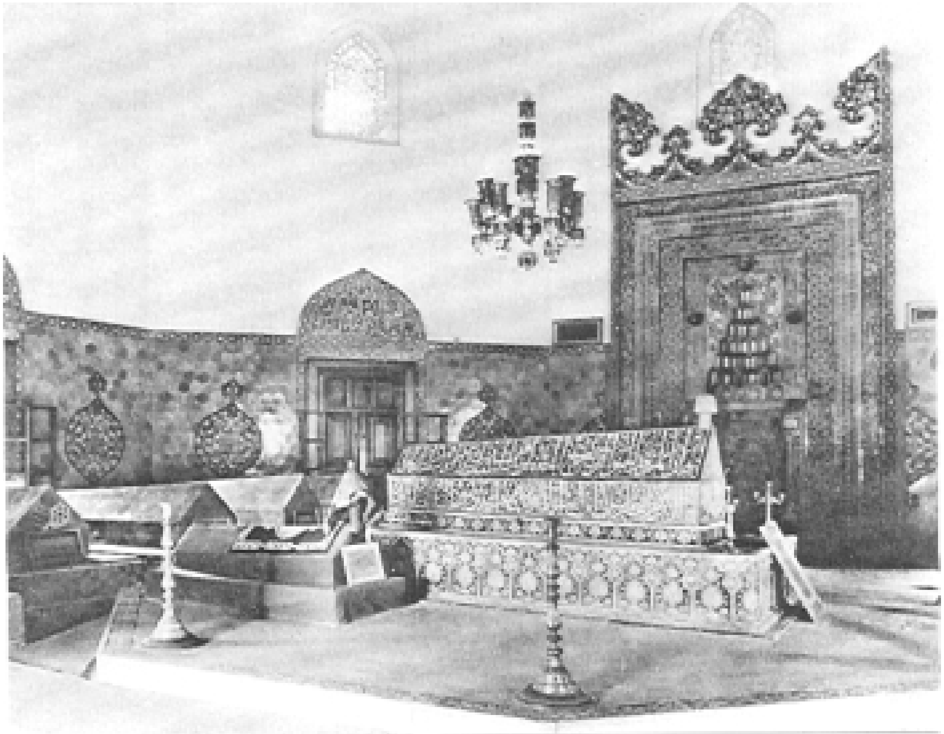

Fig. 4 Interior of Yesil Türbe after M. Kural's restoration
(Photo: A. Gabriel)

while the color of Kütahya ware is pure white. The older tiles have inclined sides and their backs are flat.

4. ASSESSMENT OF DAMAGES

Repairs carried out without paying due attention to the constructional properties of the monument have caused serious damages. Especially the use of cement mortar for fixing modern tiles has created a lot of salt migration problems. Rising damp, penetration of water from the roof and through the walls have activated the salt inside the Portland cement. The movement of salts and the wetting of the binding mortar has resulted in swelling and also detachment of the tiles on the inner surfaces. The penetration of water through the top of the wall and the roof has encouraged growth of algae on the interior wall surfaces.

There are several cracks on the mihrab. It is possible to distinguish several cracks on the other walls as well. But whether they are only cracks on the plaster, or they go deep into the masonry is hard to tell merely by observation.

The structure was examined by Professor F. Ç l for its stability. Professors E. Gürdal and A. Ersen studied samples from different parts of the monument to determine the material properties of the mortars and ceramics. Damages and alterations to the building and its surfaces were inspected in detail and recorded by conservation architects B. Alt nsay, I. Durukan and Z. Eres. Damages to timber and stone elements as well as tile decoration were studied in detail. By the help of a legend, humid areas, surface erosions, efflorescence, algae growth, dirty surfaces, cracks, missing, semi- detached, bulging, cracked and disintegrating tiles, as well as damages to wooden elements like the door and window shutters were examined and indicated on plans and elevations (Fig. 5,6).

5. PROPOSALS FOR IMPROVEMENT

Rising damp is observed in the lower parts of interior walls. The drainage of water from the base of the monument and the lowering of the water-table might help to dry the crypt and walls. To improve the ventilation of the crypt is of paramount importance. To provide a reasonable access to the basement and to arrange a door which allows for free movement of air will reform the climatic conditions of the basement. Moreover, it will be possible to carry out regular maintenance of this part of the monument and to monitor the behaviour of the structure. To provide for this entrance, a small passage has to be excavated on the eastern side of the mausoleum.

At present the floor of the interior is covered with square tiles made of a concrete mix. During A. Gabriel's studies, the floor had hexagonal brick tiles, as is typical of the period [1]. The restoration of the floor using hexagonal bricks is proposed.

The monument needs urgent intervention to stop migration of salts from the exterior walls towards the interior surfaces. The second step would be to clean and consolidate the interior surfaces. Especially the detached areas of tile decoration have to be handled with utmost care. The removal of salts from the masonry will take time but it is essential to remove them as much as possible before fixing the tiles from the detached zones. To cover the areas which have lost their original tiles, is an aesthetic and technical problem. In an earlier restoration, probably the one by Parvillée, areas which had lost their original tiles were plastered with khorasan mortar and painted in a matching blue. Hexagonal patterns delineated with a sharp tool help to simulate the lost tiles. If areas still having this type of intervention are still in good shape, they may be preserved as part of the history of the building. However, if the percentage of

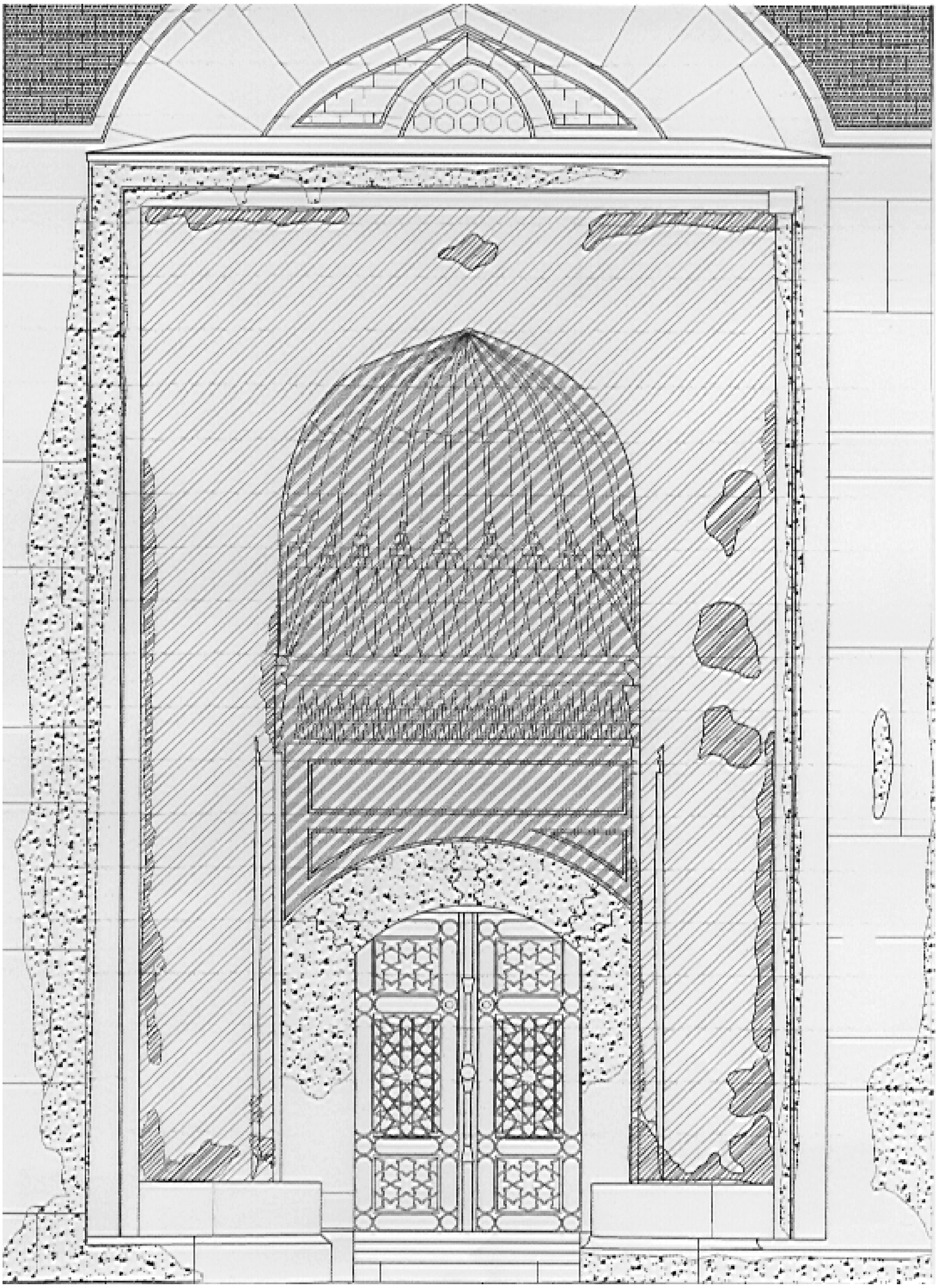

Fig. 5 The damage assessment of the entrance façade

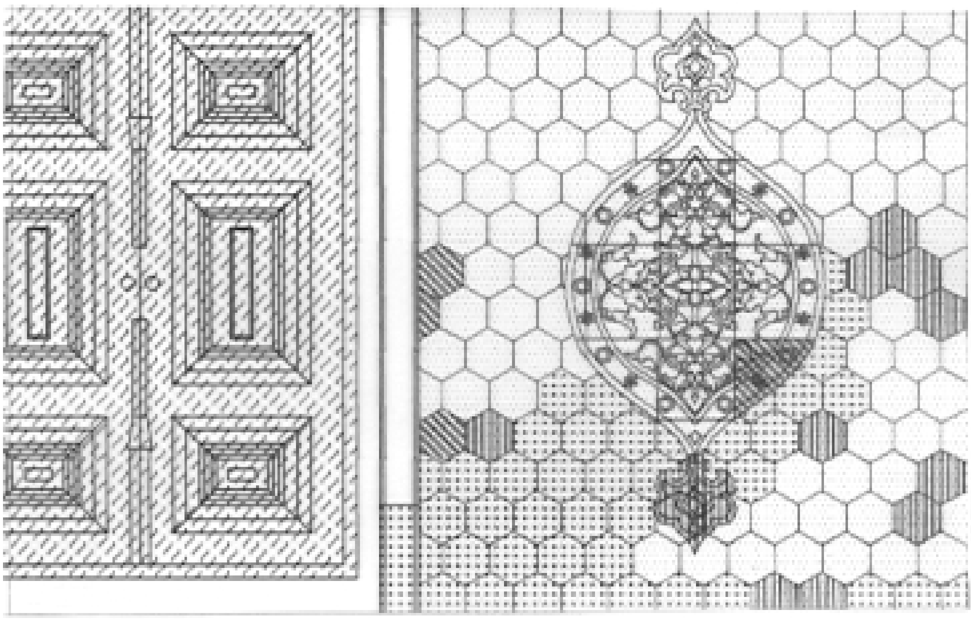

Fig. 6 Damage assesment from the west wall of the interior

plastered areas are increased, the grandeur of the interior will suffer from the change. For this reason, replacement with tiles has a priority.   To succeed in restoring the aesthetic unity of the interior, it is necessary to find good quality tiles which can harmonize with the originals in every way.

It is not certain whether the present plasters on the interior surfaces have layers with traces of earlier decoration on them. To discover some traces by inspections can contribute a lot to our knowledge of the history of the monument. In order to be able to decide on structural interventions, Prof. Çılı proposes to remove the plasters along the cracks to control their width and depth. This operation which has to be done after a sounding for decorative layers, will provide the data to evaluate the safety of the structure and measures can be taken accordingly . After these researches and possible interventions, the stains from efflorescence and algae must be removed carefully to attain homogenous interior surfaces.

The damaged areas of the plaster on the entrance façade will be repaired by using khorasan mortar. The nineteenth century painted decoration on plaster surfaces of the entrance niche needs careful cleaning and conservation. The remaining tiles from the vaulting must be cleaned and consolidated carefully. A canopy   is proposed to protect the entrance niche from northern winds and rain. Since the original form of the entrance canopy is not known and Parvillee's canopy was very much in the style of the nineteenth century, we chose to propose a simple one.

To succeed in covering the exterior surfaces with durable glazed tiles is a major issue which could not be mastered in the past. For a long-lasting restoration, it is essential to get proper materials; materials of the same size and similar quality. The need to get glazed tiles with matching color and physical properties has to be stressed. To remove all the modern accretions; the cement backing and the modern tiles will require a lot of time and expert supervision.

The cement plaster on the drum of the dome has to be removed and replaced by khorasan mortar. During this operation it will be possible to examine the masonry of the drum and obtain more information about its condition. To harmonize with the color scheme of the exterior, it is suggested to paint the drum as it is at present.

To give the final touch to the interior and exterior, all the glazed tile surfaces, the mihrab, incription panels over the windows have to be cleaned and consolidated. The gilding of window bars and retouching of some of the gilded tiles, repainting of inner cornices may be considered to please the public.

6. CONCLUSIONS

To correct the mistakes of previous restorations in order to save an important monument is a major undertaking. Methods developed for appropriate preservation techniques need to be applied to the present case. Respect for the historical repairs is due only when they were done with proper materials; cement groutings and fillings will continue to create problems which might eventually destroy the remaining fifteenth century tiles. To intervene with soft methods, to consolidate the weak elements, improve protection against rising damp, to continue monitoring and maintenance will help to eliminate the causes of further damage.

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

A STUDY FOR CONSERVATION OF THE MURYONG ROYAL TOMB BY THE GEOTECHNICAL METHODS

M. Suh, M. Koo, and S. Choi
Nondestructive Research Lab. of Cultural Property, Kongju National University,
Kongju, Chungnam 314-701, Korea (mcsuh@knu.kongju.ac.kr).

ABSTRACT

A geotechnical research including measurements of movement of the wall-structure, monitoring of groundwater level, non-destructive geophysical investigation was conducted to workout a countermeasure to conserve the Muryong Royal Tomb which is the most extinguishable cultural property of Korea. The movement of the wall-structure was measured by using the tiltmeter system. The movement of the tomb in the rainy season is measured to be twice that in the dry season. Acceleration of the movement is caused by a sudden change of temperature inside the tomb as well as the rainfall. Thus, it is necessary to prevent the water that infiltrates into the subsurface around the tomb and to keep the constant temperature of the inside of the tomb. The major pathway of infiltration is cracks found in the quicklime layer above the tomb. The cracks are mostly concentrated on the NW and SE sides of the tomb. It indicates the existence of tensional stress with direction to NW-SE, which coincides with the direction of movement of the wall-structure. As countermeasures for maintenance and conservation of the tomb, it is suggested to refill the front chamber of the tomb as the original state before the excavation and to reinforce the quicklime layer by the mud-layer method.

1. INTRODUCTION

The Royal Tomb of King Muryong, the 25th king of Bakjae Kingdom that is one of the ancient Korean dynasties, was discovered and excavated in 1971 (Figure 1). A great number of historical relics found in the tomb provided a new epoch-marking information for the study of Bakjae Kingdom's history. The tomb is located in the city of Kongju, one of the capitals of the Kingdom, located in the middle part of Korea. King Muryong (AD 501-523) died in 523 and was buried in the tomb in 525. It was reopened in 529 for the burial of his queen. Thereafter, the tomb had been left undisturbed until the discovery. After the excavation, the tomb was covered by a waterproof protection layer to prevent groundwater infiltration into the tomb and the opening part of the chamber was reconstructed to open the tomb to the public.

Recent investigations on the tomb performed for conservation and restoration purposes revealed that the tomb had a serious structural problem (Suh, 1997). The movement of the wall-structure of the tomb was monitored by measuring the slope changes using the tilt-meter system, and it was found that the tomb consisting of the four walls was moving toward the south. This movement is due to the structural instability caused by the opening of the tomb at the southern side at the time of excavation. Long-term monitoring of the tilt-meter system also showed that the movement was reinforced especially during the period of rainy season. Thus, the groundwater infiltration is considered to cause the structural instability due to decrease of the effective stress as well as the problem of groundwater seepage into the tomb.

This paper briefly describes some of the geotechnical researches conducted to solve the structural problem of the Muryong Royal Tomb.

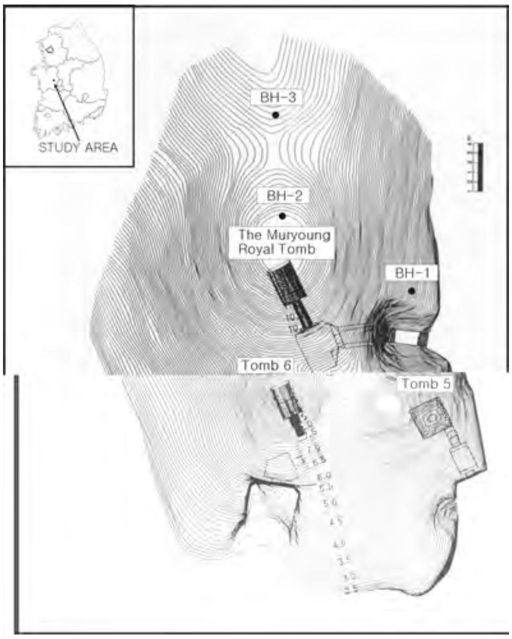

Figure 1. Location map of the Songsanri tomb site including the Muryong Royal Tomb. Three boreholes are located around the tomb.

2. THE MOVEMENT OF THE WALL-STRUCTURE OF THE TOMB

2.1. Method of measurements

The tilt-meter system including the modem and the personal computer devices is used to measure slope changes of the wall-structure of the Muryong Royal

Tomb. The tilt-meter system is made by AGI (Applied Geomechanics Inc.) of the United States. The two-pivoted tilt-sensors were installed in four places inside the tomb to monitor movements of wall structure (Figure 2). The voltage coming every 15 minutes from the tilt-sensors through the two signal conditioners was amplified and the data indicating the slope changes was recorded on the data logger. The recorded data was automatically transferred to the computer in the laboratory through the modem on the real-time basis.

In general, the tilt can be affected by the temperature, the pressure of the atmosphere, the rainfall, and the change of groundwater level (Kunpel et. al., 1988). Therefore, they were monitored together with the measurements of slope change of the wall-structure.

The movement of the wall-structure was measured by two directional components, the forward and backward direction and the shear direction to the wall. The data on measurement of slope change of wall-structure during the measuring period is shown on Figure 3.

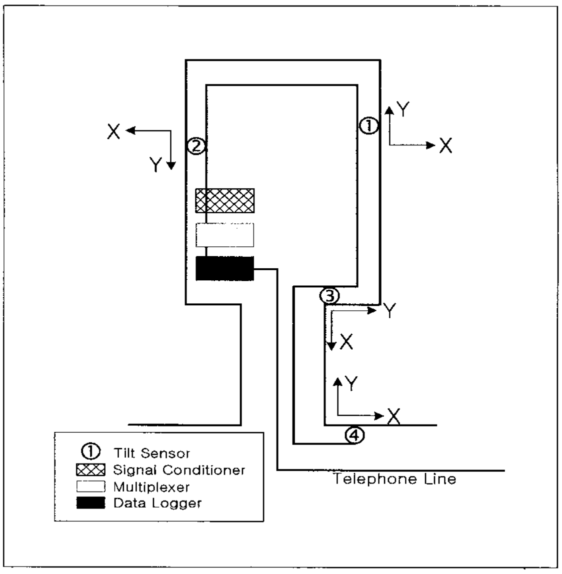

Figure 2. Distribution of tilt sensors and their measurement directions.

2.2. Movement of the wall-structure

Out of four tilt-sensors placed in the Royal Tomb, three sensors are used for measurement since July 14, 1996, and the fourth one was additionally installed on February 14, 1997. It needed some time for the adhesive agent to harden. Thus, after the adhesive agent hardened on the wall, the sensors and the wall-structure were determined to have moved together.

As shown in Figure 4, the tilting of the sensor-1 placed on the east wall of the tomb during the period of the measurement are 968.99 μradian toward the southeast, and the sensor-2 placed on the west wall moved 677.88 μradian toward the southwest, and the sensor 4 on the south wall in the passageway of the tomb moved 1688.74 µradian toward the southwest. The sensor 3 placed on the south wall of the inner chamber of the tomb shows the biggest movement. However, it was recognized later that the brick on which the sensor was placed was not so firm and concrete that the movement was interpreted as the movement of the brick, not as that of the whole wall structure.

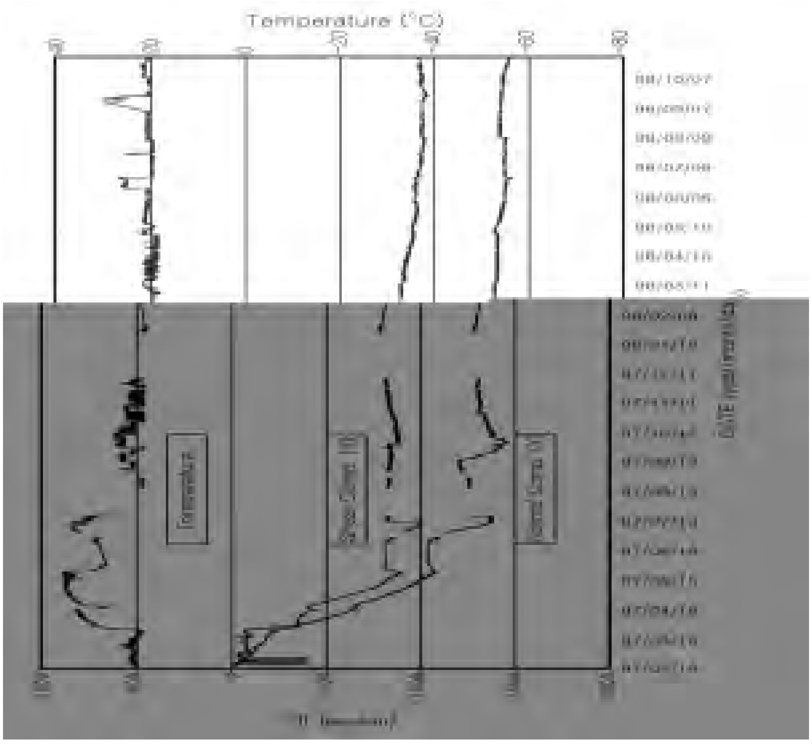

Figure 3. Tilt monitoring on sensor 4 installed on south of the passageway to the inner hall of the tomb.

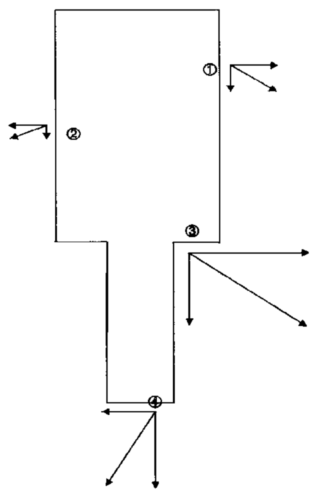

Figure 4. Total tilting vector measured from October 1996 to September 1997.

The sensor 4 placed on the south wall of the passageway of the tomb plays an important role from the safety point of view, and it was found that the normal component of the sensor 4 incessantly increased toward the south. As shown in Figure 4, all of the sensors show the movements in the same direction toward the south. This means that the movements were caused not just by the bricks on which the sensors were placed, but by the structural instability of the walls. Another directional similarity measured in all the sensors is the outward movement with respect to the walls. These movements are thought to indicate that the tomb has the structural safety problem, which is resulted from the empty space after the excavation.

A pictorial comparison of some bricks of the west wall clearly indicates that the shear component of the wall movement is acting toward the south. According to the drawing of the inside of the tomb made in 1972 just after the excavation (Figure 5a), the bricks numbered from 1 to 5 was located perpendicularly between the bricks placed horizontally in the upward and downward. However, on the photo taken in 1997, the same bricks are shown leaned toward the south (Figure 5b). This is consistent with the tilt measurements as shown in Figure 4, and it can be predicted that the movements has been progressed slowly till now since the excavation in 1971.

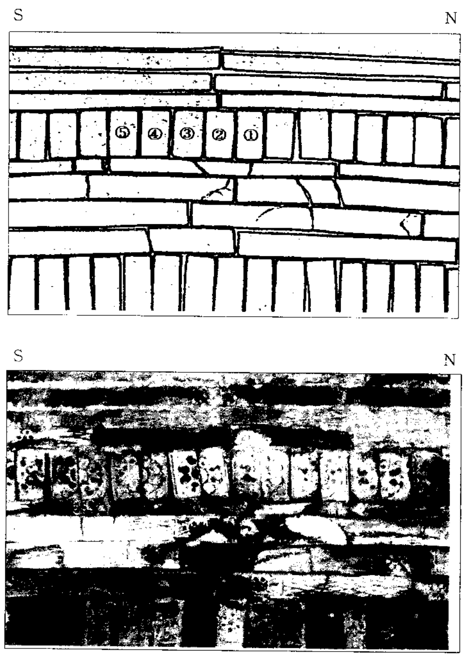

Figure 5. (a) Drawing of bricks in the western wall of the Muryong Royal Tomb drawn in 1972; (b) Photo of the same bricks taken in 1997.

2.3. Movement of wall-structure and the rainfall

Comparing the measured movements of the wall-structure to the data on the rainfall, it is recognized that the movements are mostly subject to the rainfall. Figure 6 is a plot showing the movements of the walls versus the amount of precipitation. It can be seen in the figure that the movement was reinforced especially during the period of rainy season. The tilt-movements in the period with the heavy rainfall are at least 5 times greater than the movements in the period with no rainfall. Thus, the groundwater infiltration is considered to cause not only the problem of groundwater seepage into the tomb, but also the structural instability due to decrease of the effective stress.

Changes of groundwater level in the wells around the tomb was measured, also (Figure 7). The groundwater level measured in BH-1 during the heavy rainfall period fluctuated from 6.5 to 7.5 m below the surface and 5.7-6.7 m below the floor of the inner chamber of the tomb. However, the groundwater level in BH-2 located at the north of the Muryong Royal Tomb was 30-40 cm higher than the floor of the inner chamber during the heavy rainfall period. Furthermore, according to the analysis of the images of GPR (Ground Penetration Radar) on the structure of the soil inside the grave mound, it was found that the quicklime layer of the upper part of the passageway of the tomb had cracks in several locations. These cracks are the ones where the water-leakage happened into the inside of the tomb.

During relatively heavy rainfall periods, the infiltration of the rain into the unsaturated zone increases the pore pressure, and it results in expansion of the ground around the tomb and decrease of the effective stress of the soil. For this reason, the movement of the tomb structure in rainy season is much greater than that in the dry season, and so a serious structural problem could exist in the tomb especially during the rainy season in which the tomb might be exposed to the groundwater infiltration.

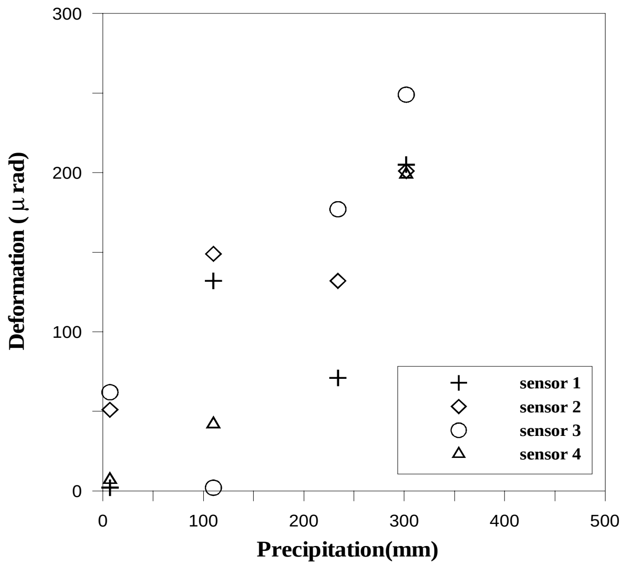

Figure 6. Movement of the wall-structure versus precipitation.

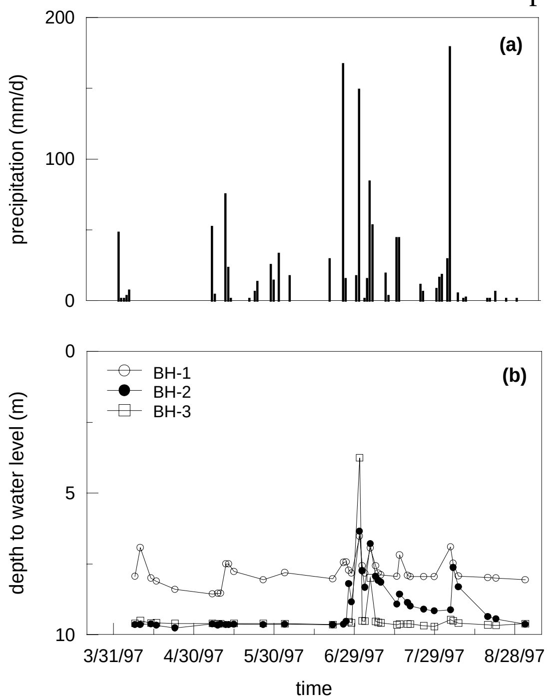

Figure 7. Changes of groundwater level in the boreholes in response to precipitation (modified from Suh and Park, 1997).

2.4 Temperature and movement of tomb-structure

With the purpose to find out the relationship between the temperature and the movement of the wall-structure, we analyzed time sequential data of temperature and tilting of wall-structure in N-S direction measured from March 25 to May 28, 1997 (Figure 8). When a sudden change of the temperature from 20 to 33 happened due to the operation of the dehumidifier in the tomb, southward movement toward the direction of the front chamber occurred. The ratio of the movement at that time was much greater than that at the time when the temperature inside the tomb remained constant. While the wall-structure moved toward the front chamber at the ratio 0.43 mm/m/yr during the period of constant temperature, it did at 6 mm/m/yr during the period of sudden rise of temperature.

When the risen temperature decreased again, the wall-structure showed a slight movement toward the inner chamber, but never went back to former state before the temperature changed. Comparison of the tilt at 24 before the temperature increase (122μrad) to the tilt at 24 after the temperature decrease (645μrad) indicates that the changed movement of the wall-structure never goes back to the original state but remains still. If the movement according to the increase of the temperature is the movement of the sensor itself, it should have been recovered to the former state when the temperature decreases again. This means that the wall-structure of the tomb has gone through a permanent deformation toward the south.

Therefore, it is considered that the devices changing the temperature inside the tomb cause the danger to the safety of the structure. Thus, it is very important to keep a constant temperature inside the tomb for the safety of the tomb.

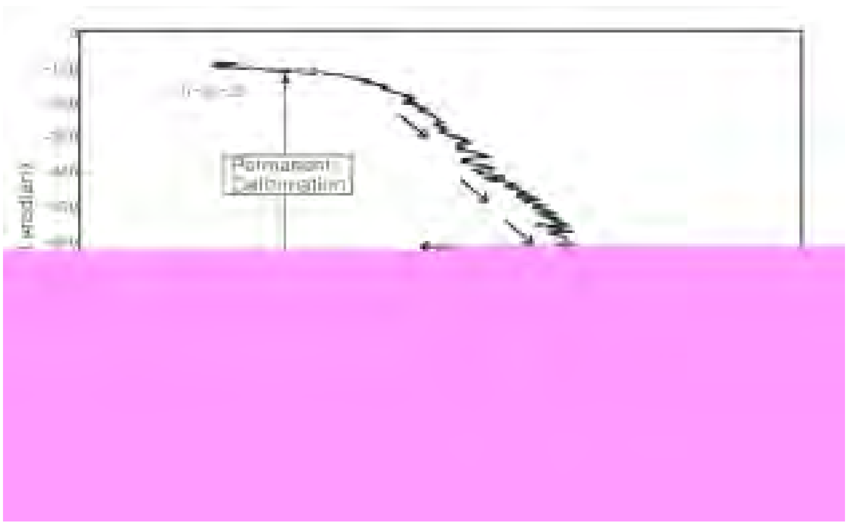

Figure 8. Hysteresis movement of the front wall to the change of temperature.

3. PROBLEM OF GROUNDWATER SEEPAGE

As described above, the movement of the wall-structure was observed to occur more severely during the rainy season. Thus, the rain infiltrating the surface around the tomb causes not only the problem of groundwater seepage into the tomb, but also the problem of the structural instability by accelerating deformation of the wall-structure.

It is assumed that there are two possible pathways of groundwater infiltration into the tomb. One is the downward groundwater movement through cracks in the protection layer in the upper part the tomb constructed after the excavation. The other is groundwater flow from the upgradient area located in the north of the tomb to the downgradient area.

It is important to evaluate these two potential pathways of groundwater infiltration. In order to identify the pathway for the infiltration due to the topographical gradient, an artificial recharge test was conducted by installing a water tank with rectangular plywoods on the northern part of the tomb (Koo and Suh, 1999). The tank was filled with water from the fire engines for the recharge test to be conducted.

During the recharge test, the groundwater seepage inside of the tomb was not observed. From the analysis of water level changes measured at the wells around the tomb, the wetting front showed to be located more than 4m away from the tomb. Thus, the major pathway of the groundwater seepage observed inside the tomb is due to the cracks distributed on the layer installed for prevention of water-leakage on the upper part of the tomb. Therefore, it is considered to be more urgent to reinforce the existing quicklime layer for prevention of water-leakage.

An investigation of the cracks on the quicklime layer constructed in 1991 as a protection layer was conducted by removing the topsoil layer. Figure 9 shows distribution of the cracks found on the surface of the quicklime. It shows that a number of cracks are distributed around the tomb, and they occur extensively on the northwest and southeast sides. Especially, the distribution of cracks developed particularly along the east-west direction coincides with the structurally vulnerable point connecting the inner chamber and the passageway of the tomb. Thus, development of cracks is thought to have the relationship to the structural deformation of the tomb.

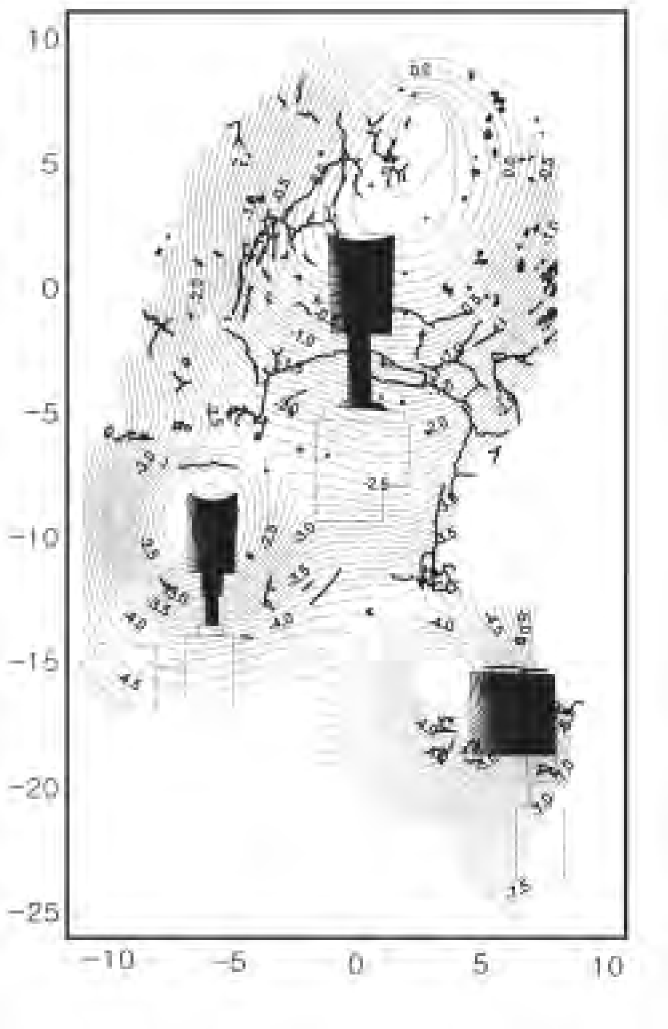

Figure 9. Distribution of cracks found on the surface of the quicklime layer.

4. CONCLUSIONS

A geotechnical investigation was conducted on the Muryong Royal Tomb of Korea to find out structural problems of the walls and to establish the policies for conservation. The following conclusions are drawn from the study.

1. The movement of the structure of the tomb occurred toward the south direction, and the east wall and the west wall showed a slight movement outwardly causing the problem for the safety of the structure.
2. The movement in the rainy season is observed to reach about twice that in the dry season. Thus, the groundwater infiltration causes not only the problem of groundwater seepage into the tomb, but also the structural instability.
3. A sudden increase of the temperature inside the tomb results in acceleration of

the movement. When the temperature goes back, it never return to the former state. Thus, this hysteresis causes the deformation to be permanent.

4. By conducting a recharge test, it was found that the major pathways of groundwater seepage into the tomb are cracks found in the quicklime layer above the tomb.
5. The cracks are concentrated on the northwest and southeast sides, and this distribution is in accordance with the direction of the movement of the walls.
6. As countermeasures for maintenance and conservation of the tomb, it is suggested to refill the front chamber of the tomb as the original state before the excavation and to reinforce the quicklime layer by the mud-layer method.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:**+90.212.2610549** e-mail:**sas2001@yildiz.edu.tr** http:**//www.yildiz.edu.tr/mim/sas2001**

ENGINEERING-GEOMORPHOLOGICAL INVESTIGATIONS IN THE SOFIA KETTLE, BULGARIA

D. Angelova
Geological Institute, Bulgarian Academy of Sciences
Acad. G. Bonchev St., Bl. 24, 1113 Sofia, Bulgaria,
e-mail: doraang@geology.bas.bg

ABSTRACT:

The Sofia kettle is a complexly arranged and functioning natural-anthropogenic system. There are also significant human resources concentrated in it. The region is characterized by strongly distributed equilibrium of the natural processes occuring in it due to the anthropogenic activities. The most hazardous processes in the kettle are earthquakes, erosion, gravitation, soil and water pollution, mining activities, etc. The Sofia kettle is defined as a "problematic territory" with strongly damaged environment. Specialized geomorphologic investigations are necessary and required for each particular case because of the diversity in the combinations: relief type - types of engineering structures - geomorphologic hazard - prediction of negative consequences - protection of relief - social-economic consequences. The present work shows the results from the performed engineering - geomorphologic investigation using the possibilities of well-developed methods with proven effectiveness. An assessment of the relief as well as a prediction of its stability for construction purposes are made on the basis of the prepared rich map documentation.

1. INTRODUCTION

The Sofia kettle is a complexly arranged and functioning natural-anthropogenic system. There are more than 2 million residents and more than 1,5 million people temporary living in the area. They are irregularly distributed on the territory of the area (Fig. 1) where the biggest engineering constructions' and residential buildings concentration could be observed in some places.

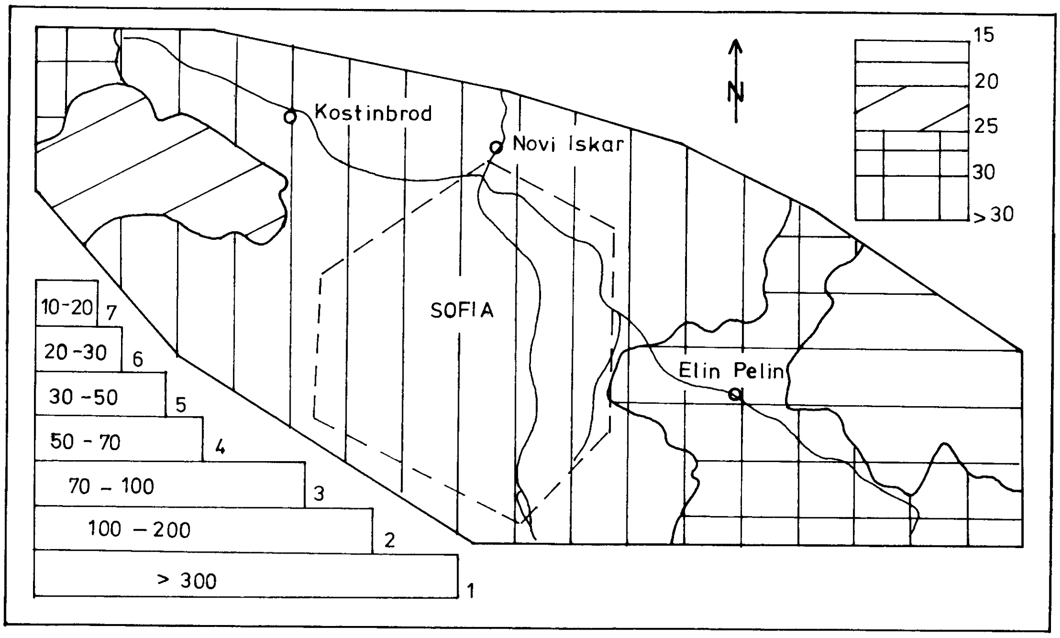

Fig. 1 Map of the human settling of housing territories in the Sofia kettle (average inhabitants on a hectare in 1992)

*N.B.: On the diagram: Human population density in respect to the settelments: 1. Sofia; 2. Elin Pelin Railway Station; 3. Kremikovtzsi; 4. Novi Iskar, Buhovo, Bankya; 5. Slivnitsa, Kostinbrod; Lozen;

The total number of the residential buildings in Sofia City is 430 253, i. e. in average 1000 people are living in 388 dwellings. The data mentioned above are from 1992. As a result of the economical and social policy restructuring in Bulgaria the normative acts concerning the binding Natural and Engineering Codes. For the reason a new city plan of Sofia is in a process of preparation. In that relation, since 1990 have been performing purposeful investigations aiming at ecological comfort creation for the people of the one of the most disastrous in respect of the ecological risk territories of Bulgaria.

The Sofia kettle is reported as a "problematic territory" with a strongly affected environment and an increased human population sick rate. A part of the results following from the performed relief investigations [1,2,3,4,5,6,7,8] are presented in this paper. These investigations were performed with a purpose of determining of the interrelation between the relief and engineering constructions as well as working out of a management strategy. The investigations are performed according to the methods adopted in Bulgaria for performance of specialized and estimative activities.

2. ENGINEERING - GEOMORPHOLOGIC INVESTIGATIONS

The relief of the Sofia kettle in its primary outlook was plain and mountain foothill one. It represents a synthesis of various types and complexes of forms, being at a different stage of development. The relief was formed on diverse geological structure under complex tectonic circumstances at the boundary between the Moezian and Aegean microplates. The important node situation of the region in the system of the Panonian - Aegean - Fore Carpatian - Pontian basins , and in the system of the Black Sea - the Mediterranean during the Quaternary, determines the great relief diversity.

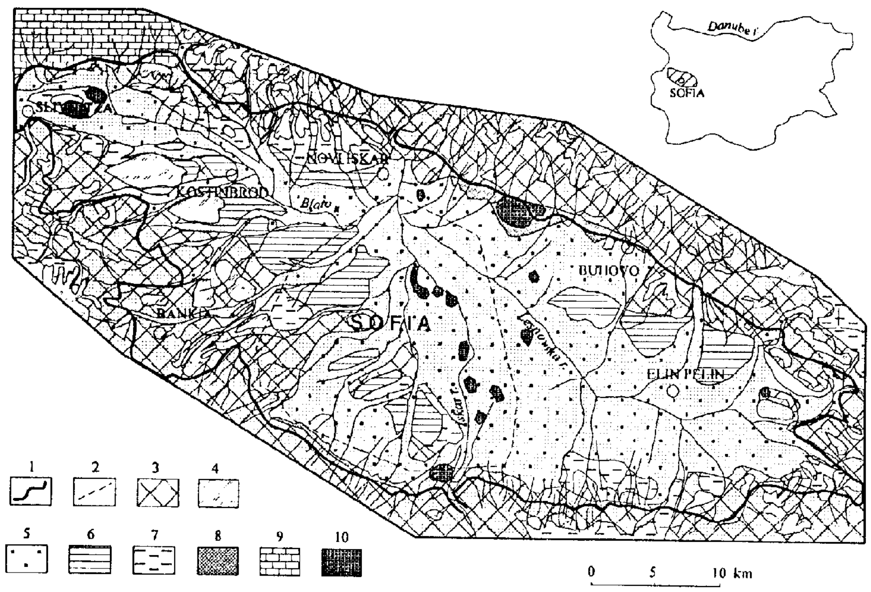

Fig.2. Types of slope surfaces in the Sofia kettle
1 - Sofia Basin boundaries; 2 - Sofia City boundaries; 3 - tectonically predetermined slope surfaces; 4 - erosion-denudation slope surfaces; 5 - accumulative slope surfaces; 6 - erosion-accumulative slope surfaces; 7 - erosion slope surfaces; 8 - gravitational slope surfaces; 9 - karst slope surfaces; 10 - anthropogenic slope surfaces

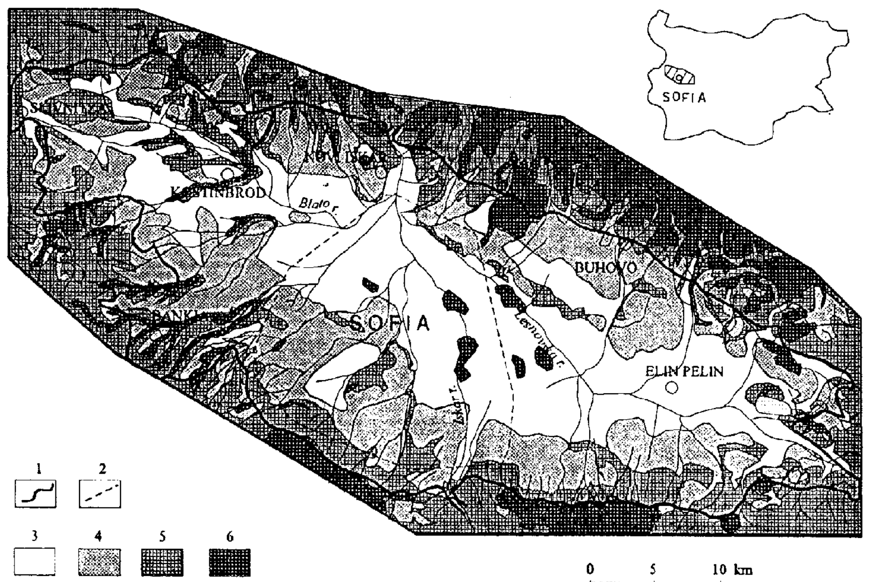

Fig3. Map of the real inclinations of slope surfaces
1 - Sofia Basin boundaries; 2 - Sofia City boundaries; 3 - slope inclination 0 - 2°; 4 - slope inclination 3 - 7°;
5 - slope inclination 8 - 15°; 6 - slope inclination >15°

some limited parts of it. Additionally, the slope surfaces are categorized and unified on base of the genetic principle (Fig. 4).

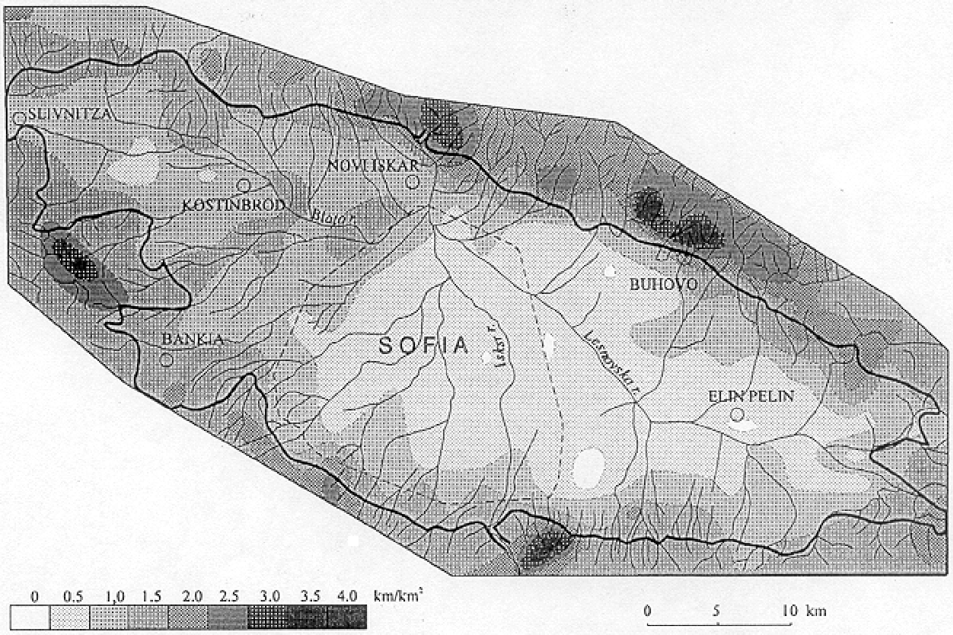

Fig. 4 Map of the horizontal dismemberment of the relief

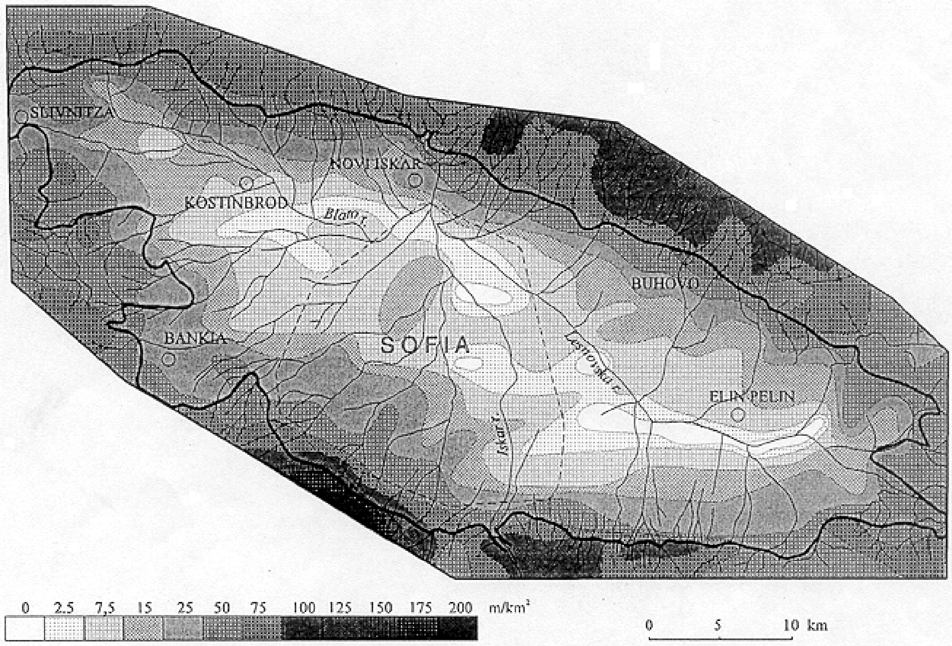

Fig.5. Map of the vertical dismemberment of the relief

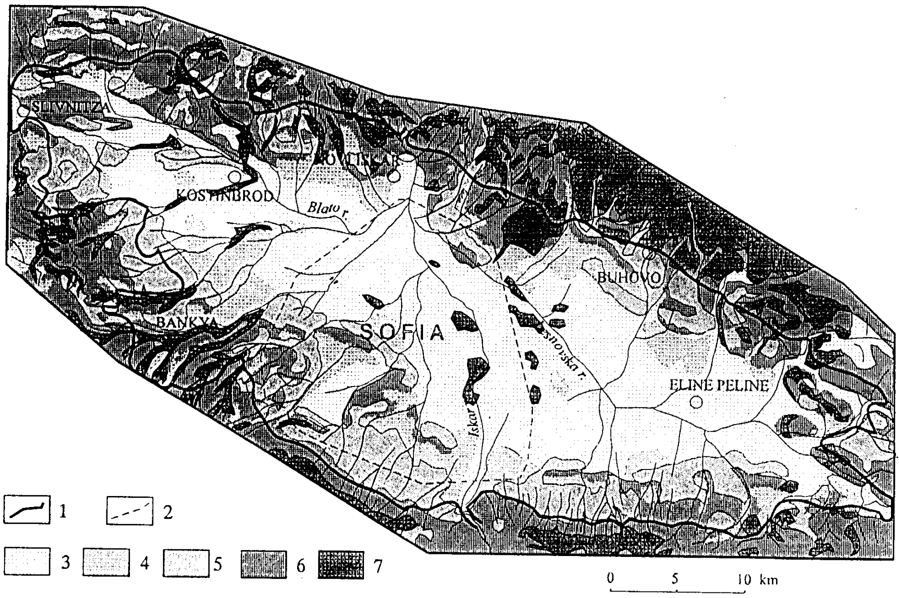

Fig. 7 Map of thesoil erosion in Sofia kettle and its periphery; 1. Kettle contours; 2. Contours of the Sofia-city; 3. Soils with no erosion; 4. Soils with small erosion; 5. Soils with average; 6. Soils with strong erosion and no humus layer; 7. Slopes with very strong erosion and no soil layer, zones with technogenic erosion in the central parts of the kettle.

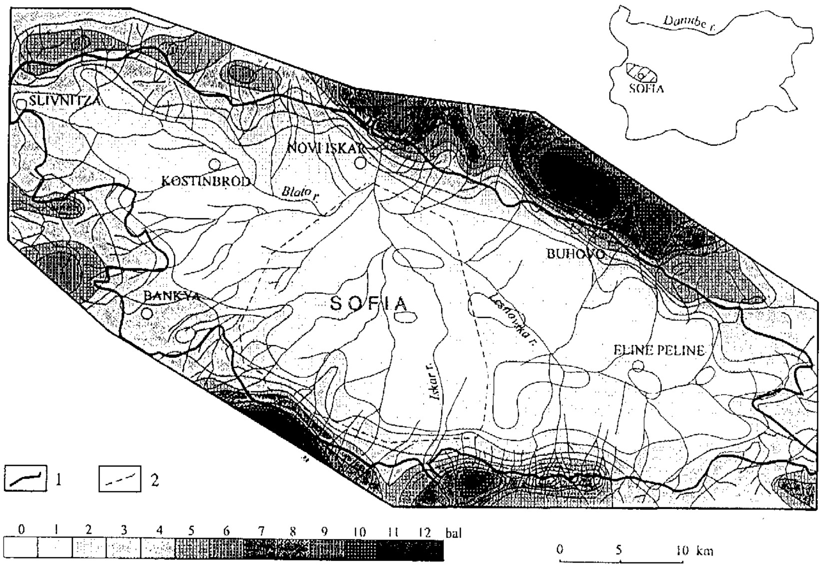

Fig. 6 Map of the intensity of erosion relief dismembering in the Sofia kettle and its periphery: 1. Contours of the kettle; 2. Contours of the Sofia -city.

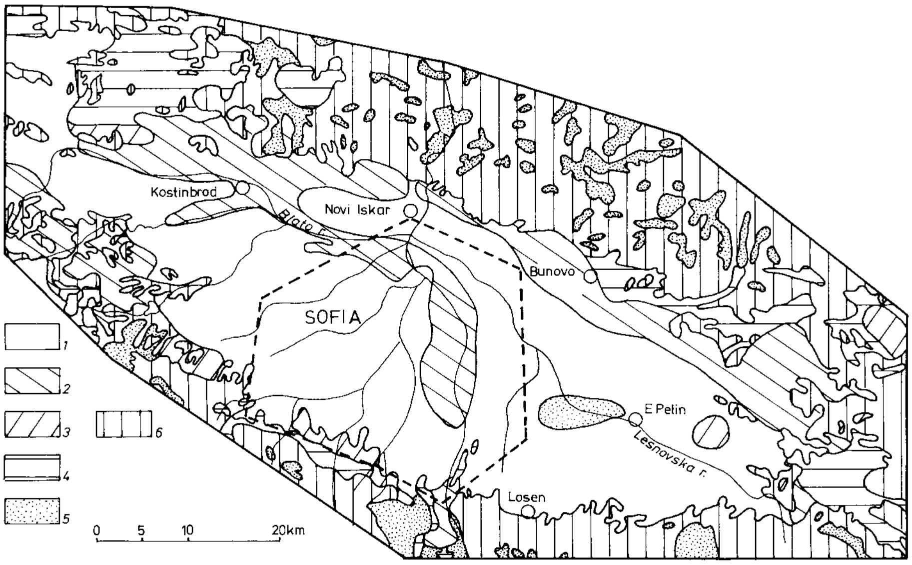

Fig. 8 Assessment of the relief for the purposes of agriculture: 1. Very good land; 2. Good land; 3. Average good land; 4. Bad land; 5. Unsuitable land; 6. Land from the forest fund.

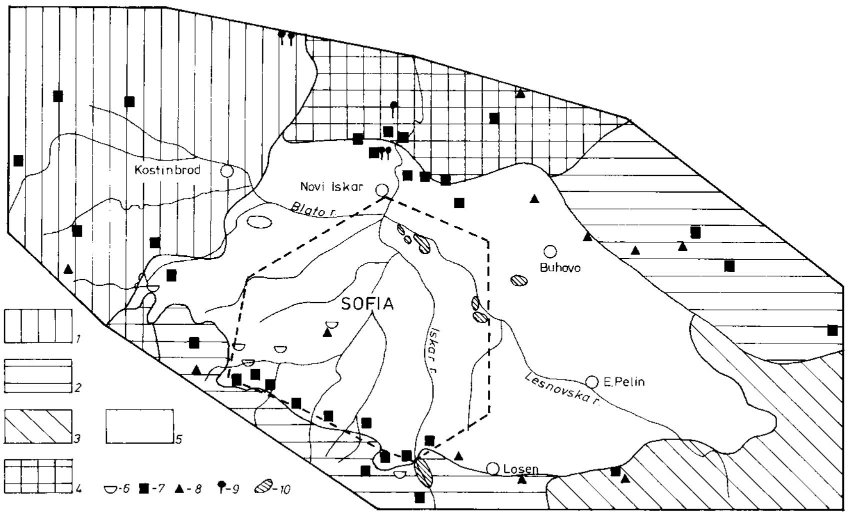

Fig. 9 Map of the recreaion resources: 1. Terrain with exceptionaly good conditions; 2. Terrain with very good conditions; 3. Terrain with good conditions; 4. Terrain with restricted conditions; 5. Terrain with unsuitable conditions; 6. Mineral spring with a bath; 7. Villa zone; 8. Historical remarkable places; 9. Rock formations; 10. Places for hunting.

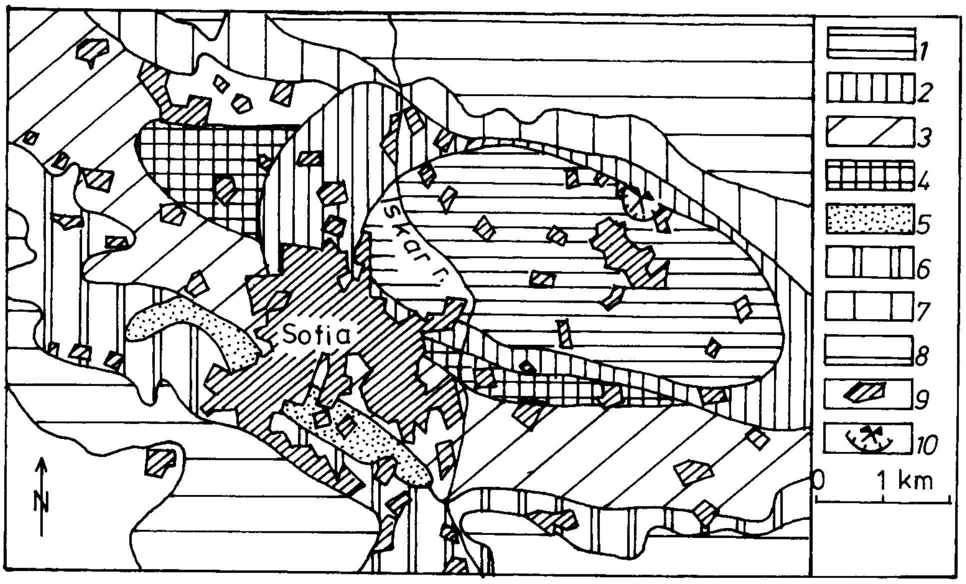

Fig. 10 Map of the complex natural-hygienne zoning on the territory of the Sofia kettle / Naumov et al., 1973 with an actualization/: 1 - Terrains absolutely unusable for dwelling in respct ot the hygienne; 2 - Terrains unusable for dwelling in respct ot the hygienne; 3 - Terrains limited because of existence of precious agricultural lands; 4 - The most suitalble terrains for development of civil works activities; 5 - Terrains suitable in respect to the existing climatic and hygiennic conditions; 6 - Terrains which are partly suitable due to air polution; 8 - Unusable terrains due to the high slope inclinations; 9 - settlements; 10 - quories;

As a result of the performed regional geomorphologic mapping a geomorphologic map in scale 1:25 000 was worked out for the whole territory of the Sofia kettle as well as maps in scale 1:10 000 and 1:5 000 were designed for

The real inclinations of the slope surfaces were estimated (Fig.3).

The last one is one of the most important maps of interest of the engineering construction activities because it gives their real values. They were included into four categories according to the needs of the microseismic zoning.
Maps of the horizontal and vertical relief segmentation in respect to a unit of area were designed (1 km^2), (Fig. 4 and Fig. 5).

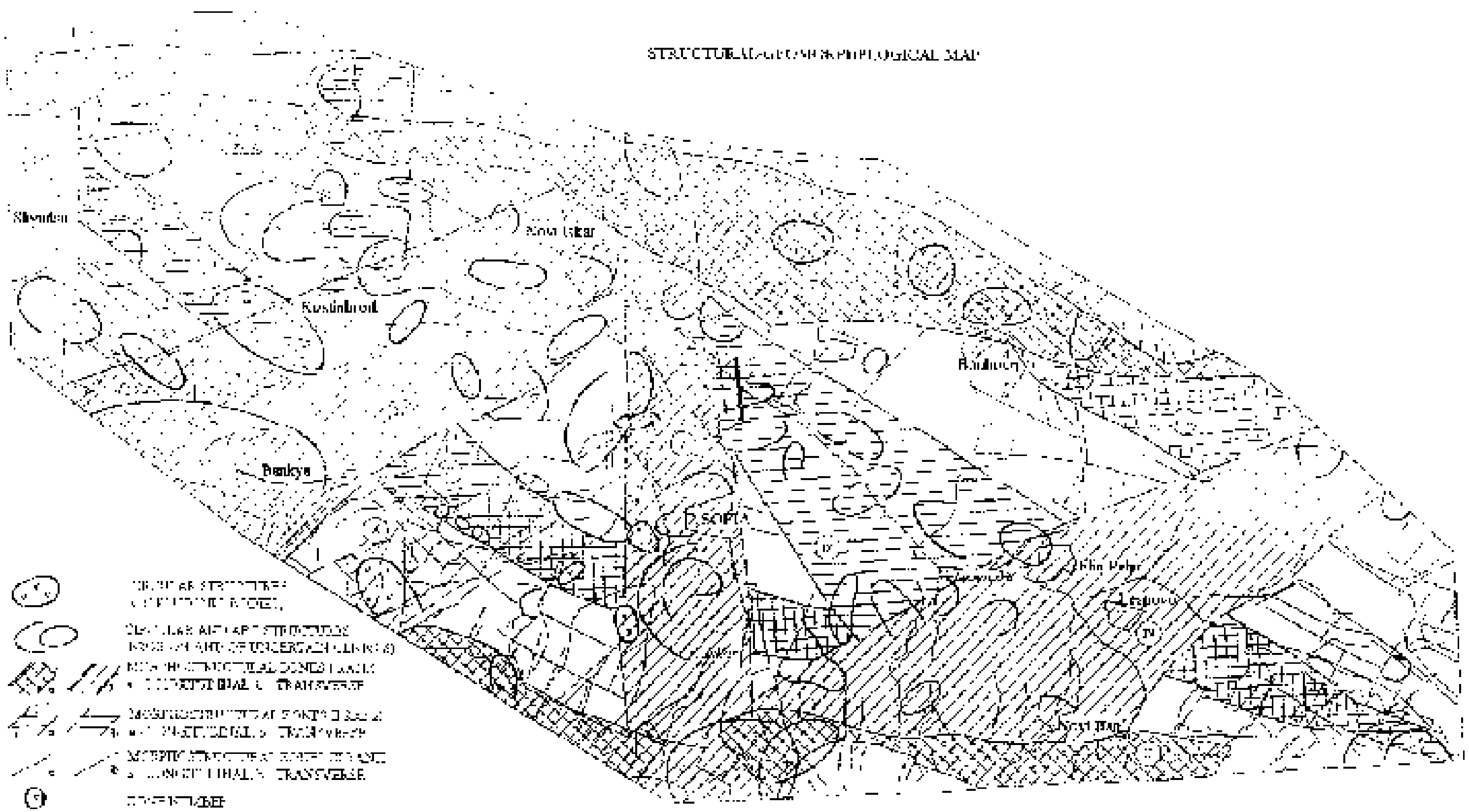

Fig. 11 Structure- geomorphological map

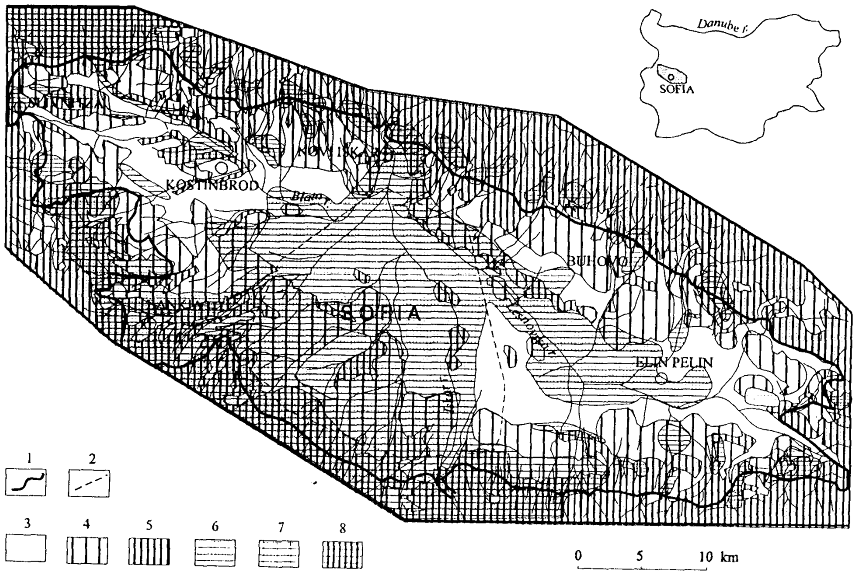

Fig.12Map of the Sofia kettle according to the suitableness for construction
1 - Sofia Basin boundaries; 2 - Sofia City boundaries; *good conditions*: 3 - slope inclination 0 - 2°;
medium conditions: 4 - slope inclination 3 - 7°-; *complicate conditions*: 5 - slope inclination ≥8°; 6 - distribution of physico-geological processes; 7 - slope inclination 3 - 7° with distribution of physico-geological processes;
worst conditions: 8 - slope inclination ≥8° with distribution of physico-geological processes

An estimation in grades of the intensity of the erosional segmentation was made (Fig. 6) as well as a soil erosion map was designed (Fig. 7) in order to be fully estimated the relief erosional grade.
As a preventive measure for the soil preservation from an eventual negative influence of the civil works in the future the relief was estimated for the needs of the agriculture (Fig. 8), recreation and tourism (Fig. 9) and health care (Fig. 10).

A schematic zoning is made according to the suitableness for construction and protection from the hazardous geological phenomena and processes on the basis of complex geological assessments of environment, engineering geological and geomorphologic conditions (inclination of slopes, type, engineering-geodynamic processes and seismic activity) (Fig. 12). It is seen that a great part of the territory of the Sofia town is not suitable for high-storey construction. The greater part of the slope processes depends on the tectonic activity which is not a completed process. This is confirmed by the high seismicity of the kettle.

3. CONCLUSION

Socio-ecological problems in the Sofia kettle are extremely rapid and have gathered heads. The huge human population concentration (nearly a quarter of the total number of the Bulgarians (residents) plus the same number of temporary living people) on a such small territory tables a lot of problems to the state and the local administration. There was a restriction of the possibility for people temporary staying on the territory of the Sofia City up to 1990. After falling away of these limitations problems occurred mainly with the dwellings and the ecological comfort on the territory considered which has a rapidly disbalansed natural equilibrium.

For the reason, a systematic investigation and multidirectional estimation of the effects on the environment in the Sofia kettle area is performed at present. The results will be useful for the new civil works. In this relation, new plans and management strategies for a limitation of the environmental disadvantageous effects are in a process of working out. As a result of binding procedures performance many new data were determined concerning the nature condition following from the improvident engineering activity. As a result of the performed specialized engineer-geomorphologic investigations it was clarified that the variety in the combinations: types of relief - socio-economical aspects requires performance of specialized investigations in each particular case.

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Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

DEFORMATIONS OF ANCIENT STRUCTURES OF ICHAN-KALA IN KHIVA CITY AND PREVENTION TECHNIQUES

N.Mavlyanova, V.Ismailov, M.Zakirov
Institute of Seismology of the Academy of Science, Uzbekistan

ABSTRACT

Ansamble Ichan-Kala in Khiva is one of the largest ancient structures in Central Asia (Horesm region). At the present time most of buildings of Ichan-Kala such as madrasahs Alla-Culi-han (1835), ancient city wall (1780), Tash-Hayli (1832), Matniyaz Divan Begi (1871) and others have deformations due to unfavoribly impact of environment.

The paper is to present some results of investigations hydrogeological, engineering-geological and geophysic conditions of Ichan-Kala for study type of deformations and their causes.

Analysis of these results shows that general cause of deformation of structures is moistening of ground foundations as result of man made influence. Therefore, most of prevention techniques for improving properties of ground foundation of ancient structures including elucidation inflow water and drainage of ground foundations.

1. INTRODUCTION

Accordingly to arheology assessment in Khiva, this city was based in IV century on " the Great silk way " [2]. In XIV century is known as one of large cities. In XVIII century the urban structures of Khiva have suffered stongly and on their place in XVIII - XIX centuries have erected new. The destroyed structures were leveled on the areas and streets, therefore in the territory of the city the large layer of filled soils was formed. This part of Khiva, received the name of Ichan-Kala (internal fortress), became administrative, political and economic downtown of that time. The rather small territory of Ichan-Kala contained two palaces, more than 60 madrasahs and fine mosques, a mosque covered market, caravans - sheds and baths, apartment houses approached of khan, officials, clergy and large dealers. Other, more free, inhabited building surrounded Ichan-Kala, extening

from west on east. It made external city Dushan-Kala, which also was protected with defence city wall [5].
Architectural complex of monuments of Ichan-Kala is a piece of work of ancient Horezm's architects of XYIII-XIX centuries and consists of several structures. The ancient monuments are less protected from negative factors of environment and human activity. Unfortunately, damage to the monuments accumulated in the course of time are inevitable.
The important condition of engineering-geology research of ancient monuments for the aims of conservation and restoration is to find out the deficiency of bearing capacity that means discrepancy between existing load and real capacity of soil foundation changed under influence of engineering-geological processes [4].

2. ANALYSIS OF INFLUENCES OF ENVIROMENTAL AND ARTIFICIAL FACTORS.

With the purpose to find the reasons of deformations of foundation of buildings of the monument Ichan-Cala and for development of techniques for improving properties of soils hydro-geological, engineering-geological and geophysical investigations were conducted:
- analysis of influences of environmental and human made activity factors influencing on the engineering-geological conditions;
- investigations of regime and chemical composition of underground water;
- investigations of properties of soils; research of ground foundation conditions within the area under the structure deformation occurred.

As result of conducted research it was established, that first of all the main reason of deformation of monuments of Ichan-Kala was the bearing capacity deficiency of ground foundation (filled soil) connected with moistening processes.
According to these evaluations all the factors responsible for deformation were classified into natural and artificial.
To the natural factors concern:
· accumulation of moisture because of infiltration of atmospheric precipitation;
· condensation of moisture under buildings and asphalt coverings;
To the artificial factors concern:
· watering of territory in a consequence of outflow from water-supply of the communications and because of a non-organized drain of water on the surface; in a consequence of absence of a proper horizontal lay-out;
· filling-up of artificial drainage systems;
· restoration works without the account of engineering - geological conditions.
Sources of accumulation of moisture are both natural, and artificial factors. They have various kind and character and influence on monuments of architecture of Ichan-Kala. For example, madrasahs Mukhammad-Amin-han is subject to numerous deformations in a consequence of accumulation of a moisture from malfunction internal and external water-supply communications.

Consequences of moistening of ground foundations of a monument results in non-uniform settlements of the bases, weathering of interbrick montar as resalt of lixiviation of salts breaking stability of monuments. (Figure 1.)
The similar undesirable processes and phenomena are observed on madrasahs Mukhammad-Amin-khan, Matniyaz Divan Begi , Mukhammad-Rahim-khan, Amir-Tur, complex Tash-Hauli, madrasah Alla-kuli-khan, citadel Kuni-Ark, tomb of Pahlavan Makhmud.

Figure 1. Destruction of the basement of a column as result of lixiviation of salts breaking stability of monuments (Tash-Hauli)

Also the natural factor influencing on the state of monuments is the condensation of a moisture appearing in the zone of aeration.
As it is known from a surface of a level of underground waters through capillary the moisture aspires upwards. This moisture in superficial parts of a ground under action of temperature evaporates and there is a process of drying [1]. However in places, where the surface of ground is blocked by asphalt covering, stones, slabs

there is no process of drying of ground, and there is a gradual accumulation of moisture in the zone of aeration. The occurrence of the condensed moisture is promoted by universal covering of the territory of the ensemble Ichan-Kala by asphalt, slabs, bricks and stones.
The next artificial factor regularly influencing on the state of the ground foundation of monuments is filling-up of artificial drainage systems. At the time of construction of the ensemble Ichan-Kala the artificial drainage systems were provided as ditch around defence wall and wells, reservoirs ("hauses").
Still up to 1858 in the city there were no main communications, because the southern wall had a lake, and there was no gate at that time. In the period from 1858 to 1867 along the southern wall of Ichan-Kala the part of the reservoir was drained and the gate has appeared only to 1873. At that time the ditch and lake played roles as drainage network, and protective structures.
During the Soviet authority, especially since 1950 the general plans of Khiva of some times were developed. They provide allocation Ichan-Kala as reserved zone of monuments. In this connection in 1970 - 1980 years in territory of Ichan-Kala all areas and the streets were covered with asphalt, slabs, bricks, stones, which in turn negatively influenced on moisten changes. Also in 1980 many wells were filled-up in the territory and ditch and lake located in a southern part of Ichan-Kala were liquidated, and were covered with asphalt and concrete plates. In result ditch and lake, which played a role of a drainage network were completely destroyed. Probably, it very strongly has affected increase moisten of ground in the basis of buildings and structures on an internal part of Ichan-Kala . Therefore, as one of the basic reasons of non-uniform deformation of architectural monuments filling-up of wells in court yard of monuments and liquidation ditch around of Ichan-Kala is considered.

2.1. Gydrogeologycal condition

The hydro-geological conditions of the territory of the ensemble Ichan-Kala depend on a relief and geological structure of the territory and results of man made influence. In territory of Ichan-Kala the level of underground waters changes from depth 7-7.20 m (in the area of Arch) up to 2.0-2.5 m (in the area of madrasah of Shergazi-khan). On all territory underground waters related to sands, water-resisting layer are of clay on the depth of 15-20 m. The waters are transparent, colourless, seldom salty .

2.2. Properties of soils

The physical state of structures depends on structure and properties of the earth bases. The bases of monuments of architecture of Ichan-Kala are filled soils and in some cases sands.
1. By the first type of the earth bases madrasah Alla-Kuli-khan, Mukhammed-Amin-khan, the complex Tash-Hauli are characterized. This type consists of filled soils (anthropogenous) by capacity from 3,2 up to 6,5 m, they include loam and sandy loam poorly condensed with inclusions of the historically usual household

dust (fragments of brick, ceramics, bones, slag etc.). Sometimes there are layers of sand (10-15 sm) moistening from 5 up to 20 %. On the depth of 5-6 m out bricks without correct sides were found. The analysis of results of physical-mechanical properties of filled soils of this type showed, that they are various on structure and density of and they are weak and semiconsolidated. The wide limits of change deformation properties of filled soils are connected to inclusions, lenses and layers of sand.

Deformation properties of filled soils are characterized by size of the module of general deformation (from 6,5 up to 30 MPa), natural moisture from 7 till 18-22 % and high porosity from 43,4 up to 49,5 %. Investigation has shown, that the monuments located on filled soils are subject to the greatest deformation. The ancient architects foresaw such moistening, therefore in the bases one or two layers (with an interval from 1 up to 2,5 m) "buira" from a cane were pawned. "Buira" (bulrush intercalation) is capable evoporate a moisture vertically driven on capillary pore. At realization of restoration works for 1960-1970 "buira" was withdrawn and partially replaced with ruberoeid. Such replacement complicates evaporation of moisture from the bases.

2. As the second type of soils of the bases perfom sands. In researched territory sand bedding is just under filled soils . Sand of yellow-brown colour by damp places water saturated (basically near to the level of underground waters). The damp sand are characterized by value of the module of deformation from 31 up to 37,8 MPa, water saturated from 20 up to 32 MPa. The researches have shown, that the bases of architectural monuments located on sand are less deformed, sometimes not deformed. To them it is possible relate southern walls madrasah Mukhammed-Rahim-khan, tomb of Pahlavan Makhmud, tomb of Seid Alauddin, madrasah of Shirgazi-khan.

Accordingly to the conducted researches the sheme of structures in territory Ichan-Kala is made by degree of deformation. The zones with average and strong deformation are identified. To the zone with strong deformation the sites with the greatest capacity of filled soils are referred as well as places, where the water communications through walls and under the bases are carried out. To the zone with average deformation the architectural monuments, partially bedding on sandy and filled soils and partially with absence of communication systems are referred (Figure 2).

3. DEFORMATIONS OF ANCIENT STRUCTURES.

Madrasah of Mukhammed-Amin-khan, is located in the western part of Ichan-Kala near of the gate Atadarbaza. It was constructed in 1851-1853 on the place former defence wall. According to the historical data the defence wall by extent 70-100 m about a gate Atardarbaza was strongly destroyed as a result of wars and in times of Mukhammed-Amin-khan they did not begin to restore the wall, but begun to build a large madrasah in Ichan-Kala. The rest of the wall on this extent on a place was planned. In this connection the capacity of filled soils here changes

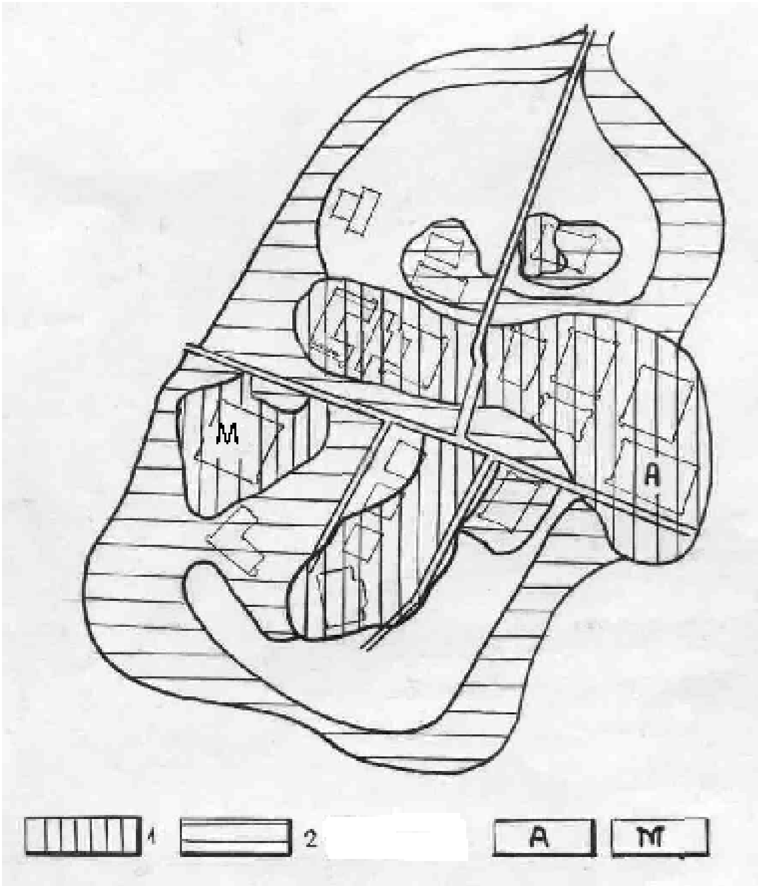

Figure 2. Scheme of deformed structures on the territory of Ichan-Kala
1. Zone of strong deformations; 2. Zone of average deformations;
A. Madrasah of Alla-Kuli-khan; M - Madrasah of Mukhammed-Amin-khan

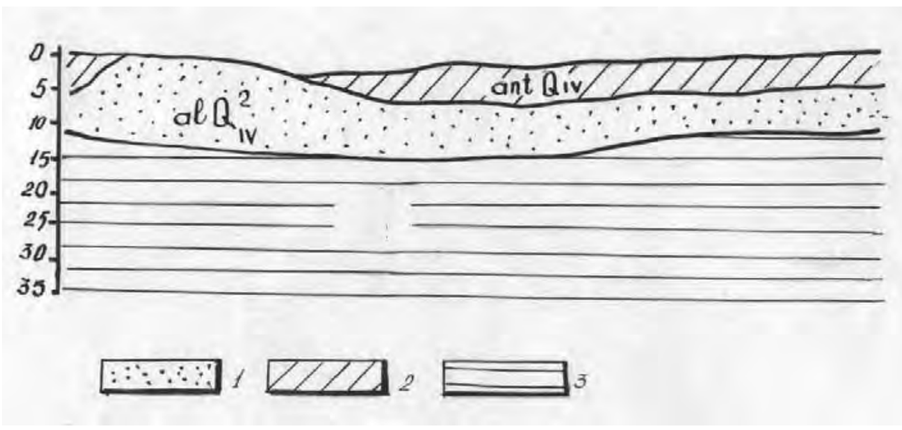

Figure 3. Cross-section of the Ichan-Kala ground foundations
1. Sands; 2. Filled soils; 3. Clays

from 3,2 up to 4,5 m (Figure 3). At the present time madrasah of Mukhammed-Amin-khan is converted and it is used as a hotel. In a building a sewer and water network, and also heating are carried out. The inspection of an external and internal state of buildings shows about presence of various size of cracks in walls and ceilings, which were formed as a result of non-uniform deposits of various parts of madrasah. The largest crack of width up to 3-5 sm is present on the southern wall of madrasah, where it crosses the wall from above downwards.
Thus width of the crack in the top part is greatest and in process of progress downwards it decreases . Underground waters on the depths of 6 m. Up to the level of underground waters the base is filled soils and fine sands. These soils in the natural state are characterized by increased value of strength and deformation properties, but at moistening it lose a significant part of these properties. In this connection the deformation of buildings is a direct consequence of condensation of the ground foundations at moistening. The outflow of water from the sewer network promoted washing away of salts, which served as the cementing substance of intermodular systems and easing of structural connections. This all has resulted in condensation of the ground foundations.
The complex of Alla-Kuli-khan consists of the caravan-saray , "tim" trade places and madrasah. Now caravan-saray of Alla-Kuli-khan has many developed cracks (Figure 4). At the present time the caravan-saray is used as department store with a complex of municipal systems. The ground foundations of the caravan-saray of Alla-Kuli-khan are filled soils by capacity more than 5 m, underlaid by sand. The deformation is shown as vertical cracks on northern and eastern walls. Cracks occur at the expense of non-uniform subsidence of filled soils of the bases of the northeast corner (column to the bottom diameter 1,5 m) caravan-saray. It was established by researches, that cracks and subsidence of the basis are connected at the expense of moistending of the filled soils [3].

4. **CONCLUSIONS**

As result of conducted research it was established, that first of all the main reason of deformation of monuments of Ichan-Kala was the bearing capacity deficiency of ground foundation (filled soil) connected with moistening processes.
According to these evaluations all the factors responsible for deformation were classified into natural and artificial. Analysis of these results showed that general cause of deformation of structures is moistening of ground foundations as result of man made influence. Therefore, most of prevention techniques for improving properties of ground foundations of ancient structures should include elucidation inflow water and drainage of ground foundations.
Now in the complex Ichan-Kala, where the water-communication systems are everywhere spent and consequently the usual balance of the structure " a monument - geological environment" is broken
The ground foundations for the most of historical monuments of Ichan-Kala are filled soils, which in a natural - dry status are characterized by rather high values

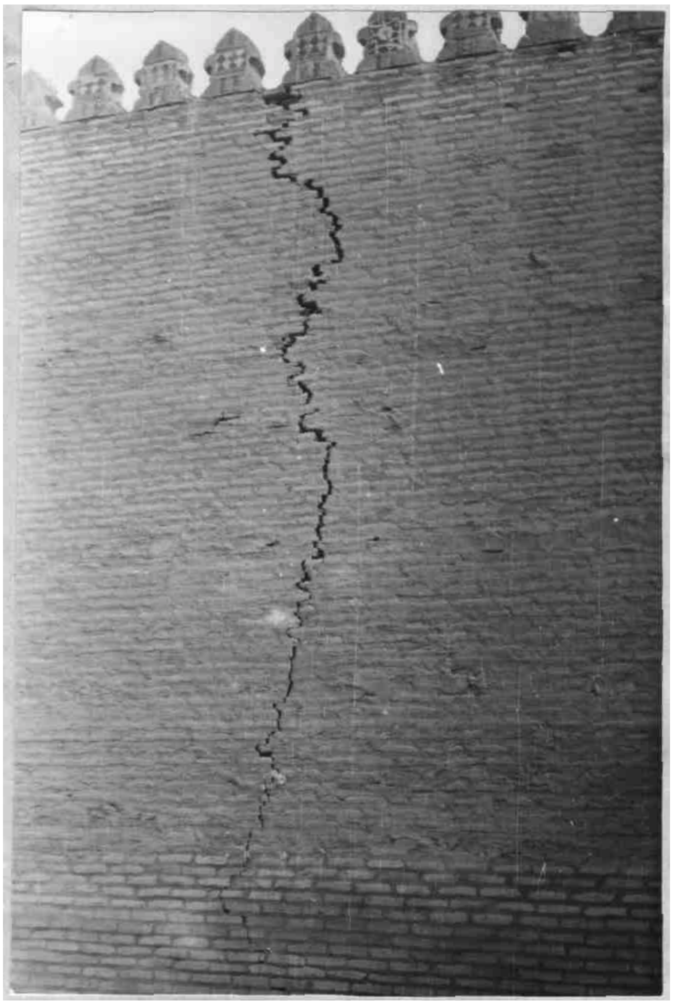

Figure 4. Cracks in the wall of caravan-saray of the complex Alla-Kuli-khan

of strength and deformation properties. However, at moistening prosesses by specific internal structures, they considerably lose (about 70-80 %) bearing ability and get propensity to condensation. The capacity of filled soils reaches 7.7 m, but in the most part of territory 4-6 m . The local moistening of the ground foundation in Ichan-Kala occurs as a result of outflow of water from a engineering-sewer and water network, unorganized drain of atmospheric precipitation and accumulation of moisture in soils as a result of condensation of moisture under buildings, asphalt and other coverings.

The underground waters are on thedepths from 2.5 to 7.5 m. Thus the high level of underground waters is observed on the southern part of Ichan-Kala on north it is lowered.

In the conclusion the following recommendations for improving properties of soils of ground foundation of structures of architectural monument of Ichan-Kala are given.

1. To organize system of a drain of superficial waters. To develop the prevention techniques for collection and removal of atmospheric precipitation, as from the internal and external areas and historical monuments and from their roofs and floors.
2. To remove all asphalt and others (brick, stone cement) covering both on the areas, and inside historical monuments. All kinds of covering (stone, brick) should be executed without application of cement and concrete.
3. To clear all filled-up wells both inside historical monuments, and on the areas.
4. To restore the drainage network around of Ichan-Kala. It is originally necessary to lay horizontal drainage on Eastern and Southern part of the external wall of Ichan-Kala. The depth of drainage network is necessary to design depending on the mark of a surface.
5. Taking into account complexity of engineering-geological conditions on the territory of Ichan-Kala and historical value of this ensemble, it is necessary to note, that all engineering-sewer and water network should be incorporated with a guarantee on trouble-free operation.

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INVESTIGATION INTO THE CAUSES OF THE FALLING DOWN OF A TOWER IN THE ANCIENT WALL OF SEGOVIA (SPAIN), AND REPAIR WORKS

J. Mª Rodríguez Ortiz (1), L. Prieto (2)
(1) Prof. Soil Mechanics. Polytech. University of Madrid, Spain.
(2) Civ. Engineer. RODIO Special Foundations, Spain

ABSTRACT

The crumbling of a tower of the Segovia Wall in August 1998 is described. Extensive research led to the conclusion of a subsidence problem due to the washing out of sandy layers alternating with more competent calcareous strata. The paper explains the geotechnical investigations, the removal of the debris, the new foundation on micropiles, the anchoring of the rocky slope, as well as the reconstruction of the shaft by means of a hollow concrete cylinder covered by the original masonry.

1. INTRODUCTION

The origin of the present Wall of Segovia goes back to the times of the “Reconquista”, i.e. the end of the XIth century (kingdom of Alfonso VI of Castile), though it shows restorations and elements of subsequent times. Originally it had a perimeter of 3 Km and it comprised 80 towers, 7 gates and 5 doors.

In the evening of the 27th to the 28th of August of 1998 the sudden falling down of the so-called no. 23 tower of the wall (close to the Santiago’s Gate) occurred, without, fortunately, personal fatalities in a frequently visited area (fig. 1). This tower, 14 m high, was deemed very risky in an inventory 10 years before.

The crumbling originates in the shear failure of the masonry, following an angle of some 60º with the horizontal, starting from a preexisting crack in the forward third of the prismatic plinth that was supporting the cylindrical shaft of the tower.

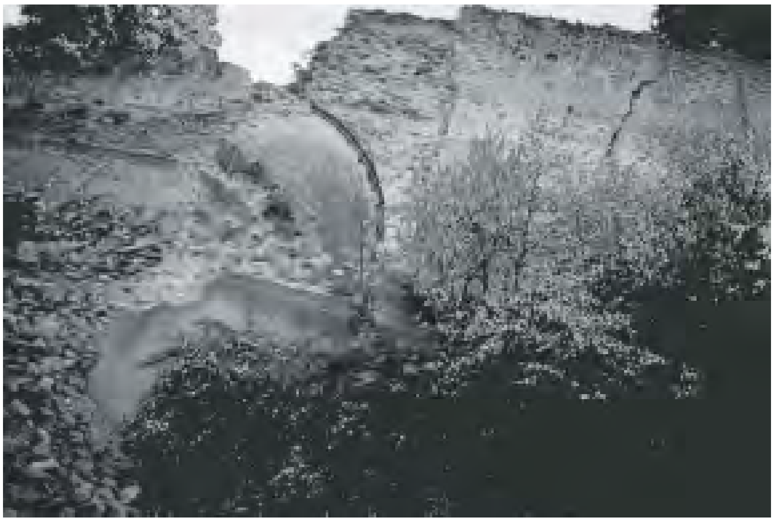

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Fig. 1.-View of the crumbled tower.
The nearby wall at the right shows tensile cracks.

After the failure, the City of Segovia requested the help of the Board of Castille and Leon, through its Department of Conservation of the Artistic Heritage. The repair works were qualified as an emergency and awarded to the firma Rodio, specialized in consolidation of monuments and foundations.

2. GROUND CONDITIONS

The crumbled tower was located in a small valley (the Arroyo Vallejo), filled with historical and urban debris, which formerly served as outlet to the waters infiltrated from the upper part of the hill were the city developed. The valley was filled in uncertain era to give continuity to the wall, and these poor conditions can explain the falling down of the wall in repeated occasions. In fact different types of masonry can be observed at the edges of the most recent break, as witnesses of successive repairs.

At the starting of the repair works a campaign of borings was carried out in order to ascertain the ground conditions at the site, and to define the rock profile for the future new foundations.

The borings defined, below the upper historic fill, a subhorizontal sequence of banks of sandstones and marly limestones, interbedded with silty and sandy layers down to 34 m. They were detected several big voids, up to 2 m in height, probably corresponding to open cracks from former movements of the rocky hillslope. Some other voids originate in the internal erosion of sandy layers. It followed a substratum of impervious siltstones and marls.

3. ANALYSIS OF THE CAUSES OF THE FALLING DOWN

To the unbalanced effect of the loose backfill and the poor foundation, it was added throughout the centuries the action of the underground water which has eroded by piping the silty sand layers included into the limestones and sandstones which form the promontory in which Segovia is seated. Nowadays these waters mainly originate from leakages of the water mains and sewages of the city, as well as the infiltration of rainwater. The natural gradient of all these waters is toward the Eresma river, which flows along this northern part of the Wall which is severely affected by caves, collapses and rockfalls.

As the silty clay has been washed out the undermined rocky strata above have partially lost their support. When the gap grows into the slope, the strata may break in bending as a slab supported at three edges, or the span reaches some of the existing vertical rock joints, and the strata fall to occupy the void (fig. 2). This can be interpreted as a special type of subsidence. If the gap occur very deep, the rocky slabs above can span it or reduce subsidence, so that its effects in surface are almost imperceptible. On the contrary, when the void is close to the surface it results in steps or depressions that can severely affect to the buildings or structures at the surface.

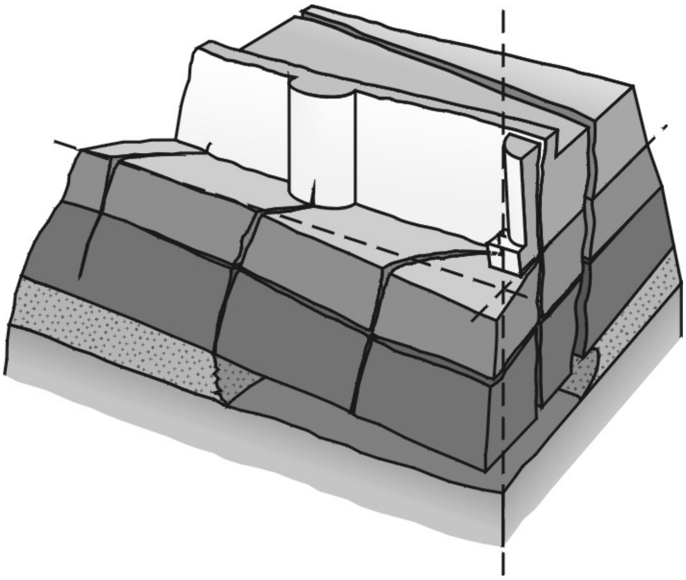

Fig. 2.- Schematic interpretation of the subsidence

In addition to the natural waters, the ramp in front of the damaged tower has been affected, in the last times, by frequent breaks of the supply pipeline that carries water to some neighborhoods of the north of the city.

The conclusions above supported the initial idea of the intervention:

a) To found the new tower in a level not affected by the subsidence of the upper rocks, voids, cracks or layers with risk of piping.

b) To anchor the tower and the adjacent wall to resist the thrust of the backfill.

It was seemingly clear that the deep foundation, across the rocky overburden, only could be performed through micropiles, reaching a competent ground, below the detected voids and cracks.

When clearing the site and excavating the backfill it was uncovered the upper part of a number of big, near vertical, cracks, part of them already detected in the borings. The principal crack highlighted was 50 cm wide and its depth exceeded 30 m.

4. ADOPTED SOLUTION AND EXECUTION OF THE WORKS

As stated above, the solution adopted should fulfil the twofold aim of reconstruct the tower on a competent foundation and to connect the same to the existing parts of the wall, being able both elements to withstand the thrust of the final backfill. A complete scheme is shown in fig. 3.

Consolidation of the wall, removing of debris and crack filling.

The precarious state of the adjoining parts of the wall posed important risks for clearing the site. Thus, the first operation was to fix the separate parts of the adjoining wall. This was achieved by putting on the external face a grid of steel profiles anchored by tendons passing through holes drilled in the wall and fixed to some rocky outcrops in the hillside.

The removal of the debris was carefully accomplished in order to re-use the best stones for the reconstruction of the tower. All the stones were piled in a nearby space. A 60% of the quarried pieces of the original cornice were retrieved.

The clearing out was hindered by a large part of the tower, almost a quarter of the cylinder, which remained intact on the debris, without being crumbled. It was necessary to demolish said rest with help of jackhammers, climbing on the debris.

The filling of the highlighted cracks (figs. 4 and 5) was accomplished from the surface, with conventional concrete poured through a tremie-pipe. Almost 1.200 m^3 of concrete were spent. The operation was made by steps in order to allow for the setting of the concrete, thus avoiding the developing of high hydrostatic pressures against the remaining part of the wall.

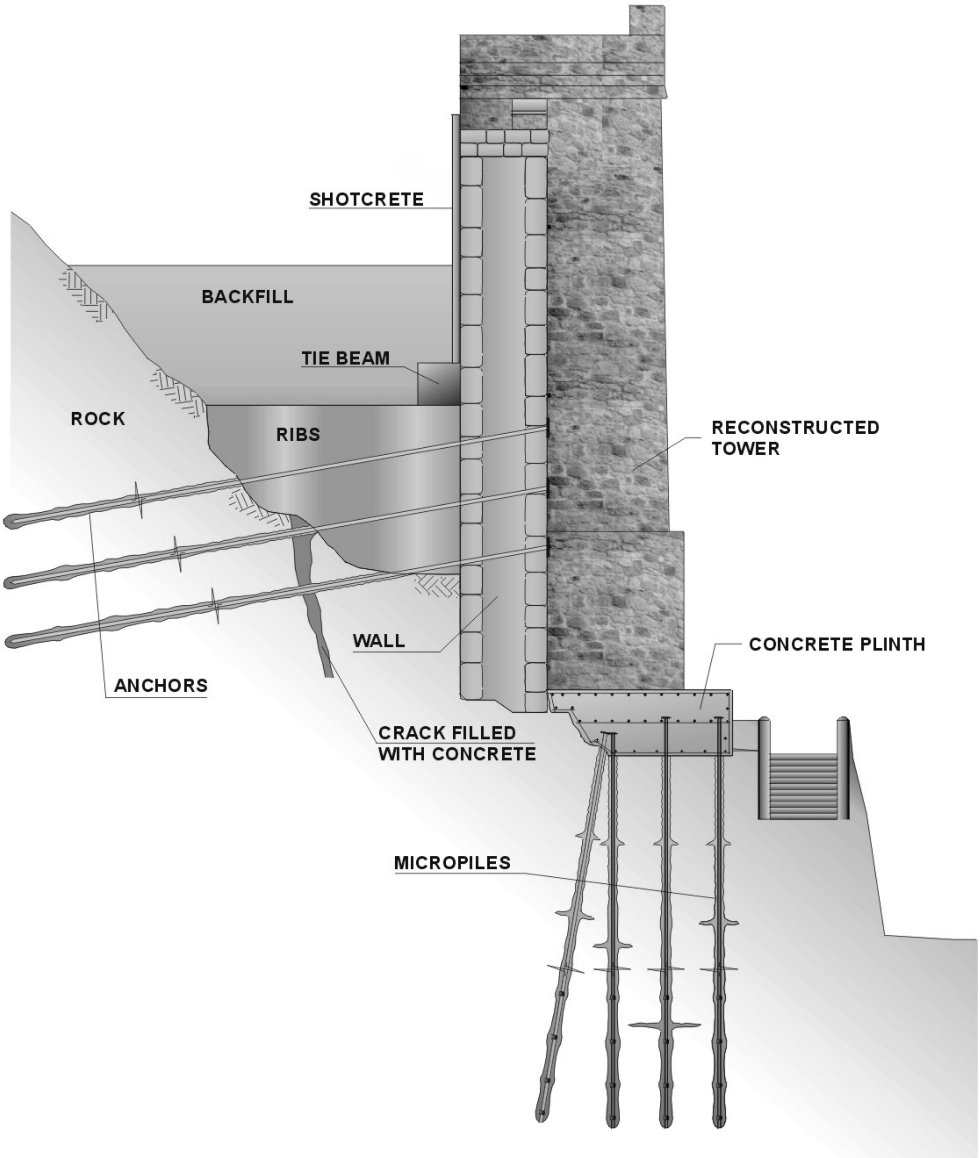

Fig. 3. The complete solution

4.2. Micropiles

The foundation of the tower consisted of 32 micropiles of 30 tons of capacity, about 32 m in length. They only carried a part of the total weight of the tower (in its final light version) as it was supposed that the so underpinned surface rock would be able to support most of the load. The micropiles were drilled with 150 mm in diameter and were reinforced with a St-52 steel pipe of 70 mm of external diameter and 10 mm of wall thickness. The 9 final meters were carrying sleeves, every 1 m, to improve the ground through injection of cement grout and to guarantee, by the applied pressure, a good contact with the surrounding area

The micropiles went disposed in 4 rows of 8 units. In the 3 external rows they were vertical, while those of the 4th had a slope of 5º, to accomplish a light anchorage function.

The micropiles were capped through a large plinth of reinforced concrete of maximum dimensions in plant 9,40 x 5,90 m. The plinth was stepped in order to soften the visual impact of the prismatic concrete block.

In the execution of the micropiles the problem of crossing the existing voids, some 2 m high, arose, since they allow the filling grout to escape, without filling the lower part of the drilling and leaving the pipe without protection against corrosion. Furthermore, the risk existed of pipe buckling.

As a solution, the voids found when drilling were filled first with a very dry mortar, so that a mortar cone was created around the drilling axis. After filling all voids the micropile was executed in the customary form.

4.3. Anchors

During the execution of the micropiles, the lower set of anchors was also carried out from the rocky face close to the tower and the walls of a massive stairway constructed several years before, in an attempt to stabilize the area where the movements were already apparent. These anchors were intended to nail and to consolidate the rocky strata that were serving as direct support to the tower and to the adjacent parts of the wall, as well as to fix the remains of the tower that subsisted.

For durability reasons threaded bar anchors of GEWI type, Ø 32 mm in diameter, with a capacity of about 30 t, were installed. As the head of many anchors was loading against the masonry, it was not convenient to use anchors of greater capacity.

The bars were placed in 90 mm drill holes. The head carried a steel plate of 20 x 20 x 2 cm and a nut, with which a small tension, of about 5 tons was applied.

In total they were executed 86 anchors: 42 units in the rocky base; 17 units close to the tower base and 27 units in the upper part of the wall and tower

In the cases where voids were found during the perforation of the anchors it was applied a special procedure to settle this drawback. Upon detecting the void in the drill hole, the bar was placed inside a PVC casing, 75 mm in diameter, with outside packers corresponding to the length across the void. Thus the anchor could be grouted inside the PVC in all its length and externally only in the sections outside the void. In this way they were not grout losses and the part crossing the void remained protected by the injection inside the PVC casing.

The anchors were inclined some 10º to make easier the filling with grout. As a rule their length was fixed for having a minimum of 5 m of bulb after the last detected crack. This resulted in very variable lengths, between 12 and 18 m (fig. 5).

The execution of the anchors did not posed special problems in the lower part of the wall since they crossed rocky ground or cracks filled with concrete.

However it was not advisable to install anchors across the ancient backfill, as the wall could lean against the ground and the necessary addition of new fill would induce important bending in the anchors, thus breaking their protective casing.

This was avoided creating some parallel "ribs", in ditches filled with concrete, perpendicularly to the wall, through which the anchors were drilled until the rock (fig. 6). The ditches were adequately braced, and the concrete ribs were vertically fixed to the rock and horizontally to the wall through cemented bars of Ø 32 mm. These ribs acted as authentic buttresses of the wall. In total they were executed 9 ribs 2 m wide and with a variable length variable between 5 and 8 m at the upper level. In vertical section the ribs have an approximately triangular section, to be adapted to the profile of the rock.

For the execution of the upper anchors as well as to some demolitions and to the reconstruction of the tower an important scaffolding was necessary.

Fig. 4.- Detail of vertical crack in the ground at the toe of the wall

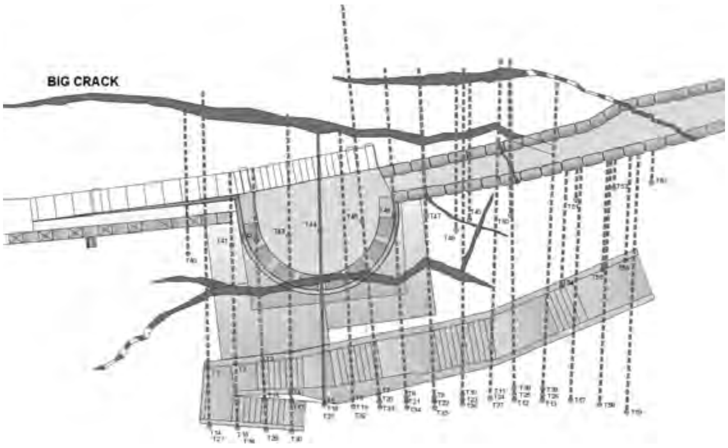

Fig. 5.- Plan of the cracks and anchors

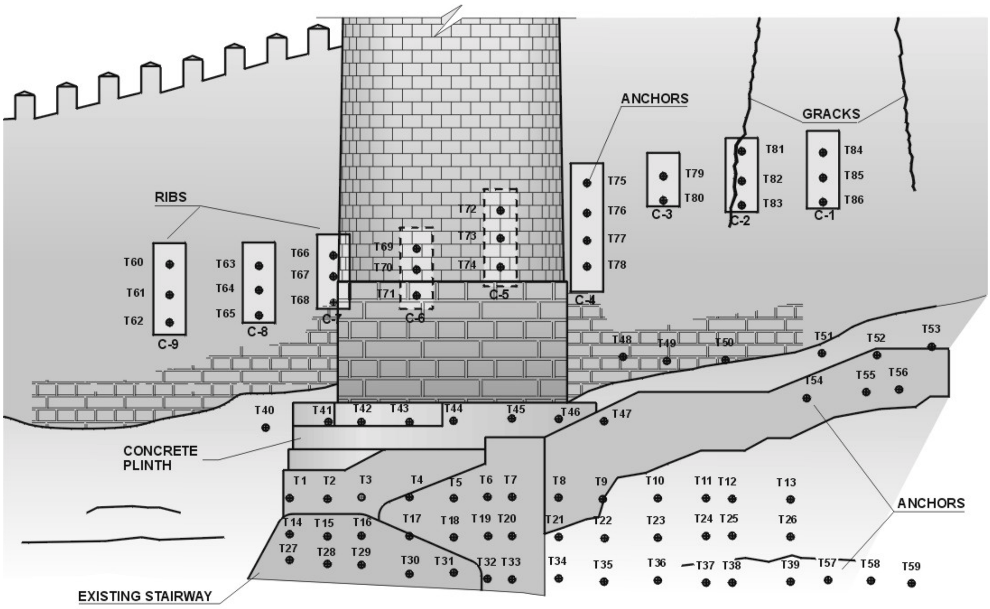

Fig. 6. Front view of the ribs and anchors

Consolidation and reinforcement of the wall and nailing of cracks

Upon unearthing the back of the wall in search of the cracks, it could be observed the poor condition of the same, with a ill cemented masonry.

It was decided, therefore, to improve said masonry with a protective cover of shotcrete of up to 30 cm in thickness, applied on a wiremesh of 150 x 150 x 10 mm, fixed to the masonry through steel spits. The toe of this lining was connected to a soldier beam, 1 x 1 m in section, also working as a tie-beam of the concrete ribs, as described above. Thus an excellent connection between the wall and the anchorage system to the rock was achieved.

Within this phase the nailing of the two big cracks open in the wall to the right of the fallen tower was also performed

To this end, the outer lips of each crack were sealed with mortar and the big voids inside filled with concrete. Afterwards, the strengthening of the crack was carried out through inclined cemented bars.

The composition of the mortars was studied to obtain a coloration matching the general tonality of the wall. They were used lime and cement mortars with natural dyes of iron oxide. They were also made numerous tests for the mortars of sealing the anchor heads.

The reinforcement of the wall was accomplished through threaded bars of stainless steel 12 mm in diameter, placed in 45 mm drill holes. The bars were located in the stones of greater size, according to an approximate mesh of 1,50 x 1,50 m. In total they were installed 30 bars on the left part of the tower and 72 in the right part. Through these bars the connection of the outer leaves of the wall to the lean masonry inside was improved. The cement grout injection also resulted in an acceptable filling of voids an fissures.

4.5. Reconstruction of the tower and finishings

Once completed the micropiles and anchors it was proceeded to the concreting of the cap block until the springing of the tower shaft.

It was widely discussed the solution for the new tower but finally it was adopted a traditional solution, close to the original appearance, in order not to shock the customary visitors of the wall and the Segovia citizens. However the base of the tower was left as a concrete block in order not to disguise the performed intervention.

The shaft of the tower was built with the original stones, but as different styles appear along the wall it was decided to use a traditional Segovian masonry.

It was attempted to preserve the original geometry of the tower, as refers to its dimensions. The cornice was reconstructed with the recovered original pieces and the lacking parts were replaced by approximate copies.

However it was decided to lift a hollow tower (by reasons of reducing the loading on the foundation and to simplify the work) with a cylindrical internal lining of reinforced concrete, 30 cm (fig. 7) of thickness, and an external thick veneer of masonry, also of thickness not below 30 cm. The masonry was used as external formwork, while the concrete lining was poured within a climbing steel form, raised by sections of 1- 1,50 m. The masonry was connected to the concrete by small steel pins, thus creating a monolithic shaft.

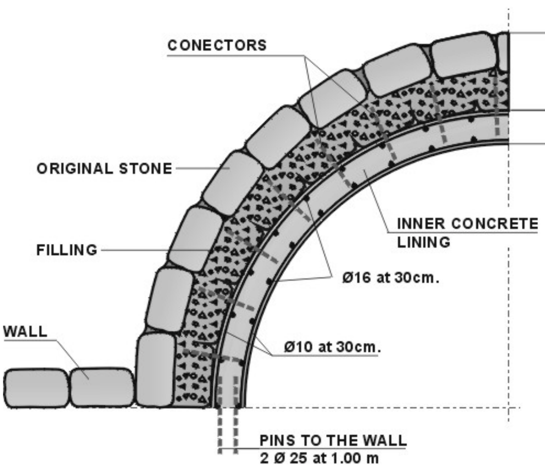

Fig. 7.- Cross section of the new tower

Fig. 8.- View of the finished tower

Th… ed by a floc… s, supported at its edges by a circular beam as a hidden cornice of the inner lining. This slab was covered by a dampproof sheeting and a pavement of granite slabs of 60 x 40 x 2 cm.

Several discreet ventilation holes were open in the lower and upper part of the tower to avoid condensation dampness. The reconstruction was ended with the upper crenellation (fig. 8).

In order to eliminate the water infiltrated through the backfill an impervious sheet was placed at the top level of the concrete ribs, with drainage to two gargoyles that cross the wall. These gargoyles have been carved in granite and recall others existing in the zone. The water falls vertically and impacts on a slab in V, also of granite, being channeled through a small stack until the edge gutter of the ramp.

Equally they have been conditioned with rubble masonry (originating from the debris of the tower) the erodible earthy zones appearing in the base of the wall.

Some repair work was also devoted to the original stairway partially destroyed at the base of the tower.

A temporary access stair to the top of the tower, 1 m wide, was constructed on columns raised on the concrete ribs, in order to allow the visitors to enjoy the splendid sight of the lands located to the North of the City.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
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THE RECONSTRUCTION OF COLTZEA TOWER IN BUCHAREST

E.S. GEORGESCU
The National Building Research Institute – INCERC, Bucharest, Romania

ABSTRACT

The Coltzea Tower of Bucharest was completed in 1715. It was an unique slender bell tower, with public clock, a masonry structure of over 50 meters height, with a midheight open perimetral terrace, floral, heraldic patterns and inscriptions in stone. Some tradition said that it was built by Swedish soldiers of King Charles XIIth.

The upper half collapsed during the Great Vrancea earthquake of 14/26 October 1802. For more than 170 years, even after damage, it was the tallest, most quoted building, an urban symbol of Bucharest City, until it was demolished in 1888.

The paper will present an interdisciplinary study and multicriterial analysis for recovery of architectural-structural characteristics of the Tower, using archaeological data, archives, images and stone remnants, evaluation of dynamic model and damage mechanism for the reassessment of the 1802 earthquake size, preparing a project for the reconstruction.

1. THE COLTZEA TOWER AND THE BUCHAREST IDENTITY

The now disappeared architectural and historical master piece of Middle-Age heritage in Romania (whose southern part was the Kingdom of Wallachia), the Coltzea Tower of Bucharest, was founded and built in the period 1710-1715 by the Great Landlord and High Army Commander Mihai Cantacuzino, as a part of a monastic complex, including the Coltzea Church, the first public hospital with pharmacy and a school, surrounded by a wall. It was the first building of this kind and height in European/Germanic style, in the Kingdoms of Wallachia and Moldavia (fig. 1).

For a long time, this beautiful and impressive, but unusual building, was considered by the popular tradition and belief of many historians, to have been built by some Swedish soldiers, or even by King Charles XIIth, after the Poltava battle of 1709. Some travelers of the age compared the Coltzea Tower with the San Marco Tower of Venice or with St. Stephan Tower of Vienna. [1, 2].

After the collapse of the of 1802 earthquake, the remaining part withstood until 1888, when it was demolished. For all these reasons, the Coltzea Tower was for more than 170 years the highest, the most known, and quoted building, an urban mark and symbol of the Bucharest City.

The study aims at reevaluating the historical, architectural and archaeological data useful for both earthquake protection and a full restoration – reconstruction of the tower.

2. THE COLTZEA TOWER IN THE HISTORY AND GEOPOLITICS OF ROMANIAN KINGDOMS

The relationships of Romanian countries with the Ottoman Empire during ages were complex and difficult. The founder of Coltzea Complex, Mihai Cantacuzino (1650-1716) was a son of Postelnic (High Rank Counselor, Foreign Affairs Minister) Constantin Cantacuzino (1598-1663); the rich Cantacuzinos left Constantinople (then Istanbul) in the 16th century and they became a family of elevated intellectuals defending the Latin origins and the sovereignty of Romanian Kingdoms.

During the reigns of Wallachia rulers such as Prince Serban Cantacuzino (1678-1688), Prince Constantin Brancoveanu (1688-1714) and Prince Stefan Cantacuzino (1714-1716), the Stolnic (Head of Food Central Administration) Constantin Cantacuzino (1650-1716), the brother of Mihai, was the de facto ruler of foreign affairs. He insistently worked for European integration and modern enlightenment, preferring closer relationships with Austria and Russia, and limiting the Ottoman pression, but with due care to keep a proper balance.

During the long reign of Prince Brancoveanu, culture and civilization flourished and many new monumental churches and palaces were built and a new style became dominant, as a combination of oriental, vernacular and Italian/European (Baroque) patterns, now considered as “brancovenesc” style.

The Cantacuzinos and Brancoveanu were close relatives and collaborators, but also rivals in politics, both killed by the Ottomans in Istanbul, for their European options. The ruling Prince Constantin Brancoveanu, was executed with his four sons and his Counselor Ianache Vacarescu in 1714, while The Stolnic Constantin Cantacuzino with his son Prince Stefan Cantacuzino, were killed in 1716. The Spatar Mihai Cantacuzino also perished in 1716, during the same repression.

The Coltzea Tower was finished between these tragic events. The historical sources said that besides the usual accusation of betrayal to the Ottomans, the prosecution of Brancoveanu referred to his wealth and modern and rich decorated palaces, while for the Cantacuzino family, the case was related to the building of Coltzea Tower. After 1716, the Ottomans changed the way of enforcing the rulers of Romanian Kingdoms, giving the throne to "Fanariots", faithful Greeks originating of Istanbul.

For Romanians, the belief in the legend of the Swedish constructors of the Coltzea Tower shall be considered as a message about their wish for independence and equilibrium, under the pressure generated by the three great surrounding empires.

The sympathy for the Swedish King fighting the Russians, was also a challenge to Istanbul politics, since King Charles XIIth resisted also to Ottomans who left him without support after the Poltava battle. Sulzer (1781), who presented the Tower in his book after visiting Bucharest, [6], witnessed the presence two painted soldiers in some German/Austrian type uniforms (as a matter of facts deriving from Swedish uniforms), as guards on the gate buttresses. The geo-political significance is also proved by the alleged request of the Ottoman authorities to cover the figures of Swedish soldiers with plaster. Since such a request was not yet accomplished until 1780, it seems that the rulers of Wallachia successfully resisted the Ottoman pressure.

The Russian Army in 1770 used the Tower for topographic measurements, drawing it on a map. Doussault [2] made in 1843 several engravings of the damaged Coltzea Tower. Later on, Begenau (1845) in a watercolor drawing added on the tower entrance stone "Carol XII", an inscription that never existed, while Pappazoglu [1, 4], caused scandal among historians when he put in circulation in 1879 a sketch of the Tower with the "famous" Swedish soldiers at the gate.

After the Great Bucharest Fire of 1847, the tower was locally repaired and was used again as fire watchtower, two more small timber stories being added (fig. 3), as it was, anyway, the highest building until 1888. Unfortunately, in 1887, a new campaign aimed at making the Capital City of the Romanian United Kingdoms "more European", led to new requirements for larger streets. The decision to demolish the Tower became a source of disputes, the intellectuals addressed petitions to the King Carol Ist of Romania, to save this city symbol, and a special gazette called "Coltzea Tower" was edited, but the tower was demolished.

3. THE ARCHITECTURAL-STRUCTURAL PATTERNS AND SEISMIC BEHAVIOR

The main data on structure can be found in the drawing of Oteteleseanu [1, 2] published in 1838, as it was "initially" built; Ioan sin Dobre of Batistei included a Tower description and sketch in an amateur chronic [2,3]. Besides Doussault engravings, Angerer in 1856 and Szathmary in 1869-1870 left us some photographs (fig. 2), while Niculescu got images before the tower was demolished (1887 -1888).

The Coltzea Tower was a main gate and bell tower of the Coltzea complex. The thick walls were made of masonry, the strong foundation walls of raw stone. The entrance gate was on the ground floor, under a large vault bearing, having buttresses at corners. The West façade, was decorated with a large explanatory inscription on a stone plate, with a small inscription in Greek, presumably an older tombstone ("The memory of death is useful to life", 1709), other stucco baroque ornaments etc. The side towards East was decorated with a stone plate with the heraldic symbols of Cantacuzino Family – double headed eagle in a medallion held by two lions (fig. 1).

The intermediate floors were presumably on timber beams. The midheight levels, decreased in width and included a room with sculptured door frames leading to an open terrace supported by stone cantilevers with lion heads/gargoyles. The parapets of the terrace were sculptured in stone with floral and heraldic patterns. Other round stone plates with perforated floral ornaments covered small openings. The clock room had dials on four sides and the bells occupied the next volume. The roof was very sloped, with four small corner lanterns and covered with tiles. There was a watchtower at the top, under a conical roof, two quite spherical additions covered with tin and a large cross. The total height was believed to reach ca. 54 m [4].

Panait [4], 1970, made archaeological excavations, proving the vernacular building techniques and materials, The foundations were built as a rough rectangle on an area of 10.50 m by 9 m, with the depth of 1.6 m, a double H plan, of some 100 m^2, with a current width of Tower of ca. 7 m of East and West facades and of ca. 7.5 – 8.5 m on North and South facades. Unfortunately, the foundations were partly destroyed in the 1980's, by the subway tunnel trench.

The famous "History of Bucharest" of Ionnescu-Gion, (1899) [1], mentions that in 1802 the upper part collapsed, falling towards North – East, confirming the general direction of isoseismal ellipses caused by great Vrancea earthquakes; the remaining part showed a corner damage towards N- E, below the former level of the clock, as represented in the drawings of Doussault in 1843 and in other photographs in 1856, 1870 and 1887.

It is interesting that the lower part of the Tower was not even cracked even after almost 170 years of existence, despite being subject to at least 18 large Vrancea earthquakes (magnitude over M_s= 6, intensity over MSK= 7). Out of these, the Coltzea Tower resisted the earthquakes of 1738 (M_s= 7.5, I_{max}= 9.5 MSK), 1740 (I_{max}= 8.5 MSK) and 1790 (M_s= 6.8, I_{max}= 8 MSK). The remained part resisted some other large earthquakes, as that of 1829 (I_{max}= 8.5 MSK), 1838 (M_s= 7.3, I_{max}= 9 MSK) etc. Thus, the behavior of the Tower can be considered as a proof of a Local Seismic Culture.

4. MULTICRITERIAL ANALYSIS OF ARCHITECTURAL ROOTS AND SEISMIC BEHAVIOR OF COLTZEA TOWER

Different sources of inspiration may explain the unusual aspect and architectural patterns and behavior of the Coltzea Tower. In order to select the true ones several criteria can be considered:

- historical criterion: the source to have been built long enough before 1715, in order to have time to enter in the architectural practice as a model;
- criterion of distance: the source to be in a zone where the builder usually traveled;
- criterion of relevance: the borrowed patterns to be enough similar to the originals;
- seismic criterion: which are the patterns that may provide earthquake resistance.

Concerning the possible sources from Romanian Kingdoms, the bell towers of a Wallachian and Moldavian type are squat and stiff, Romanic patterns, preserved during history due to seismic conditions and their defense role. There is a certain architectural and conceptual influence from the Transylvanian area of German colonists burgs (Siebenburgen). Such tall towers built before centuries XVI-XVII still exist in Sibiu, Cisnadie, Sighisoara, Medias, Saschiz, quite far from Vrancea seismic zone, while lower towers exist in Brasov, near the source; some other slender towers exist in North-West of Transylvania in Baia Mare, Targu Mures, etc.; in the less seismic areas the builders could have not been aware about the likely resonance effects in case of slender structures. As an opposite pattern, the height and slenderness of Germanic towers in Transylvania decreases, as they are closer to Vrancea seismic source. Some Romanian bell towers in Maramures have a similar appearance, but are made in wood.

Concerning the possible sources from Europe, the preference for a slender bell tower (campanile), can be explained as a consequence of school studies of Cantacuzinos in Italy (Padova). This influence is obvious in the idea of a public hospital, adopted from the “Lazaretto” of Venice [7], therefore some influence of San Marco Campanile can be accepted. The addition of the upper terrace gives some similarity with the campanile of Palazzo Vecchio in Firenze, Palazzo Pubblico in Siena, while the four small corner towers of bell tower of Duomo in Siena may prove another source. In case we shall consider this type of campanile “imported“ from Italy, we may understand that shallow earthquakes produce short period motions and the resonance do not occur for slender structures.

In countries with Germanic culture heritage, the the very common towers of Gothic age have most of Coltzea Tower patterns in closer countries as Austria, Hungary, Slovakia or distanced territories as Germany, Switzerland, France, Holland, Denmark, England, Sweden, Norway, etc, mostly in non-seismic zones or from countries of Germanic civilization, where earthquakes are not frequent)

Concerning Swedish sources, one should take into account that the King Charles XIIth had a specific education in architecture, planned and directed the rebuilding of Stockholm, considering a central tower. Some engravings present bell towers at the Cathedral of Strängnäs (1631 and 1723), Riddarholmskyrkan Cathedral in Stockholm, Katarina Kyrka of Stockholm, towere Jäders Kyrka, Södermanland; the modern architecture of the City Hall Tower - Stadhuset, 1911, Stockholm) continued that pattern.

Anyway, the way of an allegedly Swedish involvement is not proved; Sulzer (1771) and Cernovodeanu [3] 1966, admitted at most that some soldiers could have been barely engaged in some final works, as masters, workers, or even painters. Although there was no time for a direct involvement of King Charles XIIth in all works and he did not pass in 1714 through Bucharest, other officials from his staff did and they visited the plundered Castle of Brancoveanu at Mogosoaia.

The strength of the legend and the reported painting of Swedish soldiers at the gate, may support the hypothesis that between 1713 and 1714 some new architectural information concerning the height, functions and appearance of the upper part could have been transmitted to Cantacuzinos by some secret messengers or Swedish soldiers in disarray. A German / Transylvanian master of works could have been required at least for the installation of clock and bells manufactured in Wien [2, 4].

Therefore the Coltzea Tower can be seen a combination of a local materials, techniques and type of tower in the lower part, with an Italian open terrace, rich ornaments and Germanic patterns in the upper part (clock and roof). The mixture of structural and architectural patterns taken from seismic and non-seismic zones may explain the weakness of the upper part in comparison with the lower part.

4. OBJECTIVES , METHODS AND PHASES OF RESEARCH ABOUT THE COLTZEA TOWER

Since we miss a scientific analysis of the causes and patterns of this contradictory pattern of damage and collapse of Coltzea Tower at Vrancea earthquakes, an interdisciplinary analysis is obviously necessary. The research is important from an architectural, historical, engineering and urbanistic point of view, since the 14/26 October 1802 earthquake is considered by far the greatest in the history of Romania, with Richter magnitudes M=7.5…7.8, epicentral intensity in Vrancea I=IX-X MSK, intensity in Bucharest I=VIII MSK.

The first accelerogram useful for engineering purposes was obtained in Romania in March 4, 1977 earthquake at INCERC Bucharest site. The long period spectral content was obvious and the damage of slender structures was very spread. The Carlton Building (14 stories, the tallest reinforced concrete structure in Bucharest), that collapsed due to the November 10, 1940 (M=7.4) earthquake, is located close to the Coltzea area. Thus, the 1802, 1940 and 1977 earthquakes represent successive warnings about the risk of using slender structures under the specific site conditions of Bucharest.

Under presented circumstances, the suggested research has the following objectives and methods of study [8, 9, 11]:

- Phase 1 (1999 – 2000): preliminary study and recovery of the general tower characteristics (geometry, structure, building materials), using historical documents, archaeological data, stone remnants and alternative/comparative, multicriterial structural-architectural hypotheses;
- Phase 2 (2001): detailed dimensional characteristics and evaluation of the dynamic model and damage mechanism during earthquake and assessment of the likely seismic motion size and patterns of the 1802 earthquake in Bucharest central area, in relationship with the recorded damage, in order to improve the assessments on the "maximum credible earthquake" for earthquake scenarios;
- Phase 3 (2001 – 2002) deriving some conclusions about the correlation of the damage data with the local site conditions of the central area, possibly about the motions with a spectral content able to affect slender structures, useful for microzonation and earthquake protection of tall buildings. Preparing a project for a possible reconstruction of the Coltzea Tower.

5. A CHALLENGE FOR 2002 – RECONSTRUCTION OF COLTZEA TOWER

Almost all Romanian important historians referred to the Coltzea Tower, but their studies concentrated on the Swedish involvement and less on the architecture and structure; for a long time nobody was concerned about the Tower reconstruction, except for an exhibition about Bucharest, organized under the patronage of the late King Carol II-nd of Romania, in 1935, when the Coltzea Tower was featured as it was after 1802.

Some reconstructions of the Coltzea Complex were suggested by a medical doctor N. Vatamanu (drawings of N.Vatamanu and R. Pava in 1962 and another by R. Pava, quoted in 1974). As stone pieces remaining today in museums after the demolition of 1888 (Al. Tzigara Samurcas, 1908) [5], one can mention the great entrance stone, the heraldic stone, the Greek inscription stone; some other stone pieces, reported to be saved and last in time quoted in 1908, are not identified at present.

For the architectural and structural design of the new Coltzea Tower, the external aspect will be as closer as possible to the "initial" one (as believed to be in 1715), using for decoration some replicas of the stone remnants, the internal layout functions can be shared by a small Panorama Café in the top watchtower. It seems that after 1802 earthquake the terrace parapets were dismantled. The most important group of 12 stone plates "fleurons" that presumably belonged to the parapet of the terrace are embedded into the veranda of the Coltzea Church (fig. 4), but some dimensional inconsistencies showed that their origin and number in the original situation needs still to be proved (Georgescu, 1999) [8, 9, 11].

Since the safe reconstruction of the Tower using masonry will be almost unfeasible, a composite structure can be foreseen. Because the original location is now cut by the subway tunnel, only the drawing of the former foundation can be retraced on the pavement (as it was between 1970 and 1986); for the Tower itself, one may consider an alternative location in the very near free place close to the Northern wall of the Coltzea Hospital. A first urban study is necessary and required permits obtained. As a preliminary step for testing the urban setting and the public acceptance, one may think to an in situ Tower laser hologram, visible during the night.

6. CONCLUSIONS ABOUT THE USE OF RESEARCH RESULTS

The project is a challenge aiming to repair a historical mischance of the Coltzea Tower in 2002, 200 years after the Great 1802 Vrancea Earthquake damage and more than 100 years from its demolition. This attempt can be regarded as an active commemoration of the first Romanian “entrance” in the family of modern high-rise architecture, aiming to understand the combined roots of Romanic, gothic, late Renaissance and Baroque architecture taken from Italy and Central-Western Europe.

The author is launching an invitation for an European partnership in funding this project of research and recovery of history. The suggested study will help specialists:

- to highlight the relationships between the local architectural and structural patterns of the bell towers from Wallachia, Moldavia and Transylvania, and from the European countries of the age;
- to reveal some unknown connections of history between Romania, Turkey, Sweden, Russia etc. and the possible involvement of King Charles XIIth and his soldiers in building the tower;
- to rebuild the Bucharest historical, architectural and urban city symbol and landmark, a space with its specific destinations: bell tower, public clock, sightseeing place for city panorama, observation tower;
- to demonstrate the possible extension of the restoration concept, up to the rebuilding of important monuments, allowing thus to remember and possibly correct the mistakes of the past, that led to the demolishing of the Tower in 1888;
- to enhance the role of interdisciplinary restoration studies in earthquake prone areas, in order to understand the Local Seismic Culture, to recover and check a series of controversial historical data for heritage protection and recovery, as well as for seismological and engineering purposes.

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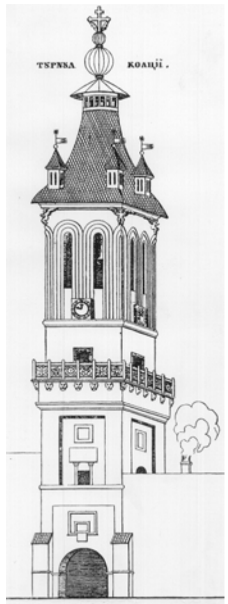

Hata! Bağlantı geçersiz.

Figure 1

The Coltzea Tower between 1715 and 1802, (Drawing by N. Oteteleseanu 1838) [1] (to the left) and the damaged Coltzea Tower, repaired after 1847, with additional timber stories for firetower, as seen from the West side (Photo around 1869, by Carol Popp de Szathmary) [1] (to the right)

Figure 2

“Fleurons” - stone plates with sculptured flower and eagle models, supposed to originate from the Tower’s terrace parapets, embedded between the entrance columns of the Coltzea Church in Bucharest (Photo E.S. Georgescu, 1999)

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ADDITIONAL REINFORCEMENT IN HISTORICAL MASONRY STRUCTURES – DETERMINATION OF ANCHORAGE LENGTH AND THE STATE OF STRESS IN ANCHORAGE AREA

P. Štěpánek (1)
(1) Brno University of Technology, Brno, Czech Republic

ABSTRACT

The contribution describes the problems of additional reinforcing of masonry structures. It deals with the experimental and theoretical analysis of the state of stress determination in the anchorage area, the anchorage length and the influence of some factors (diameter and surface of reinforcement, height and depth of grout, physically mechanical properties of the individual components) on these parameters. To find the anchorage length, the analytical formulation of basic equation and its solving was made. The mathematical simulation of the tests by the finite element method was used for the control of analytical solution.

1. INTRODUCTION

Strengthening by additional reinforcement is the effective method for reduction of cracks onset in the walls and arches of historical masonry structures. This maintenance method is largely used in practice. At present, the additional reinforcement is designed on the basis of empirical relations rather than on the state of stress analysis. Precondition of the proper function of the additional reinforcement is its anchorage in the end areas where the tension forces are transferred through mortar from reinforcement into masonry. The main problem is to determine the state of deformation, strain and stress at an anchorage area of reinforcing bar.

2. ANALYTICAL RELATIONS FOR BEHAVIOUR IN ANCHORAGE AREA

For deformation and state of stress tenseness determinations there can be deduced a simple differential equation based on a simplified model of anchorage area. The model scheme of anchorage area for analytical solution is given in Fig. 1

Fig. 1: Scheme of anchorage area

When deducing the differential equation which describes the problems of anchorage area we begin with assumptions of linear-elastic material behaviour and the validity of theory of small deformation within the case of plane stress. We also begin with the assumption that the grout transfers only shear stresses and with the assumption of the big masonry rigidity i.e. that the masonry does not deform itself.

Following the stated assumptions there can be deduced the homogenous differential equation for reinforcement displacement:

$$E_v \cdot \frac{\partial^2 u_v(x)}{\partial x^2} - \frac{o}{A_v} \cdot \frac{E_z}{2 \cdot (1+\mu_z) \cdot t} \cdot u_v(x) = 0\,, \qquad (1)$$

where E_V (E_Z) is the modulus of elasticity of reinforcement (of grout), o is the circumference of reinforcement surface, A_V is the cross section area of reinforcement, t is the thickness of grout, and μ_Z is the Poisson's coefficient of grout.

Solution for equation (1) we can find in the form:

$$u(x) = C_1 \cdot e^{a \cdot x} + C_2 \cdot e^{-a \cdot x}\,, \qquad (2)$$

where $a^2 = \dfrac{o \cdot E_z}{2 \cdot A_v \cdot E_v \cdot t \cdot (1+\mu_z)}$.

The normal stress in the reinforcement and the shear stress in the grout can be calculated from relations

$$\sigma_v(x) = E_v \cdot a \cdot (C_1 \cdot e^{a \cdot x} - C_2 \cdot e^{-a \cdot x})\,,$$

$$\tau_{xz}(x) = \frac{E_z}{2 \cdot t \cdot (1+\mu_z)} \cdot (C_1 \cdot e^{a \cdot x} + C_2 \cdot e^{-a \cdot x})\,. \qquad (3)$$

In relations (2) and (3) where C_1 and C2 are unknown integral constants which can be deduced from boundary conditions which we assume in two following variants:

a) variant A

$$\sigma_v(x=0) = \frac{P}{A_v}\,, \qquad (4)$$

$$\sigma_v(x=l) = 0 \quad . \qquad (5)$$

The second boundary condition is based on assumption that we know the length of the anchorage area 1. By this way we acquired two equations which are not dependent on each other and which are applicable for determination of constants C_1 and C_2. We can deduce

$$C_1 = \frac{-P}{E_v \cdot A_v \cdot a \cdot \left(\left(e^{a \cdot l}\right)^2 - 1\right)}, \qquad C_2 = \frac{-P}{E_v \cdot A_v \cdot a \cdot \left(\left(e^{a \cdot l}\right)^2 - 1\right)} \cdot \left(e^{a \cdot l}\right)^2 \qquad (6)$$

b) variant B

The first boundary condition will be coincident with the variant A – equation (4). At the end of the anchorage area there must be fulfilled the condition:

$$\tau_{xz}(x = l) = 0\,, \qquad (7a)$$

which is equivalent - relating the formation of general solution - to the condition

$$u_v(x = l) = 0\,. \qquad (7b)$$

By this solution we will acquire

$$C_1 = \frac{P}{E_v \cdot A_v \cdot a \cdot \left(\left(e^{-a \cdot l}\right)^2 + 1\right)} \cdot (e^{-a \cdot l})^2, \quad C_2 = \frac{-P}{E_v \cdot A_v \cdot a \cdot \left(\left(e^{-a \cdot l}\right)^2 + 1\right)} \qquad (8)$$

3. NUMERICAL MODEL OF ANCHORAGE AREA

3.1. Description and scheme of linear numerical model

The model of the anchorage area which is used for the solution by the finite element method (FEM) is formed from the block of brick masonry in which there is by means of grout anchored the additional steel reinforcement. This reinforcement is loaded with the constant load force F = 10 kN on the left end. On the left side the masonry block and one part of the grout lean on the steel slab which is stiffened by angle steel bars in such a way that there cannot happen the deformation caused by application of loading force F. In the steel slab there is placed the inlet in such a way that the anchoring reinforcement can pass through it. On the whole surface of the steel slab there is prevented from the displacement towards the reinforcement axis (the direction of the rebar axis is in accordance with the axis z). On the upper and lower surface there is fixed the slab. The brick of masonry at the upper and lower edge is prevented from displacement towards axis y. The other edges are left free. The particular materials are modelled by means of space (six wall, eight nodes) finite elements. The model scheme is in the Fig. 2.

The state of stress in the anchorage area changes in dependence on

- the inlet dimensions in the steel slab which the reinforcement passes through the placement of the anchoraged reinforcement in the masonry
- the reinforcement shape and material
- the grout shape and material
- the masonry material

- the length of the embedded reinforcement, i.e. on the length of anchorage l
- the boundary conditions (the way of supporting, loading)

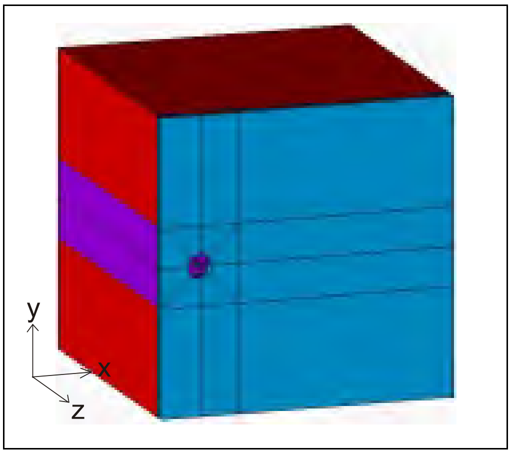


Fig. 2: Model scheme of anchorage area of masonry

In the carried out calculations (numerical and analytical) there was considered with:

- masonry as the composition material from the baked solid bricks P 15 into mortar M 150. The masonry was modelled as the continuum with substitute rigidity. For the mathematical model there were stated values according to the standard CSN 73 1101 (the module of masonry elasticity E_{def} = 5,0 GPa, the module of masonry elasticity under shear G_{def} = 2,0 GPa, Poisson's coefficient calculated from the elasticity modulus μ_{def} = 0,25 , the masonry strength under the main tension at joint failures R_{t1d} = 0,12 MPa, at failures of masonry block building materials R_{t1d} = 0,40 MPa, masonry strength under pressure R_d = 2,4 MPa
- grout PP (double- component styrene resin Poly Plus, strength under pressure after four hours is 50 MPa, after 7 days 65 MPa, strength under tension after 1 day is 6 MPa, the elasticity module E_{PP} = 25 GPa, the elasticity model under shear G_{pp} = 10,5 MPa, Poisson's coefficient μ_{pp} = 0,2)
- reinforcement H6 (HeliBar 6, the particular diameter is 6mm, the elasticity model determinated according tests - the average value E_{h6} = 115 GPa, the cross section area 9.01 mm^2). The reinforcement is modelled in the cross section as the annulus.
- reinforcement O6 (concrete reinforcement 10425 (V) according to the CSN 731201, the diameter 6 mm, the cross section area of reinforcement 28.27 mm^2, the elasticity modulus E_{o6} = 210 GPa, shear modulus G = 81 GPa, Poisson's coefficient μ_{o6} = 0,3).

Calculations within the numerical model were carried out with assumption of physically linear and physically non-linear behaviour. More detailed specification of physically non-linear behaviour and modelling was given in [1].
Studies of problems within the anchorage length by means of mathematical modelling require the accomplishment of greater amount of sufficiently precise numerical calculations. At the method of finite elements the calculation accuracy depends especially on the delicacy of model division and the kind of used finite elements. The accuracy is dependent mostly on the division delicacy within the area of introducing the force from the reinforcement into the grout and brick masonry. For the reason that reinforcement dimensions are in relation to the height and the width of the anchorage masonry too low it is necessary in the contact area of reinforcement and grout to divide the model into very small elements. According to system of reinforcement division there is dependent the division of grout and brick masonry. Contingent upon the numerical solution stability there is at the finite element BRICK 45 in the FEM program system ANSYS in the proportion of the side length within the interval (0,05; 20). By this way there come into the existence a great amount of finite elements which result into highly time consuming demands of calculations and then especially these ones which are non linear. This problem can be solved by determination of the smallest dimensions of the modelled object. According to carried out numerical studies there was found out that:

- state of stress within the reinforcement is substantially influenced by dimensions of solved block masonry cross sections which are smaller than 100/100 mm,
- the minimal applicable length of anchorage block is 200 mm.

3.2. The Influence of Grout Placement inside the Examined Anchorage Block

According to technological standards how to carry out the additional masonry reinforcement there mostly results the placement of reinforcement in a horizontal direction. The depth of the reinforcement embed from the masonry facing runs in the span between 25 - 40 mm, the effort is to minimise this depth because of easy accomplishment. In the vertical direction the reinforcement is placed into the bedding masonry gaps. The influence of reinforcement location on the state of stress of examined block in the vertical direction depending on the state of stress within the anchorage area was tested in the anchorage block with cross section diameters 300/450 mm, the distance of reinforcement mass centre from the vertical block edge is 25 mm, the distance of reinforcement mass centre from the low horizontal block edge is h = 225, 300 and 375 mm.
For each material (reinforcement, grout, masonry) the percentage force difference (relating to particular material) was expressed in selected cross sections of the anchorage block according to the relation:

$$\text{difference} = \frac{\left| F_{M225} - F_{M375} \right|}{F_{M225,poc}} \cdot 100 ,$$

where FM225 is force in given material for model h = 225 mm in cross section z, F_{M375} is force in given material for model h = 375 mm in cross section z, $F_{M225,poc}$ is force in given material for model h = 225 mm at the beginning of anchorage area (z = 0).

In Fig. 3 there is given the influence of the vertical reinforcement placement in the anchorage block relating to state of stress in particular materials for the models h = 225 and 375 mm.

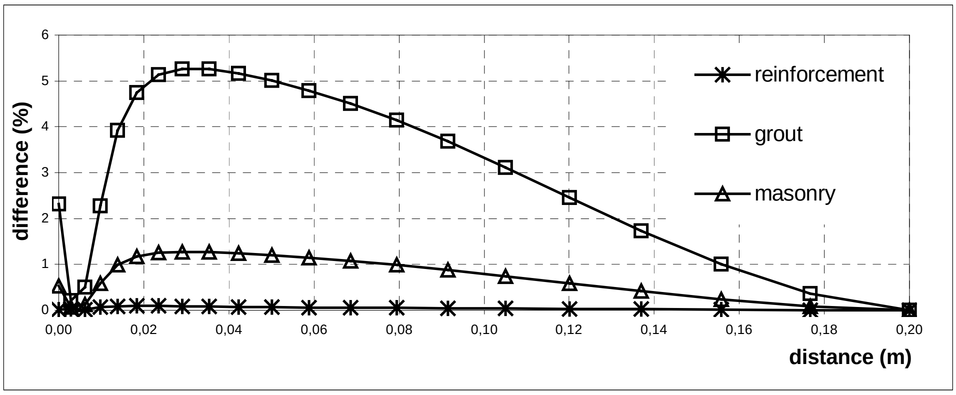


Fig. 3: Percentage difference between symmetrical and non-symmetrical reinforcement placement in the masonry

The highest differences of force appear in the grout (5.3%). To the symmetrically placed grout there is prevented from deformations into higher masonry stiffness than to grout which is placed at the edge. On the contrary the axis force of reinforcement is only slightly influenced by the placement of grout in the masonry where the differences in reinforcement forces are the smallest of all the three materials (smaller than 1.5 %). This is given by the fact that with the change of grout placement in the masonry the consistence in the nearest reinforcement surrounding does not change environs at all. It can be claimed that the reinforcement placement inside the masonry block does not substantially affect the length of the anchorage area.

3.3. The influence of inlet size in the steel slab

At experimental tests of anchorage area the brick block and one grout part lean on the steel slab. This slab prevent from displacement within the axis z. So that the reinforcement at the beginning of anchorage area can be loaded with the axis force that is why there is the circle inlet inside the steel slab. The influence of the inlet radius inside the leaning slab in relation to state of stress in the anchorage area was examined numerically. There were solved cases in which the inlet diameter was chosen as the x multiple of the anchorage bar diameter (signification of solved variants is K-x, x = 3, 5, 7 and 11). In Fig. 4 (respectively 5) there is drawn the dependence of force introduced into the masonry (respectively in the grout) in relation to the length from the beginning of anchorage.

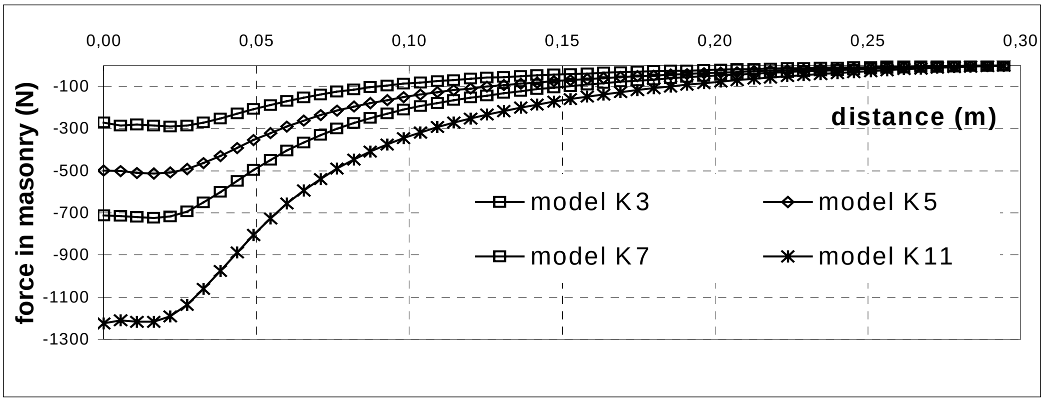


Fig. 4: Force in masonry

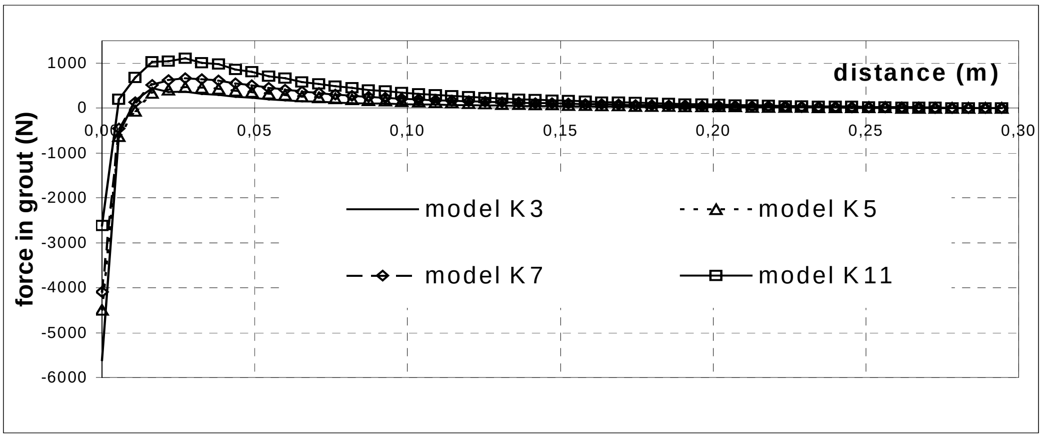


Fig. 6: Force in grout

It can be claimed that with the diminishing inlet diameter the force in the reinforcement decreases faster and by this way the distance needed for transforming the force from the reinforcement into the grout shortens. As a result there appears the diminishing of the anchorage length. Between the model K-3 and the model K-11 there is the difference of anchorage length by 30 mm.

3.4. The influence of reinforcement form

The reinforcement Helibar 6 has the shape of a helicoids which can be only determined with difficulties when modelling FEM. That is why there were used for numerical solutions simpler geometrical substitutions which follow the assumption of the same reinforcement area cross section and the same contact area between the reinforcement and the grout

- Substitution SMEZ - substitution with constant cross section in the shape of the annulus within the whole length
- Substitution SZ 2 (Fig. 6). The reinforcement is formed by two coaxial rollers of different diameters. There is dealt with the basic bar profile which is complemented with digs modelling the influence of the special shape on the reinforcement surface. The distance of digs is coincident with the rise of the spiral thread; the length of the dig is chosen to be 6 mm. The radius of the rig was determinated so as the contact area of this substitute was coincident with the original reinforcement. The load transmitting from the reinforcement into the grout is considered along the whole surface of the substitute.
- Substitute SZ 1. Geometrically the same forms as at SZ 2. It is supposed that the load is not transmitted into the tension contact part of the dig and the grout.
- Substitute SZ. The same as SZ 1, neither the traction nor the push side of the dig are calculated into the contact area.
- Substitute S - the bar of a circle cross section with the radius which is equivalent to the cross section area of reinforcement.

Longitudinal section Cross section

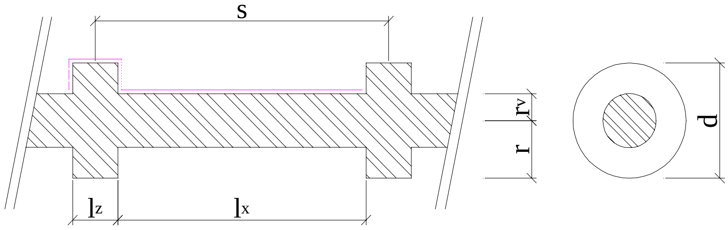


Fig. 6: Form of the geometrical substitution of the Helibar reinforcement

Courses of normal forces inside reinforcement for the model SMEZ and S are practically identical. On the contrary the course of shear forces within the reinforcement length is for particular substances different, most at the beginning of the anchorage area. The appropriate form choice of the substitute bar and the way of load transmitting has the domain signification and this especially at non-linear calculations.

4. EXPERIMENTAL OBSERVATION

Tests on anchorage reinforcement inside the blocks of brick masonry have still been carried out on six experimental objects (anchorage blocks); next tests are being prepared. Three objects were reinforced with concrete reinforcement V6 (signification according to the standard CSN 73 1201), three blocks were reinforced with rust-resistant reinforcement HELIFIX. On the reinforcement there were brazed with brass labels which measured the deformations within the bar length, on the rust-resistant reinforcement there were not attached the labels so as not to decrease the reinforcement tension strength when brazing.

The lengths of anchorage reinforcement inside the blocks were at particular experimental objects 600, 450 and 300 mm. Inside the block there was always only one reinforcement bar. The labelling of particular experimental objects is as follows: X-l, where X indicates the reinforcement type (X = B for concrete reinforcement, X = H for rust- resistant reinforcement), l is the length of reinforcement anchorage in mortar (l = 300, 450 and 600 mm).

Blocks with reinforcement V were not pinched in vertical direction, the second trio was pinched with joiner clips - the upper surface with steel slab against the lower board made from steel slab. On the loaded bar end there was attached the cleat with thread M8. On the facing part of the block there was attached with gyps mortar the steel slab for the loading equipment. There were measured the following values:

- change of width along the horizontal and vertical masonry gaps
- displacement of reinforcement within the bar length
- displacement of the end of the reinforcement bar

The scheme of tests arrangement and diagrams of measured values can be found in Fig. 7 and 8.

Fig. 7: Scheme of tests arrangement within the reinforcement anchorage in masonry

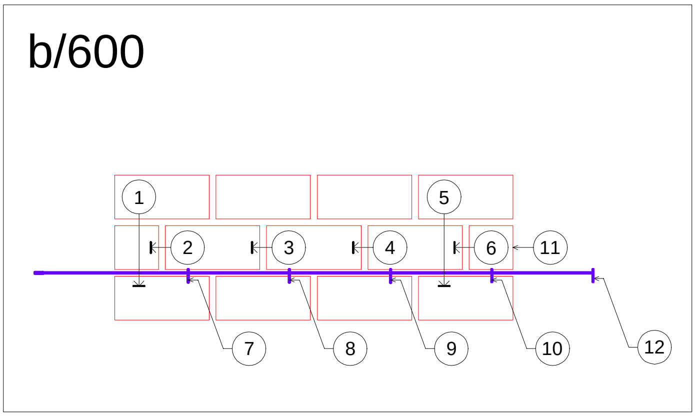


Fig. 8: Measured values

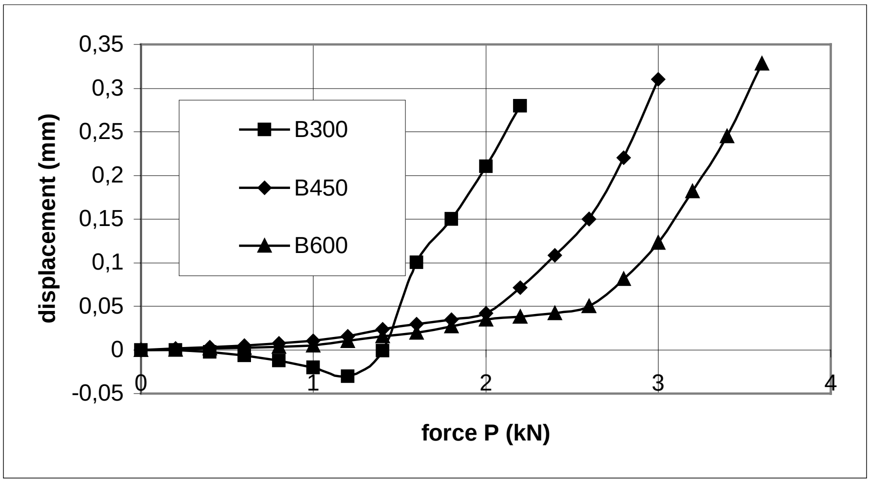
In Fig. 9 there is drawn the relation of free end reinforcement displacement in dependence on acting force. In comparison with experimentally found out relations for the concrete reinforcement and the reinforcement HELIFIX there is obvious that:

- the anchorage length of HELIFIX reinforcement is smaller than 300 mm, the anchorage length of concrete reinforcement is higher than 300 mm
- the anchorage of HELIFIX reinforcement in lengths 300 and higher failures at reinforcement tensions which are more than 700 MPa, at concrete reinforcement there was the tenseness at anchorage failures about 80 - 90 MPa
- the relation graph of non loaded end in dependence on acting force inside the reinforcement is considerably rigid - plastic while at concrete reinforcement there appears the dependence elastic - plastic

4. THE ANCHORAGE LENGTHS, CONCLUSIONS

The table 1 presents as the absolute values of anchorage lengths as the relative values of anchorage lengths in relation to the diameter of used reinforcement for various moduli with various grout elasticity which were found out by analytical, numerical and experimental solutions. In results there was not comprised the enlargement of anchorage lengths as a result of safety access as this was introduced e. g. by EC.

The relation of the anchorage length in dependence on the reinforcement diameter was found out within mathematical models. The values of anchorage lengths for the bar Helifix are stated in the table 2 (without considering the influence of safety access).



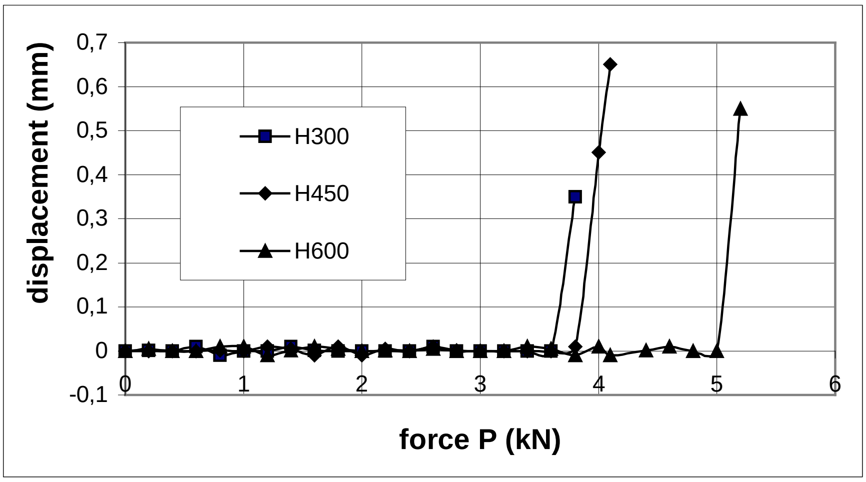


Fig. 9: Relation of free end reinforcement displacement in dependence on tension force

ACKNOWLEDGE:

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Table 1: Anchorage lengths

Reinforcement Type	Modulus of grout elasticity	particular diameter of reinforcement (mm)	absolute anchorage length (mm)			anchorage length as multiple of reinforcement diameter		
			Numerical solution	Analytical solution	Experiment	Numerical solution	Analytical solution	Experiment
Heli fix	7,8	6,0	155	130	<300	25,8	21,6	
	22,0	6,0	130	78		21,6	13,0	
	30,0	6,0	115	66		19,1	11,0	
Concrete reinforcement	7,8	6,0	385	312	370	64,1	52	61,7
	22,0	6,0	242	213		40,3	35,5	
	30,0	6,0	165	106		27,5	17,7	

Table 2: Anchorage lengths from mathematical modelling

reinforcement diameter (mm)	cross section area of reinforcement (mm^2)	absolute anchorage length (mm)	anchorage length as the multiplier of reinforcement diameter	anchorage length as the multiplier of root from reinforcement diameter
3,387	9,01	82	24,21	44,56
6,0	28,27	107	17,83	43,68
8,0	50,27	125	15,63	44,19
10,0	78,54	138	13,80	43,64
12,0	113,10	153	12,75	44,17

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ICOMOS TURKEY

A COMPREHENSIVE APPROACH TO THE REPAIR AND STRENGTHENING OF MILITARY FORTIFICATIONS: APPLICATION TO THE DEL CARETTO BASTION IN THE CITY OF KOS

Ch. Papadopoulos (1), E.-E.Toumbakari (2), V. Georgali (3), Ch. Vachliotis (1)
(1) “Domos” Consulting Eng., Athens, Greece
(2) National Technical University and Office for the Acropolis Conservation, Athens, Greece
(3) EKET, Hellenic Cement Research Center, Athens, Greece

ABSTRACT

On the basis of a case study, the bastion Del Caretto in the city of Kos, a methodology for structural assessment is proposed, which appears applicable to similar structures. The fortifications of the city of Kos were built between the 15th and 16th century. The structural problems of a specific area of the monument, the bastion Del Caretto (named after the great Magister who initiated its construction in the 16th c.) consist of wide cracks that run vertically and horizontally at the level of the keystones at the interior spaces as well as certain exterior locations of the bastion. The first part of the investigation comprises the characterization of the existing mortars. The understanding of the constructional details and of the building materials and their pathology forms the basis for the subsequent structural analysis. The main results of the analysis are commented and compared to the observed structural pathology. Finally, the structural evaluation of the bastion offers the basis for the proposition and justification of the interventions.

1. INTRODUCTION

Fortification walls and other defensive structures form a large part of the built Cultural Heritage. Nowadays, many of those structures pose serious conservation problems, either due to the deterioration of their building materials or the damage of the bearing structure system or both. Nevertheless, the literature on this issue is rather limited. Aim of the present paper is to describe the conservation study relative to the bastion Del Caretto in the island of Kos. On the basis of this case study, a methodology is proposed, which appears suitable to this type of structures

2. DESCRIPTION OF THE MONUMENT AND THE PROBLEM

2.1. The fortifications of the city of Kos and the bastion Del Caretto

The fortifications of the city of Kos are located on the peninsula that forms the eastern part of the city port. The bibliography regarding the ancient and byzantine fortifications of the pensinsula is very limited. The present fortifications were built on the foundations of the previous phases and have undergone many repairs and modifications, especially under the rule of the Knights. The defense system consists in two fortification walls, one interior and one exterior, which were constructed at two different periods. This succession and the specific construction typology highlight the transition from the use of traditional weapons to the artillery. The interior wall was built at the beginning of the 15th c., whereas the exterior is dated back to the end of the 15th c. to the beginning of the 16th c. and was constructed as a defense against the Ottoman expansion that was taking place at this period. Since then, the fortifications underwent various repairs and interventions. The last ones were performed between 1912-1920 approximately. The Del Caretto bastion, which is the subject of the study, is located at the southwestern corner of the exterior fortification wall. It has the shape of a truncated cone. The interior consists of two galleries with scuttles, where the cannons were placed. The first is located approximately at the base of the bastion, whereas the second is constructed at the half of the total bastion height. Finally, at the bastion's terrace six more scuttles were also constructed. Thus, cannon shots could take place at three different levels. The bastion elevation plans are shown in Figure 1 and Figure 2.

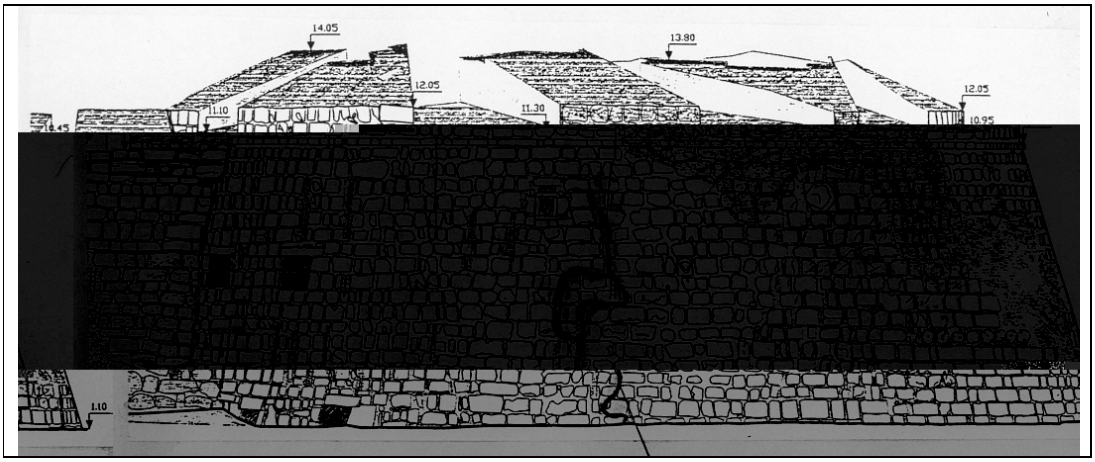


Figure 1. Northwestern elevation of the bastion

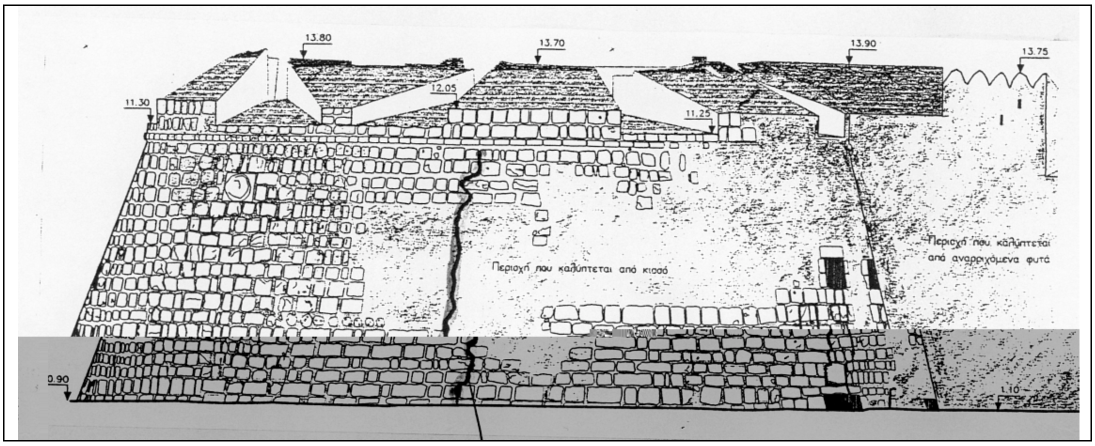


Figure 2. Southwestern elevation of the bastion

2.2.Position of the problem

The bastion Del Caretto presents structural and conservation problems. The structural survey identified the existence of vertical and inclined large cracks at the exterior wall surface. A network of smaller cracks alongside vertical large cracks on the keystone and the sides of the vaults of both galleries (probably corresponding to the external ones) is also recorded [1]. In addition, there exist conservation problems related to uncontrolled water penetration and high relative humidity inside the galleries.

Within the framework of a scheduled broad conservation campaign, it was decided to begin with the assessment of the structural condition of the Del Caretto bastion. The architectural study was already completed [2].The setup investigation programme comprised the assessment of the state of conservation of the bastion, the structural analysis and the interpretation of the origin of the structural pathology, the assessment of its possible evolution and the determination of repair measures to be taken, including the design and application of repair materials.

3. INVESTIGATION PROGRAMME

3.1. Sampling of building materials

This is considered as the first step to the investigation. The characterisation of the mortar types offers a justified basis for the design of the repair materials. Moreover, it permits the evaluation of the mortars' mechanical properties, which, together with the corresponding properties of the building stones, is necessary for the structural modelling and analysis.

After a thorough inspection not only of the Del Caretto bastion (but also of the rest of the fortifications), sampling of mortars was performed at different locations at the interior and exterior of the bastion. Criteria for sampling were (a) the representativity of the locations, (b) the variety of the encountered mortars and (c) the possibility of obtaining sufficient materials quantities, in order to perform the necessary laboratory tests. As the decisions regarding the sampling positions and the subsequent analyses are based on the macroscopic assessment of the mortars – and should usually be performed on a limited time period -, the following guidelines are of importance:

1. A good collaboration with the responsible architects and archaeologists is necessary, in order to derive information on the various constructional phases.
2. It is of the utmost importance to gather information regarding the origin of the building materials. If there are local technicians, they should be consulted because they often give valuable informations. Also, if there are local habits regarding construction, they should be known.
3. A rough mapping of the various mortars and constructional phases must be done, before sampling may begin.
4. Even if the characterisation of the pathology of the materials is not part of the study, it should be considered for two reasons: samples for characterisation of the mortar type should be obtained from sane material. Thus, it might be necessary to remove the altered external mortar layers before obtaining good samples for analysis. Moreover, the pathology gives information regarding the design of the repair materials.

3.2. Experimental program for the characterization of the building materials

The experimental programme was designed to comprise tests, which permit the characterization of the existing mortars but, also, quantify properties that should be considered for the design of the repair mortars. The performed tests were: (a) petrographic analysis of thin sections; (b) determination of the insoluble residue content; (c) determination of the apparent density and porosity and (d) X-ray diffraction analysis. Chemical analysis was also performed in order to provide support to the conclusions of the previous methods. The required information concerns the type of the aggregate and the type of the binder, the grain-size distribution of the aggregate and the determination of the binder : aggregate ratio. This information in combination to the values of the physical characterisation (density, porosity) performed on the mortars as well as the stones are considered necessary for the design of the repair mortar. The petrographic analysis was performed with a JENAPOL (Karl Zeiss Iena) optical microscope. The X-ray diffraction analysis was carried out with a RIGAKU D/MAX-IIIVC Geigerflex diffractometer. The determination of the insoluble residue was done with HCl acid attack following Norm EN 196-2, whereas the apparent density and porosity were determined following Norm EN 993-1. The oxide determination was done through titration, whereas the alkalis content was determined through AAS. For the characterisation of the building stones, petrographic analysis of thin sections, density and porosity determination and compression mechanical tests were mainly performed.

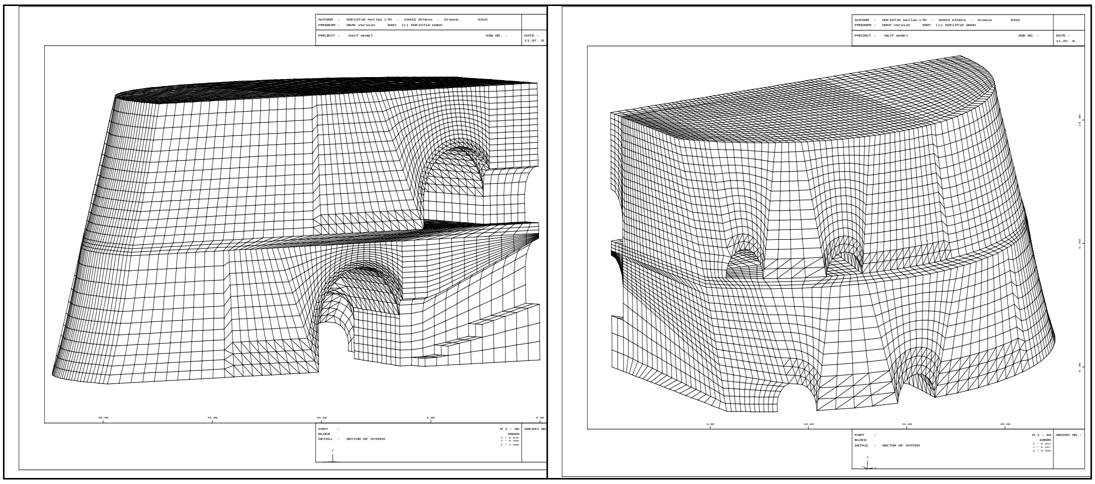


Figure 3. Model’s axonometric views.

3.3. Structural analysis approach

The bastion model

Modeling techniques widely applied in the field of geostructures, have been adopted at the analysis process, as the bastion’s structural system fairly resembles to that of an underground geostructure with galleries. The outer and inner stone masonry leaves are modeled with shell finite elements of various thickness (ranging between 80cm and 120cm), depending on the type and the location of each element group (e.g. group of higher gallery inner leaf etc). The internal loose masonry filling (mixture of raw stones, ballast and mortar) is treated as a typical granular soil material and is modeled with brick finite elements. The Young’s modulus ratio between masonry leaf and filling material is assumed conservatively about 10. Spring elements with suitable vertical stiffness (according to the finding of the geotechnical investigation) simulate the soil-structure interaction, whereas horizontal restraints have been adopted at the bastion-metabastion walls boundaries. The properties of those elements are based on the results of the materials’ experimental programme.

A linear elastic analysis is performed as it provides a global and sufficient view of structural behavior, in respect with the computational effort it requires. A non-linear analysis, adopting non-linear material constitutive laws is rather non-justifiable, considering the uncertainties of the material properties and the high computational cost it demands. Besides, the material law should be robust enough to fulfill practical requirements of the design. For the analysis the software package ASE of Sofistik GmbH is used. Axonometric views of the interior and the northwestern elevation are illustrated in Figure 3.

The bastion response under seismic action

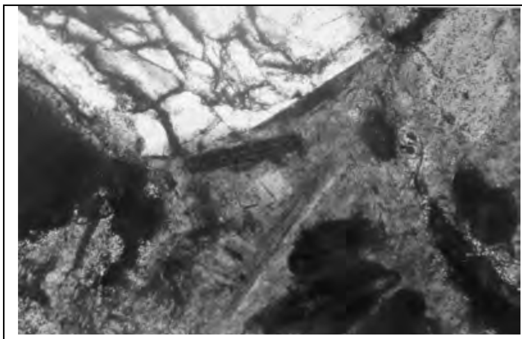
The structural system morphology (massive and robust stone walls) dictates a synchronous motion with the ground, instead of an independent vibration under a seismic event. Consequently the structure's seismic response corresponds to the starting point of the ascending branch (period T<0.2sec) of the seismic spectrum, (e.g. $\alpha_0 = \alpha_{g,\ max}$). According to [3] the peak horizontal acceleration (with a recurrence period of 500 years), for the island of Kos is $\alpha_{g,\ max}$ = 0,25g. Considerable attention should be given to obtaining reliable field data concerning the in-situ soil conditions, which modify dramatically the expected site response. Seismic action has been applied to the model as an equivalent static loading. The structural analysis for the earthquake loading justified a primary hypothesis readily arisen from the bastion macro-scale pathology observation. Earthquake is not a predominant action for the bastion distress, though it may locally aggravate stressing conditions from permanent loads. Photos available in the local archives, taken before the 1933 catastrophic (for the island of Kos) earthquake, testify that the intense vertical cracks on the outer leaf of the bastion preexisted and could not be attributed to a severe past seismic event.

4. RESULTS AND DISCUSSION

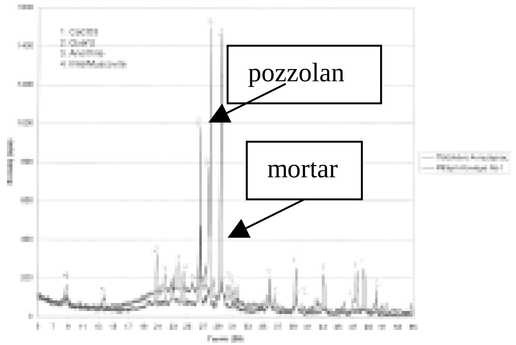
4.1. Characterisation of the in situ materials

The petrographic analysis revealed the presence of both siliceous and calcareous aggregate. The most often encountered siliceous aggregate are quartz, feldspars and pumice. The aspect of the paste is attributed to the presence of submicrocrystalline calcite, which probably originates from the carbonation of calcium hydroxide. Similar results are obtained in all the thin sections studied. A ccharacteristic photo is shown in Figure 4 (a). The presence of reaction rims around certain aggregate permits, as a first step, to assume that the studied mortar is hydraulic, and precisely of the lime-pozzolan type. After investigation of the building habits and techniques in collaboration with the local craftsmen, local raw materials, which seemed to have a pozzolanic action ("earth of Antimacheia") were obtained, analysed and compared with the available samples. The results of the X-ray diffraction analysis are shown in Figure 4 (b).

The X-ray diffraction permitted to identify the presence of anorthite, muscovite/illite and a substantial amount of amorphous material within the "earth of Antimacheia". The same phases are found in the mortar, in which, in addition, calcite is also detected. Moreover, the presence of a diffused band is associated to the presence of amorphous material in the two samples. The agreement between the two diffractogrammes is excellent and supports the evidence already obtained through optical microscopy. Thus, the mortar type can be considered of lime-pozzolan one and, moreover, the used pozzolan was possibly detected.



(a)



(b)

Figure 4. (a): the inhomogeneity of the paste is evident as well as the reaction rim at the interface between paste and siliceous aggregate (x Nickols x200) – (b): Comparison between the diffractogrammes of the earth of Antimacheia and sample 1 (fraction smaller than 63μm)

Additional characterisation comprised the evaluation of the grain size distribution of the aggregate, which was measured on each thin section. The determination of the paste : aggregate ratio was performed following the point-counting method and gave results between 1:3.5 and 1:3.8. The apparent density and porosity of the samples is shown in Table 1. The relative scatter of the obtained values (even within the same sample) highlights the inhomogeneity of the mortars. Finally, the chemical analysis performed on one sample is also presented in Table 1. The high content of CaO in combination to the low Insoluble Residue content suggests the existence of limestone aggregate within the tested sample. Thus, the results are not representative of the binder composition. Nevertheless, the percentage of the total oxides is an indication of the presence of an important content of soluble silica (not measured). The type of siliceous aggregate contained in the samples is not susceptible to yield substantial amounts of soluble silica under HCl attack. Thus, the expected high soluble silica content would be attributable to calcium silicate hydrates, which are the main phases of a hydraulic binder [4].

Table 1. Physico-chemical characterization of the sampled mortars

Sample N°	**Apparent density [g/cm^3]**	**Apparent porosity [%]**	**Chemical analysis of a mortar sample**	
1	1.38	39.06	% Ins.Res.	6.37
1	1.67	31.61	%Al_2O_3	0.36
1	1.32	41.34	%Fe_2O_3	0.20
20	1.60	35.07	%CaO	41.66
average	**1.49**	**36.77**	%MgO	0.40
			%K_2O	0.044
			%Na_2O	0.035

4.2. Results of the structural analysis

The macro-scale pathology of the bastion, consisting mainly of wide extensive vertical cracks on the outer stone leaf and severe crack patterns at the intrados of the galleries' vaults, is primarily attributed to gravity loading. Structural analysis establishes that all the cracks located at the intrados of the galleries' vaults, are attributed to dead overloading. The high overburden filling layers loading the vaulting system, generate significant tension stresses (Figure 5), resulting to intense crack patterns. The bastion structure exhibits a prevalent axial splitting behaviour, apparent on the outer stone leaf, attributed to vertical loading and to the high geostatic lateral pressures of the loose filling material. In order to clearly illustrate and appraise the axial splitting effect, a simplified model of a truncated cone (cut at the top) is generated. The model is analysed with the 3D finite difference program FLAC 3D of ITASCA. FLAC 3D simulates the behaviour of structures built of geomaterials (soils, rocks, etc), that may undergo plastic flow when their yield limits are reached. A discretization of the different structural zones (e.g stone leafs, loose filling, etc) corresponding to different material properties is performed. Simple constitutive laws (with appropriate constitutive parameters based on the findings of the investigation program) following the Mohr-Coulomb failure criterion are adopted for each material zone. The simplified model is analyzed only for vertical loading. Model views, principal stress vectors and max principal stress contours are depicted in Figure 6.

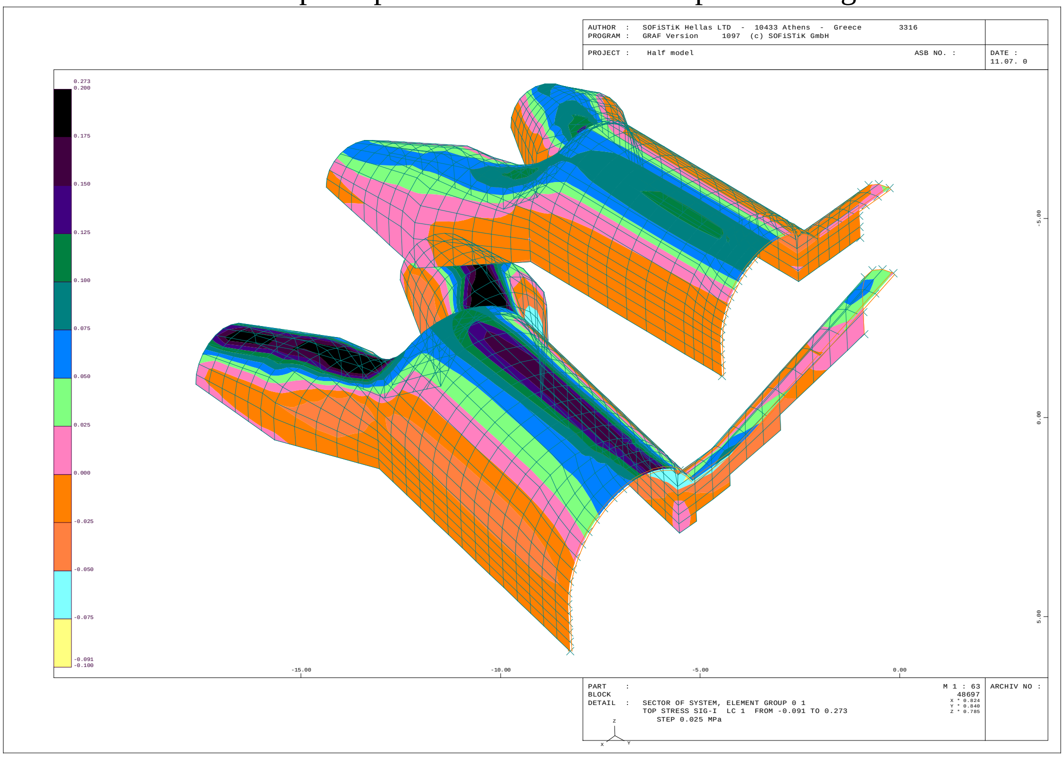


Figure 5. Max principal stress contours at the intrados of the galleries' vaults.

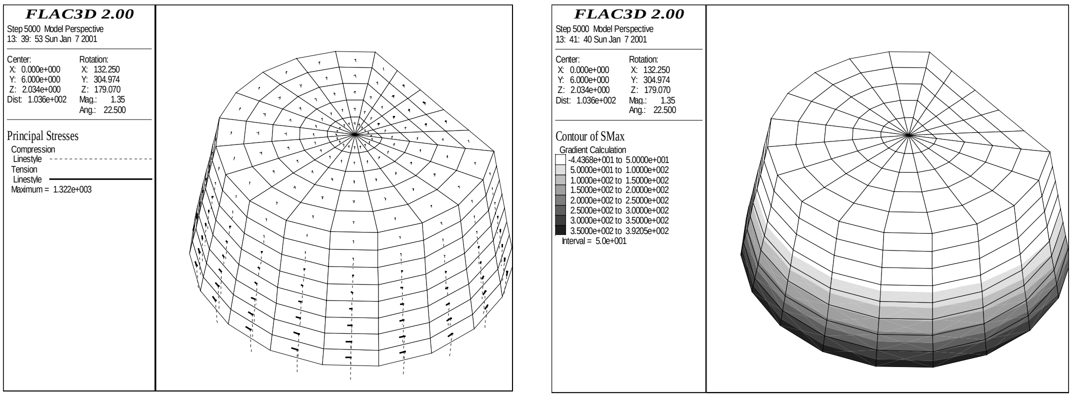


Figure 6. Principal stress vectors and max principal stress contours for the simplified model.

Maximum principal stress developing at the basement of the bastion exhibit peripheral vectorial direction with magnitude about 0.4 MPa, significantly higher than the outer masonry's leaf typical tensile strength (≈ 0.15 MPa, considering the masonry type and the properties of the constituent materials, as obtained by the corresponding analyses). The resulting stress pattern could cause vertical crack bursting, localised in weak areas with concentrated irregularities, so justifying satisfactorily the observed severe extensive cracks at the outer leaf.

4.3. Selection of repair measures

On the basis of the conducted studies, the principal conclusion is that the structural state of the bastion is stable and a careful monitoring of the cracks' evolution is sufficient at the moment. Thus, the structural analysis permitted for large interventions to be avoided. The conservation problems may be treated with mild interventions, which comprise the application of a repair mortar in the damaged areas and a flowable mortar (or concrete) in order to seal the big vertical cracks at a depth of approximately 0.8-1m inside the structure. The design of the repair materials (mortars, grouts) is based on the characterisation of the existing ones, in order to assure compatibility between them and to use, as much as possible, local raw materials. Finally, measures for the impermeabilisation of the bastion terrace and for the elimination of the high relative humidity of the galleries are proposed.

CONCLUSION

Fortification walls and defensive civil engineering structures constitute a large part of the built Cultural Heritage. The conservation problems that have arisen in the past years require a global approach for their solution. The first aim of the paper was to describe a methodology suitable to this approach. In addition, it discusses computer modeling issues for the structural analysis of this type of monuments.

Finally, it shows that the analysis of the building materials is not only useful for documentation reasons, but also it is necessary, in order to provide data for the structural analysis as well as the design of the interventions. Especially in earthquake-prone areas, such a global approach is fundamental in order to assure the safe repair and strengthening of the structure with the least possible interventions.

Acknowledgements

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
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STRENGTHENING AND TRANSPOSITION OF THE CHURCH OF THE TORNIKI MONASTERY IN GREECE

George G. Penelis (1), Kosmas C. Stylianidis (1), Ignatakis E. Christos (2)
(1) Professor, (2) Assistant Professor
Dept. of Civil Engineering, Aristotle Univ. of Thessaloniki, Greece

ABSTRACT

The Torniki Monastery complex, situated in north-western Greece, was built during the 14th century by Aliakmon river. A series of damages due to aging appeared to the abandoned complex and were intensified by the Kozani-Grevena earthquake (1995). The Church of the Monastery is a heavy two-storey stone masonry building having an interior totally covered by frescos of high artistic and historical value. The location of the Monastery complex is going to be flooded by the artificial lake of the dam of St. Ilarion. The only way to preserve the historical Church is its strengthening and transposition to the top of the nearby hill.

The first stage of the project refers to the design of the strengthening measures, including grouting, repointing, repair of the existing wooden tie beams, instalation of new steel longitudinal and transverse t

ie-rods and measures to secure the frescos against unstucking. The second stage of the project includs the design of the transposition technique finally approved, which consists of the uplift of the monument and its transposition as a whole on a linear steep sloped ramp, made of railroad tracks, to the top of the hill.

1. INTRODUCTION

The Torniki Monastery complex was built during the 14th century near Aliakmon river, a few kilometers from the village Panagia of the department of Grevena (Northern Greece). It consists of a two-storey Church (Katholikon), a wing of cells and secondary buildings (Fig. 1). The Monastery has been abandoned for a long period of time and it has suffered a series of damages due to aging, which were intensified by the Kozani-Grevena earthquake (1995). Temporary shoring centered to the Church was carried out before and after the earthquake by the competent 11th Ephorate of Byzantine Antiquities and a metal protective cover was constructed. Since the Greek Public Power Corporation (P.P.C.) intends to exploit the hydroelectric potential of the Aliakmon river, the location of the complex is programmed to be flooded by the artificial lake of Ilarion dam. The Lab of R/C structures of the Aristotle University of Thessaloniki has been assigned by P.P.C., in cooperation with the 11th Ephorate of Byzantine Antiquities, to carry out a research programme, aiming at the investigation of the strengthening and the transposition of the Church at the top of a nearby hill, above the level of the dam. The rest of the complex will be abandoned, but the possibility of partial reconstruction at the new location is under consideration.

This paper is a detailed presentation of all the phases of the strengthening study, as well as of the preliminary study of the transposition. It must be pointed out, that the strengthening of the Church has already been completed.

Fig. 1 General view of the Monastery from the south

2. IN SITU AND LABORATORY MEASUREMENTS AND RESEARCH

2.1 General

The 11th Ephorate of Byzantine Antiquities has delivered to the research team surveying and pathology drawings of the complex, photographs for documentation and a Technical Report concerning the architectural restoration [1]. The P.P.C. has also delivered the topographic diagram and the geological study of the nearby hill, where the Church is about to be transposed.

2.2 Geometrical - Structural surveying of the Church

The Church is a two-storey stone-masonry structure covered by a semi-circular barrel vault and it has in plan dimensions 4.5x6.5m at the ground floor and 4.5x5.9m at the first floor. The vault is covered with tiles resting on mortar. The inclination of the tile covering must have been reduced in the past, since an uplift of the crown with flagstone masonry can be seen at the north and south wall (Fig. 2). The wooden floor of the first storey is covered with ceramic tiles. The height of the ground floor is 4.00m and the height of the first floor is 3.75m. The respective wing of cells, is in touch but has no structural connection to the Church. On the eastern wall of the Church, there are semi-cylindrical projections covered by tiled quadric-domes forming the apses of the sanctuaries of each floor. It must by noted that, owing to the fact that the first floor has smaller length than the ground floor, the eastern wall of the former is not resting directly on the wall underneath, but on a vault having two embedded strong wooden beams resting on the transverse walls of the ground floor. Small openings and apses appear on every wall, but specifically on the eastern wall there is one big apse (prothesis) next to the sanctuary on each floor.

Fig. 2 North wall of the Church

The vault is made of flagstone masonry, whereas the walls, 50 to 60cm thick, are made of quarry stone and small parts of stones and tiles wedged into the uneven lime mortar joints. Some ashlar corner stones have also been used in the structure. The mortar is quite strong and it is made of the characteristic gray sand of the Aliakmon river. The exterior side of the walls is not plastered, whereas the interior surfaces are plastered and fully covered by frescos. The foundation is shallow (50 to 70cm) without widening of the stone-masonry. Owing to the inclination of the bed-rock the sanctuary is resting on deposits, whereas the rest of the Church is resting on conglomerates. The wooden beams, embedded in the masonry, are not continuous and not crossed at the corners. The north and south longitudinal walls are connected to each other by two wooden tie-rods per storey and by four wooden beams at the floor of the first storey.

2.3 Pathology - Materials - Temporary interventions

The eastern wall of the Church has a series of structural weaknesses leading to stability problems, such as the eccentric placing of the wall of the first floor in relation to the ground floor, the interruption of continuity, the weakening and the inability of the wall to act as diaphragm, due to the openings and apses, and the absence of continuity of the wooden-beams, which are cut off by the projections of the sanctuaries. These weaknesses, in combination with the loosening of fixed ends of the wooden tie-rods and the thrust of the vaults, caused cracking along the key stones of the vault and the quadric-dome of the sanctuary at the first floor, local collapse of the sanctuary of the ground floor and disconnection along the height of the northeastern and southeastern corners. The earthquakes in 1995 intensified the cracks, thus resulting to the light rocking of the eastern wall of the first floor around the strong wooden beams of the floor. This rocking caused local collapse of the sanctuary of the first floor and disconnection of the eastern part of the vault (Fig. 2,3). The total collapse of the Church was prevented by the strong wooden beams, supporting the eastern wall of the first floor and connecting the north to the south wall, as well as the dense and strong internal and external shoring and buttressing of the Monument by the 11th Ephorate of Byzantine Antiquities.

Chemical analyses and strength tests on healthy specimens of virgin mortar proved that it is a strong lime mortar made of coarse sand having a high percentage of binding material (binder/aggregates ≈ 1:1) and compressive strength in the order of 1.5 to 2.0 Mpa. The wooden tie-rods are in a relatively good condition except from their ends in the masonry, where intense corrosion is observed. The external wooden beams are in bad condition, some of them being completely disintegrated. The walls are heavily cracked, especially at the eastern part of the Monument. The metal cover, which was constructed after the earthquakes in 1995, prevented the complete destruction of the frescoes from rain coming in through the gaps of the vaults and the walls.

3. STRENGTHENING STUDY OF THE CHURCH

3.1 Static analysis - Justification of damages

In order to estimate the bearing capacity and to justify the damages appearing at the monument, the structural system of the Church was modeled and analysed.

- Method of analysis: Linear elastic analysis with the programme SAP 90.
- Model: 966 shell elements for the masonry and 10 beam elements for the wooden tie-rods and the beams of the floors.
- Mechanical characteristics of the stone-masonry:
  - Characteristic compressive strength: $f_k = 4.5MPa$
  - Design compressive strength: $f_d = f_k/\gamma_M = 4.5/3.0 = 1.5MPa$
  - Modulus of elasticity: $E_w = 3000MPa$
- Loading:

- Combination of vertical loads: 1.10G+1.50Q
- Design seismic coefficient: $R_d(T)$ = 0.324g, in correspondence to the Greek aseismic code for high importance structures made of stone-masonry with horizontal embedded wooden beams and fundamental period T = 0.13sec.

- Scenarios for historical phases - Changes of the model:
  - Virgin condition: Active tie-rods, fixed foundation, (model I).
  - Loose tie-rods: Inactive tie-rods, fixed foundation (model II).
  - Differential settlement of foundation: Active tie-rods, foundation on elastic ground with linear reduction of the spring constant of the ground at the region of the sanctuary (model III).

Following results and conclusions were drawn from these analyses:

- Model I: Satisfactory behaviour with local cracking at the walls and the vault. Intense damage caused by exceeding tensile and sometimes compressive strength at the sanctuaries due to the defective bearing system. Intense activation of the wooden tie-rods.
- Model II: Worsening of the condition with cracks at the supports and the key of the vault and the crown of the walls.
- Model III: Worsening of the condition at the region of the sanctuaries and cracks at the eastern parts of the north and south wall.

3.2 Rehabilitation and strengthening interventions on the bearing system

On the basis of analysis results and the pathology of the structure, interventions aim at the following:

1. Rehabilitation of the continuity and the structural integrity of masonry.
2. Rehabilitation of the function of tie-rods or introduction of new ones.
3. Strengthening of the wall intersections at the northeastern and southeastern corners.
4. Strengthening and improvement of the response of the eastern wall.

Suggested interventions are:

1. Rearrangement and strengthening of shoring.
2. Removal of the tile cover from the vault and quadric-domes of the sanctuary.
3. Reconstruction at the region of the sanctuaries and insertion of stone shear keys.
4. Replacement of damaged wooden beams.
5. Deep repointing.
6. Injections both at the stone-masonry and at the vault.
7. Insertion and light prestressing of steel tie-rods at the north-south direction near the existing wooden ones and below the strong wooden beams at the floor of the sanctuary of the first storey. The existing wooden tie-rods are kept in position after maintenance.
8. Insertion and prestressing of double-sided steel ties in two levels at the perimetric walls.
9. Replacement of wooden beams and boarding of the floor of the first storey.
10. Reconstruction of tile covers at the vault and the quadric-domes.

Since the removal of frescoes was not accepted, interventions no 5 and 6 were executed only from the external side, leading to a significant reduction of their effectiveness. The composition of rebuilding and repointing mortars is determined on the basis of the physical and mechanical properties of the construction mortar. Alternative compositions have been proposed with differentiation on the proportion of lime and pozzolana and the addition or not of a small quantity of white cement.

3.3 Dimensioning of interventions

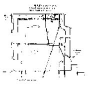
- Tie-rods at the north - south direction: The cross section and the prestressing force of the steel tie-rods were determined according to the criteria of their compatibility to the axial stiffness of the wooden tie-rods and the withdrawal of a significant portion of the tensile stresses at the supports and the key of the vault.
- Ties at the perimetric walls: The cross section and the prestressing force of the steel ties were determined according to the criteria of the withdrawal of the overturning moment of the eastern wall (Fig. 3) and the total withdrawal of the horizontal tensile stresses along the height of characteristic sections at the north and south wall (Fig. 4).
- Anchorage plates of tie-rods and perimetric ties: The dimensions of each plate were determined according to the criterion of avoiding the punching of the stone masonry walls under the yield force of the anchored bar.

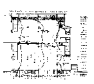
The interventions were presented on a series of general and specific drawings (an indicative drawing is given in Fig. 5).

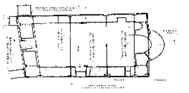
4. PRELIMINARY STUDY OF THE TRANSPOSITION

4.1 General

It is the particularly brittle character of the bearing system of the Church that prohibits the sharing of the structure into pieces and its transposition and the re-coupling of its parts at its new location. Consequently, it was decided to transpose it as a whole. The basic requirement for any transposition method is the consolidation, the strengthening and the stiffening of the Church. Critical parameters for the selection of the transposition method are the self-weight of the structure, which will reach to 3000KN together with the stiffening constructions, as well as the distance and the difference in height between the old and the new location (107.5 and 28.5m respectively). Such transpositions have been performed during the last decade both on an international level and in Greece. Most recent transpositions of stone or brick masonry structures performed in Greece are:







(a) Transposition of Agioi Saranta Church at Kifisia, Athens [2] (self-weight 1200KN).
(b) Transposition of Peter and Paul Chapel at the new international airport of Spata, Athens [3] (self-weight 3000KN).
(c) Transposition of the historical building of the Greek Railroad Organization, Thessaloniki [4] (self-weight 20000KN).

Common characteristics of these transpositions are that the structures were transposed as a whole and that the transposition road had almost zero inclination.

4.2 Alternative methods of transposition of the Church

The preliminary study of the transposition began with the collection of information from the three previously mentioned cases of transposition and the examination of the possibilities of lifting and transposition devices in disposal in Greece, as well as of the advantages and the disadvantages of respective alternative methods of transposition. Consequently, following methods were studied comparatively:

1. Lifting, turning around vertical axis and setting at the new location by a crane.
2. Repeated lifts, turns around vertical axis and setting by a crane.
3. Lifting by a crane and road transposition on a special platform.
4. Lifting by a hydraulic special platform and road transposition.
5. Lifting by a system of hydraulic jacks and rail transposition, alternatively
   (a) along a polygonal route having low inclination and successive turns.
   (b) along a straight route having high inclination.

The three first methods were rejected mainly for technical and economic reasons. It is specifically noted that lifting by crane is dangerous for brittle constructions, because of vibration shocks. The fourth method was rejected due to the high cost of underpinnings for putting and removing the platform underneath the structure at the original and final location respectively, and due to the great length and width of the transposition route under low inclination. Similarly, method 5(a) was rejected due to the high cost of the turning devices.

4.3 Preliminary study of the transposition method

Lifting by a system of hydraulic jacks and sliding on a straight, high inclination route (26.3%) is advantageous, yet it demands a special system of minimum pull out ability $H = W*tg\varphi = 3000KN*0.263 \approx 800KN$, functioning hydraulically, in order to ensure normal movement and to provide, at the same time, safety against sliding downwards. Similar systems are mainly used at bridge and great underwater construction and they are characterized as Strand Moving Unit systems (SMU systems).

<u>The preliminary study of the transposition includes following stages:</u>

(a) Consolidation and strengthening of the Church (it is completed).
(b) Construction of a platform made of a R.C. grid of beams under the floor of the Church. Crossed beams are in contact with the masonry foundation either intersecting it or not (Fig. 6).

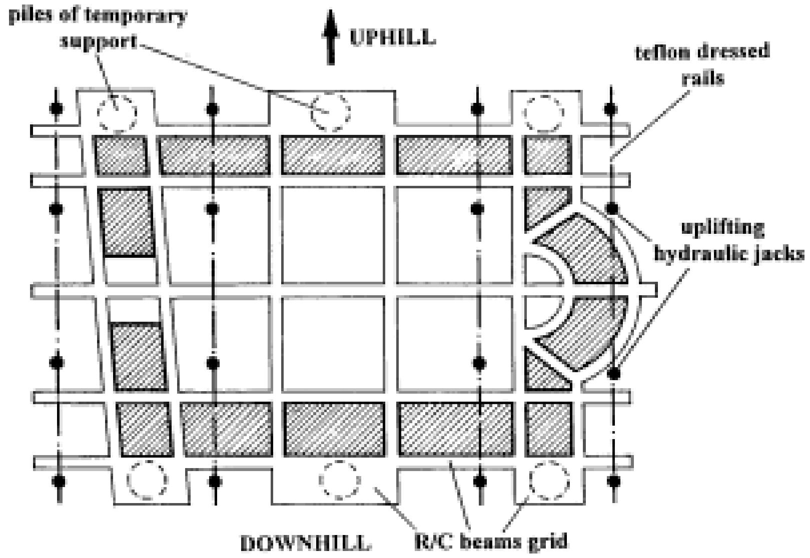


Fig. 6 Layout of R.C. grid of beams at the foundation, arrangement of the piles, lifting jacks and tracks of sliding

(c) Construction of at least six piles out of the perimeter of the structure to support the grid of beams.
(d) Stiffening of the Church by external steel frame and internal 3D truss connected to the grid of beams. Steel plates are fixed on this steel structure, lightly confining the walls of the Church while foamy material is inserted. The system must be checked, in order to keep the deformations during the transposition under certain limits corresponding to brittle stone-masonry.
(e) Construction of the transposition route, made of reinforced concrete and shaped as a canal with constant inclination. On this route, four longitudinal beams are constructed and teflon dressed rails along with anchorage rails of the SMU system are fixed on the beams. The route reaches the final location at the top of the hill, as well as under the Church after undermining. It is noted that during undermining, the structure's self-weight is transferred through the R/C grid of beams to the six piles.
(f) Construction of underpinning at the final location and of a group of piles for the anchorage of the SMU system.
(g) Construction and insertion of a special steel, wedge-shaped, 3D truss under the R/C grid of beams. The teflon dressed sliding blocks, the system of lifting jacks and the anchorage heads of the cables of two SMU systems are fixed on the platform. The lifting system consists of three groups of jacks connected by two autonomous hydraulic circuits (Fig. 7).

<u>The stages of the transposition are the following:</u>

(a) The SMU system devices are anchored to the piles cap at the final location and to the anchorage rails.

(b) The system of jacks is activated and the grid of beams bearing the structure is lifted from the initial resting location on the piles (Fig. 7).
(c) The SMU systems are activated. Throughout the climbing, the mechanical locks of the systems are set down on the toothed rails, preventing any sliding downwards in case of malfunction of the hydraulic system (Fig. 7).
(d) When the Church reaches its new position, it is left on the resting points under the grid of beams prepared in advance. Then follows the dismantling and the removal of the SMU systems, as well as of the steel, wedge-shaped, 3D truss and the foundation is complemented (Fig. 7). During the stages (b), (c) and (d), special instruments are recording the deformations of the Church, of the grid of beams and of the steel, wedge-shaped, 3D truss.
(e) The external and internal stiffening frame, including the steel plates, are dismantled and finally, the floor of the Church is formed.

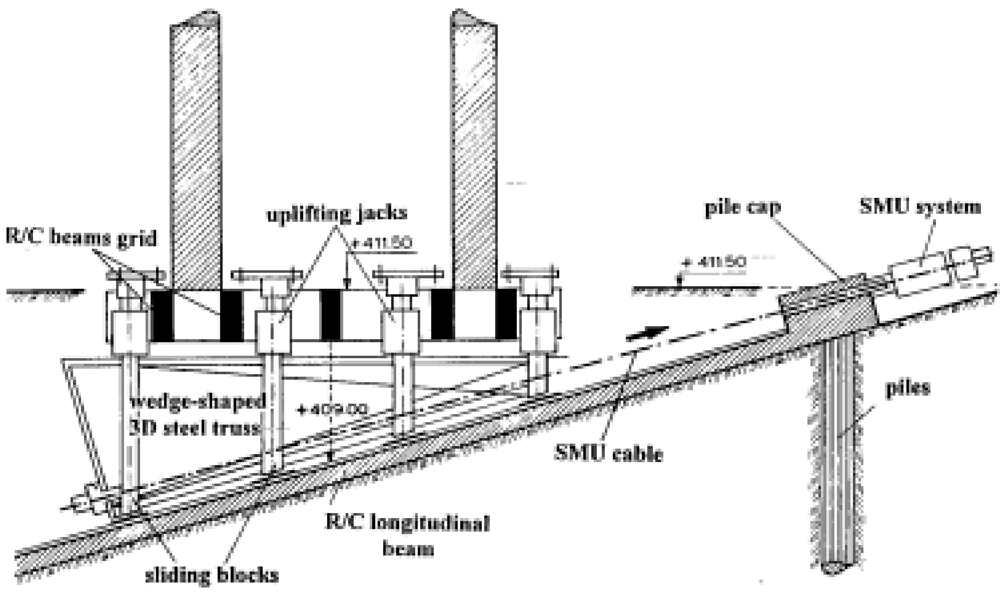


Fig. 7 Section of the lifting and pulling layout

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REPAIR OF MASONRY BUILDINGS DAMAGED BY EARTHQUAKES IN GREECE

E. Stavrakakis, M. Karaveziroglou-Weber, S. Mavrikakis
Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece

ABSTRACT

This work refers to masonry buildings in cities, towns and villages in Northern Greece, where damage has appeared, caused by earthquakes in 1995. Research was carried out on old buildings of brick or stone masonry commonly found in the seismic-prone areas of Greece. Many of these edifices are historical listed buildings or monuments. Damage to the structures, in their bearing or non-bearing system (foundation, masonry, floors, roofs, plaster, ceilings, installations), is examined with relation to the geometry of the buildings, the materials used in their construction, the use to which they were put and their location with reference to the epicentre of the earthquake.

1. INTRODUCTION

On May 13th, 1995 an earthquake measuring 6.6 on the Richter scale occurred in the Northwest of Greece. The epicentre of the earthquake was fairly close (20km) to the city of Kozani, which is the largest city in the area. The ground motion was accurately recorded by a seismometer which was located in the city during the occurrence.

Despite the fact that the seismic zone map of Greece classifies this epicentre area as being one of the least liable to experience strong ground motions (seismic zone I), this earthquake caused widespread damage to a variety of structures- not only to old stone and brick masonry buildings and churches but also to contemporary reinforced concrete structures within an area of approximately 400 square kilometres. Unfortunately, many historical monuments in this area suffered serious damage. Thus, in the village of Eani, located very close to the epicentre, the church of The Virgin Mary (11th century AD) sustained severe damage while the stone masonry in the church of Taxiarchis (12th century AD) was totally destroyed

[1], [2]. Numerous other relatively old structures in the prefectures of Kozani, Grevena and Kastoria, mostly built of stone or brick masonry, were also heavily damaged. Damage was also sustained by modern structures in the area built with reinforced concrete elements.

2. THE AREA UNDER INVESTIGATION

The area struck by the earthquake of May 13th 1995 includes, as was previously mentioned, the prefectures of Kozani, Grevena and Kastoria. To facilitate the comparison of the results of damage done to buildings in this area, the researchers drew a distinction between provincial towns and cities.

In this work, some results are presented from that part of the investigation which is still in progress and refer to buildings in villages or towns of Kastoria, Kozani and Ptolemaida (a province of Eordaia), which are indicated as regions I, III and V respectively on the map in figure 1, together with those of the cities of Kozani and Ptolemaida (regions II and IV respectively on the map).

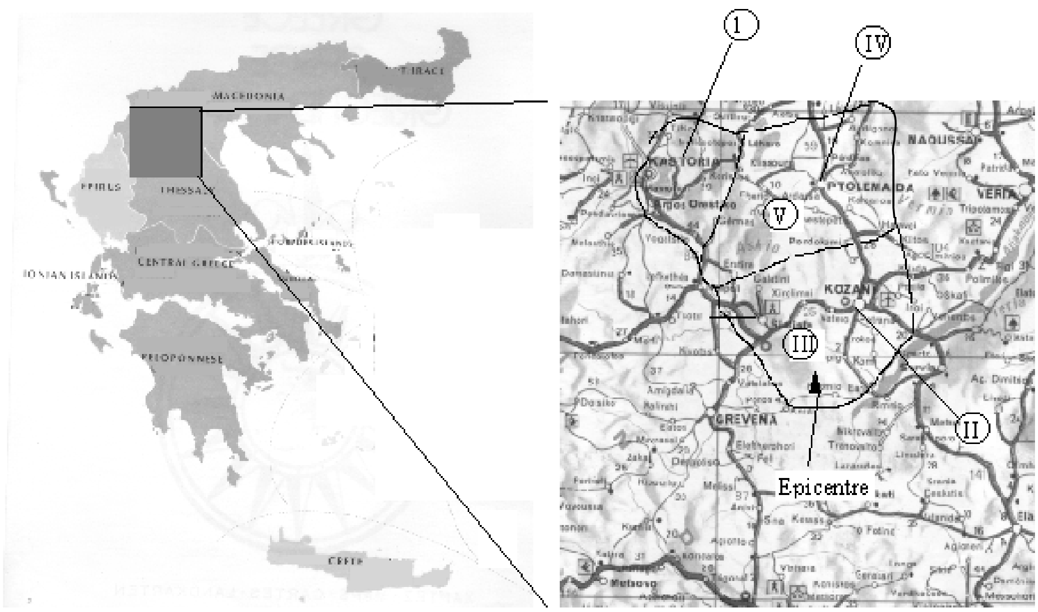

Figure 1

3. THE CLASSIFICATION OF BUILDING CHARACTERISTICS

A total of 303 buildings have been examined in the investigation presented in this work. These include houses, commercial buildings and public gathering places, 145 of which are in the provinces and 158 in the cities of Kozani and Ptolemaida. In this sample, all the types of buildings found in Western Greece are represented. These buildings have a bearing system either of old stone or brick masonry, modern reinforced concrete or a composite one of brick and stone masonry, as shown in figure 2 for the region investigated.

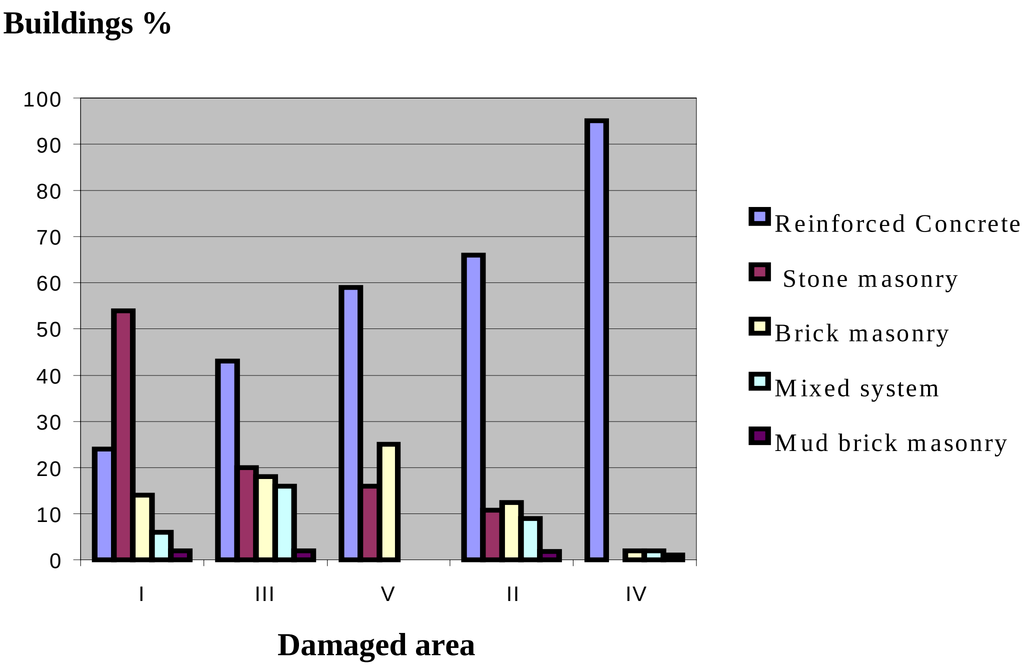

Figure 2

With reference to the type of structural system of the buildings in each area, it may be noted that in the villages and towns of the Kastoria prefecture only 24% are made of reinforced concrete, while this percentage is much higher in the other two provinces (villages of Ptolemaida 59%, villages of Kozani 43%). This is indicative of the age of the buildings in these regions. Foremost is Kastoria, a province which has prospered for many centuries and is known for its important buildings. Several of those still standing today are historical listed buildings or monuments. Further evidence of its antiquity is the large number of buildings in its towns and villages made of stone or brick masonry (54% of the whole sample in this region), while the corresponding rates for the two other provinces are much lower. In the random sample of repaired buildings in the city of Ptolemaida, 95%

are made of reinforced concrete. This is a result of the development of this city during the 60's and later, when a steam-electric power plant was built there. The few stone buildings in this relatively modern town are some municipal structures from the beginning of the 20th century, which survived the strong earthquake without damage.

The structural characteristics which are used as parameters in this investigation are as follows:

- The geometrical form of the building (area and shape of plan view, height, number of storeys, existence or non existence of basement)
- The type of construction
- The use to which the building was put
- The bearing system
- The type of damage – repair work
- The total amount of repair costs.

The year of construction has not been taken into account because this was not always mentioned in the repair studies which existed in the archives of the Department for the Rehabilitation of Earthquake Victims which was used as the information source in this investigation.

4. MASONRY BUILDINGS

Most of the old masonry buildings in western Greece are from 100-800 years old and are officially listed historical period buildings. These structures were built as churches, schools, administration buildings, barns, mansions and ordinary houses. In some two- storey houses the ground floor was used as a shop or storeroom.

The main construction materials of the old masonry buildings in the above mentioned area are local stone, brick and wood. The width of the outer rough stone masonry is about 70cm while the internal walls are made of stone or full brick masonry (with or without plaster) or, very often, of timber. The roof covering is made of slates or factory-made pan-tiles. During renovation, in many old structures, the original wooden parts have been replaced by reinforced concrete or iron. Reinforced concrete elements can also be seen in masonry buildings from the beginning of the 20th century.

As has already been mentioned, the old masonry structures in western Greece are of considerable age and have survived earthquakes in the past with little or no damage. However, the most recent strong earthquake in this area (that of May 1995) caused extensive damage to many buildings, which of course nowadays are suffering from ageing, although a few remained unscathed.

The results of this research refer to brick and stone masonry buildings which were damaged by the earthquakes of 1995 (the main shock occurring on May 13th, 1995) and which could be repaired. Irreparably damaged buildings which had to be demolished in accordance with orders given by inspectors from the Ministry of Public Works, have not been taken into account. The characteristics of the buildings investigated are shown in table 1.

Table 1

Parameters	Characterisation	Stone masonry %	Brick masonry %	Composite system %
Height	1-storeyed	36	59	12
	2-storeyed 3-storeyed 4-storeyed	64 - -	41 - -	64 12 12
Basement	-	74	84	82
	complete	20	13	12
	partially	6	3	6
Structural system	detached	70	75	65
	consecutive	30	25	35
Plan shape	rectangular	90	97	76
	non rectangular (T, L, Z)	10	3	24
Usage	residential	88	89	71
	commercial building	8	10	29
	church	10	1	-
Location	region I	54	19	18
	region II	12	19	29
	region III	18	22	41
	region IV	-	5	12
	region V	16	35	-

5. DESCRIPTION OF DAMAGE AND REPAIR COSTS

The evaluation of the reaction of the buildings to the earthquake on May 13th, 1995 was the result of a detailed compilation and registration of the damage in their bearing or non-bearing structural components. The gathering of these data and the information on the characteristics of the buildings previously mentioned, and the sum of their repair costs, was made at the local offices of the Department for the Rehabilitation of Earthquake Victims (Ministry of the Environment, Land use and Public Works) and was based on studies of the respective archives.

The total amount of repair costs for earthquake-stricken buildings as well as the respective loan approved by the State has been defined according to the invoice for repair work on damaged structures issued by the Greek Ministry of Public Works just after the earthquake of May 13th, 1995 in Kozani.

The prices in the invoice refer to completed works, including the preparation work, the supply and in situ transportation of all the materials, the depreciation, wear and tear of tools or machinery, the contractor's profit, the payments for social security benefits and so forth, as well as the cost of compensation for the study and supervision of repair. In the invoice, 35 articles are included, which refer in detail to all allocated works, from earthworks to water supply and electrical installations.

In order to facilitate the supervision and evaluation of the damage in the buildings, the investigators decided to summarise the invoice articles of the Ministry in 19 "types" of damage – repair work, that are briefly described in table 2.

Table 2

Type of damage	Description of damage – repair work
1	Excavations – Landfills
2	Masonry with slight cracks
	Artificial or natural stone masonry with serious cracks
3	Heavily damaged masonry – reconstruction
4	Strengthening of foundation
5	Masonry repair with jacket
6	Repair or strengthening of reinforced concrete bearing elements
	Construction of new reinforced concrete elements
7	Reconstruction of floor
8	Construction of belts, lintels of concrete B225
9	Repair with steel profiles
	Repair of serious cracks in reinforced concrete with stainless steel
10	Reconstruction or repair of roof
11	Repair of ceiling
12	Repair or reconstruction of ceiling plaster
13	Repair – reconstruction of insulation
14	Repair of installations
15	Repair of chimney
16	Repair of cracks in R.C with ties
17	Repair of cracks in concrete with epoxy resins
18	Repair of cracks in stone masonry with injections
19	Repair of reinforced concrete joint

The damage recorded after the earthquake for the investigated buildings, according to the damage- repair work types of Table 2, is shown in the diagram of figure 3 for stone masonry structures, in figure 4 for brick masonry structures and in figure 5 for structures with a mixed bearing system (stone and brick masonry walls). Results on damage in mud brick structures are not given here because of the relatively small number of investigated buildings with this kind of bearing system.

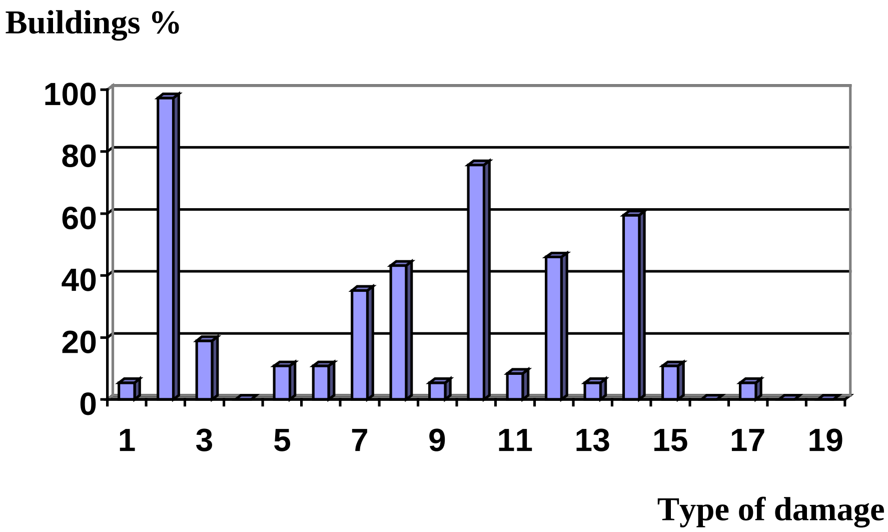

Figure 3

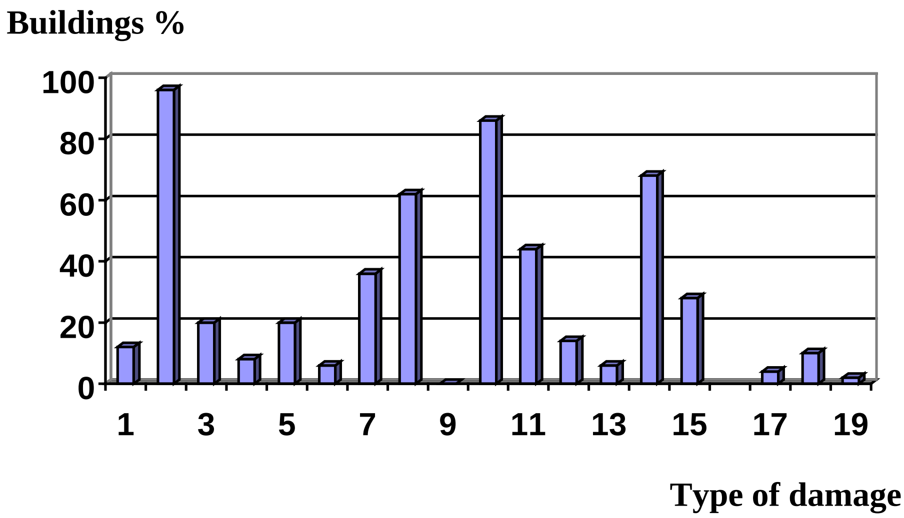

Figure 4

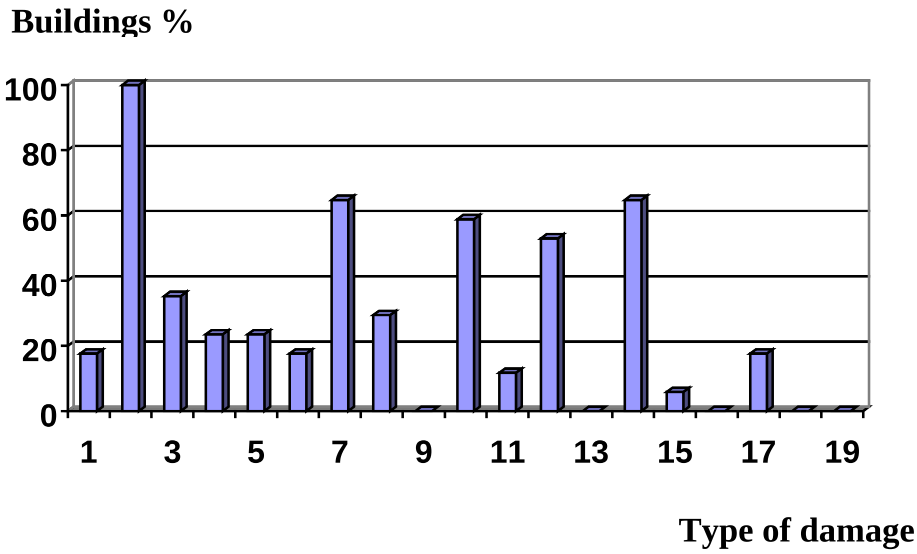

Figure 5

On observing figures 3, 4 and 5 it can be seen that old buildings with stone or brick masonry walls present an almost similar picture of damage (fig. 3, fig. 4), while structures with a mixed bearing system of stone and brick masonry (fig. 5) show a different picture. Furthermore, if the damage types of table 2 are also taken into account, the following results may be noted:

- Most of the old buildings, regardless of the bearing wall system, suffer from cracks in the masonry walls (damage type 2) at a rate greater than 90%.
- Roof damage (damage type 10) exists at a rate of from approximately 60% to 80%.
- Ceiling plaster damage exists at a rate of about 45% in structures with stone or mixed masonry. These are older than those with brick masonry; the rate in brick masonry buildings is low (about 15%) as a great number of these structures have no plastered ceilings.
- In all types of structures the damage to the floor is quite high (40% to 60%) and calls for reconstruction.
- Damage to lintels and belts in the brick masonry buildings (fig. 4) exists at a rate of about 60%, which is easily seen to be greater than that sustained by stone or mixed masonry structures (fig. 3, fig.5), perhaps because in brick masonry apertures are wider than in the other masonry types.
- Damage to installations (water supply, electricity and drainage systems - damage type 14) exists at a rate of approximately 60% for all types of structures investigated.

- A small percentage (5%) of damage has been found in the insulation (damage type 13), mainly due to the fact that it had been installed in only a very small number of buildings.
- The stone buildings (fig. 3) have survived the earthquakes of 1995 with very few problems in their foundations (damage types 1 and 4 less than 5%); the amount of foundation damage increases in brick masonry buildings (about 10%) and it reaches 20% in structures with a composite bearing wall system of stone and brick masonry (fig.5).

6. COMPARISON OF COSTS

The results of the investigation with respect to the cost of repairs to the buildings damaged by the earthquake are presented in the diagram in figure 6, where the costs of repair per m^2 of plan view of the examined buildings for each type of bearing structure and each investigated area are noted.

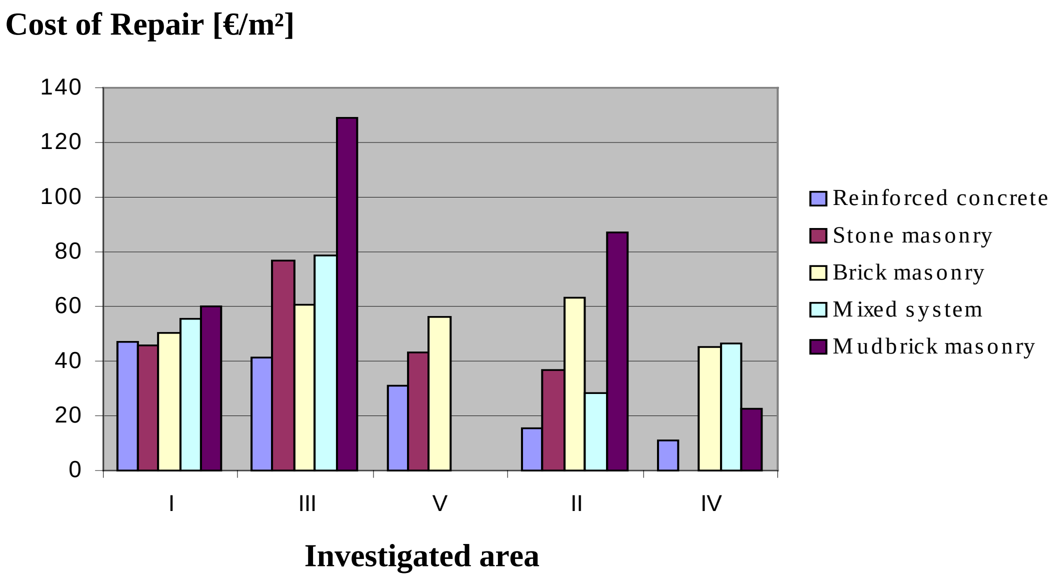

Figure 6

Careful observation of this diagram brings us to the following conclusions with regard to the total amount of repair costs.

- The investigation of area III, which refers to buildings in the villages of Kozani, shows a higher repair cost than that in the villages of Ptolemaida and Kastoria for structures with bearing systems of stone masonry, brick masonry or both (mixed system). This result is due to the shorter distance of the Kozani area from the epicentre of the great earthquake of May 13th, 1995. The only exception is the higher repair cost for reinforced concrete structures in the area of Kastoria in comparison with the respective cost for the villages of

Kozani and Ptolemaida; according to the investigators' opinion, this is due to the poorer quality of concrete constructions in this area.

- In both villages and cities repair costs are lower for buildings made of reinforced concrete, whereas the repair costs for old structures with bearing systems of stone and brick masonry are higher. Any extra cost involved however should be considered as money well spent since there are some listed buildings among the old structures.

7. CONCLUSIONS

The data for damage and repair work to buildings in areas of west Macedonia, presented in this work, constitute part of a wider investigation which is being carried out in the areas struck by the earthquake of May 13^{th}, 1995. The purpose of the investigation is to increase the resistance of old structures to earthquakes and hopefully the knowledge gained from the detailed study of the damage will make this possible. All results cannot be included in this presentation, since the investigation is still in progress.

Regarding masonry structures and their damage picture after earthquakes, it should be noted that, generally speaking, the superstructure is badly affected. The brunt of the damage is sustained by the bearing masonry wall system (belts and lintels included) but floors, ceilings and roofs also suffer damage after a strong ground shock. During the restoration of an old masonry building, great attention must be paid to the installations (water supply, electricity and drainage systems) since these are very sensitive to earthquakes and repair work is rather expensive.

The total cost of repair work to old masonry structures hit by an earthquake is, without doubt, higher than that for modern reinforced concrete buildings in the same area. It should be taken into account that old structures suffer from ageing and their repair requires skilled craftsmen as well as the proper materials which are not always readily available among the numerous products on the market. The financial difference between restoring old masonry buildings and contemporary reinforced concrete ones should not, however, prevent us from attempting to save our architectural heritage even in zones of high seismic activity.

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STRUCTURAL RESTORATION OF THE ACHEIROPOIETUS BASILICA IN THESSALONIKI

George G. Penelis (1), Kosmas C. Stylianidis (1)
(1) Professor, Dept. of Civil Engin., Aristotle Univ. of Thessaloniki, Greece

ABSTRACT

The Church of Panagia Acheiropoietus is one of the biggest Basilicas of the eastern Mediterranean Basin and it dates back to the 5th century B.C. At the strong Thessaloniki earthquake in 1978, the monument suffered extensive damages, namely excessive cracking and inclination of masonry walls and colonnades. A first attempt to analyze and design the remedies within the framework of the structural restoration led to an extended and heavy intervention, which was rejected by the Authorities responsible for the monument. As a result, the authors of this paper were assigned to re-examine the problem. The methodology and the results of the new attempt are briefly presented in this paper. The approach followed proves that the best criterion for accepting or rejecting the results of the analysis is the degree to which they justify the existing crack pattern and the deformations. Finally, a much lighter intervention was proposed and was approved by the Authorities. The restoration works have almost been completed.

1. HISTORICAL BACKGROUND AND STRUCTURAL FORM

Acheiropoietus is the best preserved basilica in Greece having an almost intact 5th century interior. In its current state, five major periods of construction including modifications, repairs due to earthquakes and modern reconstruction, can be distinguished. The first period corresponds to the initial erection (third quarter of the 5th century) and the last one to the drastic repair in 1912-14, during which significant reconstruction was carried out.

From the architectural point of view, the Acheiropoietus is a three - aisled Christian basilica with a narthex (Fig. 1) covered by timber roof. The three aisles are formed by two colonnades in the east - west direction. The overall dimensions of the Church are 51.9m in length, 30.8m in width and 22.0m in height at the top of the roof and 14.0m at the top of the external walls. The thickness of the brick and stone masonry walls is about 1.0m.

From the structural point of view the vertical load bearing system consists of the external walls and the two colonnades (Fig. 2,3). At the middle of the height of the two out of three aisles, there is a wooden floor carrying the loads from the quarters intended for women. The structure is covered by three timber non - thrusting truss systems.

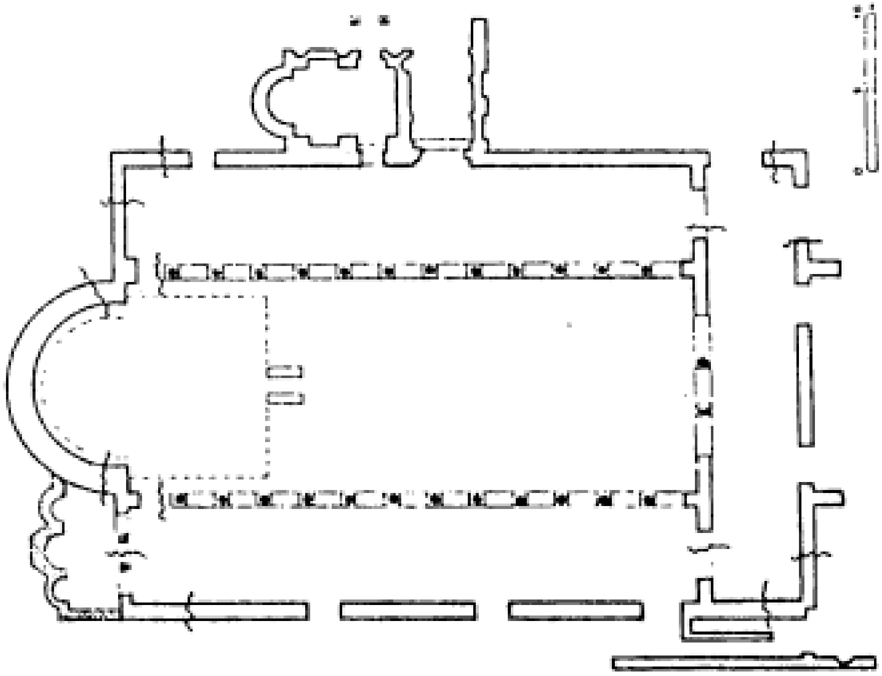

Fig. 1 Plan of the Church showing the regions of the main vertical cracks

2. PATHOLOGY

The major problem of the structure is the excessive deformation mainly appearing in the weak north - south direction and consequent cracks. More specifically, as a result of their rocking, the colonnades incline outwards at their ends and inwards at their middle, the maximum inclination being 3.5% (Fig. 4) [1]. The rotation of masonry arches connecting the columns is also apparent. Inclinations of the north and south walls (especially of the latter) in the order of 3.0% are usual. As a consequence, vertical cracking of the walls especially near the corners at the structure have been induced. There is also an extensive vertical cracking of the masonry arches connecting the columns and at the keystone of the quarter - spherical dome of the sanctuary.

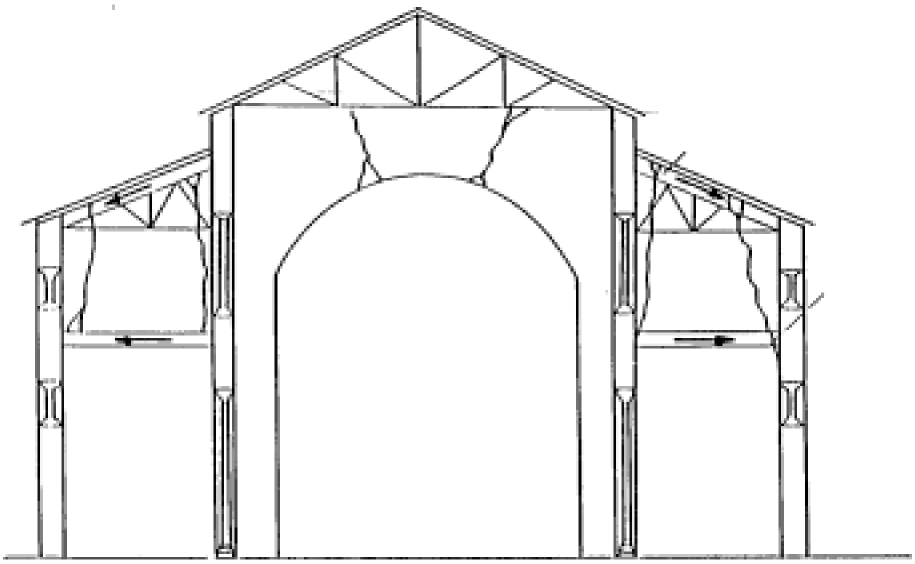

Fig. 2 North - south cross section of the Church

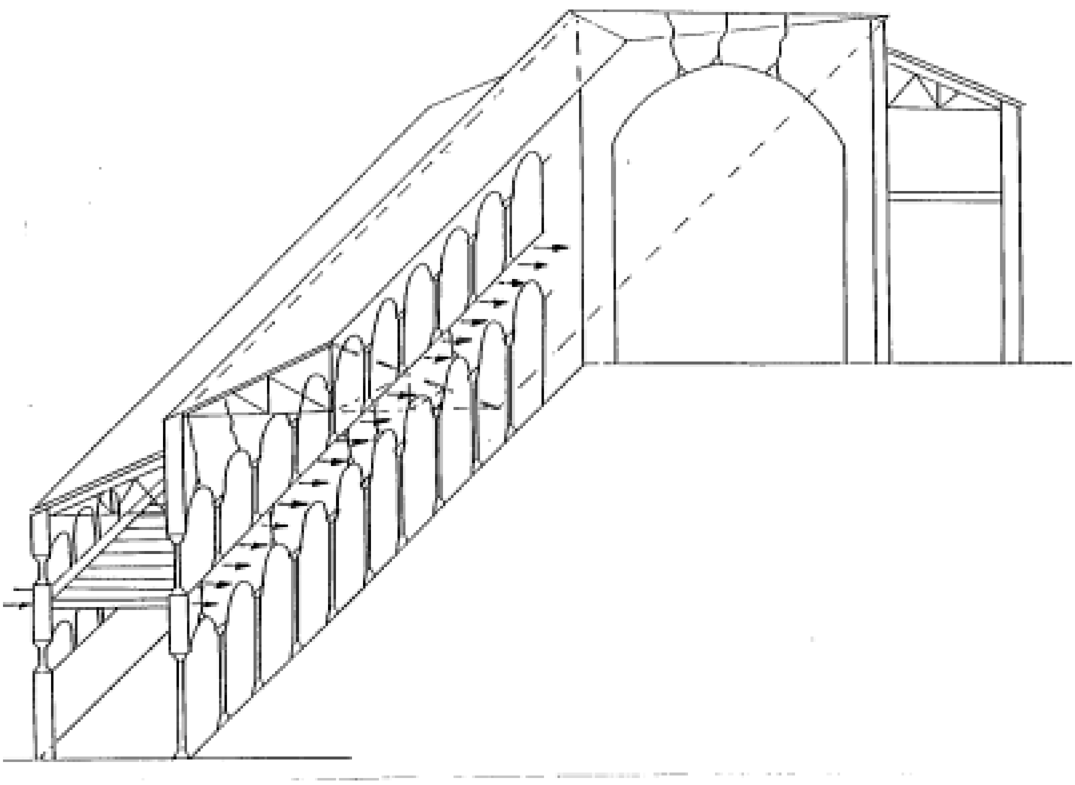

Fig. 3 Cutaway isometric view of the Church from south - west

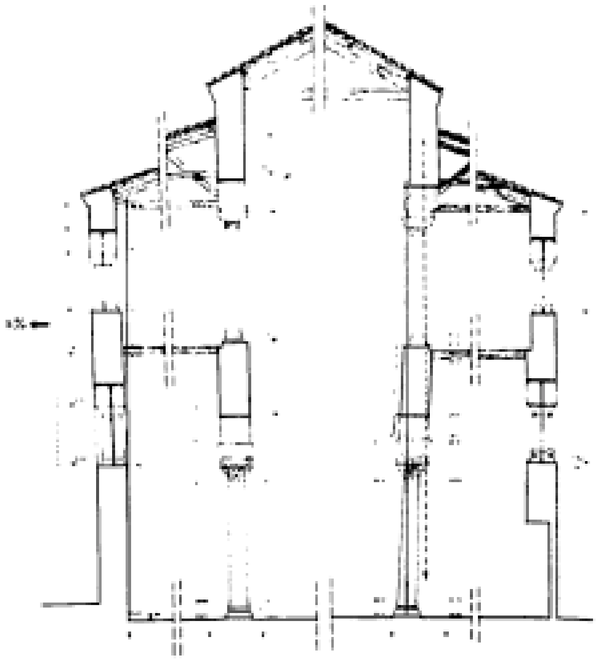

Fig. 4 North - south cross section showing the inclination of the walls and the colonnades

3. STATIC AND DYNAMIC BEHAVIOUR OF THE MONUMENT

It is reasonable to expect for this kind of structures that under seismic loads the walls behave as free standing cantilevers in their transverse direction, since the floor at the middle of the height and the timber roof cannot behave as rigid diaphragms, transferring the seismic loads to the walls parallel to the seismic direction and minimizing the damage. In the case of cantilever behaviour, excessive damage (or even collapse) should be expected, the main cracking being horizontal at the bases of the walls; but, this kind of cracking was not actually observed. This remark leads to the conclusion that the floor and the roof presented an intermediate behaviour, in any way beneficial, acting partly as diaphragms and transferring a significant portion of the seismic loads to the walls parallel to the seismic action. Under the light of this hypothesis of partial diaphragmatic action of the floors and the roof, the expected cracking pattern matches very well with the existing one.

To verify this scenario, the predominant natural period of the structure was calculated on the hypothesis of cantilever action and was found to be 2.13 to 3.30sec, depending on the degree of fixity on the ground. Additionally, the period was measured in situ and was found to be 0.60 to 0.65sec, meaning that the actual structure is much more rigid than that of a free standing cantilever.

4. PROPOSED INTERVENTION SCHEME

Under the light of the aforementioned remarks, a new scheme of general and local interventions was proposed [2], being estimated that it can minimize the seismic sensitivity of the monument.

General nature interventions aim at providing controlled strength and stiffness to the already existing floors and roof. Strength and stiffness can be ensured by several alternative structural techniques, which will be discussed later on. The resulting diaphragms transfer a significant portion of the transverse seismic load to the walls of the sanctuary and the narthex, which are parallel to the seismic action. In order to withstand this action these walls have to be lightly strengthened by external tierods. Previously mentioned interventions improve the static and dynamic behaviour of the monument drastically. The resulting system reaches the serviceability limit state under a seismic coefficient $\varepsilon=0.12$ and the ultimate limit state under $\varepsilon=0.16$ - 0.18, which corresponds to a return period of 500 years. The magnitude of the improvement is obvious, considering that, despite the interventions of the first restoration attempt, the ultimate limit state corresponded to $\varepsilon=0.05$.

Local nature interventions aim at restoring the structural integrity of extensively cracked walls and repairing those regions of the structure which have presented damages due to aging. These interventions include injections using traditional materials, repointing, local reconstruction, stitching etc.

5. ALTERNATIVE TYPES OF DIAPHRAGMS

Several alternative types of diaphragms were considered and evaluated, the main ones being:

(a) Providing strength and stiffness to the diaphragm, by means of a grid of passive stainless steel tendons 26mm in diameter, placed in the form of a rhombic truss.

(b) Formation of a wooden diaphragm, made of a double boarding and an intermediate wooden leaf. The diaphragm is strengthened at the perimeter, by means of a metal beam (140 - 80 - 7) connected to the masonry by anchored metal bars (Fig. 5,6,7).

(c) Formation of a diaphragm, made of a K-truss of precast elements, dressed by a double boarding and strengthened at the perimeter as in case (b).

(d) Formation of a diaphragm, consisting of a perimetric metal beam, a double boarding and intermediate wavy steel sheets.

The Central Archeological Council approved proposal (b) of the wooden diaphragm, strengthened by a metal beam at the perimeter. Within the framework of a research program, the Lab. of R/C Structures elaborated this particular proposal.

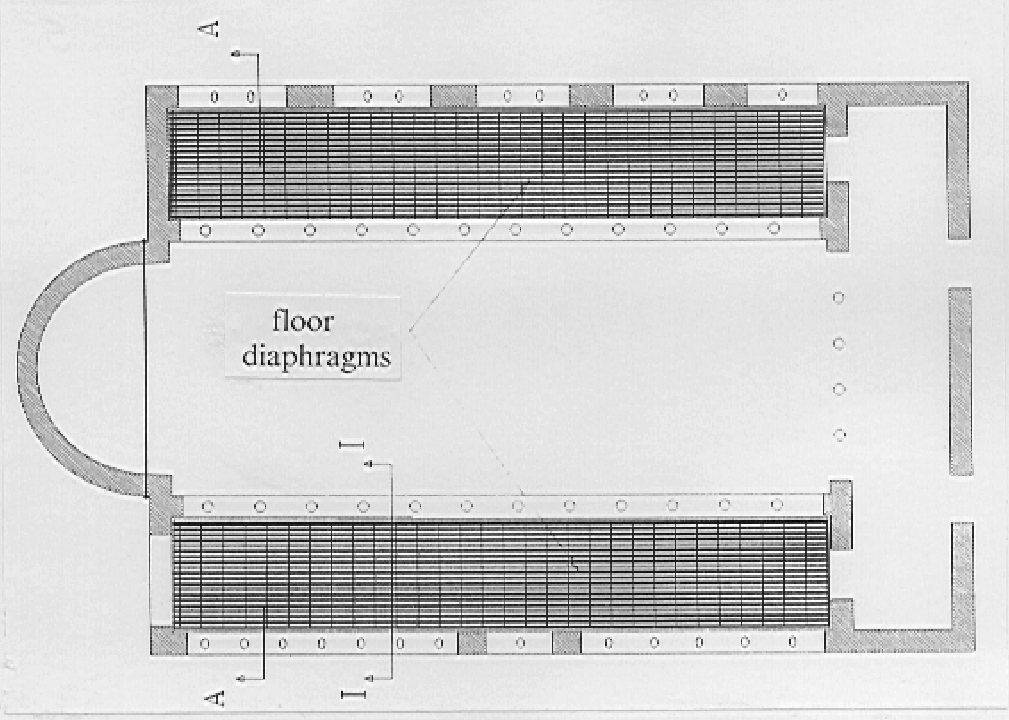

Fig. 5 The lay-out of the floor diaphragms in plan

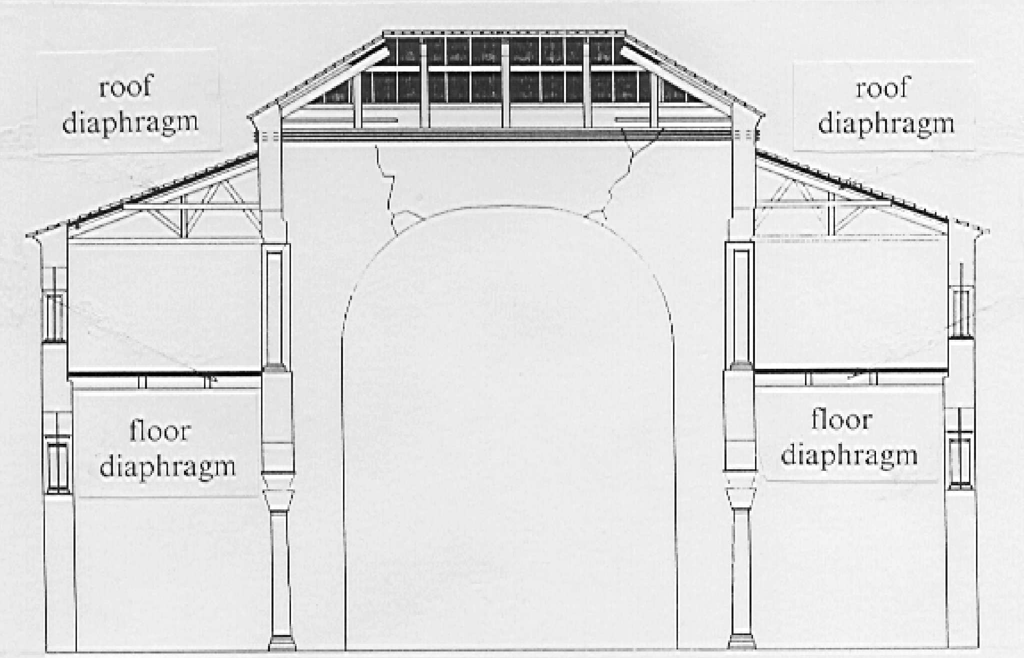

Fig. 6 The lay-out of the diaphragms in cross section

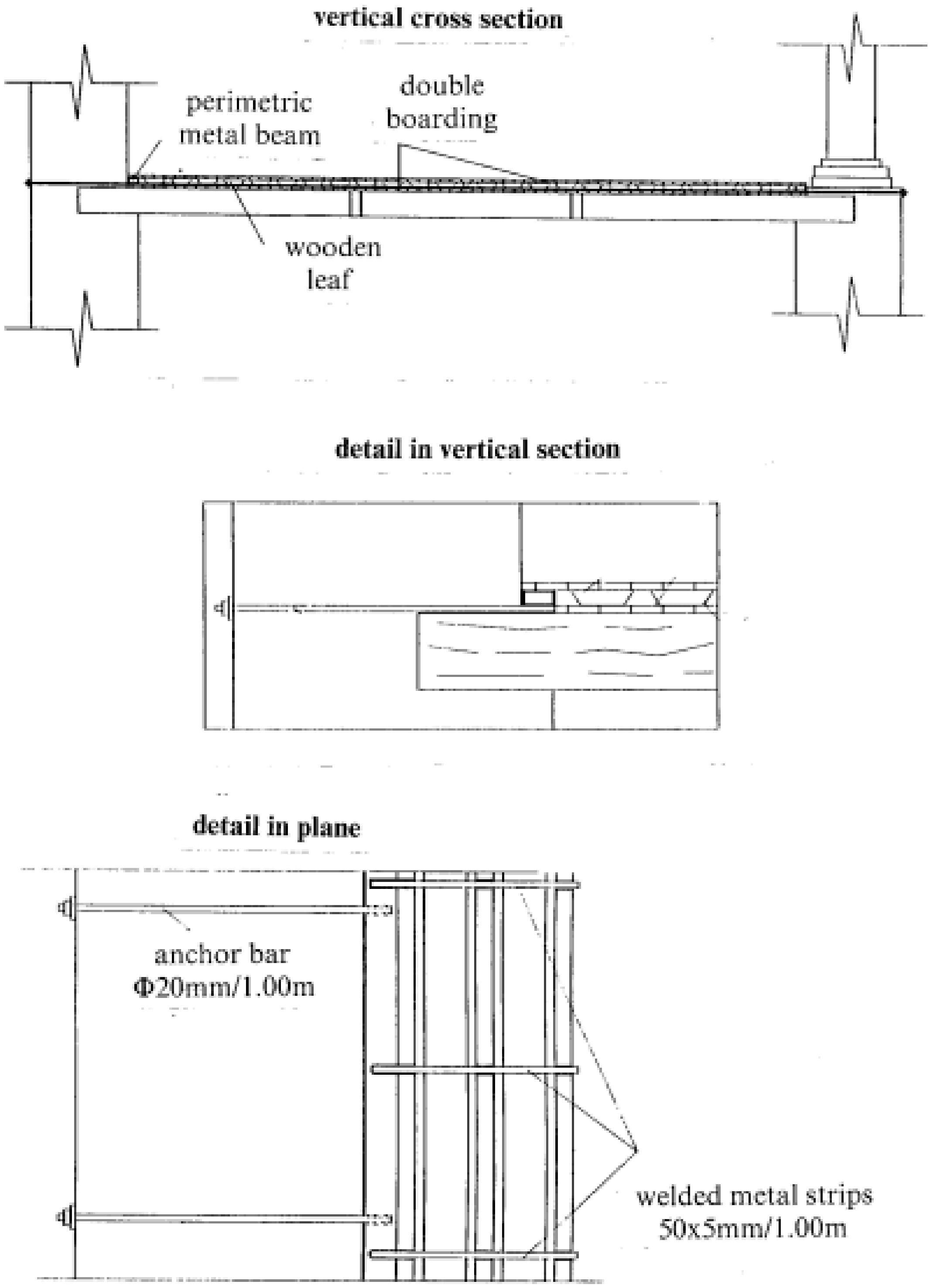

Fig. 7 Details of the wooden diaphragm

6. STRUCTURAL ANALYSIS OF THE MONUMENT

6.1 Basic assumptions

For the analysis of the monument the SAP90 program was used on the assumption of elastic behaviour. The monument was modeled as a 3D structure using shell elements for the masonry walls and frame elements for the columns.

The roof of the central aisle was modeled by frame elements, whereas the roof and floors of the other two aisles were modeled in two different ways. More specifically, in the case of the existing structure, the roof and the floors were modeled by frame elements, whereas in the case of their transformation in wooden diaphragms of controlled strength and stiffness, they were modeled by shell elements. It is obvious that two different models were formed, one corresponding to the current state and one to the state after the intervention. In the second case, the determination of the strength and stiffness of the diaphragms was critical. These values were determined via primary extended analysis, partially based on DIN 1052 - sheet 1 and 2 [3] and on the work of K. Mohler [4].

The analysis under seismic load was performed using equivalent static analysis. For the determination of seismic action, the fundamental natural period was estimated to T_1=0.61sec for the north - south direction and T_2=0.17sec for the east - west direction. These values were derived by in situ ambient vibration measurements. The response spectrum used corresponds to a seismic event having a return period of 500 years and was derived via probabilistic extrapolation of the response spectrum of the earthquake in 1978, in combination with in situ cross-hole tests. The behaviour factor of the monument was determined for both cases (before and after the intervention) by means of P-δ diagrams, corresponding to the displacement of the top of the longitudinal walls on the assumption of inelastic behaviour of the masonry. The resulting values were $q_{init.}$=1.5 and $q_{strength.}$=2.0. The combination of the fundamental periods, the elastic response spectrum with a return period of 500 years and the behaviour factors led to the adoption of following values of the seismic coefficient: $\varepsilon_{init.}$=0.16 and $\varepsilon_{strength.}$=0.12.

6.2 Evaluation of results

Previously described analyses resulted to the following conclusions:

(a) Critical for both cases (before and after the intervention) is the combination of gravity loads to the north - south seismic action.

(b) The cracking pattern of the monument caused by the earthquake in 1978 matches very well with the analytical results.

(c) The formation of wooden diaphragms at the floors and the roof improves drastically the stresses and the deformations of the bearing system to such an extend that the monument can withstand the design earthquake without even cracking.

7. INTERVENTION MATERIALS

The intervention scheme includes two categories of works:

(a) Reversible works, which include the wooden diaphragms with their metal perimetric strengthening.

(b) Irreversible works, which include injections, repointing and stitching of the cracked corners of the church.

For reversible works, common materials are used, without having to fulfill specific requirements, such as pinewood, plywood for external use, galvanized steel beams. For irreversible works, materials fulfilling the requirements of compatibility and durability are used [5]. Therefore, as far as the injections and mortars are concerned, specific compositions studied at the laboratories of Aristotle University of Thessaloniki were used. These compositions were based on research on the chemical, mineralogical and mechanical properties of the existing mortars of the monuments. Specifically for injections, a thin colloid composition was selected for the improvement of the penetration of the material to the fine pores of the virgin mortar [6]. Such compositions are the most modern approach to the problem of penetration to fine pores, yet they demand specific high-speed mixers for the preparation of the colloid mixture. Finally, titanium alloy was used for all metal elements (connectors, stitches) embedded into the masonry.

8. CONCLUSIONS

On the occasion of the present structural restoration of an important monument, following general validity conclusions were once more confirmed:

(a) At regions of high seismic risk, earthquakes are the main reason for damages or collapse of monuments and historical buildings. These buildings have suffered the consequences of seismic events for centuries and some of them have survived under a process of natural selection. Only well designed and well constructed buildings have reached our times.

(b) As a result, in the case of intervention, the structural system should not be altered. Only local interventions or improvements of the virgin structural system (as in the present case of strengthening of wooden diaphragms) could be accepted, since there is no guarantee that the modified structural system will have greater probabilities to survive than the older one, which has already been tested.

(c) To estimate the bearing capacity of a monument, in the perspective of interventions to the structural system, in situ measurements and research, laboratory tests and complex and detailed static and dynamic analyses are necessary. Only deep knowledge of the virgin structural materials and the structural behaviour of the monument can justify an intervention.

(d) In case an intervention is decided, it must not been forgotten that the main aims of structural anastilosis are the conservation and the preservation of the historical and aesthetic values of the monument. As a result, any intervention should be based on respecting the virgin materials and the authentic elements. This choice imposes strict limitations on the selection of materials and techniques of intervention.

(e) The key to the selection of the materials and the techniques to be used in a structural anastilosis is the distinction of those techniques into reversible and irreversible ones. The materials used in reversible techniques are subjected to very few limitations. On the contrary, the materials used in irreversible techniques have to be durable and compatible to the existing materials.

(f) Finally, structural anastilosis constitutes an intervention of high skill which demands cooperation of specialists coming from several scientific fields and strong support from laboratories and computational infrastructure.

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 e-mail:sas2001@yildiz.edu.tr http://www.yildiz.edu.tr/mim/sas2001

THE STRUCTURAL RESTORATION OF THE NATIONAL LIBRARY OF GREECE IN ATHENS

Gregory G.Penelis[1], George Gr.Penelis[2]
(1) MSc, DIC, Phd candidate Aristotle University of Thessaloniki, Greece
(2) Prof. of Concrete Structures Aristotle University of Thessaloniki, Greece

ABSTRACT

The National Library of Greece is hosted in a magnificent neo-classic complex of URM buildings built at the beginning of the 20th century, which have been damaged by the 07.09.99 Athens quake. In order to achieve a light and reversible intervention the design consisted of extensive in situ and laboratory tests concerning the mechanical, chemical and mineralogical characteristics of masonry, special considerations for the composition of the enemas to be used in order to prevent any impact on the frescos, and sophisticated analytical models and procedures including a pushover analysis and evaluation using the ADRS methodology.

1. INTRODUCTION

During the 07.09.1999 Athens quake on mount Parnitha a lot of buildings had been damaged within the city limits. The National Library Building is a neo-classic complex of buildings located in the centre of the city of Athens on Panepistimiou Str. and was designed and built in the beginning of the 20th century by the famous architects Hansen and Schiller (fig.1). The complex is composed of three independent rectangular parallel wings and three walkways connecting the two side wings to the main wing (fig.2). The buildings are built from Unreinforced Masonry (URM) constructed externally with smoothened marble megastones combined with marble kions while the floors are composed of steel beams filled with brick vaults in between. The main wing is decorated with beautiful frescos, which should obviously be preserved.

The building is the actual National Library of Greece and therefore besides being a monument it is being used everyday by hundreds of people who after the earthquake are at great risk as can be concluded by the pathology.

Fig.1: View of the National Library Buildings

2. BUILDING PATHOLOGY

The buildings had three different type of damage; (I) Time related, (II) Damage from the 1981 quake which had not been repaired, and (III) Damage from the 1999 quake.

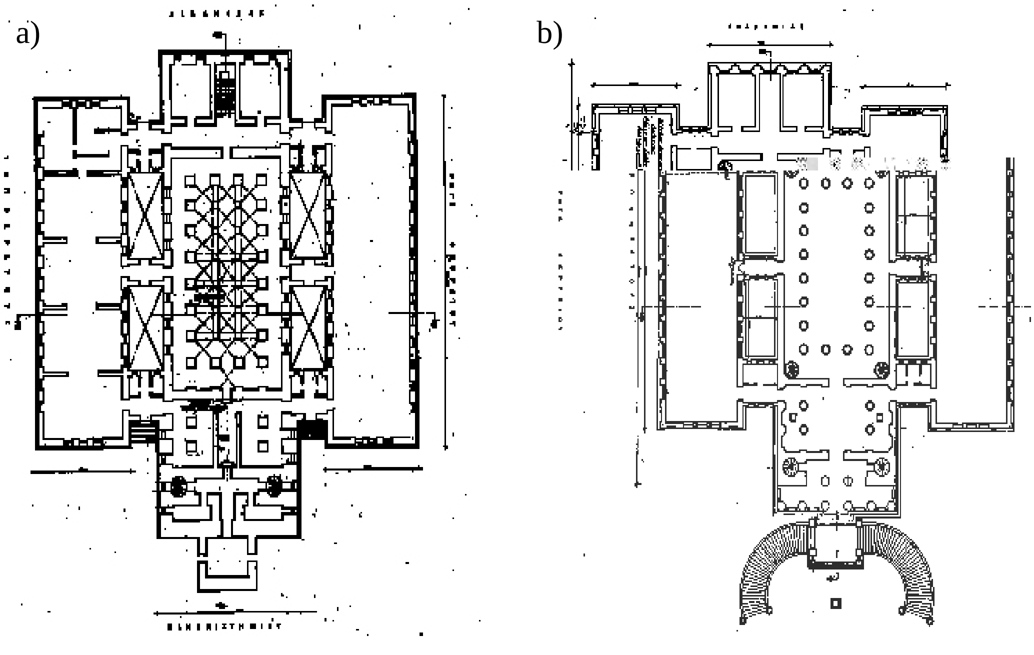


Fig.2: Plan view (a) Ground floor, (b) First floor

In all three wings the type (I) damage consisted mainly of water leakage and oxidisation of the steel beams, while the damages of types (II) and (III) are different for each wing.

More specifically the two side wings presented inclined cracks at the edges of the transverse walls typical of independent out of plane behaviour of these walls due to the lack of diaphragm constraint at the floor and roof levels. Furthermore horizontal cracks were presented at the foot of the piers of the longitudinal walls due to in plane flexure. The spandrels of the longitudinal walls suffered small vertical cracks indicative of tensile stresses.

The main wing had significantly less damage which can mainly be attributed to its higher rigidity and robustness (longitudinal walls) and the intermediate transverse walls which prevented independent out of plane behaviour of walls.

3. SITE INVESTIGATIONS AND LABORATORY TESTS

The site and laboratory investigations and tests aimed at the determination of the ground type and the mechanical and chemical characteristics of masonry. Regarding the ground type according to the Athens Metro boreholes performed by MECASOL, just in front of the complex, and their evaluation, it is a slightly weathered limestone classified as type A regarding the determination of the seismic forces and certainly able to bear the foundation loads.

Regarding the URM the investigation consisted of destructive (6 core samples) and non destructive (hammer test for masonry) tests and analysis. Special chemical and mineralogical analysis were performed at the Reinforced Concrete lab of AUTH in order to determine the chemical and mechanical characteristics of the mortar in order to achieve a high compatibility (chemically, mechanically and aesthetically) of the restoration enemas to be used, having in mind the importance of the building and the sensitivity of the frescos. The mechanical properties of the URM as derived according to EC6 and DIN1053(1974) on the basis of the tests are shown in table 1.

Table 1: Mechanical properties of URM; characteristic values

Compressive strength	f_{wk}= 4.50 MPa
Shear strength	f_{vk} =0.22+0.40σ_d MPa
Tensile strength	f_{wt} = 0
Tensile strength (out of plane)	f_{wx1} = 0.18 MPa (Horizontal cracks) f_{wx2} = 0.31 MPa (Vertical cracks)
Elastic Modulus	E = 4500 MPa
Shear modulus	G = 1800 MPa
Poisson ratio	ν = 0.25

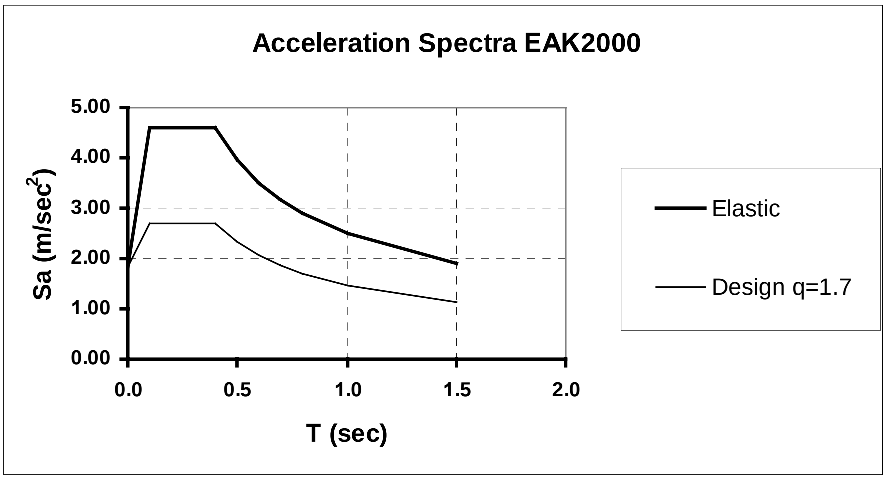


Fig.3: Elastic and Design spectra as defined in Greek Seismic Code

(a) vertical stresses σ_{zz}

(b) Horizontal stresses $\sigma_{\chi\chi}$

fig.4: Elastic Dynamic Analysis of Side wings

4. ANALYTICAL MODELS

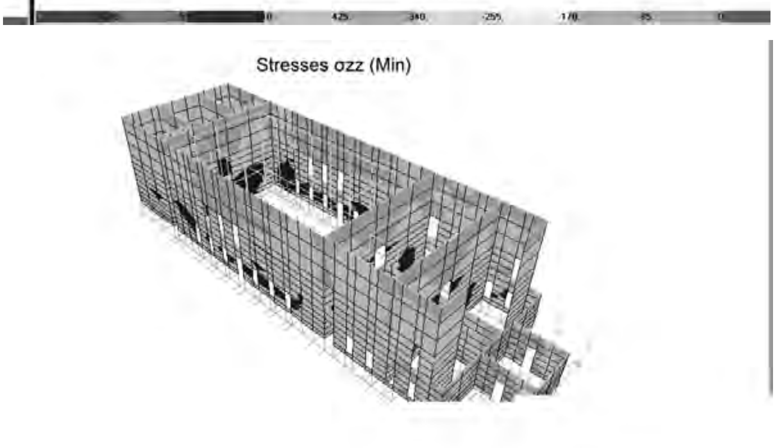
Two different analytical approaches were selected for the buildings. At first stage all three wings were analysed using elastic dynamic spectral analysis of a F.E. mesh of plane (shell) elements in order to identify the areas of stress concentration and the overall behaviour of each wing. In second stage, nonlinear static (pushover) analysis of the two side wings which presented extensive cracking during the earthquake, were performed, using equivalent frame models, since their cracking suggested nonlinear behaviour. For both the analysis the seismic loads were determined by the Greek Seismic Code spectra for seismisity zone II (pga=0.16g) (fig.3)

4.1 Dynamic F.E. Analysis

(a) Side wings

Regarding the two side wings the results were similar and are therefore presented together. So the building had a low period of 0.21 sec and presented only

(b) Horizontal stresses $\sigma_{\chi\chi}$



(a) Vertical stresses σ_{zz}

fig.5: Elastic Dynamic Analysis of Main wing

transitional modes due to its symmetry. Tensile stresses were developed locally at the spandrels explaining the cracks presented there, and higher tensile stresses were developed at the piers justifying the horizontal cracks presented there (fig.4). Of course the analysis of the model did not produce the pathology attributed to the out of plane behaviour of the two transverse walls since, in the analytical models, they were connected with the longitudinal ones, which suggested that the main deficiency of the structural system is this connection which, obviously, had to be restored.

(b) Main wing
The main wing building was found to be stiffer than the two side wings with a natural period of 0.165 sec. It presented only transitional modes due to its symmetry and high torsional restraint attributed to the perimetric masonry walls. The stresses were significantly lower that the ones developed at the side wings (fig.5), since there are no openings at the first floor, smaller openings at the ground floor and the ratio of URM wall over sq. meters (m^2) of plan is higher in both directions. These results were in complete agreement with the minimal damage observed at this wing and lead to the conclusion that a more sophisticated analysis was not required for this wing and only local restorations would be needed.

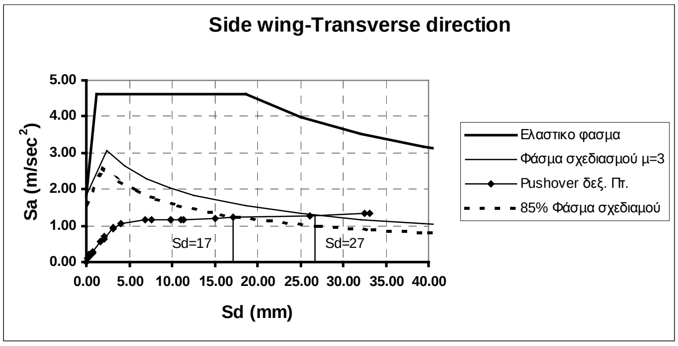
4.2 Nonlinear Static Analysis

The pushover analysis of the two side wings was performed using plane equivalent frames. The model used was a frame element model with areas of concentrated inelasticity. The nonlinearity was concentrated in rotational springs located at the ends of the piers and the spandrels. The Moment-Rotation (M-θ) diagrams of the URM elements had been derived based on a procedure validated in [1], and these had been used as constitutive laws for the nonlinear springs.

The use of two independent plane equivalent frames (one per direction) is obviously a conservative assumption since the participation of the transverse walls is neglected and as has been shown in the dynamic analysis torsional modes do not exist.

The evaluation of the pushover analysis and the determination of the target displacement was based on the Acceleration – Displacement Capacity – Demand (ADRS) spectrum procedure prescribed by ATC-40 [4]. The inelastic spectra have been derived by applying the formulas of Fajfar [3] on the Elastic Acceleration Spectra of the Greek Seismic Code for zone II.

From these (fig.6) it is obvious for both directions that the building can withstand the design earthquake but by consuming most of its inelastic capacity. This means that in both directions the building would sustain under the design earthquake with serious but not critical damage (fig.8). So the pushover analysis validated completely the results of the elastic dynamic analysis and directed towards a light intervention.



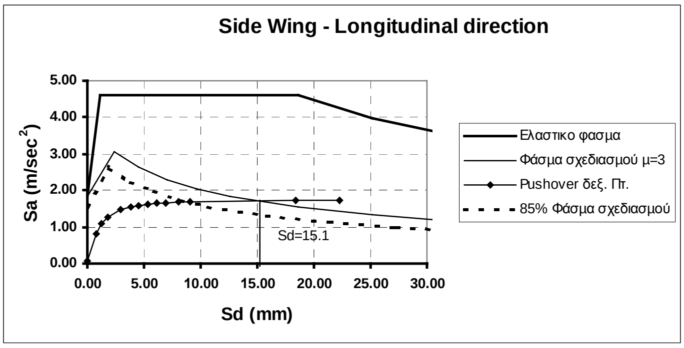


Fig.6: ADRS format capacity demand spectrum

5. PROPOSED INTERVENTION SCHEME

As has been aforementioned the intervention mainly concentrated on the side wings except for type I damages (time dependent) which also existed in the main wing. Furthermore all the intervention has been directed towards being light and reversible.

So, in that context, for the two side wings, the structural restoration consisted of the implementation of a perimetrical, internal zone consisting of beams on the roof level, in order to restore the diaphragm constraint, either using concrete with stainless steel as reinforcement or uniformly stainless steel profile in order to avoid future corrosion. Furthermore four titanium stitches per corner per wall were suggested in order to secure the uniform behaviour of the longitudinal and transverse walls. The cracks on URM were filled with enema with specially selected composition in order to conform chemically, mechanically and aesthetically with the existing mortar using the sophisticated laboratory tests that had been performed and the existing database at the Reinforced Concrete Lab of AUTH.

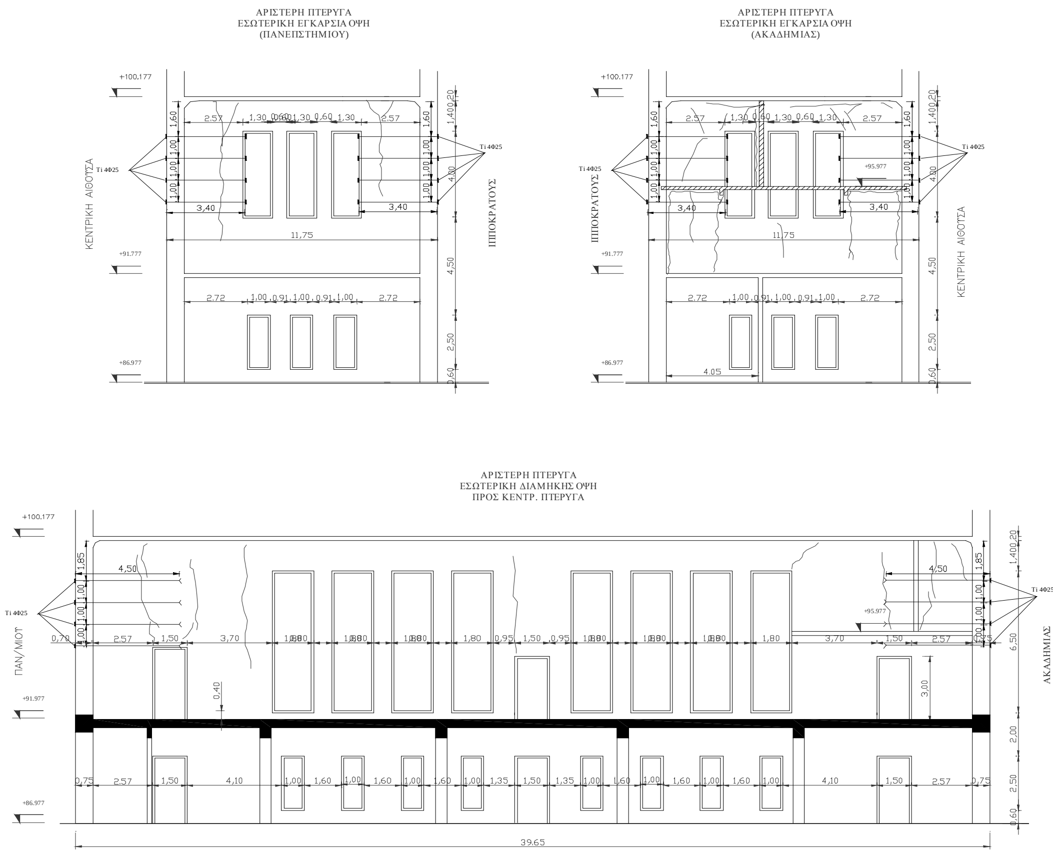


Fig8: Titanium stitches layout

6. CONCLUSIONS

All the restoration techniques used in the case of the National Library building in Athens may not be innovative, but the fact that all the state of the art in laboratory and in situ tests and analysis has been used successfully and efficiently (time wise, within two months) in order to securly reach a very light intervention scheme for the restoration of a monument which is being not only admirred as a monument but used everyday by handreds of people is certainly interesting.

Regarding analysis it has been shown that the most recent trends in earthquake engineering can indeed be used in the analysis of URM monuments and increase the level of confidence and safety of the practising engineer who is confined (by the authorities), with the limitations of a light intervention.

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Fax:+90 212 2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001
ICOMOS TURKEY

MYRELAION CHURCH / BODRUM MOSQUE RESTORATIONS

A. Erdem
Yıldız Technical University, Istanbul, Turkey

SUMMARY

Bodrum Mosque, formerly known as Myrelaion Church, is a monumental building built in the 10th Century. It had been originally used as monastery and church and converted into mosque in the 16th Century. It has suffered fires and restored for 2 times in the '60s and '80s. The building located among a heavy texture of houses and business-places in Laleli is used as mosque at present.

Myrelaion Church has lost its characteristic historical texture becuse of heavy building sites in its environs and has demolished structurally, as well, due to such reasons as fire, excavation, abandonment and unfunctionality. This purpose of this paper is to review the architectural characteristics and complex problems of this monumental building as well as to analyse the restorations made on it. Thus, we will shed some light on whether the restorations made on it enabled the building to maintain its historical evidence or not, as well as on whether functionality-seeking efforts saving the building from destruction impair the integrity, typological characteristics and spatial relations of the building or not.

1-LOCATION AND HISTORY OF THE BUILDING

The Myrelaion Church or as it is otherwise known the Bodrum (Basement) Mosque in Laleli, is on a structural block surrounded by high buildings. The rotunda is beneath a terrace found on the northwest and is referred to as the Round Building or the Myrelaion Cistern.

The existence of the Myrelaion Church was first mentioned as "Myreleos" in the middle of the 16th century by Pierre Gilles (1). Various opinions have been offered in the past as to the church's construction date and identity but it has now been ascertained that it was built in 922 by Byzantine Emperor Romanus I. Lecapenus (2).

I. Lecapenus had a home or a palace built in the area referred to as "Langa" on a rotunda belonging to the fifth century and when this building was later converted into a nunnery, a mausoleum was constructed for his family in the nunnery's church (3). Myrelaion Church continued to be used as a nunnery in the 10^{th} and 11^{th} centuries but it was destroyed during the Latin occupation as the result of a fire in 1203. In the 14^{th} century the basement floor was redesigned as a burial chapel (4) The church at the beginning of the 16^{th} century was turned into a mosque by Grand Vezir Mesih Ali Pasha and given his name (5). It was repaired following the fire of 1782 in which it was damaged (6). In 1816 the Arpa Emini Salih Agha, had a fountain and spigots for ritual cleansing built on the outside of the building. The mosque was destroyed again in the Mercan fire of 1911 and abandoned (7). In 1930 Talbot Rice and Theodor Macridy conducted archaeological studies on the building and the cistern next to it (8). The domes of the structure then being used as a depot for the St Sophia Museum were repaired in 1955 (9) and the external walls in 1964-65 by the Museums Directorate (10). In 1965 Cecil L. Striker carried out a study of this building. In 1986 the building was again repaired under the supervision of the Foundations Directorate Istanbul District and since then has been used as a mosque.

2-ARCHITECTURAL CHARACTERISTICS OF THE BUILDING

The Myrelaion Church suits the early Macedonian period architecture of the center of the empire both stylistically and architecturally (11) and it is a typical example of churches with four columns and an enclosed Greek cross form (12). The two-story structure, thanks to the platform created above the substructure, reached the upper level of the rotunda next to it.

2.1.Plan Characteristics

The church level was set within a rectangle laid out in an east-west orientation. On the west side of the rectangle there is the narthex in three sections and on the east side is the main area with three aisles and four columns. The narrow sides of the narthex on the north and south are semicircular plan.The main area stretching from west to east. In the wide central aisle is the sanctuary that had four columns in the Byzantine era (13) and today has four piers. The east ends of the aisles terminate in semicircles inside the building and in triangular apses on the outside (See, figure 1).

The external contours of the substructure are revealed through the niches that the rectangular buttresses create and show how suitable they are for the planned design of the building and the weight-carrying system. The substructure's plan resembles that of the church floor plan is made up of a main section with three niches and a narthex stretching north and south (See, figure 2) There are four columns with Corinthian capitals in the middle of the main area and in line with the niche walls. It is thought that the entrance to this floor was secured from the door on the south side of the main area up to the 14th century and from the door on the south side of the narthex after that (14).

2.2.Façade Characteristics

The façades at the Myrelaion Church are dynamic. This dynamism is provided by the semi-circular cylindrical supports in all the façades except the east one. There is an understanding of design that reflects itself in partitioning in the internal space and vertical lines and symmetrical order on the facades. The vertical lines, broken up with a marble molding, and in saw-toothed cornices.

The entrance façade on the west is designed in three sections with four cylindrical buttresses and a minaret of hewn stone from the Ottoman period in place of the fourth buttress on the left. The north and south façades have been created from six cylindrical buttresses in the façade of five sections. In back of the third and fourth buttresses in the center that end at a higher level than the others, first there is a barrel vault with arches at intervals and saw-toothed cornices and afterwards that the sanctuary dome rises on a high drum (See, figure 4,5,8). On the east façade the middle apse of the three apses is more in front than the others.

2.2.Structural Characteristics

All of the walls of the church floor are of brick. However in the wall of the big apse on the east and in the external surfaces of the northern and southern walls one sees bands of rough ashlar. Four piers made of rough stone in the main area carry the high-groined vaults and the pendentives that provide the articulation with the dome.The side sections of the narthex and the crosswise branches and the corners of the crosswise branches and the altar portion are covered by a groined vault, the middle section of the narthex by a dome and the side apses by small flat domes.

The walls of the substructure that supports the church level and the terrace on which it is found were made of rough ashlar and brick. The four columns in the main area support the barrel vaults of the cross plan whose branch on the east is longer. The corners of the cross design, the narthex area and the niches that are reflected on the outer façades are covered with barrel vaults.

3-CHANGES TO THE BUILDING

For long years after the fire during the Latin occupation the building wasn't used but it was repaired at the beginning of the 14th century and began to be used again (15). Traces of the repair carried out in this period are especially clear in photographs of the south and east façades taken prior to the 60s. Because the fire destroyed all of the marble elements on the building's façades, repair work was concentrated generally on the central sections in the south and north as well as on the central apse on the east. The number of triple windows determined to be in these sections was reduced to one, and the remaining empty spaces were filled with stone and brick giving it the character of a wall with alternating layers. The windows by the entrance door in the west were also closed during this period. As for the substructure, the earthen floor was covered with brick, the burial sections were made for the main area (16) and when the fill-in wall at the south door of the narthex was remowed, this door began to be used as the entrance door.

The biggest change made during the Ottoman period is the sandstone minaret added to the southwest corner. During this period the marble columns inside the structure were changed with stone piers, a wooden gallery was added and painted decorations were made on the walls along with additions such as mihrap and minber (See, figure 10). On the façades generally square or rectangular windows with a low parapet and marble frames were used. Again in this period a wooden latecomers' section was added to the entrance of the building and the north façade and, while the buttresses on the north and west facades were cut for the construction of this part, a small mihrab was built in the northwest corner (See, figure 3).

4-EVALUATING THE REPAIRS MADE IN THE REPUBLICAN PERIOD

Documents were not sought out on which to form the basis of the restoration prior to the repairs carried out in 1964 and 1965, no survey and restoration project was prepared and permission was not secured from the High Committee for İmmovable Ancient Works and Monuments. During this restoration the north and west facades were rebuilt. Data from the late Byzantine period on the ordering of the windows was basically gotten but not those of the entrance façade, and the marble frames belonging to the Ottoman period, the square windows, the doors, and the plaster were remowed. The character of the fill-in wall belonging to the late Byzantine period was completely destroyed in the south façade and partially in the east façade. Again in the south façade, the saw-toothed cornices and the wall section over the cylindirical buttresses on the left side of the central section were destroyed during this repair. As for in the central section, the part of the saw-toothed cornice and the brick pediment that existed at least to the point of giving an idea about it and was above this cornice that completed the semicircular arch of the crosswise arm was also remowed (See, figure 7, 8). In the east façade the three rows of saw-toothed cornices of the apses and the conical roof covering the central apse were destroyed. No terace remains today of the frescos, mosaics, colored marble revetments, terrocotta friezes (17), stone revetments and ornemental handwork because all of the plaster in the interior section of the church level was removed (See, figure 10).

As a result one understands that the purpose behind this restoration was to wholly restore, according to the dictates of a certain period, the external facades of the building that was in a ruined state. With the completion of this, the structure in part embraced an aesthetic unity; however it wasn't thought necessary to put in the doors and windows because they weren't functional or cover the upper part with brick tiles or some other material. The substructure, full of rubble, was never entered.

The restoration carried out in 1985 again gave rise to talk about the lack of the documentation. In spite of the existence of the surveys made by the Striker in 1965, the restitution project was not prepared and the restoration project presented to the commission was deficient. In spite of the fact that an association shouldered the cost of the repair, the repair offices preferred to carry it out by paying low prices. Because the mosque function was being restored to the buildings additions such as the toilet section and the ritual cleansing section were added in the vicinity of the mosque. When it came to the repairs, it wasn't thought necassary to remain tied to the approved restoration project. The detail of the roof slopes on both sides creating a pediment above the crosswise wings of the structure was not applied and it remained bound to the semicircular form of the vaults that create these wings (See, figure 11,12,9). The upper part of the building was cowered completely with cement a la turca in place of covering it with tiles or lead and three saw-tooth cornices became two.

Additionally after the restoration that did'nt have permission a wind guard of aluminum and an eternit roof were added to the church entrance, and additional buildings such houses for the imam and muezzin were placed in the archaeological area in a form adjoining the mosque. Again without permission the interior of the substructure and south façade were plastered with cement mortar, the door that provided entrance to the main area was closed and in its place a door was opened in the south wall of the narthex.

6-CONCLUSIONS

Painstaking care during restoration and repair was not shown although the Myrelaion Church deserved it was one of the oldest extant examples from the middle Byzantine Period. The value of this monumental building as a historical document and art was ignored. In both restorations essantial studies prior to the restoration work were not carried out, and every level of the the restorations was not documented with drawings, photographs and reports. The restorations especially those made by government institutions ought not to become topics of discussion as a result of lack of documentation and evidence, restoration work have to suit scientific rules.

In restoration carried out to day, the purpose definitely must not be to achieve unity of style. But in the first restoration especially it was attempted to protect the characteristics of the monument that belonged to the Byzantine period but aside from the minaret that additions from the Ottoman Period were eliminated.

Functionality is essential to make a monument live. However the mosque function given to this building does not spoil the structure's spatial relations and typological characteristics but the additional buildings necessitated by this function spoils the visual unity of the building.

Restoration that requires expertise is an expensive business. So in order to lower costs compensation was gotten from the original characteristics of the building. Low cost restoration bureaus and people who weren't experts were chosen.

The building can not even be percieved from the streets around ıts block because of the high buildings in the vicinity and heavy commercial activities. So improving the area surrounding the building which is on a important archaeological site has to be carried out as soon as possible.

In conclusion the restoration of works such as this one that is a choice example of the period in which it was built and has the right to be included among the first-degree monuments because of its historic past, must benefit from the advice of universities and no sacrifice must not be skimped.

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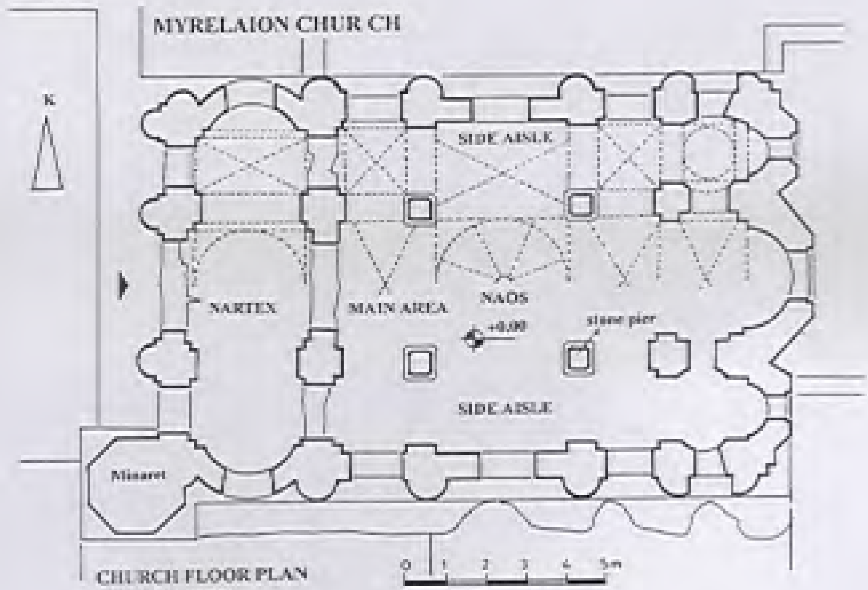
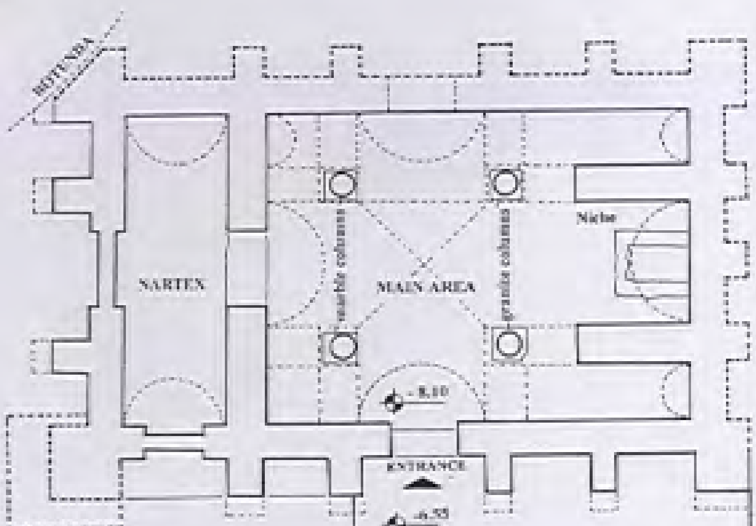


CHURCH FLOOR PLAN
(SURVEY, 1982)
Figure 1



SUBSTRUCTURE PLAN
(SURVEY, 1982)
Figure 2

Figure 3-Myrelaion Church, View From Northwest, 1940 (Istanbul Archaeological Museum, Encümen Archives).

Figure 4-North Façade, 1982.

Figure 6-West Façade, 2000.

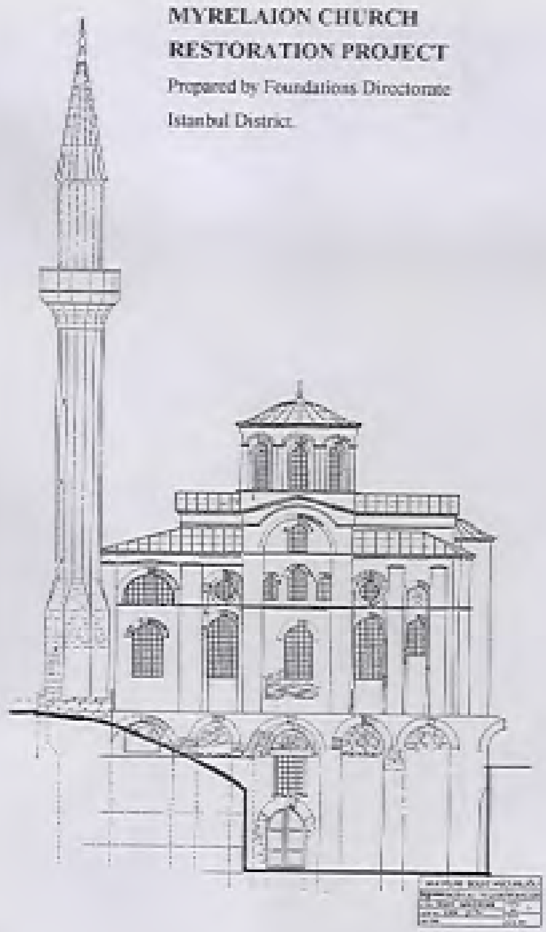
Figure 5- West Façade, 1982.

Figure 7-Myrelaion Church, South Façade, 1940 (Istanbul Archaeological Museum, Encümen Archives).

Figure 8-South Façade, 1982.

Figure 10- Interior of East Façade, 1910 (Striker, The Myrelaion, Figure 42).

Figure 9- South Façade, 2000.



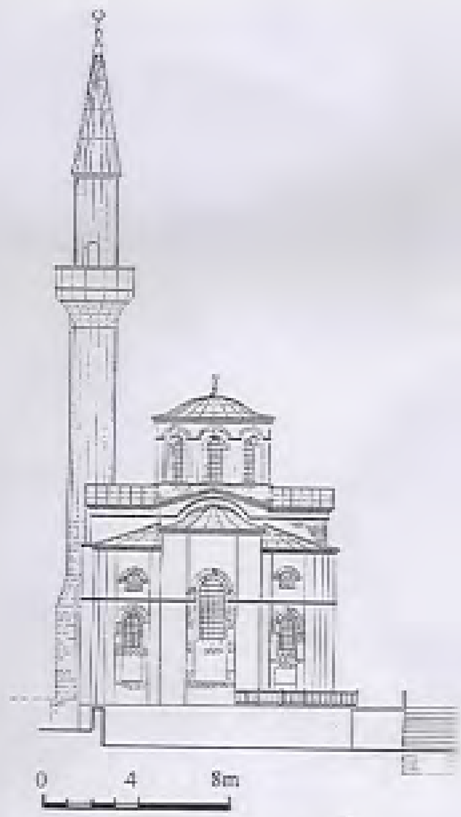


Figure 12-Church, East Façade.

Figure 11-Church, South Façade.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

KÜPUÇURANLAR TOWER IN BİRGİ, İZMİR, TÜRKİYE: EVALUATION OF THE RESTORATION APPROACH AND THE END-PRODUCT AFTER CONSTRUCTION

M.Hamamcıoğlu
Dr., İzmir Institute of Technology, 35430, İzmir, Türkiye

ABSTRACT

Küpuçuranlar Tower is an ancient structure built in late Byzantine or early Aydınoğlu period in Birgi – the capital of the principality of Aydınoğlus and the cultural centre of its region during Ottoman period. This structure is not only a significant historical document, but it has also been an architectural product waiting to be re-functioned within its present context. Therefore, the problem has been defined as the proposition of an appropriate approach of restoration for this structure of fortification. Although the general concept of the approach of restoration has been sustained at the end of the phase of construction, some problems have evolved because of the lack of appropriate policies of management.

1. INTRODUCTION

Prior to the decision making phase of the restoration process, first, the remaining structure was identified both within its urban and architectural contexts. Second, historic information about the life cycle of the remain has been analyzed. Consequently, it has been concluded that Küpuçuranlar Tower was originally built as a defense structure utilized to observe the plain of Ödemiş. On the basis of this hypothesis, intervention decisions were formulated. Finally, the success of the application has been discussed with reference to the architectural end-product and project decisions.

2.SETTLEMENT PATTERN OF BİRGİ AND THE TOWER

Birgi is an ancient settlement located at the south slope of Bozdağ mountains. This slanted positioning of the settlement has given the way to the formation of a series of green terraces organized around the two sides of Birgi brook and degrading in the direction of Ödemiş plain. Deciphering of the urban formation requires understanding of the historical process in which various voids and solids have been organized on each terrace level.

Within this frame, Küpuçuranlar Tower is a significant artifact giving an idea about the silhouette of the ancient city. The tower is perceived from Birgi-Bozdağ road, which is the main axis of approach. An open space organized as a park urrounds the building. In fact, this area provides an opportunity for the exploration of the traces belonging to the historical settlement pattern at this area. The leveled spatial order of the settlement is repeated in the organization of the park as well. The park is separated from the surrounding with level differences and two terraces are formed within the park. A restaurant neighbors the tower, located at the south border of the upper terrace. This new addition not only hides the tower at the eastern direction, but it also presents an unqualified background with the form and proportions of its mass, organization of its facades, detailing of the line of juxtaposition, suitability of the interior spatial order for the function of restaurant, and construction technique and material.

Apart from the restaurant, underground toilets have been provided at the west of the tower. Their positioning has been appreciated, although there are problems with the design details. The Sıbyan School at the south border has been recently repaired. The channels running through out the park in north-south direction are parts of the watering system of the urbanscape. Finally, the presence of an underground channel in human dimensions and linking the brook to the tower, and then continuing in south direction has been heard, but its traces could not be observed.

3.IDENTIFICATION OF THE TOWER AS AN ARCHITECTURAL PRODUCT

The building is conceived as a cylindirical object with its dodecogon sides each about 2.20 m. long and height of 5.75 m. (Figure 1) The organisation of the interior space is characterised by the scarcity of the openings providing exposure. Therefore, an introverted and centralised spatial order is considered. Clearly, this space is divided into two floor levels each composed of a single unit, and linked to each other with an L planned staircase situated along the walls neighboring the entrance opening (2.15 m. in height, 1.10 m. in width). Apart from this single opening at ground level, there are four windows (1.20 m. in height, 0.60 m. in width) placed in an axial manner at the upper level. (Figure 2)

The timber skeleton superstructure is a compressed pyramid with twelve faces. The walls (1.70 m. in thickness up till 0.80 m. from ground level and 1.25 m. in thickness at upper levels) are of rubble stone, slate stone and brick put together with mortar in random order and there is no plastering. A variation of this composite order is observed at 2 m. above ground level: Three rows of brick (each 30 x 30 x 5 cm in size) are put together with mortar. The same brick work is repeated at the two vertical sides of windows. Another peculiarity of the walls is the presence of series of holes with squarish profiles (10 cm. each side) and running through out the wall thickness at 1.60, 3.30 and 4.30 m. from ground level. The first floor together with the stairs are composed of a set of timber beams and covering. (Figure 3) The timber beams of the stairs are supported by a masonry platform that links the timber steps to the three stone ones at ground end. The covering of the ground floor together with the platform is slate stone. Apart from the peculiar thickness of the walls, the constructional features reflect the local building technology of the monuments and houses in the settlement.

There are some minor structural problems such as thin cracks, slipping among the crack line and partial disintegrations observed at the wall surfaces. However, the deformations at the entrance wall are thorough and dangerous. Similarly, the structural system and materials of the first floor are in poor condition. Powdering is seen at some portions of the brick work.

The alterations in the morphology and the building technology of the tower are as follows: First, the irregularity in the finishing of the walls and lacking of appropriate detailing at roof-wall connection are the traces that support the view that the roof is additional. At the same time, the top sides of windows are missing and the walls are very thick (1.25 m.). Second, the interior elements of the windows are missing. The poor quality of the timber frame and wing of the door, the irregularity of the wall finishes bordering its opening and the insensitivity in the construction of the wall piece within which it is located at makes one think that this side of the dodecagon is renewed. Third, the authenticity of the first floor system and the timber stair system may be questioned on the basis of lack of any organic relationship between both the walls supporting them, and the series of construction holes. Fourth, the present slate stone observed at the ground level makes one think that this is the original covering. However, since the authenticity of the location of the door is debatable, it has been thought that the original ground level may only be clarified after an excavation.

4.HISTORICAL EVALUATION

Unfortunately, there are no primary historical documents related with the building itself. In the travelogue of G.Weber (1), who visited the site in 1891, the building is mentioned as ‘the octagonal structure between the houses at the east and by the great bridge’. It is also claimed here that the building belongs to the Middle Age. According to the oral sources, the building takes its name from a group of rebels who blew earthenware jars from the tower onto the plain. It is also claimed that the walls of the tower continue under the ground as long as its observed height.

One of the primary anxieties of the historical research has been to question the original function accepted as ‘tower’ at present. It is known that towers are design components of castle complexes. Although there is no detailed study discussing the concept of castle with reference to Birgi, the Conservation Report (2) refers to an archaeological site, which can be interpreted as the ruins of an old castle. This is an elevated open area at the east side of the valley of Birgi and faces the plaza of the Great Mosque. The boundaries of this site are composed of wall pieces constructed with rubble and slate stones. On the basis of these traces, the site can be questioned as to have possessed the function of castle. In addition to this, the walls of the platform on which the Great Mosque and the houses neighbouring it are situated may also be ruins of an old castle. A comprehensive survey is required in order to observe any further trace that may be evaluated as a piece of the castle system.

Although it cannot be claimed that the tower is certainly a piece of the castle of the city, it may be thought that it has functioned for some kind of defence activity, depending on its strategic positioning with the view of the plain, its characteristics of mass and plan scheme. It may also be asserted that this is an observation tower situated before the castle walls at the higher levels. This final view is supported by the preference of the usage of the term 'tower' in written and oral sources.

Unlike the productiveness achieved in the discussion of the function at a considerable extend, the date of construction could not be clarified. Since there is continuity of the local building technology through out periods, the dating of the tower cannot be based on this phenomenon. It is known that towers have lost their significance in the period of principalities. (3) Therefore, Küpuçuranlar Tower may belong to Byzantine era as well. Further comparative study is necessary in order to figure out these implicit points.

5. PRINCIPLES OF RESTORATION AND INTERVENTION DECISIONS

In its most general frame, the primary principle was to conserve the original architectural features considering the authenticity of material, workmanship and details, but to provide the additions necessary for the establishment of the contemporary function which in turn would bring the continuos survival of the architectural document. (4) This primary principle has given way to the conservation of the monument with minimum interventions. At the same time, the additions, which are indispensable for refunctioning of the building could have been honestly made in accordance with the characteristics of the contemporary architecture. In parallel with the intentions of the Municipality of Birgi, whose the owner of the tower, the potential of refunctioning the building was searched on the basis of the research and documentation studies. Finally, it was decided to use the following restoration techniques in the phase of implementation:

First, the wall pieces that presented thorough structural problems were strengthened. Second, the building was reintegrated morphologically via the completion of deformed window openings, wall finishes and the 'image of tower'. (Figure 4) Third, the interior was equipped with the furniture necessary for contemporary way of living. The theoretical basis of refunctioning the tower as an offering space in which local food is to be served may be listed as follows: Refunctioning is a tool for saving historical buildings from demolishment. (5) It is known that this principle is referred when the restoration of buildings with prominent historic and artistic quality are considered. In the case studied, authenticity of architectural elements such as the first floor, staircase and roof are questionable. Therefore, it was concluded that historical spatial quality would not be ruined, if these elements were altered during refunctioning. It was also assumed that the decisions related with refunctioning would always be under control since the owner is not an individual, but the Municipality.

After this mental process, the problem was defined as the exploration of a way of organising an offering space within a historical building. The tower was originally an urban element that was distinguished with its verticality within the silhouette of the old city of Birgi. At the same time, it was a listed building belonging to Second Group. (6) In accordance with these criteria, it was decided to reorganise the altered interior space without preserving the elements such as the first floor, staircase and roof, but preserving the authentic characteristics such as the location of the staircase and the first floor, stone stairs and slate stone covering pieces nearby the entrance, and holes providing information about the construction phase. The intention was to provide the continuity of the memory of the historical spatial characteristics. A metal structure independent of the old masonry structure was added into the cylindrical body and a new storey system including a transparent top floor addition, which is 3 m. of height, was attached to the new structure. As a result, it was possible to read the historical information about the verticality of the tower whose original height was higher than that of the remaining one. However, the ambivalence in the details of this formation were clarified through a series of hypothetical proposals. On the contrary, the contemporary reality of the new structure was underlined through the tension between the old and the new. (7) It was kept in the mind that the contemporary additions were brought chiefly for to preserve the values of the old building. So the old architectural elements were chosen to be presented instead of being hidden.

Similarly, semi-dark character of the historical space was continued by preserving the original illumination level. The implementation of the metal structure was not a prerequisite of the load bearing capacity of the old walls, but it was preferred because of spatial intentions. Pipe columns as long as the new building height were placed at the corners of the dodecagon and at the centre. I beams were brought together in the order of a grid to make up the new floor systems. The pyramidal form of the present roofing was continued, and over and under tiles were chosen as the covering material in order to provide harmonious relations with the traditional roof texture. Timber covering for the top and first floors, and slate stone for the ground one were preferred. The frames and wings of windows were suggested to be made of rectangular profiled iron since there was no remain of the original elements. Unsound timber elements of the entrance opening were replaced with new ones of the same material and workmanship. The ease in accessing the intervention technologies under the conditions of Birgi were taken into consideration, while choosing them. The distribution of the sub-functions within the chain of suggested space levels was as follows: Service necessities would be fulfilled within the units in the neighbouring additions. The ground floor, which is very dim, was preferred for to be organised as a bar. The first floor, which extends to four different directions through its four windows, was to be organised as a traditional resting space. The top floor, which has a full panorama of the surrounding, would be a contemporary cafe. (Figure 5)

On the other hand, the restaurant and the toilets located within the park area circumscribing the tower were regarded as contemporary additions. However, the kitchen unit juxtaposing the tower was decided to be removed, because it was an unqualified structure hiding the tower and diminishing its aesthetic character. This implementation, which was ratified by the Conservation Council, may be named as cleaning. (8) In place of this kitchen, its alternative was constructed taking into consideration the requisites of contemporary additions. The restaurant building was reorganised with similar anxieties. (Figure 6) Although it was concluded that the entrance opening was added in some time within the life cycle of the building, this was left as it was. Finally, the transparent top floor added may be named also as a contemporary addition providing ease in refunctioning, but it may simultaneously be regarded as reintegration.

In the case of the discussed tower, refunctioning was one of the prerequisites for the survival of the building. However, the architectonic data and documents necessary in order to form a sound restitution proposal were missing. It may be claimed that the building was reintegrated so as to make the limited information about the existence of the tower within the silhouette of the old city legible. Missing wall and opening finishes whose existence were questionable were also suggested to be completed with a similar restoration technique. In fact, this final reintegration type is indispensable for the usage of the building. While completing the brick work around the windows, it was decided to use brick units with marks of our time. With similar anxieties, textural variety was desired in the wall surfaces and ground floor covering that would be completed. Reintegration work in wall pieces was also necessary because of structural reasons especially around the entrance opening. At this spot, unsound filling had to be removed after providing the necessary structural supports. Then, the wall could be completed. (9) Another type of intervention that could be carried out in the walls was strengthening of the thin cracks on the surfaces via injection technique.

No problem stemming from the load bearing capacity of the ground was observed. Similarly, surface water was probably drained by the help of the present channel system and underground water caused no problem for the building. Therefore, no new drainage system was suggested around the building.

6.CONCLUSIONS

The design of the project was carried out in Fall 1996 and it was approved by the Conservation Council in May 1997. The implementations were completed in January 1999. As a result, the image of tower has been reintegrated. The building has started to be used as an enjoyable café. (Figure 7) However, lack of any technical personnel controlling the suitability of the application to the project, the choice of poor quality of workmanship and material, and bad intentions of achieving more than ones right have decreased the quality of the implementations.

The increase in the number of service additions in the park area, enlargement of the top floor, filling of the proposed void along the staircase (Figure 8), addition of a new layer of slate stones on the present ground plane, addition of an arch and an eave to the entrance opening, addition of air-conditioning elements to the north-east elevation, carelessness in the wall repairs, and timber and metal works are the major deficiencies of the end-product. It is obvious that the sensitivity expected in the phase of design and its control is extensively missing in the phase of application and succeeding maintenance. Unfortunately, this is a reality for many other cases that are identified by the modesty of their physical structures, smallness of the settlements within which they are located at, limitations in the project budgets, and insufficiency of technical support in Türkiye. However, the process of restoration should be taken as a unity of interrelated phases such as site survey, archive and literature research, analysis, evaluation, proposal, application of decisions, and maintenance of the building after the interventions. The concept of project management should be utilized honestly in the organization of the field of restoration.

ACKNOWLEDGEMENTS

I am very much indebted to İhsan and İsmail Hamamcıoğlu, my parents, who accompanied me during the site work at various time intervals.

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6.On the basis of the Regulations of the Ministry of Culture at the time of the study, the requests of the Municipality may be interpreted among the interventions whose prerequisite is a comprehensive project and license. Moreover, listed buildings belonging to the Second Group were intervened according to the following criteria: The alterations of the facades, architectural elements and material may be carried out as long as the architectural quality and integrity of the building is not diminished. The renewals and additions should be approved by the Conservation Council and be appropriate to the limits of the Master Plan. The quality and integrity of the additions is a design problem that should be handled

within the limits of the project. The historical documents and related comparative studies on which the restoration project will be based on should also be presented to the Conservation Council. (The Directorate of Preservation of Cultural and Natural Heritage-Ministry of Culture, 1996, 'Principle Decisions of the Supreme Council of Immobile Cultural and Natural Riches', Publication No: 1816, Ankara.)

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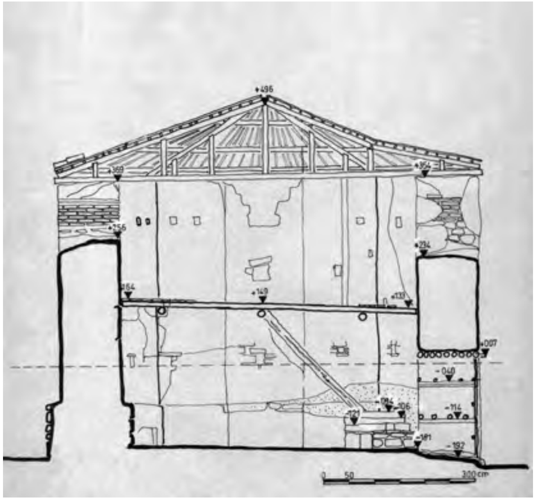
Figure 1.The north elevation of the Tower before the restoration (1996)



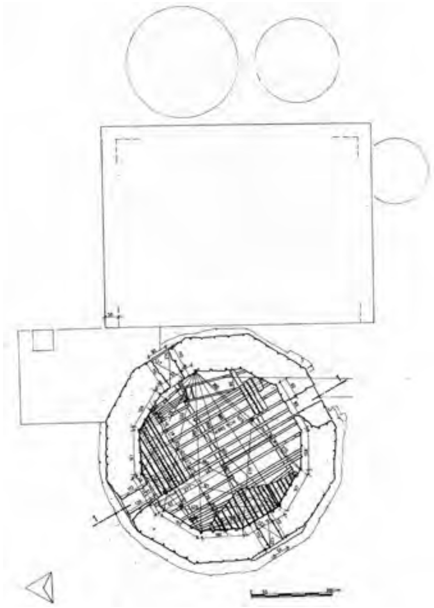
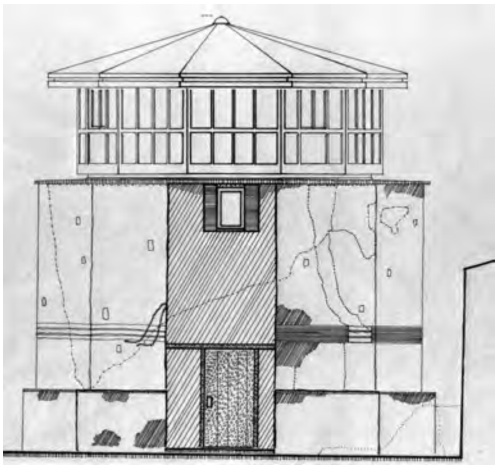


Figure 2.Section (measured survey, 1996)

Figure 3.Plan of the first floor (measured survey, 1996)



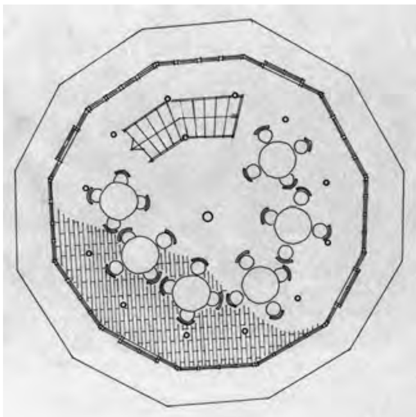


Figure 4.Intervention decisions illustrated on the proposed entrance elevation (1997)

Figure 5.Proposed top floor plan (1997)

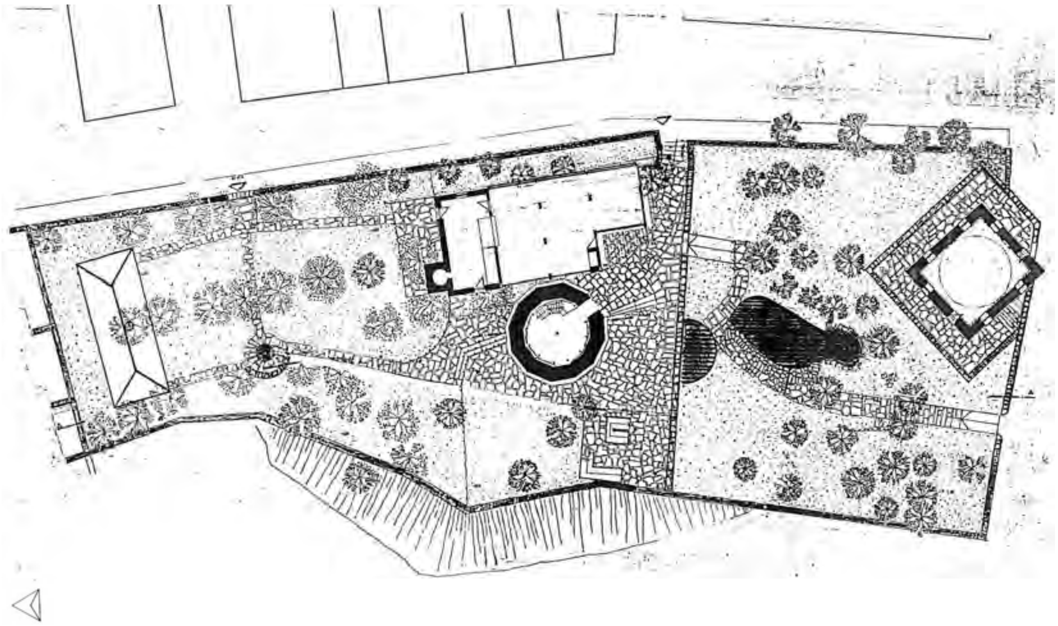


Figure 6.Plan of Küpuçuranlar Park and reorganization of the restaurant addition (1997)

Figure 7.Entrance elevation after the restoration (2001)

Figure 8.View of the interior after the restoration (2001)

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 e-mail:sas2001@yildiz.edu.tr http://www.yildiz.edu.tr/mim/sas2001

THE FORTMED EC PROJECT. A Holistic Approach for the Restoration of Castles and their reuse for the Socioeconomic Development of the Around Area. The Castle of Servia.

I. Papayianni (1), K. Theologidou (2), K. Theocharidou (3), I. Steryiotou (4)

(1) Prof., Aristotle University Thessaloniki, Greece
(2) MA, Architect – Restorer, 11th Ephorate, Ministry of Culture, Greece
(3) Dr, Architect – Restorer, Greece
(4) Dr, Architect – Restorer, Greece

ABSTRACT

In the frame of the FORTMED EC Project (2000-2003) an effort is made for developing a methodology for conservation and revitalization of the castles of the medial period. Four different types of castles have been selected from four countries of Mediterranean basin: Greece, Italy, Jordan and Turkey. In each case a systematic study of the existing situation (including history, environment, survey of pathology and documentation of the materials) will be made. Then, a justified proposal for the consolidation / conservation and revitalization of each castle will be suggested focused on the use of materials compatible with the old structure, compiling the four pattern studies, the constitution of a model methodology is attempted.

1. INTRODUCTION

The FORTMED EC project started in 2000 and aims at a constitution of a model methodology by which the medieval fortifications should be restored with respect to their historical background, to their structural authenticity and in harmonization with their modern urban centers or natural landscape. Four east Mediterranean countries are participated, having selected the following castles as case studies for the pilot application of the proposed methodology.
Greece: The castle of Serbia. Contractor and coordinator: Aristotle University,

Thessaloniki, Research and Planning.

Italy: The Castle of Konigsberg-Monreale inside the fortification system of the Piano Rotaliano in Trentino – Contractor: Instituto Universario di Architectura di Venezia.

Turkey: The Byzantine castle of Constantinople – Contractor: Technical University of Istanbul.

Jordan: Shobak castle in Southern Jordan – Contractor: Ministry of Tourism and Antiquities.

It is believed that the experience accumulated by studying medieval castles of different type, in relation to their environment and social and socioeconomic background, will much help in understanding the problems and in proposing the best solutions, in accordance to conservation principles and economy saving aspects.

What are expected from the appliance of the proposed model methodology?

- Better quality and less costly repair work.
- Minimization of the repair work, to preserve the authenticity.
- Documentation of history, materials and different techniques of construction.
- Enhancement of local economy by creating sites with major tourist attraction.
- Promotion of traditional techniques and local low potential materials.
- Protection of historical physiognomy of the city/area.
- The cultivation of mutual respect of culture and ethics (that is of paramount importance for the co-existence of people).

2. BACKGROUND

Fortification is one of the most important parts of Architectural Heritage. Castles are often extensive, massive structures, easily viewed, on the top of mountains or they surround citadels and harbor entrances. They have early attracted the interest of restorers and citizens, since they are witnesses of the past, a source of historical and cultural references, a place where the memory still exists and could take another role, participating in the life of today as a symbol not of a military power, but of cultural value. In 1949 the International Castles Institute (IBI) was set up and established Castellogy (awareness for protection and revitalization of fortifications). In 1990, it was united to Europa Nostra. A number of 52 IBI Bulletins have been produced, devoted to many aspects concerning historical and architectural documentation, legislation, principles and techniques of restoration, and policy for tourist promotion. They are focusing, in particular, on the necessity of historical documentation.

During 1998, in the frame of INTEREG II, a joint (Greece-Italy) EC project aimed at the valorization of coastal castles, under the title Castro periplous-Castrorum circumnavigatio. More than 35 castles, mostly from the medieval period (some of them incorporating classic or archaic remains and later construction phases up to the 19th century), were included. The program focused mainly on the interventions related to visiting facilities and not on conservation / restoration needs.

The up to date experience showed that the problems envisaged in restoration/ revitalization of fortifications are closely connected to the type of castles and the perspectives, for the recast or recreation of the area and broader region. Small forts, ruined fortresses and citadels in country side and city walls in modern urban centers can serve as mere visiting places, being open-air museums of themselves, but can also shelter new uses (small local museums, exhibitions, etc.) in the interior of their towers and rest buildings. In any case castles attract a great number of people, and especially of young age, and since they are so closely connected with the pure history of the certain area, (defense, survival of the population through the centuries), require a more “educational” and visual presentation, in order to reveal their historical values.

Furthermore, the consolidation and conservation of the remains is work of high cost, since: a) The castles are usually located on isolated and non-easily accessible areas. b) The historical and archaeological documentation takes much time because of their great size, their long past and bad state of preservation, that very often requires extensive excavation, in order to reveal the entire fortified enclosure with its contents. Furthermore the extended repair works that are executed for safety reasons, affect undesirably the authenticity of the castles.

Therefore, a well-defined effective methodology (of multidisciplinary character) is necessary to prolong the life of repaired parts and avoid interventions incompatible to their historic value and to the local environment.

3. THE PROCESS OF A PATTERN STUDY

It consists of three stages A, B, C. The first (A) deals with the evaluation of the existing situation and always precedes of B and C. In the stage (B) the repair works and activities for conservation and rearrangement of the area around, are included. In the stage (C) well-justified proposals are suggested, based on the historical and cultural added value, of the restored castles. Plans for housing arrangement, recreation, development of cultural tourism, educational programs are presented, aiming at serving modern social requirements and enhancing local economy. In the following schedule of the proposed methodology the pivots of work packages are shortly described.

The first stage (A) is devoted to research of archives, historical sources, laboratory and site investigations, selection of all relevant data and photos. The second stage (B) is the main works for the implementation of a restoration project. Scientists of all specialties such as archaeologists, architects civil engineers, material engineers as well as trained technicians should cooperate for that. For the work packages of the (C) stage the participation of authorities and local society is necessary for the realization of the plans. Since the available budget is usually limited it is essential to define the priorities in the developing plans.

4. THE CASE OF THE CASTLE OF SERVIA.

4.1. Historical note.

The town of Servia is located in Western Macedonia, at a distance of 25km from Kozani and 155km from Thessaloniki. It is a small town with a population of 10.000 inhabitants. Geomorphology is the main characteristic of the area. It is a narrow land among the mountains of Pieria, Titario and Kamvounia and the river of Aliakmon. The castle was built on a hill. Two ravines, extremely steep, were protecting it, in the east the ravine of St. George and in the west that of Chouni. In the past, the area was of strategic importance, as it was one of the three passages, which connected Macedonia to Thessaly, and one of the two passages which connected the upper to the lower Macedonia. The castle, together with the naturally strong defensive position, resulted for the area to be impregnable.

The date of its erection is not exactly known. Many researchers position it in the 6th century. However the first written reference is owed to Konstantinos Porfirogenitos in 10th century. For a short while it was under the char of Bulgarians Samuel (995-1001). The Byzantine Emperor Basil II (976-1025) won the Bulgarians in 1001 and demolished the castle in 1018, to avoid reoccupation. In 1204 Franks crusaders occupied Servia, while in 1216 it came under the Despotate of Hepirus. Stefanos Dousan occupied Servia, for a short period, in 1341. From 15th cent. Up to 1912 it was under the Ottoman rule.

4.2 Description.

Two enclosures and the Acropolis formed the castle. The outer enclosure was the most populated and the civilians inhabited it. The military lived in the inner enclosure and the sovereign in Acropolis. Round and rectangular towers strengthened the walls.

The outer enclosure is not fully saved and its outline is not completely known. However, here are still preserved, in relatively good condition, two churches of small dimensions and a basilica in ruins. It is the church of St. John the Baptist (14th century) and the church of St. Theodore (11th century) with a tiny aqueduct in its courtyard. The latter was the church of a monastery. The Basilica of Catechized, or St Demetrius (11th century) was probably the cathedral. Furthermore, traces of churches were discovered in the same area, during archaeological excavations. It seems that this part of the castle was the religious and administrative center. In addition, traces of walls are visible everywhere, which prove a dense building.

The inner enclosure is better preserved. It has a polygonal form and it was the second line of defense and the shelter for the population, in case of capture of the outer part. It was thinly inhabited. The ruins of buildings, which are sparse, prove this.

Acropolis was the last line of defense. There existed the house of the sovereign and military buildings. Some remains of them are still visible. Acropolis has a quadrilateral form. Two rectangular towers preserve most of their height. One of them was partly demolished by the earthquake of 1995. The foundation of another triangular tower is visible.

Pretty early, the area outside the castle was inhabited, as well. The church of St. Anargiri, (by the end of 16th century) was outside the fortified town and very close to the entrance of the walls. Gradually more inhabitants moved outside the walls. Acropolis and the inner courtyard were firstly depopulated. The whole castle has been abandoned until the end of the 17th or the beginning of the 18th c.

Rectangular and circular towers, connected with high walls, formed the castle. They were stone masonry structures. Very often bricks were additionally used and in some cases they formed decorative motives. Lime mortars were mostly connecting stones and bricks, though mud mortars, related to the later phases of construction, are also found.

STAGE A (Work Packages WP 1-5)
<u>Documentation and evaluation of existing situation</u>

WP1: Natural environment: Key words: Location, climate, geomorphology geopolitics, flora and fauna.

WP2: Socioeconomic status: Key words: Ownership, legal frame of the state and local community, economical activities of the region, resources, main occupation educational level.

WP3: Architectural Structural and Technological data: Key words: Designs of topography and architecture of the structures included. Survey of pathology and construction techniques. Documentation of old materials. Old regional techniques of construction.
.

WP4: Historical data: Key words : Ethnology, recursion of the history, historic events, references, everyday life inside and outside the castles.

WP5: Evaluation of the selected data : Keywords : Definition of the basic axis or eminent characteristics which should be alleged and of the piriorities of activities.

STAGE B (Work Packages, WP1-5)
<u>Consolidation, conservation, restoration and revitalization of the castle ensemble.</u>

WP1 : Repair works : : Key words : Interventions for solidification conservation (cleaning, consolidation, pointing reconstruction, reinforcement of foundation sheltering, conservation of work of arts included in the ensemble.

WP2 : Excavation for further archaeological documentation : Key words : Find data for "dark" historical periods.

WP3 : Plans for the functional rearrangement of the site : Keywords : Access, Protection of natural and architectural physiognomia, lightening, readibility of the history.

WP4 : Plans for connection with other monuments of architecture : Keywords : Pedestrian, archaeological walk, place of sightseeing and relaxation.

WP5: Establishment and operation of monitoring system : Keywords : Long-time behavior of repaired parts, record of visitors Regulations.

STAGE C (Work package 5 WP 1-3)
<u>Management and exploitation of the site after restoration</u>

WP1 : Use for educational Purposes : Key words : Plans for regular and occasional activities in cooperation with local and state authorities.

WP2 : Enhancement of cultural activities : Keywords : Festival, infrastructure for theatre performance, meetings, events.

WP3 : Plans for development of local economy : Keywords : Ecotourism, local bus, guides for visitors, activation of municipality and periphery in participation joint development projects.

4.3. State of preservation.

The castle suffers from extended demolition. Furthermore cracks of different types and width, inclination from vertical, weathered joints, lose masonry and losses of adhesion of the building materials are problems, which appear to most of its parts.

The main cause of deterioration is abandonment and neglect. Human action was another main cause of decay. The reuse of building materials, during the centuries, for the construction of new buildings was a very usual action. At the period between the two world wars a forest with pine trees was created to cover the hill of the castle. The roots of the trees must have caused serious damage to the remains. Moreover, earthquakes, weathering, ageing, climatic conditions and especially frost, as well as the bad quality of ground are some other causes of decay.

4.4. Archaeological research and consolidation works.

The size of the castle and its state of preservation need extend archaeological research, to reveal the missing parts of the walls and the remnants of the houses and different buildings. This research will help to understanding the layout of the castle, the different types of buildings, such as houses, churches, handicrafts, and public buildings, and get useful information about the community, its activities and the everyday life. Archaeological research was sparse until recently.

Consolidation works were mainly focused on churches and small parts of the walls to avoid collapse. The church of Ag. Anargiri has been fully conserved. The conservation of mural paintings was also included. A major plan for the restoration of the basilica of Catechized has started five years ago. Besides consolidation of the existing structure, the project includes partial rebuilding of missing parts and partial covering, for the protection of frescoes on the walls and graves revealed during excavation works, under the floor of the central aisle. The systematic analysis and record of the old materials as well as the design of the new repair materials (in order to be compatible with the old ones) is made in the frame of the FORTMED EC project.

Ministry of Culture – 11th Ephorate of Byzantine Antiquities is responsible for the protection of the castle. Furthermore, a convention among the Ephorate, the Treasury of Archaeological Funds and the Municipality of Servia has been signed for the conservation and enhancement of the monuments in the area.

4.5. Exploitation of the castle.

The size of the castle, its position and its state of preservation entail long lasting archaeological research and consolidation – conservation works. Therefore, a step by step approach is necessary for its preservation and exploitation. The consolidation of the superstructure, threatened by collapse is the most urgent action. Archaeological research to reveal foundations in some cases should be necessary. Lighting of specific parts of the castle together with the cut of a limited number of trees, so that the castle is visible from long distance, as it used to be, is another action that could start. An archaeological walk in the castle with certain points of station, where information material could be positioned on specific plates is another step of priority, in order to bring people to the castle and make known its history and structure. Educational programs for all ages could enrich this walk. Cleaning of the uncontrolled vegetation in selected areas could help a better understanding of the remnants. Furthermore, some cultural events in open areas would bring many visitors and make it well known. The conservation of all the churches together with their direct environment is a second step. A further step could be the revelation of the perimeter of the towers and the walls by excavation works, so that its exact size and form become known. The conservation and enhancement of these parts should directly follow. Furthermore the choice of specific parts, (such as Acropolis, the administration center, areas where traces of handicrafts have been noticed, churches, baths) for excavation works should be made so that the whole organization of the castle gradually comes to light.

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Figure 1. Castle of Servia. A view from Acropolis.

Figure 2. Parts from the inner enclosure.

Figure 3. Basilica of Catechized.

Figure 4, 5. Towers from Acropolis. State of preservation.

Figure 6, 7. Tower from Acropolis and its state of preservation.
Detail from loose masonry.

Figure 8. Detail showing roots action.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

STRUCTURAL INTERPRETATION OF STANDING ARCHAEOLOGICAL MONUMENT
Conservation Project of Socerb Castle in Slovenia

M. Guček (1), M. Stokin (2)
(1) art historian (senior conservator), BA, MA - ICOMOS/SI; Institute for the Protection of Cultural Heritage of the Republic of Slovenia
(2) archaeologist (senior conservator), BA, MA - ICOMOS/SI; Institute for the Protection of Cultural Heritage of the Republic of Slovenia

ABSTRACT

The purpose of this paper is to identify the best approach to assess and evaluate the feasibility of conservation project of Socerb castle and in the context of cultural landscape. The essence of “Conservation Heritage” in Slovenia is planning for the best long-term use of cultural resources. The article is a contribution towards the established methodology in conservation policy and how to manage the cultural heritage in the end of the 20^{th} century.

Socerb castle represents the unique standing fortification situated on the natural cliffs, which was once a political boarder between the Venetian Republic and Habsburg monarchy and had an important strategic and political function during medieval period. Nowadays the castle become as a state owned property of national importance.

The cultural landscape consists of prehistoric, Roman and medieval settlements: ruins of castle (Valvazor 1679, 233-234), prehistoric hillforts (Marsetti 1903, 61), graveyards from prehistoric and Roman period (Moser 1903, 115-138), medieval village (Ciglič 1989, 102-107) with stalls and houses underneath the castle, the ruins of parish church of St. Socerb (Valvazor 1679, 233) and caves of "natural beauty" with prehistoric, Roman and early Christian finds.

The archaeological sites of standing features represents an unique opportunity after cleaning to display the mentioned sites in the context of open archaeological air museum. It is important to mention that the research is based especially on non-destructive tehnicques with very limited classical archaeological interventions to

upgrade the existing archaeological and especially to interpretative the intensity stratifical standing structures.

Two prehistoric walls of the hillfort are in the semi-circular line protecting the cliff where the ruins of the castle stand. With intensive cleansing we received new data about constructions of the walls and the evidence of the large medieval rebuilding. The castle was a typical example of architecture from medieval period. The military castle Socerb changed its character many times during the last five hundred years, while in the end of 18th century was burned and from this time it lost its " fairytales" image. In the same time he lost the military function and became a countryhouse for wealthy aristocratic families from Triest. The last owner of the Socerb castle was the Demetrius de Economo from Triest made the final interventions work in 1924 and 1925. The intervention work of the ruins was made in a simple manner, but with conservation knowledge from the beginning of the 20th century. For this reason the identification of original medieval structures is extremely complicated. In spite of a few interventions the Socerb castle remain as a ruin until today.

Our aim was to prepare a conservation program, which is feasible for different presentation solutions, and options having in mind the medieval castle and its cultural landscape, romantic historic ruin on the outskirts of Triest. In the beginning of all conservation projects the perfect documentation is essential and for this reason we developed a special computer program for database and 3D visualization of the castle.

Metric documentation of the present state of the castle was measured by photogrammetric and geodetic means in different accuracy levels (from scales 1:20 to 1:100) and different documentation forms (surface, rendered and photo model, digital orthophotos, photomosaics, attributed photographic database). A procedure for integrating all these different products in 3D model of the castle was developed.

The condition of the castle is in the state of decline and for this reason we made a conservation project which provide the reinterpretation and reconstruction of the castle walls with modern designed architecture in its interior. After the consolidation of the castle walls and on the other side the management of the castle and its environs will play a central rule promoting the elite tourism integrated with cultural landscape with open-air archaeological museum.

INTRODUCTION

The nature of Socerb is a mixture of wild, vernacular and cultivated landscape. The cultural landscape consists of prehistoric, Roman and medieval settlements: ruins of castle (Valvazor 1679, 233-234), with stalls and houses underneath the castle, the ruins of parish church of St. Socerb (Valvazor 1679, 233), medieval village (Cigliè 1989, 102-107), prehistoric hillforts (Marchesetti 1903, 61), graveyards from prehistoric and Roman period (Moser 1903, 115-138), and caves of "natural beauty" with prehistoric, Roman and early Christian finds.

Socerb castle represents the unique standing fortification situated on the natural cliffs, which was once a political boarder between the Venetian Republic and Habsburg monarchy and had an important strategic and political function during medieval period. The castle formed part of the Venetian domain for only half a century. Mostly it belonged to Austria and its margraves who, whilst living in the castle, substantially increased their power. For this reason, the castle represented an important military fort with permanently resident troops and controlled a major trading route leading from the sea to the inland province of Carniola. Nowadays the castle become as a state owned property of national importance.

The earliest information on the castle dates from the 11^{th} century. The original castle at the location of the present-day Socerb was probably nothing more than a fortified court, tower or an old fortified settlement. Its medieval appearance is not known. The oldest depictions of the castle are two drawings by Valvazor in his book The Glory of the Duchy of Carniola. In 1766 the castle was bought by the family of Montecuccoli of Modena, but a fire caused by lightning soon afterwards ruined the building. The damage was so great that the building could no longer be lived in.

Two drawings of the castle, dating from the 19^{th} century depict it as a ruin. Both the drawing by August Tischbein from 1842 and that by Albert Rieger from 1863, show a romantic castle in ruins, topped by a partially demolished tower.

In 1903 the castle ruins and a baron of Greek descent purchased the adjacent cave from Trieste, Demetrio G. Economo, who between 1924 and 1925 renovated the building. The castle's condition prior to its renovation is documented in two photographs. R. Konviczki took the first in 1894 from the village below, depicting the castle together with the protruding rocky plateau. A. Calafati took the other in 1905 from the access path along the cliff edge. Unfortunately, these works are not documented but, according to preserved photographs, encircling defense walls were rebuilt, complete with the round tower while, within this shell, small residential buildings in no way connected with the castle itself were erected. In all construction works, stones scattered around the castle were used as construction materials.

The urgency to improve the present-day condition of the reconstructed castle ruins and the general desire to carry out a quality consolidation of this important cultural monument have resulted in the preparation of an integral-approach renovation project which includes planning the castle's future function according to the plan of preserving the entire castle complex and its broader surroundings. The management cycle started with collecting and evaluation of archives and literature on the construction works so far carried out at the site have been examined and research into the castle and its surroundings has been conducted.

Written archaeological sources reveal that Socerb and its immediate surroundings were settled as early as in the pre-historic age, while the intensity of settlement through different archaeological periods constantly varied.

A conventional topographical survey of Socerb and its immediate surroundings was carried out in winter when vegetation is at its lowest. Despite the thick Mediterranean vegetation, the survey of the terrain was successfully completed. In addition to archaeological sources, aerial photographs were used in the field-survey of archaeological structures located in the immediate vicinity of Socerb.

The interpretation of the partially preserved archaeological remains speaks of the continuity of settlement in the area, starting from the Bronze Age and continuing throughout the Hallstatt and La Tene ages, Roman times and late Antiquity to the Middle Ages. Archaeological excavations will mostly focus on the site of medieval buildings underneath the castle and small-scale archaeological probing as part of the assessment of prior non-destructive research.

The archaeological sites of standing features represents an unique opportunity after cleaning to display the mentioned sites in the context of open archaeological air museum. It is important to mention that the research is based especially on non-destructive techniques with very limited classical archaeological interventions to upgrade the existing archaeological database of the sites.

Two prehistoric walls of the hillfort are in the semi-circular line protecting the cliff where the ruins of the castle stand. With intensive cleansing we received new data about constructions of the walls and the evidence of the large medieval rebuilding. The castle was a typical example of architecture from medieval period. The military castle Socerb changed its character many times during the last five hundred years, while in the end of 18th century was burned and from this time it lost its " fairytales" image. In the same time he lost the military function and became a countryhouse for wealthy aristocratic families from Triest. The last owner of the Socerb castle was the Greek count Demetrius de Economo from Triest made the final interventions work in 1924 and 1925. The intervention work of the ruins was made in a simple manner, without any existing documentation and without conservation knowledge. For this reason the identification of original medieval structures is extremely complicated. In spite of a few interventions the Socerb castle remain as a ruin until today.

Metrical documentation of the Castle of Socerb was made from the geodetic and photogrammetric measurements. The all ready existing digital surface 3D model of the castle, with its surrounding, was upgraded into the photo-realistic digital 3D model. For the relevant detail of the facades, digital ortophotos and digital photomosaics were made. There were metric and non-metric images used. Attributed-photographic database was made as the link between the photographic products and the corresponding descriptive contents. All the products made for the project “The castle of Socerb” were put into the adequate analogue form.

The photo-realistic model allow the castle to be shown in its natural form, because the visualization and presentation of the castle is realistic and close to the human perception of the castle.Photo-realistical presentation of the castle was made from the surface 3D model and from metric and non-metrical photographs. Images were first rectified and then pasted to the surface model. Images were distributed in two groups. For the first group of non-metric images the so-called graphical rectification procedure was used, based on the plane transformations, that were all ready included in some of desktop publishing software. The absolute accuracy after rectification was not prescribed. The graphical rectified images were used only for 3D visualization purposes. The other group of photographs was metric and their absolute accuracy was prescribed as very high. For this group of images the exact photogrammetric equations for rectification were used. Each rectified image was then pasted into the surface model using the standard function of AutoCADr14 software.

The structure of dwg file of photo-realistic model is consisting from the vector and the raster data. The vector data belong to the surface model and are structured in 18 different layers with different colors, so that data were very easy to handle. The scanned and rectified analogue black and white images with 8-bit radiometric resolution are representing the raster data in 13 different layers. Their geometrical resolution was adjusted to the scale of visualization with the possibility of multiple zooming, so that separability of detail was still possible. The photographs were taking with two different cameras: photogrammetric camera Rolleiflex 6006 metric with reseua crosses - Rollei Fototechni and nonprofessional camera ECX1 – Samsung.

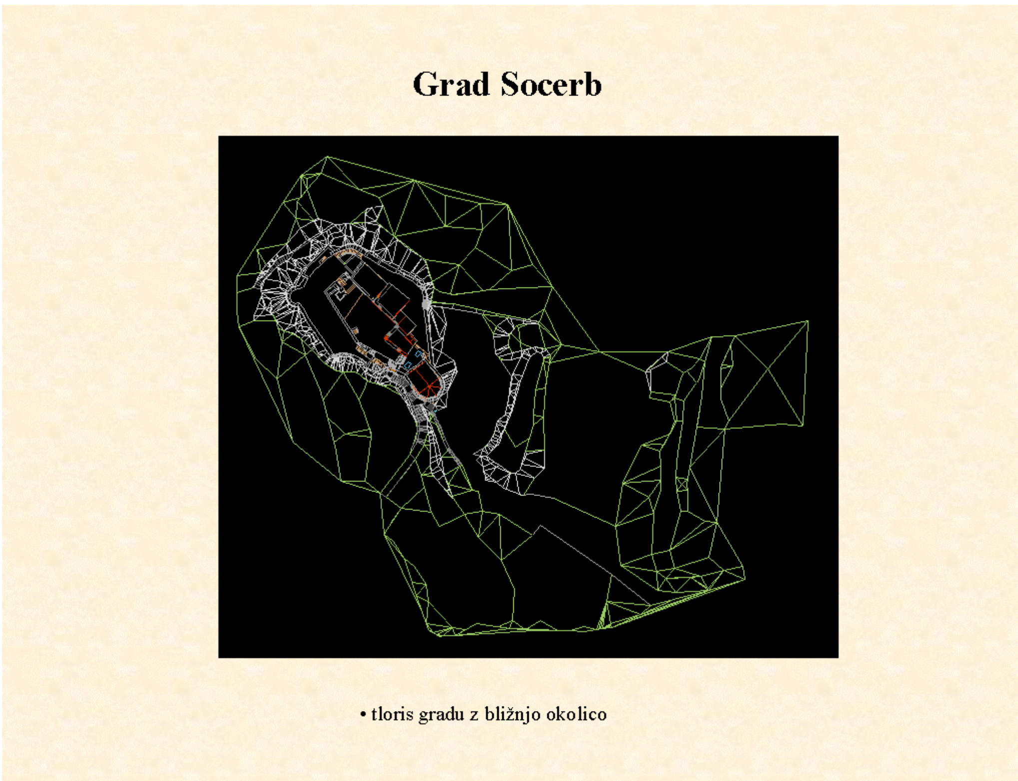
The photo- realistic 3D model of the castle was upgraded with the attributed-photographic data base, which was made as the link between the photographic products, like digital images, ortophotos, photomasaics, etc., and the corresponding descriptive contents, like some technical description of images, notes etc. For this purpose the application named FOTOAT 1.0, which runs inside the AutoCADr14 environment, was made.

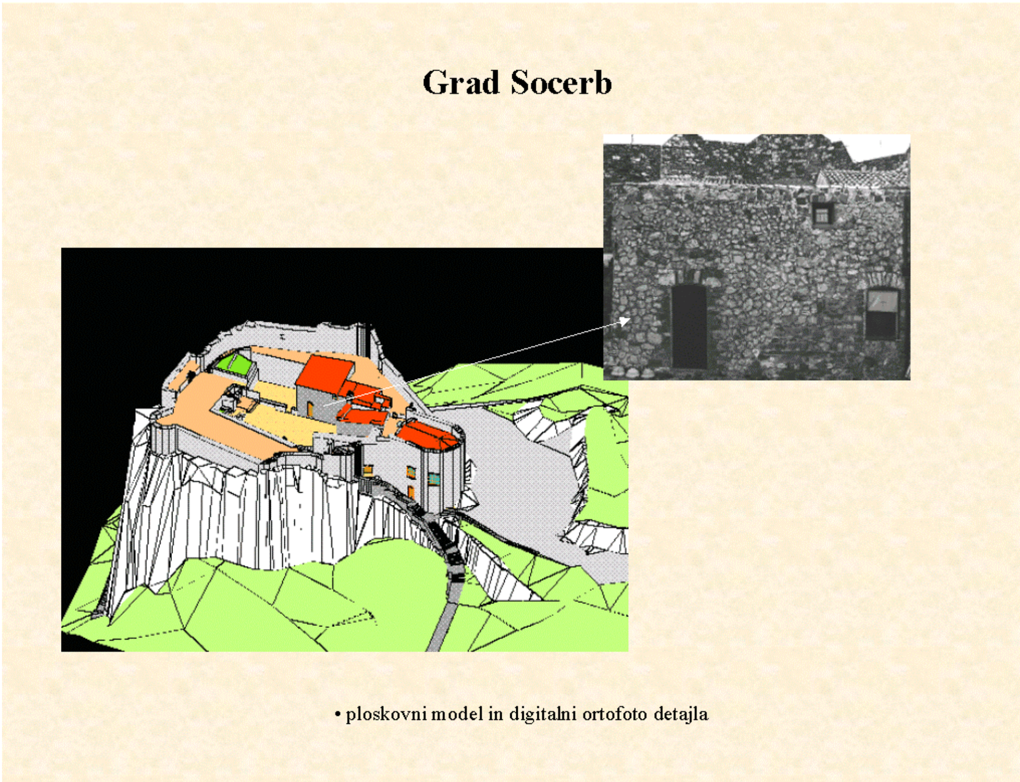
Our aim was to prepare a conservation program, which is feasible for different presentation solutions and options having in mind the medieval castle and its cultural landscape. In the beginning of all conservation projects the perfect documentation is essential and for this reason we developed a special computer program for database and 3D visualization of the castle. Before we started the project we produce a data base which is divided on different stages: archaeological record of past archaeological research and of updated modern topography and radar survey, architectural and art-historical inventarisation of all standing structures (castle, village, caves, prehistoric hillfort, military objects, etc.). We made an evaluation of archive sources, historical maps and bibliographic reports and medieval archives. In the last two years the research was focused on different laboratory analyses, especially on castle walls. All collected records mentioned above will be collected on CD and we are preparing a WEB site on internet.

CONCLUSIONS

The condition of the castle is in the state of decline and for this reason we made a conservation project which provide the reinterpretation and reconstruction of the castle walls with modern designed architecture in its interior. In the beginning of the project we prepare preliminary conservation program. The main goal of this program (with agenda of non-destructive research) was to consolidate the ruin of the castle in the context of conservation doctrine. Different procedures to reinforce "in situ" ruins of the castle were not necessary having in mind the results of static research and there was a need only for small static interventions after endoscopic analyses. Last year we provide a detailed research on wall stratigraphical research before we started the consolidation. For the consolidation we used an original copy of mortar after the laboratory analyses. In the future years our project will be orientated on other castle structures where the consolidation will be much more complicated especially on those outside walls where the biodegradators destroy completely the construction of the walls and the standing structures. If we are producing a very updated documentation for culture heritage we should provide more recording efforts for vernacular, authentic and cultivated natural landscape.

The ruins of the castle display as a ruin and probably with modern reversible architectural implementations will play a central monument of the whole cultural landscape. General conservation program is trying to protect the whole cultural and natural landscapes without any new interventions (anastylosis, fragmentary reconstruction,). The only method (except non-destructive techniques) in this moment is cleaning, consolidation and recording of the standing structures. The management of the castle and its environs will play a central rule promoting the healthy tourism integrated with cultural landscape with open-air archaeological museum.

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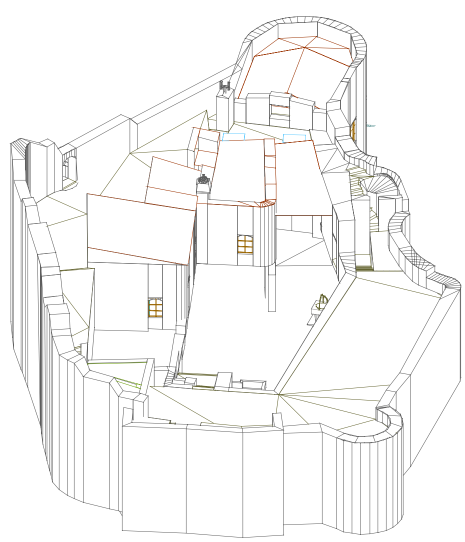

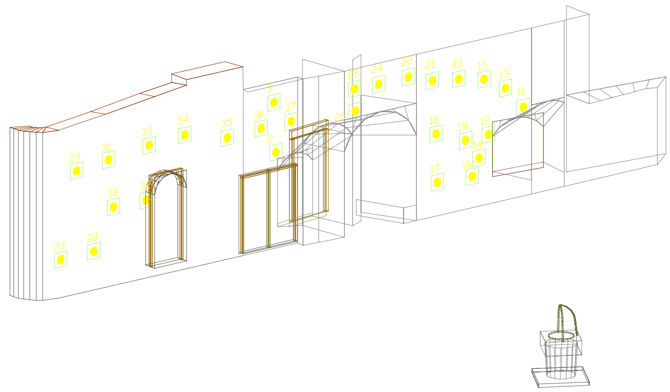

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CHAPTER VI

ENVIRONMENTAL ASPECTS
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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 e-mail:sas2001@yildiz.edu.tr http://www.yildiz.edu.tr/mim/sas2001
ICOMOS TURKEY

ENVIRONMENTAL CONCERNS AND HERITAGE CONSERVATION IN EL-MOIZ LDINALLAH STREET OF HISTORICAL CAIRO

M. Atalla(1), Nadia Sh. Guirguis(2)
(1) Consulting Engineer, Egy-Tech Group, Cairo, Egypt
(2) Professor, Building Research Center, Dokky, Giza, Egypt.

ABSTRACT

Several authorities in Egypt are concerned with the environmental affairs as related to the heritage conservation. This paper deals with one of historical Cairo districts namely El-Moiz Ldinallah Street which is the main street of Fatimide Cairo. Environmental concerns are exposed and discussed with concentration upon the ground water control problem and its effect in the extremely valuable numerous Islamic monuments in the street and the near by districts El-Gamalia and El-Ghoria.

1. INTRODUCTION

It is increasingly evident in the last decade that environment protection and heritage conservation are coupled and interrelated. This is reflected in the high concern of several authorities in Egypt as the Ministry of Culure, Supreme Council for Antiquities (SCA), Minsitry of Tourism, Cairo Governorate, Ministry of State for the Environmental Affairs, Civil Society and also interested in Egyptian Antiquities foreign sponcors.

One of the conservation projects upon which these authorities are working is the upgrading of historical Cairo. Concentration of heritage in historical Cairo, namely Coptic and Islamic monuments lies in Old Cairo district and Elgamalia-Elghoria districts. Atalla [1] reviewed the environmental management and protection of these two historical heritage districts. If the Fatimide Cairo is the heart of historical Cairo, El-Moiz Ldinallah Street is the heart of Fatimide Cairo. Islamic monuments in historical Cairo according to the Islamic monuments index of the Surveying Department Map: Islamic Monuments in Cairo [7] are 622.

More than one third of these 622 monuments lie in the El-Gamalia and El-Ghoria districts. It is estimated that only El Moiz Ldinallah Street comprises 40 Islamic monuments. Also tens of the most precious monuments are lcoated in the surrounding near by area in the eastern and western parts of the considered street.

Fig.(1) shows the noticable concentration of Islamic monument in El-Moiz Ldinallah Street as derived from the Surveying Department Cairo Map for Islamic monuments [7].

The Northern part of the street to the north of El-Azhar street extends from point 1 to point 2 while the Southern part extends from point 2 to point 3 in Fig. 1.

2. HERITAGE IN EL-MOIZ LDINALLAH STREET

El-Moiz Ldinallah street is considered the main street or the greatest street for Fatimide Cairo. The street can be divided into three parts :

1- From Bab El-Fotouh Gate to El-Azhar street,
2- From Al-Azhar street to Bab Zewella Gate,
3- From Bab Zewella Gate to El-Kalaa (the Citadelle) street.

The first two parts have a length of about 1.5 km and contains together with the surrounding area tens of Islamic monuments. In this length of the street four Fatimide Mosques exist, namely : El-Hakem Beamrallah, El-Akmar, El-Azhar, El-Saleh Talaeh. These four Mosques together with the Northern Cairo fence (with its two gates Bab El-Fotouh and Bab El-Nasr) and Bab Zewella Gate are the six Fatimide Monuments in the considered area which had been constructed during the Fatimide era (973 AD to 1171 AD).

The most famous of Islamic monuments of fatimide Cairo is El-Azhar Mosque (969 AD). El-Azhar Mosque lies at the intersection of El-Azhar Street and El-Moiz Ldinallah street (the theme of the present work). In the year 1969, Cairo city celebrated its 1st millennium (969-1969) as in the year 969 AD the commandor Gawhar the Sicilian Constructed Cairo City

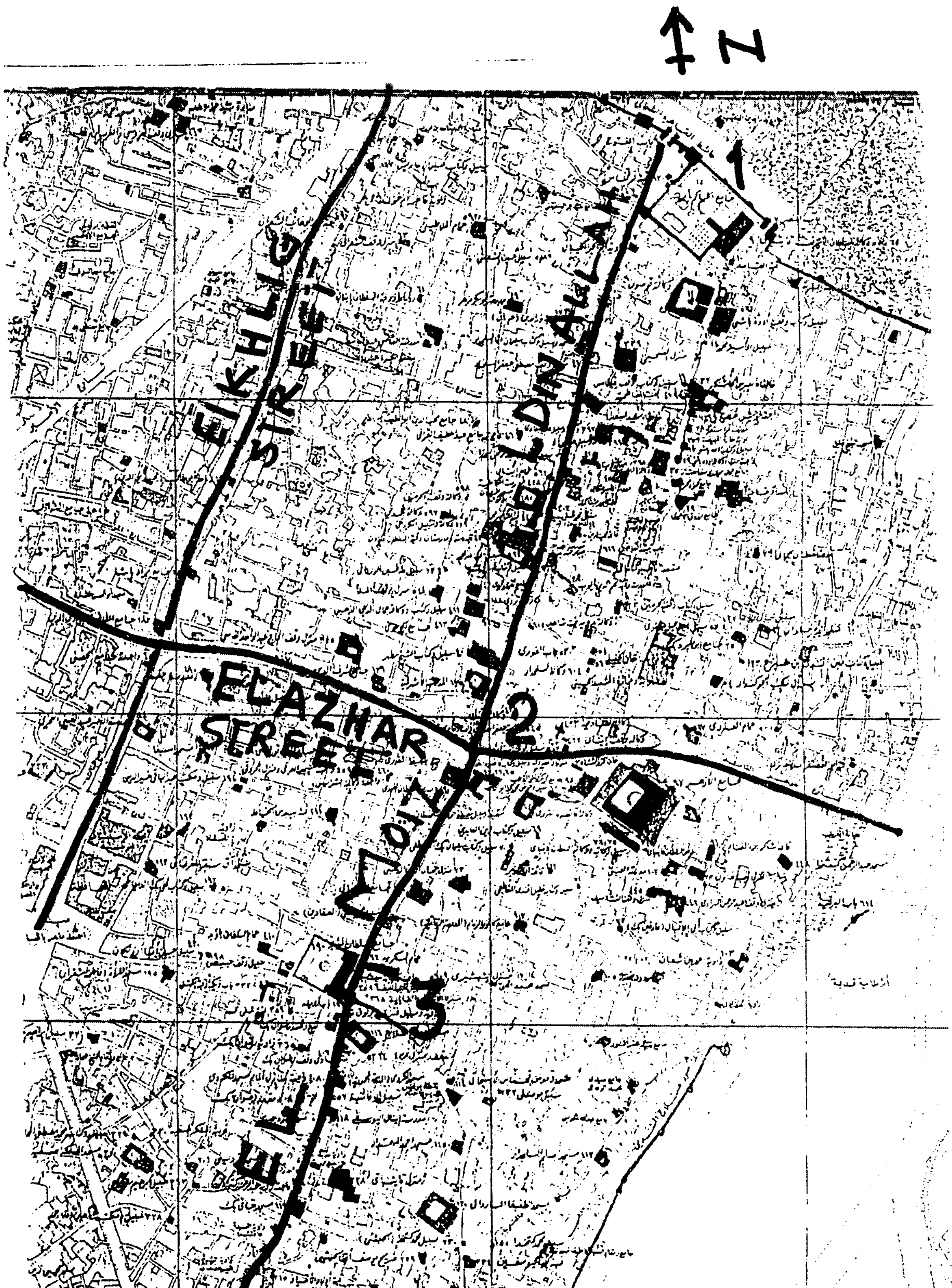

Fig 1: Concentration of Islamic monuments in El – Moiz Ldinallah street
1 to 2 Northern part : From Bab El-Fotouh to El-Azhar street
2 to 3 Southern part : From El-Azhar street to Bab Zewalla

(El-Kahira) and El-Azhar Mosque. Compared with he 7th millennium of ancient Pharaonic Egypt, Fatimide Cairo looks much younger.

The Fatimides (Shiite, pronounced shiaa muslems) ruled Egypt from 973 A.D to 1171 A.D. This period is called the Fatimide State. Names of all rulers in the Fatimide State are related L'Dinallah (To the Religion of Allah). The first of them is El-Moiz Ldinallah (the dearest to the religion of Allah) after which the street is named ruled Egypt from 973 A.D. to 975 A.D.

The rest of the Islamic monuments in El-Moiz Ldinallah street and the surrounding area are from eras that followed the Fatimide era. These monuments are typically old houses, historical buildings, drinking water outlets (sabils buildings), old schools, trade halls, shops and centres (Wikalas) and public baths.

Available maps of Islamic monuments in Cairo are :
- Surveying Department Map for Islamic Monuments, 1948,
- Cairo Governorate Map for monuments in El-Moiz Ldinallah Street, 2000.

3. ENVIRONMENTAL CONCERNS IN EL-MOIZ LDINALLAH STREET

Environmental concerns in El-moiz Ldinallah street can be summarized as :

1- Over crowded residential, commercial, small industries and handicraft shops due to the "occupation" or renting of these places.
2- Problems resulting from heavy traffic and the pollution resulting from cars exhaust.
3- Audio-visual pollution due to items, 1 and 2.
4- Solid waste resulting and accumulated due to mentioned activities.
5- Problems resulting from infrastructure water supply and sewer systems and necessity of their upgrading.
6- Problem of ground water control and its effect on he monuments, specially these parts below the street level.

From these six concerns, the present work concentrates on the latest item concerned with ground water control and its effect on the monuments. It is increasingly evident that no mentioning or occasion concerning any specific site of hitoric Cairo is free from complaining from the damaging effect of ground water.

4. GEOGRAPHICAL, GEOLOGICAL AND GEOTECHNICAL FEATURES :

Figure 1 shows how El-Moiz Ldinallah street crosses the Fatimide

Cairo (El Kahira) from Bab El-Fotouh at North to Bab Zewela at South, passing by El-Gamalia, Khan El-Khalili and El-Ghoria districts. It slopes down in a north-south direction from + 23.00m at Bab El-Fotouh to + 20.00m at Babl Zewela [4],[5]. In general, the bulk of upper soil horizons in Cairo is due to Nile sedimentation. However, the basin in which these deposits were formed, geologically speaking, belongs to relatively old formations, (Pliocene deposits) which due to errosion from rainfalls and subsequent streems have caused different alluvial deposits to form below the recent Nile sediments. Exposures of Pliocene deposits may appear at the edges of the cultivated valley [4],[6].

As all areas east of the "Khalig El-kebir" (now Port Said Street), the Fatimide Ciy had not suffered flood attacks at all because of their relatively higher levels [4], [5].

Old town remains occupy most of the zone of El-Moiz Ldinallah Street. Soil sections in Fig. 2B may declaire the picture, where a FILL of 4.0 to 6.0 m thick in average is the prevailing layer. It connects the ground surface and the bottom SAND within the northern part of the street (El Gamalia Zone). As going south, a brown stiff CLAY begins under the FILL. The thickness of this clay layer as Fig. 2A shows may aquire considerable thicknesses and occasionally extends from ground surfce. A brown SILT layer underlains the clay layer around the middle part of the street, including lentils or relatively thin layers of brown to dark clay. Bottom SAND then appears [4].

5. GROUND WATER CONTROL PROBLEM

5.1 Ground water investigation

As the ground water control problem is the most crucial of the enivornmental cocnerns, it deemed necessary to investigate the ground water conditions in the considered area. Moreover, it is almost certain that all authorities concerned with antiquities conservation projects for Coptic and Islamic monuments raise the issue of ground water problem. This is due to the ground water effect on these unique monuments.

Ground water occasionally floods the monuments flooring specially the parts below the street level and could be also below the ground water level. Also the humidity problem is clearly noticed due to this issue.

Now, it is almost certain that the extent of this problem needs solutions that minimize or mitigate the ground water effect. Any ground water control project, either regional or site specific, must be precedented by a ground water investigation in the considered area. This investigation includes the monitoring, study of ground water movement vertically and

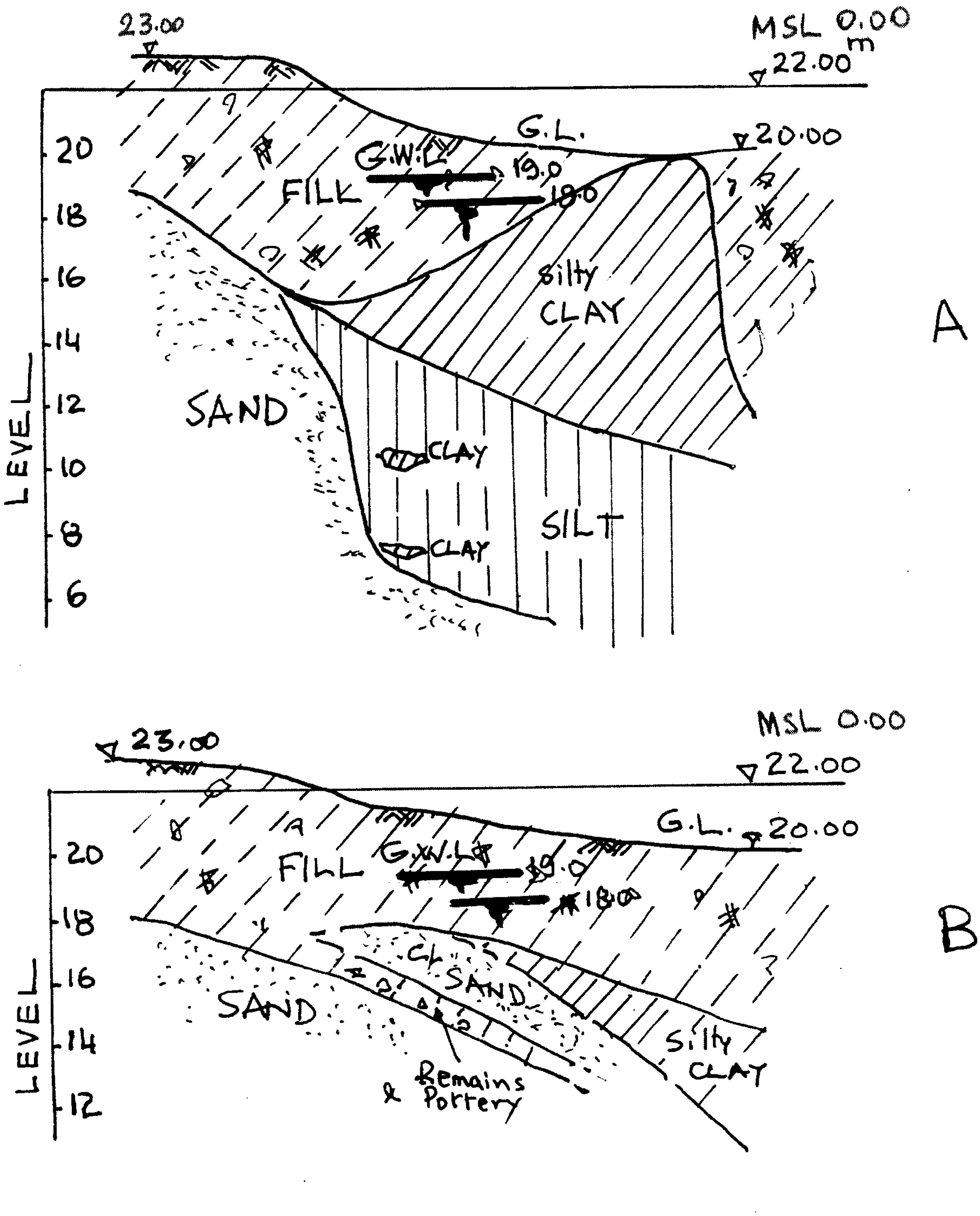

Fig 2: Prevailing soil conditions in the area of El – Moiz Ldinallah street
A- Soil section to the west of the street.
B- Soil section to the east of the street.

horizontally, kinds of ground water, levels and analysis of the ground water. Monitoring has to be carried simultaneiously in several points and for a reasonable period of time not less than one year.

Also ground water control is a continuous process pending on the continuous monitoring and observation of the ground water conditions. Only after performing the ground water investigation recommendations on solution and engineering of ground water control projects can be adopted. Such projects may be on regional scale, site specific scale or both.

With the concentration of Islamic monuments in El Moiz Ldinallah and the near by areas it would be practically difficult to control the ground water for each specific site individually.

Worth noting is the lately starting project of upgrading the sanitary drainage net in Fatimide Cairo to improve the situation in El Gamalia, Elghoria and El Darassa districts. It is usually emphasized that this upgrading of sewage net would help to lower the ground water by avoiding the problem of leakage in the net and problem of blockage of the lines.

However, the upgrading of the sanitary drainage nets would lower the perched ground water resulting from leakages from the net.

In a study by Atalla [2] concerning the ground water in Elgamalia two kinds and levels of ground water were observed, namely: perched ground water and ground water related with the ground water and its movement in the Greater Cairo.

Fig. 3 shows the fluctuations and differences in the piezometric level in the multi-level piezometers for a site with a clay layer acting as a practically impermeable layer hindering the vertical movement of ground water. Also, Fig. 3 shows the absence of perched ground water level where the soil formation and its permeability in another site allows the vertical movement of ground water [2].

The source of ground water would be the infiltration of water from zones higher than the district under consideration with ground water movement heading towards it. Such water would not be lowered by upgrading the sewage net in the considered area but by studying the source of the ground water and upgrading the sewage net in the higher area.

For all these reasons, it deems necessary to carry ground water ivnestigation in Fatimide Cairo from which El Moiz Ldinallah Street and the near by area are chosen in the present study.

Execution of this study can be carried by sinking a number of multilevel piezometers in which both kinds of ground water can be monitored. Also these piezometers can be used to check the efficency of sewage net upgrading by monitoring before and after the completion of this project. Similarly for any ground water control project the before and after measurements can be used to supervise the effectiveness of such projects.

Propsoed piezometers are of multilevel type, mainly above the could be clay layers, and quite deep in the deep ground layers. Also simultaneously continuous automatic monitoring in several stations is required.

5.2 Ground water effect

Two direct main ground water effects exist:

a- Flooding of monuments floorings if it lie below the street level and also the building parts below the ground water level as crypts, trenchs and basements. Several mosques are built with their flooring higher than the street level, with stairs leading to the flooring. However, under these mosques a sort of basement exists which was used as shops.

b- Humidity problem caused by capillary rise of ground water into the walls and columns.

All Islamic monuments in the considered area have special type of stone foundations which is immediately put on soil and the walls have no horizontal insulation. It does not need big effort to notice the damaging effect of the ground water and the stone deterioration caused by dampness caused by the capillary rise of the ground water. Four to five meters of dampness rise in the outer walls and is notied by naked eyes.

Moreover, stone deterioration is happening due to crystalization phenomena of the salts (mainly chlorides, carbonates and sulphates) left on the outer surface of the walls and columns. Similarly is the deterioration caused by micro organism biologically affecting the outer surface of the walls.

6. STAGES OF THE PROPOSED GROUND WATER MONITORING PROJECT

The conservation project proposal consists of three stages :

1. Data collection and documentation about environmental conditions in El-Moiz Ldinallah street. Three monitoring stations at points 1,2 and 3 (Fig. 1) are to be surveyed and the type and details of piezometers are to be decided.
2. Execution of the piezometers after getting the necessary approvals for sinking the piezometers in the chosen locations from the concerned authorities. One year monitoring of the ground water levels, types in the chosen three stations.

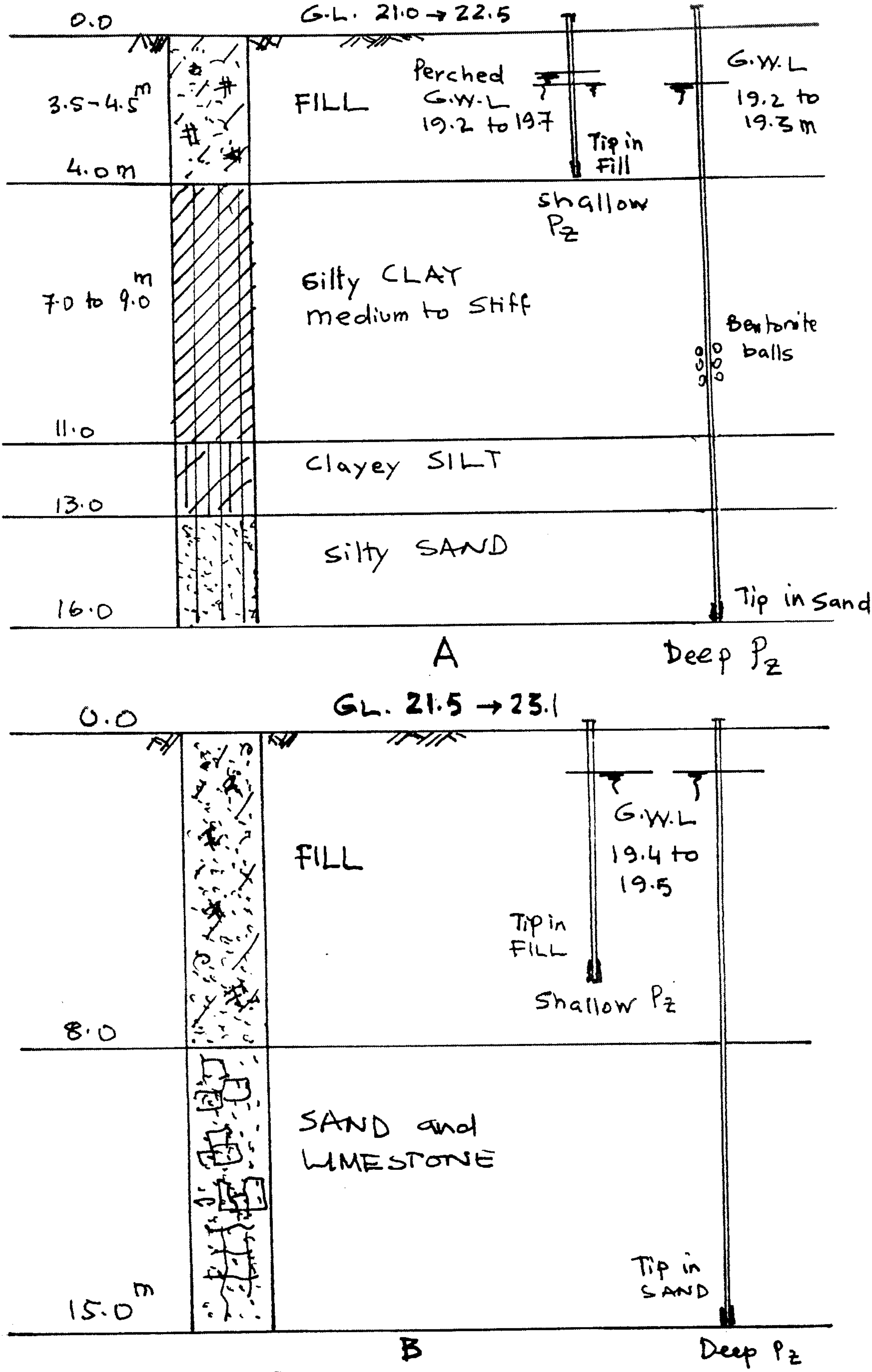

Fig 3: Fluctuations of ground water level in two sites:
A- Case of perched ground water level due to the clay layer
B- Case of absence of perched ground water level.

3. Final report and recommendations on possible solution of ground water control (regional and site specific) of El-Gamalia and El-Ghoria districts.

7. RECOMMENDATIONS AND CONCLUSIONS

1. As environment protection improvement measures, the concerned authorities are thinking of converting El-Moiz Ldinallah street to only pedestrian precinct and keeping the traditional handicraft shops and non-polluting commercial shops. Also shifting of over crowded occupied houses and small industries shops to other places. However, the substitution of these places is required to the inhabitants, which constitute a major difficulty. Lately, Cairo Governorate is planning to contract a specialized company to clean the monumental areas to solve the solid waste pollution problem.

2. As heritage conservation measures, the upgrading of the infrastructure program has started, however, the issue of ground water control would not be properly analyzed and designed without the prerequisit of a comprehensive ground water investigation and montioring as propsoed in this present paper.

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NOT ONLY VAULTS ARE MENACING WITH "TUTANKHAMEN'S CURSE"

B. Janinska
Institute of Structural Engineering, Poznan University of Technology, POLAND

ABSTRACT

„Those who shall enter this holy tomb, will soon be embraced by the wings of death". This, according to the press, was the inscription placed on the wall of Tutankhamen's grave three thousand years ago [1]. H. Carter, the man who discovered the grave, maintains that there was no curse at all [2].
Until this day, both the treasures unearthed in the Valley of Kings, and the speculations as to the causes of sudden and mysterious deaths, continue to stir up mixed feelings among the scientists and the general public.
Has it been the curses, or perhaps was it the mould fungi, that were the reason of unfortunate events which happened alongside the exploration of the tombs? Can the risk similar threats be faced during the renovation of old historic buildings?
The author of this paper has explored the influence of the environment on the toxic effect of mould fungi growing on building materials. The results of the research are presented below.
Although many scientists and researchers disclaim the existence of "Tutankhamen's curse", utilising the results of our research in the practice of restoration and conservation of old constructions may help protect, or even save, the lives of Lord Carnavon's followers.

1. ROYAL VAULTS AND THEIR CURSES

A sensational discovery in 1922 of the grave of Pharaoh Tutankhamen, an ancient Egyptian king, raised a wave of emotion all over the world. Excavating the treasures was overshadowed by the myth of a curse cast by Egyptian priests which, supposedly, was to bring death upon anyone who dared disturb the peace of the pharaoh's grave. The reason of deaths of the members of the team conducting excavations in the Valley of Kings, including the death of Lord Carnavon, was to be solely Tutankhamen's curse.

Some authors quote the connections between fatal accidents and a large number of deaths and curses Contemporary researches of the history of Egypt (for example, T.Howing [6] and D.Silverman from the Pennsylvania University [1]) claim that none of the inscriptions found on walls may be regarded as curses.

Some maintain that it was mould fungi that were the source of toxic effect on people entering graves. The pharaoh's tomb had spores of such mould fungi. Some sources state that it was the *Aspergillus flavus* species fungi [12], some, that *Aspergillus niger* species has been identified [1].

In Poland, we have our own "curse of the Jagiellonian dynasty". In the 1980s, in Cracow, restoration and maintenance work was carried out on the grounds of the royal castle of Wawel, an ancient seat of Polish kings. After the graves had been opened in the royal vault of King Casimir the Jagiellonian, the members of the restoration and maintenance team began to rapidly die off, one after another.

A similar story, highlighted by a Latin inscription *Violator operis infelix esto* (Be damned, you who shall destroy my work) placed on the wall of former Royal Chapel in the Vilnius Cathedral, and a series of deaths of those who explored the royal graves, strengthened the belief in the "Jagiellonian curse".

Just like in the case of the " Tutankhamen's curse", the "Jagiellonian Kings' curse" is associated with the activity of various toxin producing mould fungi.

During archaeological work carried out at the Wawel Castle, the crypt of King Casimir the Jagiellonian was examined. The crypt had not been opened since the day of the king's funeral in 1492 [11].

In 1973, that is, nearly 500 years after the burial ceremony, microbiological tests were carried out in order to identify the microbiological organisms present in the crypt (in the air, on the walls and ceiling, in the samples of wood and mortar from and around the coffin, and the coffin dust). As a result of the research the following species of mould fungi were identified there: *Chaetomium globosum, Aspergillus niger, Penicillium, Trichoderma* [16]. Bibliographical source [18] maintains that the *Aspergillus flavus* fungus was found in the Wawel Castle crypt.

The characteristic feature of the mould fungi identified in the Wawel Castle crypt is their strong biochemical activity in the process of wood and silicone and lime mortar degradation, they adapt very well to the environment in the old buildings.

It was the mould fungi that were blamed for the misfortunes accompanying the disturbance of peace of kings and rulers. As it turned out, the killer was lurking from the walls of crypts, and thus, the myth of a "curse" had been discarded.

Therefore, if it is not a curse that kills, but toxic mould fungi, could such a danger be come across in old, fungus-infested buildings?

2. THE MOULD FUNGI

2.1. Environment conditions determining the development of mould fungi

Mould fungi is a large family of heterotrophic organisms (25 000 species), rather undemanding as far as nutrition needs are concerned [3, 4, 5, 7, 9, 14, 15, 20]. The mould fungi which grow in buildings, use the components of paint and wallpaper and micropollutants which land, with dust, on the surfaces of partitions and walls as their nutritional base. The partition walls are also easily contaminated, because there will always be fungal spores in the atmosphere. Parameters of the indoor microclimate are nearly optimal for the development of moulds (the temperature of air indoors is t_i=20 to 25°C, and there is access to natural light and oxygen). Mould fungi, nonetheless, may only develop if the humidity in their environment is high. They can take in water both from the atmosphere and from the base on which they grow.

2.2. The problem of environment humidity

In microbiological laboratories, mould fungi are grown on special organic media, in the conditions of stable, relatively high temperature t=25÷30°C. Their water requirements is described by means of a water activity index, a_w. It describes the humidity of the medium in the conditions of hygroscopic equilibrium with atmospheric air, and is equivalent to the relative humidity of the air, φ (for example, a_w = 0,6 is equivalent to φ = 60%). The majority of mould fungi grown in laboratories, do grow when a_w>0,6, and as to the *Aspergillus flavus* fungus, when a_w>0,9. Therefore, microbiologists use a single parameter to describe both the humidity of the air, and the humidity of the medium on which the mould fungi grow.

Unfortunately, the water activity index should not be used to identify the humidity conditions in buildings, because it does not reflect the character of phenomena which occur there. The water content in inorganic materials, under the conditions of hygroscopic balance, results from the humidity of air, but also depends on ambient temperature and on the structure of a given material, e.g. on its texture and porosity.

Another separate issue is the humidification of materials in partitions, resulting from vapour condensation on their surface, and from the capillary movement. In those cases, there will be no direct relationship between the a_w factor which describes humidity requirements of the mould fungi and the instantaneous relative humidity of air and the water content in the material.

2.3. *Aspergillus* fungi

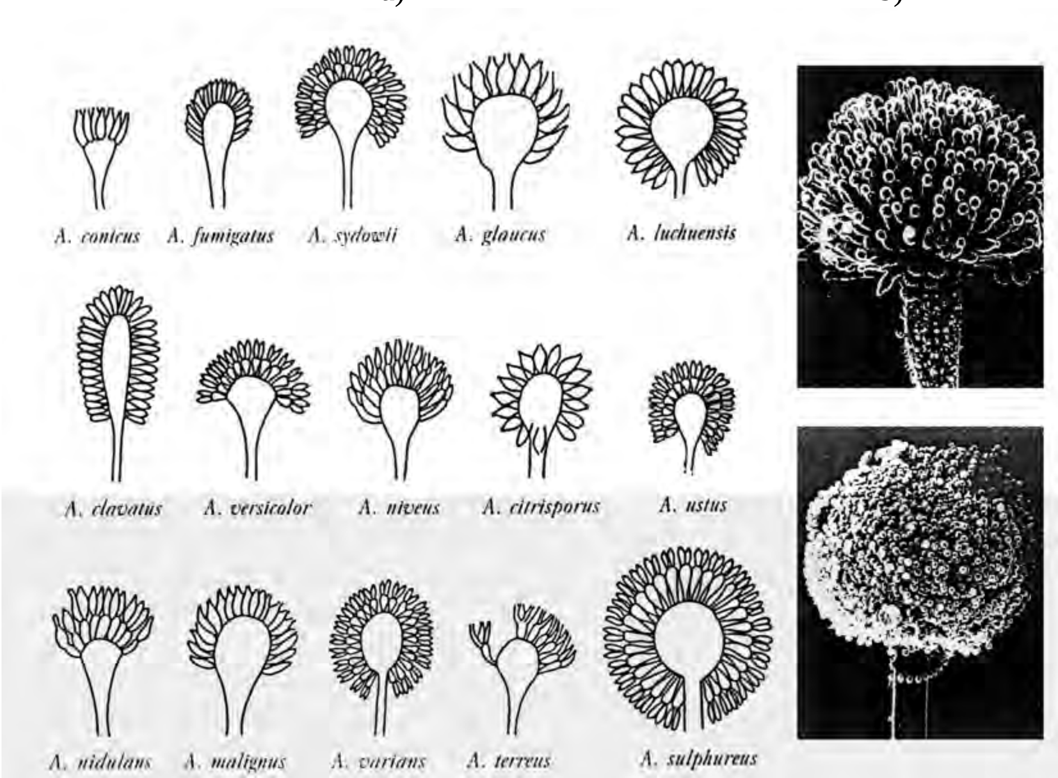
It is assumed that the oldest generic names of mould fungi (*Aspergillus* and *Mucor*) have been given to them by the Royal Botanist of the Prince of Tuscany as early as in the 17th century. Since then, a large number of botanists have described new species and genera of mould fungi, concentrating mainly on those features which constitute a basis for their classification - structure and manner of reproduction.

Identifying the species of mould fungi requires extraordinary precision. It is easy to make an error of judgement because, as it is illustrated if Fig. 1, the distinctive features used to identify the species are often merely minute differences in the anatomy of those microbiological organisms.

There are many species of *Aspergillus* fungi all over the world. They often occur in the soil and on food produce, and some species can be quite toxic (they can case a variety of diseases, from typical allergies to general inflammations which may be fatal), other mould fungi produce antibiotics which help overcome diseases.

Both in Tutankhamen's tomb, and in the Jagiellonian Kings crypt, two species of *Aspergillus* fungi have been identified: *Aspergillus flavus* and *Aspergillus niger*. The *Aspergillus flavus* species is regarded to be the major producer of aflatoxins (ccerogenous toxins), whereas *Aspergillus niger* is a species commonly occurring in buildings which are damp, but not as dangerous.

a) b)



c)

Fig.1. The structure of *Aspergillus* fungi
a - selected types of conidial heads of different species [14],
b - *Aspergillus flavus* [5], c - *Aspergillus niger* [5]

3. HISTORIC BUILDINGS AND THE MOULD FUNGI

3.1. Problems of toxicity in historic buildings restoration

The problem of toxic character of mould fungi may be pertinent either to the toxic character of preparations used as fungicides, or the toxic products of the mould fungi themselves which may result in many diseases, including allergies, athlete's foot, they may hinder normal development or organs, and even cause cancer [3].

Putting up a struggle against mould fungi is, in most cases, limited to eradicating the reasons for increased humidity, and using preparations which destroy microbiological organisms and are, simultaneously, non-toxic for humans.

Toxicological investigations are normally focused on identifying the dose and type of substance which is best suited to become a future lethal weapon against the fungi. In case of the disinfecting historic buildings, what is important is that the preparation be efficient, that it did not destroy the historic structure which is being cleaned from fungi, and that it did not leave any traces.

The problem of mycotoxins, that is, toxic mould fungi, surfaced as late as in 1960, when 100 thousand turkeys were found dead, poisoned by *aflatoxin* (the mycotoxin produced by the *Aspergillus flavus* fungus)

In recent years, it has been proved that many species of mould fungi produce mycotoxins (*aflatoxins, ochratoxins*, and so on) – toxic compounds which can be produces at all times, or only under specific conditions. One of the factors mobilising fungi to produce toxins is, for example, overcooling.

It has been a strong belief that those mycotoxins are dangerous which penetrate into the human body through the digestive tract. Recent research has proved, nonetheless, that the compounds are most strongly toxic when they are inhaled. The inhaled mycotoxins are approximately 40 times more toxic than those which penetrate through the digestive tract [10, 15].

Today's chemical analysis (cytotoxic screening test, chromatography) is able to identify mycotoxins and assess the toxic compounds in the air and building materials in the restored historic buildings.

3.2. Environment conditions in the historic buildings

Old buildings, covered by dust and layers of dirt, are usually damp. In such conditions, mould fungi may grow on the surfaces of walls and ceilings, and on some elements of the interior decoration. Historic buildings are often unused and, consequently, not heated and this, in turn, may be a reason of overcooling and an impulse for the production of fungal toxins. Restoration work (for example, replacing old plasterwork, painting the walls) usually increases the humidity of partitions.

B. Flanningan [4] quoted the minimum values of water activity index a_w for different kinds of mould fungi growing on paper made from paper pulp coated with emulsion paint. (see Table1.).

As the results shown in Table 1 point out, the lowering of temperature is accompanied by the increase in the a_w index which is intuitively interpreted as water requirement. As it transpires, in lower temperature, in spite of the higher value of the a_w index, the amount of water held in the air, indispensable for the growth of fungi, is definitely lower. It signifies the fact that, in a lower temperature, fungi grow in an environment with lower water content.

Table 1 The values of the water activity index a_w – [4], and the equivalent values of vapour content in the dry mass of air x, according to the author

Mould fungi	t_i **= 18°C**		t_i **= 12°C**	
	a_w **[-]**	x **[g/kg]**	a_w **[-]**	x **[g/kg]**
Aspergillus versicolor	0,79	10,17	0,87	7,58
Penicillium brevicompactum	0,83	10,69	0,87	7,58
Penicillium chrysogenum	0,85	10,95	0,87	7,58
Cladosporium sphaerospermum	0,92	11,87	0,93	8,11
Stachybotrys atra	0,97	12,53	0,98	8,55

3.3. Examples of mycotoxic pollution of historic buildings

In old buildings there are conditions fostering the fungal growth. There are occasions, such as restoration works, when mycological investigation may be carried out. For example, the species and types of fungi found during research in a number of historic buildings, have been listed below:

- *Aspergillus niger, Aspergillus flavus, Chaetomium globosum, Penicillium, Trichoderma* were identified in the Tutankhamen's grave and in the crypt of Jagiellonian Kings [1, 12, 16, 17],
- *Penicillium, Auerobasidium* and *Aspergillus, Cladosporium* occurred in the air and on the walls of historic buildings of Cracow [13],
- *Aspergillus*, *Cladosporium* and *Penicillium*, *Stacybotrys atra*, *Alternaria* were discovered in the old manuscripts storage areas, located in old buildings in the centre of Cracow [17],
- *Penicillium*, *Aspergillus*, *Alternaria*, *Fusarium* and *Cladosporium* are fungi identified mostly in historic buildings [4, 20].

These fungi are potential producers of mycotoxins.

If, therefore, mould fungi grow in old buildings, the companies carrying out building restoration works are exposed to inhaling fungal spores and, consequently, may be exposed to toxic influence of mycotoxins.

4. AUTHOR'S OWN MYCO- AND TOXICOLOGICAL RESEARCH

4.1. Research description

The research entailed the following:

- Growing mould fungi in different environments (field work),
- Identification of the species of fungi and assessment of the degree of mycological pollution (mycological investigation),
- Carrying out tests to state the presence of mycotoxins (toxicological research).

Between September 1999 and March 2000, in two buildings (portacabin type containers meant for human habitation), mould fungi were grown on the surface of different building materials placed on free standing internal partition walls. The following elements were assessed: plasterboard, wallpaper, cellular concrete building blocks, thermal insulation materials.

From September until the end of December, the portacabins were not heated. The heating and humidification was turned on in January. In some interiors, forced air circulation was initiated, in other, the air was still. The conditions fostering the growth of mould fungi were created: the levels of relative humidity were kept at $\varphi \geq 70\%$, and the ventilation had been limited.

The surfaces to be tested were polluted with fungal spores (sprayed by sediment, or the pollution was self-induced, straight from the air – by way of a bioaerosol). Some of the samples had been earlier covered by a thin layer of organic medium standing in place of common dirt, other samples were deprived of the medium. The following mould fungi were used to contaminate the materials: *Stachybotrys atra* Corda, *Alternaria alternata* (Fr.) Keissler, *Aureobasidium pullulans* (de Bary) Arnaud, *Cladosporium sphaerospermum* Penz., *Ulocladium tuberculatum* E. Simmons.

4.2. Temperature and humidity of samples in the experimental structures

During the experiment, the temperature and humidity of air indoors were controlled, as well as the temperature and humidity of the materials being investigated. The measurements were taken using non-invasive methods.

The investigation embraced three characteristic periods of time. In September and October, the temperature was kept at the levels of $t_i = 25 \div 15^{o}C$, in November and December, it dropped to the levels of $t_i = -5 \div 0^{o}C$, and from January to March 2000, the temperature was kept at the level of $t_i = 20 \div 25^{o}C$).

The temperature of surfaces of the materials was close to the temperature of the air indoors.

The mass humidity of plasterboard was found to be close to the level of sorption humidity $u_M \cong 1\%$. Concrete cellular building blocks dried out during the investigation – from the humidity level of $u_M = 30\%$ to the sorption humidity at $u_M \cong 7 \div 9\%$.

4.3. Mycological and toxicological research results

The species content of fungi isolated on the surfaces of the materials under investigation had been identified as early as 3 weeks since the beginning of the experiment, and was as follows [7]:

- from among the species used for the experiment, the occurrence of: *Alternaria alternata, Stachybotrys atra, Cladosporium sphaerospermum, Ulocladium tuberculatum, Auerobasidiom pullulans* was stated on the surfaces of samples,
- there were fungi which had not been included in the contamination mixture, nonetheless, they grew on the containers, namely: *Penicillium*, *Aspergillus,*
- *Penicillium*, *Aspergillus, Cladosporium,* were identified as dominating species.

The results of the toxicological tests confirmed the occurrence of *ochratoxin A* in the samples of the tested materials (tests to corroborate the presence of only this mycotoxin were performed [10]). Simultaneously, no correlation was noted between the amount of the toxin and the amount of spores contaminating the surfaces of the investigated materials. Nevertheless, the biggest amounts of the toxin were found on samples placed in the room where the circulation of the air was forced.

Ochratoxin A is produced by different species of fungi classified as *Penicillium* and *Aspergillus*. The *Penicillium* and *Aspergillus* fungi did not constitute any part of the contaminating mixture but, as it was shown, grew naturally, on their own. Also, *Stachybotrys atra* fungus, producing *satratoxin*, a very strong toxin, was identified on the samples.

As it results from the research, mould fungi develop on the surfaces of building materials. The fungi may produce mycotoxins if the interiors are damp and temporarily not heated. In the air indoors, there is a huge number of fungal spores, microscopic in size. And the air, therefore, is also contaminated by mycotoxins.

Table 2. The results of mycological and toxicological investigations

Type of material	**room 1**	**room 2**	**room 3**	**room 2**	**room 3**
	bioaerosol	**sediment**			
	organic medium			**no medium**	
mycological pollution [jtk/g]					
wallpaper I	$6,3 \times 10^3$	$8,0 \times 10^3$	$3,0 \times 10^5$	$2,3 \times 10^4$	$8,2 \times 10^5$
wallpaper II	$1,7 \times 10^3$	$1,46 \times 10^6$	$3,7 \times 10^6$	$2,1 \times 10^4$	$1,2 \times 10^6$
mineral wool	$2,0 \times 10^5$	$3,0 \times 10^6$	$3,4 \times 10^6$	$4,6 \times 10^4$	$6,2 \times 10^5$
cellular concrete	$5,4 \times 10^3$	$1,7 \times 10^7$	$5,5 \times 10^5$	$7,5 \times 10^4$	$3,7 \times 10^6$
styrofoam	$2,2 \times 10^5$	$1,4 \times 10^7$	$3,7 \times 10^6$	$2,6 \times 10^5$	$8,2 \times 10^5$
amount of *ochratoxin A* mycotoxin [ppb]					
wallpaper I	0,61	0,49	0,53	0,61	2,69
wallpaper II	0,14	0,27	0,36	0,22	2,74
mineral wool	not found	not found	4,90	not found	not found
cellular concrete	not found	not found	not found	not found	not found
styrofoam	not found	not found	not found	not found	not found

5. SUMMARY

- The conditions in historic and old buildings often foster the intensive development of mould fungi, such as dirty areas where dirt nurtures the fungi, as well as high humidity of air and in partitions and walls. Initiating air circulation inside the unused spaces and rooms makes it easier for the spores to spread and increases the degree of mycological pollution of the air. The humidity and overcooling in historic buildings may be an impulse mobilising mould fungi to produce mycotoxins.
- Human exposure to mycologically polluted interiors is dangerous, because the harmful toxins are inhaled in the process.
- The recently proved harmful effect of mould fungi on human health forces a new approach to the problem of toxic character of fungi during the renovation of historic buildings. There is a need of defining methods of renovation and restoration of historic buildings in view of the danger carried by mycotoxins.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 e-mail:sas2001@yildiz.edu.tr http://www.yildiz.edu.tr/mim/sas2001

EVALUATION OF THE OLD HOUSES OF DIYARBAKIR IN TERMS OF COOLING LOADS IN THE HOT PERIOD

G. Zorer Gedik
Yıldız Technical University, İstanbul, Turkey.

ABSTRACT

In this paper, the old houses of Diyarbakır is evaluated in terms of dominant climatic elements characterized by high temperatures and solar radiation. Moreover the summer room of a traditional dwelling is compared with a new dwelling's room designed with a new technology and materials according to the thermal insulation regulations of Turkey. For this comparison the cooling load calculation method developed for dwellings by ASHRAE is used.

1. INTRODUCTION

Climate is a principal physical environment factor in the design of the buildings and settlement. Climatic design create comfortable, energy efficient and environmentally wise buildings. Climatic design can also be learned and inspired by observation of the old traditional buildings. The old houses of Diyarbakır are striking as an example of successful climatic design. The basic characteristics of Diyarbakır's climate are high temperatures and dryness. The hot period is rather longer than the cold period in Diyarbakır. Therefore, the hot period conditions must be dominant in the design of the buildings.

2. CLIMATIC DATA FOR DİYARBAKIR

Diyarbakır is situated in the hot-dry region of Turkey. The basic characteristics of it's climate are high temperatures and dryness (low humidity). The high variations between night-day and summer-winter temperatures make adaptation to the climate difficult. Strong wind may raise dust and create a dust haze. Collected climate data for Diyarbakır is shown in Table 1. [8]. The seasons when artificial heating is, and isn't required in Diyarbakır is shown in Figure 1 [1].

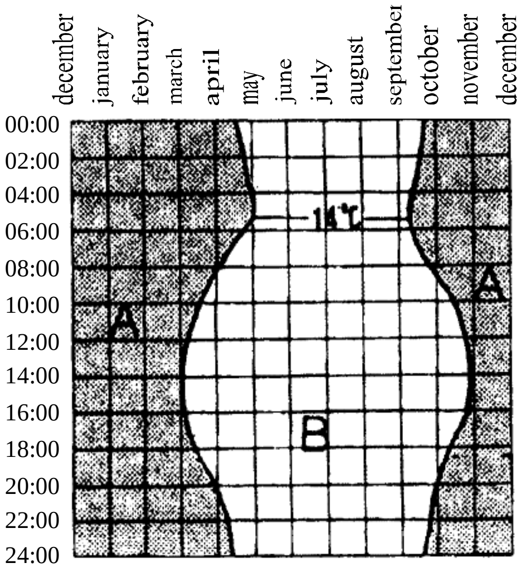


Figure 1.

The value of outdoor temperature (14°C) is basic factor in the determination of the heating period and this is taken from Turkish standart 2754 [2]. As seen in figure 1, the hot season (from April to November) is rather longer (about 8 mounths) than the cold season in Diyarbakır. Therefore the hot period conditions must be dominant in the design of the buildings.

A: The period when artificial heating is required.

B: The period when artificial heating isn't required.

Table 1. Climatic data for Diyarbakır, Latitude: 37°55', Longitude: 40°12' East

Climatic Variable			Units
Temperature	Mean Summer months	30,5	°C
	Mean Winter months	3,7	°C
R.Humidity	Mean Yearly	53	%
	July-August	24(min)	%
	December-January	77(max)	%
Precipitation	Winter	71,4	mm/m^2
	Spring	59,8	mm/m^2
	Summer	3,9	mm/m^2
	Autumn	28,3	mm/m^2
Wind	Winter (S-NW)	33,8	m/s
	Spring (W-NW)	21,6	m/s
	Summer (SW-NW)	23,1	m/s
	Autumn (NW)	20,6	m/s
Solar Radiation	Mean yearly total radiation in horizontal plane	16	Mj/m^2gün
	Mean yearly direct radiation in horizontal plane	10,4	Mj/m^2gün

3.THE EFFECTS OF DIYARBAKIR'S CLIMATE ON THE TRADITIONAL BUILDINGS.

The old settlement and dwellings of Diyarbakır, bordered by the walls of the fortress, are typical examples of buildings adapted to a hot-dry climate. Investigation of the settlement in terms of dominant climatic elements characterized by high temperatures and solar radiation are as follows: [8]

- Closely clustered low courtyard buildings with flat roofs leave less external space at ground level, therefore a high proportion of shaded buildings and roads are seen (Figure 2) [9].

Figure 2.

- The axes of the streets are located on N-S and E-W orientations. Air flow from the north goes into the old settlement and consequently natural ventilation is obtained.
- The compact and low buildings with small courtyards provide protection from solar radiation and shelter from hot dusty winds.
- With inward-looking dwelling forms and windowless thick basalt stone boundary walls, the building form is continuous with one building sheltering the next,
- The massive buildings with a high volume to surface ratio are advantageous since this will reduce the high range of external air temperature.
- A cooling effect is provided by limited planting of the court and water in a small pond often spread by channels to the floors of the courtyard. Evaporative cooling from the surface of the courtyard floors which are made of pored basalt stone is efficient.
- The rooms facing onto the court benefit from the coolness of the courtyard.
- Taking into consideration the interior plans of the old dwellings, it is seen that, (Figure 3). [4,5,7]
    - Rooms for summer use are placed on the south part of the court and oriented to the north for protection from solar radiation,
    - Rooms for winter use are placed on the north part of the court and oriented to the south,

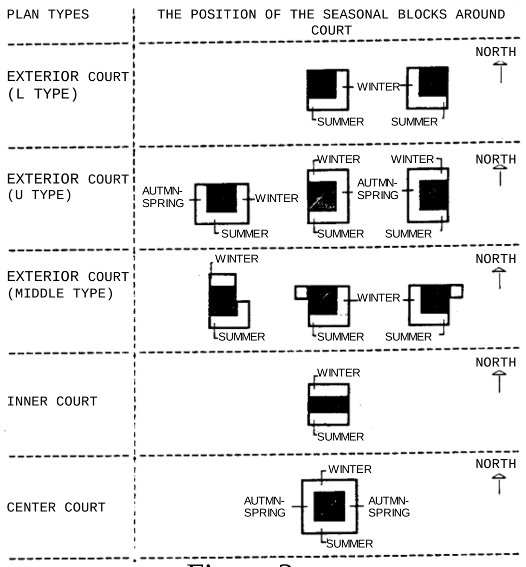


Figure 3.

- In the “u” type dwellings, the rooms for spring and autumn seasonal use are placed on the east or west side of the court alongside summer and winter rooms.
- In some plan types which don’t have a north block, winter rooms are placed on the east or west part of the court.
- In the majority of plan types, there is a half open space (three of the sides are closed, the front side is arched and open to the court) called “eyvan” oriented to the north and placed in front of the summer rooms. (Figure 4) [9]
- In the summer rooms of some old buildings the water from a system called “selsebil” provides the cooling effect. In this system water is poured from the window to a small pond in the room. (Figure 5) [9]
- The summer rooms have high ceilings, large wall and floor areas and many windows facing to the court. In these rooms, mean radiant temperature is low and air movements by convection are efficient. (Figure 6) [9]
- The winter rooms have low ceilings, small floor area and very few windows. The walls of these rooms are wooden lined and consequently mean radiant temperature is high and air movements are very limited. (Figure 7) [9]

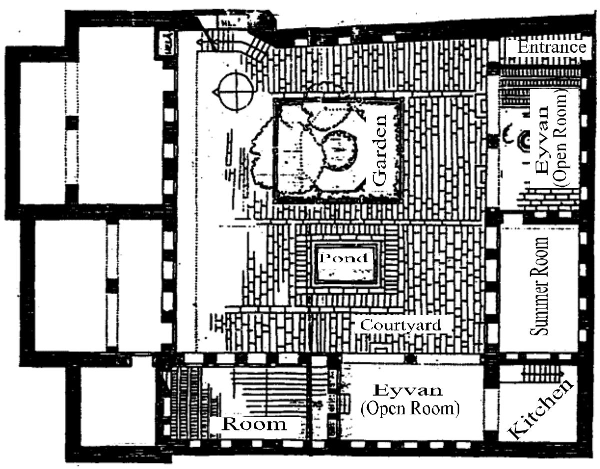


Figure 4.

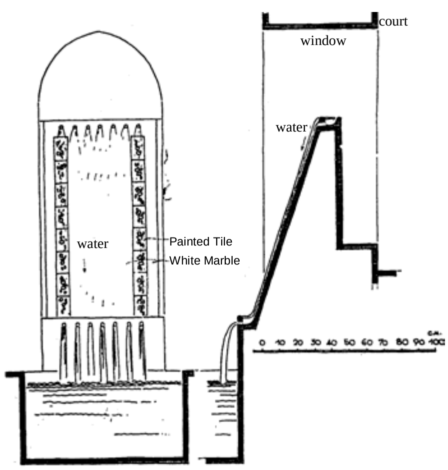


Figure 5.

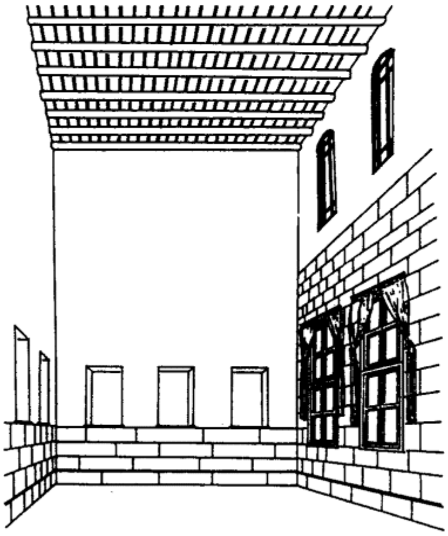


Figure 6.

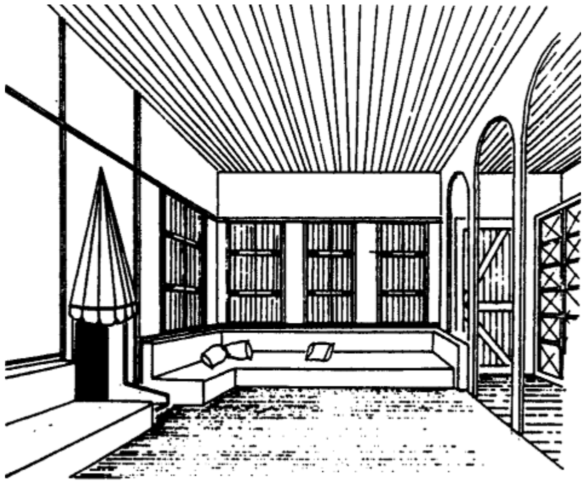


Figure 7.

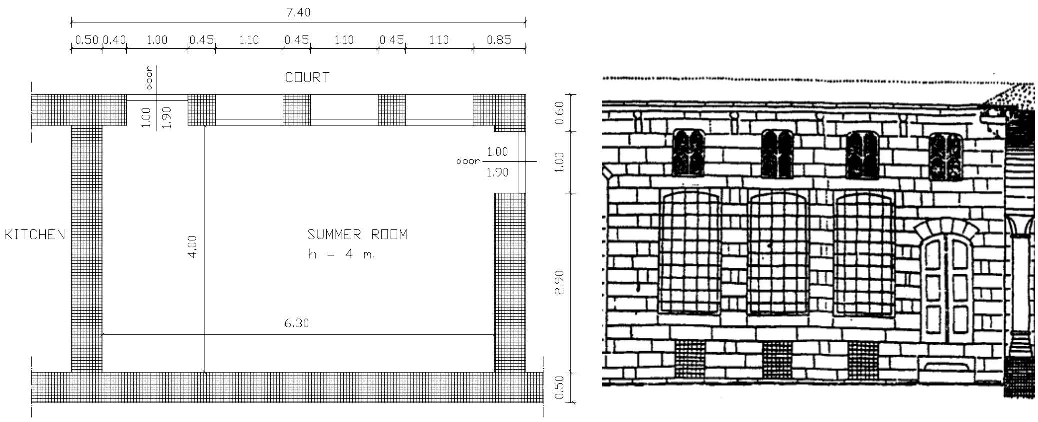
4.COMPARISON OF THE OLD AND NEW DESIGN DWELLINGS IN TERMS OF COOLING LOADS

In the new settlement area of Diyarbakır high rise apartment blocks are seen. It is known that especially in the hot season, occupants of these buildings complain of high levels of thermal discomfort in these blocks. High apartment blocks are totally unsuited to Diyarbakır's climate as they are highly exposed to solar radiation and do not provide sheltered outdoor spaces for the occupants. The structures of the building envelope and the planning characteristic of the buildings faced to the different directions are identical. As a result of their design these buildings don't provide shade and cool spaces. These are classic apartment type buildings and similar structures may be found in all regions of Turkey.

Taking into consideration the undesirable design characteristics of the apartment blocks mentioned above, the best features of traditional buildings should be incorporated in future designs. The new houses should be of low -rise construction around shaded courtyards, using new technology and materials. Therefore, in this study, the summer room of a traditional house (it is taken from the old house plan given in Figure 4) is compared with a new dwelling's room designed using the latest techniques and materials according to the new thermal insulation regulations of Turkey. For this comparison, the cooling load calculation method developed for dwellings by ASHRAE is used. [3] The cooling load calculation determines total sensible cooling load due to heat gain,

- Through structural components (wall, floors and ceilings) and windows,
- Caused by infiltration and ventilation,
- Due to occupancy.

The plan and the view of a traditional dwelling's summer room is shown in Fig. 8.



plan view from the court

Figure 8.

The new dwelling's room has the same orientation features, floor area (16.38 m^2) and transparency ratio in the front wall (33%) but the heights of the rooms are different; the old one 4 m. and the new design 2.60 m. As the heights of the rooms are different the area of the walls and the window's glass in the front wall is also different. Structurel elements of the building envelopes of the rooms are also different. Structures of the walls, windows, doors and the ceiling of the traditional dwelling's summer room and a new design room are shown in Table 2.

Table 2. Structures of the building envelopes of the old and new dwellings.

The traditional dwelling's summer room	A new design dwelling's room
Walls: pored basalt stone, Thickness:0.5 m. Coefficient of heat transmission: 0.5 w/mk, u-value: 0.93 w/m^2k	Walls: internal plaster (0.02 m., λ=0.87 w/mk), hollow brick (0.19 m., λ=0.45 w/mk), insulation (0.035 m., λ=0.031 w/mk) external plaster (0.03 m, λ=1.40 w/mk) Total thickness: 0.275 m. u-value: 0.566 w/w/m^2k
Windows: regular sing. glass, thickn. 0.003 m.	Windows: regular double glass.
Doors: massive wooden door, u-value: 1.82 w/m^2k	Doors: Ext. door, wooden or plastic, u-value 3.5 w/m^2k
Roof: black coat (0.04 m.) clayey earth (0.20 m.) tough clay (0.20 m.) chip matting (0.15 m.) lining of the ceiling (0.02 m.) u-value of the roof: 0.37 w/m^2k	Roof: plaster (0.02 m, λ=0.87 w/mk) Reinforced concrete (0.15 m., λ=1.3 w/mk) Insulat. (0.12 m, λ=0.031 w/mk) u-value of the roof: 0.30 w/mk
Note: Assuming the floor isn't external surface, it isn't taken into consideration.	

The sensible cooling load due to heat gains through the walls, and the ceiling of a room is calculated using appropriate cooling load temperature differences (CLTD) and U values for summer conditions. CLTD values are taken from ASHRAE Fundamentals Handbook (Chapter 25, Table 1). [3] Daily range (outdoor temperature swing on a design day) significantly effects the equivalent temperature difference. This table lists daily temperature ranges classified as high (greater than 14 °C), medium (9 to 14 °C), and low (less than 9°C)according to the design temperatures. For determining the CLTD values of Diyarbakır the design temperature (mean temperature of July 21st) is assumed to be 35°C and to have a high daily range (greater than 14 °C).

CLTD values are used for the calculations of Diyarbakır are as follows.

- All walls and doors
  - North 4
  - East and West 10
  - South 6
- For the roof 23

Cooling load due to heat gain through the windows is calculated using appropriate window glass load factors (GLF). Window glass load factors modified for single glass and including solar heat load plus air to air conduction are taken from ASHRAE Fundamentals Handbook (Chapter 25, Table 3 and 4). [3] The GLF value used for single glazed north windows of a traditional dwelling's summer room is 73. When applied, the area of each window is multiplied by the GLF. The steps followed in the calculation of transmission cooling loads of the old summer room and the new room are summarized in Table 3 and Table 4.

Table 3. Transmission cooling load for the old summer room.

Item	Net Area, m^2	U, w/m^2k	CLTD °C	GLF, w/m^2	Equation	Cooling Load, kw
North wall	14.77	0.93	4		q=U.A(CLTD)	0.054
North door	1.90	1.82	4		q=U.A(CLTD)	0.013
North windows	8.53			73	q=(GLF).A	0.622
East wall	14.10	0.93	10		q=U.A(CLTD)	0.131
East door	1.90	1.82	10		q=U.A(CLTD)	0.034
South wall	25.20	0.93	6		q=U.A(CLTD)	0.140
Roof	25.20	0.37	23		q=U.A(CLTD)	0.214
					Total	1.208

q: the sensible cooling load, kw, **A:** area of the surface, m^2
U: thermal transmittance, w/m^2k ,**CLTD:**cooling load temperature differences, °C
GLF: window glass load factor, w/m^2

Table 4. Transmission cooling load for the new room.

Item	Net Area, m^2	U, w/m^2k	CLTD °C	GLF, w/m^2	Equation	Cooling Load, kw
North wall	9.08	0.56	4		q=U.A(CLTD)	0.020
North door	1.90	3.5	4		q=U.A(CLTD)	0.026
North windows	5.40			60	q=(GLF).A	0.324
East wall	8.50	0.56	10		q=U.A(CLTD)	0.047
East door	1.90	3.5	10		q=U.A(CLTD)	0.066
South wall	16.38	0.56	6		q=U.A(CLTD)	0.055
Roof	16.38	0.30	23		q=U.A(CLTD)	0.113
					Total	0.651

The calculations for the old summer living room and the new room, where

q=U.A (CLTD) (1)

for the walls, roof and door and

q=A (GLF) (2)

for the windows are outlined in Table 3 and 4. [3] Moreover, the internal and infiltration sensible cooling loads are calculated as follows. Total sensible cooling loads for the old room and the new one are summarized in Table 5.

Infiltration:

The old room

Q = ACH (room volume) x 1000/3600 (3)

Q = 0.5 (4 x 6.30 x 4) x 1000/3600 = 14 L/s

q = 1.23 x Q x Δt (4)

q = 1.23 x 14 x (35-24)= 189.42 w = 0.18 kw..

The new room

Q = ACH (room volume) x 1000/3600

Q = 0.5 (4 x 6.30 x2.6) x 1000/3600 = 9.1 L/s

q = 1.23 x Q x Δt = 1.23 x 9.1 x (35-24) = 123.12 w = 0.12 kw.

Q: Volumetric air capacity, L/s q: The sensible cooling load, kw.

ACH: Air Changes per Hour, I/h

Δt: The difference of design temperature between indoor and outdoor, °C.

ACH value is taken from ASHRAE Fundamentals Handbook (Chapter 25,Tabl. 8) for indoor temperature of 24°C and outdoor design temperature of 35°C.

Occupancy: Sensible heat gain per sedentary occupant is assumed to be 67 w. Assuming the number of occupants, 6 for the old room and 4 for the new room,

q = 67 x 6 =402 w. = 0.402 kw. q = 67 x 4 =268 w. = 0.268 kw.

Appliances: In these days, appliance loads are concentrated mainly in the kitchen and laundry areas. A sensible load of 470 w is divided between kitchen and laundry and the adjoining rooms. Taking into consideration living conditions of traditional houses, appliance loads are neglected for the old room but for the new room assuming that 50% of the kitchen appliance load is picked up in the living room,

$q= 0.5 \times 470= 235\ w =0.235 kw$

Table 5. Summary of sensible cooling loads estimated for the old and new dwelling's room.

	Cooling Load for the old room, kw	Cooling Load for the new room, kw
Total transmission cooling load	1.202	0.651
People	0.402	0.268
Appliances	0	0.235
Infiltration	0.180	0.120
Total	1.790	1.274

As seen in the Table 5, the total transmission cooling loads of the new dwelling's room (designed using the latest techniques and materials according to the new thermal insulation regulations of Turkey) is about half that of the old summer room's transmission cooling loads. The total thickness of new insulated building envelope (0.275 m.) is also half of the old building envelope's thickness (0.50 m.). The results of these calculations show that if the building envelope is designed according to climatic conditions and the thermal insulation regulations, more energy efficient dwellings may be designed compared with the old traditional houses in Diyarbakır.

5.CONCLUSION

Architects should pay maximum attention to designing buildings adapted to the local climate in order to provide comfort by using minimum artificial energy and consequently decreasing environmental pollution.

As seen in this study, the old houses of Diyarbakır are typical examples of buildings adapted to a hot dry climate. This has been achieved by the effect of the old living style requirements and the use of local materials and techniques available in the period in which they were built. Today, in spite of new technological advances, techniques and materials, identical buildings are still constructed and climatic design isn't considered important in Diyarbakır. Consequently this situation causes thermal discomfort or increases in the use of artificial energy.

As also seen in the results of the cooling load calculations of this study, by designing the building envelope with insulation according to Turkish thermal insulation regulations, more energy efficient and successful buildings would be constructed in comparison with the old designs.

In conclusion, the new buildings should be inspired from the design features of traditional buildings by using new technology and materials.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:**+90.212.2610549** e-mail:**sas2001@yildiz.edu.tr** http:**//www.yildiz.edu.tr/mim/sas2001**

LIGHTING AND ACOUSTICAL PERFORMANCE OF A WORSHIP SPACE: KADIRGA SOKULLU MOSQUE

Z. Karabiber, R. Ünver, E. Çelik
Yıldız Technical University, Faculty of Architecture, İstanbul, Turkey

ABSTRACT

Mosques are one of the most important building types of Muslim Architecture. As in many other religions, worshippers at mosques sometimes need solitude while at other times they must feel themselves in absolute unity with the community. Acoustical and visual environment of the mosque space should contribute the worshipping process and facilitate the constitution of the proper physical environment. The aim of this paper is to exemplify the comfort situation of a space well known from perceptional point of view besides architectural properties. Data obtained from architectural, acoustical and lighting measurements as well as investigations held in-situ have been compared with the comfort criteria to reach the aimed goal. The building chosen for this purpose is Kadırga Sokullu Mosque, which is one of the spaces being investigated within the CAHRISMA Project (EC Fifth Framework INCO-MED Research Projects, Project No. ICA3-1999-10007)

1. INTRODUCTION

Human beings have created various types of buildings for different purposes throughout the history. Religious buildings are one of them and every religion has its own style of praying and structure. Although the religious buildings differ in the interior usage and architectural styles according to the religion type, they have been the most magnificent and important architectural buildings almost in every era throughout the history. On the other hand, the purpose of constructing a building is to enable a suitable physical environment for the users needs such as light, sound, heat and etc. This is the same with the religious buildings. The purposes of religious buildings can be cited as; to create a suitable environment for the prayers, to bring the believers together, to let feel the strength of the religious power, to enable the spread of the religion, etc.

Mosques are places of mass worship. In Islamic way of worshipping there are two different actions, which can be performed together or separately; the physical action (namaz) and the mental action (praying). During namaz performed by groups the men follow and repeat the movements of the Imam. Those who wish to pray and pull the prayer beads sit on the floor before and after namaz. Some of the believers might wish to read the Holy Koran. Reading is realised by putting the Koran on rahle's (low reading desk). The people should be able to see and hear the Imam. Friday sermons are one of the most important activities realised in mosques. Mevlüd, which has a musical basis, is performed rather frequently, upon the will of the believers in order to commemorate or celebrate the death or birth. In other words, the main acts performed in the mosques for religious purposes can be summarized as follows.

- Performing namaz (1),
- Reading the Kuran,
- Listening the Kuran, Mevlüd (2), hymns and sermons

(1)Namaz: Action of making physical movements (like kneeling, standing, etc.) while praying

(2) Mevlüd: Religious ceremony during which the mesnevi (mystical poem) telling about prophet Mohammed's birth and life will be chanted.

Establishment of the necessary comfort conditions for the activities mentioned above, depends basically on the sufficiency of acoustical and lighting properties besides other comfort elements. In other words acoustics and lighting are especially important in the buildings to affect the religious, mystic and spiritual feelings of the people as well as emphasizing the architectural magnificence of the building.

The aim of this paper is to exemplify acoustical and visual comfort situation of a space well known from perceptional point of view besides architectural properties. Data obtained from architectural, acoustical and lighting measurements held in-situ would be compared with the comfort criteria to reach the aimed goal. The building chosen for this purpose is Kadırga Sokullu Mosque It was built in the Ottoman period at 1571 and always has been regarded as one of the masterpieces of the well-known Turkish architect Sinan. Kadırga Sokullu Mosque is one of the spaces being investigated within the CAHRISMA Project [1]. CAHRISMA is a research project within the Fifth Framework of European Commission and it covers; the evaluation of historical religious buildings together with comfort elements besides others, the comparison of recent and ancient conditions of those spaces, the virtual conservation and revival of architectural heritage.

2. ACOUSTICAL PROPERTIES OF THE SOKULLU MOSQUE

There are three distinct acoustical requirements for mosques; to hear the namaz orders of the Imam, to understand the sermon of the preacher and to listen or to join to the recital of the musical versions of the Holy Koran [2]. Thus, intelligibility of both speech and sound is paramount. On the other hand, mosques have to be silent as well.

2.1 Methodology of Acoustical Investigation

In order to define the acoustical properties of the religious spaces; a large survey has been realised by different teams participating to the CAHRISMA Project. The methodology of acoustical identification and evaluation consists of the following steps.

1.Objective identification and evaluation

- Determination of architectural properties,
- Determination of acoustical absorbance properties of different surfaces,
- Determination of the noise environment,
- Acoustical measurements covering room acoustical parameters related with musical and speech activities,
- Calculations (simulations) of acoustical properties,
- Auralization of the sounds depending on the simulations,
- Evaluation of the data obtained from measurements, calculations and simulations.

2. Subjective identification and evaluation

- Psycho-social and psycho acoustical surveys to determine the perceptional properties of the space,
- Laboratory surveys on two different subject groups in order to determine the preferences of listeners, using auralised sounds of simulations,
- Evaluation and comparison of the survey results with the objective data.

In this paper only the work realised by Yıldız Technical University have been summarized. Although measurements of the room acoustical parameters are not directly the work of YTU, measurements have been repeated in the same conditions and compared with the results of Danish (DTU) and Italian (UNIFE) teams.

2.2 Description of Works Realised

First of all architectural projects of the building have been collected and controlled in-situ and necessary corrections have been realised. Ali Sami Ülgen's projects were the basis of the work (Figure 1) [3]. Then a detailed work on the absorption of the materials has been realised. All of the different surfaces have been determined and marked as different colours on the plans and cross section. Sound absorption coefficients of the surfaces have been estimated using different lists taking place at the literature. The list showing the materials and their sound absorbtivity of Kadırga Sokullu Mosque is given at Table 1.

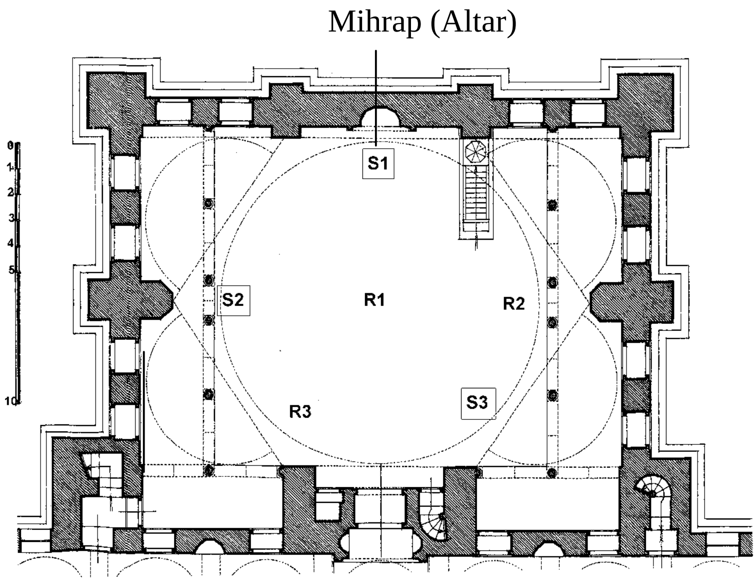


Figure 1 Source (S)-and receiver (R) positions on the floor plan of Kadırga Sokullu Mosque

Table 1 Estimated sound absorption coefficients of the materials at Sokullu Mosque

	MATERIALS	SOUND ABSORBTION COEFFICIENTS Frequencies (Hz)					
		125	250	500	1000	2000	4000
FLOOR	Marble floor + carpet (6mm)	0.04	0.04	0.16	0.25	0.28	0.30
	Boarded floor + carpet (8mm)	0.10	0.12	0.26	0.29	0.30	0.32
	Marble floor + carpet (5mm)	0.04	0.04	0.16	0.23	0.26	0.28
	Boarded floor + carpet (6mm)	0.10	0.12	0.26	0.28	0.28	0.29
	Shoes shelf						
WALL	Painted timber	0.20	0.16	0.14	0.10	0.06	0.04
	Partly stained glass windows	0.25	0.23	0.18	0.12	0.08	0.07
	Carved marble	0.03	0.12	0.20	0.30	0.33	0.20
	Stone	0.01	0.02	0.03	0.05	0.07	0.08
	Glass of seperation (%50)	0.30	0.24	0.18	0.12	0.07	0.04
	Wooden part of seperation(%50)	0.30	0.20	0.15	0.10	0.08	0.10
	Marble Muqarnas of Pendentives	0.02	0.08	0.15	0.16	0.18	0.20
	Marble with holes	0.02	0.03	0.04	0.09	0.09	0.10
	Marble	0.01	0.01	0.01	0.01	0.02	0.02
	Glass 4 mm (%80)	0.35	0.25	0.18	0.12	0.07	0.04
	Wood finishing (%20)	0.12	0.11	0.10	0.09	0.09	0.09
	Carved panel door (8cm)	0.13	0.12	0.10	0.09	0.08	0.07
	Wooden cover (3cm)	0.18	0.15	0.12	0.10	0.09	0.09
	Wooden ornament	0.18	0.15	0.12	0.10	0.09	0.09
CEILIG	Stone + painted coating	0.01	0.01	0.02	0.03	0.04	0.05
	Curved ceiling with stone + coating with white wash	0.01	0.01	0.05	0.07	0.09	0.09
	Stone + painting ceiling	0.01	0.01	0.02	0.03	0.04	0.04

Background noise measurements have been realised using B & K Type 2236 Precision Integrating Sound Level Meter. Table 2 gives the results.

Table 2 Background Leq and octave band noise levels at Kadırga Sokullu Mosque

	dBA									
Measurement Point	**Leq**	**31.5 Hz**	**63 Hz**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
1 (Mihrap)	31.9	49.0	48.0	37.0	30.0	28.5	26.3	27.5	23.0	18.0
2 (Mahvel)	33.8	51.5	53.0	38.0	38.5	32.0	26.0	18.0	20.0	15.0
3 (Balcony)	35.8	52.0	54.0	39.5	39.0	34.8	31.3	28.0	24.2	19.5

Most important work in defining the acoustical properties of the mosque is the measurements of room acoustical parameters. For this purpose 01 dB Symphonie System dBBATI32 has been utilised. An octahedral loudspeaker has been used to generate a pink noise. Reverberation time, which is one of the most significant criteria, has been measured in three receiver positions and two heights (0.80m and 1.50m to simulate people sitting on the floor and standing still), three sound source positions have been utilised to simulate real sources. Source and receiver positions are given at Figure 1. Four measurements have been realised consequently in each of the positions in order to be in accordance with ISO 3382 1975 (E). Table 3 gives the average results of the reverberation measurements for three source (S, h:1.50 m) and receiver positions (R, h:0.80 m).

Table 3 RT for three source(S, h:1.50m) and receiver positions (R, h:0.80m)

Frequency (Hz)	**Reverberation Time (s)**								
	S1R1	**S1R2**	**S1R3**	**S2R1**	**S2R2**	**S2R3**	**S3R1**	**S3R2**	**S3R3**
125	3.58	3.55	3.81	3.90	3.88	3.45	3.82	3.86	3.51
250	3.86	3.70	3.90	3.88	3.84	3.50	3.74	3.66	3.66
500	3.28	3.39	3.36	3.52	3.43	3.22	3.41	3.61	3.42
1000	2.77	2.75	2.68	2.73	2.76	2.70	2.71	2.72	2.72
2000	2.24	2.17	2.28	2.15	2.12	2.06	2.14	2.13	2.21
4000	1.55	1.55	1.52	1.49	1.39	1.53	1.58	1.50	1.49

Room criteria such as early decay time (EDT), clarity (C) and definition (D) have also been measured for one source and one receiver position. An example to the results is given at Table 4.

Table 4 Room criteria

Frequency (Hz)	**Early Decay Time (EDT) s**	**Clarity (C) dB**	**Definition (D) %**	**Intelligibility**
125	2.80	-1.7	36.1	RASTI:0.51 STI: 0.55
250	2.81	-4.4	24.0	
500	3.14	-1.1	38.3	
1000	2.35	1.7	52.5	
2000	1.76	1.2	45.5	
4000	1.20	4.1	65.0	

2.3 Evaluation of the Acoustical Properties

Room shape is one of the important aspects that affects acoustics. Symmetrical spaces and special geometrical shapes such as cubic and spherical forms penalise acoustics, causing acoustical defaults such as irregularities in room modes, echoes, fluttering echoes and focusing.

Kadırga Sokullu is one of the typical domed mosques of Sinan's. It has a rectangular plan and the dome is placed on a rectangular prism. The focusing area is high enough from the audience to let the sound being diffused until reaching them. The ratios of the dimensions may be regarded as appropriate also. Therefore, generally speaking the geometrical shape of the building seems to be acceptable.

In modern room acoustical science, uniform diffusion and absorption of the sounds throughout the space has been valorised. Kadırga Sokullu Mosque has surfaces having different irregularities, favouring diffusion. On the other hand in mosques, most important absorbtivity takes place at the floor (carpets) where as other surfaces are generally reflective. This fact should be examined carefully to find out the possible negative effects.

Background noise measurements seem to be within the limits of acceptable noise levels, which have been established as Leq 35-40 dBA for worship spaces.

Reverberation time measurements have been realised in empty spaces. Although it is obvious that the values will decrease in the presence of audience, they are still higher then the optimum levels (T_{opt}: 1.50 s-Rettinger, for Protestan church) for speech activities [4]. However for the activities concerning music, they might be regarded as available (T_{opt}: 2.58 s-Maekawa, for church music) [4]. On the other hand, it should be mentioned that measured RT were compared with the optimum values for churches, as there is no available literature for mosques yet. Great differences on the reverberation time of high and low frequencies may also cause sound coloration.

Primary results of psycho acoustical surveys have shown that users of the mosque are generally satisfied with the acoustical properties of the space. This can be interpreted as the necessity to establish special optimum values for mosques.

3. VISUAL PROPERTIES OF THE SOKULLU MOSQUE

Light has been used to assist a basic element to the actions and accentuate the magnificence of the building. The basic religious acts such as following/seeing the action of the imam/speakers and reading the Koran are performed sitting on the floor of mosques related to the visual comfort of believers.

3.1.Medhodology of Visual Investigation

In order to define and simulate the visual properties of the Kadırga Sokullu Mosque, various studies have been realized by different teams of the CAHRISMA project. Definition of the visual performance of the mosque is the charge of YTÜ.

Some of the data such as light reflectance/transmittance and colour properties of inner surfaces have been determined as the data to be used in the visual simulation of the space. The methodology of visual identifications and evaluation steps are follows:

- determination of architectural and lighting systems properties.
- determination of the light reflectance/transmittance and colour features of inner surfaces.
- illuminance measurements.
- evaluation of the data obtained from measurement related to the visual comfort.

3.2. Description of Work Realized

In this section, only the features and measurements on the natural and artificial lighting systems of Kadırga Sokullu Mosque have been given.

Natural lighting

The natural light enters the mosque through 96 windows, 20 of them are on the central dome, 16 on the half-domes and 60 on the walls. These are placed at 5 different levels. The dimensions of windows on the first row are 1.3x2.4 m and their sill height is 0.4 m. Glasses of the first and second row are clear and their transmittance is approximately 75 %. The other windows have stained glass, their average transmittance is about 50 % and they are protected by big perforated plaster elements causing a significant decrease of glass/window ratio. Daylight illuminances are between 10 - 210 lm/^{m2} in spring on the floor. Measurement results are given in Table 5 and shown in Figure 2.

Artificial Lighting

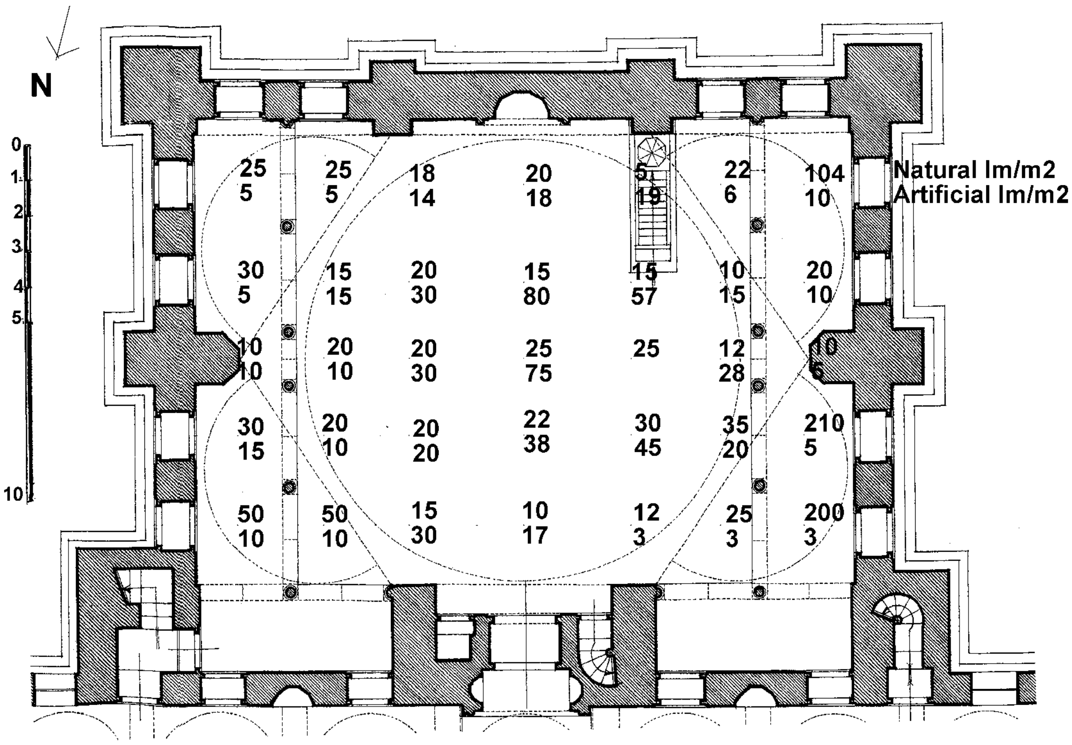
The artificial lighting system consists of iron chandeliers suspending from the dome, half-domes, 2.5 m above the floor. According to the historical documents, there used to be oil lamps on the iron chandeliers. Today, there are 40 W incandescent lamps in clear glass bowls on them. There are about 400 lamps, but half of them were out of order at the measurement days. Artificial illumination levels are between 3 and 80 lm/m2 on the floor. Measurement results are given in Table 5 and in Figure 2.

3.2. Evaluation of the Lighting Systems

Evaluation of illuminance measurements in the Kadırga Sokullu Mosque are summarized as follows and in Table 5.

Concerning the daylighting:

- Illuminance is insufficient according to the actions. Measured values are about one tenth of the standards.
- Distribution of the illuminance is not uniform. Uniformity ratio is lower the standard ratio.
- Lighting quality of natural light is diffuse and relatively shadowless. Light colour is white.



Natural illuminances 28-29 May 2000; h:14:30
External horizontal illuminance; 35.000 lm/m^2

Figure 2 Measured illuminances on the floor

Natural lighting system does not provide necessary conditions for visual comfort related to the recommended values (Table 5) It should be mentioned that, since recommended comfort values of mosques do not exist, the applied values are derived from churches [5, 6, 7] The reason of the insufficiency of the illuminance and uniformity in the examined mosque is basically the scarcity and smallness of the windows. The big perforated elements used at the windows cause an important decrease in the effective glass area thus natural light. In addition to, external obstructions such as trees, building are very effective on decrease of the interior natural illuminances.

The windows at the side-walls, dome and half-dome contribute to the diffusion of the daylight into the interior and perception of the construction of the building. Windows at the mihrap (altar) region, which are opposite to the main entrance, create the local illumination and provide the accent at the mihrap (altar). The side windows contribute to the general lighting. On the other hand, daylight flowing down from the main dome has been used to emphasize the magnificence of the dome and to gather the people under the dome. The stained glasses used mainly for the windows at higher levels contribute to the colouring of daylight and to strengthening of the mystic atmosphere.

Table 5 Lighting properties of Kadırga Sokullu Mosque

Characteristics of Kadırga Sokullu Mosque			**Recommended values**
Construction year		1571	
Floor area		15.5 x 18.8=288 m^2	
Inner height		22 m	
Inner sufaces	Wall material / Floor material	(blue tiles + marble + paint) / Colorful carpet	
	Average reflectance	0.40	
Daylighting	Number of windows (dome, half domes, walls)	96 (20, 16, 60)	
	Glass characteristics 1. and 2. row / t	clear / 0.75	
	Glass characteristics of the other rows / t	stained glass-plaster / 0.50	
	General illuminances (on the floor)	10-210 lm/m^2	>100 lm/m^2
	Distribution uniformity (on the floor)	0.05	(min/max)>0.8
	Vertical illuminance (on the altar; h= 1.15m)	5-20	>300 lm/m^2
	Horizantal illuminance (reading desk, h=0.4m)	20 - 250	>300 lm/m^2
Artificial lighting (effective height is 2.5m)	Number of lamps	200 (400)	Incandescent, halogen, some types of flüorecent
	Type of lamps	Incandescent, halogen	
	Colour of lamp Colour temperature Colour rendering	warm 2700 K 1 A	White / warm < 5500 K 1 A -1 B
	General illuminances (on the floor)	3 - 80 lm/m^2	>100 lm/m^2
	Distribution uniformity (on the floor)	0.04	(min/max)>0.8
	Vertical illuminance (on the altar; h= 1.15m)	10-30	>300 lm/m^2
	Horizantal illuminance (reading desk, h=0.4m)	10- 95	>300 lm/m^2

Concerning the artificial lighting:

- Illuminances under the main dome region are higher than side parts. But, all of the artificial illuminance values are lower than the standards, namely they are insufficient.
- Distribution of the illuminance is not uniform. Uniformity ratio is lower than the standards.
- Lighting quality of articifial light is diffuse and relatively shadowless. The colour of light is warm.

Artificial light is provided by chandeliers equipped with incandescent lamps and suspending from ceiling. Some of lamps are out of order and locations of the chandeliers are not suitable to create necessary conditions. Therefore, existent artificial lighting system does not provide the necessary general illuminance and uniformity on the floor according to the recommended values (Table 5). As mentioned before, recommended values are adapted from churches [5, 6, 7].

4. CONCLUSION

Early results show that room acoustical properties of the space are not perfectly adequate for the vocal activities performed in mosque. However, the optimum values taken into consideration are the values given for churches. It is obvious that liturgical differences of the religions may cause different requirements.

The results of subjective preferences support the necessity to establish new optimum values, designed especially for mosques. In fact, one of the goals of the CAHRISMA Project is to establish these values. It is obvious that to reach statistically meaningful findings, a great number of space, should be investigated. To reach these values might be difficult within the scope of one research, however accumulated data will provide a basis to reach the required values.

Measurement results show that lighting system properties of Kadırga Sokullu Mosque do not provide necessary visual comfort conditions. It should be noted that the natural and artificial systems when used together, provide better visual comfort conditions than their individual usage. However, necessary illuminances are still below the required levels. Although, it is not possible to make an improvement or adjustment for natural lighting in this historical mosque, artificial lighting system can easily be controlled.

Findings of acoustical and visual assessments show that Kadırga Sokullu Mosque's properties are not adequate when compared with the optimum values taking place in the related literature. On the other hand, it should be repeated that more detailed work is needed due to the absence of optimum values (both in acoustics and lighting) designated especially for mosques.

ACKNOWLEDGEMENTS

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ARCHITECTURAL ARGUMENTS AND PROBLEMS FOR NEW USE IN OLD BUILDINGS

S. Tönük
Yıldız Technical University, İstanbul, Turkey

ABSTRACT

Putting buildings to new uses and thus retaining the existing substance is a process that has gone on throughout history. Buildings erected for a certain function inevitably had to be adapted to changed circumstanges in the course of time. In the past this process of change occured imperceptibily. Since the middle of 20th century, the pace of technical development has increased rapidly, with the result that the adaptation of existing structures to new uses became increasingly problematic. The arguments and the problems for the new use in old buildings will be explained in this study.

1. INTRODUCTION

At the beginning of the 1970s the preservation of old buildings and old building structures was still regarded purely from a historical-conservational standpoint. A change of use of old buildings was considered. The increasing butgetary commintments of local authorities and a more economical and ecological way of thinking led to a change of emphasis, whereby buildings that would formerly have been condemned to demolition were put to further use. More and more arguments spoke in favour of the preservation and reuse of old buildings and their site amenities. In recent years there has been an increasing awareness of the problems associated with the conversion and reuse of empty or/and old buildings among representatives of local goverment and other authorities, planners and the population at large.

The character of a city and especially a city center is often strongly influenced by the empty or/and old buildings. In many cases, they played an important role in the social and economic life in the city. The continued use and the rehabilitation of existing structures also provide positive impulses for the economic, social and cultural life of a city or a particular district.

In addition to many reasons in favour of the conversion and reuse of existing buildings, there are a number of problems that have to be resolved in the process. The arguments and the problems for the new use in old buildings will be explained in this study under the following items.

2. URBAN PLANNING ASPECTS

Local authority planning policy in european countries has come to focus more and more on the conversion and extension of existing settlement structures. By means of urban rehabilitation, attempts are beeing made to enhance the attractivity of inner city areas for their inhabitants, to maintain established urban structures and to fill them with new life. The city has in that way a positive influence on the structure of the urban environment.[1]

Figure 1 : Urban Rehabilitation Plan of Donauwacht - Regensburg
(Existing Situation on 1957 and Rehabilitation Plan 1980)
Schmidt, H.U.

The reintegration of buildings, furnished with relavant new uses, into the urban structure, means that familiar, old surroundings are retained for local inhabitants. The naturally evolving tissue of towns and cities, with its adjacency of habitation and work, leisure and recreation, is thus preserved and can be reorganized with care and restraint. Mayor urban surgery, with its often negative consequences for the social life of a district, can thus be avoided. [2]

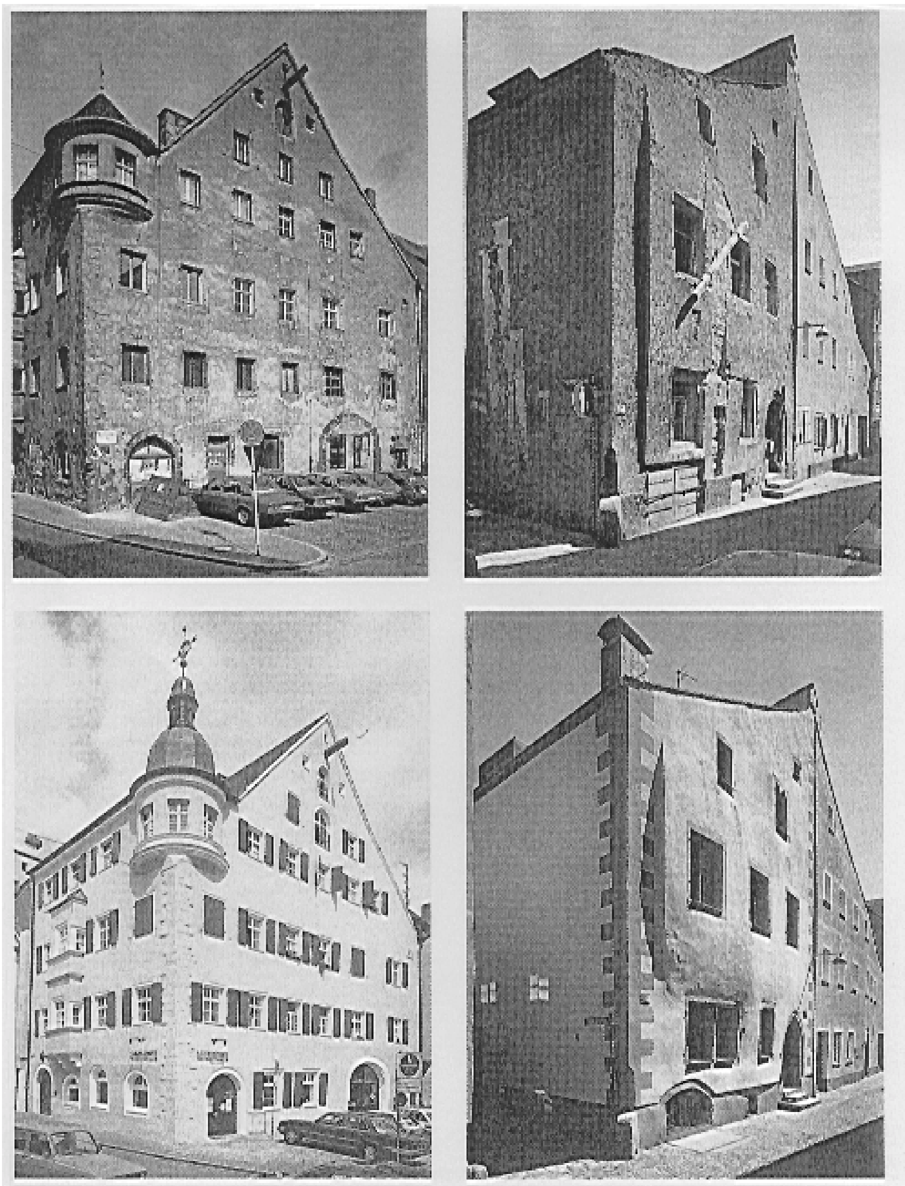

Figure 2 : Buildings befor and after Rehabilitatin and Reuse
Regensburg - Fischmarkt 5, Engelburgerstrasse 13
Schmidt, H.U.

The great majority of such sites are situated close to city centres. Existing transport facilities and technical services are available. Costly additional infrastructural measures, which also consume large areas of land, are unnecessery.
Finding an appropriate use for the great floor areas is not easy and a number of problems that have be resolved in the process. New attractive funktions usually result in an increase in the volume of traffic in the surroinding areas. This imposes a greater burden on local residents in the form of emissions and noise and a shortage of parking spaces, which is particularly disturbing. Especially the reintegration of the great floor areas, like industrial sites and the central locations of these sites leads to an improvement in the habitable quality of a city city or a particular district as a whole. In this context urban areas for example, in which poorer, 'ordinary' people formerly lived suddenly become attractive for other social classes - income groups. The outcome of this can be observed in many actual examples. Rents rise and the old, established population is slowly but surely pushed out. The longstanding social structure of the area, which was really the original object of protection, is ultimately destroyed.[3]

2. ECOLOGICAL ASPECTS

To find new uses for old buildings also represent a sensible exploitation of existing resources. By preserving a building, old and valuable materials are saved from destruction. Some one these are no longer obtainable today or can no longer be economicaly produced. In this way, energie and raw materials are also saved and the environment is spared the cost and effort of having to produce new building materials.
"European Charter for Solar Energy in Architecture and Urban Planning" describe die mission of architecten as following : [4]
Preamble : The aim of our work in the future must to be design buildings and urban spaces in such a way that natural resources will be conserved and renevable forms of energy will be used as extensively as possible, thus avoiding many of these undesirable developments.
Materials and forms of construction : Load-bearing structures and the skins of buildings must be of great durability so as to ensure an efficient use of materials, labour and energy, and to minimize the cost of disposal. An optimal relationship between production or embedded energy, (also known as enbodied energy), and longevity should be achieved.
Adapting the old buildings to new functions offers at first reduced production and in this context saving many arts of energy, in the first instance there are : [5]
Embedded and embodied energy is the energy invested in building materials through the processes of production, assembly, maintenance, alteration and demolition, and in the course of recycling components or materials.
Operating energy, the enrgy necessary for maintaining required levels of comfort and operating conditions in buildings.

Induced energy, energy consumption caused indirectly through the process of construction ; e.g. commutter traffic or the supply of goods.
The physical properties of old buildings also represent a positive aspect. Built with massive brick walls in many cases, they offer a high thermal retention capacity and good sound insulation, which in turn mean saving of energy. In addition, the natural materials used in the construction, such as bricks, timber, stone and glass, help to create a healthy indoor climate at a time when more and more emphasis is being placed on balanced, biologically sound construction and habitation. This is obviously another important aspect in favour of the reuse of buildings of this kind.
Under the heading "ecological aspects " the conservation and reuse of old buildings ca be seen to have besides saving energy some of positive effects too. In the environmental context they are an important factor, even if, at first glance, they may not seem particularly significant. By reuse of old buildings there is a reduction in the amount of building rubble and refuse, the disposal or storage of which is becoming increasingly problematic, due to lack of space and, in part, the nature of the materials. As a result of the central location that old buildings usually enjoy, transport access already exists. No new roads or other access routes have to be built.

3. ASPECTS OF PLANNING AND USE

Where old buildings are to be reused, the planner's task consists of adapting the existing structur to fit the new funktions. In terms of construction and design, the existing sets of relationships ofter an opportunity, within the given parameters, to achive quite different solutions from those that would be possible with new construction.
The architect's responsibility lies to a great extent in retaining the overall appearence, whilst at the some time setting new outward accents that will reflect the new funktion. This is certainly no easy task, and it can only be accomplished with a great deal of imagination. [6] In many cases a greater floor area will be available than is actually required by the spatial programme. It may, therefore, be possible to incorporate additional functions in the building, increasing and diversifying the mixture of uses. Large, continuous floor areas, high rooms, ...etc. and many other features that provide an excellent background for especially social kinds of activities. Large spaces and continuous floor areas offer a greater degree of latitude and flexibility for the proposed uses. Future changes of use, reductions or extensions of the spatial requirements will be possible.
An important aspect of any conversion work is to respect the architectural structures of the building. Often these will take the form of richly articulated façades, colums, walls, ...etc. ; and the interior may also have been executed with great craftmanship and architectural skill. In many cases nowadays work of this kind will no longer be possible, whether for reasons of cost or because of a lack of craft skills. If examples of such craftsmanship can be integrated into the new user

programme in the course of conversion work, the richness and diversity of the architectural vocabulary will often be seen in its true light.

Figure 3 : Gare d'Orsay - Paris
Reuse of the Railwaystation as the Museum
Cantacuzino, S.

As a rule, one can assume that the structural condition of a building will permit its reuse without major changes. What will be necessary, is a more or less extensive sheme of rehabilitation and restoration. The extent of this will depend on the proposed use. New mechanical services will be necessary at all events, plus the relevant fitting out of the interior with partitions, etc. The primary structure will usually require little conversion work.[7]

Figure 4 : Gare d'Orsay - Paris
Reuse of the Railwaystation as the Museum
Cantacuzino, S.

In the context of conversion and reuse, building regulations can sometimes present great obstacles. Adapting existing buildings to comply with modern building law, in terms of fire protection, and other planning requirements, not infrequently renders the realization of such projekts questionable, or at least leads to a considerable increase in costs. But it is not just compliance with modern building law as a fire regulations that presents a problem. The fact that the character and appearance of a building may be seriously impaired as a result of such measures in another aspect.
Another aspect that can pose a problem in a conversion sheme is finding a partner for the development. It is not always possible for a municipality to carry out a planned programme of revitalization on its own. This is often the case even where the building is already in the possesion of a public authority. In such cases it may be necessary to find a private developer to finance the conversion of the existing builings. In view of the problematic conditions and uncertainty in respect of the costs, the search for a private backer frequently represents the end of all attempts to realize the project. There are still too few investors who see a future in shemes of this kind. [8] The question of finding a backer for such measures is, the concept for the proposed new use of the building. A precise analysis of market requirements should from the basis of any such considerations.

4. CONSERVATIONAL ASPECTS

In the 1970s the preservation of historic buildings was still the domain of conservationists. In the main, it was the 'classical building monuments' that were

preserved, objekts such as palaces and churches, rather than examples for example of industrial architecture, which, from the point of view of the history of art, did not enjoy the prestige of ecclesiastical buildings or other architecyural monuments. With the process of rethinking that began to take place in favour of the retantion of all kinds of old buildings, yhe whole field of conservation assumed a new significance. An important criterion for the retention of a building for the conservation authorities is that, it can be put to sensible, long term use. It must, therefore, be possible to make certain changes necessitated by the new funktions to which such buildings are to be put. It should also be possible to make these changes in such a way that they further the aims of conservation and are not in contradiction to them. In order to achieve this, a close collaboration between conservation bodies and planners is necessary, as well as a flexible attitude on the part of the conservation authorities themselves.
The underlying aim of conservation should therefore be the retention of the existing substance. What is of interest in this respect is not merely the appearance of a building or complex at the time of its erection, but the way in which it has changed in the course of history.[9] That means retaining the building in its present state. This can only be achieved, if the conservation authority is prephared to interpret its responsibilities in a flexible manner.
A new use necessitates a certain amount of restrained change to the old building substance. In spite of certain concessions made by offices for the conservation of historic buildings in the course of conversions, the remaining regulations and conditions still pose constructional and functional problems, and in a particular a burden in terms of the financial investment required.

5. ECONOMIC ASPECTS

The economic aspects are important and complicated in many programme of conversion and reuse of existing buildings. The problem to be faced before beginning the conversion is the uncertainty over the actual level of the costs involved. In spite of the many conversion shemes that have been carried out, there are still not enough comparable figures available to make an accurate estimate. In many cases, a comprehensive, detailed picture of the state of a building is only gained after construction has started. Problems arising in the course of conversion work can lead to a considerable increase in costs.
Asuming a relatively sound, intact carcass, the necessary refurbishment costs will be well below those for new construction. In the light of information optained from conversion shemes published to date, one can assume that converting an old building to a new use will result in a 20-40 per cent saving over comparable new developments. The final figure will depent on a number of factors, which may either reduce or increase the actual level of costs. Because of imponderable factors cost planning is onlypossible to a degree of accuracy of ± 25 per cent.[10] In designing and building in existing structures is the preliminary estimating cost

planning very difficult, because every conversion work is a unique work and it can never give the same examples or shemes and no recipe.[11]
In addition to the above considerations, subsequent post-construction costs, such as those for running and maintenance, also have to be borne in mind. In view of the age of the building structure they can be considerably higher than those for new structures. Although old buildings usually have a massive construction,the state of the structure cannot be compared with that of new structures, despite renovation. Regular maintenance costs will certainly be necessary on a larger scale.

The gradual rethinking process that has taking place and the increased sensibility in the treatment of abandoned buildings have led to a reorientation of planning objektives and the setting of new prioteries. In the past, attention was directed to the planning of new developments or the extension of existing settlement patterns on a large scale. In recent years there has been a shift of emphasis towards more restained, small-scale measures in the realm of urban development. A major factor within this realm has been the rehabilitation and reuse of old buildings and facilities that had been deprived of their functions ; the reclammation of derelict areas and their reintegration into the structural tissue of towns. Instead of creating additional infrastructural amenities on the periphery of towns, existing buildings in the town structures should be reactivated with new uses.

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

REVITALISATION OF THE SKOPJE'S OLD BAZAAR - METHODOLOGICAL AND PRACTICAL ASPECTS

M. Tokarev, J. Aleksievska
Faculty of Architecture-Skopje, Republic of Macedonia

ABSTRACT

For the needs of urban planning of the Skopje's Old Bazaar (Charshia), we made a more detailed study for its architectural heritage. Conditions for the development of the Bazaar have been established, so as the reasons for its decay up today. We made complex inventarisation and analysis of the architectural heritage and on the basis of that we did its valorization and we proposed a regime for its protection. That procedure enabled us to make certain directions for urban planning where the heritage achieves its appropriate place.

1.INTRODUCTION

Because of the intensity and character of life, that is still pulsing in the Old Bazaar, we can call it heart of the city. Although it takes only a small part of the city, it still represents one of its most important parts. The identity of the city, for the most part, is expressed through the characteristics of the Old Bazaar and people more and more prefer the business activity that proceeds in it.

The returning of life in the Old Bazaar increases its value and the interest for restoration of old objects and building of new ones. If this, so-called new pressure on the Bazaar is not regulated in the appropriate way it can lead towards repeated degradation of its architectural heritage. Unlike that, the new interventions that will be in the context of historical ambience can increase the total value of the Bazaar.

While creating the Study we reviewed critically the results of the former researches and interventions in the Bazaar and we clearly saw the gaps that should be filled up. In order to achieve the wanted result, we established a widespread methodology of

work according to the “step by step” system, because the revitalization of the Bazaar is understood as an obstacle race on long tracks.
As forefront of the research, we made thorough documentation of the present condition with a special accent on the architectural heritage. The Institute for urban planning and architecture “Skopje” appears as a partner in the creation of the documentary basis of this Study.
For the needs of the Study we made whole new detailed inventarisation of the architectural heritage by recording all needed data for the objects. We paid special attention to the old architectural units and ambiences with cultural-historical characteristics. Every object that owes any cultural-historical value is marked on the existing site plan.

2. DEVELOPMENT AND DECAY OF THE OLD BAZAAR

The Skopje’s Old Bazaar is one of the most authentic preserved bazaars in Macedonia. Its complex tissue consists of old units and objects built many centuries ago. Its chronological development is connected directly to the development of Skopje City in late-ancient and middle-aged Slavic period and especially to the period of Ottoman kingdom. The present rich fund of objects includes great number of old churches, mosques, palaces, houses, etc.
The Old Bazaar is formed in the bottom of a triangular terrace that mounts 46m above the Vardar River. The first settlement developed on that terrace in the late Neolithic period and life in that area continues up to III century BC. After the destruction of the neighboring Darden-roman settlement Skupi from the earthquake in 518, a new representative city is built on that terrace. A great number of historians think that new city is actually the magnificent Iustiniana Prima. A suburb with a trading-craft character developed in the further development of the settlement.
After Slavs occupied Skopje in 695, alternately the city was under different government: Macedonian, Byzantine and Serbian. In 1282 Skopje becomes Serbian metropolis where 17-20 churches and a great number of palaces, houses and public objects were built. In the doorway of the XIV century, beside the Upper City, the Lower City is formed, almost completely, and protected with fortifications. Then Skopje becomes major regional trade center with developed craftiness.
In 1392 the Turkish occupied Skopje who gradually change its structure and proclaim it sediment of the Balkan Rumelia. A great number of mosques and public objects are built on the foundations of old churches, which are the most characteristic for the end of the XV and the first half of the XVI century. During the XVI century Skopje grows and this continues in the XVII century when there are about 90 neighborhoods (mahalas) and lot of mosques.

In the Bazaar which takes the central part of the city, there was a lot of crafts and developed commercial ties from Asia Minor to Venice. In 1689 Skopje is totally fired and destroyed by the army of the Austrian general Pikolomini who is forced to withdraw before the attacks of the Turkish. As a result of that, a lot of significant objects are damaged and in the following 100 years Skopje stagnates in its development.

In the beginning of the XIX century, Skopje and its Old Bazaar experience new blossom on economic and social plan. Craftiness gets progress and the commercial ties are spreading to Trieste, Leipzig and Kiev. The previous wooden ground floor small shops (duchans) that existed till then, where replaced by buildings called trading stores (magazis), made of solid materials. The Sultan allowed cultural autonomy of the Christian people, so in the frames of the Old Bazaar the old churches were reconstructed and new objects were built. Architectural influences arrived from Western Europe in the city and the Old Bazaar changed its oriental image, but it keeps the medieval urban conception.

As a result of the different historical accumulations, the Skopje's Old Bazaar, from typological point of view, has complex medieval oriental character. Its original urban structure has underlined linear composition that develops from the bridge of the Vardar River towards Bit Pazar (Big Market Place), in north-south direction. The most significant civilian monumental objects are built by the axis of this composition. Later on, near them, units with trading-craft and catering objects are built and in that way the Bazaar gets complex typological-morphological structure that maintains till the end of the XIX century.

Lately, the decay of the Old Bazaar is caused by the development of industry and the decay of craftiness. In parallel with that begins the so-called modern urbanization with penetration of new motor streets and construction of new massive objects next to or within the Old Bazaar itself.

In 1963 Skopje was destroyed in an earthquake that caused a lot of damage on the cultural-historical objects. With the financial help from the foreign countries and with a great effort of home experts, almost all significant objects are reconstructed following the aseismical principles. With the reconstruction of the Old Bazaar after the earthquake, its decay is not completely stopped. That is a result of inconvenient combination of social and technical causes.

3.INVENTARISATION AND ANALYSES OF THE HERITAGE

For the needs of the Study we made new detailed inventarisation of all architectural objects and spatial entities with a special accent on those that have cultural-historical value. The inventarisation also includes all former confirmed or potential

archeological locations, especially those that document the period till the XIV century.
In the frames of the Old Bazaar, 13 monumental objects were under protection of the Law before we made this Study. The new inventarisation also encloses 8 monumental, 8 other objects with memorial attributes, a lot of medieval stores, stores from the XIX century and magazis.
Undeniable is the fact that under the whole territory of the Bazaar there are archeological remains from the late-antique and medieval period before the Turkish one (X-XIV century), but also from the Turkish period till 1689. Their locating and surveying is very delicate because over them there is alive urban structure. In any case, the whole space around the mosques should be considered as potential archeological locations of old churches and old Islamic monumental objects.
Archeological remains of characteristic periods in the development of the Old Bazaar occur in different depths: the late-antique and the remains of objects from the period before the XIV century occur in depth of about -6 meters and the objects ruined in the fire in 1689 occur in depth of about -1.5 meters. With more profound survey we made a preliminary inventarisation with 26 confirmed and potential archeological objects. All that is documented on the site plan of the Old Bazaar.
Beside former negative influences on the persistence of the architectural heritage, the **architectural units** with miscellaneous constitution and constructive fund are relatively well preserved in the Old Bazaar. On the site plan of the Old Bazaar they are classified in 6 groups consisted of: monumental objects, monumental objects and small stores, civilian objects from the XIX century and stores, only stores, only houses and stores, and only civilian objects from the XIX century.
The architectural units consisted of stores (21) and the units consisted of stores disposed around the monumental objects (8) predominate in the Old Bazaar. The analysis shows that the stores, as the most numerous objects, are the least preserved or unsuitable interventions are executed on them. Trade is the most present in the content of the units, then craftiness and services while habitation is present very little. In that respect, the biggest negation represents the poor presence of contents of a cultural character.
The specific relationship between the units in the Old Bazaar forms picturesque **ambiences** of a special value. Lately, the number of the valuable ambiences is in constant decrease which is a result of the unsuitable preservation of the objects (of the stores in the first place), the unsuitable interventions on them and the pressure of massive new objects built on the borders of the Old Bazaar.
With the survey in this Study it is concluded that in the narrower area of the Old Bazaar there are about 35 ambiences of miscellaneous value. This number should be understood conditionally because the ambient space in the Bazaar could be seen wider thus few “smaller” ambiences can be connected in bigger one. But, dividing the

space into smaller ambiences is more practical because in that way more detailed researches can be done and the priority operations for the improvement of the architectural structure can be defined.

On the basis of the available documentation and the completed inventarisation we made **detailed analyses of the architectural heritage** from different aspects and different levels. We paid special attention to the historical-artistic and archeological aspects and to cultural-esthetical characteristics of the Old Bazaar.

The analysis of the **architectural objects** with memorial attributes is made for each separately thus we explored the development at periods for 40 significant objects and we concluded the time of their big damage and the time of their big reconstruction. We made the necessary chronological and typological analyses for three important types of stores.

This research is built on with the analysis of the physical condition of the objects after the earthquake in 1963 and the interventions made on them till 1997. All those analyses are systematized in tabular surveys and presented on the site plan of the Bazaar.

Cultural-esthetical analysis encloses the cultural scenery and the visual characteristics. The preservation of continuity in the development of the Bazaar, its location and measure in the space and the spirit of the place (genius loci) are explored in frames of the **cultural scenery analysis**. At the same time, we concluded that only smaller valuable part of once rich architectonic-urban structure is preserved substantially.

We may conclude that the ambient continuity of the Old Bazaar has breaks which is especially characteristic for the middle of the XX century. The biggest breaks are clearly seen in the eastern part of the Bazaar where “modern” objects have been built and motor streets are traced. In the nucleus of the Bazaar before the earthquake in 1963 building new objects or conversion of the old ones made some unsuitable interventions. All interventions in its nucleus are regulated more strictly after the whole Bazaar was proclaimed a monument of the culture in 1963.

With the **visual analysis** we studied the valuable silhouettes and panoramas of the Old Bazaar, urban-architectural dominants and the major lines of sight towards them that make special recognizable ambiences. At the same time we concluded that on the borders with the Bazaar and in it there are 9 significant urban points and dominants with 22 valuable lines of sight towards them. These analyses represent important basis for production of the following phases in the study:

- valorization,
- regime for protection,
- creating directions for urban planning and architectural designing.

4.VALORIZATION AND REGIME FOR PROTECTION

On the basis of all previous researches we made revalorization on the Old Bazaar as a complex and 13 architectural objects which were proclaimed monuments of the culture before 1963. It is concluded, with the new valorization, that 8 more monumental and 8 other objects have cultural-artistic attributes. **The valorization of the heritage** is made according to its attributes, importance, function, age, insecurity etc. Its cultural, usable and emotional values were taken into consideration.
Evaluating the total values of the architectural heritage (objects, units and ambiences) we classified it in the following three categories:

- The **first category** includes the heritage that has exceptional value, i.e. has rare cultural-artistic attributes;
- In the **second category** we place the heritage that, according to its total value, has great national and regional significance, and
- The **third category** includes the heritage that, according to its total value, has narrower significance; so special subgroup represent the objects and entities that have only ambient value.

According to the above mentioned system of valorization, it has been concluded that in the Bazaar there are: 8 monumental **objects** and several medieval stores of I category, 3 monumental objects and several stores of II category while all other objects are of III category or have only ambient value.
The **architectural units** in the Old Bazaar have the following values: in I and II category there are 4 units in each category, between II and III category there are 6 units, while all other units are in III category or have only ambient value. It was concluded that in the frames of the Bazaar exist: 2 **units** of I category, 14 units of II category and 18 units of III category while 9 units have lost its cultural-historical value.
The new valorisation that we established, could help concluding that the cultural-historical attributes of the Old Bazaar and its parts differ when compared to those from 1963, when it was proclaimed monument of the culture. That is why it was imposed the idea for **redefinition of the borders of the Bazaar** and its division to: central nucleus, 3 contact zones and 1 zone that connects the nucleus with the Upper City (Kale). For all these zones, so as for the nucleus, in the frames of the Study we presented the architectural-urban characteristics with their values and negatives. It is certain that the central nucleus has most values and the contact zone of the nucleus with the Upper City is the most sensitive.
Depending on the established cultural-historical value of the heritage, we suggested a **regime for its protection** that is specially defined counting on whether it concerns an object, unit or ambience. At the same time, the general scientific assumptions and

legitimate specifications for that problem and the special characteristics of the heritage of the Bazaar were taken into account.
In frames of the first degree for protection we included the **objects** from I category, for which we predicted strict protection, and also strict behavior in their immediate surrounding. With the regime of second degree we included the objects of II category, for which we predicted bigger protection so the relationship towards them and their immediate surrounding should respect the authenticity with parallel satisfaction of contemporary needs. Under the regime of the third degree we put the objects of III category, where separable valuable component or the whole object as part of a valuable ambience is protected.
The regimes for protection of the **units** are defined in the following way: the first degree includes strict protection without disturbances in the spatial structure and appearance. The second degree includes relative freedom for adjustment of the inner structure of the unit while its appearance mustn't be disturbed. The third degree protects more valuable components of the unit or its general characteristics as inseparable part of a valuable ambience.
The protection of all 35 **ambiences** in the Bazaar includes three degrees: the first degree encloses all those ambiences that should keep their present spatial structure with small interventions in order to return their authenticity. The second degree includes the ambiences that need partial protection and partial return of their authenticity. The third degree protects separate characteristics of the ambience (spatial content, integral façade, street net and so on) or its general characteristics as common denominator of the ambience.
The valuable categories and degrees for protection of the heritage, except with tables, are presented graphically on the site plan so it can be clearly seen for what reason and in what way the actual heritage should be protected. The executed valorization and the suggested regime for protection enable to compose the directions for urban planning of the Bazaar and the conditions for architectural designing in its frames.

5.DIRECTIONS FOR PLANNING

Directions for planning in the Old Bazaar are created depending on the concluded values of its heritage, the needs for its protection and the needs for modern functioning. These directions represent final product of all previous researches. In the Study we described precisely our suggestions about **architectural-urban relationship towards separate zones in the Bazaar**: central nucleus, the three contact zones and the binding zone of the nucleus with the Upper City.
We elaborated in more details the directions for future planning of the Bazaar in the **suggestions and references to the formation of particular units**. So, we took into account the multicolor of the Bazaar in chronological and cultural-artistic sense: the

net of cultural-historical objects, the characteristic micro and macro pictures. We recommended to keep the so-called horizontal disposition of the Bazaar with the objects' height of 3-6m. and with range rows of equal elements (stores).
Special delicacy represents the **formalization of areas for new suitable construction**. Those areas are obtained by taking away worthless objects (warehouses, "factories" and substandards), and not by occupying free areas that are integral part of valuable ambiences. Typical for the Old Bazaar is that the underground level, where rich archeological heritage can be found should also be treated as a "free area". For that purpose, during the reconstruction of the old objects we indicate to lower the inner level of the object to a horizon of about –6m, if with an archeological sonde is found older stratum. We suggest to lower the level to –6m in units of stores that are divided around inner yard, during their reconstruction, too. After this procedure, the archeological heritage should be presented as an integral part of the Bazaar.
The essential reference represents to design an **urban project** before any intervention, in any part of the Bazaar that will define more precisely the rules and conditions for revitalization or new construction.
We explained, in more practical way, the previous directions for each unit (block) separately and in that way we defined: extent of the operation, the grade line of the object, its silhouette, integral façade of the street etc.
In the end of this Study and before the beginning of the urban planning, we formed so-called other references that should contribute to more qualitative protection and revitalization of the Bazaar as:

- concept for usage of the area and more significant units,
- concept for solving the traffic and open areas,
- concept for stages in the realization.

6.CONCLUSION

This new Study of the Skopje's Old Bazaar confirms the thesis that the architectural heritage, periodically, should be studied again, revalorized and put under new corresponding treatment in frames of the modern city. At the same time we concluded that some values of the heritage are lowered, some disappeared, but some new qualities also appear. All that should represent one of the important conditions for qualitative urban planning and architectural designing.
By the example of the Old Bazaar we showed that for an integral protection and revitalization of the heritage, a close cooperation between architect-conservator (who has understanding for the neceseties of the modern city) and architect-urban planner (who has respect towards cultural-historical values) is needed. That kind of cooperation on the example of Skopje's Old Bazaar in 197/98 showed fruitful.

Fig.1. Panoramic view on Skopje's Old Bazaar in 1998

Fig.2. Characteristic architectural unit of the Skopje's Old Bazaar

Fig.3. Characteristic architectural ambience of the Skopje's Old Bazaar

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 e-mail:sas2001@yildiz.edu.tr http://www.yildiz.edu.tr/mim/sas2001

CONTEMPORARY URBAN PLANNING OF THE CITY CENTERS, AND THE ARCHEOLOGICAL HERITAGE. (ANALYSIS OF THE COMPETITION FOR SOFIA CITY CENTER AREA PROJECTS - 1999)

K. Boyadjiev
Bulgarian Academy of Sciences,
Center for Architectural Studies, Sofia, Bulgaria

ABSTRACT

Ancient tradition and monuments, Early Christian tradition and monuments, Ancient and medieval sites. Town plans from 1880 to 1999. Brief presentation of the national competition. Competition's programme and approach to the archeological and historical heritage. Analysis of prized projects. Problems concerning the contemporary exposure of archeological monuments. Conclusions and evaluations: presence of an approved conception for a new approach to architectural heritage in urban planning.

1. HISTORICAL INTRODUCTION

The history of Sofia as a city began with the name Serdica, which came from the name of a Thracian tribe Serdi. The determining factors for situating the city there, were the mineral springs, good natural and climate conditions and the crossing of the main road from Central Europe, through the Balkans to the East and Asia with the road connecting Northern Europe with the East Mediterranean. The archeological data shows that until the invasion of the Romans the city had a regular street network and districts as most Hellenic towns [6].

In 29 B.C. the Roman legions broke in the territories of the Serdi and invaded them step-by-step. During the next centuries Serdica became a well organized and flourishing city. The city street network followed the roman model with north-south (cardo) and east-west (decumanus) orientated streets. The administrative buildings, several mineral baths and temples were located around the Forum [6]. In II c. A.D. the Romans began the construction of the city wall. The archeological researches had located with great accuracy the position of the wall and the towers. The area enclosed within the wall was about 164,000 m^2, it covered more public buildings and fewer residential ones. Part of the inhabitants lived in villas on the outer side of the wall. This pentagonal area is now under protection. Around this central core are situated 4 protected zones (I, II, III, IV), which coincide almost perfectly with today's public spaces of the town (fig. 1). The reconstruction made by arch. S. Bobchev witnesses the presence of the ancient treasure hidden underground (fig. 2).

The Early Christian period of Serdica's development is connected with emperor Constantine the Great (306-337), the building of the first churches inside and outside the wall. In 343 an ecclesiastic council took place, with representatives from all over the Christian world. Several public buildings were reconstructed into churches (now the rotunda St. George in the yard of the Presidency). In VI c. was constructed the, restored today, basilica St. Sofia, where the city's name comes from.

Serdica turned into a medieval Bulgarian town in 809 when invaded by Khan Krum. The restless wars with the Byzantine Empire (986-1016) had no positive influence in the development of the city. The city was invaded in 1018. The Crusades from 1096, 1147 and 1189 had a destructive effect too. After the restoration of the Bulgarian rule (1186) the city wall was restored too, several towers were reconstructed and several small churches were built. St. Petka, St. Spas and St. Petka Samardjyiska still exist today.

Ottoman armies invaded Sofia in 1382 and destroyed the city wall. For a short time the city was in possession of the crusaders (1443). After 1444 Sofia

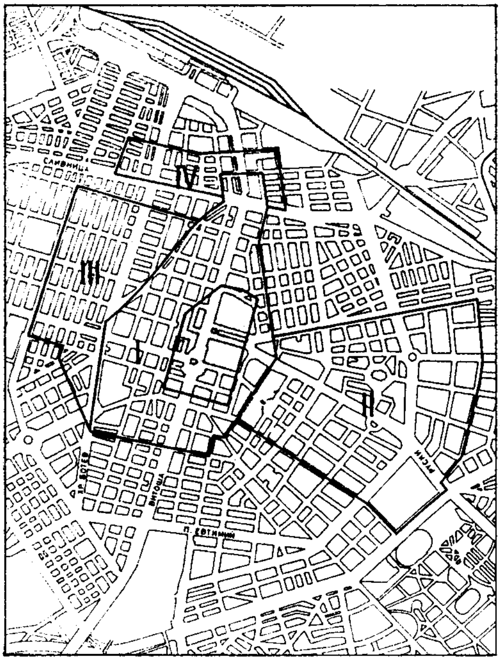

Figure 1

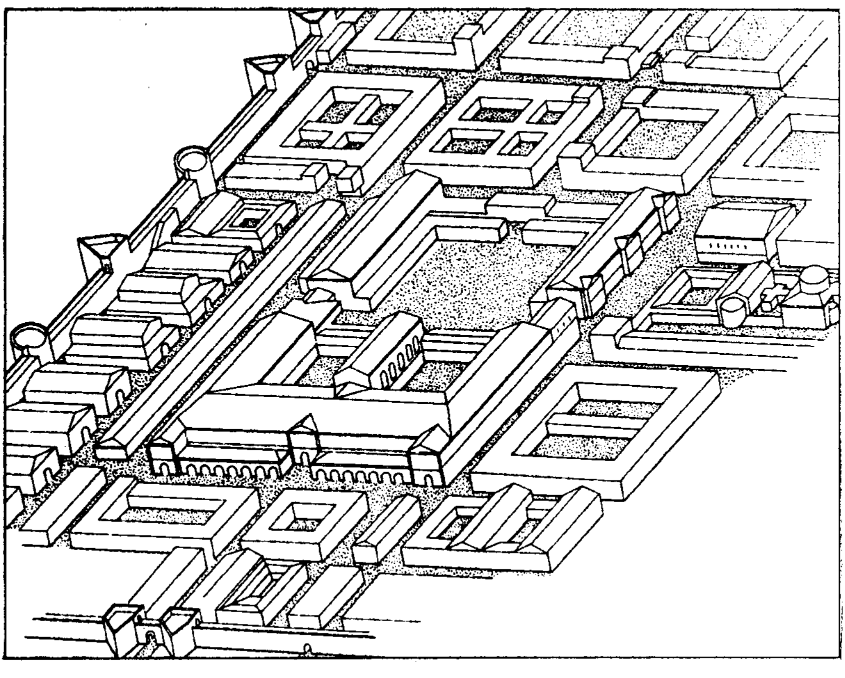

Figure 2

was the main city of Rumelia. People from different nationalities were attracted here: Jews, Armenians, Catholics (Latins) from Dubrovnik. Trade and handicrafts flourished. In the end of XVIII c. and the beginning of XIX c. there were more than 100 mosques. These were the public centers, which determined the picturesque composition of the late Middle Ages. Some of them were remarkable architectural achievements, as the still functional Baniabashi mosque. In the beginning of the XIX c. the main city center was the square between Baniabashi mosque and the Mineral Baths. This square is a central place nowadays too.

2. URBAN PLANS AND THE ARCHEOLOGICAL HERITAGE IN THE CENTER OF SOFIA

The most important feature of Sofia's urban development is the preservation of the city center at the same place from II c. till now. This accentuated continuity led to a stratification of several cultural layers, street over street, building over another. On one side this is a rareness giving great cultural potential, and a misfortune on the other, because most of the historical heritage is underground, under the actual buildings, streets and boulevards. There comes the great meaning of town planning in the city center.

The first town plan from 1880 was an orthogonal scheme and almost repeated the main streets of the ancient town center (fig.3). At the time of its execution many archeological remains were lost. The plan itself had no approach to the historical heritage. The same is true for most of the changes made to that plan until 1938. At that time the first modern town plan of Sofia was approved. Nevertheless at that time archeology in Bulgaria had received international approval, but a coordination between town planning and archeological excavations was not achieved.

After World War II the renovation of archeological researches and restoration works coincide with several plans from 1945 to 1961. The first of them assigned some minor importance in the composition to St. George rotunda. In 1961 the National Assembly ratified a general town plan, known as the "Neikov plan". It is the only legitimate one till now. This is a plan

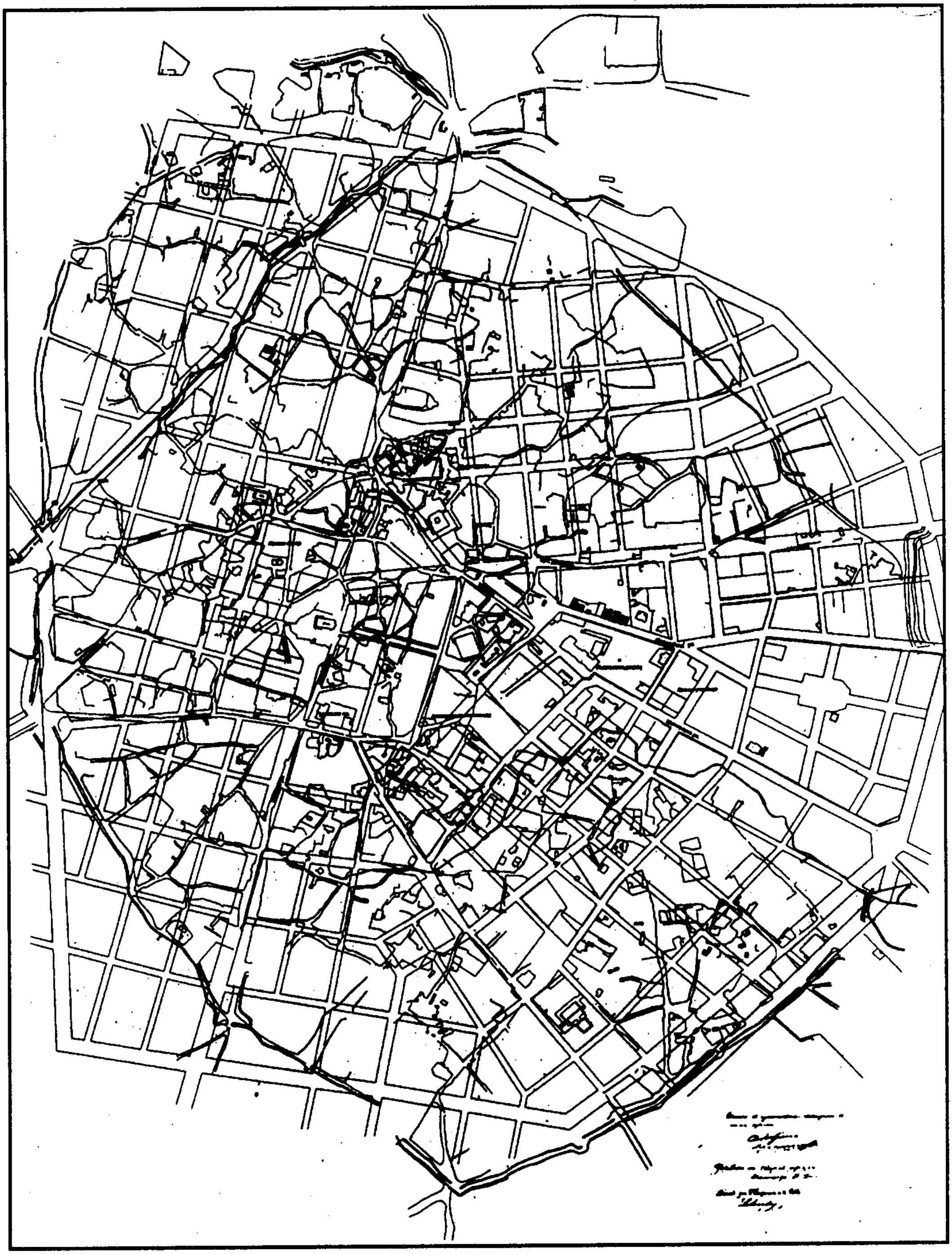

Figure 3

entirely influenced by the ideas of the architecture and urbanism of Modernism and street traffic. The next years there were several attempts to approve a new plan (1973, 1976, 1979), different conceptions were developed, but unsuccessfully [8]. During the 50 years of evolution of their ideas, urban architects and archeologists remained closed in their own fields, regardless of the fact that any elaboration included parts of the city center with precious historical heritage.

The political changes in 1989 led to a competition's announcement in 1990, for a new town plan of Sofia in 3 consecutive phases. Twenty-five teams (more than 150 participants) took part in the first phase [1]. After this first phase the competition was terminated. It turned out to be relatively unsuccessful. The objectives of the competition were orientated to the common problems of the territory and fairly to the city center. The considerable economic difficulties in the next years reduced town planning and construction of administrative buildings to its minimum. Housing construction is an exception due to the repeal of many restrictions.

3. THE NATIONAL COMPETITION IN 1999

The urban development of Sofia was marked with a particular progress and dynamics during the first mandate of the Mayor Stefan Sofianski (November 17, 1995 - October 16, 1999). The economic stabilization of the state, after 1997 and the management's initiatives of the Municipality of Sofia, led to a wide program in several levels: reconstruction and modernization of some of the main boulevards as Maria Louisa Boulevard, Ivan Geshov Boulevard, Hristo Botev Boulevard, Slivnitza Boulevard; the construction of the Sofia Metropolitan continued with stations №№ 6 and 7; the "Ancient Sofia" Municipality's Company finished the restoration of the medieval churches St. George and St. Sofia in 1997; the execution of the Beautiful Sofia Project began. The reconstruction of the boulevards in the city center and the construction of the subway station №7 Serdica emphasized the problem of the exposure of archeological heritage depending on the town planning. Under the level of Maria Louisa Boulevard was found a round tower and part of the wall of the roman fortress Serdica. A small part of that wall is exposed at the ground floor of the reconstructed building of the Central Covered Market. Another considerable part of the wall remains above the level of the station Serdica. These examples show that a large part of Serdica can hardly be discovered, without a change in the way of planning the street network.

Conditions for restoring the entire approach concerning the problems of the city, emerged from the accumulation of multiple initiatives. In 1998 the National Assembly voted a law for a new general town plan. The presence of essential differences in the concepts for the general town plan in Bulgarian town planning and the practice with similar plans in France, Britain and USA as: Plan Directeur, Development Plan, Structure Plan; should be mentioned there. The traditions and practices established during the last 100 years require a richer content of the plan and a more detailed development of the city center in scale 1:500 and 1:250. This places immediately the problem with the rich ancient heritage, including all possibilities for new conceptions.

Concerning the elaboration of a general town plan, Sofia Municipality prepared several competitions. The first one was "Ideas for Architectural, Urban and Functional Development of the Central City Areas in Sofia", which took place in the summer of 1999. In the competition's program the following main objectives were formulated:

1. Formation of areas with representative character - state and city level
2. A durable solution for the city center in urban, voluminous and functional aspects to be found
3. Finding solutions for enriching the historical appearance of the city center
4. Functional revaluation of the existing public and administrative buildings considering the changes in the political system, public relations and economic conditions.
5. Examination of the parking problem and finding solutions for it

6. Creating possibilities for further development of the western direction of the subway.

The program was prepared by a team of representatives of the Ministry of Regional and Urban Development, Ministry of Culture, Union of Architects in Bulgaria and Municipality of Sofia. The preliminary project of the program was declared and discussed in public by the architects. It should be mentioned that the problem of the archeological heritage is directly included in points 3 and 5 of the program; and is conceptually presented in the whole program. During the competition it turned out that a small part of the teams paid special attention to these requirements.

A jury of 13 experts under the chairmanship of the chief architect of Sofia Stoyan Ianev was determined. Two of the members were from the National Institute for Historical Monuments. 25 projects applied for the competition. There was no winner, but two second reduced prizes were awarded to the teams of Todor Todorov and Dimitar Mladenov; third place for the team of Stefcho Dimitrov; and another 2 reduced third prizes for the teams of Liubomir Panchev and Ivan Bistrakov. Eight more projects were awarded and redeemed.

The competition is one of the most significant events in architectural life during the past ten years. A public discussion took place after the competition in August 1999. For about a month 48 publications appeared in the daily, weekly and specialized press, as well as on radio and television. For the first time a Prime Minister (Ivan Kostov) visited the exhibition of the participating projects.

The results of the competition can be characterized as revealing 3 tendencies. Two of them are connected with the problems of the traffic, public transport and parking facilities. The third one is influenced by the historical heritage. It can be found in the projects of Todor Todorov, Liubomir Panchev and Atanas Agura (second prize, third prize and a redeemed project). These 3 projects are a small part amongst all 25 projects, but their presence at all awarded levels, demonstrates their meaning and the jury's appraisal. The fact that several of the redeemed projects were criticized in the jury's report for lack of conception for the historical heritage.

New ideas were grounded in the project of L. Panchev and the famous archeologist M. Stancheva. They are continued in another project for a competition for the transport scheme of Sofia. The key quality of the project is the integration of all archeological sites in one unified system. From architectural point of view the creation of underground spaces, archeological sites fully covered with glass roofs, and ones partially integrated into new buildings, are really valuable. Along almost 400 m in east-west direction a contact with the archeological heritage was made possible. The connection between the pedestrian traffic in the central areas, surmounted on different levels, and the archeological monuments are of great importance especially when the monuments are underground. In this case the purposive accumulation of visual impressions is an important component of the city's image. A fractional impression can be made from fig.4 and fig.5.

The project of Todorov, awarded with a higher prize for other qualities, is following the same tendency. Its main idea is the enlargement of the zone under the so called "Largo", and the ground floors of the buildings around it: the Council of Ministers and the Presidency. They will serve for museum exhibitions. The ground floor of the Presidency connects the archeological remains under the Largo (further excavations will be done) with the restored rotunda St. George with the original road covering around it from IV c. and other remains in the yard of building. The building of the Archeological Museum on the west gives a final touch to this impressive architectural ensemble. Possibilities for further development in western direction are left.

The project of A. Agura proposes more modest ideas. The principle for accessibility of the space is of importance here, not the particular solution.

4. CONLUSIONS

Sofia is older than most of the capitals in Middle and Northern Europe. The significant Thracian, ancient, Early Christian and Medieval heritage impart a unique character to the city. This is not used in town planning to its full advantage yet. One of the reasons

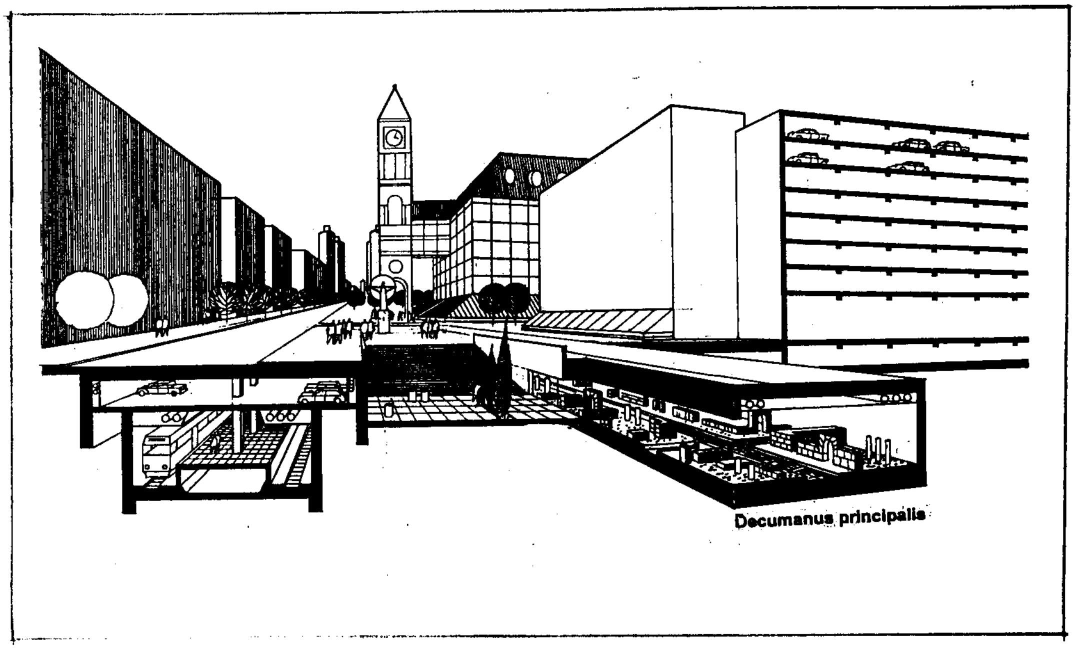

Figure 4

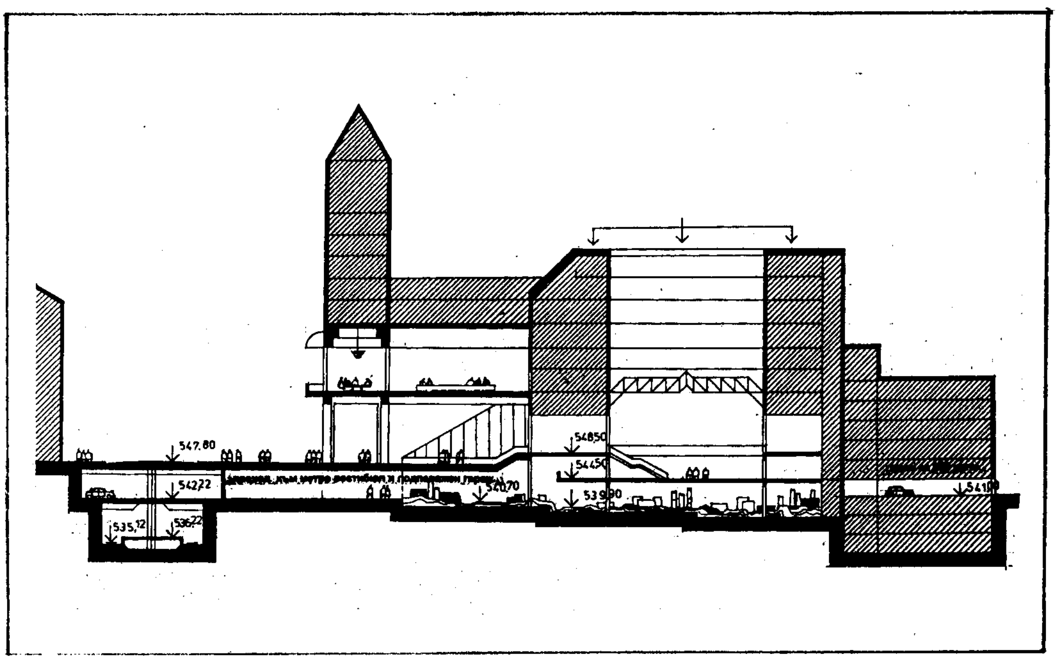

Figure 5

for this is the peculiarity of the center of the city. It evolved during centuries at the same place, so most of the monuments are underground. This requires new approaches in town planning, outlined in the competitions of 1999 and 2000 and in the discussions followed after them.

The problems of town planning of Sofia have certain international meaning, determined by the perspective of Sofia as a European city on one side, and as a city connected with Istanbul in the cultural context of the relation between 2 continents and 2 civilizations on the other. Sofia has the opportunity and the duty to play its role.

The solution of such problems is based on the positive meaning of the process of globalization. This permits to keep the national identity and regional spirit. In that specific situation, this is the issue of the "Mediterranean traditions" [2]. The pagan, Judaistic, Christian heritage in its architectural dimensions overcomes the national scientific sphere.

Everything listed above totally agrees with the main theme of the International Union of Architects' congress in Berlin 2002: "Architecture as a resource". The last evolution of the theme turns to architecture as a spiritual and cultural resource.

The outlining of the problem as it is; shows that the traditional researches of ancient structures: public buildings, fortresses, bridges etc. are today insufficient for solving the problem. Even now those traditional researches are not used to their full extend. This is determined by the fact that there are not enough participating experts in the domain; in the elaboration of the programs for the competitions; and in the teams. Town planning is the domain where the interdisciplinary synthesis can be done.

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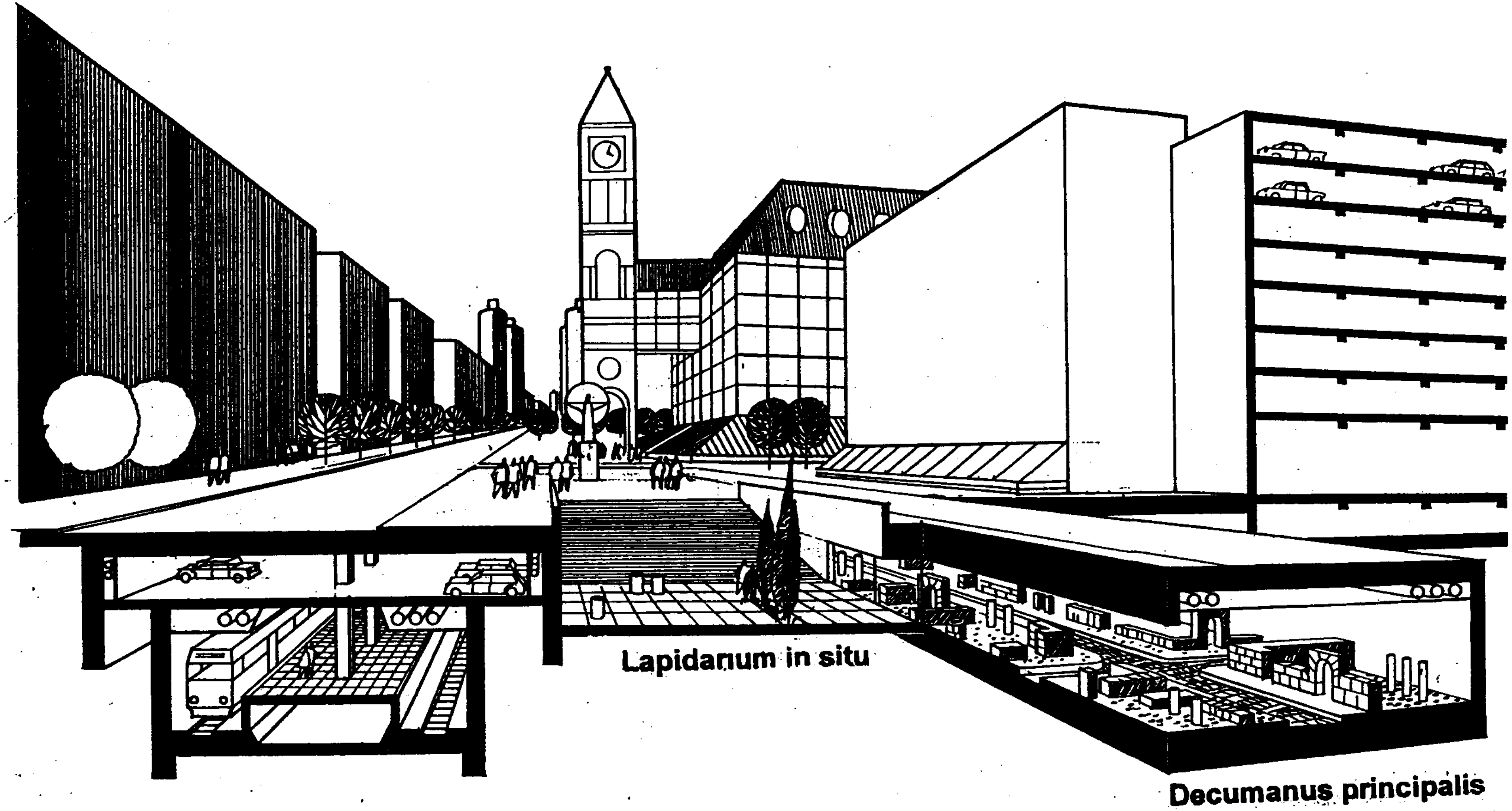

Figure 4

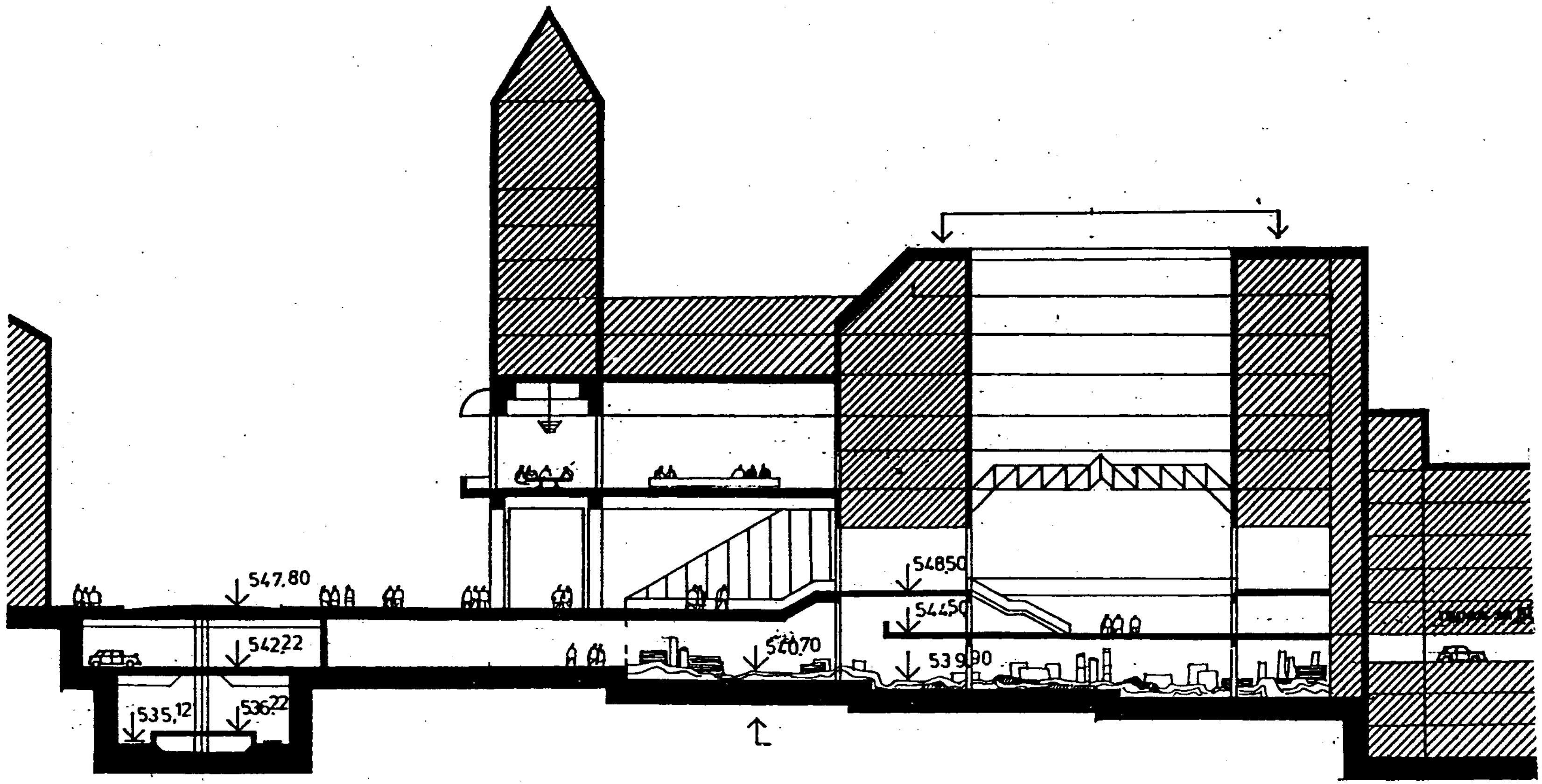

Figure 5

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TRANSFORMATIONS IN THE HISTORIC URBAN AREA OF "SANTA MARIA", IN CASTRO URDIALES, SPAIN.

M. A. Flórez de la Colina,
Architect, PhD. Associate Professor,
Building Technology Department, Polytechnic University of Madrid, Spain.

ABSTRACT

Some buildings and some areas in our cities are the result of many years of history and culture. One of the difficulties in dealing with such places is that they have been built with the collaboration of artists and profesionals from several periods and different skills. Each time they have to be repaired, because of damage from natural phenomena or as they must be used for other purposes than the original, the issue of how it should be done, which layers or elements can be removed and which others should not, is always discused.

The purpose of this paper is to point out some of the criteria which can be used for some of these interventions in Ancient Structures, looking through the historical documents, the cartography, the natural surroundings and conditions of the site and buildings of a singular area in the center of Castro Urdiales, in Northern Spain. The transformatins this small town has suffered would be evaluated under these criteria, explaining how some Roman remains were integrated into medieval constructions or the traumatic effects of the modifications to enlarge the harbour in the XIX century.

Finally, some measures to protect this Historic Heritage would have to be proposed, refering specially to the coordination of public administrations involved in emergency reparations due to storms, when the need of consolidation of the Ancient Structures is so urgent that it may lead, if it is not carefully directed, to damage to some of its historical and artistic values.

1. THE SITE AND ITS HISTORY.

The urban area surrounding the medieval church of "Santa Maria" in Castro Urdiales, a small town located in the north of Spain can be defined as exceptional, due to its impressive natural beauty and to the traces it has kept of our past in its constructions.

On a large rocky point between the bays of Castro and Urdiales, the small elevation of the land dominates the main part of the town. The inhabitants constructed some fortifications around the main fortress and the church of “Santa María”, connecting some of the boulders nearby through bridges, as it can be seen in the layout drawing of the architect E. Laredo, which also shows the new breakwater to enlarge the harbour built at the end of the XIX century [Fig.1] .

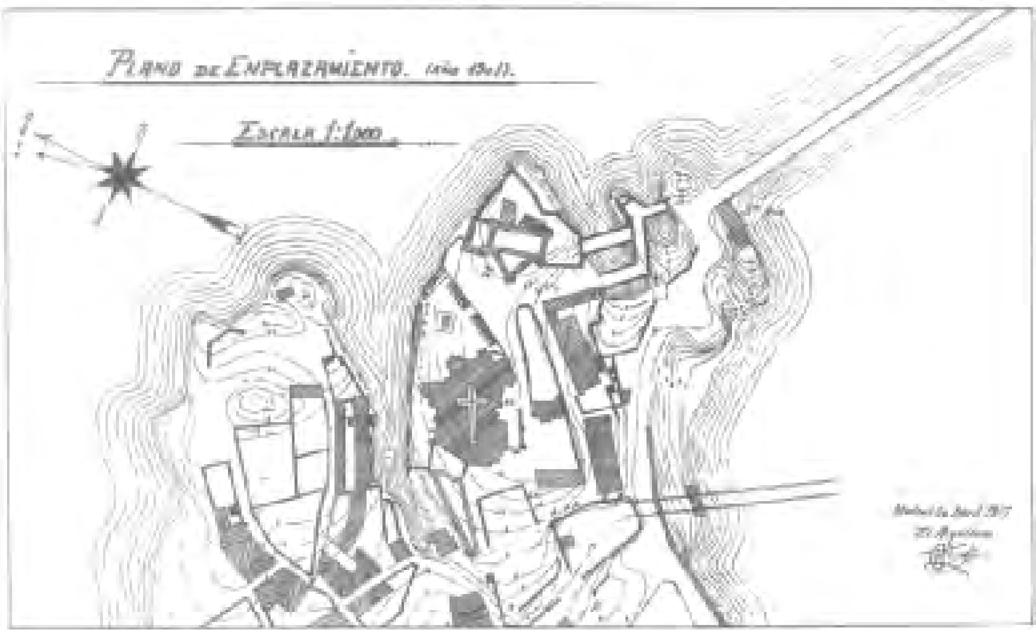

Figure 1. Site Layout, Castro Urdiales, 1901, by the architect E. Laredo.

1.1. The origins : from “Portus Amanum” to “Flaviobriga” (I st. century B.C. to IV th. century A.D.).

The oldest references of the city appear under the name of “Portus Amanum” and “Castrum Vardulies”, the latin terms “Portus”and “Castrum” refering to a harbour and fortified town, in the area between “Amanum” and “Vardulies” , two populations found in the area and mentioned by Estrabo. Several findings of this period include ceramic, metal fibulae and the bronze statue of a sea god later called Neptune.

Plinium, in his description of this coast, mentions it as “*Amanum Portus, ubi nunc Flaviobriga, Colonia civitatum IX*...” (1), the Harbour of Amanum, were Flaviobriga is now located, a Colony of nine cities.... Later, historians found the names of this nine cities to be: *Uxama, Segisamunculo, Antecuja, Deobriga, Vindelia, Sallionca, Tritium, Metallum* and *Viruesca* (2). The tranformation of the town into a Roman colony is established by historians between 69 and 96. A.D., probably about the year 74 when emperor Vespasiano gave the latin law to all "Hispania". The reasons for doing it, are both militar and economic, to control the mines and trade with "Galia" (now France), being the ideal location for a natural harbour, protected against the northern gales in the Cantabric sea.

Several findings in the city and in the villages around it explain its importance during the Roman period: ceramic, mosaic teselae, coins of different kinds, some bronze, some gold; medals under the city walls, of Antonino Pius and his wife Faustina, from the period between 138 and 142, discovered in 1866 when the city walls were knocked down, or under houses, as the bronze medal of Marco Aurelio dated in 171 found in 1881, the silver medal of Tito dated in 80, the small bronze medal of Claudio dated between the years 41 and 54; mile stones of the road built in this period between "Flaviobriga", now Castro Urdiales, and "Pisoraca", nowadays Herrera de Pisuerga; the remains of tombs, and more spectacular, a silver dish found in the nearby village of Otañes, 974,5 grammes, 21 centimeters diameter, with scultures of the water deity of "Salus Umeritana", from the first century (3).

In front of the main facade of Santa Maria, a cilinder of stone, a Roman mile stone of 61 A.D., found also in Otañes, remembers this period of history. The inscription on it, translated into English says: "Nero Claudio, son of the divine Claudio, Cesar, Augusto, Germanico, Pontifice máximo, being a tribune for the eigth time, the empire for the ninth and the consulate for the fouth time. From Pisoraca, one hundred and eighty miles" (4).

1.2. The early medieval Town (V th. to XII th. century A.D.).

Early medieval times were hard for the inhabitants of the old Roman city of Flaviobriga. Documents mention attacks by pirates, as bishop Indalecio writes about the devastation of this coast in the year 456 (5). Most of the population migrated to the interior and abandoned the town.

Hauberto Hispalense explains that the city was repaired or reconstructed "*Flaviobriga prope occeanum, reparata est a Cantabris anno quingentessimo octuagessimo quinto*" (6).

The memory of the Roman colony vanished and even the name is forgotten. But the remains of the Roman fortifications are still there and the old manuscripts refer to the city as "el Castro de Castella Vetera", the word "Castro" meaning stronhold, "Samano", recalling its previous name of "Portus Amanum", and

“Castro de Ordiales”, very close to its name today, as it appears in a document of XII th. century explaining the visit in 1102 to the city of García Aznarez, bishop of Burgos (7).

The Old church of “San Pedro” is from this period, when probably the Roman fortifications were also consolidated. Only some ruins remain today.

King Alfonso VIII of Castille begins the economic growth of the town, by giving it a priviledge called “Fuero de Castro”, dated 10th march 1163. As the king was then eight years old, it is reasonable to attribute the decision to Lope Diaz de Haro, ruling this area and Vizcaya in his name (8). At the end of XIIth century, Castro Urdiales was a town with a comercial harbour of a certain importance, due to the measures established by Alfonso VIII to favour navigation and trade by sea. This King visited the city on several occasions in order to verify the construction of Santa Maria and the Castle; this is the reason why a palace was built for him, used later for the meetings of the “Cabildo”, an organisation charged to deal with all the maters related to the celebrations in the church, the works to improve it or to repair the damage caused by sea storms..., a body which varied from fourteen to sixty people in the period of the town splendour.

1.3. Splendour and crisis (XIII th. to XVI th. century A.D.).

The 4th May 1296 a powerful organization of the eight more important towns along the Cantabric coast, called “Hermandad de las Marismas” , the Brotherhood of the Marslands, is created to defend their commercial interests and to solve the problems between them. Due to its strategic location between Cantabria and Vizcaya, Castro Urdiales is chosen to be the seat were the representatives of the towns would meet.

Its economic growth increases and from this period dates the construction of the church of “Santa Maria”, the Palace of King Alfonso VIII and several of the medieval stone buildings still existing in the town. What we know today as “the castle”, where a lighthouse is located, is mostly from this period, but was probably founded on Roman bases.

In the XVI century, the “Hermandad” divides and the importance of Castro Urdiales disminishes. The discovery of America and the new orientations of Spanish sea trade, the beginning of the “Atlantic era”, and a plague which reduced the population from 600 to 200 inhabitants at the end of the century marked the end of its splendour.

1.4. Evolution and transformations (XVII th. to XX th. century A.D.).

Castro Urdiales and its inhabitants, continued nevertheless to contribute to Spanish history and economy. Their experience at sea, whaling very far from the Spanish coast, made them participate in several expeditions where the Spanish navy was involved and to trade with northern Europe.

Documents and buildings from the beginning of XVII th. century (9) show the coat of arms of the city, given by the king a century before. Some of the constructions of the area appear in it, as symbols of the town: the castle, the bridge and the chapel of "Santa Ana", two ships and a whale, as in the medieval seal of the town [Fig. 2] .

Figure 2. Coat of arms, Castro Urdiales. Medieval & XIX th. century.

Another flourishing period for the city is related to the exploitation of mines in the region. But the harbour is not very big and in the XIXth century they managed to enlarge it. [Fig. 3] .

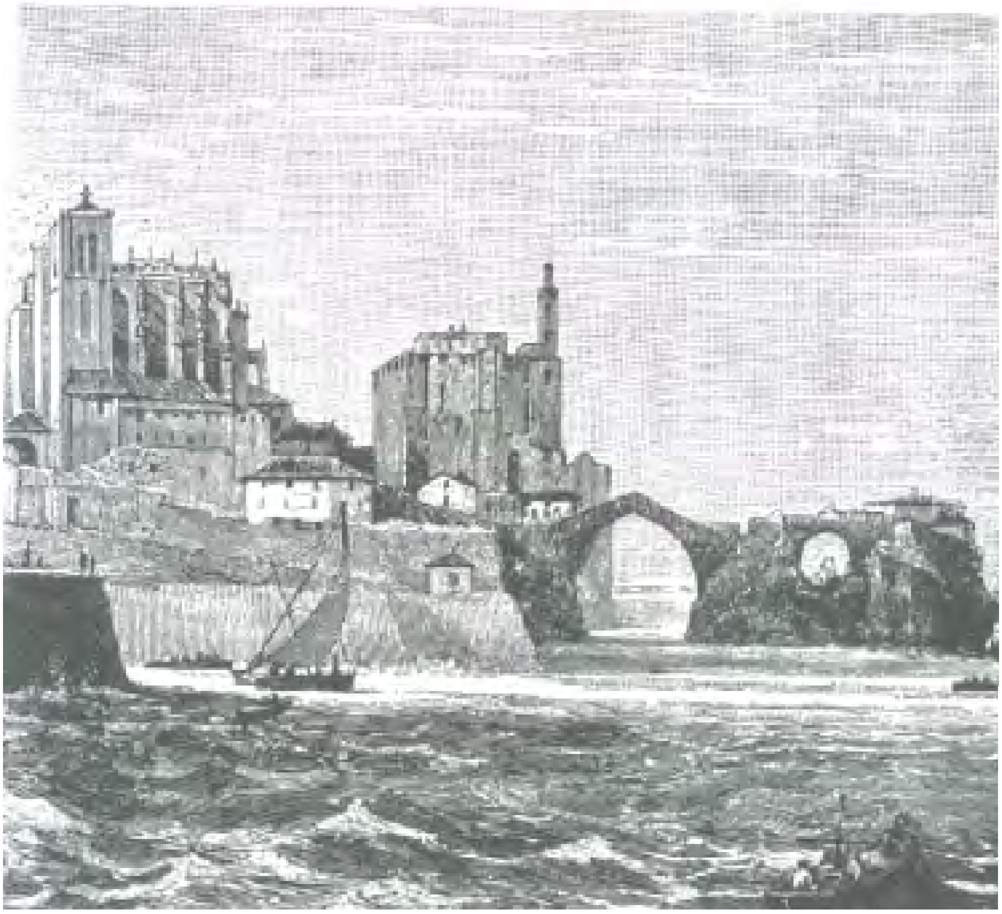

Figure 3. General vue, Castro Urdiales, XIX th. century.

The new breakwater made strong transformations in the area , and some of the Roman and medieval bridges disappeared. Other transformations in the area, are related to allowing vehicles access to the front of the church and moving the cemetery from the church to a place outside the city.

The tourist development in the sixties expanded the city, and made new changes from that period up to today, consisting in new pavements and the destruction of some of the old walls remainning in the area.

2. URBAN TRANSFORMATIONS.

The church of “Santa Maria” is the most impressive of the constructions located in the place. It appears today like an isolated building, but it has not always looked like that. The medieval building was a part, and was linked to, the fortifications of the area. Even today, it is easy to establish the architectural and visual relation to the castle and the other constructions nearby . Its main facade, oriented to the norwest, was protected by a wall from the sea storms, connecting it to a house that architect E. Laredo explains that "only a facade was left of the old palace of King Alfonso VIII" (10). This old wall and the palace facade had nearly disappeared due both to the effects of gales and of a proyect to readapt the area in front of the church. A photo from the beginning of the XXth century still shows what the palace facade looked like then (11). Other constructions in the area are the castle, the remains of the church of "San Pedro", the bridge, and the chapel of "Santa Ana".

2.1. The church of Santa Maria.

The church is gothic, with three naves, the central one more elevated in relation to the side aisles. The layout of the apse, with an ambulatory around the altar, recalls the drawings of Villard de Honnecourt, a very interesting manuscript of XIII th century (12) [Fig. 4].

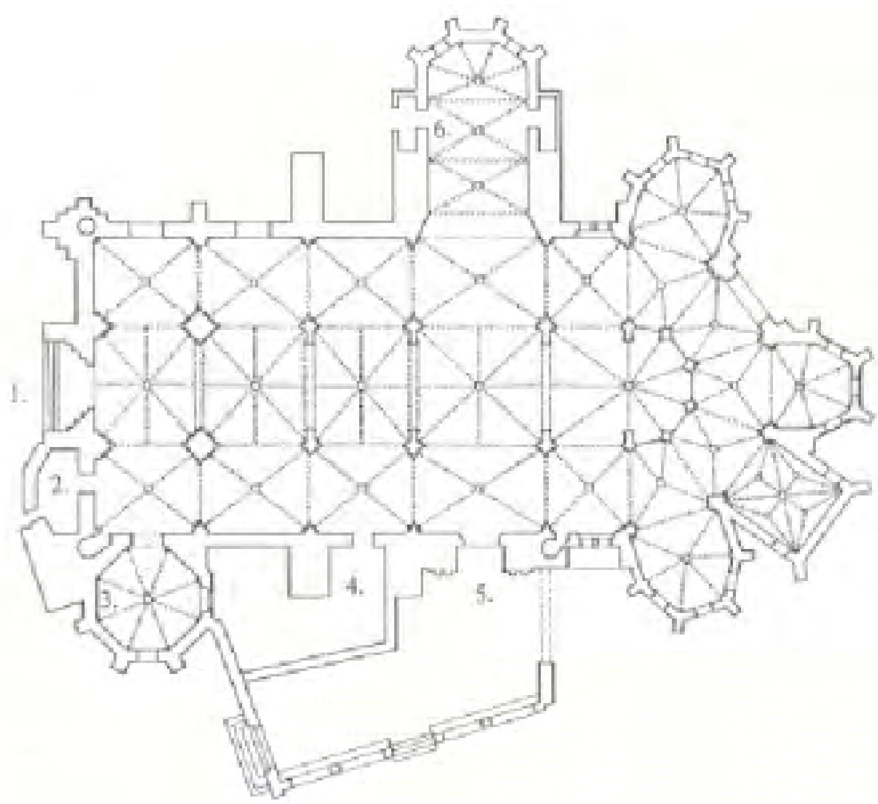

Figure 4. Plan of "Santa Maria", Castro Urdiales, Spain.
1. Main entrance 2. Baptism chapel 3. Chapel of "Santa Catalina"
4. Sacristy 5. Men's Portal 6. Chapel of "San Jose"

The design of the church was probably done in the XIII th. century, and the chosen site was not the same as the existing “San Pedro”, so it was not destroyed. The portal and part of the main facade can be dated also to the XIII th. century, while the three naves, the apse and its three exagonal chapels, and the tower were built in the XIV th. century. A rectangular shaped chapel was added in the XV century to the apse aisle, and a small baptism chapel as well as the octogonal shaped chapel of “Santa Catalina” were constructed in the XVI th. century. The sacristy was built in the XVII th. century and the Men’s Portal, in neoclasical style in the XVIII th. century. Damage caused by sea gales and the proximity of the cementery made architect E. Laredo add the Chapel of “San Jose” in the XIX th. century. Maybe, this architect was also responsible for removing some of the aditions to the Main Portal, also called the Women’s Portal as he pointed out in his proyect the need for doing so (11).

All this work was done with the collaboration of craftmen, using compatible building techniques that have not created problems in the building, repairing all the damage caused by storms and ageing.

2.2. The castle.

The castle was probably built at the same time as “Santa Maria”, but as previously stated, using Roman foundations. It has a pentagonal shape, with strong cilindrical towers in the angles. An external wall encloses the outer bailey, creating another line of defence. The ancient access gate, in the norwest of the promontory, with traces of what may have been the location of a portcullis, lead to an area of the castle not used today; it shows that the level of the ground was higher and that, may be when the cemetery was transfered, they filled in this zone to level it off.

Transformed into a lighthouse, it is the only of its kind in Cantabria. Its survival may be related to its new use, but has destroyed the upper part of the fortress.

2.3. The bridge and the chapel of “Santa Ana”

Close to both buildings, in the southern part of this area, we find the only remaining bridge of what was probably a series of arches, connecting the castle with some rocks close by and thus, protecting the entrance to the old harbour. When the new breakwater was constructed, two of these arches disappeared and they had to add several flights of stairs for the access to the chapel of “Santa Ana”, on one of the rocks.

The chapel of “Santa Ana” is very difficult to date, as it is a masonry construction with a wooden roof covered with tiles. Its shape and foundations may be quite old, going back to medieval or even Roman, but its upper part is clearly much morerecent. It has always been a symbolic feature at the entrance to the harbour, and part of the coat of arms of the city, as well as the castle and bridge.

In this part, there are some small constructions dating from the last century, related to several nautical services, such as the “Cofradia del mar”, a building for sailors and shipowners, or the “Fabrica del hielo”, which can be translated as an ice factory but which was in fact only a storage for ice to preserve the fish.

Another almost buried building, was constructed at the same time they improved the access of vehicles to the church, where some restaurants are now located. When the new pavements of the area were laid in the early nineteen eighties, several walls were removed, making the last vestiges of the Palace of Alfonso VIII almost disappear. Only a barbican and part of a wall have remained.

3. CONCLUSIONS.

Five years ago, the 8 th. February 1996, during a very strong winter gale, the bridge was badly damaged. The different bodies of administration involved took such a long time to coordinate themselves, that the work to consolidate and to repair it was done almost in the summer, with a risk of even greater damage to the bridge. This is just an example, but with some of the problems involved in those cases.

As so often happens, the whole area has been declared of historic and artistic interest. Some work has been done which enables people to visit it. But there is not any kind of emergency plan, coordinating the different authorities responsible for this area: the municipality, harbour authorities, fine arts commision in Santander and in Madrid, the catholic church ...Having gales with waves nine meters heigh from time to time, and strong northwest winds even more frequently - wind reached 109 kilometers per hour when the bridge parapet was destroyed (14) -, something must be done.

Keeping some funds to deal with these problems quickly, choosing people from the public areas involved to form an emergency commitee before the damage occurs, having accurate documents and studies of the present state of the constructions and work to be done..., will help not only to deal with these problems in time, but also to protect our Historic Heritage.

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

CORROBORATIVE STUDY ON ALLEY SPACE IN THE ENVIRONMENT OF MULTIPLE DWELLINGS IN THE URBAN TRADITIONAL AREAS IN TOKYO

H.Ohuchi, S.Ijiri, S.Takeda, M.Sakurai, K.Yamada
Nihon University, Chiba, Japan

ABSTRACT

This study is a corroborative study of alley space in the environment of multiple dwellings of urban areas. In this study, "multiple dwelling" means the region, in which inhabitants are living relating each other. Relationship between alley spaces, living and consciousness of inhabitants was examined. Comparison and examination was made in each of the investigation areas from the results of analyses and examinations. The factor (living of inhabitants or spatial structure), which affects inhabitants' consciousness, is depending on the changing of regional spatial structure.

1. INTRODUCTION

In modern cities, the life regions have been spread, but the life space has been segmented, losing the organic relationship, and as a result, the relationship of the inhabitants has been weakened, inhabitants' interest common space environment has been decreased; the condition of living environment has deteriorated.

Tokyo, the capital of Japan, is one of the largest cities in the world. It was formed in Edo period, and has 400 years history. Edo has changed its urban structure with modernization in 1860's, Kanto Daishinsai (a big earthquake which damaged Tokyo severely in 1923), the World War II, and postwar advanced economic growth in 1960's. There are some regions with historical urban structure. The historical regions are losing their own structure as a result of redevelopments, change of lifestyle, aging of the inhabitants, and change of generation.

Focused on the change of spatial structure, this study showed general relationships between spatial structure and inhabitants' consciousness by analysis of latent factors which strongly affects inhabitants' consciousness and living activities, and spatial structure where the clarified inhabitants are living in.

2. ALLEY SPACE in TOKYO

In the historical regions in Tokyo, inhabitants have organic relation with neighborhoods. They formed life religions around alley spaces. So the alley spaces are very important the spaces for the life of neighborhoods, and the inhabitants have great interest for the environment of alley spaces.

The alley space's proprietor is private person, but the alley spaces are shared by the neighborhoods as life space. Activities of living of the neighborhoods flood into the alley space. For example, inhabitants use the alley space for drying closes or as storage. (Picture 2,3) Inhabitants talk each other standing in alley space, or sometimes it is used as occupational service yard.

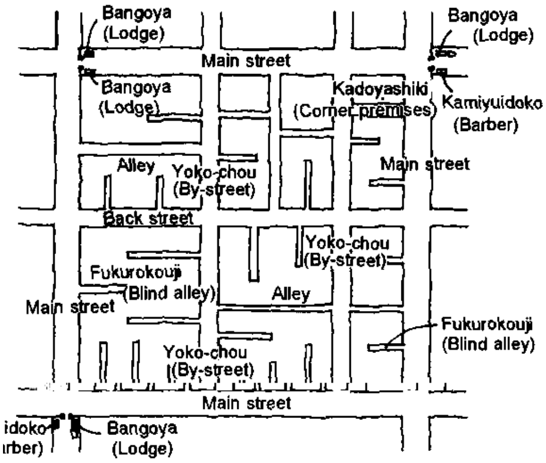


Fig1 Town construction of historical region in Tokyo

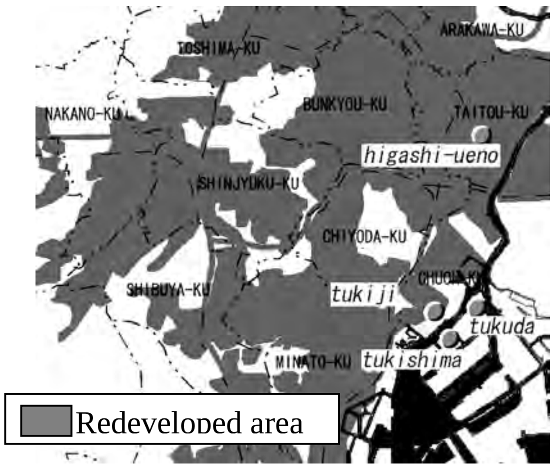


Fig2 Historical region in Tokyo

Picture 1

Environment of alley space

Picture 2

Inhabitants' communication in alley space

Picture 3

Alley space used as service yard of store

3. MATERIALS AND METHODS

3.1 Materials

The investigation regions have blocks including the alley space and leaving historical spatial structure in urban area in Tokyo. They are 59 blocks in 4 regions, Higashi-Ueno, Tsukiji, Tsukuda, and Tsukishima. The survey items are classified into individual characteristics, block characteristics, life characteristics, and consciousness characteristics.

Table1 Investigation areas and results

AREA NAME	BLOCK	SUBJECT TERM
HIGASHI UENO	HIGASHI UENO 3-20～28,3-30～39	TERM1 JULY 1995 TERM2 JUNE 1996
TUKIJI	TUKIJI 6-7～18,7-10～17	TERM1 AUGUST 1995 TERM2 JUNE 1996
TUKUDA	TUKUDA 1-1～6,1-9～110	TERM1 AUGUST 1995 TERM2 JULY 1996
TUKISHIMA	TUKISHIMA 1-16～27	TERM1 AUGUST 1995 TERM2 JULY 1996

ITEM		NUMBER OF PEOPLE				
		HIGASHI UENO	TUKIJI	TUKUDA	TUKISHIMA	(%)
SEX	MALE	38	27	20	27	112
	FEMALE	26	37	41	39	143
AGE	12～40	9	7	9	8	33
	41～55	12	10	14	16	52
	56～70	27	24	26	28	105
	71～	16	23	12	14	65
AGE OF RESIDENCE	0～15	6	6	11	5	28
	16～30	4	11	9	16	40
	31～45	22	17	11	18	68
	46～60	21	19	16	22	78
	61～	11	11	14	5	41
		64	64	61	66	255

3.2. Methods

By quantification III[1], the latent common factors in the data of the questionnaire results are clarified, the structure between survey items could be shown. And, the cluster analysis is carried out on the result of quantification III, and the inhabitants are classified. The common factor is shown as an axis in the item category-plotting figure. The factor axis is understood from result of analysis by quantification III. Then, interpretation of the factor axis and position of the classifications for the factor axes, clarify characteristics of the inhabitants. Table 2 shows each classification and their characteristics in the each area.

Table2 Result of quantification and cluster analysis

HIGASHI-UENO	AXIS OF FACTORS	1 The spatial structure and density		2 The flexibility for environment		3 Interests to environment	
		+	−	+	−	+	−
AXIS 1 0.461 AXIS 2 0.422 AXIS 3 0.404	Classification	Low-rise and high-density	High-rise and low-density	HIGH	LOW	LOW	HIGH
	Ⅰ	○		○			○
	Ⅱ		○	○	○		○
	Ⅲ		○		○	○	○
	Ⅳ	○	○	○	○	○	
	Ⅴ	○	○	○		○	
	Ⅵ	○	○		○	○	
	Ⅶ	○			○		○

TSUKIJI	AXIS OF FACTORS	1 The spatial structure and density		2 The recognition of spatial change		3 The flexibility for environment	
		+	−	+	−	+	−
AXIS 1 0.464 AXIS 2 0.413 AXIS 3 0.404	Classification	Low-rise and high-density	High-rise and low-density	LOW	HIGH	LOW	HIGH
	Ⅰ	○			○	○	
	Ⅱ	○			○	○	○
	Ⅲ		○	○	○	○	○
	Ⅳ	○		○			○
	Ⅴ	○		○		○	

TSUKUDA	AXIS OF FACTORS	1 Interest to environment		2 Residence permanency		3 Expection for mutipule dwellings	
		+	−	+	−	+	−
AXIS 1 0.446 AXIS 2 0.413 AXIS 3 0.375	Classification	LOW	HIGH	LOW	HIGH	BIG	SMALL
	Ⅰ		○	○			○
	Ⅱ	○		○		○	○
	Ⅲ	○	○	○	○	○	
	Ⅳ		○		○	○	○
	Ⅴ	○	○		○		○

TSUKISHIMA	AXIS OF FACTORS	1 The spatial structure and density		2 Residence permanency		3 Interest to environment	
		+	−	+	−	+	−
AXIS 1 0.427 AXIS 2 0.404 AXIS 3 0.390	Classification	Low-rise and high-density	High-rise and low-density	LOW	HIGH	HIGH	LOW
	Ⅰ	○		○		○	
	Ⅱ	○		○			○
	Ⅲ	○		○		○	
	Ⅳ	○			○		○
	Ⅴ	○	○		○	○	
	Ⅵ		○	○	○		○
	Ⅶ	○		○		○	

corelationship coeffecient

4. THE UNITS OF CLASSIFICATIONS' REGION IN EACH AREA

The inhabitants, of the same classification, are living in specific district[2]. Classified inhabitants' districts help to understand relationship between consciousness and the spatial structure. The relationship between such a district and spatial structure were shown by interpretation of factor axes and analysis of spatial structure focused on alley spaces.

4.1. Higashi-Ueno region

In Higashi-Ueno region, inhabitants are living in specific district classified in classification III, IV, V, VI, and VII. In the interpretation of factor axes of quantification III, the first axis shows "The spatial structure and density" (correlation coefficient =0.461), the second axis shows "The flexibility for environment" (correlation coefficient =0.422), and the third axis shows "The interest to environment" (correlation coefficient =0.404).

a) The district of classification III

There are alley spaces in this district, and it has the avenue in the front side. This classification is observed in the *high-rise and low-density* blocks. The inhabitants, belong to classifications III, are low the flexibility for environment. This block has been highly developed, and has high store occupancy rate.

b) The district of classification IV

There is no alley space and in this district, though they have some elements (roads or large buildings) dividing neighborhoods' region into parts. This classification is observed in such a block which in the process of spatial structure changes from *low- rise and high-density* to *high-rise and low-density*. The inhabitants who live in the district of this classification have low interest to the environment. Historical communities are lost by the redevelopment that breaks the relation of the region.

c) The district of classification V

There are alley spaces that form the edges of the district. This district adjoins developed grounds such as building construction, and the boundary with the *high-rise and low-density* block has remained as an alley space. This classification is observed in the block where spatial structure has changed from *low-rise and high-density* to *high-rise and low-density* as well as classification IV, though the relationship of the block is remained. The inhabitants of this classification have high flexibility for environment, and the residence permanency is high. The neighborhood regions have kept their relationship, and inhabitants' life is open for the region space.

d) The districts of classification VI and VII

There are alley spaces in these districts, and the roads are the edges of the district. These classifications are observed in the *low-rise and high-density* blocks.

The inhabitants of classification VI have low interest to the environment, and the inhabitants of classification VII have high interest to the environment.

Conclusion

In Higashi-Ueno, the spatial structure has been changed intensely, such as construction of the building, etc. Therefore, the change of the environment mainly on the alley space is intense. By the influence of the change of the spatial structure, the neighborhoods' relationship in the historical region space was been lost, as well as the life and consciousness of the inhabitants. Comparing the block without the change of the spatial structure, it is proven that the change of the spatial structure affects life and consciousness of such inhabitant.

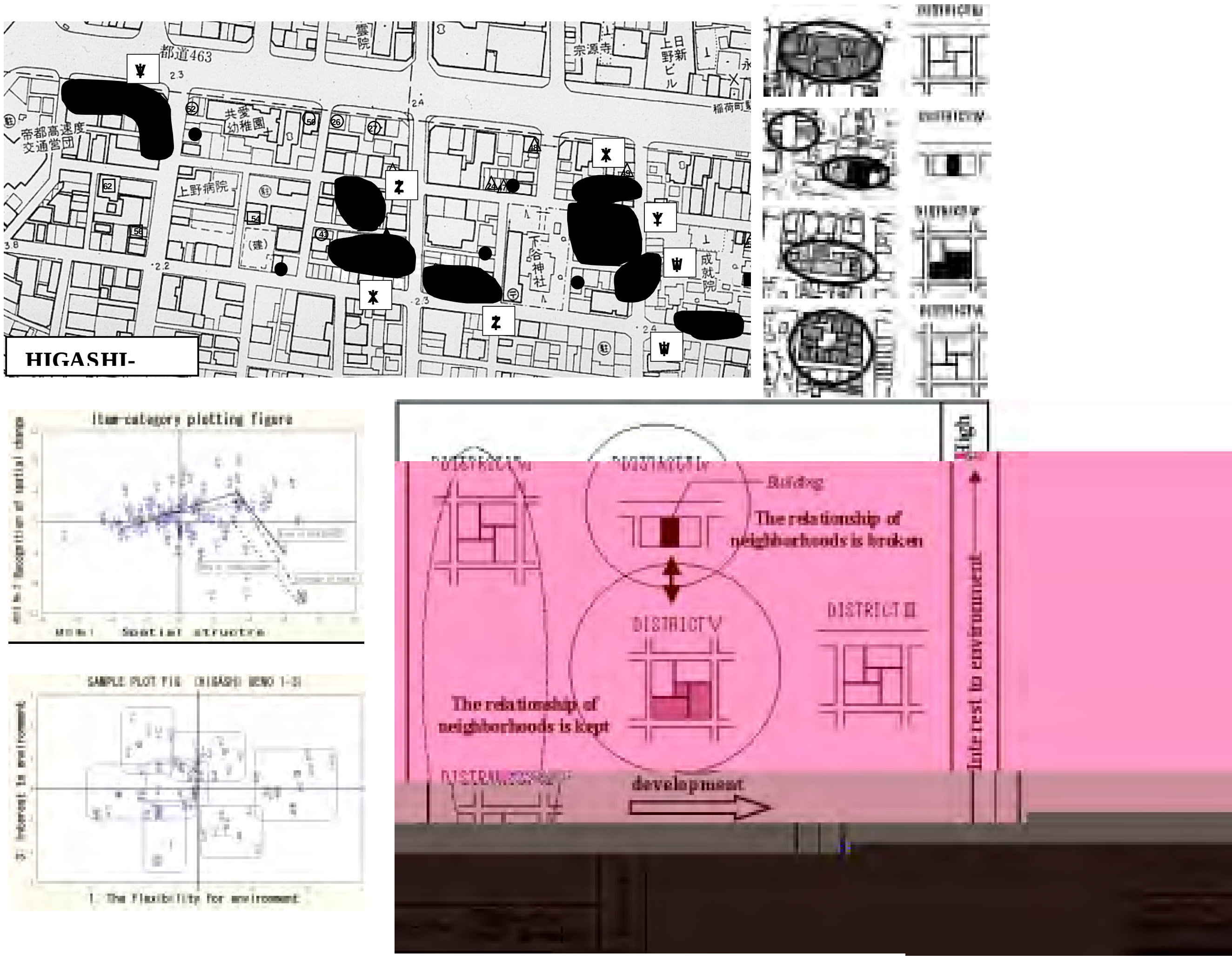


Fig3 Relationship between spatial structures and inhabitants (Higashi-Ueno)

4.2. Tsukiji region

In Tsukiji region, inhabitants classified in classification , , and are living in specific district. In the interpretation of factor axes of quantification , the first axis shows “The spatial structure and density” (correlation coefficient =0.464), the second axis shows “The recognition of spatial change ” (correlation coefficient =0.413), and the third axis shows “The flexibility for environment” (correlation coefficient =0.404).

a) The district of classification

There are alley spaces in this district in the *low-rise and high-density* blocks. The inhabitants have average flexibility for environment. Two different spatial elements (historical dwellings and large urban buildings) are in a same block, and they break the relation of the region. In this region, inhabitants have high recognition of spatial change.

b) The district of classification

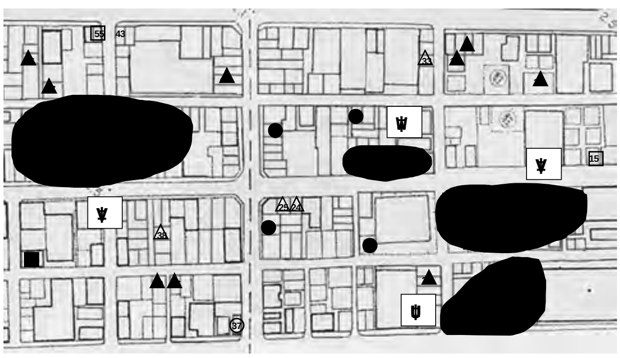
There is alley space in this district, and the roads are the edges of the district. This classification is observed in the *high-rise and low-density* block. The inhabitants have average recognition of spatial change and flexibility for environment in the Tsukiji region.

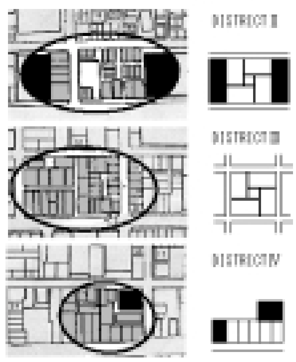
c) The district of classification

In this district, there is no alley space, and large buildings are constructed, but relation of region is not broken. This classification is observed in the *high-rise and low-density* block. The inhabitants have high flexibility for environment, and keep historical relation with neighborhoods. And, the inhabitants have low recognition of spatial change, because of the continuity for the region space is kept.

Conclusion

In Tsukiji region, spatial structure has been changed intensely, as well as Higashi-Ueno region. In this region, behavior (activities of life and consciousness) of the inhabitants is dependent on the relationship of the neighborhood regions.





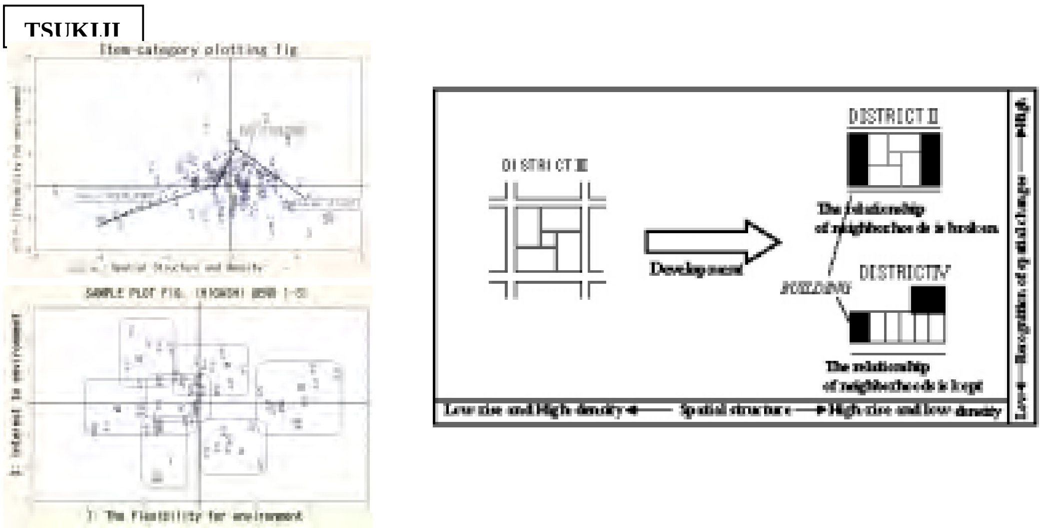


Fig4 Relationship between spatial structures
and inhabitants (TSUKIJI)

4.3. Tsukuda region

In Tsukuda region, the inhabitants, living in specific district, are classified in classification , , and . In the interpretation of factor axes of quantification , the first axis shows "The interest to environment" (correlation coefficient =0.446), the second axis shows "The residence permanency" (correlation coefficient =0.413), and the third axis shows "The expectation for multiple dwellings" (correlation coefficient =0.404).

a) The district of classification

There are alley spaces in this district, and it have avenue in the front side. The inhabitants have high interest to the environment, and low residence permanency and expectation for multiple dwellings. In this district, inhabitants recognized the changes of the regional environment, but main part of their life is not in the avenue but in the alley space.

b) The district of classification

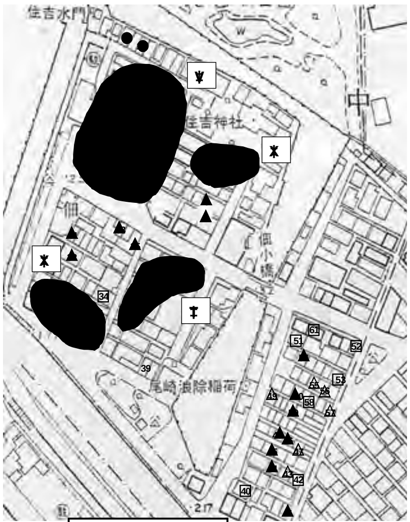
There are alley spaces in this district, and the roads are the edges of the district. The inhabitants have high expectation for multiple dwellings. This spatial structure is the main and historical in Tsukuda region. The inhabitants are satisfied with their present living environment, and the neighborhoods' relations are extending for other districts.

c) The district of classification

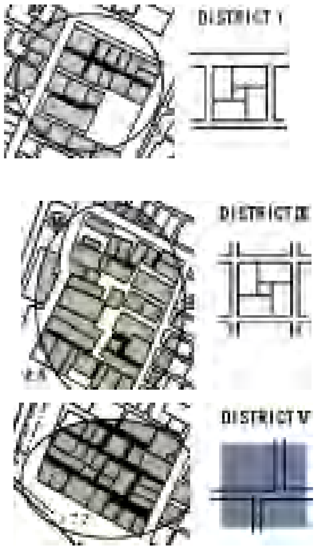
There are alley spaces in this district, and the roads are not the edges of the district. The inhabitants have high residence permanency and expectation for multiple dwellings. All the life of inhabitants is concluded in alley space, so their interests to environment are not extend to other districts. Because of this tendency, inhabitants feel their district unsociable.

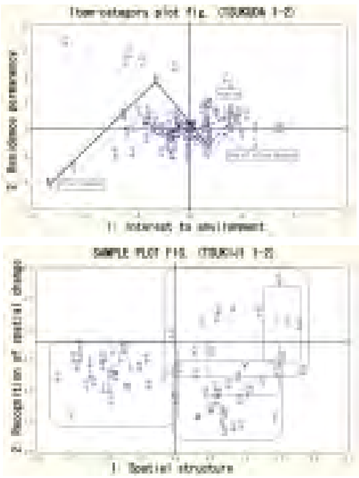
Conclusion

In Tsukuda region has the region with historical spatial structure construction of the large buildings unlike Higashi-Ueno region and Tsukiji region. In a whole region, stabilized and historical spatial structure is still kept. In this region, the activity of inhabitants' life begins to spread to the alley space. The classifications of the inhabitants are influenced more strongly by change of spatial structure than inhabitants' lifestyle.



TSUKUDA





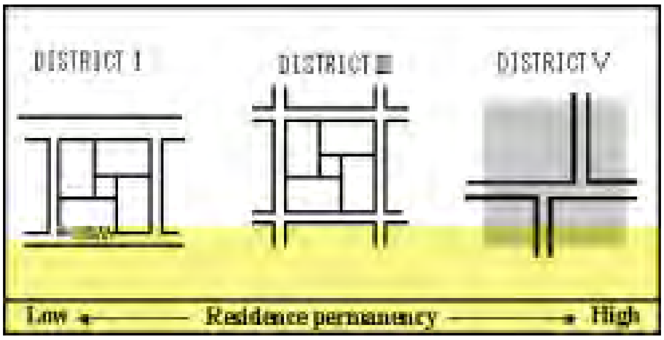


Fig5 Relationship between spatial structures and inhabitants (TSUKUDA)

4.4. Tsukishima region

In the Tsukishima region, inhabitants who classified in classification , and , are living in specific district. In the interpretation of factor axes of quantification , the first axis shows "The spatial structure and density" (correlation coefficient =0.427), the second axis shows "The residence permanency" (correlation coefficient =0.404), and the third axis shows "The interest to environment" (correlation coefficient =0.390).

a) The district of classification V

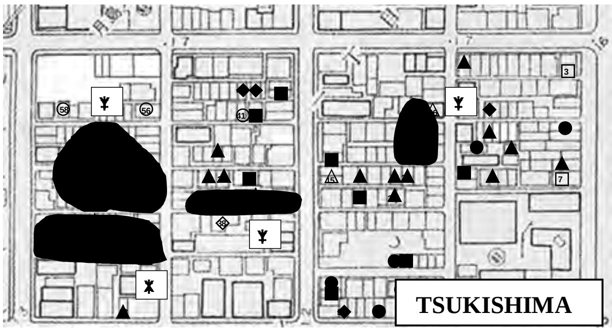
There are alley spaces in this district, and it has the avenue in the front and back street as edges. This district is in the block where its spatial structure in the process of changing from *low-rise and high-density* to *high-rise and low-density*. The inhabitants have high residence permanency and interests to environment. The inhabitants recognize changes of environment of neighborhood region with changes of physical space or landscape more than their activity of life. They have positive attitude to change their living environment better. This attitude is due to their situation that they must adapt to new regional environment.

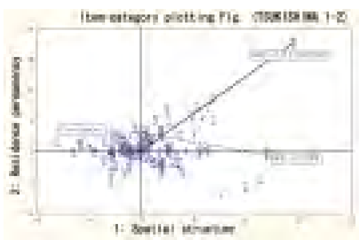
b) The district of classification VI

There are alley spaces in this district, and the roads are not edges of the district. There are the blocks, which have the historical spatial structure. The inhabitants have high interest to the environment. The activities of life in the regional space are done mainly in alley space.

Conclusion

Tsukishima region has the historical spatial structure without carrying out construction of the building, like Tsukuda region. In a whole region, stabilized and historical spatial structure is still kept. The activities of inhabitants' life begin to spread to the alley space. The classifications of the inhabitant are influenced more strongly by change of spatial structure than inhabitants' lifestyle.





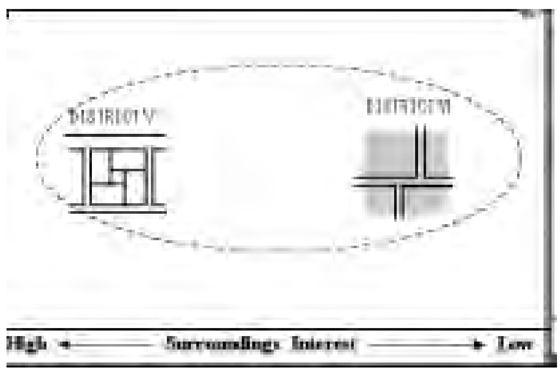


Fig6 Relationship between spatial structures and inhabitants

5. CONCLUSION

The shape of neighborhood region has great effect with inhabitants' living activities and consciousness. The changes of spatial structure decide inhabitants' behavior rather than presented physical forms.

In the historical urban district in Tokyo, developments such as the construction of the building are carried out, and the spatial structure of the regional space has been changed. In such regions where spatial structure has been changed intensely, the classifications of inhabitants are under the influence of spatial structure. On the other hand, in the region where spatial structure has not been changed so much, the classifications of inhabitants are effected by their life activities. The relationship between regions affects consciousness of inhabitants, in case it is broken off, inhabitants fell alley space unsociable. The inhabitants who are satisfied with present living environment have low interests to the environment.

Analysis of the relation between the spatial structures and classifications of inhabitant shows the conditions of historical urban dwellings in Tokyo. The most important thing is spatial relationship in neighborhood region, and it affects strongly on consciousness and life activity of inhabitants.

Footnotes

1. Quantification : The purpose of this analysis is to classify samples from relationship between categories (characteristic items) and the samples. The result is shows as scatter diagrams.

   The procedure of the analysis is

   1) the relationship between categories are analysed,
   2) from the result, reveal latent common factor showed as axes of scatter diagrams (Item category plotting fig.) .
   3) By the possession of samples on these scatter diagrams (Sample plotting fig.), they are classified, and their characteristics are grasped.
2. District: in this paper it means "an area of homogeneous character, recognized by clues which are continuous throughout the district and discontinuous elsewhere." (Kevin Lynch, The Image of the City, pp.103.)

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

RELATION OF TOURISM TO CULTURAL HERITAGE SUSTAINABILITY

M. F. Drdácký
Academy of Sciences of the Czech Republic, ITAM-ARCCHIP, Prague,
Czech Republic

ABSTRACT

Paper analyses relation of mass tourism to cultural heritage stability based on knowledge taken from Central European experience. It presents a sample of the contemporary situation in the Czech Republic with the relevant economy consequences. There are studied impacts and risks generated by a high attendance of visitors to cultural monuments as well as risks to visitors and their reduction possibilities. The contribution also deals with the role of cultural tourism in social and economic stability of cultural heritage sites and the needs of tourism concerning development planning. Conclusion contains some recommendations for creation of tourism management policy.

1. INTRODUCTION

At the threshold of this century tourism reached immense proportions and became a mass means of recreation. Tourism for recreation and entertainment greatly outnumbers so called cultural tourism whose focus is historical and cultural heritage monuments. Nevertheless, it is expected that the latter type of tourism will develop very quickly and might almost reach the volume of recreational travel.

Central and Eastern Europe are not typically disposed towards the ideal conditions of recreational tourism. Of course, a great amount of well preserved cultural monuments and the density of historical cities attracts many cultural tourists. In past years cultural tourism was often strongly combined with shopping, which is one of the hidden aspects of tourism. Even today a visit to the Czech Republic presents a convenient possibility for the cheaper purchase of quality crystal or other goods, and thus is a good destination for many tourists. On the other hand, we do not observe any heavy increase of cultural tourism in the country recently and the number of visitors did not overcome historical data.

2. SITUATION IN SMALL CZECH CULTURAL HERITAGE SITES

It is very difficult to forecast development of tourism in Central European countries because there is little experience with such a situation. From the recent data it follows that increase in number of tourists will be rather dependent on Czech citizens than on foreigners, on accompanying cultural or recreational opportunities and, naturally, on economic situation in the country. As examples of this contemporary development some results of recent investigations are presented.

In summer 2000, a questionnaire campaign was completed in Telč by students of the Telč College for Travel and Tourism. Telč is one of the World Heritage Cities listed by UNESCO and protected as a Czech Town Reserve. From this campaign it is clearly seen that the majority of 4458 respondents were cultural tourists, Fig. 1, and mostly Czech citizens from the whole country, Fig. 2. It has been further discovered that it is the site, i.e. the renaissance square, which attracts the tourists more than a famous renaissance Telč Castle, the National Monument.

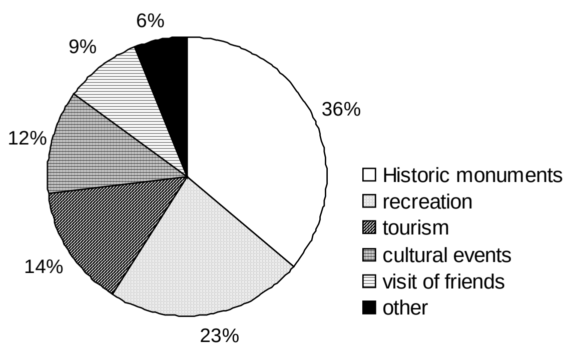


Figure 1
Reason for visiting Telč (summer 2000 questionnaire campaign)

The number of visitors in the Telč Castle oscillates about 90 000 persons/year and the site thus belongs to the group of Czech castles of the highest attendance. For comparison a development diagram from a small Roštejn Castle, (8 km distant from Telč), is presented in the Fig. 3. Here is apparent a constant increasing rate in visitors number during the last years, which is related to increase

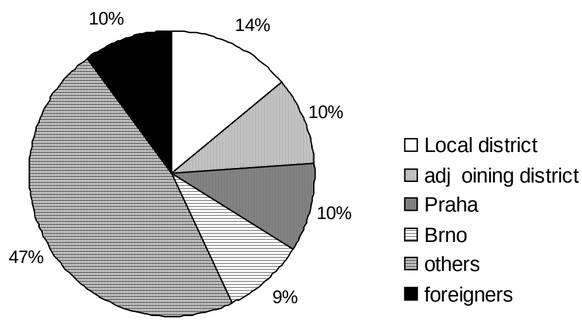
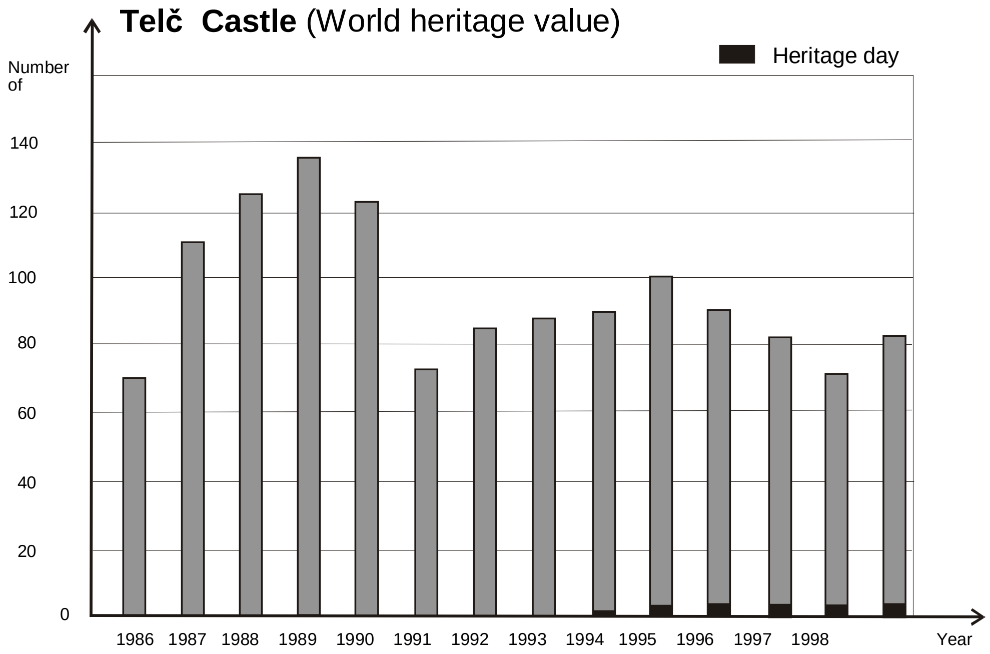


Figure 2
Citizenship of visitors

of biking activities for which this castle is a pleasant goal of rides. In any case, taking into account an estimated number of visitors in the Telč City being roughly 200 000 persons/year, those figures are well beyond the typical visitors numbers in countries where cultural tourism may be combined with mass recreation activities. This fact must be considered for evaluation of benefits from tourism in small Czech cities.



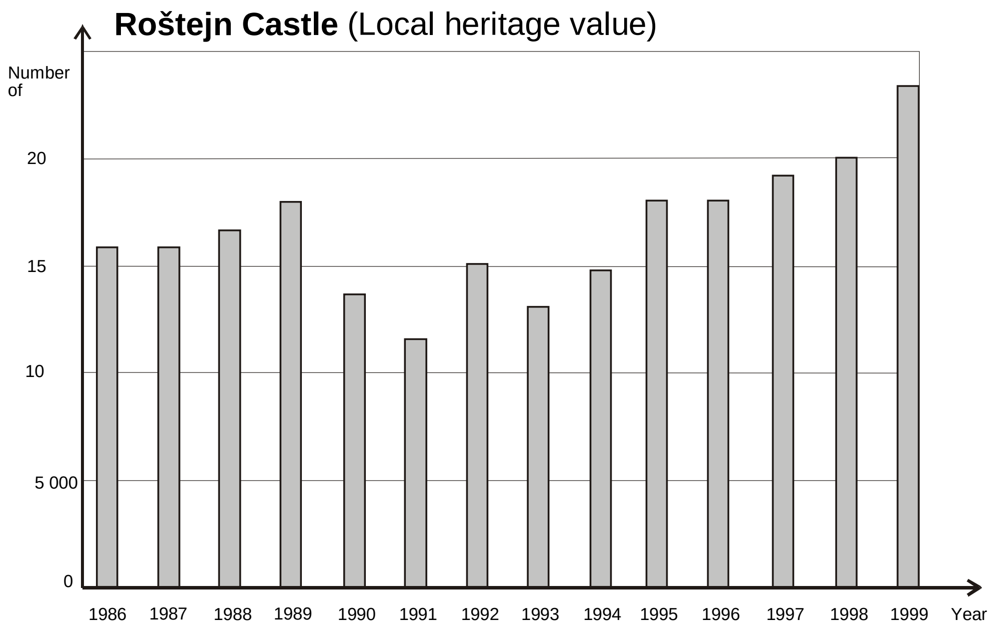


Figure 3
Development of attendance of two types of Czech castles

3. INCOME / COSTS RELATION

National income from tourism represents also in the Czech Republic a very substantial percentage in the NGP. Nevertheless the benefits directly associated with individual cultural monuments are not sufficient to balance maintenance and operational costs. The ratio of income generated by the Telč Castle, (mostly from the entrance and rental fees), to the maintenance and operational costs is shown in the Fig. 4. The State subventions increase faster than local direct income in which, moreover, the important part yields from use of the Castle for historic movies production, which occasionally limits its availability for visitors.

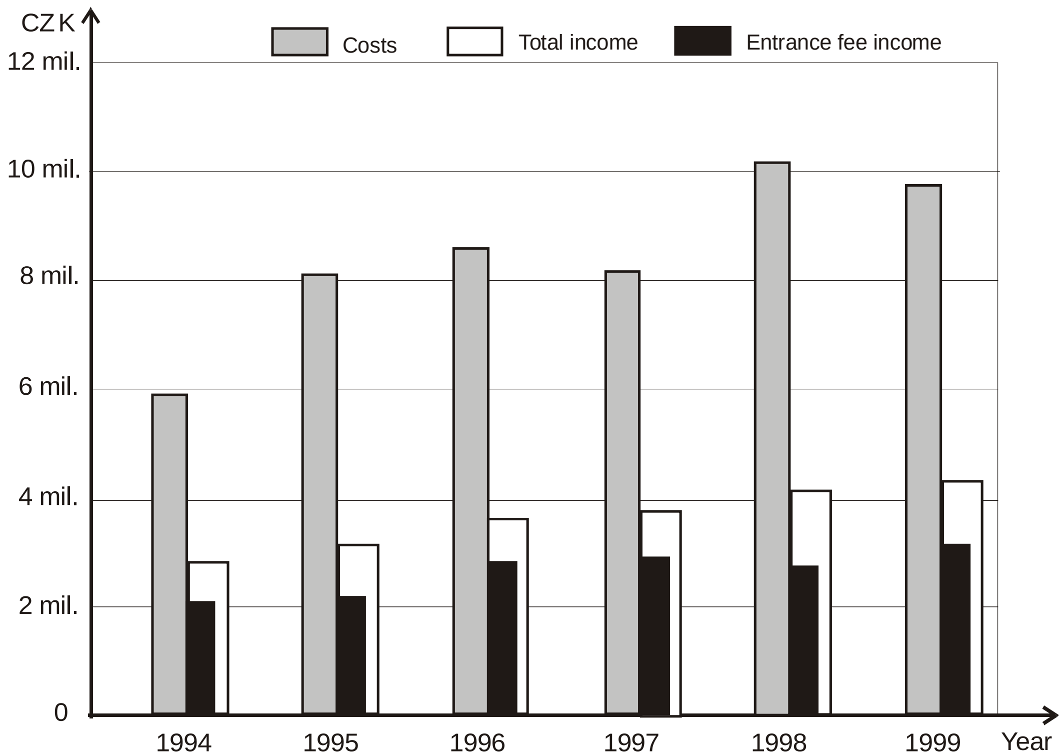


Figure 4
Income / costs ratio development it the Telč castle

4. IMPACT AND RISKS OF A HIGH ATTENDANCE ON CULTURAL HERITAGE OBJECTS

4.1. Impacts and risks generated by visitors

It is practical to distinguish four groups of impacts and risks generated by visitors.

The ***environmental aspects*** include namely ***moisture and temperature changes, increase of dust deposits and radiation (light)***. They may cause mechanical damages due to constraint volumetric changes, create environment suitable for biological or electrochemical deterioration and together with dust deposits may intensify staining. Light attacks mainly stability of colours.

Movement of visitors is accompanied with an ***increased mechanical wear*** of historic structures, which decreases their life cycles. Many historic objects have to suffer from everyday increase of loading and sometimes even overloading. Fortunately, those structures are mostly sufficiently robust and sustain the above described situations without critical damages. Dynamic action may be a problem for wood joist ceilings over long spans. Frequent damages on floors are caused from shoe heels and on walls due to kicked off corners.

Unfortunately, ***intentional damage*** cannot be omitted. Also cultural heritage objects are targets of vandalism and terrorist actions. The former is represented namely by graffiti movement as well as by "souvenirism", i.e. a desire to transport a particle or even a part of a cultural heritage object home. Those tourists do not differ very much from professional thiefs who belong to this group, too.

Considerable damages are caused also by ***ignorance and negligence*** of tourists, especially by groups of youth. Typical problems are associated with soiling by rests of foodstuffs, cigarettes and chewing gums.

4.2. Reduction of risks generated by visitors

According to the above-mentioned types of impact relevant reduction measures may be applied.

First of all, the ***number of daily visitors*** must be ***limited***. In the Telč Castle, e.g. the maximum daily capacity of about 1200 visitors has been determined. Only guided visits are offered and, according to the local conditions, there are 40-50 visitors in one group on the trail A and only 25 for the circuit B, where the interior is more fragile. The regulation is ensured by means of time entrance tickets.

Guided visits are the best tool for ***control of movement and behaviour of visitors*** in the cultural heritage environment. They enable an easy supervision, regulation of velocity of movement as well as warning of visitors.

Risks from mechanical wear as well as from intentional damages can be reduced by ***prevention of historic fabric from close contact with harmful environment or visitors***. Sensitive materials must be appropriately permanently or temporarily covered, light should be reduced and its intensity kept under recommended levels (50 lux). Dust and cloth fibre deposits decrease rapidly with the increase of distance of moving visitors from exposed objects which should be covered during out-of-season periods.

Soiling can be effectively reduced by limitations in visits during climatically unsuitable periods, (rainy spring and autumn months), as well as by ***education of visitors***.

4.3. Impact and risks to visitors

The high attendance of cultural heritage sites may generate two groups of problems in connection with action toward the visitors. The first is associated with ***quality of presentation and interpretation*** of cultural heritage issues. There appears again a question of guided visits in contradistinction to free, (museum-type), visits. The former due to direct contacts with guides gives to visitors a possibility to obtain deeper and qualified explanations of points of individual interests. Of course, there is still a danger of misinterpretations and mystery stories presented by some guides in order to increase an attractiveness of a place.

However, the visitors of cultural heritage objects meet a real danger of ***injuries*** mostly due to ***falls on stairs or floor level changes*** especially in dark rooms. Fortunately, the percentage of those cases is rather low reaching a fraction of per mile.

Another category of risks yields from ***inappropriate equipment*** of historic objects, e.g. missing handrails and elevators. Insufficient are very often also facilities – technical as well as exposition - for handicapped visitors. Some visitors may be victims of an ***overestimation of their own capability***, which is a more frequent case at natural or archaeological sites, but also in high towers where are recorded heart attacks after climbing the steps.

4.4. Reduction of risks to visitors

The above mention impact and risks can be improved or reduce by means of ***passive (technical) measures*** through installation of railing, elevators, providing caution paints, (if possible), and warning tables.

Here it seems again very useful to utilise ***active measures***, namely voice explanations and warning by guides who are properly trained and educated.

5. ROLE OF CULTURAL HERITAGE ISSUES IN SMALL SITES WITH RESPECT TO TOURISM

5.1. Attractiveness of sites with rich cultural heritage features

Historic places are enormously attractive for visitors as well as for their inhabitants. The roots we can find not only in their monuments but first of all in their ***human symbolic values***, [1].

One of the basic symbols of historic towns seems to be a symbol of ***home***, a symbol of a ***safe place for natural life***. It contains not only space aspects of the context between site and environment but also natural life aspects, rhythm of life being the most valuable. From the miracle of a waking morning, through the busy or celebrated day and calm evening till a quiet and dark night.

The symbol of home and natural place for life is strongly felt not only by the town citizens but also by the town visitors and this feeling helps to protect our heritage, because it is understood to be our ***common wealth***.

However, there remains a difference between the citizens and the visitors in a historic town, and this fact must not be changed, because it is one of our barriers against the aggressive internationalisation, especially the tourism industry. The visitors or guests understand this symbol in a general sense. For the citizens it has a very actual and real meaning, i.e. the home with developed relations and communications network between the children, neighbours, citizens and the town governors, citizens and tourists, with relations of differential polarity and content. Here the historic town becomes a symbol of a ***consentient peace life***.

5.2. Risks for citizens and problems in cultural heritage sites

Only few places succeeded to conserve this intimacy of the historic town life. Not many prevented the place from becoming a theater stage illumination in order to maintain a harmony with the space intimacy. Even though the archaic approach has a substantial mediating influence in directing the mankind to ecological behaviour and it is believed that one day will be restored, today the tourism calls rather for night illumination and entertainment.

Thus the first risk from tourism can be seen in a danger of breaking historic continuity, context and memory. Tourism is thus negatively marking the ***stability*** of conditions necessary for the protection of natural life and tradition in the historical core of the town. Private and personal profit is for the entrepreneurial citizens the only goal aimed at with no regard to protection of public interest. This is evident in the care for historical monuments and also in the approach to the development of tourism which gradually destroys the natural functions in the historical town and transforms it in its first phase into a cheap attraction; usually represented by markets, tourist shops, festivals and by the theatrical illumination of monuments. All this securely drives out of town the natural life, which leads to the contentment of businessmen and some inhabitants who don't live in the historical core. The historical part of town thus becomes a place and an ***object of tourist consumption***.

An artificial renaissance of historical operation including historical requisites takes place following this, leading to the creation of a distorted model of life in the historical core. This illusion can be so good as to delude a tourist from noticing the deception, especially when coming from a different cultural region. A citizen of the town on the other hand knows the truth and the historical centre is dead for him. This situation vulgarises citizens' approach to monuments and brings a number of other problems particularly out of season when historical parts of town are continuously empty, [2].

Tourism has a very strong ***impact on infrastructure*** in historic sites. It demands a special infrastructure which in other areas of a small town's life is not useable. Such an infrastructure stays idle for a majority of the year in cases of seasonal tourism and requires costly maintenance. In question is mainly the capacity for ***room and board***. A bigger problem we encounter is ***parking*** and perhaps the worst consequence of tourism for the infrastructure is the remarkable change in the composition of the ***business net*** in the historical core. Tourist shops gradually drive out of the centre an assortment of goods necessary for the inhabitants and inhibit the year round liveliness of the business spaces.

5.3. Integration of cultural heritage into the life of society

Cultural heritage issues and their utilisation for tourism have, of course, many positive consequences, too. As we have mentioned above, it increases the ***attractiveness*** of the place, it improves conditions for ***cultural life*** and enriches that life by many activities and events. ***Socio-economic impact*** can be reasonably influenced by means of proper development planning and management of tourism, which is based on integration of cultural heritage into the life of society.

6. TOURISM AND DEVELOPMENT OF CULTURAL HERITAGE SITES (CHS)

It is possible to manage and lead a historical town to permanent livability only with a complete knowledge of the ***town's interior development potential for tourism*** and with a well ***prepared strategy***. In regard to this notion it is necessary to support such activities which ***satisfy the needs of tourists*** while demanding the ***participation of inhabitants***. For example: In Telč we support a creation of so-called "distributed hotel", which means small accommodation possibilities in historical houses on the square. This is an effective use of free spaces serviced by owners who live in these houses. This arrangement is convenient for the city also from the perspective of income due to the tax system in place. Private capacities are completed by a few small hotels (around 25 beds) with dining possibilities. This helps to preserve life in the town core and as well offers to tourists an attractive service which enables a high concentration without disturbing the existing scale and rhythm of the towns life.

In addition to the ***stabilisation of natural life*** in CHS, it is necessary to ***balance infrastructure*** at least in i) composition of services and shops in historic areas and ii) special needs for transport. In regard to parking lots in Telč, the preferred policy is their wide dispersion within the area of town, while restraining their size. Newly constructed lots are designed in the form of a park of mature trees. The spatially convenient solution of underground parking garages is financially unbearable for the city and its need is so far unappreciated.

The development potential "map" as well as the created strategy is then reflected in land use plans and ***urban planning documents***.

7. TOURISM MANAGEMENT POLICY RECOMMENDATION

In conclusion several points should be stressed, which would help to sustainability of tourism in cultural heritage places, [3].

7.1. Targeted and interdisciplinary research

Tourism brings in problems which concern many spheres of cultural heritage site preservation. Many consequences are still not well known, some experienced only in a narrow field. This is why we consider it to be necessary to carry out special inquiries and focused research in order to be able to define these problems complexly and find an appropriate solution optimal for a wide range of social, economic, technical, cultural and political viewpoints. In many cases the problems of tourism are still being dealt with monothematically and by amateurs.

7.2. Tourism strategy on all territorial levels

Strategy of tourist management ought to be prepared not only on the level of towns, regions and nations, but as well on the international level. Travel and tourism has become a profitable industry and travel agencies operate in a space with no borders and often with out consideration for local culture. What is thus called for on international level is a partner protecting the global interests of cultural heritage.

7.3. Scaling and dispersion on all levels

The general policy, which should be kept in cultural heritage regions, is to prevent the creation of mass tourism centres, villages or enormous hotels. The activities are aimed at being scaled according to the sustainable capacity of the places of interest. In the Czech Republic, there is an effort to disperse cultural tourists onto a larger area and offer them places to visit other than monuments e.g. inscribed onto the list of UNESCO.

7.4. Reflection of tourism needs in urban planning

As it has been already mentioned all planning documents have to contain measures reflecting needs of sustainable tourism in territories with important cultural heritage characteristics.

7.5. Training of professionals

Another necessity for a successful tourist management are educated experts. Starting from the year 1997 the city of Telč has a specialised college aimed at travel and tourism. Similar educational programs might be installed at high schools and colleges in a majority of important historic cities and for their creation would be useful to collaborate within the framework of international associations or bodies, e.g. UNESCO, OWHC or the Council of Europe. It is not enough to organise conferences and publish declarations; it is necessary to prepare tools for application of appropriate tourist management in practice.

7.6. Quality instead of quantity in cultural heritage tourism

It is believed that social and economy impact as well as sustainability of cultural heritage tourism might be substantially improved by seeking for quality measures rather than by a continuous increase of number of visitors of cultural heritage sites. There is further necessary to find a balance between modern information technology possibilities and simple human personal experience in learning and enjoying cultural heritage.

8. ACKNOWLEDGEMENT

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THE PROCESS OF TOURISM DEVELOPMENT AND THE INFLUENCE OF TOURISM ON THE HISTORIC HERITAGE IN LIJIANG, YUNNAN, CHINA

T. Yamamura, T. Kidokoro and T. Onishi
Department of Urban Engineering, The University of Tokyo, Tokyo, Japan

ABSTRACT

In this study, we have examined the present state of use, type of user, and ownership of historic buildings in the old town of Lijiang, China, in order to investigate the process of social transformation. Along the progress of tourism development, the uses of historic buildings originally built as residences by the *Naxis*, the indigenous ethnic group of Lijiang, have drastically changed. Today over 50% of building units are in commercial use for tourism. Furthermore, about 40% of the household users are temporary residents and over 90% of them have moved to Lijiang in and after 1995. The large majority of them rent rooms from indigenous owners and is running shops or restaurants for tourists. These findings suggest that the minority's community and their culture have been rapidly changing along tourism development.

1. INTRODUCTION

In the People's Republic of China, the conservation of historic districts has been in effect based on "the Historic-Cultural Cities Conservation System", which have yielded certain results so far. However, the tourism development, the change of housing-market system and family-registration system have caused rapid social transformation in the historic districts, such as rental and commercialization of historic buildings, and population inflow into the conservation areas. In fact, a lot of local governments with historic districts have difficulties in finding good means of adjusting various conflicts between conservation and problems caused by social transformation and tourism development. Under these present circumstances, it is important to grasp the shortcomings of the existing conservation systems and to take some actions to improve them immediately.

There have been several studies on the conservation systems for historic districts in China (Ye et al. 1997 [5], Yuan 1995 [6], etc.). However, as previous research in this field has been restricted to the frameworks of the conservation systems and their application, relatively little attention has been paid to the actual situation of conservation and the influence of tourism development upon the historic buildings and the local society.

The objective of this study is to clarify the process of social transformation in historic cities influenced by tourism development. We have chosen the historic district in Lijiang, Yunnan, China as the subject of our case study. The historic district of Lijiang, called “the old town”, was registered as “World Heritage” in 1997 by UNESCO, and also designated for a “national historic-cultural city” in 1986 by the central government of China. Because the designation made Lijiang famous both in China and abroad, the tourism industry has been growing rapidly to make Lijiang a notable sightseeing spot.

2. PROCEDURE

In order to investigate the process of social transformation in the old town, we have examined the present state of use, type of user, and ownership of historic buildings. The sample consists of all the first-floor rooms of roadside buildings located in the central district of the old town (figure 1). This district, extending approximately 230m (north and south) and 200m (east and west) large, has not only been the center of the old town historically and geographically, but also the core of the highest-priority conservation area (56.775ha) designated in the detail conservation plan (Government of Lijiang county 1997 [2]). In addition, the plan places restrictions on the outward appearances and materials of buildings in this conservation area, so that the extension and remodeling of architecture except the interior is strictly limited and building new architecture is generally prohibited.

Now in the old town, it is very usual that one house originally built for one household has been divided into some parts by more than one user, while it is also common that a terraced house originally partitioned into some units has become one big unit by removing the walls between units. Therefore we have defined the ways of counting houses and their users as follows:

Unit: one unit denotes one part of buildings. It is physically separated from next rooms or houses and at the same time used by one independent household (including individual), shop, or organization. Therefore, when more than one household or organization are using one building, each part, which is used by one household, is counted as one unit.

User: one user denotes one household living in each unit when the unit is for residential use. If it is in commercial use such as a shop or an office, the term will imply the manager, shopkeeper, or organization. Therefore the number of units and the number of users will be identical in principle.

For the objective mentioned above, the field survey and interviews with the users were conducted from May to June 2000. First of all, we checked if each room of the first floor in every roadside building was occupied or vacant. It turned out that the sample comprised 366 units and 353 users in 186 buildings (Table 1). (Because 13 units were vacant, the number of users was less than that of units.) Then the present state of use for each unit was identified. At the same time, in order to clarify the categories of users and the ownership, the interviews were conducted with all the 353 users. The interviews were carried out in Mandarin (standard Chinese) and each interview was based on a series of prepared questions.

Table 1. Architectural Categories of the Sample

Ground plan of building	Number of buildings				Number of units		
	One-storied	Two-storied	Three-storied	Total	Occupied	Vacant	Total
Terrace style	21	137	3	161	322	11	333
Courtyard style	1	23	0	24	30	2	32
Other*	1	0	0	1	1	0	1
Overall	23	160	3	**186**	353	13	**366**

* Other: a public restroom

3. RESULTS AND DISCUSSION

3.1. Present State of Use of Units

Figure 1 and Table 2 show the present state of use of units in the first floor of roadside buildings. As can be seen from the data in table 2, 78.1% of units is identified as commercial use as opposed to 16.7% as residential-only use. Moreover, there are almost twice as many commercial units for tourists as those for local people. Overall, the table appears to suggest that this area have been commercialized especially for tourism. In fact, according to the historical record [1], there used to be a lot of shops in this area throughout 1930's, most of which were handling food and daily necessities for local people. However, it is not clear when commercial units for tourists began to increase, since the past statistics are not available in the central and local government.

Figure 2 provides the year of opening of all the existing commercial units for tourists. As can be seen, 176 out of 189 units (93.1%) have opened from 1995 onwards. Nevertheless, these findings should be treated with some caution, since the records showing their former-state of use are not available. Even so, there is a good possibility that commercial units for tourists began to increase around 1995, because the number of tourists and the tourism income has been rapidly increasing since 1995, as reported by the Tourism Bureau of Lijiang prefecture [3]. In addition, 10 out of 10 county officials have the same outlook about the history of tourism-based commercialization saying that, as far as they can remember, the increase of shops and restaurants for tourists in the old town started at that time (according to the interviews with 10 officials in the government of Lijiang County, conducted by the authors in 2000).

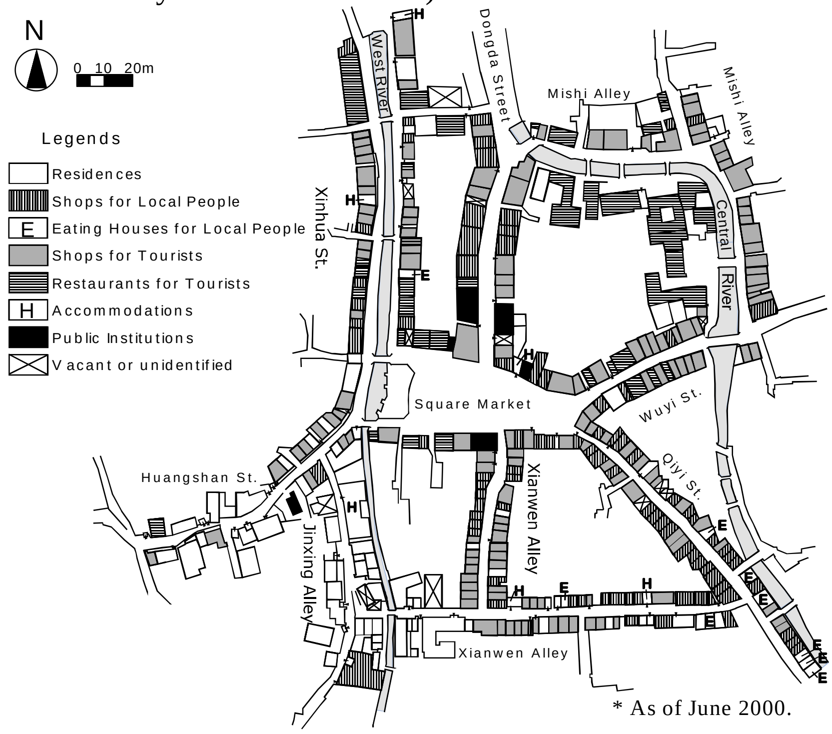

Figure 1. Present State of Use of Units

Table 2. Present State of Use of Units

Category of use of units*	Number of units	Percentage
Residential only	**61**	**16.7%**
Commercial	**286**	**78.1%**
For local people	97	26.5%
Shops[1]	88	24.0%
Eating places[2]	9	2.5%
For tourists	189	51.6%
Shops[3]	145	39.6%
Eating places[4]	38	10.4%
Accommodations[5]	6	1.6%
Public institutions	**6**	**1.6%**
Vacant or unidentified	**13**	**3.6%**
Overall	**366**	**100.0%**

*Only the units in the first floor of roadside buildings were identified.
[1]E.g., general store, clothing shop, barbershop
[2]E.g., local eating house
[3]E.g., souvenir shop
[4]E.g., restaurant, tearoom, bar
[5]E.g., guesthouse, inn
[6]E.g., bank, post office, branch office of the water department, public restroom

As a matter of fact, in order to develop Lijiang as an international tourist city, the local governments (Yunnan province and Lijiang county) have encouraged citizens of the old town to modernize and utilize the interior of their house buildings for tourism use since 1996 [7]. It is highly likely that this policy is one of the backgrounds of the rapid increase of the commercial units for tourists for these several years.

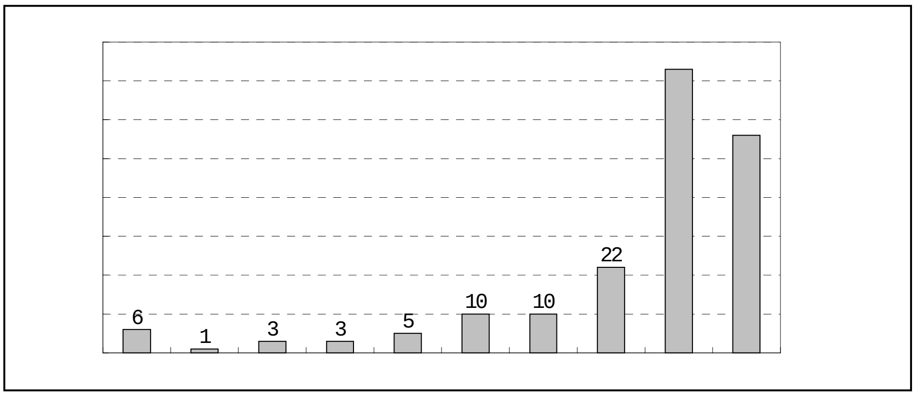

Figure 2. Year of Opening of All the Existing Commercial Units for Tourists

3.2. Categories of Users

Table 3 shows that over 90% of users are households (including individual users). Moreover, their residential-qualification categories and ethnic composition are shown in table 4 and Figure 3, respectively. As can be seen, 59.9% of households are permanent inhabitants who have permanent residential qualification, and they consist mainly of the *Naxis* (the indigenous *Naxi*-minorities). On the other hand, 39.5% of households are temporary residents who do not have permanent residential qualification but temporary one. They have immigrated into Lijiang from other provinces or counties, and over 80% of them are the *Hans*, the major ethnic group of China.

Table 3. Categories of Users

Category of User				**Total**
Households	Private corporations	Public institutions	Unidentified	
324 91.8%	20 5.7%	6 1.7%	3 0.8%	353 100.0%

According to Kanno (1996) [4], since the latter half of 1980's, "the Reform and Open Policy" and the relaxation of restrictions on population movements by the central government have caused a large-scale inflow of rural population into urban areas. As concerns social systems, the high percentage of temporary residents mainly consisting of the *Hans* shown in table 4 and figure 5 can be attributed to the liberalization of population movement by these policies.

Table 4. Residential-Qualification Categories of Household Users

Use of unit	**Category of Household**			**Total**
	Permanent inhabitants	Temporary residents	N.A.*	
Residential only	**55**	**4**	**2**	**61**
Commercial	**139**	**124**	**0**	**263**
For the local people	51	28	0	79
For tourists	88	96	0	184
Overall	**194** **59.9%**	**128** **39.5%**	**2** **0.6%**	**324** **100.0%**

*N.A.: No Answer

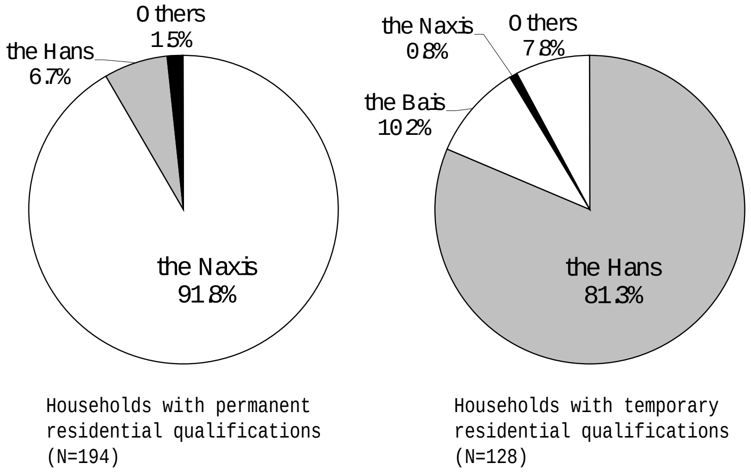

Figure 3. Ethnic Composition of Household Users

However, as shown in figure 4, 116 out of 128 temporary residents have moved to Lijiang in and after 1995. If we now compare figure 2 and 4, we can see that the year of opening of the commercial units for tourists and the year of moving in Lijiang of temporary residents indicate a very similar tendency. This can probably be accounted for by the correlation between the population inflow and the commercialization for tourism in the old town. In fact, as can be seen from the data in table 4, 124 out of 128 (96.9%) of the temporary residents are using their units for commerce, and 96 out of these commercial units (77.4%) are for tourists. In other words, the results indicate that many of the newcomers moved to Lijiang are apt to open shops or restaurants for tourists.

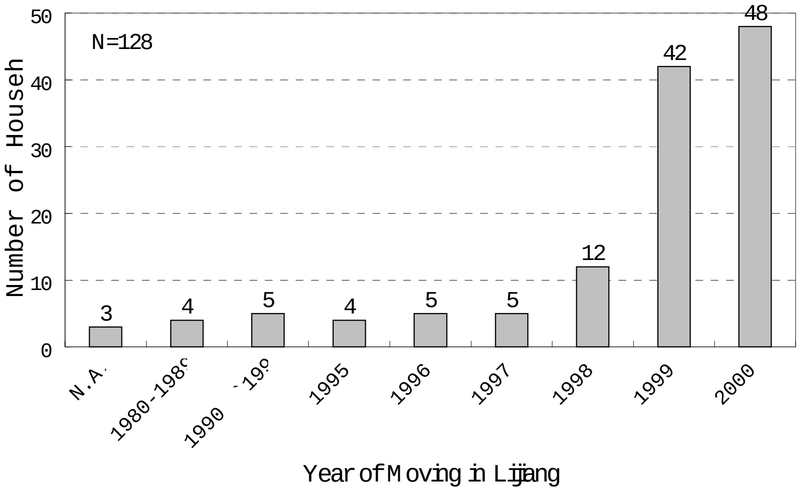

Figure 4. Year of Moving in Lijiang of Temporary Residents

3.3.Ownership of Units

Table 5 gives the ownership categories of 322 units for the households (except for N.A. in table 4). As can be seen, almost half of the permanent inhabitants are using their own houses and over 90% of the temporary residents are using rented houses. Moreover, most of the rented houses are in commercial use.

Table 5. Ownership Categories of 322 Units for Households

Category of household	**Category of use of units**	**Number of units**	**Ownership category**				
			User's property	Rented houses			
				Private owner	Public owner	Company owner	Unidentified, Others
Permanent inhabitants	Residential only	55	52	1	2	0	0
	Commercial for local people	51	13	22	10	6	0
	Commercial for tourists	88	29	39	17	2	1
	Sub-total	**194 100%**	**94 48.5%**	**62 32.0%**	**29 14.9%**	**8 4.1%**	**1 0.5%**
Temporary residents	Residential only	4	2	2	0	0	0
	Commercial For local people	28	0	18	9	0	1
	Commercial for tourists	96	2	60	23	6	5
	Sub-total	**128 100%**	**4 3.1%**	**80 62.5%**	**32 25.0%**	**6 4.7%**	**6 4.7%**
Overall		**322 100%**	**98 30.4%**	**142 44.1%**	**61 18.9%**	**14 4.3%**	**7 2.2%**

Overall, the results seem to suggest that the existence of the rental-house market mainly under private management enables the high percentage of opening shops and restaurants for tourists by newcomers. In fact, the opening of the rental-house market was a consequence of the reform of a real-estate market system by the central government from 1980's onward, and today this kind of social phenomenon can widely be seen all over the mainland China.

On the other hand, table 6 shows the ethnic composition of the owners of 142 private rented units and their place of residence. As can be seen, 140 out of 142 owners are the *Naxis*. In addition, 44.4% of them live in the old town, while 33.1% of them in the new town that lies next to the old town. The new town has been constructed since 1985 in order to improve the standard of housing, because the stagnation of the housing policy until 1980 had caused a serious housing shortage and a deterioration of the housing standard in the old town. Moreover, since the designation of Lijiang as a national historic-cultural city by the central government in 1986, in order to conserve the old town, the local government has adopted a density control policy to the old town. Thus, it is also placed as one of the important motivations of the new town construction to decrease population and architecture density in the old town. Under these circumstances, inhabitants who demanded more modern and spacious housing commenced purchasing ready-built houses in the new town or buying the right to use land in the new town to have their houses built. As a result, they have moved to the new town and started renting out their former houses (or rooms) in the old town to newcomers.

Table 6. Ethnic Composition of Private Owners and Their Place of Residence

Place of residence	**Number of owners**			**Percentage**
	The *Naxis*	**The *Hans***	**Total**	
Lijiang county				
Old town	61	2	63	44.4%
New town	47	0	47	33.1%
Others	3	0	3	2.1%
Sub-total	**111**	**2**	**113**	**79.6%**
Other areas in Yunnan province	**6**	**0**	**6**	**4.2%**
N.A.* , Others	**23**	**0**	**23**	**16.2%**
Overall	**140**	**2**	**142**	**100.0%**

*Some tenants don't know where their owners live.

4. CONCLUSIONS

Our survey demonstrates social phenomena that have taken place in the old town of Lijiang, from three angles concerning buildings: present state of use, categories of users, and ownership. The results can be concluded as follows:

1. The majority of units (51.6%) are in commercial use for tourists and 93.1% of them have opened in and after 1995. Furthermore, the year of 1995 almost corresponds to the time when the local government adopted a tourism-development policy and the tourists started rapidly increasing in number.
2. About 40% of the household users are temporary residents and over 90% of them have moved to Lijiang in and after 1995. In addition, 96.9% of temporary residents are using their units for commerce, and 77.4% of them are for tourists.
3. Over 90% of the temporary residents are using rented houses and the majority of their owners are the *Naxis*. On the other hand, approximately 30% of these *Naxi* owners live in the new town.

These overall findings indicate the process of tourism development and commercialization in the old town as follows:

a. In order to develop Lijiang as an international tourist city, the local governments have encouraged citizens of the old town to modernize and utilize the interior of their house buildings for tourism use since 1996. In addition, the number of tourists visiting Lijiang and the tourism income has been rapidly increasing since around 1995. In consequence, the commercial activities in Lijiang were vitalized and commercial use of buildings especially for tourism has increased.
b. Since the central government has improved real-estate market and the county government started to construct a new town, it has been possible for the indigenous inhabitants to move form the old town to the new town and rent their previous houses out to newcomers. Thus in Lijiang, the rental-house market has been formed and it started to supply housing to newcomers.
c. Furthermore, the serious housing shortage caused by the stagnation of the housing policy until 1980 and the strict restriction of the outward appearances and materials of buildings have also promoted the move of the old-town inhabitants to the new town.
d. Under these circumstances, the population mainly composed of the *Hans* has been moving to the old town from other areas and they are apt to run shops or restaurants for tourists.

On the whole, it is highly likely that the social systems and the central and local-government policy have strongly influenced the social transformation of Lijiang. Moreover, there is also a strong possibility that, as the tourism is developing, the minority's community and their culture will be deformed rapidly. In the existing regulations, there is no restriction on building use. Thus, further discussions not only on the conservation of architectures but also on the preservation of local culture and the controls of tourism development seems essential. To be concrete, it would be necessary for the local people, especially the indigenous Naxis, to play a vital role. They are expected to understand, interpret and respect their cultural heritage, both tangible and intangible, and take advantage of it in the tourism development. In addition, the local government would have to find the way to foster local-community's participation therein.

It should be noted, however, that this survey is limited to the condition of the first-floor rooms of roadside buildings located in the central area of the old town. Therefore, unfortunately, we are unable to determine from this data whether any social changes have occurred inside blocks or in other part of Lijiang. Notwithstanding this limitation, this study does suggest the general process of tourism development and one aspect of its influence on the local community in the old town of Lijiang. Hence, the authors wish the information presented here be of use to some local governments involved in trying to adjust many conflicts between conservation and tourism development or adopt a new policy to conservation and maintenance of historic district.

ACKNOWLEDGMENTS

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:**+90.212.2610549** e-mail:**sas2001@yildiz.edu.tr** http:**//www.yildiz.edu.tr/mim/sas2001**

RESTORATION AND SETTLEMENT OF HISTORIC URBAN AREA FOR ABORIGINES

C.H Lai P.S.Lin (1) ;D.H.Jiang & S.J.Lin(2)
(1) Hwa Lien County ,Taiwan,ROC.
(2) Feng Chia University,Taichung ,Taiwan,ROC

ABSTRACT

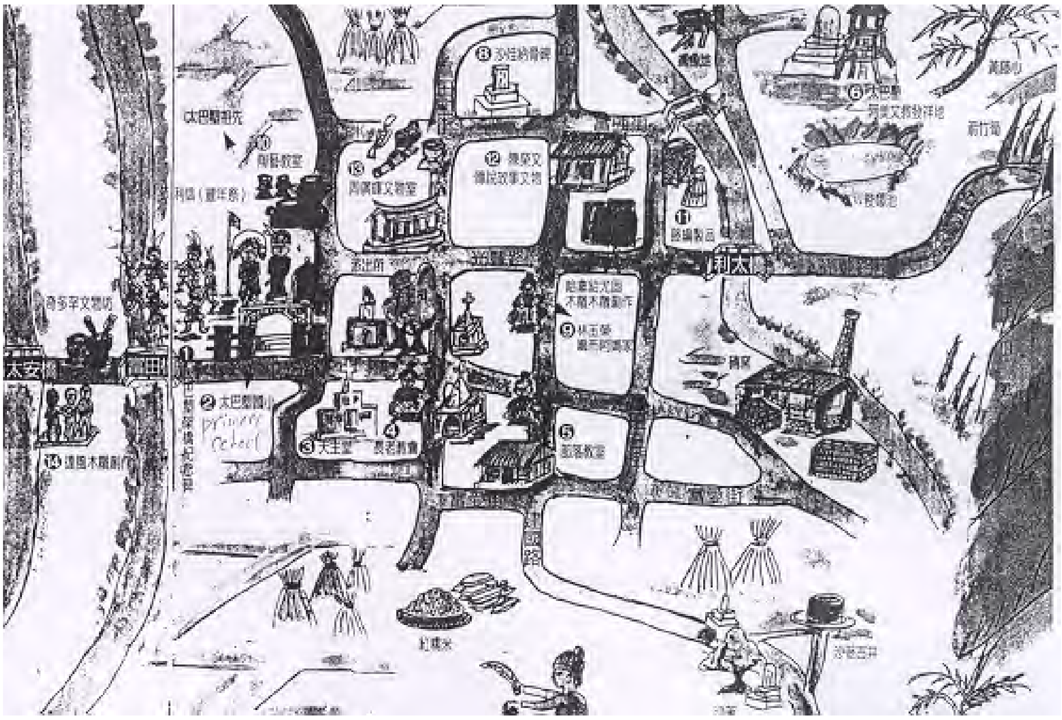
Hwa Lien locates in the Eastern Taiwan. Here is rich in natural scenes. Tourists visit Taiwan, especially the Japanese tourists, will not miss this place. In the high mountain there are several different aborigines villages due to the modernization of the higher living standard are going to be modified. How to keep its originality with modern comfort is the task of Hwa Lien County government. We study first the environment of its existed urban area with its location, dimension, spacing and the original building materials. Further more their social structure like member of family, tradition and neighborship etc. are also involved in the study. The influence of foreigners in there history and shown on their living environment are specially mentioned. With this influence we can develop modern housing and urban area but keep the spirits of its origin.

1. INTRODUCTION

Tabalong is a village locates at the central part of the Hwa Lien-Taitung rift valley in the eaatern Taiwan. The name Tabolong means "strong and rich land" is one of the oldest and well developed region of Ami aboriginal tribe. The geographic location of this area is between coastal mountains on the east and two branches of Vataan river on the west. There is another branch of Hwa Lien river run by the north. Only the south are well cultivated land. According to the myth of Ami tribe, they were come from the south. When people die the face of the dead body has to face the south. It means facing the rich land and their ancester. Across the two branches of Vataan river is the administrative center of the town of Kwangfu. Where are also railway and highway are there. So Tabalong is isolated thus keeping their culture well preserved. Inside in the village the streets are crossed each others where different occupation and temples or churches are spreaded. There are only one way to the center of the town and another way over the eastern coastal mountain to the Pacific Ocean. It is well located for the defense of the tribe.(Fig.1)

Fig.1Map of Tabalong

1. Monument for Pridge Across Vataan River



2. Primary School
3. Catholic Church
4. Presbyterian Church
5. Classroom of Tribal Culture
6. Cradle of Tabalong Culture
7. Ancestral Temple
8. Monument of Lady Sawa
9. Weaving Factory
10. Ceramic School
11. Rattan Weaving
12. Museum of Tabalong Culture
13. Tribe Chief's House
14. Wood Carving Factory

The area belongs to the eastern weather district of Taiwan, which is characterized by high temperature and heavy rainfall. The average temperature is 23°C with average annual rainfall of 2300mm. From May to October is the wet and typhone season where the crops, plants and other properties are frequently damaged.

Tabalong actually is a village cluster formed by four hamlets. The population of this village community is about 5500. They are a typical matrilineal society. The principal local unit among the people is the village community. The age class organization is an altered form of system. Every four years, a new class was accepted through an initiation ritual into the organization when the oldest class retired. This age class organization which is based on the concept of a hierarchical system was the education, military, political, religious and productive body of the community and therefore beyond the context of the system nothing would be considered as legal or functional properly. This concept of hierarchy not only served as the basic theme of social structure, but also followed in the religious and other aspects of the culture such as building or clothes etc.

2. HOUSING

The materials for construction of houses are wood, bamboo, grass and rattan. There were kinds of houses: the main or dwelling house, public house or men's club, ritual house and accessory buildings such as granary, field lodge, etc.

The dwelling house was constructed on plane ground. The site was generally rectangular in shape and the dimensions ranging from 4.5*3.5m. to 12.5*11.5m. For the large public houses are eighteen wooden posts for each house placed on the four sides of the site, and the wooden beams, ridgepoles and purlins were tied by rattan strips to these posts.(Fig.2 ,3.) After completion of the framework, the plaited bamboo walls were added and then the building was thatched with a grass roof. The floor of the house was covered completely by a bamboo platform except the base of the fireplaces near each of the two gable walls. The bamboo platform raised 80cm to 1 meter from the floor served as bed and place for all domestic activities.

The construction of a dwelling house, either rebuilding or new construction, was the responsibility of the members of the ward within a hamlet. Except free meals of luxurious food, the people who took part in the construction did not receive any payment.

The dwelling house of present time is actually the received form of the original house. The bamboo platform remains except at the entrance which now serves as the reception room. Usually, planks are erected on the platform to separate it into compartments. The fireplaces have been moved into the annex which serves both as kitchen and storeroom.(Fig.4.)

The ritual house and public houses of the Tabalong Ami were in similar to the dwelling house in structure. The ritual house or village temple served as the place for various important ceremonies. Pictures of many culture heroes of the Tabalong were carved in the main posts of the ritual house. The public house or men's club was actually composed of several buildings on a campus. Besides the dwelling places for the young service men, there were buildings for the upper class members and headmen, and there was an assembly building. These public buildings, therefore, were essentially the home of the age-class organizations and based on these the form and the function of the age-class system have come into effect.

Fig.2. Wooden Truss Tied by Rattan

Fig. 3. Column&Purhins Tied by Rattan

Fig. 4. Dwelling Made by Wooden Plank

3. DEVELOPMENT OF HOUSING

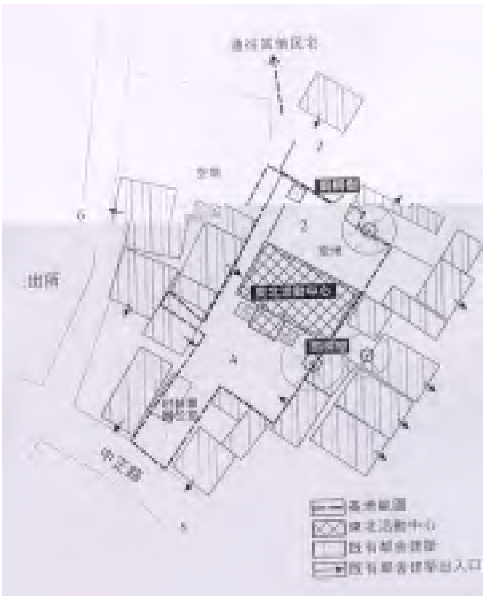
In general, Tabalong housing originally was made by thatch roof and bamboo wall with thatch in between then tied by rattan.(Fig.5).Thatch has to be renew for every 3 years. Then the shingle board and wood siding wall were used for dwelling .The wooden frame were dip into oil to protect the corrosion. The building materials were in the neighbourhood and men were gathered to build it. It was easied to be damaged by typhone but also easied to rebuild. Then come to the clay tile roof and brick or plaster wall. It was imported by the Japanses but only a few people can build it. Because it was costly, comparing to their living standard. After 1960 when the Christianity are entered reinforced concrete building occupied nearly all the village. The building materials were modernized giving more open space but the spirit of Ami Tabalong are vanishing. In the thatch house they can feel the spirit of epoch making of their ancester. Repairing the house link the people togather and helping each other. In fact thatch house is healthy and better in seasonal climate change. So Tabalong people want to rebuild their tribal culture, poaring energy to survive their tribe. In order to unify the whole village they use traditional way of building thatch house to call for people working together refeeling the spirity of helping each other and getting the tacit understanding of cooperation. The Hwa Lien County Government takes notice on their cooperation and respecting to their decision. Furthermore, the county government helps the community to build up the Ami aborgineal culture and living zone to preserve the cultural resoures not to be commercialized.

Fig. 5 Tabalong Tribal Classroom

4. PROJECT OF THE CONSTRUCTION OF THE PUBLIC ENVIRONMENT OF TABALONG COMMUNITY

As we mentioned before Tabalong has good location and well developed community. Under the community global cooperation people built up by themselves, using the ancient technology and local materials, to decorate their own house and garden in the whole village. Some people in the village like Mr.T.K.Yang, the assemblyman of Hwa Lien County Assembly, donated his land to build tradition house as classroom to educate people of their own culture. This is a place for tribal people to exchange their knowledge and preserve the traditional technology of building construction. Other classrooms for handcreaft like weaving, ceramic, rattan and wood carving are also established. Preservation by community themselves can have better implementation of the project. The project actually create a spirit to wake up people to rethink how to determine to make the community flourished and grow. They are not only preserving traditional technology and refining the village environment, but also attracting people to return and developing their own community. Recently a large community center will be built on a knife shape ground locates at the center of the village. This is a place originally for the festival of the village but then occupied by Japanese temple and then Chinese temple where it is followed by the colonial administration. This knife shape ground now cut the colonialism and returning to the tribal people(Fig.6).It will be a renaissance of the Tabalong Ami culture.

1. Old Japanese
 Chinses Temple
2.Bachyard
3.Old Community
 Center
4.New Community
5.Village
Administration
 Center
6.Police Station



5. FINAL REMARKS

Without any modern high tech or high profit service business Tabalong build up a public echo to redevelop their own culture by educating people to do the same way as their ancester to rebuild traditional house and community. With the spirit of mutual help learned during the construction they are further developing their community and attracting people coming to work with them. The development of culture activity is a new renaissance not only the environment by also the economic profit.

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80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

THE IMPACT OF "EGNATIA MOTORWAY" ON CULTURAL ENVIRONMENT

G. Penelis (1), S. Lambropoulos (2)
(1) Vice – President of "Egnatia Odos S.A.", Thessaloniki, Greece
(2) General Manager of "Egnatia Odos S.A.", Thessaloniki, Greece

ABSTRACT

"Egnatia" a new modern motorway 680 km long, following to a degree the traces of ancient Via Egnatia from Ionian Sea (Igoumenitsa) to the Turkish boarders (Kipi) is under construction. This big project, with a budget of 3.6 BECUS, is funded partly by the Greek government (35%) and partly by E.U. (65%).

Passing through Northern Greece from East to West this motorway constitutes a major intervention to the environment in general and subsequently also to the cultural heritage. In fact, passing from areas like Dodoni, Veria, Thessaloniki, Kavala etc. it contributes on one hand in discovering new hidden archeological findings, but it might have easily a negative impact on them on the other.

Task of this paper is the presentation of the policy followed on this issue by the Company "Egnatia Odos S.A." responsible for the project in cooperation with the Ministry of Culture. This policy may be summarized as follows:

- Preliminary archeological cuttings to prevent damages of hidden archeological treasures during construction.
- Changes of alignment of the motorway in plan or elevation in case of serious findings.
- Promotion of existing or new findings through proper interventions.
- Funding of the whole campaign by "Egnatia Odos S.A."

Finally some case studies are given (i.e. Dodoni, Polymylos, Lefkopetra etc.) so that the implementation of this policy in practice is lightened.

1. INTRODUCTION

The Egnatia Motorway, of a total length of 680 km, is a road axis of international importance, because it constitutes part of the Trans-European Network for Transportation and connects three seas (the Adriatic, the Aegean and the Black Sea) and two continents (Europe – Asia) (Map 1) from Ionian Sea (Igoumenitsa) to the Greek – Turkish borders. At the same time, it is an axis of national importance, because it allows for the fast, quick and safe transportation of people and goods. In its final form, it will be a dual carriageway with a central reserve. Each carriageway will have two traffic lanes and an emergency lane in each direction and the overall width of the road pavement will be 24.5 metres. Along the 680-km route, 720 km of service roads and roads for agricultural, urban and other special uses, 50 interchanges connecting the road with the existing national, provincial or local road network, 353 underpasses and overbridges, 18 large bridges crossing plains, rivers or important torrents with a total length of 40 km in each branch, 70 tunnels of which 15 large ones and many smaller ones of an overall length of 40 km for each bore, 43 smaller watercourses crossings and 11 grade-separated junctions with railroad tracks will also be construted.

The Egnatia Motorway connects five ports and six airports and, in combination with its nine vertical axes, provides access to the Balkans and other countries of Eastern Europe. The project has National and European Funds in the order of 3,5 billion euros, 0,35 of which, that is 10%, is estimated to be allocated for environmental protection, and, in particular, for the protection of the cultural heritage and the ecological systems which are disturbed by the construction of the road.

2. THE PROTECTION OF THE CULTURAL HERITAGE

Modern Egnatia Motorway crosses Greek mountainous and plain landscapes of exceptional beauty and great ecological importance and has highly important natural resources in its immediate vicinity. Its alignment is almost parallel to the historic Via Egnatia, which was constructed in the 2nd century B.C., after Macedonia and Epirus were conquered by the Romans in 168 B.C. [2].

Passing through Nothern Greece from East to West it constitutes a magor intervention to the environment and subsequently also to the cultural heritage. In fact passing from areas like Dodoni, Veria, Thessaloniki, Kavala e.t.c. it contributes on one hand in discovering new hidden archeological findings, but it might have easily a negative impact on them on the other (Map 2).

The policy implemented by Egnatia Odos SA the company authorized to manage the realization of Egnatia Motorway (always in cooperation with the Ministry of Culture and the Local Authorities of Antiquities) for the protection and the development of archeological sites during its construction and operation, is the following:

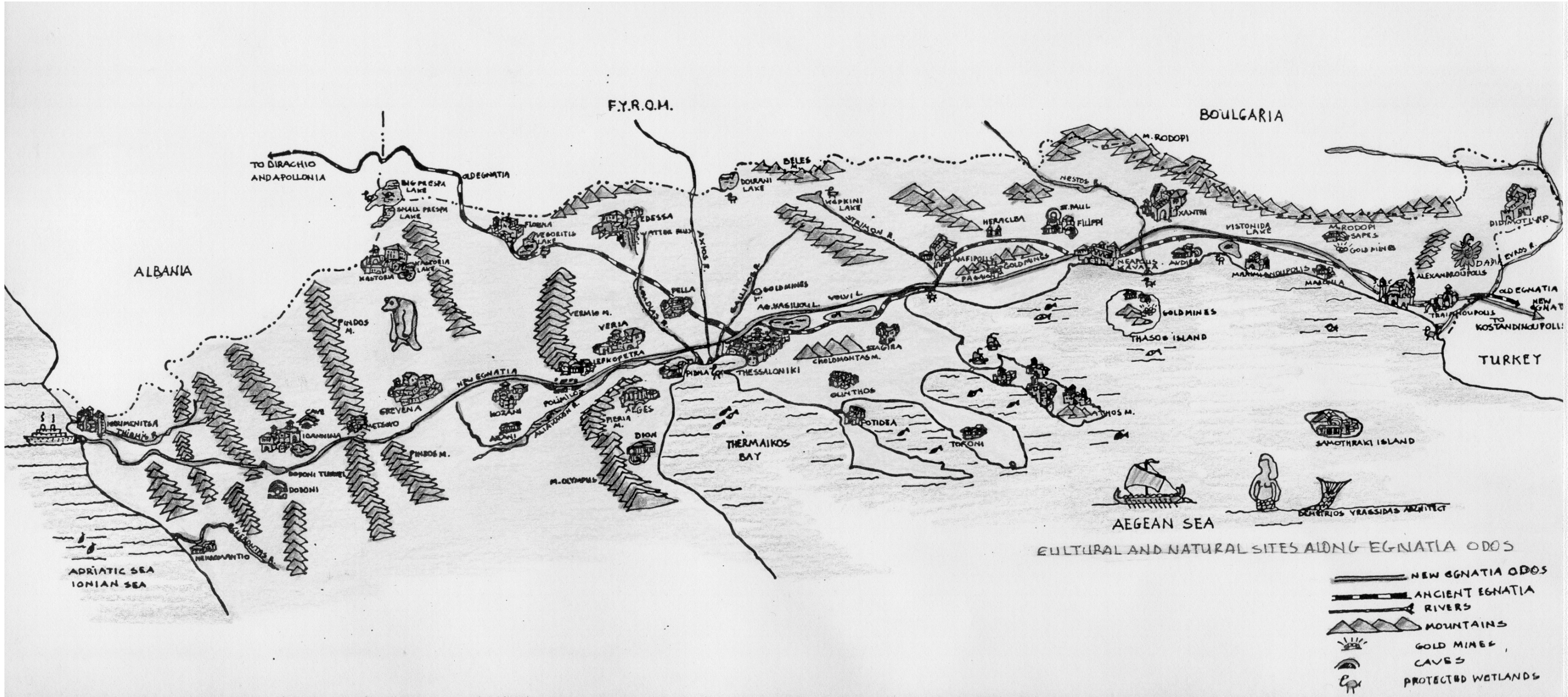
a. Design of the road in such a way as to avoid the destruction not only of those historical sites and monuments that are on the surface of the earth, but also of possible underground areas and locations.

b. Determination of the areas and locations with possible underground archaeological findings and performance of excavations before the performance

EGNATIA ODOS S.A.

MAP 1: EGNATIA ODOS AND VERTICAL AXES
ARCHEOLOGICAL EXCAVATIONS SITES

DATE: JANUARY 2001



MAP 2: Sketch of main cultural and natural sites along Egnatia Odos

of the project, or even before the invitation to tender for the project, whenever feasible.

c. Modifying the road alignment, either horizontal or vertical, if important archaeological findings are found.

d. Exhibiting important existing or new archaeological findings with suitable accesses.

e. Funding the archaeological excavations in their entirety and the works for the exhibit of the findings in part.

All the works for the construction of Egnatia Motorway are performed always in the presence of an archaeologist, appointed by the Local Authority of Antiquities, as its representative. If any antiquities are found on the surface layers of the ground or if there is even a hint that there are antiquities, the construction works stop and the area is investigated by a team of archaeologists who perform archaeological exploratory sections to determine the kind and the importance of the ancient findings.

If there are important archaeological findings, a regular archaeological excavation is performed and after it is completed, museum works are also performed for the preservation of the findings. If the archaeological sites are of major importance, EOAE considers the possibility of modifying the alignment or constructing special structures in order to protect them

The above-mentioned course of action, has been adopted in the following cases:

a. In the archaeological site of Dodoni (Oracle of Dodoni). In this case, the alignment had to be changed a dual longer tunnel to be constructed so that the traffic noise and lightening does not cause a degradation of the cultural environment. This increased the cost by approximately 10 billion drachmas.

b. In the area of Lefkopetra, the horizontal alignment was modified for a length of 0.5 km incurring an additional cost approximately equal to 0.3 billion drachmas in order to bypass the archaeological site.

c. In the area of Asprovalta, a Byzantine Inn of the ancient Via Egnatia was revealed. In this case, the road alignment was modified for a length of 0.5 km at an additional cost of 0.3 billion drachmas to bypass the archaeological site [Fig 1].

d. In the area of the Polymylos interchange, the ancient city of Evia, which had a 1500-year history, was discovered and the nine-metre-long overbridge that was going to be built is decided to be changed into a seventy-metre-long bridge in order to preserve a very important part of the said discovered city dating from the Hellenistic years, with pottery laboratories and kilns, of an area of 0.5 hectares. The cost estimate of the projects is approximately 0.8 billion drachmas.

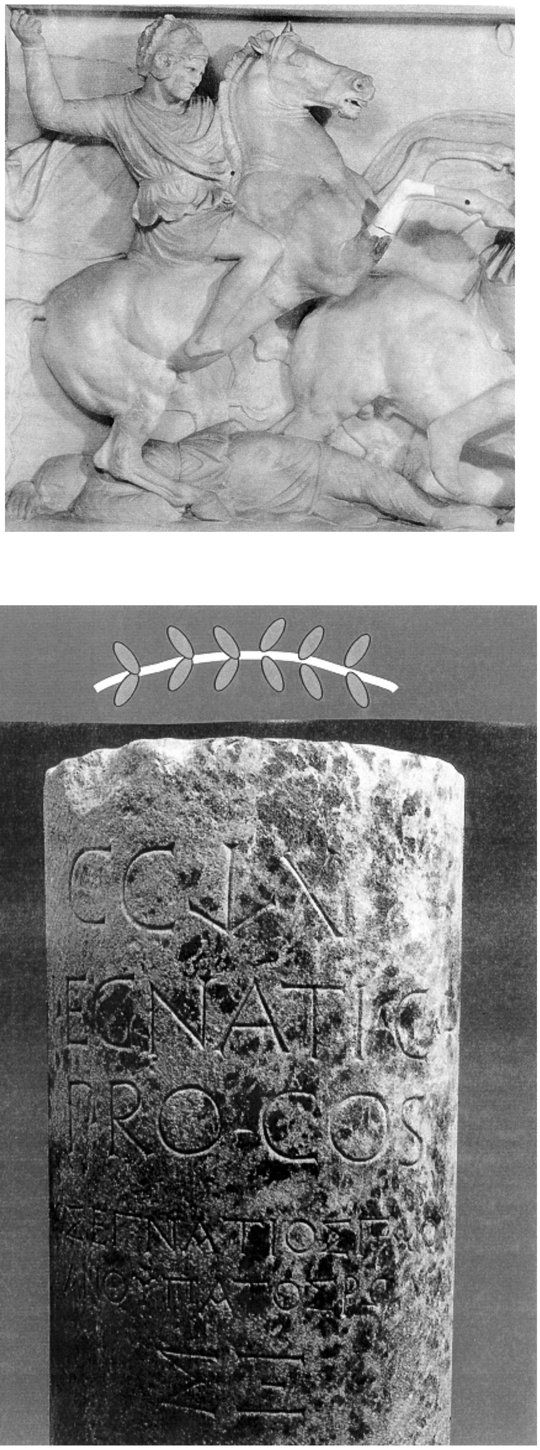


Figure 1: Examples of possible road identity landmarks

e. In the area of the 4,000-metre-long Justinian wall, which intersects the Egnatia Motorway near Iasmos, a special construction embankment, with a cost of approximately 0.125 billion drachmas, was constructed to protect and display the wall.
f. In the Derveni area, close to Thessaloniki a Thracian type ancient tomb with rare paintings from the Hellenistic era has been found and a special shelter is going to be constructed for its preservation.

All above changes have been terms of related archaeological licences imposed to the project. In total, an amount approximating 11.5 billion drachmas has been spent on such modifications to the Egnatia Motorway.

3. ARCHAEOLOGICAL EXCAVATIONS AND MAJOR FINDINGS

As it was mentioned before, EOAE financed extended archeological excavations, which were or are performed, in 31 locations (Map1). The overall cost up to now for these excavations is of the order of 2.44 billion drachmas. This cost if added to the cost of the motorway modifications mentioned in par. 2, results to 13.94 billion drachmas which represents almost the 1.5% of the total project construction cost. The most important findings from the archeological excavation up to now are the following.

3.1 Kozani Polymylos (Ancient Evia)

This is an ancient town mentioned by Diodoros, the lifetime of which extended from the prehistoric to the Roman years. Excavations extending over an area of 2 hectares revealed spacious residences, rooms for various residential uses, circular and rectangular pottery kilns, stone carving, pottery and coroplastic workshops. This excavated area has provided rich findings, such as coins, clay vessels, small statuettes, matrices of statuettes and vessels, metal objects and inscriptions. The findings belong to the Bronze Age and the Late Bronze Age and give a new dimension to the history of the region of Upper Macedonia and Macedonia in general, providing irrefutable testimony of the national identity of the population and evidence of the unity of Greek civilization. (Fig2, Fig3, Fig4) [4].

3.2 Kozani Valley of Kremasti

The findings date back to the Early Neolithic Era. The excavation revealed a long row of refuse pits containing pottery vessels, stone tools, parts of pottery statuettes and seals. A major finding was also found, a bone pipe from the 4h millennium B.C. In two of the pits, two interments were found where the dead bodies were contracted. Moreover, a trench, ten small pits and twenty-three burials – cremations were also revealed. These findings are unique in Greek territory and, therefore, extremely important both for research into the prehistoric ideology and research of the burial customs and the ethnological composition of the area. They were outside the residential area of the settlement, where the activities exercised were related to the economy, technology and ideology, which classifies the

Figure 2: Area of pottery workshop with furnaces at the archaeological site of Kozani, Polimilos

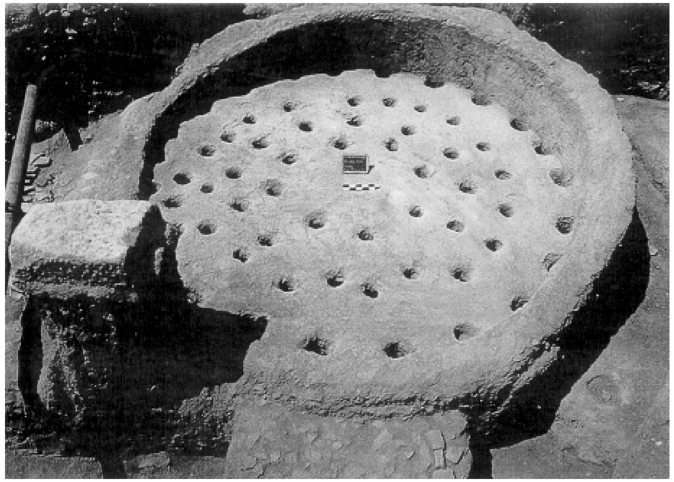


Figure 3: Cyclic furnace for ceramics found at the archaeological site of Kozani, Polimilos

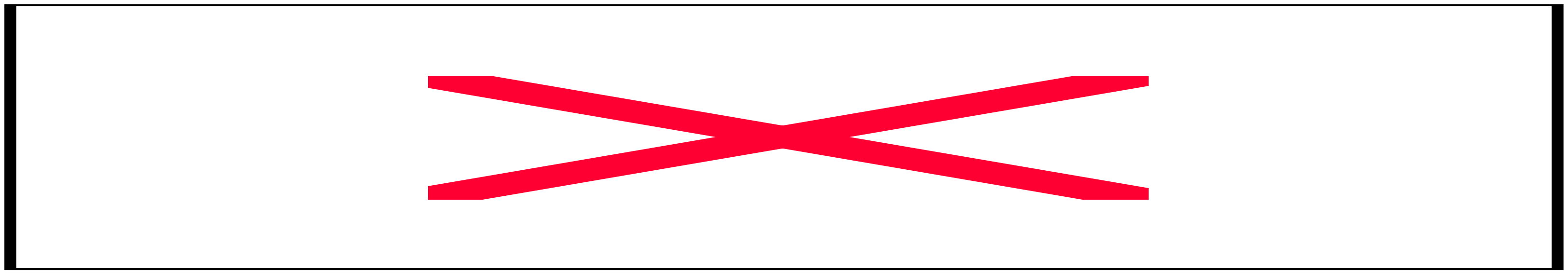


Figure 4: Maquette showing Egnatia Odos a bridge for seen to protect the archaeological findings of Ancient Evia at Kozani, Polimilos site

archaeological excavation among the most important prehistoric locations of the Greek territory [5].

3.3 Xerolimni of Kozani

This is a settlement of the Late Neolithic Age (4000 – 3000 B.C.) which was detected in an area of approximately 0.5 hectares and was exactly on the axis of the Via Egnatia. The settlement must have been inhabited mainly during the Early Neolithic Age while pottery from the Late Neolithic and the Early Bronze Ages has been unearthed. Moreover, the relics discovered have been dated back to the Hellenistic and Roman times. A considerable number of coins (about 3,500 pieces) going back to the 4^{th} century B.C. were also found. Finally, at a distance of 3 km a cemetery from the Roman times was discovered consisting of 16 pit-form burials and a refuse pit. The above findings can be used to draw conclusions about the customs of the people who lived in the above-mentioned ages [3].

3.4 Derveni of Thessaloniki

It is a circular burial monument which is considered as belonging to the Early Hellenistic Era and is dated in the late 4th and early 3^{rd} century B.C. It consists of a road – access, a rectangular antechamber and a circular chamber. The floors of the chamber and the antechamber were coated with colour plaster. The walls of the road were covered with plaster. It was covered with tiles, supported on wooden planks [6].

3.5 Asprovalta of Thessaloniki

The archaeological excavation brought to the surface an agricultural complex from the classical – Hellenistic times of exceptional interest due to the fact that it dates back to early times, the very good condition in which it has been preserved and the fact that almost the entire complex has been found. More specifically, a tripartite central building surrounded by a tiled corridor and yard was discovered. The complex, the excavation of which lasted 14 months, is unique in Central and Eastern Macedonia because of its early origin (late classical times – early Hellenistic times) and the good condition in which it has been preserved, which makes it easy for a lay visitor to understand it. It has provided a wealth of information on the agricultural activities of the area, on the communication of the inhabitants with other regions and on the organisation of the exploitation of farms and the control of strategic points of the area [7].

4. CONCLUSIONS

From the above presentation the following conclusions may be drawn:

a. The construction of a big modern motorway has always an immense impact on the cultural environment and therefore special measures must be taken for its protection and promotion.

b. These measures constitute an important construction cost representing about 1.5% of the total project cost, therefore must be taken seriously into account in advance.
   The total cost for the environmental protection of a motorway, might reach 10% of the total project cost.
c. In the case of "Egnatia Mororway" a holistic policy has been followed aiming at:
   - the protection of existing known cultural heritage
   - the discovering through archeological excavations of new findings
   - the promotion of all this heritage through special works

5. ACKNOWLEDGEMENT

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YILDIZ TECHNICAL UNIVERSITY FACULTY OF ARCHITECTURE
80750 YILDIZ, İSTANBUL, TURKEY
Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

SIGNIFICANCE OF HISTORIC URBAN FABRIC FOR ITS FUTURE FORM

N. Özaslan
Anadolu University, İstanbul, Turkey

Contemporary city panorama of many ‘developing countries’ is characterised by dilapidating historic urban settlements, ‘modern’ pieces inserted into the urban fabric and unhygienic squatter areas, as reflected in the present image of many of them, such as Istanbul. One of the major aspects in those cities is the question of renovation and conservation of historic urban cores. We will argue that the problem of urban design in those historic quarters cannot be tackled merely by restoring its surviving pieces, as is the current tendency, which is mostly formal, stylistic and superficial. Historic urban fabric has a great importance for the future of its own built environment not as a conservation area but as an inspiration source for new designs. Therefore understanding its form is crucial. We assert there is a need to understand its true architectural values and inherent qualities embodied in the buildings, walls, street, and gardens. This understanding, however, is hoped to generate creation rather than imitation. It is also hoped to emphasis that historic urban fabric is not a ‘model’ for future environment but it is a ‘resource’, which has a great architectural value in it. This paper proposes that the historic urban fabric should be a source of inspiration for its new form rather than an ‘object’, a ‘model’ or a ‘setting’ for any intervention in its fabric. Here it will be attempted to outline a methodology for reading and understanding the architectural structures and qualities of historic urban fabric.

1. INTRODUCTION

In parallel with growing industrialisation and urbanisation in the West, modern architecture tended to increasingly ignore the natural world and man's position in it, with all his social and cultural structures. The apparent result of the new life style has not only changed physical environment of the modern culture but also the inspiration sources for its creation and production. The objection of history due to the absolute faith in future resulted in the reduction of values attributed to the cultural heritage for many years. The initiators of modern architecture set up new rules to response the present requirements of the industrial society. So-called traditional ways and means of pre-industrial conditions were declared to be insufficient to form the futuristic society. This was true for the considered cultural heritage of urban areas that is namely a historic centre whose value did not match the newer requirements. The contemporary city fragmented and decomposed in which dilapidation of the historic urban heritage from neglect as well as from the intentional destruction was the common prospect.

However increasing concern in the problems of Modern City paralleling with the questions of the modern life has led to a generating appreciation of historic urban fabric in both the West and Other. The respect to history resulted in revitalisation of historic contents of the contemporary culture. The new researches on vernacular and traditional tend to read historic urban parts as the material products of specific historical conditions. The subject of study for this new trend was to decipher the historic features that now were seen as inseparable and constitutive parts of the built environment. Therefore the cultural heritage as the material evidence of a particular historical and cultural being need to be protected against to the modernist assaults. This has resulted in intense conservation movements and strongly influenced new design in Europe and gradually many non-European countries; and over the last four decades has become a major focus of discussion in architecture and urban planning issues.

2. CONFLICTS IN CONSERVATION

While early attention was directed at historic buildings, mostly those defined as monumental, new developments in the second half of the 20th century drew attention not only to dilapidating monuments but also other material heritage. In the 1950s and 1960s more modern buildings and even whole cities were built. As a result more old cities were destroyed, leading to growing public opposition. However the rapidity of change which "...has been difficult for people to absorb" (Appleyard 1979: 19) and the impacts of the change threaten the individual's and society's cultural identity. As a result, continuity is broken and without it as Peter Marris states, "...we cannot interpret what events mean to us, or to explore new kinds of experience with confidence" (in Appleyard 1979: 19). In other words, we began to lose not only our sources of form of being, that is identity, but also the sense of eternity of life, due to the break in continuity. We turn to the past as a repository for our sentiments and values (Appleyard 1979: 19). In spite of some material advantages of modern cities the old city did represent the human scale, showed care for the natural environment, promoted individuality within a coherent totality and a richness in terms of depth of meaning and culture. The old towns become the core of interest in the re-establishment of our cultural identity. Gradually the historic city became the major concern of conservation movement that gained new dimensions not only in terms of its area of responsibility and its principles but is also manifest in virtually every part of the world.

However, increasing discussion about the past and subsequently its conservation has showed that it has both, "...healthy and ...neurotic aspects" (Appleyard 1979: 21). The problems of physical conservation, concerned with its ideology, ethics, methods of repair and reuse, have raised much controversy leaving the many questions without answer: How do we deal with the past? What should be preserved? How much and in what ways? John Ruskin who agreed to the preservation of our precious inheritance from the past presented an earlier approach concerning the ethics of restoration. He maintained that restoration: "...means to most total destruction out of which no remnants can be gathered: a destruction accompanied with false description of the thing destroyed" (Ruskin 1899: 325). He, therefore, argued that; "...it is impossible, as impossible as to raise the dead, to restore anything that has ever been great or beautiful in architecture" (Ruskin 1899: 353). He suggests that the only message to take from these edifices of the past is the power of ancient architecture (Ruskin 1899: 360). But he warns that this influence should not be their formal expressions, such as squares or streets but the essence of their spatial qualities. Similarly, John Warren urges that authenticity of an ancient fabric once destroyed: "...can never be re-created. It may be reproduced, but a reproduction is merely a reproduction" (Warren 1980: 11).

On the other hand attempts at resurrecting the past have led to historicism and nostalgia that has been criticised by Hewison (1987) in the case of England. For him, looking back in nostalgia:”has become an economic enterprise, as the commercial interests of manufacturers and advertising have recognised" (Hewison 1987: 29). He calls this new business the Heritage Industry that is an attempt to exploit the economic potential of culture. He argues that: "The growth of a heritage culture has led not only to a distortion of the past, but to a stifling of the culture of the present" (Hewison 1987: 10). Similarly, Lowenthal (1993) criticised historicism, stating that "We can use the past fruitfully only when we realize that to inherit is also to transform", and continues: "The past remains integral to us all, individually and collectively. We must concede the ancients their place ...But their place is not simply back there, in a separate and foreign country; it is assimilated in ourselves, and resurrected into an ever-changing present" (Lowenthal 1993: 412).

It was seen that the nature of conservation in the sense of a reproduction of the past contradicts its own argument about continuity since it perceives an historic urban form as an `object' rather than a `process'. The betterment of the contemporary environment cannot solely rely on conservation because it has inherent conflicts.

One cannot deny the effect of ongoing time on the identity of a culture and accordingly on its products. However conservation alone, having the conflicts documented briefly above, cannot be a sufficient response to the problem of urban design in a contemporary context of the historic city, which suffers an identity problem. These conflicts may be lessened if they are designed according to the local characteristics of the conservation subject. Conservation is clearly an intervention in the form of repair, replacement or reconstruction. Each of these interventions, we argue, needs to consider the existing object carefully, be it a monument, a cultural artefact or historic urban fabric. The principles of intervention need to be derived from the characteristics, or in a broader sense, from the `essence' of the urban fabric, which in turn can only be grasped by careful analysis.

3. METHODS OF READING THE HISTORIC URBAN FORM

Contemporary studies on the architectural analysis of urban form led to investigations of the relationship between buildings and their context. Although the discussion of `type' and typology began earlier, the more recent works on urban morphology by Saverio Muratori at the Venice School of Architecture were not commenced until 1950 (Samuels 1983: 2). He saw the division between the historic city and the contemporary city, and rejected the idea of the Modern Movement, which proposed the reinvention of the city. He criticised contemporary architecture for its neglect for the concepts of connection with the past and its gradual change, indicating that the crisis was thought of as from within the problem of the crisis in the contemporary city. Therefore, he suggested that the urban fabric and the evolution of the relationships between buildings and their context must be studied only through typological analysis (Panerai 1979). Typology was seen as the essential methodology of this analysis, which was followed by his students, notably Paolo Maretto and Gianfranco Canigga. The implications of this method are seen as two fold. Firstly, it is useful to urban conservation both in order to repair the tissue, and also to determine design considerations of contemporary designs within a context that is compatible with its surroundings, in terms of form and use (Samules 1983: 4). Secondly, possible application of the method is in the case of reconstruction, particularly after an earthquake, bombing or even a poorly considered speculative development. The analysed continuity of the urban tissue of the other parts of the city would be the determining rule for planning the reconstruction. It is intended by this means to avoid making copies of previous buildings and design the new according to the existing tissue (Samuels 1983: 4).

Aldo Rossi and Carlo Aymonino (1985) at the Venice School of Architecture followed Muratori's ideas (Samuels 1983: 5). Aymonino and Rossi expanded Muratori's ideas and developed a new direction for contemporary architectural design. The form is the permanent character of the architecture for Rossi but he rejects the idea of reinventing form as maintained by the Modern Movement. So types became important for his design. Subsequently two French urbanist, Jean Castex and Phillipe Panerai, based at the Unite Pedagogique d'Architecture No:3 at Versailles, were also influenced by Muratori's and Caniggia's ideas and studies (Samules 1983: 6). They developed a methodology to analyse urban form, which is considered the most comprehensive yet devised.

Panerai stated that their main objective "...is to work towards the understanding of the relationships between architecture and the city. over fashions and styles" (In Castex 1979: 85). For them, the approach to the history of architecture through typological analysis requires the same understanding of architecture, "...to gauge their interactions and to perceive how one or the other contributes to the construction of towns" (Castex & Panerai 1982: 94). They urge that each town draws on a special architectural history, which should not be reduced, into a general `model'. Therefore, they criticise Leon Krier's deduction that European cities are in the same forms as all European towns. Castex and Panerai (1971) suggest four main steps in analysing urban structure. First is the typology of elements, second is the analysis of growth, third is the articulation of urban space and fourth is the legilibility of urban space. The first step, the typological analysis of the elements, follows four phases. At first an inventory of types from the urban system is prepared in order to compare the formative elements to identify, classify and regroup the types. The elements that are the subject of the typological analysis are of two kinds: firstly the buildings, and secondly the unbuilt areas. The typology of the buildings requires several criteria for the analysis **a**) their relation with the public spaces - direct or indirect, **b**) their associative qualities: that is between the elements (buildings and unbuilt areas) and to their surroundings; their characteristics as leading factors in the urban form; association of elements as linear or multidirectional form or as a configuration of both states, **c**) their distributive properties, and **d**) their composition of facades which can be classified according to their characteristics such as homogeneous / composite or symmetrical / unsymmetrical.

The typology of the unbuilt areas (des spaces non batis) concentrates on circulation spaces such as streets and and their intersections and squares. The relation of a street within a street network, definition of space and surrounding constructions such as walls, will all help the analysis of the individual elements. Squares can be looked at according to their form, relation to streets, and their relation with any exceptional elements, for instance, a tower or a religious building. Lastly, there are major elements in the unbuilt spaces such as bridges, viaducts, ditches all of which break into the tissue.

The second phase of the method is suggested as the analysis of the growth (croissance), which follows certain rules. There are two basic modes of growth: uni-directional (linear) and multi - directional (organic). These can be combined, and occasionally there are conflicts. In addition, there are limits to growth, which may be physical barriers such as rivers, forests, or protected areas; or another city, or internal barriers, which define the phases of growth. The typological inventory of urban elements, and the analysis of the growth process, can be seen as a preparation for reading complex relationships. The third phase looks at the articulation of urban space at two levels, hierarchical and superimposed (imbrications): the private, daily and urban levels. The private level concerns firstly, the individual, and subsequently the collective spaces such as houses, offices etc. The daily level concerns individual buildings but within collective life, a quarter. The urban level, however, concerns all the relationships and the structure of the space, including administrative bodies, monuments, boulevards and symbols. Besides superimposition is involved with the motives of articulation and collision of urban space.

The fourth phase is legilibility of the urban and monumental. The former considers visual characteristics: roads, arteries, junctions, identified sections, barriers and landmarks. In the latter, monuments are accepted as exceptional elements within the urban system, identified by their function and form. However, monuments are not isolated and can only be read within their urban context. The method of analysis of the monumental system follows three steps: firstly, the repertoire of monuments with their names, original function, creation date, transformation, spoliation, area of influence, area of reference and formal type; secondly, their influence in the urban structure, their axis and role. Thirdly, a monument and finally their role in the city as a whole represent the identification of symbolic role of monuments if a quarter. This whole analysis is carried out simultaneously on several levels. The method of analysis developed by Castex and Panerai outlined above, was applied to several cases; the town of Marcillac in France (Castex & Panerai 1972: 22-24) and Tunis Medina by Berardi (1971) are successful examples among them.

3.1. Criticism on the Method

Before moving to our proposal the presentation of the above methods needs to be discussed in order to justify our proposition. The major aim of this method is to grasp the abstracted rules of an urban structure by the analysis of relationships between buildings, understood as `types', and the urban whole, understood as a `formal entity'. This is based on the idea expressed by Argan that in the historic city, buildings have been formed for their morphological configurations (in Bandini 1984: 75). The idea, in its inner meaning, is a reaction to the Modern Movement, which strongly emphasised function as the major formative motive of design. As a consequence of the emphasis given to type, Typology became the core method of this analysis. From this were derived the crucial concepts of the type, the form and the relationships between building types and urban form. Type is understood as the essence of various, seemingly unrelated forms in the history of architecture and can perhaps best be discovered through a study of science and philosophy (Quincy in Anderson 1982: 112). It is a priori idea of form that can be abstracted from a building. The type is general and constant. This gives us an opportunity to categorise buildings according to various types. Type then becomes the abstraction of a form of a building into a simplified, summary form of a particular function building. Two dimensions only define it, emptied from its actual content and disconnected from its relationships. Thus, it becomes an element of a `formula' but not the representative of actual environment. To reduce buildings to simple geometric forms to in order to `analyse' and understand the urban form may be a helpful method but should not be the core aim and therefore not the main focus of the analysis.

Besides, the abstraction of building forms into certain types isolates them from their determinants, i.e. from their conditions of time and place that provides the content of the form. This thought contradicts Rossi's (1991: 40) argument that maintains the type is not merely a form, but it has content because it is developed according to social need and aspirations for beauty. However, we argue that urban elements need to be accepted in their `actual' forms, rather than the reduction of their forms into types. This is an important diversity in an attempt to establish a method of analysis. From this we can argue that all these courtyards cannot be reduced into one type, as in the case of the Tunis Medina studied by Berardi. The content of a courtyard is important; this includes its present and historical function, location and status (being private or public space); its significance for society which is reflected in the urban fabric, and its relationships to its surroundings. Content determines its role and importance within the entire urban fabric. Form, on the other hand, is only `actual' and significant within this content and has a meaning within the network of relationships, which makes the `space', that is, in turn, contained within a form.

We can argue that the coherent formal structure in the towns is not because of the permanent character of the form, as Rossi claims, but because of the continuous traditions, way of life, architectural culture and in particular, continuing spatial relationships. This can be seen clearly in the contemporary context of historic cities where the spatial relationships were disrupted in parallel with the disruption in their culture. Therefore one would suggest that permanence in the city is in the spatial relationships that are to be established by architecture. The permanence of an urban fabric is the architecture itself, which takes care of existing and creates new phases of its ever-changing structure, according to its own rules. It follows that architectural considerations are very important in making the city, which is itself embodied in its own historic urban fabric. An analysis based merely on form and type helps to see only the formal relationships, but not the spatial dimensions, which also involve function, plus social, cultural, economic and environmental factors and architectural culture to express them.

The relationship between building types and urban form also sees the city as a formal entity and denies its actuality. The suggested relationship is one of them, but not the only one because the city is a network of relationships, among many different elements. Therefore, a good working method to analyse the historic urban fabric needs to be based on themes, which refer to a network of relationships. In detail, the method should focus on urban elements, which involve not only architectural elements but also institutional ones that have a direct role in forming the city. In contrast, unlike the above-discussed methods, we argue, that combining (or articulating) the elements can play a crucial role in the planning of urban space and therefore needs to be carefully examined. They are very crucial to this argument because they represent the tangible, the actual quality of the relationship. A conceptual framework of a reading method based on such an understanding will be outlined in the following part.

4. CONCEPTUAL FRAMEWORK FOR A READING METHOD

Here we would like to draw attention to the fact that in other study methods, the object i.e. the physical entity of a city, judged as a formal entity, becomes the most important consideration and independent from its maker. But, we argue that the maker and user are more important because they have the knowledge (about how) to create the city. In this sense urban space is not independent; on the contrary, it is very much dependent on and bound up with the human condition. The first step, which is also a prerequisite of an adequate built environment, is to re-establish the connection and make the city once more dependent on a human scale (in its literal and wider sense). This connection can be reached, first of all, by careful definition in order to understand its totality, its `knowledge', its `essence'; followed by finding ways for reintegration with its system and at the same time reflecting the qualities of time. These requirements can be reached by fastidious historical and architectural research, and analysis, which are essential for studying the evolution of a town. When the aim is to understand the `essence' of the historic urban fabric in order to generate future designs, one may ask how `inventions', the formation of the `new', while avoiding historicism and kitsch designs, are possible from the `old'. Piaget's theory of cognitive structure provides the answer, as he argues that in order to `invent' one should first `understand' (Gage & Berliner 1992). Thus the understanding of urban fabric becomes crucial in future `inventions'. The method of understanding then becomes a primary procedure and must be developed.

Understanding, in the case of historic urban fabric requires an initial preparation: reading the city fabric, in order to make the city `legible'. This is necessary because the system in which the historic urban fabric was developed differs dramatically form the system in which we are now. Wittgenstein argues that, "All testing, all confirmation and disconfirmation of a hypothesis takes place already within a system" (In Brand 1979: 9). So, if one speaks about an element or a fact belonging to a particular system, the invention and the language of this argument needs to belong to the same system. In this case, the reader and the object to be read belong to different systems, which logically makes reading impossible. But, architecture as another system, provides a language encompassing both, and thus reading becomes possible. Since architecture is universal in its essence, it is the common ground of all man-made physical environments. Schulz supports this by stating that, "There are not different kinds of architecture, but only different situations which require different solutions in order to satisfy man's physical and psychic needs" (Schulz 1980: 4). Consequently our approach proposes two major phases in the analysis of the historic urban fabric; `reading', and `understanding'.

Each town draws on a special architectural history that should not be reduced to a general model (Castex & Panerai 1982: 94). In an attempt to understand the essence of an urban form it is necessary that the endeavour be based on the local conditions and resources, which related to the production process of the built environment. It is argued in the field of archaeology that, "...local knowledge can be gained from a real past, the excavation of which forms the only authentic path to cultural identity" (Rowlands 1989: 37). A similar attitude may be presented in the architectural field by the suggested methodology of reading the city to grasp its knowledge. Reading the urban fabric can be seen as a tool for "...reactivation of local knowledge" (Rowlands 1989: 37), which appears as an important means to resist the hegemony of `outsider' form. Local culture and identity spring from "...local knowledge as an authentic, i.e. true, source of creating a sense of difference" (Rowlands 1989: 37). At this point one may suggest that the centralized character of the urban form of a city can be converted to become once more decentralized, and this will support authenticity, by regaining local values. Therefore, because of the significance of the rediscovery of genuine values, being able to create again should be the ultimate goal of any repressed culture. In this matter, the self-realisation of any cultural body would only come about by the application of freedom in the sense of, "...being able to `see through' and to challenge the conditions that divert living subjects from a real understanding of their interests and their conditions of existence". With this statement in mind, we suggest that the analysis of the historical urban fabric of a city may provide us with the rediscovery of its architectural culture from which its `essence' may be grasped.

5. CONCLUSION

The method to grasp the town's architectural essence is hoped to generate creative new designs rather than imitations. It is also hoped that by giving emphasis to the historic urban fabric, it will not be used as a `model' but rather as an `inspiration-source' from which to plan future urban environments. The connection with the present and this `past' architectural quality is necessary to achieve an autonomous, identifiable urban form. Therefore we argue that only then we may be able to recreate integrated and harmonious cities again. And only then may architecture appear in the cities. The next question arises as how this understanding can become a design source and how architects and others can work with it. The response is to come from architects who work and design in these cities since the responsibility of making the city is with architecture.

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A PLANNING / FINANCE MODEL FOR THE HISTORICAL CONTINUALITY OF TRADITIONAL CIVIL ARCHITECTURE IN TERMS OF SOCIO-CULTURE AND FUNCTIONALISM

N. F. Akıncı
Yıldız Technical University, Istanbul, Turkey

ABSTRACT

Because of social, physical, functional changes, Traditional Turkish Houses, one of the Turkey's Cultural Values, entered an economical wearing period. In the introduction of this paper, the importance of the Cultural values is emphasized. And by explaining the meaning of social, physical, functional changes and the economical wearing conceptions, the seriousness of the subject and the need to a solution urgently is appeared. In the conservation of cultural values, explaining the insufficiency of the current conservation Model in Turkey is emphasizing the importance of the subject one more time. The aim of defining lameness of the current model is to form a base for the new model. The importance of cultural values and lameness of the current model directed the papers conclusion as a new model. Spiritual values of people are firstly considered in the model, taking place in building-conservation-finance intersection. The model is formed by considering scale, content, deportment, time dimension of the problem and related to the planning and progression. The datum related to the financial organization with the association and institutions that will be in the model are defined.

1. INTRODUCTION

The system to reactivate the traditional Turkish Housing needs a coordinated participation of the physical and socio-cultural factors of present environment, but also the administrative mechanism and its application fields, the users wishes and the investors' efforts in whole country measures. All these show the multidimensional structure of the problem.

In the suggested model, the necessary operations are collected in stages as problem determination, data collection, analysis, concept development, synthesis, decision application and evaluation (feed back). (Figure 1. process model and players).

2. EXPLORING THE MODELLING PROCESS

2.1. Problem Determination;

The main problems in the model are determined as the destruction of traditional civil architecture, interruption of cultural continuity, demand on habitation as a result of the population increase in country measures, the need on stabilized cultural continuity in country measures.

2.2. Data Collection*;* Existing literature in Turkey should be investigated closely in historical perspective and social and physical deformations be exposed; The reasons for the deterioration of the present civil traditional architecture should be created under the titles of physical, functional, social deformations and economical deterioration. Related international studies should be searched after completing the collection of all kind of information concerning the traditional civil architecture.

2.3. Analysis; In the model, primary decisions should be defined from the point of the view of the country, district, province, township, quarter, building, area, building components and users. Decisions should be made in every stage covering financial, technological, legal, social, geographical, geological, ecological fields.

2.4. Concept Development; The evaluation of determined performances resulting from the analysis should be aimed to protect and survive the traditional civil architecture in all measures. The specialists and authorities should develop concepts according to these evaluations in order to make the necessary financial, organizational, legal and educational decisions.

2.5 Synthesis and decision; The physical decisions should be made according to the legal, organizational, financial, educational decisions and the final definition of monument protection should be concretized. The planning decisions can be clarified in measures of country, district, province, township and single building. These are;

Strategically Planning in Country Measures;

Constitution of development plans and determination of the industrial and tourism areas having priority

Planning of population movements in country measures.

Constitution of necessary data for infra- and superstructure according to the movements of population.
Organizing the economical data sufficient for the population movements.
Preparing the necessary monetary values in primary budgets.
Determination and removal of legal and organizational weaknesses.
Development of education and participation of protection conscious increasing programs in educations.
In the model for country, the places for the institutions, establishments and organizations should be determined.
The protection policy and plans oriented to the strategically planning in country measures should contain:

The constitution of culture policy and strategically planning

The planning for solutions and removal of the pressures or cavities resulting from the population movements in country measure in the areas to be protected.
The constitutions of the conditions for the infra- and superstructures in the protection areas according to the population movements.
Activities necessary to determine the protection areas.
Organizing the economic data able to drive these motions and planning for converting the added value resulting from these organizations into a finance to be used for the protection activities.

Regional Planning Decisions; **The geographically separated regional borders of Turkey can be protected in this model (Marmora, Black Sea, Central Anatolia, Aegean, Mediterranean, East Anatolia and Southeast Anatolia)**
Regional Planning Decisions should be constituted considering regional dynamics detailed, but the general principles are:
To procure the protection of the area by considering the reality in mind that traditional housing texture protected in district measures provides an aesthetical integrity.

To protect the regional prototype and under the title of this prototype, constitution of principles of intervention.

Loading the functions to balance the regional condensation, motivating the usage for habitation.
Not to have big scale alterations in the whole infrastructure of the district.

Province Planning Decisions; The Province Planning Decisions should be formed for every province separately and for the protection and development of the traditional texture.

Traditional Housing Textures Provincial Planning Principles:

Loading the functions to balance the provincial condensation, motivating the usage for habitation.

Not to have big scale alterations in the whole infrastructure of the province.

To protect the provincial prototype and under the title of this prototype, constitution of principles of intervention.

The constitution of aesthetical integrity by protection of traditional housing textures in province measures.

Township Planning Decisions;

Decisions concerning single building measures are in these Planning Decisions also included.

Determination of the problem in constituted Township Planning Decisions can be realized by direct application of the user. Related township planning principles are:

Loading the functions to balance the condensation in the township, motivating the usage for habitation.

Not to have big scale alterations in the whole infrastructure of the township.

To protect the township prototype and under the title of this prototype, constitution of principles of intervention.

The constitution of aesthetical integrity by protection of traditional housing textures in township measures.

In the planning decisions of building measures constituted under consideration of the decisions of planning of country, district (region), province and township:

The ensure the protection of the building by supporting the present structure;

To protect the original or similar function of the building and not allowing the problems resulting from pressures of function changes in long term to disturb building specific characteristic;

To protect the building in its original position and remove the additions formed during the changing period;

During the constitution of comfort conditions and new adding securing not to destroy the originality and structure of the building;

Securing material and workmanship appropriate to the building originality during repairs;

To protect the relation established between the building and the road structure, and to strengthen this relation by coloring and arranging the frontal fullness - emptiness ratio;

Determining the user profile and requests;

The building decoration details should be planned satisfying the comfort and social needs of the user.

2.6. Application and Evaluation (Feed Back); Appropriate Production Alternatives should be constituted in connection with the valid conditions during the application of the prepared plans from the country measure to the single building measure. During the realization of the application by the specialists of their fields, the compatibility of the processes to the plan should be steadily checked. Negative data and results should be feeding data of the process of model in every stage.

3. ORGANIZATION MODELL (ORGANIZATION OF INSTITUTES AND ESTABLISHMENTS AND FINANCE)

The duties and responsibilities of the institutes and establishments are determined in the model and the finance subject to application tried to be clarified.

3.1. INSTITUTES AND ESTABLISHMENTS

Organization Diagram in figure 2 shows the communication between institutes and committees systematically. Information concerning the duties, responsibilities and authorities and staff of the proposed establishments and institutes are given below:

3.1.1. (KTVK) Superior Committee for Protection of National and Cultural Monuments: In the present model, KTVK Superior Committee is considered as the unit gives principle decisions for protection and determination of monuments in Turkey measures, determines country protection policy, orients application units appropriately, controls the conformity of the activations to the determined policy and develops the international relations. It is an above politic technical formation. KTVK Superior committee should contain architects, town planners, archeologists, art historians, civil engineers, sociologists, geophysicists, geodesy and photogrametry specialists, economists and statisticians. Besides this fixed staff, the representatives of the Ministry of Culture, State Planning Organization, Foundation General Directory, National Property Department and other related Ministries should be included. KTVK (district) committee presidents should participate in the Superior Committee meetings to enable the coordination with the KTVK committees. The educational elements of universities should take part in the meetings during decision stages to act as consultants. It should be possible the participation of one representative from each of the public organizations and profession organizations to express their problems during the decision stage of the meeting to the superior committee. The operations should be collected under the establishments named “Monuments Data Bank” (covers registration information) and “Research and Project Production Center”. Besides that, the Monuments Protection Education Unit and Monuments Introduction Unit in connection to the superior committee should also take part. The Monuments

Protection Education Unit should undertake all the necessary educational activities for the Importance and Protection of traditional texture and organize or let organize courses to train specialist worker and masters in their fields. The mission of Monuments Introduction Unit consists of creating public opinion and attention concerning the importance of traditional texture.

3.1.2. KTVK committees (district): In the present protection model, these committees are used as equivalent to the KTVK protection committees in district basis. Their number is limited to the number of present districts to enable the division of authority and responsibilities. These are committees for the control and organization of applications in district measures of the policies constituted in country measure.

KTVK committees should contain architects, town planners, archeologists, art historians, civil engineers, sociologists, geophysicists, geodesy and photogrametrie specialists, economists and statisticians. Besides that the representatives of the Ministry of Culture, Foundation General Directory, and National Property Department should also be included. Besides that fixed staff, representatives of the public organizations and profession organizations could be involved in problem determination functions. The scientists from the universities should be able to function as consultants in their related specialty fields during the committee meetings. To enable the communication and coordination the decisions taken in the District Committees of Local Administration and KTVK Committees should be conducted to each other. The representative of the Superior Committee should also take part in the meetings to enable the coordination of the operations of the district committees with the Superior Committee.

The necessary operations should be realized in the Data Banks and Research and Project Development Centers constituted in district measure. According to the proposals of the KTVK Superior Committee, courses and educational activities in district measures should be organized and the constitution of necessary consciousness and specialized staff and workers obtained.

3.1.3. KTVK Sub-committees: KTVK Sub-committees do not exist in the present model. It can be expressed as the equivalent to some KTVK committees operating in some big provinces but in the model proposed to constitute these subcommittees in every province of the country. Sub-committees determine the application decisions and control the applications in province measure of the properly detailed regional protection policies constituted in country measure.
KTVK sub-committees should contain architects, town planners, archeologists, art historians, civil engineers, sociologists, geophysicists, geodesy and photogrametrie

specialists, economists and statisticians. The representatives of the Ministry of Culture, Foundation General Directory, and National Property Department should also be included in the fixed staff. The scientists from the universities should be able to function as consultants in their related specialty fields during the committee meetings. Besides that, coordination with the local administration should be enabled thru the representatives.

The realized studies and operations should be developed in Project Production Centers and the decisions taken should be collected in the Data bank Bureaus. Necessary educational activities should be realized in settlement unit measures.

3.1.4. KTVK Township Committees: KTVK Township committees should be formed for every township containing traditional texture and historical monuments according to the determinations of the KTVK sub-committees. It is a committee takes plan and finance decisions, determines legal problems in township measure.

KTVK Township committees should contain architects, town planners, archeologists, art historians, civil engineers, sociologists, geophysicists, geodesy and photogrametrie specialists, economists and statisticians. Additionally people specialized in the fields of restoration, architecture history should also be involved as single measure planning decisions are also taken in this committee. The representatives of the Ministry of Culture, Foundation General Directory, and National Property Department should also be included. The representatives of the public and profession organizations should be allowed to take part during stages of determining problems in the activities. The representatives of the local municipalities should also take part in the meetings to establish the coordination in the phase of decision taking.

The decision taking activities of township, building and building components measures should be carried out in the research and project production centers. Determinations concerning single building measure should be found in the units of data bank.

KTVK township committees are institutions, owners can obtain the decisions concerning their buildings directly or thru the quarter committees. The issuing institution of the permission to the registered building owner for repair is the KTVK township committee. The township local administration recovery bureaus issue the approvals for repair.

3.1.5. Quarter Committees are units operating under the KTVK township committees. The representatives of the Culture Ministry and KTVK township committee should be charged in this committee for the purpose of coordination.

The purpose of the quarter committees is to establish the communication between the decision mechanism and the owner-user. The owner of a registered building is able to obtain all the necessary information with related building from these committees but also assistance in application procedures. Every owner of a registered building should be accepted as natural member of this committee in quarter measure. The quarter committees realize the preparation of the questionnaires and their application to determine the requests of the members of the quarter when necessary. By realizing the determination of the problems, collection of data the quarter committees take the biggest share in making correct decisions and updates. The quarter committees should be in touch with the public and profession organizations.

3.1.6. Ministry of Local Administrations: At the present the local administrations are connected to the Ministry of Interior Affairs. The responsibilities of the Ministry of Interior Affairs expanded to a very large coverage. Because of this reason, Ministry of Local Administrations is constituted in the model. It is necessary to be in contact with the Culture Ministry to ensure not to be against the target of the Development and Protection of the Traditional Texture during the activities of the Ministry of Local Administrations. Besides that, for the problems encountering in the targets of the local administrative operations, contacts with related ministries should be established steadily.

3.1.7. Local Administrations district committees: The Local Administration district committees should be constituted in every district of Turkey and meet in certain times and solve urgent problems occurred in local administration in regional bases. This committee should be constituted of the mayors of local municipalities. To avoid taking decisions against the targets of the KTVK committees' continuous communication is necessary.

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3.1.8. Local Administrations (Metropolis): The local administrations are responsible from the necessary operations and works to protect all kind of monuments in settlement unit measure, appropriate to the determined protection policy of country, districts and settlement units.

3.1.9. Township Local Administrations: Township Local Administrations are bound to Local Administrations. These are administrations related with operations and decisions of planning and finance in township measures. Township Local Administrations activities are carried out under the responsibility of their bounded units Local Administrations Recovery Bureaus and Reconstruction Bureaus. Concrete works should be constituted in independent technical bureaus.

3.1.9.1. Local Administrations Recovery Unit; Local Administrations Recovery Unit is to activate for the determination of the deformation of the texture in regional measure and problems of the population living on this texture, and for the solution of a ghetto type structure with all its social problems. It should be in the same time in communication with the KTVK township committees to ensure the approval for repair to the owner of registered building owner.

3.1.9.2. Local Administration Reconstruction Works Bureau; Same as present, but staff with experienced personnel and stronger controls.

3.1.9.3. Independent Technical Bureaus; Local Administrations should be able to fulfill all the reconstruction activities of planning and application in the settlement unit under own control by independent technical bureaus. Their bounded profession organizations, public organizations, KTVK township committees and quarter committees should inspect these bureaus continuously.

3.1.10 Profession Organizations:
Aim of the profession organization is to collect the members of the same profession under the same organization and provide better service to the public and solidarity between members of the same profession. These organizations need to be reconstructed today.

3.1.11. Public Organizations: Under the title of protection are lots of activities public organizations can manage. Thru these organizations the control of the central administration can be possible and common people rendered conscious.

3.2. FINANCE

To get rid of the shrinking in the only source for the protection of present values finding new finance sources are necessary. To activate the proposed new finance sources the legal and financial arrangements mentioned in the process and organization sections of the model should be realized.

3.2.1. Creation of Special Finance Sources

3.2.1.1. Finance by Evaluation Traditional Housing Textures as House- stock

Related Banks, Governmental Institutions and Private Sector Establishments can finance the Traditional Turkish Houses as an answer to the demand on Houses by adding value to target of protection of cultural values in the same time.

3.2.1.2. Reception of the Increase in the Values as a Finance Input for the Protection of Traditional Housing Textures: The historical texture in province can be activated with new functions for provincial development. With the applications of the plans, decisions and, arrangements for this purpose shall create the finance in the same time.

3.2.1.3. Capital Market / Bourse: Considering the above-mentioned constitution, Real Estate Investment Corporations should be established and the shares processed in the bourse.

3.2.1.4. Transfer of Public Rights by the Operative Attraction Center:
To make use of the finance power of various companies in different sectors, the public rights of management could be transferred conditionally to create attraction centers. These firms would evaluate these buildings as prestigious and should constitute various attraction centers. This occasion would bring to the region alternating economic activities resulting the collection of extra taxes for public interests.

3.2.1.5. Sponsors: Sponsors support protection-aimed projects realized by logical systems. The sponsoring expenses of sponsors should be exempted from taxes.

3.2.1.6. Lottery etc. Ensuring finance thru public opinion indexed systems:
Thru the chance game organizations targeted to the benefit of monuments protection in country or regional measures but also single building scale, a structure could be constituted public donations could be transferred into continuously.

3.2.2. Creation of Public Finance Sources

3.2.2.1. Foundations Management: The Foundation Management grants the repair expenses of foundation goods

3.2.2.2. Finance Ministry: The Finance Ministry grants the repair expenses of the goods of Treasury. The Finance Ministry exempts the taxation (or lower taxation) of the traditional Housing Texture.

3.2.2.3. Loans: Finance constituted in funds or in comprehension of reconstruction as loans in public means are transferred to finance various projects by the intervention of private banks. These loans are of lower interest rates and public suspension. .

3.2.2.4. Using World Culture Finance Programs: Protection of local cultures is being problems of the whole world and appropriate projects could be credited in this manner.

Finance Transfer from various fees under the Title of Cultural Development in Country measure: Various funds or fees can be collected for the aims of cultural protection in the following manner: a certain percentage of the total budget of all kind of building activities in country measure, a certain percentage over the retail price of construction materials, a certain percentage over the tourism activities carried out in historical areas, a certain percentage of the local administration services as fees for the protection of monuments; all the incomes of the museums and exhibitions (exempted the operational costs) and from the independent expert technical bureaus over their activities as funds for protection of monuments

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Fax:+90.212.2610549 **e-mail**:sas2001@yildiz.edu.tr **http**://www.yildiz.edu.tr/mim/sas2001

AN ARCHITECTURAL SURVEY OF THE SQUARES AT THE OLD URBAN PATTERN AROUND SİRKECİ – YEDİKULE RAILROAD

Ö. Barkul
Yıldız Technical University, İstanbul, Turkey

ABSTRACT

İstanbul, as the capital of three Empires, owes the shape of the city fabric to the radical moves. The transformation systems caused many changes on the city fabric. Especialy the İstanbul – Sofia railroad which was constructed in 1876 caused many changes on the settlements at Historical Peninsula. This paper aimed to analyze the changes and the squares around İstanbul – Sofia railroad after construction.

INTRODUCTION

As a world city Istanbul owes the shaping of many of its elements that are present today in the general constitution of the city to the radical applications of the past. For instance: The Galatasaray and Tünel squares, are the product of the 6th building plan of the Municipality building of Istanbul. Even if it hasn't been proven to be true yet, according to many historians the Divan Yolu (Avenue) and the squares that are along this street (Sultanahmet, Çemberlitaş, Beyazit, Aksaray) are the shaping of the famous Byzantine Mese street and forums (Constantine, Tauri, Bovis and Arcadius). From this perspective, it can be said of this 12 million populated Megalopolis to be the preserver of the important historical remnants and it is formed around these remnants.

The deep historical image of Istanbul/Constantinople stems from the long political and cultural history that they have shared for years and the relations that have ensued from this interaction with the western world. When we look at the city structure of Ancient Greece, Pagan Rome and the capital city of Christian Byzantium some similarities can be observed with respect to open places. These places have continued to exist long after the establishment of the Ottoman empire, however, the social structure of the Ottoman empire and the organization of land were different and this resulted in the change of structure in these open places as well.

The most important changes in the urban structure of the Ottoman empire resulted in the period of Tanzimat. Even though Tanzimat is mainly an effort to bring order to law and sovereignty it has resulted in the desire to transform the city into a western capital city. For the governors of this period the city was a symbol of civilization. Due to the development in economical relations the city grew with the modernization of the transportation and communication systems which provide these links. The transportation methods have acted as a catalyst in the entrance to cities in the 19th century. The opening of new and large arteries have enabled the easy commuting between the districts of the cities. Better transportation means have created openings for the physical growth of the city and have also enhanced it.

The first railway that connected Istanbul to Sofia was opened to use in 1874 ([1]). The trajectory that the railway was supposed to take had been a major source of discussion in Istanbul. The Belgian Banker Baron Hirsch drew some plans and according to these the railway had to proceed along the coast of Marmara and pass right through the garden of Topkapi palace. As the railway passed through the districts of Marmara sea the trains connecting the suburbs with the city center have quickly started to function. In 1875 there were 6 stations: Sirkeci, Kumkapi, Yedikule, Bakirköy, Yesilköy and Küçükçekmece. In a map dated 1896 there appear to be two additional stations in Samatya and Yenikapi. Thus, the two suburbs Bakirköy and Yesilköy were connected to the city center. There were only two stations one in Europe and the other in Asia, whereas in the old city centers of Europe the inclination was to make many train stations

The Sirkeci Station was at a crucial point where the transportation webs intersected and it enabled fast commuting to other transportation means like the tram and ferry. The architectural style of the Sirkeci station symbolized the dichotomy between the western values and those of the Ottoman culture which had really nestled into the urbanization image of Istanbul in the 19th century. The station which was designed by Jachmund, completed in 1887 where the beaux-arts technique was embedded in a new Islamic style was set into a modern framework reminiscent of the Ottoman traditions. Sirkeci with the vast square that lay before it still preserves today, as it did then, the property of being a transportation and station square.

Ahirkapi or Cankurtaran, which are the second settlements starting from Sirkeci station to the west, are very important historical palace regions like Sarayburnu. This region has a wonderful view: Bosphorus at the east end of the peninsula, Asian part and the islands. This region was called with this name due to the fact that the barns of Topkapi Palace were there and these barns were shown in Kauffer's map.(1776) .

Figure1. Kauffer'S map 1776

Cankurtaran was formed after the conquest. The existence of the mosque and the Turkish bath constructed by the Grand Vizier Ishak Pasa show that there used to be some Turkish districts built just outside the walls of the palace in the 15th century. Behind the palace, there is Gülhane square, where the Turks used to wrestle, play jeered and wooden ball. This place was believed to be Tiscanisterion, where the Byzantium governors had played a kind of Indian polo. Mustafa Resit Pasa read the Gülhane Hatti Humayun to the public in the Ottoman time whereas now there is a station there which is just one point of the railway on that historical peninsula.

Today, as the walls have been preserved from Ahirkapi to Sirkeci and as there is only one way between the walls and the sea, there are not any buildings here. As Ayasofia- Sultanahmet region is the most visited tourism center today, the whole region from Yenikapi to Ahirkapi is the scene of a touristic construction. Gülhane square is a source of attraction for the tourists and the public due to the Archeology Museum and the historical park behind the square.

Figure 2. Kadırga and Cinci Squares (from Encyclopedia of İstanbul)

Kadirga region, which is between Cankurtaran and Kumkapi, takes its name from the galley harbor which was constructed the Byzantium time. The oldest visual documents related to this harbor are Cristoforo Boundelmonti's map and Hartmann Schedel's panorama of Istanbul. As it can be seen on Giovanna Andrea Vasvasore's bird's eye view panorama in 1520, this small bay surrounded by walls, changed into a square in time with the closing of the path connecting the harbor to the sea. Eremya Çelebi wrote that in the 17^{th} century, gipsy locksmiths used to live in small wooden houses in this square. The Grand Vezir Köprülü Mehmet Pasa had the houses destroyed and cleaned the square. At the one end of the square, there is a complex of buildings consisting of a mosque, a madrasah and a tekke which were constructed by Mimar Sinan in 1571. Today, among the buildings that surround the square wherein there is a park are the Behram Çavus mosque, Bostancibasi Aliaga mosque, the Sibyan school (primary school), and two Turkish baths. In time, the natural harbour that was formed by the sea which passed over the Cinci square reaching Kadirga square has been filled up and these two squares were formed. In truth the port street, kadirga(in Rum small ship), Kaburga street are names reminiscent of the sea, ships and ports that remain in the past.

The second square in this region is the Cinci square, which has been connected to Kadirga square (in Rum small ship) with two narrow paths. Even though this square is quite big, the charm of Kadirga square can not be seen here. In Cinci square, with its old name Cundi square, there are streets leading towards this square and there are big palaces here as well. These were designed to face the railway which was divided with the railings and which extends parallel to the coast.

Figure 3. Kumkapı

There are ruins of old Byzantium walls parallel to the coast on the part of the railway facing the sea. The Küçük Ayasofia Mosque, which is the oldest historical building of that region is seen on one street behind the Cinci square. This building was changed into a mosque by Küçük Hüseyin in the period when Sultan Beyazit II was on the throne.

Kumkapi is one of the regions like Cankurtaran and Kadirga taking place on the Marmara coast of that historical peninsula. Kumkapi has been exposed to a lot of fires in its history like many other regions of Istanbul. At first the street which had wooden houses later was made into a protected area against the fires with the Ebniye Nizamnameleri, a series of regulations issued for this purpose in the 19th century. What is more, this region gained its urban position with the constructions and the streets which intersect each other vertically and which opened during this changing process. The two or three story houses erected on a narrow parcel of land, with small gardens and stone patios, which came together to form a series of houses, have created a different aspect than the wooden mansions situated in large gardens in Kumkapi. Also, the feature of having a non-Moslem majority can easily be seen from the moldings, the plasters, the window frames and the balcony banisters which exhibit the decoration style of that period.

Transportation to this region was provided mostly by kayık (little boat) till the 2nd half of the 19th century. When the railway started to pass from here in the 2nd half of the 19th century, major changes in the physical structure appeared in Kumkapi. If the road from Kumkapi station was followed, you could reach the seashore by passing under the railway bridge. Due to the fact that the sea was not filled up that time, the sea was just behind the railway. When you turned right and went up the stairs, you could come to Kumkapi station which was a little higher than the sea level. Kumkapi is one of the suburban stations which stretches from Sirkeci to Çekmece. Most of the stations on the suburban line were built by the Germans in Ottoman period. There seem to be differences with the ones built later in terms of architecture.

The dwellers mostly earned their livings on fishing and boat rowing, and today the most important part of this region is the square full of fish restaurants. This region was reshaped in the beginning of 1990's and it became a tourist attraction with fish restaurants and pubs both around the square and along the streets. However, with the changing social structure, the physical environment has been losing its traditional feature The detached, semi detached houses have been replaced by loading gauge and parceling and high buildings and inadequate restoration examples. The population of Armenians, Rums and non-Moslems, who gave their own style to the region, have decreased a great deal. Kumkapi is still the region of commerce, service and tourism with its fish restaurants and pubs, fish market and small shops.

Samatya is the next settlement where there was not housing that much and there were some churches and monasteries here. It is supposed that the Rabdos district of Byzantion was at the seashore of Samatya. The Studios monastery, which was built in the 5th century, played an important role in the development of Samatya as an almost religion center. Samatya preserved the identity of being a Christian region, long centuries after the conquest. The Armenians, brought from Nahcivan and Tebriz, were settled in Samatya, Yenikapi and Kumkapi in the Ottoman period. As a result of this settlement, some of Rum-Orthodox churches were allotted to the Armenians. One of the most important Rum-Orthodox churches in that region is the Analapsis church, which was built in the middle of the 16th century. The Moslem population in that region increased in the 16th century. The immigration that started in 1950's changed the physical qualities of that region. High buildings began to replace the two or three-story houses.

Figure 4. Samatya (Kocamustafa Paşa) Square and the Railroad Station.

The dwellers in this region are either workers or tradesmen. There are various kinds of shops and workshops all around the region. Some of these workshops may be going on their activities on the remnants of the oldest Byzantium buildings. Today, the neglected two or three-story wooden houses form the general shape of the region. As for the grate-planned streets, there are the traces of the new building formation after the fires they were exposed to.

The last station in the region which is inside the walls on the suburban line is Yedikule. Yedikule has been out of the defense area till the construction of the Teodosius walls. In the period of Constantinus I the population growth and habitation increased and at the end of the 4th century. It spread well out of the Samatya fort. In time new districts started to form in these areas. With the construction of the walls Yedikule gained the status of a habitation area for long years these green areas have provided vegetation for the necessity of the city life and even Evliya Çelebi has mentioned them.

Figure 5. Yedikule, The Square around the dunceons and the railroad bracks.

Right after the conquest, certain groups which came from various parts of the Ottoman Empire settled in Istanbul. For this purpose the Rums who came from Karaman had created a congregation around Yedikule. The Aios Constantinos church is one of the oldest churches of this congregation. Along the coast stretching from Yedikule to Samatya there were pubs administered by minorities. In the 16th century, the minorities have gradually deserted this region. Robert Mantran wrote in the second half of the 17th century that the Yedikule region is a Moslem region. In the 19th century the ports and railways and the institutions have also changed the general apparel of the city a great deal. With the construction of the railway that connected Istanbul to Europe, the fact that the state railway institutions were in Yedikule has been a decisive factor over the character of the region. The wooden houses that were characteristic of the region have been damaged to a large extent with the fires that were caused in the region. Today, the old street structure has been preserved to a certain extent but the apartments that have been constructed at random and without quality, have spoilt the character of the region. Even though the square at the entrance of the dungeons situated over the Yedikule section of the wall has still preserved its character, it has no real significance in the overall picture. It merely furnishes some respite from the narrow streets and crowded inhabitation in the district.

Within the historical peninsula of Istanbul, the habitation along the suburban line are the oldest textures of the city that have come to our day. It has not been a great attraction in the Byzantine and Ottoman Empire periods an habitation region. It has been preferred by the low-middle income class.

Figure 6. Historical Peninsula before the railroad

Figure 7. Historical Peninsula After the railroad.

This district's land rent is lower than the neighboring ones and the inhabitants of the region still appertain to same class. The historical buildings are of hundreds of years of age. Some of these are still used today and a part of these buildings are used as small factories, storage places and these are dangerous for the structure of the buildings. The open areas and the buildings and especially the squares have the apparel of the middle areas of the closed secluded districts. When this area is examined with respect to its physical properties, the buildings in the district have not changed much except for their having added floors to their structure.

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