"OVIDIUS" UNIVERSITY FROM CONSTANŢA
DOCTORAL SCHOOL OF APPLIED SCIENCES
DOCTORAL DOMAIN: CIVIL ENGINEERING

Contributions regarding the techniques and methods of conservation and restoration of natural stone buildings

- PhD thesis summary -

Doctoral supervisors:
Prof.PhD.eng. Grămescu Ana Maria
(Ovidius University from Constanța)
Assist.prof.PhD.eng. Ana Paula Ferreira Pinto
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PhD student,
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Constanța - 2014

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To

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We inform you that on 19.06.2014, 16:00 o'clock, in the meeting room of the Board of Advisors, Mamaia boulevard no.124, will be held the public presentation of the doctoral thesis with the title ***"Contributions regarding the techniques and methods of conservation and restoration of natural stone buildings"*** elaborated by engineer **Mihaela Drăgoi**, in order to receive the scientific title of "doctor" in the field of Applied Sciences, Civil Engineering domain.
The members from the public presentation committee are:

President: **Prof.PhD. Popa Constantin**
(Ovidius University from Constanța)

Conducători de doctorat: **Prof.PhD.eng. Grămescu Ana Maria**
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We send you the PhD thesis summary with the request to send us in writing your appraisals and comments.
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With this ocasion we invit you to participate to the public presentation of the doctoral thesis.

Prof.univ.dr. Bondrea Ion

Secretar Șef ISD
Bodur Elena

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Content

The PhD thesis contains: 354 – pages and a list with 223 bibliografic titles. The summary of the PhD thesis preserves the structure of the thesis regarding the content, the number of the chapters, figures, tables, calculation formulas and the list of references.

Key words: conservation, patrimony, natural stone, consolidation treatments, water repellent treatments

Chapter 1 Introduction

1.1. The current context of conservation and restoration of heritage buildings at national and international level

In the present thesis I wanted to deepen the knowledge regarding the behavior of structures made of stone or with elements made of stone, motivated by the need to adopt a coherent attitude, intervention measures that are compatible with the constituent material, important measures for conservation and protection of the existent built patrimony. Buildings made of natural stone represent a certain category from the point of view of the material used, but especially regarding the execution technology and structural design.

In this chapter I refer to the current national and international context of conservation and restoration of natural stone structures, to the existing concerns and directions towards the research in this area, the directions that will be investigated by the specialists and decision-making authority in this area both national and international. I reviewed the legislative documents and established the working principles governing the work in this field at the moment at international level and how they were implemented at national level.

1.2. Motivation of the research

My interest in the field of conservation of heritage buildings developed in time, ever since my student years, once I participated in the 3rd year of study at the advise of prof. PhD. eng. Ana Maria Grămescu, in an international practice program regarding the restoration of historical monuments on the restoration site of Banffy Castle in Bontida, Cluj. The thesis subject is an important and very actual motivated by the fact that in our region there are plenty of heritage buildings belonging to A or B class, that need to be taking conservation and restoration measures for preserving their authentic value for future generations. The studies and research done have contributed to broadening the knowledge base and the creation and founding of interventions solutions, particulary important for the creation of a legal framework containing sets of regulation and norms relating to the conservation and restoration of heritage buildings.

1.3. The objectives of the thesis

The research plan made during the thesis had the following objectives:

[1] Identifying structural models characteristics to buildings made of natural stone;

[2] The study of the factors that contributes to the degradation of natural stone as a construction material and methods to quantify them in the appreciation of structural safety assessment, research and investigation of some case studies;

[3] Making models calculation for quantifying the results of the research conducted;

[4] Contributions regarding the techniques and methods of conservation and restoration of natural stone buildings.

Given the vast area chosen for the research project and the limited time during the doctoral research, during the theoretical research and documentation I encountered difficulties in covering the hole domain targeted and decided together with my coordinators (supervisers) to cover theoreticly all the objectives proposed initially, but for the experimental part to put accent on the analisys of specific materials and their study methodology, followed later on during the pos-doctoral studies by structural analysis and preparation of model calculations. For the experimental research it is necessary to broaden the base of knowledge by testing and studying types of stone with higher porosity, to study the water repellent and consolidation treatments eficacity, their durability in time, to identify the need of repeating these treatments at certain time intervals id it is proven necessary. The experimental research must be conducted towards the experimental tests in situ and extended to different treatment methods in order to be more effective, but it also has to be analised the action of several products on this materials.

In view of the above, I directed the experimental research towards the study of the materials specific to natural stone masonry and to possible consolidation and water repellent treatments by using a certain type of product for their treatment and a certain application technology.

1.4. The content of the thesis

The doctoral thesis is structured in five chapters.

The first chapter – Introduction – presents the importance of the research in the current context of conservation and restoration of heritage buildings, the objectives proposed during the research study plan and the way to reach them, and also the difficulties encountered during the research activity.

In chapter two – Studies and research regarding the stone structures and component materials – I made a classification of the types of stone used in heritage buildings with some important characteristics necessary in their analysis; all of these can be brought together and represent the basic elements for making an initial database specific to Dobrogea area. In this chapter I also made an identification and centralize thetypes of stone and stone masonry in our country. An important sub-chapter is the one referring to the pathology of stone structures / stone material where I identify and investigate the degradation, the factors that produce the types of degradation of specific materials and of stone masonry overall. I have centralized the research results during the documentation and in situ research in a database, outlining the terms used at international level to expres and identify the terms used in order to better express and identify the types of degradation. To highlight the terms I used photos of the research done at international level by specialist and also with photos from the historical monuments in Romania.

I highlighted once again the importance of knowing the behavior parameters and the compatibility of the materials in conservation and restoration actions. I conducted a review of the intervention measures – structural and nonstructural –

proposed at intenational and national level. I highlighted the importance of preparation of buildings for these interventions by analyzing different methods that can be used. According to the documents studied I identified and described the nonstructural conservation and restoration measures: measures to eliminate the sources of wetting, measures for the conservation of stone outdoor exposed, desalination measures, measures against biological agents, measures of mortar restoration, measures of intervention with consolidants products and measures of intervention with water repellent products. Another sub-chapter identifies and describes the conservation and restoration structural measures: measures for constructive cooperation structure, measures for making the connections between the walls, measures to eliminate the thrust side, measures for establishing the route of gravitational and seismic forces, measures to eliminate the effects of twisting and measures to replace seriously decayed stone blocks.

In chapter three – Studies and experimental research regarding the conservation and restoration of natural stone structures – I realized some experimental studies regarding the possibility of appliying water repellent and consolidation treatments on materials characteristic to heritage buildings in Romania in order to propose intervention measures of conservation and restoration. The samples were taken from Romania and some of them were tested in the Civil Engineering Faculty laboratories at Ovidius University from Constanta and most of them were tested in the laboratories of Superior Technical Institute from Technical University in Lisbon. Chapter three begins by presenting the current state of the art at international level regarding the applicability of water proofing treatments and consolidation treatments. Then the study methodology adopted is described by mentioning the testing methods used and by presenting the working plan adopted for experimental research. The materials used is characterized physicly, mechanicly and colorimetricly: types of stone in the study and products used for treating the stones. Each type of treatment is described widely in a sub-chapter that has the main objectives:

- to define the study methodology of the treatments applied on the analized stone samples;
- knowing the effect of the water repellent and consolidation action applied during the water repellent and consolidation treatments on the stones studied;
- knowing and analizing some factors that can affect the effectiveness of the water repellent and consolidation treatments.

Chapter four – Studies and experimental research regarding the conservation and restoration of heritage buildings – Histria Fortress – begins by describing some instruments and study methodology of conservation, by making proposals to optimize the inventory methodology of heritage buildings with structure or elements from the structure made of stone and by proposing the structure content of an analytical form based on interdisciplinary research of the historical monument. In the second part of the chapter the study methodologies proposed are applied on a study case – Histria fortress, a building of great importance and value for our country. There are presented the conclusions of the study made and different proposals of intervention for the conservation of the stone structure of this monument.

In chapter five – Conclusions – are presented the research results and is measured the fulfillment of the objectives proposed at the beginning of the research, putting an accent on the contributions of the thesis at developing the knowledge in the field of conservation and restoration of stone buildings. An important accent is put on the results valorification and their dissemination.

Chapter 2 Studies and experimental research regarding the stone structures and the component materials

2.1. Identification of materials specific to natural stone structures

2.1.1. Natural stone

Stone is a natural material, like wood, this being one of the aspects important in the study of this material and of the element made from this material. In this sub-chapter I made a characterization of this material and a classification based on two criterias: mineralogical nature and genesis of the stone block, emphasizing the types of stone used mainly in the resistance structure of the heritage buildings in our country. For the area of interest I identified the types of existing stone with its characteristics depending on the area of origin.

2.1.2. Binders for stone masonry

Another important material is the mortar in the stone masonry. Next I made a characterization of masonry mortars used in the past till nowadays, for the patrimony buildings, such as clay mortars, lime mortars and cement mortars.

2.1.3. Classification of natural stone heritage buildings

Zidăriile din piatră naturală întâlnite la construcțiile existente realizate de-a lungul timpului pot fi: din piatră brută (zidării de piatră brută cu mortar; zidării din piatră brută poligonală; zidării din piatră brută inclusă în beton; zidărie uscată din piatră (fără mortar)), din piatră prelucrată (cioplită, moloane, poligonale, talie) – (zidării din piatră cioplită; zidării din moloane, moloane poligonale; zidării din pietre de talie) şi zidării mixte (zidării din piatră cioplită şi piatră de talie; zidării din piatră şi cărămidă).

2.2. Degradation of materials characteristic to natural stone buildings

The deterioration of the stones is a continuous and complex process that happens in time depending on the environment. This process varies for each type of rock, for each location because there are enough small differences in the environment or the internal stone structure in order to change the way it behaves or the degradation mechanism and the velocity to wich it decayes. The deterioration phenomena of the stone buildings by alteration of the material covers various processes that conduct to the modification of their aspects, dimensions and chemical composition.

Susceptibility of degradation and the intensity of degradation of a certain material happens because of two main categories of factors: intrinsic factors (that are related to the material) and extrinsic factors (that are related to other factors, location, environment, mentainance, etc.). The relation, the link between this two types of factors (intrinsic and extrinsic) is very high.

2.2.1. Trigger factors of pathologies

The relations between aggressive agents are very complex, so that often it is not possible to establish a main factor responsible for the degradation of the material. I identified two types of factors that can trigger or amplify stone structures degradation:

1. Intrinsec factors:
    - Mineralogical composition
    - Texture and structure
    - Porosity
    - Permeability (gas / water)
    - Hardness
    - Mechanical resistance
2. Extrinsec factors:
    - Climat / microclimat
        - Temperature
        - Relative humidity
        - Sun exposure
        - Rain (quantity, composition, pH)
        - Atmospheric characteristics
            - Gas (CO_2, SO_2, etc)
            - Solid particles
    - Construction:
        - Orientation of the construction
            - Wind, rain, soil
            - Leakings
            - Dried / moist
        - Surface finishing (smooth, rough,carved, etc)
        - Soluble salts
    - Random factors
        - Physical
            - Vibrations (traffic, cars, bells, etc)
        - Chemical
            - Oxidation
            - Dissolution and recrystallization
            - Hydrolisis of silicates
        - Biological
            - Micro- and macro- organisms

Assesment scheme for evaluation of degradation state and for selecting the intervention decision can be represented:

Existing materials Sampling	Buildings history Environment	Alteration phenomena
↓	↓	↓
Analysis New study materials	Climate Microclimate Agenți agresivi	Analysis Sampling Analysis
↓	↓	↓
Analysis and interpretation of the results		
	↓	
Evaluation of possible treatments		

2.2.2. Investigation of component materials degradation

The first phase preceding the rehabilitation project of a heritage masonry building will be the inspection and the detailed measurements of the stone degradation from the building. The second phase consist in instrumental investigations, for example physical tests, petrografic and biological tests. In this sub-chapter I reviewed the nondestructive and the destructive tests that can be made in order to determine the current state of degradation of the constituent materials.

2.2.3. Classification of stone buildings degradation

In the research studies on degradation and conservation of stone, the international scientific committee for the stone material studies from ICOMOS, identified problems related to the confusion in using the right terms between the practitioners and researchers. This is why the necessity to establish a common language appeared and so was made the stone degradation illustrated glossary. From this document, the activity to identify the type of degradation started and I researched the types of degradations existing in our monuments.

I identified five possible degradation categories encountered also at monuments in Dobrogea area, such as: cracking and deformation, detachment, material loss, color alteration and biological colonization. In table 2.5. I centralized the definisions of some terms used to describe the pathology of this material for a better identification, according to ICOMOS glossary and Romanian dictionary DEX, trying to emphasize the diference between existing synonymous terms. All types of degradation are illustrated in the thesis with photographic images.

2.3. The importance of knowing the behavior parameters in the conservation and restoration action of specific materials

The studies and analysis made at this research stage contributed to the development of the knowledge base regarding the constituent material analysis at natural stone structures, analysis that targeted the mechanical parameters of the original materials and also the way these properties modified in time because of the atmospheric factors, frost – thaw phenomena, reological phenomena, physical and chemical factors that altered these materials.

To approach each one of these measures presented above a set of analysis is required, investigations and calculations to establish the safety degree – risk – vulnerability of these constructions as a whole and also of their structural components. But the answer of an existing structure is different from the answer of a new structure whose structural modeling and material is mastered nowadays. At existing structures we are working with an existing material whose diminished / reduced mechanical properties are generating reduced characteristic resistance, with structures that have a structural conformation weakned in time by events that generated displacements and remanent deformations, that have a low bearing capacity and also a specific and traditional execution technology.

At all of these aspects we can add another important factor that also complicates the restoration activity: human negligence in the construction and ignorance in selecting the best interventions measures during the using of the building / structure.

The restoration and conservation works is an integrated approach that is mandory to conduct to the preservation of historical substance of the building, to respect the execution technology used and to insert some materials that are compatible to the constituent materials. These aspects are another important part that justify the importance of mechanical characterization.

Considering the above elements in order to establish some adequate interventions measures for the consolidation and conservation of the buildings made of natural stone is necessary to identify the type of stone used, the mortars used and the vulnerable elements. So, the observations, analysis and investigations targeted:

- aproximate identification resulted from a visual inspection regarding the colour, texture, structure of the stones, that permits inclusion in a particular class of rocks;
- precise determination of diverse characteristics when sampling and laboratory analysis are necessary.

2.4. The analitycal study of natural stone structures

The objective of the analytical analysis is to represent the real behavior of stone masonry structure in mathematichal terms. Before the analysis we have to find a model that fits our requirements, a simplified calculation model – because the majority of heritage buildings from natural stone are characterized by the complexity of forms and materials. We must make some idealizations in the analytical model, namely:

- idealization of geometry: creating a geometric model whose geometric representation can be a „shell” element, a solid element or a „frame”element. The decision of using a certain element is according to the complexity of the problem.

- idealization of material behavior: the base idealizations for the material behavior (masonry) are elastic behavior (linear), inelastic behavior (nonlinear) and plastic behavior.

The main hypothesis is that the elastic behavior of the material complies with Hooke's law – increasing deformation is directly proportional with increased tensions. Plastic analysis methods usually use for determine the load conducting to the colaps of the element as main hypothesis that this materials have zero tensile resistence and infinite compression resistance. The nonlinear method allows identifying the behavior of the masonry before colaps, but such an analysis must be based on experimental study of constituent materials in order to correspond to a real behavior.

The study in this chapter continues with the presentation of calculation equations used in specialized literature for analysis of stone masonry, focusing on the elements and factors that influence the analized material properties and highlighting the importance of their experimental determination.

2.5. Preparation of stone structures

The cleaning of the stone surface has as purpose eliminating the graffiti, the dirt or various parasites. This operation is a maintenance operation and must be applied very wisely in order not to produce more damage to the monument.

The cleaning action that has the purpose to eliminate alteration products and deposit present on the surface of the stone can:

- affect the future conservation actions;
- be responsible for their future degradation.

The necessary requirements for each cleaning action are:

- the cleaning action must be suficiently slow in order to permit its control;
- lack of damaging products;
- minimum reactive action in relation with the stone.

Cleaning methods can involve:

- mechanical methods, micro-abrasive methods, water, chemical pasta, laser;
- using herbicides and biocides;
- eliminating the calcareous deposits.

The cleaning action of the surfaces does not have its proper attention nowadays. The cleaning method must be carefully chosen and thought so that we don't cause more damage to the altered structure.

A problem is also represented by the material deposits on the surface of stone (that need to be removed because are damaging the material).

Here are some aspects that need to be considered in order to select the best cleaning method:

- value of the object to be cleaned (heritage monument or civil engineering buildings);
- nature and state of conservation of the substrate (it's cohesive, is stable or not, it's resistant or not);
- type of dirt;
- risk of unwanted side effects;
- the possibility to appeal to the use of water (water is often used as a mean of cleaning but often has undesirable effects on stone conservation).

Cleaning methods:

- -water spray and brushed lightly on small areas (very fine spray and a small amount of water, well distributed);
- -pastas and compresses: with water, chemical products, clays;
- -laser – applied at Jeronimo Monastery; is more controllable (when we have a good support and a degradated support with another color), we must mentione what intensity to use during the cleaning process, how we ajust the distance to guaranty the cleaning of the substrate on all its thickness; it's an expensive solution – it not a economical solution but it's fast and has a guaranty effect;
- -micro-abrasion (a method that increases the cleaned surface roughness and conducts to two consequences: it will moisten more quickly and it will degradate more faster because increases the surface water permeability); it is done by dry or wet sanding (sand jets sprayed with compressed air); it's important the dimension of the particles, air pressure, distance from the object;the training of the operator and his dexterity increases the surface roughness and increases water retain and the possibility to be affected by degradating factors.

2.6. Nonstructural conservation and restoration measures

In this chapter I will present a part of the intervention nonstructural measures on the existing buildings, measures that were taken or are still adopted in restoration projects, not only for heritage buildings.

2.6.1. Measures to eliminate sources of wetting

When you can see the alteration of stone due to moisture, the first measure is to find the cause - the source of water. If there are infiltrations those will be eliminated. There can also be leakings due to flaws in running water or sewage pipes. For the last ones the solution is to repair the water networks. Also, unproper heated spaces during the winter that don't have a proper ventilation can conduct to condensing, one of the most important sources of humidity in the construction elements. The solution will be to eliminate the causes.

To reduce the quantity of water from precipitations that affects a historical structure a first measure is to change the rain collecting system (spouts, gutters, sidewalks, etc). if the humidity is caused by the soil then the measures are more complex. In [26] F. Frössel makes the analysis of several situations indicating the protection measures necessary. From all of the measures proposed we mention: horizontal isolation in various versions (cutting and placing waterproof screens, drilling and injections) and vertical isolations (based on bitum or other waterproffing or waterrepellent products). However, horizontal isolations of stone masonry is difficult to make and at historical nuildings we also have severe restrictions for interventions. Vertical isolations will be designed and executed in conjunction with the situation in situ.

At the same time, to remove the humidity wich rises by capillarity in stone masonry there were also used methods like making a new foundation under the existing one, isolation of the foundations, designing ventilation gaps and electro-drainage.

2.6.2. Measures for conservation of outdoor exposed stone

Research carried out in order to find damaged stone conservation methods exposed outdoors, not led, so far, to the development of secure solutions. The process of silicification tried on stone surface has not proved effective. Preventing moisture exchange between the material and exterior the silicification actually caused a speedy decay of the stone. As a result, various solutions have been developed in order to preserve the scope - limited small stone elements to be stored in museums, in particular air conditioned space and components of buildings made of stone, small in size, which can be detached from the the place treated in the laboratory, and then brought back into work (statues, carvings, items modernatura).

If the parts to be kept in museums, special climate conditions, protective films can be made with wax, resin or silicone, for the treatment of parts that are to remain or to be brought into the open, in place, it is necessary that the building does not impede vapor exchange between inside and outside and also to lead to the regeneration of the protective crust.

Fig. 2.107. Conservation of a stone wall – São George castle in Lisbon (Portugal) – Protection of stone structures in museums

2.6.3. Desalination measures

A process for desalination of stone masonry surfaces recommended by American specialists in the restoration of historical monuments is the "cataplasms". Although the term is in the medical field, cataplasms were applied to historical buildings in order to do: a cleaning and degreasing surfaces that will achieve frescoes (the basic material of the clay paste); b delete the various dirt and contaminants insoluble in water, the stone walls and statues (in this case, add the pasta and chemical components).

In order to remove entrained salt water, which was recrystallized on the surface of the stone, having a scrub, using the extensive washing with running water and when the stone is not crumbly. Smaller stone parts, that are in poor condition, dress with absorbent filter paper. Moisture penetrates the material, and when it evaporates takes with it salts that remain soaked in the paper.

2.6.4. Measures against the biological agents

Plants or microorganisms growing on the surface of the stones can be removed by applying herbicides or fungicides - biocides. The components of the most widely used biocides are: organic chloride, copper salts, amines, borates, quaternary ammonium compounds, zinc salts. They apply as concentrate solutions on dry surfaces.

In some cases the existing colony on a stone surface biologist should be consulted to prescribe the correct treatment surface. For each type of problem we have found the optimum solution treatment, best product to be used to have the desired effectiveness.
We must have several tests on different areas to see how biocides work and to determine the correct amount of product to be applied. What matters the least - and sometimes is an economical solution - is that this test to be done in time, to make the test and wait a certain period of time to see how the product works on that area - and to apply gradually in phases. It is preferable (and at the same time efficient and economical) to apply 3 times 1% than once 3%.
Methods for selecting biocides:
- Experimental;
- The test panels in situ.

2.6.5. Measures for mortars restoration

Rehabilitation practice some requirements have become axioms. Thus, masonry mortars may include the following "restricted" basic: a restoration mortar should be compatible with that of the depth of the joint; b grout restoration not more resistant or waterproof than the original and have a low elasticity module, not more dense than masonry blocks connected; c mortar restoration to be easily replaced without damaging the wall surface.
Of course, we add "secondary" requirements such as: a restoration mortar is possible to have the same composition as the original historic structure; b grout restoration to be sustainable, at least for a time predictable and acceptable; c mortar restoration to fulfill both the role of the matrix component mechanical strength and rigidity to various actions and role of protection against moisture infiltration or heat loss from the enclosure of masonry; d grout restoration to help maintain the appearance of authenticity historical monument which is subject to rehabilitation.

2.6.6. Measures of intervention with consolidant products – consolidation treatments

Consolidation is a treatment that works in depth. Consolidated material must have a higher mechanical strength and to be resistant to environmental aggressions. Requirements to be met by consolidating products were originally set by Heaton. Heaton, in 1921, defined the features of the “ideal” consolidation product that can be used to treat stone, which remain largely valid today. By this author consolidating products:

- must penetrate easily and deeply, and stay in the stone during treatment; seems redundant but it's not, consolidants based on organic polymer should be applied with solvent in an greater or lower amount, solvent which are volatile substances and when applied two things can happen: a) the place where the product is applied moisten more; b) volatiles substances will come out in time and will bring with them to the surface area also the reactive substance that must remain in the depth of the stone;

- should not focus on the surface but to determine the formation of a hard crust that should strengthen sufficiently the altered areas and to make them resistant to degradation;
- it must not allow the entry of water, but at the same time allow water vapor exit;
- does not have to modify the color of the stone or change in any way its appearance;
- it needs to expand and contract similar to stone such a way that exfoliation doesn't appear;
- must not be corrosive or harmful when handled;
- must lead to economic solutions;
- must have a permanent action.

The consolidant agents can be:

- Inorganic compounds;
- Organic compounds;
- Compounds based on Si.

Product performance evaluation is done by determining the initial effectiveness of the treatment, the degree of harmfulness of treatment on the material and durability of treatment. Consolidation action depends on the characteristics of the support, the type of product applied, the application method and the amount of product applied.

The ideal consolidating product must satisfy three conditions:

- to strengthen the altered area of the stone on its thickness;
- the resistance obtained in this area has to be comparable to the resistance of the stone;
- the increasing of the resistance obtained on the altered thickness must be variable on the length of this zone according with the loss of cohesion of the stone in that area (the product has to penetrate deeper in some places and to stay near the surface in others, so that the total average penetration thickness is at least1.5 cm).

The choice of proper consolidation treatment depends on:

- Initial effectiveness;
- Potentially harmfulness;
- Durability of the treatment.

The literature has defined four main groups of consolidating products: inorganic products, alcosilani; synthetic organic polymers and waxes. The main groups of products are presented in the paper with advantages and disadvantages for each type of product.

2.6.7. Measures of intervention with water repellent products – water repellent treatments

The water repellent product has the role to reduce the penetration of water without clogging the pores. According to BS 6477:1984 “British standard specification for water repellents for masonry surfaces”, British Standardization Institute (BSI) in London mentiones that the water repellent treatments have:

- a reduced influence on the visual aspect of the treated samples;
- stability to chemical agents;
- UV stability;
- low permeability to water in liquid form;
- water vapor permeability;
- reversibility, or at least to be easily removed when its action is finished; when we are referring to the treatment of a certain material the reversibility principle that has to be applied to historical monuments accordint to Vienna Cart refers specifically to the compatibility of the materials used;
- absence of harmful products;
- easily to apply.

Product performance evaluation is done by evaluating the initial efficacy, the potential harmfulness of treatment and durability. The water-repellent action depends on the characteristics of the support, the type of product applied, the application method, the amount of product applied, the ability to inhibit the action of water absorption in the presence of soluble salts.

Water repellent products can be:

- Silani;
- Siloxani;
- Polisiloxani.

Water repellent treatment can be applied by:

- Brushing;
- Spraying;
- Rolling.

The selection of water repellent treatment has three criterias according to prof. Pinto:

- initial effectiveness;
- potential harmfulness – analising the secundary effects;
- durability – products that have an action for a long or short period of time, few years.

The objective of an water repellent product is not to prevent the total absorption of water, only to prevent it from penetrating deeply and to reduce the quantity of water absorbed in a certain period of time.

2.7. Structural conservation and restoration measures

In this chapter I will present some consolidation solutions recommended in the national code P100-3/2008 in order to be adopted depending on the type of the structural deficiency.

2.7.1. Measures for constructive structure cooperation

This category of work is required in cases where links between walls, corners, junctions and intersections are lacking or are insufficient to ensure adequate vertical sliding force transmission behavior of the composite section (shape in plan I, L, T). Development / reconstruction of these links is one of the conditions necessary for the "box" of space.

To achieve strengthening ties usually use the following procedures:

- Insertion of round steel bars in drilled holes sloping masonry and subsequently filled with mortar;
- Insertion of round steel bars in the joints of the elements involved;
- Insert concrete pillars at the intersection of walls;
- Introduction of girdles / tie rods in the floors;
- Post-tensioning.

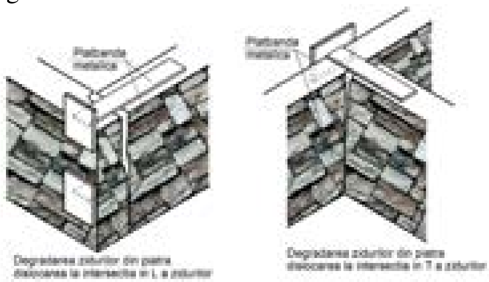


Fig. 2.117. Detail for stone walls consolidation with steel straps

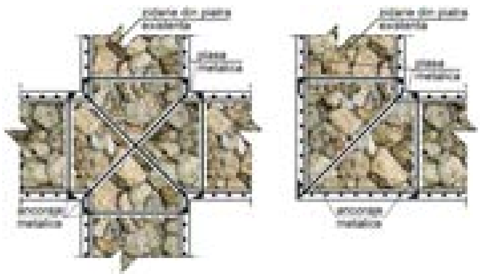


Fig. 2.118. Strenghtening walls intersections

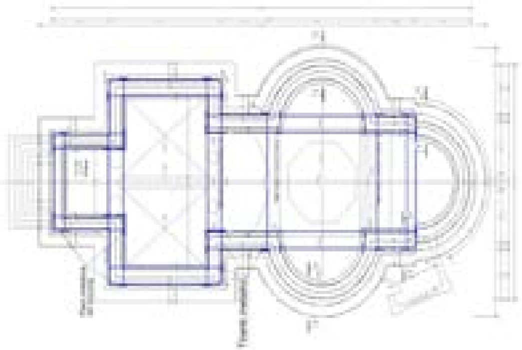


Fig. 2.119. Distribution of the metallic tie rods in an stone building structure

2.7.2. Measure for eliminating the effects of lateral thrust

The elimination of the side thrust by introducing:

- Steel tie rods, properly anchored in the masonry; is recommended that these tie rods have a slight pretension;
- Concrete girdles.

Lateral thrust data frameworks can be eliminated by:

- Adding additional elements recommended in the bottom soles, designed to take thrusts;
- Restoration roof structure as a static scheme without thrust.

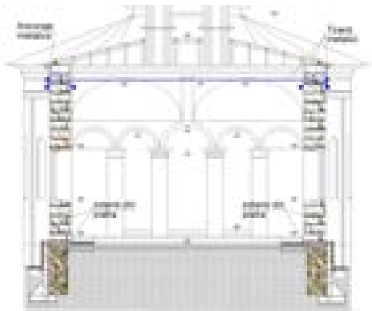


Fig. 2.120. Measures for eliminating the effects of lateral thrust

2.7.3. Measures for consolidation of stone foundations

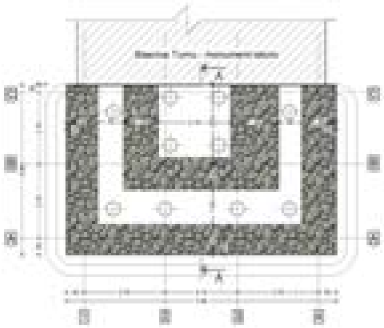
The consolidation processes for foundations are:

- injection of mortar in masonry stone foundations without mortar;
- reinforcement of the unreinforced masonry foundations;
- making another foundation under the existing foundations to achieve frost depth or layers with sufficient strength;
- widening the foundations.

The efficiency of this type of intervention is conditioned upon:

- ensuring cooperation with the existing structure for all types of loads;
- integration of new elements foundations throughout the building, taking measures to avoid differential settlements.

Fig. 2.122. Consolidation measures for the stone foundations of heritahe buildings – study case: the church from Târgşor



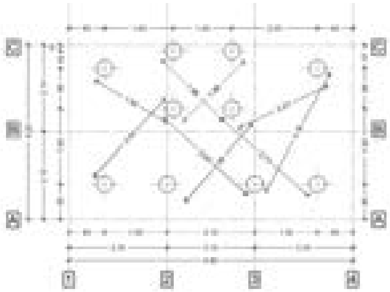


Fig. 2.126. a. Location plan of historic existing walls – b. Location plan for pilots

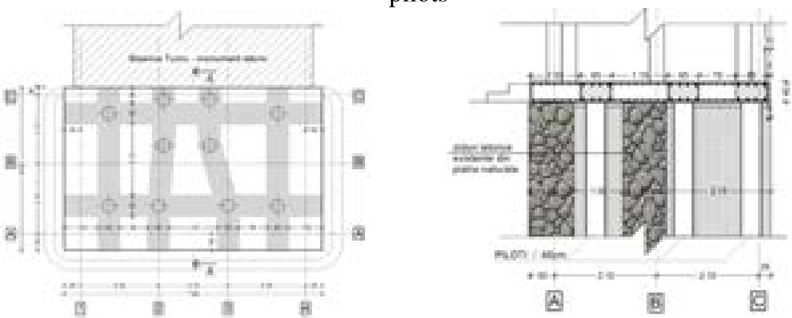


Fig. 2.127. Location plans for structural bound beams

Section a-a

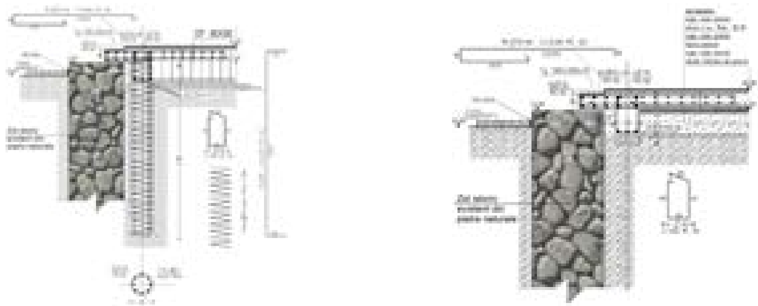


Fig. 2.128. Intervention example for a stone foundation

2.7.4. Measures for establishing the path of gravitational and seismic forces

To correct this deficiency we can proceed as follows:

a. structural walls are added to complement the initial discontinuities drainage system or efforts to restore the original structural system where the discontinuity is due to a further intervention.
b. add vertical elements, possibly only pillars, to take over direct vertical forces for bearing slabs with higher order.
c. make a system of girdles.

If the measures proposed are not made from different considerations we must examine the routes "diverted" from the forces and weaknesses identified in order to determine solutions to local consolidation.

2.7.5. Measures for increasing the redundancy

These measures are necessary when the existing structure does not meet the requirements specified in P100-1/2006 regarding structural redundancy, 4.4.1.2. Increased redundancy is achieved by:

- adding of new structural elements (masonry walls or columns) in the areas where the breaking of one element may lead to loss of stability of the whole building (e.g., in the case of “spaleților” / small-sized pillars at the corners of buildings);
- equipping other structural elements with adequate ductility enhanced by building works.

The elements added should have the strength and rigidity of the same order of magnitude as that of the elements with which they cooperate in the horizontal withstanding. Solution strengthening elements whose breaking endangers the stability of the building can be accepted only if the process used ensures a sufficient ductility.

2.7.6. Measures for eliminating / limitating the twisting effect

To remedy this shortcoming some structural walls can be added with sufficient rigidity to reduce twisting of the whole structure. To increase the effectiveness of this intervention it is recommended:

- introduce new walls in positions as far away from the center of stiffness of the floor;
- examining the possibility of increasing the stiffness of contour walls by boarded and closing the openings; the solution is especially recommended in the case in which the voids were created by the subsequent interventions.

When the measures proposed are not made of different considerations will be examined by a spatial calculation method that takes into account all structural irregularities, the state efforts will determine the structure and building solutions to local elements of which exceed the total request capacity of the respective strength of more than 10 ÷ 15%. Local strengthening considers the increasing strength and ductility of the items.

2.7.7. Measures for replacement of decayed stone blocks

It sometimes happens that some blocks of stone masonry to be so degraded that they cannot be rehabilitated, endangering safety and structural element they belong. In this case, although we are dealing with a monument, we will have to replace these buildings. Of course, it will necessarily observe some restrictions, such as: a. replacement stones will be as close to original viewpoints geological, color, texture, and porosity; b. the processing stones will reproduce as accurately as possible the originals; c. mortar connection will be compatible with the existing old structure; d. rebuild local engineering will be, if possible, a reproduction of the original, such as construction elements comply rehabilitated historic initial appearance; technique's occupational safety measures are strictly observed to avoid any kind of injury during intervention.

Chapter 3 Studies and experimental research regarding the conservation and restoration of natural stone structures

3.1. Initial considerations

In this chapter I pursued the realization of experimental studies research on the possibility of applying waterproofing treatment and consolidation treatment of specific construction materials specific to buildings in Romania, in order to propose possible solutions for intervention for their conservation and restoration.

Samples were taken from Romania and some of them tested in laboratories with nondestructive and destructive mechanical testing of the Faculty of Civil Engineering, University "Ovidius" of Constanta under the guidance of the scientific coordinator prof. Ana Maria Grămescu, and most of them were conducted in the laboratories of Superior Technical Institute from the Technical University of Lisbon, Portugal under the guidance of the scientific coordinator assist,prof.PhD.eng. Ana Paula Pinto and with the help of engineer Bruna Silva and the team of academics from both universities and technical personnel. In the first instance I have performed the characterization of the materials taken from the point of view of physical characteristics and mechanical properties (in situ and in the laboratory). Then after this characterization, according to the results of the tests I have established a work plan for experimental research. I kept in mind that the samples obtained from the material collected are reduced in number and therefore I sought to optimize the experimental and realize on the same samples as many tests, but this meant extending over more time.

Internationally and nationally there are defined rules, procedures, standards and recommendations for the characterization of materials (especially stone, mortar and brick), but nevertheless, in terms of the conservation of material these are not compatible with those commonly used for characterization of a new material used. There are differences in terms of size and the minimum number of samples that can be used in a study on the conservation of material, as in this area, in this vast area, number and size are imposed by specific study and the amount of existing material.

All the above mentioned and the studies on the subject existing in the literature justifies adapting these rules, procedures and recommendations in each situation to its original form, even in some cases they come to represent merely a starting point in defining methods and techniques used for research. Regarding the methodology of the study of the action of the products needed for conservation action the situation is similar. Although there are international regulations and recommendations regarding the work methodology and I recall here the RILEM [184, 185] and NORMAL [168] - specific to heritage building, analysis of various published works in literature is verifying some working procedures more frequently. In order to compare results with different tests in the literature the working procedure to be used has to be the same in both studies, and even in this case the comparison becomes difficult due to the diversity of product application procedures adopted and the state of conservation actual knowledge that does not yet sufficiently developed to study normalization methodology conservation treatments so has to satisfy all the needs of investigation and conservation practice.

ll the above confirms the idea that this area of study has many elements yet to be investigated and regulated.

In this context, it was considered that it is not sufficient to cover all existing available recommendations and was chosen to present a description of all test methods and recommendations followed in this experimental study.

3.2. Current state of the art

A great number of historical buildings, heritage buildings are made of natural stone, both nationally and internationally. If conservation is the objective, or reducing their damage or loss prevention the first step we must do is to characterized the types of stone (existing material) that can be identified, the state of degradation in time that can be measured by its spreading at this stage, severity and identified the risk of its loss. Then we need to understand and identify the causes and mechanisms of degradation and then we can understand the type of stone behavior in the context of the environment there.

In this process the material characterization is important to specify that although some stones may have similar chemical compositions, their behavior may differ greatly. A first criterion for identifying the type of stone can be based on the percentage and relative ratio of pores and cracks goals [216]. A second criterion for identifying the type of rock is achieved according to the degree of absorption of water into the stone [68; 73]. A third criterion for identification is by the strength of the material [131; 10]. It can be identified also other subdivisions of the three depending on the composition, texture, uniformity, but are less important in terms of overall performance of the material.

When the stone blocks are degraded in a very advanced stage there, one of the solutions that can be adopted is to strengthen the surface using the product. The role of this action is to try to return the stone as close to the initial strength. Treatment should be less expensive, easier to apply and to be used safely. Shall remain effective over time (decades) in a maintenance cycle to another. Treated stone block will have the same behavior when interacting with water, thermal expansion and elastic modulus as untreated stone to avoid domestic efforts and to ensure compatibility.

In terms of building products, they must have the following properties:

- ability to penetrate inside the structure of the stone;
- low viscosity and low contact angle;
- to strengthen the property when you reach inside to increase the strength of the stone.

These requirements can be obtained through:

- application of a liquid substance at an elevated temperature to harden as it cools (eg wax); this method has the disadvantage of not obtaining a low viscosity without excessive high temperature;
- using a consolidant dissolved in the solvent; as a disadvantage we cannot assume that the consolidant penetrates so long as the solvent and there is always the risk that consolidantul to be pulled back to the surface as the solvent evaporates;
- use a low viscosity system that undergoes a chemical reaction in situ which results in a solid product.

Stone consolidanțs are applied to the surface by brush, spray, compresses, pipette or immersion and penetrate inside the material by capillary action. Most of the materials that have been tested as of stone were consolidated with organic polymers, but there were also some inorganic materials that are worth mentioning because it is somewhat different way: calcium hydroxide and barium hydroxide. Then there are listed and described types of treatments that can be used: treatment of the calcium hydroxide $Ca(OH)_2$, barium hydroxide treatment - $Ba(OH)_2$, treatment with organic polymers.

3.3. Study methodology – techniques and testing methods applied

It is very important for the experimental research to establish ever since the beginning a study methodology, to set the objectives of the study and the desired results. In this chapter I will describe the tests done and the technology adopted during the study. As I mentioned before, a first stage is the initial characterization of the materials used.

3.3.1. Physical characterization of stones specimens

Physical caracterization of the stone types [184] and of other historical materials such as mortar and brick, can be done by tests that define:

- the internal structure of the analyzed material:
  - porosity accessible to water;
  - real density and bulk density;
  - maximum percentage of water absorption;
  - air permeability;
  - pore size distribution by porometry and mercury intrusion;
- properties related to the presence and movement of water:
  - saturation coefficient;
  - absorption of water by capillarity coefficient;
  - absorption of water under low pressure (box method or Karsten tubes method – pipe method);
  - water vapor conductivity coefficient;
  - evaporation curve;
  - linear dilatation coefficient due to water absorption;
  - absorption of microdrops of water.
- internal cohesion (structure):
  - dinamic modulus of elasticity by pulse velocity;
  - dinamic modulus of elasticity using using resonance frecquency measurements;
  - the“pull-out” test;
  - ultimate tensile strenght;
  - ultimate compressive strength;
  - ultimate bending strenght;
- mechanical properties of the surface:
  - surface hardness;
  - abrasion resistance;
  - surface hardness measured by rebound tester (sclerometer);
- durability of the material:
  - cristallisation test by total immersion (for untreated stones);
  - cristallisation test by total immersion (for treated stones);
  - cristallisation test by partial imersion;
  - frost resistance;
- different characteristics:
  - external aspects of the stones;
  - sampling method;
  - thermal expansion;
  - electrical conductivity.

In order to characterize the materials studied tests were carried out related to the internal structure of the material, properties associated with the presence and movement of water, the internal cohesion, surface and mechanical properties of the various other features.

3.3.2. Mechanical characterization of stones specimens

The mechanical strength of stones imposes their behavior to external mechanical action and its mechanical strength depends on its mineralogical components and its inter-crystalline connections. Mechanical characterization of varieties of stones was made by reference to tests that allow assessment of internal cohesion, such as its resistance to bending or compression strength. Other properties, such as velocity of propagation of ultrasound give indirect information on the mechanical properties. To achieve mechanical characterization I used the following tests:

- velocity of propagation of longitudinal waves;
- mechanical resistance to bending;
- compressive strength;
- profound resistance by micro-drilling method.

3.3.3. Colorimetric characterization of stones specimens

Colorimetric characterization of the material was carried out in a quantitative form by using a colorimeter.

The colorimetric characterization of the samples was carried out by a form of quantitative measurement with a colorimeter; the equipment, working principles and methodology adopted to achieve this characterization of the evidence is based on ASTM E308 [133].

Methods set out in the pointed norm was developed to be applied on surfaces appeared monochromatic and therefore need to establish their applicability in terms of surface elements necessary mediation results in this area, the number of readings that must be performed at each determination, and so on. Quantifying color could be obtained using the chromaticity coordinates of the CIE 1931 colorimetric system of reference in uniform color space CIE 1976. Was used for evaluating color CIELAB system, determining the colorimetric coordinates L *, a * and b *.

The quantitative assessment of color is presented via the CIELAB coordinates L *, a * and b * and complement the values of chrome, ie color saturation, C *, which is obtained from the formula $C^* = \sqrt{a^{*2} + b^{*2}}$. Complementary to the chrome, hue angle can be determined - H and can have values between 0 ° and 360°: $H_{ab} = arctg\,(b/a)$

It can also be determined the color differences of samples analyzed:

- color difference ΔE is the geometrical distance between the corresponding points with coordinates L1, a1, b1, respectively L2, a2, b2 corresponding test sample 1 and sample reference 2: $\Delta E = \sqrt{\left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]}$

- total color difference ΔEab can decompose in components defining the difference in brightness, chroma difference and hue: $\Delta E_{ab} = \sqrt{\left[(\Delta L)^2 + (\Delta C_{ab})^2 + (\Delta H_{ab})^2\right]}$

An important method of visual investigation of the surface of specimens is the optical microscopic method that was applied in this study. This allows the first optical study of surface specimens to identify surface defects or identify if the ladder allows it the intrusions of various substances.

3.4. Presentation of the work plan

In this research specimens were taken from several buildings in the south - eastern Romania and not only from their resistance structure. After identifying them, each block of stone taken was characterized and analyzed in order to extract from it a large number of identical samples, comparable samples. After analyzing and cutting the samples, I agreed with my supervisors to make a study plan for these specimens. This plan included:

- Identifying and finishing specimens obtained;
- Physical and mechanical characterization of specimens by non-destructive methods;
- Chemical characterization (when conditions permit) of specimens;
- Physical and mechanical characterization of specimens by destructive methods
- Dividing specimens for consolidation and waterproofing treatments;
- Applying waterproofing treatment and establishing environmental conditions and storage of specimens;
- Application of treatments to strengthen and establish storage conditions and environmental specimens;
- Physical and mechanical characterization by non-destructive methods of test specimens after treatment;
- Chemical characterization (when conditions permit) of specimens after treatment;
- Physical and mechanical characterization of specimens by destructive methods after treatment;
- Establishing the conditions for preserving specimens;
- Establish the possibility of achieving durability tests.

To characterize the specimens was attempted to do all of these tests on the same sample before and after treatment in order to obtain comparable results on the same sample and between samples. The first test performed was the color, the visual and optical characterization with the original color of the surface of specimens and to observe whether treatments applied later, especially products used will have the effect of modifying the original appearance of the stone, which is particularly important if the stone masonry remains apparent. These tests were followed by determining the porosity of the specimens, the application of the ultrasound method, the absorption of water under low pressures through the Karsten tubes, a water absorption by capillary action, the determination of the evaporation curve, the microdrilling and then the mechanical resistance destructive test such as vapor permeability. Mention that among non-destructive testing samples were dried according to RILEM recommendations in an controlled laboratory environment until reaching constant weight.

After this treatment, the samples were kept in the laboratory to constant weight at least 28 days, then all the initial tests have been repeated for each treated sample. All the preparation in the laboratory testing was conducted during the year in the laboratories of Superior Technical Institute in Lisbon and the Faculty of Civil Engineeing in Constanta and in situ testing period spread over three years. Each test was characterized by a period of preparation of samples for testing and material testing actual period. For example, to test the porosity accesible to water the preparation of the test lasted for 5 days (samples were in the oven for four days and 1 day in a desiccator vessel) and the actual test lasted 4 days, the test preparation of the water vapor permeability test lasts for 7 days (environment creation, assembly cells, cutting samples and drying them) and actually test lasted 14 days. Most other tests lasted one day, but the preparation of samples for testing lasted between 4 and 14 days.

3.4.1. Evaluation of treatment action – analysis criteria

Evaluation of the products used in the treatment was done by studying the initial effectiveness of treatment and its harmfulness on treated surfaces. Due to the heterogeneous nature of the stones that characterize any natural material and due to the relatively small number of samples available, it was always possible to achieve the same characterization of samples before and after treatment, trying to limit such variables that may affect the analysis results.

Procedures for applying products in the treatment of materials correspond to the application by brushing, by capillarity and by immersion of the the sample and were selected according to the objectives that they want to meet. The characterization of the presence of the product, associated with each of the study treatment was carried out by means of quantification at each stage of application of the values related to the use of the product, the quantity of product absorbed by the material and the dry mass.

Product consumption means mass difference between the beginning of the treatment and at the end of its application (weighing the recipient of the product) per unit area treated. In order to determine the real amount of product consumed the amount of product must be regarded as absorbed, the losses that would be present for various reasons, as well as losses of solvent due to evaporation during the application procedure have to be quantified. This form of accounting for the consumption of the product can be used during works in situ, but can also be accounted during certain laboratory operations.

Quantity of the product absorbed by the material is obtained by making the difference between the weightings of test specimens before and immediately after treatment (per unit area treated).

Dry mass was determined after the treatment by the difference in weight recorded before treatment and after one month after the treatment, relative to the initial weight before treatment of the tested sample. Dry mass of product is expressed as a percentage relative to the initial weight of the specimen. Application of the products was carried out by brush in the laboratory at a temperature of (22 ± 5) ° C and a relative humidity of (50 ± 20)%. The samples were first dried in an oven and then cooled in air and kept under laboratory conditions for at least a period of 14 days. Brush application was made to the refusal of the treated area, meaning that if the refusal is reached for a period of 30-60 seconds treated surface remains wet.

3.4.2. Evaluation of initial eficacity of water repellent treatments

Initial efficacy of waterproofing treatments was assessed on the basis of the alteration suffered by the material in terms of:

- water absorption - with the help of tests for water absorption under low pressure (Karsten tube method) and water absorption by capillary action;
- profundity treatment - waterproofing products can lead to different depths of penetration into the material depending on the application used and thus can produce alterations in the characteristics of the treated material. For the evaluation of the treatment were used tests such as water vapor permeability and water absorption by inverted capillary.

3.4.3. Evaluation of potential harmfulness of the water repellent treatments applied

Evaluation of potential harmfulness of the waterproofing treatment was carried out by alterations produced in terms of:

- permeability to water vapor - with the aim of measuring the rate of water vapor transmission of the product; it is necessary to use the same substrate as the substrate characteristics influence this rate. In this respect, the treatment in this feature was made for each of the different varieties of stone;
- drying features - curve determination was carried out by evaporation and drying index. It was assumed for the determination of the final drying of the stones the same time that was used before treatment as recommended by NORMAL;
- visually aspects - by quantifying color variations.

3.4.4. Evaluation of initial eficacity of consolidation treatmemnts

The consolidant must be applied so that it can be guaranteed adequate penetration in the porous structure of the stone, the penetration being affected by the absorption characteristics of the support, the nature of the solvent, the product concentration and application time. The initial treatment with enhanced efficacy can be evaluated based on the changes undergone by the samples of rock properties in terms of:

- internal structure: assessed, directly or indirectly, by determining the velocity of propagation of ultrasound, microdrilling resistance, mechanical resistance to bending and compressive strength with the exception of and Porosimeters. All these measurements were performed on samples before and after treatment with consolidated under the same conditions, except porometry.

- profundity of penetration of the treatment: assessed directly or indirectly through resistance variation at microdrilling profoundly by profiling the propagation velocity of ultrasonic, vapor permeability profile and determining water absorption by capillary reversed.

Some time ago the consolidant products had no objective in alterating the absorption characteristics of the support, its presence inside the material should, in principle, produce some reduction in water absorption capacity. For this reason, it can be used in the assessment of treatment and induces alterations in terms of:

- superficial absorption of water - by means of determination the absorption time of microdrops;
- water absorption - by means of the determination of water absorption under low pressure and water absorption by capillary. After the analyses made I could only do those tests related to water absorption.

3.4.5. Evaluation of potential harmfulness of the consolidation treatment applied

Evaluation of consolidation treatments potential harmfulness was done in accordance with the stipulations of the alterations produced by waterproofing treatments in terms of:

- permeability to water vapor;
- drying characteristics;
- visual aspect;

and alterations can be made in the expansion characteristics:

- thermal expansion;
- the absorption of water.

From the point of view of assessing the harmfulness of consolidation treatment in the experimental study were able to achieve only the first three tests mentioned here.

3.4.6. Durability of consolidation treatment

Although very difficult to assess, the behavior in time of the treated sample is an important aspect conditioned on one part by its own composition of products used and on the other side by the alterations that these products produce in the original material, that may in some cases accelerate the degradation process. In the laboratory we can evaluate the relative behavior of different treatments of artificial ageing tests. In these tests, for specimens subjected to ageing we are trying to assess their behavior over time. This objective can be achieved by salting tests, exposure to ultraviolet radiation and prolonged immersion in water. Determination of the alteration produced by each of the various actions of artificial ageing is made based on the comparison of the experimental results obtained before, during and after the tests referred to.

3.5. Description and characterization of investigated materials

3.5.1. Initial considerations

After the selection and preparation of the samples in order to fulfill the codes requirements for nondestructive and destructive testing, I had left a number of 20 stone samples. The samples were taking from the resistance structure of two ortodox buildings classified as group A in the national list of monuments, church Dara from 1650 and the church of Ratesti monastery in 1835, both of them in Buzau region, also from specific Dobrogea buildings, constructions from 1780, 1887, 1920 or more (Histria Fortress or Enisala) – constructions placed in historical sites or protected areas [87].

The research was donealso in the laboratory and in situ. For the laboratory work the samples were taken from different structural elements such as exterior walls or foundations. The stone blocks were prepared and cut into shapes according to the national and international standards. The preparation of the samples constitute in cutting the stone blocks in regular shape samples, finishing the surfaces to be as straight as possible, removing the dust particles, measuring and weightning them.

Fig. 3.23. Equipment used for cutting the stone blocks and making the samples

3.5.2. Characterization of the types of stones studied

For the physical, mechanical and colorimetric characterization the samples were dried until constant mass in the oven at (60 ± 5)ºC and then cooled down till the temperature of the environment in the exsicator. The constant mass is reached when the diference between two successive weightings at an uinterval of 24 hours is not more than 0.1% from the mass of the sample, determined with a oprecision of 0.01%. After systematic attempts on different types of stone studied it was concluded that the constant mass is reached after 96 hours, and this is the time that was considered as reference time for drying of the samples till constant mass during the tests. For the tests that this reference time was not respected I will refer to in the text by describing the initial conditions. The drying temperature recommended by RILEM is of 60±5^{o}C, temperature chosen over a greater one in order to avoid deterioration of organic materials used for treating the sample. Microscopic optical caracterization of stone samples was done in the material laboratory of Superior Technical Institute in Lisbon.

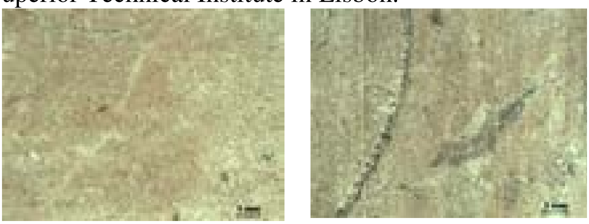


Fig. 3.25. Microscopic view – stone specimen type E

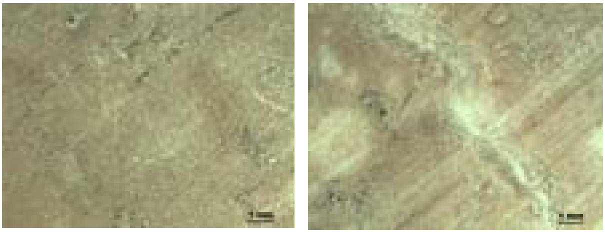


Fig. 3.26. Microscopic view – stone specimen type F

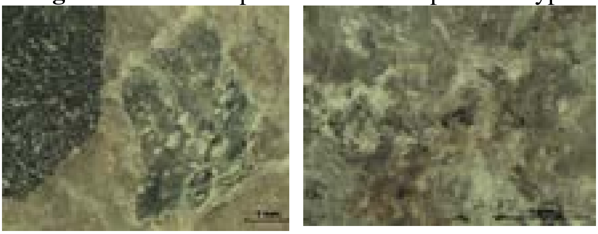


Fig. 3.28. Microscopic view – stone specimen type H

The samples for the porosity test have a reguar shape in order to be able to compare them, usually cubes of 4 or 5 cm, because this gives a better omogenity between the samples especially regarding the degree of alteration. I analysed samples from all four types of stone blocks (E,F,G şi H) from the area of interest. The data was registered in table 3.3.

Tabel 3.3. Values of porosity accessible to water for the analyzed samples

Stone block	No. of analysed samples	Porosity[1]
E	3	1,15% (±0,05)
F	6	1,87% (±0,10)
G	8	1,14% (±0,08)
H	8	2,54% (±0,20)
C	14	21,84% (±0,10)

Also for real densities the data was collected and centralized in table no. 3.4. where we can observe the volumic masses are not very different, the average value of real density is ~ 2700 kg/m^3 and apparent density is ~ 2634 kg/m^3 those values being characteristic in the literature to pure calcareous.

Tabel 3.4. Values of real and bulk densities of samples studied

Stone block	No. of analysed samples	Porosity	**Real density [kg/m^3]**	**Standard deviation**	**Bulk density [kg/m^3]**	**Standard deviation**
E	3	1,15% (±0,05)	2698	± 5	2667	± 6
F	6	1,87% (±0,10)	2700	± 7	2571	± 8
G	8	1,14% (±0,08)	2703	± 6	2672	± 8
H	8	2,54% (±0,20)	2694	± 7	2626	± 9

[1] Values presented represent medium values of the analysed samples for each type of stone specimen

	14	21,84% (±0,10)	2648	±9	2070	±23

For the determination of the saturation coefficient it is necessary besides the colectin of the data for the maximum percentage of water absorbed, to also registered the data with the amount of water absorbed in 48 hours. This percentage corresponds to the volume of the pores in which the water can enter easily, and it is expressed by the quantity of water that enters the samples pores in a period of 48 hours of immersion at normal atmospheric pressure reported to its dried mass. In table no. 3.5. someof the results obtained are registered:

Tabel 3.5. Values of the saturation coefficient

Stone block	No. of analysed samples	Porosity	% of water		CS
			Maxim (W_{max})	48h (W_{48h})	
E	3	1,15% (±0,05)	0,43 (± 0,1)	0,37 (± 0,5)	79 (± 6)
F	6	1,87% (±0,10)	0,71 (± 0,4)	0,59 (± 0,7)	83 (± 4)
G	8	1,14% (±0,08)	0,43 (± 0,1)	0,40 (± 0,2)	82 (± 2)
H	8	2,54% (±0,20)	0,97 (± 0,2)	0,48 (± 0,1)	80 (± 6)
C	14	21,84% (±0,10)	10,55 (±0,60)	7,80 (±0,30)	74 (±5)

* Values presented are registered average values.

The values for the water absorption by capilarity coeficient are presented in table no. 3.6 and were determined on samples of 5 cm. These coefficients allow us to distinguish two separate categories of materials with different absorption capacities: one mostly average (C) and stone H (including E, F and G) with low water absorption capacity. This behavior is justified by the values registered from porosity characterization.

Tabel 3.6. Values of the water absorption coefficient

Stone block	No. of analysed samples	Porosity	Water absorption coeficient by capillarity $x10^{-4}[g/cm^2s^{1/2}]$	Water absorption coeficient by capillarity $[g/cm^2h^{1/2}]$
E	3	1,15% (±0,05)	Unable to be defined	Unable to be defined
F	6	1,87% (±0,10)	2,58 (±0,30)	0,019
G	8	1,14% (±0,08)	3,61 (±0,25)	0,072
H	8	2,54% (±0,20)	29,00 (±1,72)	0,178
C	6	21,84% (±0,10)	392,03 (±82,38)	3,600

* Values presented in the table are average values of the registration made on the number of analyzed samples

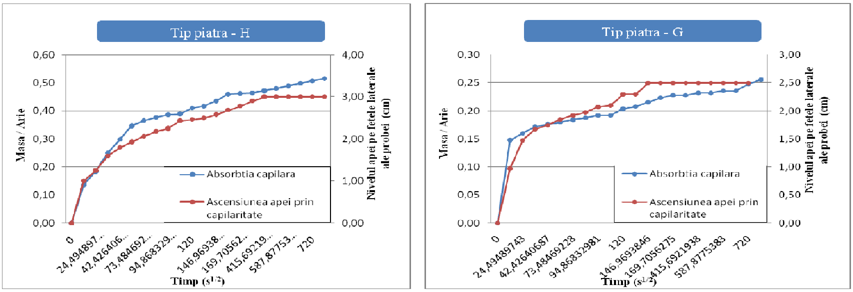


Fig. 3.33. Average curves of water absorption by capillarity determined experimentally for the types of stone studied (initial caracterization) and representation of the water level on the lateral faces of the sample: a. Type of stone H; b. Type of stone G.

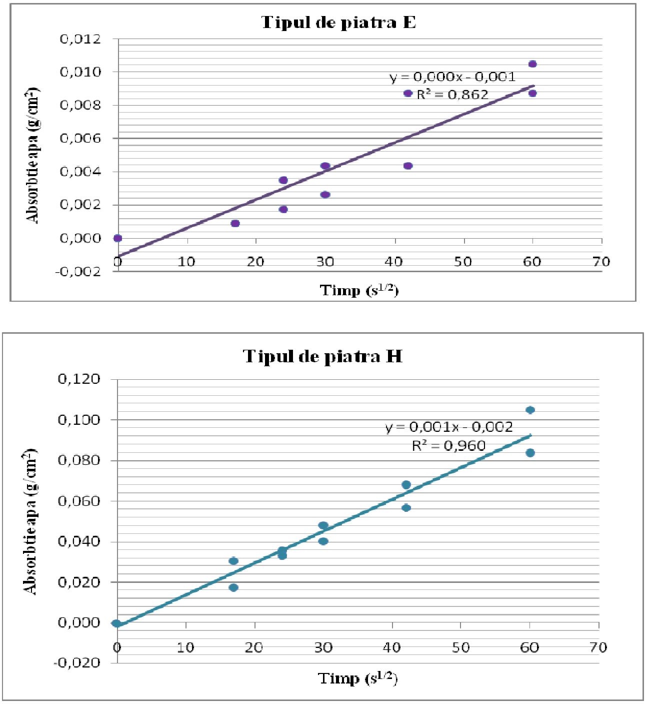


Fig. 3.35. Water absorption under low pressure in time for the types of stone analysed (average values)

Tabel 3.7. Values for the water absorption coefficient under low pressure by Karsten tube method

Stone block	Quantity of water absorbed in an hour [cm^3]	Water absorption coefficient [$g/cm^2s^{1/2}$]
E	0,055 (±0,005)	0,004

F	0,150 (±0,028)	0,008
G	0,200 (±0,051)	0,010
H	0,600 (±0,069)	0,050
C	2,65 (±0,47)	0,220

* Values presented in the table are average values of the registrations realized on the number of samples analyzed.

Fig. 3.37. Utilization of vertical Karsten tubes – dimensions

Tabel 3.8. Values for water vapor permeability coefficient

Stone block	No of analyzed samples	Water vapor permeability coefficient $x10^{-9}$ [kg m^{-1} h^{-1} Pa^{-1}]
E	3	Unable to determine
F	3	0,08 (±0,03)
G	3	0,12 (±0,05)
H	6	0,20 (±0,05)
C	6	9,49 $x10^{-6}$

* Values presented in the table represents average values registered on the number of analyzed samples

When you study water evaporation from a sample of stone is only possible to evaluate the flow, ie water loss per unit area versus time, it is not possible to obtain direct information about the state of water distribution in porous space. The study has been constant temperature and relative humidity in the environment have been preserved specimens and evaporation was performed. The average temperature during the test for stone and brick samples was 22.5 ° C (± 1) or 23 ° C (± 1.31) while the average relative humidity of 52% was recorded (± 0.04) and 65% (± 0.10).

Drying index characterizing the stone specimens studied ranged from values of 0.112 and 0.287, indicating a small value, as opposed to the brick test pieces having a dryness index of 2.588.

The mechanical properties of the stone can be assessed by determining the velocity of propagation of longitudinal waves, although the results may be influenced by various factors, in particular on the type of porous material and the percentage of water.

Tabel 3.10. Velocity of propagation of longitudinal waves

Stone block	No of analyzed samples	Average velocity registered values [m/s]	Apparent density [kg/m^3]	Porosity [%]	IQ [%]
E	3	6000 (±20)	2667 (±6)	1,15% (±0,05)	90,09
F	3	5545 (±112)	2571 (±8)	1,87% (±0,10)	83,25
G	3	6213 (±203)	2672 (±8)	1,14% (±0,08)	93,28
H	6	5288 (±98)	2626 (±9)	2,54% (±0,20)	79,40
C	6	4000 (±114)	2070 (±23)	21,84% (±0,10)	-

It can be seen that for specimens of stone blocks recorded values approaches "perfect" velocity value.

Determination of resistance towards micro-drilling method was performed on specimens dried under laboratory conditions, namely dry air oven or stabilized in the laboratory environment. These tests were performed with equipment SINT TECHNOLOGY [211], model DRMS Cordless 2006.

To avoid introducing errors due to bit usage, given that the analyzed material has a high mechanical strength (according to the study by destructive tests - compressive strength), early testing by this method was performed by microdrilling on a material whose properties are known - Anca stone, stone specific to Portugal, with a very high porosity around 28% ... 30% - and all the curves were registered, so that after every 20 minutes the procedure was repeteated on the same sample Anca stone to check if there are differences from the original curve recorded.

Tabel 3.11. Values of the maximum forces registered by microdrilling

Stone block	No of samples analyzed	Maximum force [N]
E	1	Unable to determine
G	1	Unable to determine
H	2	39,50
C	3	26,33

The colorimetric characterization of the samples was carried out by a form of quantitative measurement with a colorimeter. Equipment, working principles and methodology adopted to achieve this characterization of the evidence is based on ASTM E308 [133].

Tabel 3.12. Colorimetric coordinates and corresponding values of the chrome

Stone block	No of analyzed samples	L^*	a^*	b^*	C^*	H
E	3	68,80 (±1,88)	6,13 (±0,52)	5,49 (±0,54)	8,23 (±0,71)	0,73 (±0,03)
F	3	68,50 (±2,22)	5,67 (±0,36)	4,67 (±1,60)	7,41 (±1,30)	0,69 (±0,13)

G	4	74,04 (±1,18)	3,63 (±0,27)	3,86 (±0,65)	5,30 (±0,62)	0,82 (±0,07)
H	8	73,81 (±0,50)	3,87 (±0,48)	7,73 (±1,06)	8,66 (±1,09)	1,11 (±0,05)
C	12	44,32 (±2,15)	24,20 (±1,22)	27,92 (±2,07)	36,96 (±2,34)	1,12 (±0,05)

3.5.3. Characterization of the products used for stone treatments

Products used in the treatment of materials characterization study was conducted based on the product data sheet issued by the manufacturer, since the products used are commercial products and that the manufacturer is the entity best suited to characterize the products. It is Indicated, if it is possible, to verify the product declared characteristics by the manufacturer in order to remove any doubts and deviations regarding product properties used. Due to the lack of necessary equipment that could not be achieved and working hypothesis were considered real for all the features declared in the product data sheet. Next, I will describe the products used in the treatments of samples, focusing on their technical characteristics and application method recommended by the manufacturer.

Waterproofing product used to treat the samples was AGUASIL 100 and the manufacturer recommends it for that materials such as concrete, bricks, tiles, cement-based plaster or lime, natural or artificial stones, etc. AGUASIL 100 product is a solution with the solvent (polar solvent - containing less than 16% oil) containing siloxane oligomer with a concentration of 8% of active substance. The product has a high capacity for diffusion and thus guarantees, according to the manufacturer, good penetration into the material. Nonstick polysiloxane product hydrolyzes. The product belongs to the group of oligomers, polymer molecules permit for the walls to "breathe", in other words, permeability to water vapor.

To use this product to treat materials for waterproofing is important to respect several conditions:

The surfaces to be treated must be clean;

- Large cracks and holes must be repaired prior to treatment;
- Adjacent surfaces, windows and woodwork must be protected;
- Action repellent for more than 10 years;
- When joint mortar filled the joints of the facade it is preferable to wait for at
  least 8 days before application of the product due to the very high alkalinity;
- In the presence of lime in the mortar is preferable to wait 28 days before applying AGUASIL100;
- The waiting period remain valid for the fresh concrete;
- Crumbly supports must be treated with a curative consolidation agent (e.g. TEGOVAKON V) before treatment in order to restore the original mineral binder and the structure;
- the support treated with AGUASIL100 can be painted with a paint of the same chemical base (masonry, concrete, plaster).

For the consolidation treatments TEGOVAKON product was chosen, an ethyl orthosilicate mineral product used for consolidation of mineral materials disaggregated. The product is distributed ready for use, having at the base an silicon ester and methylsiloxane esters with consolidation effect (TEGOVAKON V) and water proofing effect (TEGOVAKON T). It is recommended to be applied on damaged stones, concrete and bricks with material loss from the surface and affected joints.

The main characteristic of the product TEGOVAKON are:

- The effect of consolidation;
- Monocomponent;
- Active substances compatible with the materials of construction;
- High power of penetration;
- Dry to the touch;
- Resistance to weathering;
- Conservation permeability;
- Normally it will not cause any optical alteration of treated surfaces.

3.6. Water repellent treatments

3.6.1. Initial considerations

Experimental study of waterproofing treatments aimed at contributing to:

- defining a methodology for the study of the application of these treatments on analyzed stone types (detailed in chapter 4);
- knowledge of the effect of the action of water repellent product applied in the treatment of analyzed stones specific to Dobrogea region;
- identification and analysis of factors that may affect the effectiveness of treatments.

3.6.2. Evaluation of initial eficacity of the treatment

Potential factors influencing the effectiveness of waterproofing treatments are:

- Amount of product applied: the methodology adopted in this study allowed the assessment for each type of specimen of the ideal amount of product to be applied to achieve maximum effectiveness, as was demonstrated that efficacy is directly proportional to the amount of product applied;

- Variation procedure for applying by brush;
- Method of application of the product (brush, by absorption through capillarity, by total immersion);
- The contact with the water: during the execution of the test certain situations have been detected with low initial effectiveness and alterations after the tests involving repeated and prolonged contact with the water, particularly because they were subject to various tests for water absorption and the determination of the porosity.

Determination of the percentage of water absorbed in 48 hours was found to be informative with regard to the capacity of the product to reduce the water absorption capacity under a total immersion. For application of the product by brushing, the values recorded are given in Table 3.14:

Tabel 3.14. Water repellent treatment. Percentage of water absorbed in48 hours

Samples	No of samples	Percentage of water absorbed in 48 hours E_{W48h}
E	3	37,83%
F	3	32,20%
G	3	12,50%
H	4	20,83%
C	6	10,25%

In the case of stone specimens under 3% porosity, the registered values must be considered very carefully so that the measured values do not present errors from testing. In the case of stone samples type H stone and samples type C test results were relevant and have demonstrated efficacy.

Tabel 3.15. Water repellent treatment. Absorbtion of water under low pressure

Samples	No of samples	Absorption of water under low pressure E_{ps_K}
E	3	98,18%
F	3	99,33%
G	3	99,50%
H	6	91,66%
C	6	96,22%

It was observed that the waterproofing treatment effect delay water penetration up to 5days. The effect of this is precisely not the fact that water will not penetrate the material, but the time that it will take to do that leads to a reduction in the amount of water absorbed in our study between 20-50%.

Tabel 3.16. Water repellent treatment. Absorption of water by capillarity

Samples	No of samples	Absorption of water by capillarity 24h E_c [%]
E	3	66,66%
F	3	52,38%
G	3	77,77%
H	4	80,55%
C	6	94,40%

3.6.3. Evaluation of potential harmfulness of the treatment applied

The alteration of drying surface characteristics produced by applying waterproof treatment may be responsible for the high sensitivity of the materials to some degradation processes, and in particular to salt crystallization. Thus, it becomes important to know the influence of the action of a certain product on the drying conditions of the material in order to be possible to evaluate the changes and potentially damaging treatment.

3.6.4. Conclusions

From the literature study it was noted that applying waterproofing treatment by brushing initially demonstrated appropriate and effective. In the future, the same type of stone would be interesting to carry out the study treatment by applying compresses, by spraying, by immerging or by absorption by capillarity for comparison of the technique and to demonstrate what is the appropriate technology to apply - especially at the very porous structure.

The absorption of water by capillary action, and the percentage of water absorbed after 48 hours are tested waterproofing products sensitive to the nature of the treated support. Using the concept of efficacy and based on the test of water absorption by capillary action, and the percentage of water absorbed in 48 hours, has been shown useful in determining the ability of the product to reduce the water absorption of the treated material. From tests carried out to assess the effectiveness of treatments, water absorption under low pressure is unique in that it can perform in situ. This leads to the need to increase information that is usually obtained by its use, therefore it is recommended that the test duration is increased to 24 hours or until the 4 cm^3 of water absorption are absorbed.

To assess the depth of penetration achieved by treatment the kinetics of water absorption by capillarity and the microdrops absorption [25] are the methodologies most informative and of general application.

The results confirm the idea that the action of existing products varies according to the material to be treated. It is therefore recommended that the study treatments is done on the representative material surface that is to be treated in the laboratory before it is done in situ.

3.7. Consolidation treatments

3.7.1. Initial considerations

The effectiveness determined on the microdrilling test is defined as a percentage ratio between the diference of the average forces at micridrilling on consolidate material thickness of the treated sample (MF_T) and of non-treated sample (MF_{NT}) reported to the average microdrilling force for the non-treated sample (MF_{NT}).

The effectiveness determined on the ultimate bending test is defined as a percentage ratio between the diference of the average bending forces for the consolidate sample (σ_{f_incT}) and the non-treated sample(σ_{f_incNT}) reported to the average bending forces for the non-treated sample (σ_{f_incNT}):

$$E_{\sigma f\_inc} = \frac{\sigma_{f\_incT} - \sigma_{f\_incNT}}{\sigma_{f\_incNT}} \cdot 100$$

The effectiveness determined on the ultimate compressive strength test is defined as a percentage ratio:

$$E_{\sigma c} = \frac{\sigma_{cT} - \sigma_{cNT}}{\sigma_{cNT}} \cdot 100$$

The effectiveness determined on the ultimate bending test is defined as a percentage ratio between the diference of the average compressive strength for the treated sample (σ_{cT}) and the non-treated sample (σ_{cNT}) reported to the average compressive strength for the non-treated sample (σ_{cNT}).

The effectiveness determined based on ultrasound velocity is defined as a percentage ratio:

$$E_{us} = \frac{V_T - V_{NT}}{V_{NT}} \cdot 100$$

The effectiveness determined based on the ultrasound velocity is defined as a percentage ratio between the diference of the average ultrasound velocity values registered for the treated sample (V_T) and the non-treated sample (V_{NT}) reported to the average ultrasound velocity values for the non-treated sample (V_{NT}).

The effectiveness determined based on water absorption under low pressure is defined as a percentage ratio:

$$E_{ps\_K} = \frac{P_{NT} - P_T}{P_{NT}} \cdot 100$$

The effectiveness determined based on water absorption under low pressure is defined as a percentage ratio between the quantitative diference of water absorbed in a certain interval of time before the treatment (P_{NT}) and after the treatment (P_T) reported to the absorption in the same time interval before the treatment.

The effectiveness determined based on water absorption by capillarity is defined as a percentage ratio:

$$E_c = \frac{C_{NT} - C_T}{C_{NT}} \cdot 100$$

The effectiveness determined based on water absorption by capillarity is defined as a percentage ratio between the quantitative diference of water absorbed in a certain interval of time before the treatment (C_{NT}) and after the treatment (C_T) reported to the absorption in the same time interval before the treatment.

The potential harmfulness of the consolidation treatment is being evaluated by color alterations, water vapor permeability and drying characteristics. In the same way as for evaluation of the initial effectiveness the evaluation of potential harmfulness of the treatment is done by assessing the material characteristics before and after treatment.

Ther potential harmfulness was evaluated by registered alterations of vapor permeability characteristics (N_δ) and by drying characteristics (N_{IU}).

Potential harmfulness of the treatment based on vapor permeability is determined with the relation:

$$N_\delta = \frac{\delta_{NT} - \delta_T}{\delta_{NT}} \cdot 100$$

Potential harmfulness of the treatment is determined based on the diference between water vapor permeability coefficient (δ_{NT}) and after treatment (δ_T) and the water vapor permeability coefficient before the treatment.

Potential harmfulness of the treatment based on drying characteristics is determined with the relation:

$$N_{IU} = \frac{IU_{NT} - IU_T}{IU_{NT}} \cdot 100$$

Potential harmfulness of the treatment is determined based on the diference between the drying index before (IU_{NT}) and after treatment (IU_T) and the drying index before the treatment..

3.7.2. Evaluation of initial eficacity of the treatment

There is a close relationship between the characteristics of the consolidant and the applying technology process. For this study we used a single application procedure of the product - brushing, but feel the need to remark that when more products are analyzed by several methods applied, it becomes even more important study of the factors which may influence or condition the consolidant action. Such a study of the influence of different applying treatment modalities consists of a comparative analysis:

- Increases surface hardness resulting from treatments applied by immersion, capillary absorption, compresses and brush;
- Microdrilling resistance, the resistance of the treatments applied by immersion, capillary absorption, compresses and brush;
- To reduce water absorption over time for a period of treatment applied by immersion, capillary absorption, compresses and brush;
- Variations in color (brush / suction capillary / compress);
- The profundity achieved by the consolidant action in treatment resulting from immersion / brushing / suction capillary / compresses;
- The increase in flexural strength and speed of propagation of longitudinal waves and water absorption alterations made in immersion / capillary;
- Microdrilling resistance (brushing / different quantities).

Following research in the literature we have found that the application by brush leads to enhanced actions similar to immerged of sample as proven by professor Ana Paula Pinto [76].

Tabel 3.22. Consolidation treatments. Increasing of ultrasound velocity

Type of stone	Velocity [m/s]		Increase E_{us} [%]
	NT	T	
E	3200 (±80)	3670 (±80)	17 (±1)
G	4520 (±260)	4960 (±370)	16 (±5)
H	4950 (±120)	5240 (±30)	7 (±2)
C	4750 (±200)	5190 (±160)	7 (±1)

Determination of microdrilling resistance as a method to evaluate the action of an consolidation treatment is a very good method that offers lotds of informations, in laboratory testing and in situ also, especially referring to the distribution of the consolidant inside the depth of the material.

Tabel 3.23. Consolidation treatment. Microdrilling resistance.

Samples	Microdrilling resistance [MPa] NT	Microdrilling resistance MPa] T	Increase of the microdrilling resistance E_{MF} [%]
C	26,33	35,63	35,32%

The compressive strength results and the increase of compressive strength resistance after the treatment is presented in table 3.24.

Tabel 3.24. Consolidation treatment. Compressive strength resistance

Tipuri de piatră	Compressive strength resistance		Increase of the compressive strength E_{σ_c} [%]
	NT	T	
C	52,36	66,12	26,28%

Compressive strength resistance certify the conclusions drawn by the results obtained by microdrilling.

The presence of the consolidation products in the thickness of the material is reflected in the alteration of porous space of the original material and, by consequence, of the characteristics related to the presence and movement of water in its interior. These alterations don't permit the direct evaluation of the consolidant action but offers us with important informations regarding the global evaluation of the consolidation action.

Tabel 3.25. Values for porosity accessible to water

Samples	Porosity [%]		No of samples
	NT	T	
C	21,84%	19%	10

Tabel 3.26. Consolidation treatments. Parameters related to the alterations of water movement in the porous space

Samples		Porosity	Percentage of water absorption %		Saturation coefficient	No. of samples
			maxim	48 de ore		
C	NT	21,84%	10,55	7,80	74	6
	TG	19%	8,70	7,66	88	6

3.7.3. Evaluation of potential harmfulness of the treatment applied

The importance of knowing the different characteristics in the consolidated areas and the original material for estimating the potential harmfulness of the applied product conducted to the necessity to apply a certain consolidation product most representative for the thickness that needs toi be consolidated.

All the consolidation treatments were responsible for superior reductions of 10% for permeability of samples according to table 3.28.

Tabel 3.28. Consolidation treatment. Water vapor permeability coefficient

Samples	Water vapor permeability coefficient $\cdot 10^{-9}$ $[kg / m \cdot h \cdot Pa]$		Decreasing of water vapor permeability N_{δ} [%]	No. of samples
	NT	T		
C	9,49 x 10^{-6}	8,36 x 10^{-6}	11,90%	3

All the consolidant products generates alterations of the water evaporation kinetics for the stone samples studied with an drying time of 820 hours but the alterations overall are insignificant.

Alteration of colorimetric characterizations produced by consolidation treatments was made for all types of analyzed material. The coordinates L^* and b^* were most afected by the application of the consolidant having registered at all the stones the reduction of L^* value and increasing of b^* that can be translated by the darkening and yellowing of the treated surfaces. If $\Delta E^* > 5$ then the variations of color are visible to the human eye [120].

3.8. Final considerations and new experimental research directions

3.8.1. Final considerations

After the analysis procedure and results for waterproofing treatments I proposed a methodology to study these treatments applicable to stones studied. The task of keeping historical and artistic value of buildings made of stone is a complex one that requires particular care in defining conservation interventions. The complexity comes from the diversity of situations encountered, especially stone varieties, forms and processes of degradation present in buildings, as well as various environmental exposure conditions.

Interventions on a particular monument must be well studied in particular for that monument, that type of material, because the use of procedures, methodologies and inadequate product may be responsible for irreparable damage leading to loss of valuable items and buildings high heritage.

In recent decades there has been in our country a beginning and an increasing need to adopt higher conservation of heritage in all its forms, with the objective to treat or delay the processes of degradation and thus extend life that monument. Current state of knowledge in this area does not allow for easy of a decision most situations, particularly those that relate to the application of treatment products. The definition of the study methods and criteria for acceptance or rejection of products for treatment are priority issues in the area of conservation of stone. Defining methodologies accepted consensus study the existence or non-applicability criteria of applicability are presented as two fundamental aspects in deciding on intervention planning and choosing the right product. This study tried to help define the methodology for use in the study of the product's Wet stones on specific Dobrogea area especially, but not only. Conditions in which the tests and the previous ones and they will have to be carefully controlled and identified in terms of the percentage of water in the treated materials and the time interval between treatment and baseline.

The ability of water-repellent products to reduce the water absorption of the material support is adequately measured by water absorption test by capillary action. Using the concept of efficiency (Ec) defined throughout the test proved quite informative. Test pressure low water absorption achieved for an hour proved less informative. The method may be useful if its duration is prolonged to 24 hours. The results of this test can be expressed by the concept of effective (Eps_K) refers to the amount of absorption 24 hours. Due to the recommendations of the laboratory provision that all the side faces to be waterproofed, the determination of the percentage of water absorption after 48 hours is an easy and rapid execution method, quite a lot of data that are based on the ability of the product to reduce the water absorption of the carrier. The action of the products may be expressed by defining efficacy (EW48h) measured by this test.

Knowledge of the relative depth of penetration achieved by the product can be obtained by means of the Absorption of water by capillary action down. When using the latter test, it is recommended to characterize heterogeneous materials absorbing water by capillary action through the opposite face of the treated prior to application of the waterproofing treatment.

Study the potential harmful treatments waterproofing should be done with two objectives: on the one hand the possibility that products must be evaluated to produce significant changes in visual appearance of the surface and on the other hand, evaluating the possibility that they are responsible for the growth or development of new forms of media decay.

Chromatic alterations of the surface can be evaluated qualitatively by visual observation and quantified by determining changes in chromaticity coordinates. Characterization by the permeability to water vapor and the evaporating curve is not carried out and easily performed. After such treatment, the evaluation is important to assess the harmfulness and crystallization of salts.

Regarding the exposure, when conditions permit, it is recommended that the subject be treated and followed over time in terms of the sustainability of treatment in terms of its evolution over time in real terms exposure.

3.8.2. New proposals for experimental research directions

The study treatments in subsections 3.6. and 3.7. developed interesting aspects that can become lines of investigation for the development of future work, for example:

- Verify the possibility of generalizing the methodology proposed here for waterproofing and strengthening treatments applied to all varieties of stone specific area of interest - Dobrogea;
- Develop specific work procedures with the objective of defining normalized study on the conditions of application and exposure before and after treatment, the time to be observed between baseline and procedure application and effective enforcement of the products;
- Criteria for acceptance / rejection of waterproofing and building products;
- Development of specific studies with the objective of assessing the stability of waterproofing treatments to situations of contact with water and consolidation treatment in time - their sustainability;
- Stability studies for samples exposed to the natural environment;
- Development of specific studies that allow correlation of potential harmfulness waterproofing treatments produced changes in the course of water evaporation test.

Chapter 4 Studies and experimental research regarding the conservation and restoration of heritage structures – Histria fortress

4.1. Instruments and study methodology of conservation

Following theoretical and experimental research carried out during the five years of study, I proposed a study methodology for waterproofing treatments and consolidation treatments that can be applied in the study of stone conservation treatments, as guidelines, based on my the results outlined in Chapter 3 and 4. This chapter will gather all knowledge acquired during these five years of study based especially on the experience gained during the conservation and rehabilitation work where I had the opportunity to participate due to my PhD supervisors, Prof. univ.dr.ing. Ana Maria Grămescu - participation in projects to rehabilitate the national heritage buildings made by Ovidius University, Faculty of Civil Engineering, for example: Ratesti Monastery – Buzau County, "Schimbarea la fata" Church - Constanta County, Târgşor Monastery – Prahova County and with ş.l.dr.ing. Ana Paula Pinto, along with PhD student Bruna Silva - participation in the project of Conservation of Moorish Castle in Sintra, Portugal, in order to propose methodologies for specific study on heritage buildings designed to ease the task of specialists in conservation.

The proposed study methodology for waterproofing treatments include the following sequence of steps:

1. Preparing the study by sampling and cutting specimens, material characterization that is intended to preserve - natural stone - from physical, chemical, mechanical, optical, petrographic point of view and also conservation product choice. Another important aspect is to set goals based also on the preparation of a work plan. It is important to keep in mind that the study is indicated to be done both in laboratory and in situ, as for the results to be as close as possible to actual behavior.
2. Determination of initial effectiveness: it aims to assess the ability of the product to achieve an effective treatment by direct evaluation of its action and prior determination of the conditions under which this can be achieved, namely the quantity of product and application procedure.
   At this stage it must be defined the "ideal" quantity of product which must be applied. This is obtained on specimens with regular size because of the ease of application of this treatment by brush and the possibility to compare the results obtained.
   The "ideal" quantity of water-repellent product is obtained when the absorption determination tests of microdroplets and the contact angle of water with the surface material have higher values (100%, namely 90°), namely when the water absorption under reduced pressure determined on a 24-hour test time does not show significant alterations to the values previously reported on product application. If the increase of amount of product applied does not work and does not allow to meet the above

conditions, it is recommended to end the product study and to begin the study of a new product. This stage concludes by evaluating the deterioration of water absorption characteristics of the product by capillary action, and the percentage of water after 48 hours, on specimens that have four side waterproof faces, namely 5 of 6 waterproof sides.

If it can be seen with open eyes the discoloration of the treated area in a building heritage with genuine value, then you may decide that the product will not be used, even if the action of water yielded favorable results and trends.

3. The stability assessment of potential treatments: this stage aims to assess alterations of color produced by products application and the stability to ultraviolet radiation. At this stage, the stability of sealing treatment is assessed as defined above, through tests which includes ultraviolet radiation (due to the fact that these treatments are used in the outside environment and thus exposed to the sun), though tests involving prolonged or repeated water contact and evaluating color deterioration. Products that satisfy the requirements of previous stages pass in the fourth and fifth stage of the study, steps that can be implemented in parallel.
4. Evaluation of potential harm: this stage assesses the potential harmful products, with the objective to obtain information that will allow the assessment of associated risks on product application.

   This phase aims to assess the potential harmful products used and thus obtain information enabling the estimation risk associated within its application. This objective is very difficult to assess because there are certain shortcomings in this area. At this stage, it is proposed to evaluate the behavior of untreated and treated samples in relation to crystallization tests of salts and the ability support to "breath", the last one achieved by quantification of alterations characterized on evaporation and permeation curve to water vapor after the treatment.

   It is recommended to abandon the products study that lead to significant reduction of drying characteristics and resistance of the support to salts crystallization and completion of this stage. It is important at this stage to carry out these assessments, if the material allows, on the same specimen, in order to better action of the product, comparing the same area, not different areas.
5. Evaluation of sustainability in the natural environment: this stage evaluates the exposure in real conditions.

   At this stage it is recommended:

   - Preparation of treated and untreated samples of considerable size (pieces of stone wall) - testing will be done in situ or in situ-like conditions;
   - Characterizing the wetting ability by determining the contact angle of water with the surface, absorption of water under reduced pressure for a test period of 24 hours and quantification of color alterations produced by the treatment, to the extent that these tests may be carried out;
   - Implementation of regular time control actions embodied in a building maintenance plan; identify situations of low stability of waterproofing

treatments at the end of an year of exposure leads to the suggestion proposed that this evaluation will be done annually [25];

- When the analyzed areas present loss of repellent characteristics (eg determining the contact angle <90°, water absorption with low pressure - directly in situ) it is recommended to analyze the evolution of water absorption characteristics and if after a year of exposure there are yet recorded losses, these products present a low practical interest because it requires maintenance works with incompatible periodicity in economic terms.

The study methodology proposed for consolidation treatments is a general guide for the study of the product consolidation action that was established based on the principle that is worth conducted the study treatments which have an action of effective consolidation.

The first stage has as main objectives the assessment of potential applicability of condolidation products and defining the application conditions that allow to obtain satisfactory treatments which must be carried out in two phases: assessing the potential applicability of consolidant and the selection processes. It is recommended that during the first stage, the assessment of the consolidation products applicability will be realized through the results based on the determination of resistance to microdrilling, thus being the most direct assessment procedure of consolidant action. Little experience of using this procedure along with lack of indicative criteria understood as esential for obtaining an effective consolidation action, slows the presentation of acceptance/rejection conditions of the product. From the literature studied and shared knowledge from experimental work of my tutors, it is recommended the detection of consolidation action on a minimum thickness of 15 mm - this is an acceptable baseline. Application of consolidation products by capillary action in the first phase, is recommended for a period of 3 hours - process characterized by low product consumption and repeatability. If the test results do not lead to the depth of the material, then we can try testing the application for more than 3 hours. If satisfactory results are obtained (the presence of strengthening on a thickness near the value of 15 mm) the study should be abandoned.

In a second phase of this stage there is intended to determine the evaluation of the consolidant by determining the possibility to achieve the same or similar result through other application process, such as immersion for 24 hours or brush. In situ treatment is more handy an application treatement by brush, but it is quite difficult to determine at this stage the depth to which the product has reached especially if the porosity of material is relatively low. This will be achieved if the first stage results were obtained in depth of material. The interest for the application process by brush is based on the fact that in situ is the most common and easy method to achieve. Dependence of the product's application method leads to the proposal that the study will be continued in the next steps, on specimens treated according to the procedure, with the best results in the first stage.

The second stage aims treatment characterization on color deterioration, porosimeters, water absorption and superficial charateristics toward ultraviolet radiation, the evaluation stability of such treatment with X product. As a conclusion in the second stage there should be made following actions:

- Characterization of porosimeters and water absorption by capillarity;
- If the product will be used in an indoor environment, this stage ends with the assessment of color deterioration, by controlling the total color differences; otherwise it will go to:
  - Exposure of treated samples to a number of hours (the number is determined based on the natural environment) of ultraviolet radiations (e.g. Pinto in [25] propose for research studies 1000 hours);
  - Evaluation on the stability of surface hardness characteristics to UV radiation, after the determination of hardness by scratching the surface, in cases where the surface hardness recorded at the end of exposure hour is lower than the original hardness of the support; it is recommended the selection of a new product to achieve the desired objective;
  - Evaluation of color deterioration, in the case where the the treatment indicates characteristics stability after exposure to radiation; if there is no deterioration on visual appearance that is considered limiting ($\Delta E^* \leq 5$) and reducing UV stability is not detected, we can proceed to three and four study stages.

In third stage we propose the evaluation of recorded alteration to "breathing" capacity of supports (by the characteristics of drying / evaporation and water vapor permeability, a water absorption at low pressure), alteration of water absorption (per samples treated by immersion in vacuo) and the relative behavior of treated and untreated specimens toward the crystallization of the salt stress tests, in other words the potential harmful effects of the treatment. It is recommended the relinquishment of study product which produces important alteration on "breath", "expansion" characteristics and support resistance to salt crystallization substrate, due to harmful potential. It can be continued the study on products suffering only alterations related to "breath" and "expansion" characteristics of support, given the lack of internationally accepted criteria for these characteristics.

The stage four aims to estimate, in real exposure conditions, the durability of treatment and the posibility that these might be responsible for reducing support durability that has been applied. In methods, during this phase is recommended:

- Preparing and exposing treated and untreated specimens of significant size in situ and in the laboratory;
- Assessment of consolidating stability proceedings using as reference the behavior of untreated specimens;
- Characterization of surface hardness, resistance to micro drilling, water absorption under reduced pressure and color deterioration;
- Adoption of annual control actions since the trial sequence has determined early superficial degradation of specimens consolidated at the end of a year of exposure.

In order to verify the applicability of products in real in situ conditions, it must performs the following:

- Characterizing treated supports, when possible, supported by a specimens study in laboratory;

- Determining the altered profile, by determing the resistance to micro drilling, with the objective of determining the thickness of material required to consolidate;

- Application of consolidants according to procedures selected based on laboratory studies, or, if this is not possible with other methodes more appropriate to actual conditions described in the work study;

- The quantification of product consumption and the quantity of product absorbed by the support material;

- Assessing treatment outcomes through micro drilling resistance (especially in the case of treatment with compresses or brush);

- Treatment results evaluaton by compressive strength (in contrast to the water repellent treatment, the consolidate treatment changes the internal structure of the building material on which it is applied and thus the mechanical tests demonstrate their relevance)

- The control results over time, through periodic inspection actions that allow the determination of maintenance actions and / or repair and obtaining relevant information supporting future interventions.

In case of preserving treatments, the decision to intervene with consolidation products must be well analyzed and verified because it produces changes inside the material, irrreversible changes. I believe that in this case should focus on the sustainability of intervention and its harmful potential, such as work product. This research should be extended to microscopic, chemical, both the support material and product used.

The proposed methodologies for conservation treatments were based primarily on experimental research conducted on experimental analysis and research material that I attended along with my coordinators.

Another tool developed following the research conducted is sheet analysis of a building heritage in order to select the method of intervention and appropriate conservation treatment. Based on research conducted by me, in conjunction with norms of 18 April 2008 approved by the Ministry of Culture and National Heritage on the inventory, classification of historical monuments, I performed a grid analysis of research and historic buildings made of stone, grid which I consider particularly important in the analytical quantification of the structural elements that provide strength and stability in operation at a time and also employment and appropriate intervention measures.

SHEET REGARDING THE EVALUATION OF TECHNICAL CURRENT STATE OF HERITAGE STRUCTURES MADE OF NATURAL STONE

Chapter 1. Identification of heritage building		
1.1.	Current name	
1.2.	Previous name	
1.3.	Category according to MCPN classification	
1.4.	LMI Code	
1.5.	Location (state, county,city, street, no.)	
1.6.	Nomination of previous location if it is the case (if the monument was moved during his history)	

1.7.	Identification specifying cartographic mapping system used	
1.8.	Type of property (public property, private, mixed)	
Chapter 2. Characteristics of the monument		
2.1.	Historical identification (construction year, authors, craftsmens, painters)	
2.2.	Identification according to the artistic components (style, area, cultural and natural landscape elements)	
2.3.	Current function and previous function	
2.4.	Features of the site / location (in urban area, geotechnical and geomorphological point of view), framing from current standards point of view	
Chapter 3. Description of the historical monument		
3.1.	Plans (building area, developed area)	
3.2.	Height regime	
3.3.	Façade description	
3.4.	Roof description	
3.5.	Description of annex buildings and extensions	
3.6.	Description of structural constructive system and constituent materials	
Chapter 4. Description of the monuments from the structural point of view		
4.1.	Specific elements of the period in which the monument, original feature original elements	
4.2.	Description infrastructure (as the construction material used, execution technology, original and authentic elements)	
4.3.	Description suprastructure (the material used, the structural system adopted, execution technology, original and authentic elements)	
4.4.	Description of constructive solution to the current floors (material, execution technology implementation, elements authentic, original elements)	
4.5.	Description of roof (material, presenting constructive solution, presentation technology implementation, elements authentic, original elements)	
4.6.	Specifications for intervention work history structural works	
Chapter 5. Arhitectural works		
5.1.	Exterior finishes (materials used, technologies, elements of authenticity)	
5.2.	Finishes in walls (materials used, technologies, elements of authenticity)	
5.3.	Interior finishes at ceilings (materials used, technologies, elements of authenticity)	
5.4.	Analysis of stained glass (materials used, technologies, elements of authenticity)	
5.5.	Carpentry analysis (materials used, technologies, elements of authenticity)	
5.6.	Analysis floors (materials used, technologies, elements of authenticity)	
5.7.	Analysis roof (materials used, technologies, elements of authenticity)	

5.8.	Specifications for intervention works in the history of architectural works	
Chapter 6. Analysis of installation works of the historical		
6.1.	Heating (materials, technology, authenticity)	
6.2.	Electrical installations (materials, technology, authenticity)	
6.3.	Analysis canal water systems (materials, technology, authenticity)	
6.4.	Analysis of ventilation (materials, technology, authenticity)	
6.5.	Specifications for intervention work history these plants	
Chapter 7. Elements regarding the technical state of the historical monument		
7.1.	The technical condition of the building in terms of building strength and stability based on visual observations and in conjunction with current technical requirements and rules (it is considered the general elements of structural compliance under current provisions realizing a comparative analysis of structural elements compliance they possess structure)	
7.2.	The technical condition of the building in terms of operational safety requirements in conjunction with the current technical regulations	
7.3.	The technical condition of the building in terms of fire safety in conjunction with the requirements of current technical requirements	
7.4.	The technical condition of the building in terms of hygiene, human health and environmental restoration	
7.5.	The technical condition of the building in terms of thermal insulation, waterproofing and energy saving	
7.6.	Objective requirements under current technical regulation on protection against noise	
7.7.	Issues on how to comply with current building facilities related technical requirements and rules	
Chapter 8. Way the owners / managers have complied with the historic lens existing obligations concerning use in accordance with Order 2684/18th of June 2003 of the Ministry of Culture and National Heritage		
Chapter 9. Analisys of risk factors that are affecting the historical monument		
9.1.	Seismic risk (presentation employment history of the site in accordance with legislative provisions on seismic design of buildings and summarizing the events known as objective response to this risk)	
9.2.	The risk of climate actions (wind action, snow, presenting historical events / accidents recorded for the objective review)	
9.3.	The risk arising from the establishment of the monument chemical aggressiveness (aggressiveness risk climate, pollution, acid rain)	
9.4.	The risk of aggression marine	
9.5.	Risk on aggression soil and groundwater aggressiveness	
9.6.	Erosion risk on objectives located in coastal Black Sea waters on slopes	
9.7.	Flood risk	

9.8.	The risk of landslides caused by natural factors or human actions	
Chapter 10. Analysis of the material constitutive behavior (degradation, reduction of specific resistance) to establish measures of intervention and maintenance solutions compatibility		
10.1.	Identify the characteristics of authentic constituent material	
10.2.	Presentation investigation method for assessing vulnerability and response to contact with risk factors	
10.3.	Specifications for the depreciation of the material to identify critical areas	
10.4.	Setting parameters for choosing the solution consistent comparison of local and general restoration of affected	
Chapter 11. Identification of technologies used for authentic historic achievement		
11.1.	References on the structure	
11.2.	References to elements of interior and exterior	
11.3.	Elements regarding installations	
11.4.	Analysis of compatibility of conservation and restoration work integration of these technologies	
Chapter 12. Analysis of integrated conservation of monument construction		
12.1.	Proposals for preservation and security limited	
12.2.	Proposals for conservation and rehabilitation of structural components	
12.3.	Proposals for conservation and restoration of architectural components	
12.4.	Proposals for conservation and rehabilitation of the plant components	
12.5.	Proposals for conservation and rehabilitation of the whole structure	
12.6.	Proposals for conservation and rehabilitation of the material constitutive	
12.7.	Proposals for conservation and rehabilitation providing construction employment in important classes according to function	
12.8.	Proposals for conservation and rehabilitation to post-use objective	
12.9.	Proposals for conservation and ensure the strength and stability of existing components to introduce the tourist circuit	
12.10.	Proposals to downgrade the monument	
Interdisciplinary team		
Expert / Specialist MCPN certified according to law 422/2001 Owner / Manager Structural engineer Architect Engineer geotehnician Specialist artistic components Historical Laboratory Testing / Schedules for laboratory testing results NDT Specialist		

Representative of the local authority responsible in the conservation and protection of historical monuments

The sheet analysis conducted is intended to be a analysis and recording tool extremely useful for specialists in conservation. It is the basis of preparation of relevant databases for natural stone heritage buildings in our country - even from each region - as a starting point in deciding the optimal response to each case. Of course that with the in-depth research of the topic, this statement may be altered.

4.2. Histria fortress – conservation study

A section of the analyzed material during this research study was a material taken from Histria in Dobrogea. Histria was the first Greek colony on the western shore of the Black Sea and the oldest city in Romania. According to historical analysis conducted, Histria was founded in the mid-seventh century BC (About 657 BC by the historian Eusebius) by settlers from Miletus. Since the Greek period and until the Roman-Byzantine, the city grew continuously for 1300 years. There were periods that have left their mark on the city, such as its destruction by Slavic and Avar attacks at the end of the sixth century and the seventh century, which led to its gradual abandonment by its residents. The ruins of this city, started to be investigated since 1914, constitute a very important source for understanding the history of Greco-Roman Dobrudja. In the history of the city there is outlined the Greek period (seventh century - BC), the Roman period and Roman – Byzantine period.

This chapter summarize the obtained results on the characterization of H-type specimens, the specimens being cut according to the dimensions recommended by RILEM rock samples taken from Histria.

After initial characterization of the samples and identification of the degradation stage, it could be prepared a study plan for testing specimens with a waterproofing product type and a building one. Given the small number of samples (11 specimens), the planning study was an important step to determine the time of the tests to be performed and the order in which they should be made in order to have as much information about specimen. In case of heritage, the building material is always insufficient and therefore the one taken must be used effectively.

I proposed to be carried out two types of treatments: one water repelant and a consolidation treatment according to the methodology outlined in section 4.1. with the same product described in Chapter 3. After applying treatments, there have seen a good initial efficacy of waterproffing treatment and reduced potentially harmful. The consolidation therapy has not proven its initial efficiency in an obvious way. Outcomes showed a tendency to improve its behavior, but we can not say unequivocally that the end result will be positive and lasting. The amount of product consumption was very low due to low porosity of the material. For this type of rock with such low porosity, the treatment with consolidate products of a kind used in Chapter 3 does not lead to satisfactory results and also affects the internal structure of the material. The best preservation solution in this case is the application of a waterproofing treatment to reduce the effect of water action on the material and to slow down its degradation.

After this treatment the water repelant characteristics related to the movement of water were modified as follows:

- The percentage of water absorbed after 48 hours had suffered a decrease of approximately 20% baseline;
- Water absorption with reduced pressure experienced a reduction of initial values of approximately 90% baseline;
- Absorption of water by cappilarity suffered a decrease of initial values of approximately 80% baseline.

Following the completion of tests to verify the potential harmful effect of the treatment, they showed a slight decrease or maintain the existing initial parameters. The visual appearance was not affected after applying waterproofing treatment. As future research directions I recommend repeated tests at regular intervals in order to observe the change of characteristics recorded in the tests and time evolution post treatment. In order to compare and choose the best version, I recommend also test specimens with different category of waterproofing products in order to compare results and find the best product for treatment. I would also recommend and implement testing several versions of the product (not just brush) to determine the best solution in terms of the amount of product absorbed by the surface.

Concluding the analysis in this chapter I can say that in this case, in terms of preserving, a solution that can be adopted is to treat the material with waterproofing products, surface treatment that does not affect the internal structure of the material. Of existing products on the market, during this study there was only a product tested by brush on the test surface, product that has proven effective in the results recorded. Very important is the testing of the application of this product in situ on a section of the existing wall in order to observe the behavior in time of those areas under the influence of climatic factors, process after which it can be recommended to apply all over the walls.

Chapter 5 Conclusions

5.1. Research results. Fulfillment of the thesis objectives

This chapter exposes the results of studies obtained during the research program and recommendations for future research directions in the field of conservation of elements or structures from natural stone. The research was both one documentary on the current state of knowledge, but especially one experimental, both in the laboratory and in situ. In situ research in the first phase, I focused on evaluating the current state of degradation by observations through experimental study in situ using nondestructive testing methods and then sampling more in order to test in laboratory. Experimental research in the laboratory allowed us to establish working procedures in order to determine the effectiveness of treatments applied, the potential harm of treatment and determining priorities to assess the sustainability of conservation treatments.

It is difficult to establish an idealization and a particular solution of intervention to be accepted in a given situation for a monument, because each historical monument has a unique character that must be examined and evaluated accordingly. So there is not a preset recipe that can be applied. What can be done, through existing research studies and case studies from literature, is a procedure to be followed in the analysis of such a monument. It can make a methodology for the study, evaluation and analysis of a heritage building. Such a proposal was made by the author in Chapter 4, section 4.1.

In the research program, the activities support the development of beneficial attitudes preservation and protection of historical monuments by providing invaluable elements to engineers dealing with rehabilitation of historical monuments, but also the factors responsible in their management. The objectives of the research contributes directly to the implementation and promotion of measures contained in the legislation and also to highlight those components designed to improve the actions supported by the legislative framework. The fact that currently in Romania there are technical requirements and appropriate legislation to regulate the action of conservation and protection of historic buildings, there are no guidelines, methods and procedures to support these actions; by the research conducted within my doctoral thesis, I aimed at developing knowledge in the field, creating structural analysis methods and models that constitute in material constituting guides and technical requirements in the field. The activity carried out supports the implementation and development of current legislative framework. Particularly important in restoration work I considered there is setting priorities regarding the restoration, enhancement and revitalization of monuments from the role they play in the local community.

Through research plan objectives I wanted to support the design of integrated protection of heritage in accordance with European conventions, given that each heritage property value must acquire a use in conjunction with providing structural requirements and processes as a catalyst social, as it presents the principles adopted by the Venice Charter 1964.

The objectives of the research focused on the development of actions to support sustainable development of protected areas based on integrated conservation of heritage property. Entire research plan is a comprehensive approach based on measures and principles acquired in my professional training in the protection of immovable cultural heritage as an engineer that must be able to provide with intervention measures the required capacity of a structure in the context of conservation and enhancement of heritage elements. The educational program learned in college, masters courses and doctoral training I learned a volume of theoretical knowledge in this field and also have acquired a considerable experience in the work done by the multitude of case studies addressed by research performed in our laboratory in the Faculty of Civil Engineering and the stage in Portugal.

In this regard I appreciate that I had the opportunity of an outstanding professional training with trainers from our country and abroad, who possess vast experiences. Both PhD supervisors and the entire team of doctoral research from the Faculty of Construction and Technical Superior Institute of Lisbon, have an activity for decades in restoring historic buildings, mostly made of stone structure, are persons certified as technical experts with remarkable achievements in this field nationally and internationally. I received training in this area from both institutions, assuring a coherent attitude to protect historical monuments.

In this respect I could mention: in Romania - I participated at stone restoration course, including Bonțida practice; during the courses I prepared my degree based on large part of the lectures on restoration and preservation of historical monuments, the property assessment course completed in order to acceptance my membership in UNEAR, offered me the chance to specialize in historic buildings evaluation, and each case study I worked in the doctoral program was a unique experience which has added extra value to my professional training .

During the educational program developed at Lisbon - though Ovidius University – Erasmus program, I graduated the training courses on "inspection plans and maintenance of buildings" and "constructions Rehabilitation Techniques" organized by FUNDEC - Association of Training and Development Civil Engineering and Architecture; case studies taken in the laboratory tests were carried out with great thoroughness under the guidance of prestigious specialists (ş.l.dr.ing. Ana Paula Pinto Assoc. João Gomes Ferreira and prof. Fernando Branco), contributed to the perfection of objectives 2, 3 and 4 doctoral research plan.

During the research conducted in the laboratory of Lisbon of Higher Technical Institute, which represents the elements of originality in solving PhD topic, we conducted several tests on samples taken from historical monuments in Romania and Lisbon, a significant number of samples, following real quantification of mechanical characteristics, physical constitution materials and also the interpretations of the composite masonry stone.

Laboratory tests were made on the durability, tensile strength, compressive strength, porosity, capillarity, permeability, drying index and others, including analysis on artificial aging procedures for obtaining parameters as close to a actual behavior of the building. The theoretical and experimental was presented in detail in Chapters 3 and 4.

For each experimental research it has been made up a synthetic form interpretation of results, graphical expression variations. Interpretation of research results for each parameter has been a debated topic inside a team of researchers and this communication have materialized in a series of measures and interpretations that underpinned (procedures) methods and analysis techniques and criteria for determining the factors that may change its behavior over time and can be estimated in structure calculation. They are the basis to construct the model of existing programs to new computing (computing the structures) and also represent a valuable material underlying the methods and technologies designed to conserve, rehabilitate stone structures.

The research results represents an important database to quantify the vulnerability level of historic buildings, the proposed analysis grid aimed at identifying such valuable items behind the classification of historic buildings in the list approved by the Ministry of Culture and National Heritage and also to establish the behavior in time, size parameters calculation, establish the calculation model, the rationale for urgent action to prevent imminent risk of degradation, adoption of intervention measures, conservation and even tracking of reaction over time.

In many cases these grids can provide arguments for downgrading constructions where the lack of intervention or due to passive attitude on the part of the valuable components have been impaired and has been severely affected the strength and stability.

Elements provided in the sheet analysis proposed may contribute to outline some interventation proposals in joint programs with partner countries, especially the countries belonging to the European Union. This issue relates to historic buildings that are part of UNESCO circuit and historical monuments located in the border areas.

Through research results I can appreciate that the advantage and experience gained in 2008 during Sibiu declared cultural capital of Europe and in particular to promote similar programs for its Euro-regions discussed by the European Framework Convention adopted at Madrid and ratified by Romania Emergency Ordinance No. 120/1998.

The research results were valued by preparing a number of 8 items by the author as shown in the bibliography, presented at the national and international scientific meetings, for example Nondestructive Testing Conference in Istanbul, Turkey in 2010 organized by RILEM, conferences WATER 2010 and 2012 and reports in scientific research (5) presented both in Civil Engineering Faculty of Construction and traineeships in Portugal.

With the great universities of Europe model that I got to meet during conferences and exchanges of experience, I have compiled a guide - a summary, including techniques and methods of structural analysis of historic buildings necessary for the restoration, conservation and tracking of behavior in time.

5.2. Personal contributions during the research activity

During the development work, several original elements have been adopted and incorporated into the research and thus can highlight the following contributions:

- ✓ Providing an overview in Chapter 2 documentary on the current state of knowledge in order to establish the type of damage to the elements of stone and highlight possible intervention measures;
- ✓ Providing an overview of documentaries on conservation treatments (treatments waterproofing and consolidation) in terms of products that can be applied, application technologies and solutions available that can be adopted;
- ✓ visual analysis and documentation of historic stone building in Constanta, Tulcea, Buzau in Romania and Sintra and Lisbon, Portugal;
- ✓ selecting the most representative experimental studies and conducting extensive research both in situ and in the laboratory on the state of degradation, investigation and restoration solutions adopted: Monastery Ratesti - build the church - Buzau; Monastery Targsor Prahova - research infrastructure construction and the wall support the porch; Dara church construction Buzau; Balcescu village church construction, Constanta county; Sinaia construction cloisters;

construction of the church "St. Margaret "Medias, Sibiu Biertan church building;

- ✓ during the course of the research program I participated with leaders in the development of doctoral studies on the behavior of the stone building located in seismic zones important objectives (building belonging to the monastery Ratesti, Buzau, church Dara, Buzau) or targets located in areas Marine aggressively in vulnerable areas such as slope stability Constanta Greek Church, Cathedral of St. Peter and Paul church Balcescu monument cave in Mission, building places of worship belonging to Muslim - Turkish Tatar (eg PANE Amzacea) or places of worship belonging to Orthodox worship (some mentioned above) such as "St. Great Martyr George "in Constanta; another objective that I attended and I contributed to the experimental testing of the solution of intervention, both in the laboratory and in situ, was Moorish castle in Sintra, Portugal.
- ✓ at the identified structures I analyzed the mechanical properties, chemical and physical properties of the material constitutive analysis performed both in situ and in the laboratory;
- ✓ constructive in identifying structures, analyzes performed, we established classifications constructive solutions for historic buildings analyzed based on structural composition, technology, materials used. These are currently being developed in Chapters 2 and 3;
- ✓ in the research program have identified factors that contribute to the degradation of structures resistance to degradation constituent material;
- ✓ evidence criteria and modes of intervention stone heritage buildings by reviewing the current national and international rules (laws, books, conventions);
- ✓ development of methodologies for implementing conservation treatment (waterproofing and reinforcement) to determine the effectiveness of treatment and possible adverse effects of treatment on the material; establishment of the first steps to assess the sustainability of conservation treatments applied;
- ✓ establish a means of quantifying the positive or negative effects of conservation treatments of stone types studied experimentally in the laboratory;
- ✓ drafting a form of analysis of historical monuments conservation for intervention that can be used to monitor them over time;
- ✓ four types of stone characteristic Dobrogea area we conducted experimental laboratory studies to establish effective conservation treatment (waterproofing treatments or consolidation) the results of which will be considered and used in subsequent intervention works or even used as a basis for knowledge to test other types of waterproofing and building products;
- ✓ highlighting the applicability of the proposed methodology on a relevant case study for the south-eastern Romania - Histria.

5.3. *Future research directions*

Final considerations and development of future studies specific to each type of treatment were presented at the end of Chapter 3 (section 3.8.) in this paper.

Thus, I believe that this is important to present some suggestions for future work that requires further study. One of these studies should refer to the validation and improvement of methodologies for the study of the products used for waterproofing and reinforcement treatments by:

- establish agreed procedures for implementing national waterproofing and building products;
- establish of a series of tests defined as procedures to be assessed outcome of such a study of processing;
- establish of acceptance and rejection criteria for alteration suffered by the support substrate after applying waterproofing and building products.

During the study on waterproofing treatments, a series of interesting issues came out and can be included in investigation lines for future work development, such as:

- ✓ verify the possibility of generalizing the methodology proposed in this paper for waterproofing treatments applied to all varieties of stone specific to the area of interest - Dobrogea;
- ✓ specific development work with the aim to define standardized procedures for study on the conditions of application and exposure before and after treatment, the period of time necessary to be observed between baseline and procedure application and effective enforcement of the products;
- ✓ criteria for acceptance / rejection of wet products;
- ✓ Development of specific studies with the objective of assessing the stability of waterproofing treatments to situations of contact with water;
- ✓ Stability study while samples exposed to the natural environment;
- ✓ Development of specific studies that allow correlation of potential harmfulness of waterproofing treatments with produced changes during the water evaporation test.

Another line of research would be to study the influence of pore space characteristics in order to obtain optimal results from treatments. This study should be focused on characterizing the pore space of rocks before and after treatment in order to know or estimate the ease of rocky material that would accept treatment, the outcomes and alteration characteristics related to the presence of water movement.

Intrinsic characteristics of the stone, before and after treatment, and their relationship with the mechanisms and forms of degradation by crystallization of salts is another direction in which future research directions may focuse. This can be realized by studies of crystallization of salts which allow knowledge and to explain the mechanisms of degradation of reinforced rocks, particularly those that relate to the intrinsic characteristics (porosimetry, permeability evaporation - drying, etc.) with the type of salt and the crystallization conditions.

An important aspect of the study is the characterization of the action and results of treatment products based on polyurethane resulted in a detailed study of the action, of the conditions of applicability of polyurethanes based treatments that are presented in the literature as promising. Here it can be included the study of consolidation treatments based on ethyl silicate and carbonaceous rocks pretreatment with reactive organic elements.

Systematic study on the influence of application procedures and treatment products in their action and the results are another point of interest. Knowing the procedures adopted in treatments influence the action of the product and its results, with the objective to increase the results of some products, especially those enhanced acrylic and epoxy, through the adoption of specific treatment procedures.

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