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

Theoretical and experimental study on the behavior of typical floors of heritage buildings. Restoration solutions

- PhD thesis summary -

Doctoral supervisors:
Prof.PhD.eng. Grămescu Ana Maria
(Ovidius University from Constanţa)
Assoc.prof.PhD.eng. João Gomes Ferreira
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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, 14:00 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 ***"Theoretical and experimental study on the behavior of typical floors of heritage buildings. Restoration solutions"*** elaborated by engineer Bucur Dan Pericleanu, 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**
	(Ovidius University from Constanța)
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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.

Rector
Prof.univ.dr. Bo[illegible]eanu Ion

Secretar Șef ISD
Budur Elena

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I would like to give a special thank you to my mentors and scientific coordinators, prof.PhD.eng. Ana Maria Grămescu and assoc.prof.PhD.eng. João Gomes Ferreira, who through exigency and dedication, patience, work and their wisdom have given me support and guidance through the whole period of research and elaboration of the doctoral thesis, contributing to my formation as a specialist, as an engineer in the knowledge of scientific truth.

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I would like to thank especially, from all my heart, to Ms. Enid Abreu for the help given, the moral support and practical advices. I thank her for the thrust given and for the unforgettable memories during my studying program in Portugal.

I dedicate this PhD thesis to my wife and thank her from all my heart for the moral support, help, understanding and patience given constantly and not at least, I thank my family, who always had faith in me and supported me in all activities.

The PhD thesis contains: 302 – pages, 42 tables, 302 figures and a list with 336 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 bibliographycal references.

Key words: brick, floors, heritage buildings, restoration, vault.

Content

Chapter 1 Introduction

1.1. Considerations regarding the importance of conservation and restoration of heritage buildings at international and national level

For heritage buildings, the classical definition of floor that is structural element able to take actions induced by seismic motion and transmits them to vertical structural components and also by vertical partitioning functions, becomes insufficient because these requirements are added to those related to the need for conservation, restoration of original elements and also to improve the overall strength and stability of the building.

1.2. The importance and actuality of the scientific research

Thesis topic, composition of the research plan followed in this paper, contributes to the creation of a documentary database particularly useful for current and future stage, following the direction of national and international concerns of institutions responsible in the conservation and protection of historical monuments field. Studies and research have contributed to broadening the knowledge base and the creation and founding of intervention solutions, particularly important for the creation of a legal framework of regulations related to the rehabilitation of the historic building.

1.3. Justification of the scientific research

In the current phase, heritage buildings are facing anthropic or natural hazards and knowledge of the effects of these destructive factors in conjunction with a thorough knowledge of the construction monuments in detail is an essential element for historical monuments, able to select appropriate methods and techniques of restoration structures to protect historical components valuable substance and cultural value.

In this context, by the research project I proposed that for the heritage buildings studied to be conducted theoretical and experimental research, contributions to be made in a future realized database and some intervention measures which to substantiate conservation and restoration activity, to contribute to the development of a methodology for assessing the structural safety and to support the establishment of valuable results that will be part of the future, of technical requirements in the field of conservation and restoration construction.

Analysis performed on heritage buildings, on their behavior and the response to interventions measures showed that the floor, as a structural element raises problems. Over time this has undergone a progressive evolution from the materials point of view, technologies and constructive solutions (using planar components, the vaults, the arches and other forms of curvature).

1.4. The objectives of the scientific research

We analyzed the behavior in time of these slabs, we identified structural parameters that are influencing the structural conformation and factors defining vulnerability in exploitation, methods and techniques to improve the mechanical behavior of slabs necesarry within the action of restoration and conservation of heritage buildings.

Within the activities performed, according to the research plan, I studied a significant number of heritage buildings to which I have investigated the materials used, both homogeneous structure and the composite structure, used technologies, so that the new restoration solutions proposed can be founded on the authentic elements of the monument.

I identified parameters influencing the behavior in time as well as the elements that ensure structural compliance, structural strength, stability and also I have identified factors that have a negative effect on the bearing capacity quantified to a degree of vulnerability. All these findings were summarized in charts, plans, details, helping to deepen and broaden the knowledge base in this area, on an complex sample slabs specific construction of a variety of historic heritage buildings identified as either Class A or B, or as valuable buildings located in historic urban areas or areas of historic protection.

We aimed to obtain information about building integration solutions adopted in the whole structure and their way of working with constituent materials.

Studies and investigations done during research aimed ultimately to developing methods and intervention techniques appropriate to different structural compositions of floor in order to improve its mechanical behavior. This measure was intended to support the general concerns of restoration and conservation of historic monuments and heritage buildings in general.

1.5. The structure of the research paper

In chapter 1 - Introduction - I presented the importance and relevance of scientific research work in the current context of preservation and protection of heritage values, the objectives propose to investigate and diagnose real existing buildings and the choice of intervention solutions compatible with technical solutions and constituent materials.

In chaper 2 – The floor deck – structural element and characteristic to patrimony buildings – I have presented the uniqueness of heritage buildings, their importance in society over time by cooperation of architectural styles with events conducted throughout history, with technology and constituent materials, having a scientific and educational value. I highlighted the legislation framework and methodology governing the preservation, restoration and protection of heritage buildings nationally and internationally. I presented the historical evolution of the characteristic heritage building floors, of science and technology in this area, materials used and execution technologies.

Subassemblies of vaulted floors and their classification I have presented in the research, the case studies and expertise carried out in situ in Romania and in the research study program in Portugal, making a classification by architectural style, technologies and materials used in execution depending on the composition and mechanical and geometric composition.

In chapter 3 - Techniques and investigation and restoration solutions for typical floors of heritage buildings - I conducted the investigation and diagnosis of buildings and component elements. Through investigation and research we sought to evaluate some static problems, evidenced by checking the structural behavior of masonry, the hygrothermic issues of determining the state of humidity. I also presented the typical floors restoration techniques, both structural and nonstructural. I studied the techniques of restoration with metallic elements by introducing in the resistance structure reinforcement like tie rod type to take the thrusts of the vaulted masonry floors, restoration techniques with reinforced concrete elements, restoration techniques related to binders and restoration techniques with composite materials.

At the end of the chapter, the investigations, restoration methods and techniques have been adopted and presented in the studies and research carried out in situ for some case studies:

- "Old Court" in the city of Braila; Class B monument with brick floor transmitting loads on metalic profiles;
- "Water castle" in the Municipality of Braila; historic class B monument, with concrete floor;
- "School Group Sportive No.2" in Constanta; historic class B, with wooden floor;
- "Hospital of St. Panteleimon" in Braila Municipality; historic class B, with floors made of brick transmitting loads on mettalic profiles and wood floors.

In chapter 4 – Studies and experimental research regarding restoration of heritage building floors – to maintain and preserve the struvtural integrity of buildings I proposed the implementation of some consolidation solutions, adapted to each situation.

In this chapter, I conducted various experimental tests on restoring typical floors of heritage buildings that need rehabilitation works because of their degradation and inappropriate interventions that it has been submitted.

Experimental tests were conducted both in situ and in Faculty of Civil Engineering - Ovidius University of Constanta laboratories and the Superior Technical Institute - Technical University of Lisbon. Experimental investigation targeted the quantification of calculation parameters for the resistance structure, of the results of behavior in time, in order to propose measures, restoration and consolidation solutions of vaulted floors from brick masonry characteristic to heritage buildings.

Research on rehabilitation of floors and load-bearing masonry structures of "Pombalina" type

Research on specific vaulted masonry floors, subjected to uniaxial and diagonal compression

Research on mechanical characteristics of masonry specific to vaulted floors

Research on behavior and evaluation of consolidation of vaulted floors with metal tyrants

Research on improving behavior in time by increasing the bearing capacity of restored vaulted floors with carbon fiber reinforcements

In chapter 5 – Study case: Church "St. Great Martyr George" from Constanta - In the research study I investigated the overall structural degradation and also the degradation of specific components, which are highlighted by the surveys and illustrative inventories of material degradation. I sought to identify the decayed areas, their extent, the direction of crack propagation, their location in the whole structure of the vault, all of which contribute to highlighting areas which no longer have the capacity required to ensure the continuity of the element.

In the technological investigation I included a description of the construction in terms of components, namely: type of structural elements, materials and technologies used, the characteristic dimensions of the structural components, types of connections and their functional capacity, any structure defects.

I proposed the intervention measures presented in this paper, in order to eliminate the causes that have led to degradation, to improve structural collaboration and restore degraded components in the same design with the initial construction without affecting the value of the monument .

In chapter 6 - Conclusions, contributions and future research directions – I complet the research by presenting all the contributions brought after the documentation and experimental analysis. I detailed the contributions to the development of knowledge in the protection and restoration of heritage buildings and the results of experimental research and scientific validation.

I concluded the research activity done both in the country and in Portugal and the results achieved. Finally, I proposed future directions of scientific research regarding the behavior and restoration of typical floors characteristic to heritage buildings.

Chapter 2 The floor-deck – structural element characteristic to patrimony buildings

2.1. The uniqueness of patrimony buildings – legislative framework

Heritage buildings are an expression of the society traits (economic growth, developed creative level, political stability) quantified in the dimension of time. The value of heritage buildings has a composite structure, the harmony between art and constitutive technology, between the structural composition and conformation in space, in conjunction with the events that took place at some point in this constructions.

2.1.1. Protection of patrimony buildings; conventions and charters

In the context of the law 422/2001 protection and conservation of heritage buildings are a full-scientific, legal, administrative, financial, fiscal and technical role to ensure research, preservation, maintenance, restoration, enhancement and integration in the cultural life of the community.

2.1.2. Historical evolution of floors characteristic to patrimony buildings

Analysis of technical solutions for realization of floors revealed a true evolution of science and technology in this area and their structural components, materials used and execution technologies express clearly and comprehensive the scientific, technical and artistic creation of time.

Due to the existence of a wide range of materials used such as wood, stone, ceramics, metal, etc., I made a first classification of floors characteristic of heritage buildings.

Wood floors

Wood floors have been used from the remotest times due to the materials used, low consumption of energy and relatively simple technology and execution. In principle, they are made with a simple structure of main beams parallel to each other (arranged at distances which may vary depending on various factors), filling elements, the resistance elements and finishing elements.

Fig. 2.6 – Woof floor - (photo author)

Brick floors

Floors made of brick masonry vault type were widely used in ancient times, in Romania there are such solutions, for constructions made until the early twentieth century. For the period in which they were used, were achieved impressive architecture and construction forms (fig.2.8), the main element of resistance of floors brick arch or dome constituted it made of brick under construction embodiments and various geometric shapes. For the period it was used they executed great arhitecture and impressive forms of buildings (fig.2.8), in wich the main resistance element of brick floors was the vaults or the dome made of brick under many constructive forms and different geometry.

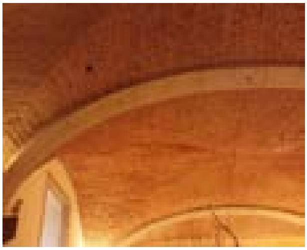


Fig. 2.8 – Brick floor – Vela vault – (author photo)

Stone floors

Although the core material is stone, easy to find locally, stone floors (Figure 2.11), experienced a rather limited use in our country. [70].

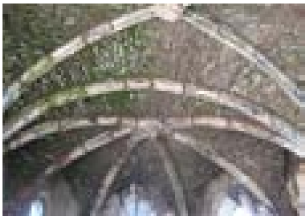


Fig. 2.11 – Vaulted stone floor - (photo: Grămescu Ana Maria)

Metalic floors

Metal floors (fig.2.12) have emerged with the development of steel technology in the nineteenth century. In our country the metal floor were used very little in heritage buildings structures, steel being used more in combination with local materials.

Fig. 2.12 – Metalic floor - Bank of Portugal/Lisbon - (author photo)

Mixt floors

In the nineteenth century with the development of steel technology have emerged and wood floors with metal profile sections I (fig.2.15). Use steel profiles Type I led to solving problems on large size wooden beams.

Fig. 2.15 – Brick floors with metallic profiles type I – Bank of Portugal/ Lisbon - (author photo)

2.2. Vaulted floors – structural subassemblies characteristic to heritage buildings

Location of vaults in time and space is achieved by identifying the technologies to execute them, the materials used and the structural composition, geometry and mechanics. Usually they were made of two distinct parts, one structural part subjected to bending for flat floors and of thrust with compression for vaulted floors and the other, an unstructural part, consisting of floor deck and finishes.

2.2.1. Elements regarding the classification of vaulted floors

Vaulted floors can be classified according to their architectural style, technology and materials used in execution and according to the mechanical and geometrical composition.

2.2.2. Presentation of subassemblies of vaulted floors

Brick masonry vaults or stone vaults were the first vaulted floors typical for heritage buildings, being floors that had to cover also small spaces like entrance halls, passages and basements, but also larger spaces like halls, salons, worship places, etc.

Vela vault /Boema

It is a partial hemisphere dome surface that downloads efforts on four semicircular arches and is used to close small spaces in area (closure of halls, passages, passageways). It is used in construction of the Gothic architectural style, especially in the late nineteenth century.

Cylindrical vault

It is a vaulted floor used since ancient times with an semicircular arch in front (fig.2.26). The name is given by the directory curve that describes it, in the Middle Ages is most often performed in vault segments called girdles or dublouri [157].

Fig. 2.26 – Cylindrical vault with masonry ribs - (author photo)

Cross vault

It is the interpenetration of two identical orthogonal cylindrical vaults, resulting a vault four calottes. In making the floor, the vaulted ribs are build first and then move on to building the arch between them, often, the arches being built taller than the dome calottes [56].

Roman cross vault (vault entering edges)

Realization of roman cross vault, is the intersection of two cylindrical vaults intersecting perpendicular axes with equal diameters. Keys vaults horizontal form perfectly straight lines, intersecting each other. Front arches are shaped like crescents and the diagonal describe half ellipse.

Gothic cross vault (ogive vault)

It is a ribbed vault made of stone or brick, with frontal arch or developed diagonal arcs. Constructed from two intersecting cylindrical vaults, with the vault key upward or horizontal line (Fig. 2.34).

Fig. 2.34 – Gothic cross vault – Jeronimo/Lisbon - (author photo)

Roman cross vault

It is derived from the cross vault, built in the Roman architectural style, the two cylindrical vault keys intersected, perfectly straight in plan view, vertical upward (Figure 2.36). [157].

Fig. 2.36 – Roman cross vault - Santa Caterina church /Lisbon - (author photo)

Starry vault

From the technological point of view, the ribs are done first, and then the masonry between them, the callotes can be built without scaffolding due to dense ribs. It is a vaulted floor (fig.2.40), used to cover large spans made of cross vaults with callotes sliced by dense ribs.

Fig. 2.40 – Starry vault - Sa Cathedral /Lisbon - (author photo)

Fan vault

Fan vault (fig.2.41), is actually a starry vault with ribs encased in supporting pillars. The vault ribs give a fan-shaped figure. It belongs to the Gothic architectural style being used to cover large areas in decorative style.

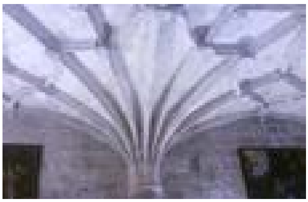


Fig. 2.41 – Fan vault - (author photo)

Mirror vault

It is a vault used to cover large areas and therefore was used in the Renaissance period, in achieving frescoes and paintings (fig.2.44). It is a wooden floor with main beams, vaulted corners, being used as a floor to the upper level [157].

Fig. 2.44 – Mirror vault – Sa Cathedral/ Lisbon - (author photo)

Vault into segments

It is a vaulted floor sideways with blind quarter vaults, being called cylindrical vault in broken arch.

Monastery vault

It is a vault with cylindrical origins, built from four blind quarters.

Net vault

The net vault is a translational simple curvature vault made of multiple fields delimited by ribs (fig.2.46).

Fig. 2.46 – Net vault - Jeronimo church /Lisbon - (author photo)

Spherical vault – cupola

Floors cupola vaults are particularly characteristic to Renaissance period to achieve the domes when were made double domes, drums or flashlight to illuminate the interior spaces (fig.2.47).

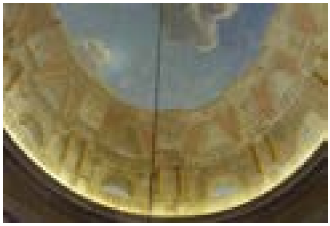


Fig. 2.47 – Spherical vault – Ajuda Palace /Lisbon - (author photo)

Bolţişoara – prusian vault

Type I profiles support bolti̦şoarele made of brick and resistance structure download the efforts being positioned parallel to each other at a spacing of up to 1.2 m

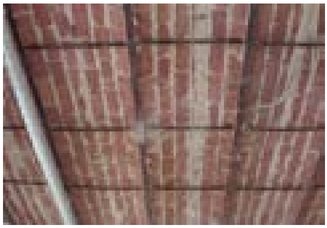


Fig. 2.48 – Prusian vault –Bank of Portugal/Lisbon - (author photo)

Moldavian vaults

Moldavian vaults style is characterized by removing support points from their base of support and that can be achieved by transforming the base of slender spiers into a rectangle square and then a circle.

2.3. Execution techniques and restoration of vaulted floors

Brick vaults are executed with constant thickness or not, thinner in the center and thicker at birth, where actions are greater. Realization of brick vaults is based mainly on the weaving technique of bricks [56]. The thickness of the vault, at the large openings is formed by weaving the brick [71], on several rows, with different types of bricks such that to carry out weaving also between the vertical rows (fig.2.51).

Fig. 2.51 - Weaving systems of masonry for vaults with large openings – (author drawing)

To strengthen and restore vaulted floors first must be made a structural support system to structural and nonstructural elements to avoid potential crashes. Along with the support system the working platform is built at the floor intrados and also the scaffolding [33].

Fig. 2.54 - Vaults with wooden shuttering centerings - (author drawing)

Chapter 3 Techniques and investigation and restoration solutions for heritage buildings

3.1. Investigation of heritage buildings

Together with technological progress we are witnessing, with the advent of new devices and technologies for investigation and research has increased the accuracy of the data collected. With the new devices is easier to investigate the heritage buildings and is a more effective method because of non-destructive and semidistructive testing.

3.2. Techniques, methods and equipment for investigation and diagnosis

With modern equipment, techniques and diagnostic investigation of heritage buildings, I have collected important data and information to achieve the objective of structural characterization and material characteristics.

Through investigation and research I sought to evaluate the static problems, evidenced by checking the structural behavior of masonry (masonry type, composition of constituent materials, the presence of any discontinuities, the load distribution efforts elastic characteristics of masonry), issues with hygrothermal caracter and determining the humidity state [34].

I conducted analyzes by the investigation in situ and laboratory on samples. We verified the dynamics of the damage observed, we determined the characteristics of masonry on the morphology and homogeneity of elements, physical and mechanical characteristics of the constituent materials and the degree of damage.

Collect data on possible structural deficiencies, degradations and construction defects was useful to draw up plans of consolidation and restoration and for establish intervention measures and determine the causes that led to the degradation of the building.

3.2.1. Non-destructive testing techniques

Nondestructive techniques provide sufficient results for the full structural characterization of the building and are typically applied in the first phase of the survey, yielding with their information on the mechanical characteristics of masonry and structural degradation [34].

Visual inspection technique

Inspection is done by eye or with optical devices, evaluating the geometric characteristics of the structure, overall materials constituents and pathological symptoms present.

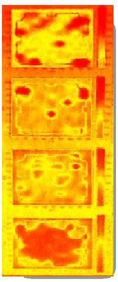
Graphical representation of observed anomalies can be very useful, given the ability to detect patterns that contain valuable information for understanding the mechanisms of damage. This is the case of cracks in walls facade cracks open and occurrence of biological organisms (presence of plants, fungi, molds, etc.), signals the emergence capillary water, degradation and cracking of foundations.

Ultrasonic pulse technique

The test is to determine the ultrasonic propagation velocity of an ultrasonic pulse through its material between two points (one transmission and one reception) which allows prediction of the mechanical properties of the material, the uniformity and the presence of any cracks, voids or other defects. The more homogeneous and denser the material, the greater will be the speed of ultrasonic wave propagation.

Fig. 3.4 - Composition of ultrasonic device Tico - (author photo)

Sonic tomography technique



The method consists of recording time sonic impulses carried by the section studied. The calculation of the speed is done by reversing the propagation time, assuming that a non-uniform field, sonic pulses do not propagate as a straight line but a curved line, as a result of refraction [50]. The measurements are recorded on a map of the distribution of the propagation velocity of sound, homogeneity and identifying areas of weakness.

Fig. 3.5 - The result of an inspection tomography - (photo João Ferreira)

Mechanical pulse velocity technique in masonry

This technique is based on generating a mechanic impulse at a point of the structure (transmitter) and capturing it at another point (receiver). Recording time (calculating the propagation velocity of the pulse) is a response of the material stiffness. Low-frequency pulses are induced by knocking with a hammer masonry and the signal is picked up by the receivers, which can be positioned in different locations.

Radar exploration technique

The speed of propagation of electromagnetic waves and producing echoes is directly related to the dielectric properties, which can be correlated with the mechanical properties of materials.

Thermography technique

Infrared thermography consists in capturing the warm areas (thermograms), invisible to the human eye but using a thermal imager that allows the identification of different types of defects (cracks, holes) and to detect differences between materials inside the structure.

Superficial hardness technique

Sclerometrul (fig.3.8), is a device that allows, in a simple manner, to determine the compressive strength of masonry and evaluation of homogeneity of the material. The method is based on the relationship between compressive strength and surface hardness of the material by measuring the residual elastic energy.

Fig. 3.8 - Mechanical Pendular Sclerometer - (photo João Ferreira)

3.2.2. Semi-destructive testing techniques

Nondestructive testing techniques described above do not allow direct quantification of parameters characterizing the mechanical behavior of materials forming the structure. Semidistructive techniques provide a qualitative structural composition and quantification of global rigidity [40].

Carotaj technique

This method consists in the extraction of samples (fig.3.9), called core, of the representative points of the construction of laboratory tests in order to evaluate the mechanical properties, physical and chemical properties of the materials. Are generally performed on samples drawn, tests of strength and deformability under the effect of compression and traction.

Fig. 3.9 – Carotaj technique – (photo Vítor Cóias)

The technique of extracting a helical sample

The method is used in situ, causing the resistance of masonry to extract, an indirect method is the tensile strength. The equipment required for this test is a drill, a drill anchors, related accessories and extraction device.

Boroscope technique

Borescopes is a non-destructive technique based on the use of an optical instrument, borescopes (fig.3.11), which enables viewing inside the masonry of any internal cavities, internal crack propagation and their openness. Borescopes is a thin rod fitted again with a glass lens and prism.

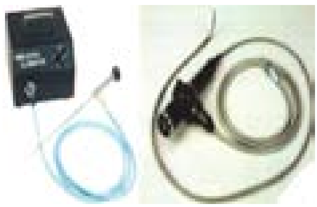


Fig. 3.11 – Boroscope equipment – (photo -Vítor Cóias)

Dilatometer technique

This technique allows direct evaluation of modulus of elasticity in the walls. It is advantageous if traditional masonry walls because it can assess the behavior of a special area of the wall.

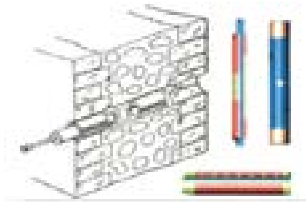


Fig. 3.12 - Dilatometer equipment – (photo -João Ferreira)

Jacking technique

Plane jacking test allows accurate evaluation of mechanical characteristics of masonry, with a low destructive. It is achieved by the introduction of reduced thickness jacks masonry joints or slots designed specifically for this purpose. This technique determines the state of the local pressure inside the masonry vault, the estimation of elasticity and compressive strength of the masonry. Flat jacks have shapes, sizes and different thicknesses are made of sheet steel welded together on the edge, with two hydraulic elbows.

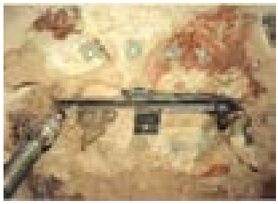


Fig. 3.14 – Simple jacking test – (photo –Vítor Cóias)

3.3. Non-structural restoration techniques for floors

Structural rehabilitation are important to the performance and durability of construction, especially when affected by moisture (condensation, infiltration). Structural restoration techniques are essentially given by repairing the anomalies associated with moisture content by creating chemical barriers by introducing impermeable barriers by replacing or reducing absorbent section by making drainage areas, conducting tubes by which to ventilate the affected area [33].

Measures to combat biological agents

Molds can withstand up to 10years, and therefore mold treatment is repeated and after treatment will ensure climatic conditions (temperature, humidity, light) not foster mold recurrence.

Measures to combat harmful salts

The best option to combat harmful salts is the reclamation and restoration of masonry, both inside and outside (with plasters far superior to conventional paints and finishes hydrophobic breathable). Renderings can be applied manually or mechanically and does not contain harmful products, compatible with structural materials, ensuring long protection.

Solutions to protect brick masonry

As preventive measures include: eliminating or minimizing damage action agents (environmental agents, biological agents), application of protective treatment, the surface inspection and enforcement processes of care and adequate protection.

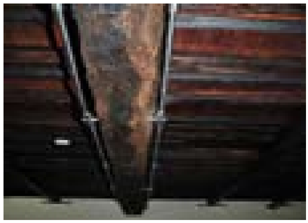
3.4. Structural restoration techniques for floors

The restoration of floors seeks total or partial removal of defects in the structure or composition of the structural elements, restoring strength and deformability properties of building materials due to the action of physical, chemical and biological.

Restoring wooden floors

Structural measures to restore wooden floors are wooden beams by changing the present structure degradation by treating and protecting wood elements by introducing new elements able to take loads floor (Fig. 3.24), by restoring or reunification wooden elements with metal parts by injecting cracks and loose sections, polymer, etc.

Fig. 3.24 - Strengthening connections between floor wooden beams and walls - (photo João Appleton)



Deformability may be further limited by two distinct processes: a first solution is to support beams with intermediate beam, creating intermediate supports made of joists and the second possibility to increase capacity suitable for greater rigidity and also a lower deformability (fig.3.28).

Fig. 3.28 - Strengthening wooden floor with platbens and metallic ties - (photo João Appleton)

Restoring mixed masonry floors - Steel

Rehabilitation solutions adopted heavily dependent on the degree of corrosion affecting metal profiles and the difficulty to directly observe degradation products in recessed areas. When it is seen that the corrosion is superficial, you need to establish to what extent is affected metal profile section, to assess the percentage degradation produced over the section and to check the structural safety requirements that must meet the floor.

Boltişoarele are affected by cracks and cracks in masonry elements and mortar joints and their restoration is done by injecting epoxy resin grout, cement and in serious cases, they will recover with existing materials or new.

Restoration of masonry floors

The structural restoration masonry floors must take into account the compatibility method applied sustainability solutions, reversibility and effectiveness of the proposed method. Measures to restore structural slabs consist in changing or enhancing their structural elements and adding new elements [27] who assume all or part loads floor. Criteria that must be met in rehab are compatibility between existing and new elements, durability, reversibility, their weight changes, ductility resulting from consolidation, structural strength and distribution of efforts between the existing structure and new elements added.

Restoring cracked vaults

In repairing cracks in the vault extrados is decopertează plaster approx. 10 cm away and across the fracture and crack length are mounted on the tubes and then is injected with mortar or crack slurry then it is covered along its entire length.

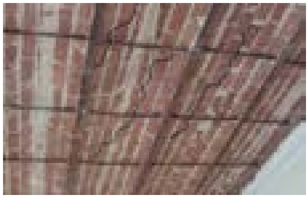


Fig. 3.36 - Cracks in brick masonry vaults - (photo author)

Restoring partly collapsed vaults

Restoration is done with existing or similar materials to those in good operation and after restoration of reinforced coating is achieved. To improve the capacity of the vaults and collaboration components are arranged in flats of carbon reinforcements arranged as curvature generators or direction parallels and meridians (the cylindrical and the spherical vaults).

Fig. 3.38 – Partially collapsed boltişoare - (photo author)

Restoring vaults collapsed

The restoration of collapsed completely vaults (fig.3.43) is carried out according to the structural remaining on the lines of birth if they have retained and fixed on the new functionality. It can be done with existing elements with new elements similar or pouring concrete thin blades, in which case just keep the original shape of the vault authenticity.

Fig. 3.43 – Vaults collapsed due to seismic action
- Carmo Church / Lisbon - (photo author)

3.4.1. Restoration techniques for vaulted floors with metallic elements

In the vaulted floors, restoring the metallic elements is done by introducing in the resistance of the lower link to retrieve thrusts masonry vaults. Tie rods are anchored in existing masonry by means of rigid components to be calculated so as not to produce points concentrated efforts of local attachment areas.

3.4.2. Restoration techniques for vaulted floors with reinforced concrete

In the last quarter of the nineteenth century, makes its way to restoration technique of reinforced concrete. The first use of reinforced concrete slab seems to have been cast by Paul Gout over the choir of Mont Saint Michel abbey in 1880, but the promoter of the theory and practice of reinforced concrete was the architect Anatole de Baudot, favorite pupil of Viollet- le-Duc, who expounds during which he taught between 1887 and 1914: "*This admirable process will help (...) to conserve our medieval buildings without their troubled spirit, provided its use intelligence and inspired by respect for the limits of forms* ".

3.4.3. Restoration techniques with binders

Treatment of cracks / crack can be performed by injecting the hydraulic binder suspension (lime, cement) with water. The bigger cracks can introduce filler (quartz dust, stone dust, sand). Synthetic resins have been widely used for bond strength and their use is recommended for the treatment of areas in depth.

Fig. 3.50 - Crack clogging with resins or foams - (photo author)

3.4.4. Restoration techniques with composite materials

The reinforcement of the floor is achieved by the application of bands of composite material and high strength composite woven fabric (glass fiber, carbon fiber) (fig.3.54), the outer valve epoxy resin, designed to withstand the stretching.

Fig. 3.54 - Solutions to restore masonry arches with composite materials - (photo João Appleton, João Ferreira)

A procedure and a method for efficient and timely work is the solution based on the use of FRP composite strips (fiber reinforced polymer) [10]. The reason is to maintain the capacity of the dome, to adapt to the structure and the action of the deformation induced by the earthquake.

3.5. Techniques and investigation and restoration solutions adopted – study cases

Research cited in the case studies included in this scientific paper we applied the work of collaboration and technical expertise, developed during doctoral internship. We conducted investigations and research in situ in each paper we sampled, we conducted onsite NDT and studied the structural conformation of construction and components. The results we have achieved the objectives and proposed solutions diagnosis intervention and restoration required.

3.5.1. Investigation and restoration of “Tribunalul Vechi din Brăila”

In this case study, we conducted an investigation in situ data aggregation based on information collected directly from documents and analyzes made prior concerned. We analyzed information on materials and technologies original structural design overview, history and state of degradation, ie, the factors that influence the structural behavior and provide useful information on the specific mechanism of damage.

Fig. 3.62 - Investigation of floors vaulted from the basement - (photo author)

We performed a structural investigation that includes a description of the building in terms of components, materials and technologies such as: type of structural elements, materials and technologies used, the characteristic dimensions of the structural components, such connections and their functional capacity, any faulty composition.

In order to strengthen and rehabilitate the floor over the basement floor made of metal profiles boltişoare brick type I and I realized a network perimeter beams located at the top of the diaphragm, the role of supporting floor elements (fig.3.68). The outer belt is coupled between the inner belt that will provide plots of the link to each linear meter.

Fig. 3.68 - Rehabilitation solutions for vaulted basement floor - (drawing author)

Wooden floor was restored by replacing the damaged wooden beams with new ones of the same section and the essence and where existing girders were damaged only at the ends, doubled their section by fitting two boards on both sides of the same section. For a better discharge of the stresses transmitted to the floor, has been achieved in the concrete perimeter beam. To achieve cooperation and seat inner perimeter beams will practice plots of reinforced concrete.

3.5.2. Investigation and restoration of “Castelul de Apă din Brăila”

This case study is based on analyzes and investigations carried out on the ground, and studies conducted in the State Archives, consultation documents relating to goal planning consulting projects, monographs and other publications with reference to objective study.The construction of the water tower is a historical monument of importance class B, appearing in the list of historical monuments code BR-II-mB-02104.

Fig. 3.72 – Investigation of cupola floor – (photo autor)

At the time, the water tower was the highest achieved in Romania. The project was prepared by the personalities of the time, namely: Elie Radu Eng, Eng C. mironescu, engineer and architect Peter G. Panait Antonescu.

Diagnosis of structures typically requires the use of experimental tests elements and materials to quantify the physical and mechanical characteristics relevant to assess the behavior of the building structure. Test procedures in existing buildings are classified according to the impact on buildings studied, destructive and non-destructive semidistructive. Through the work performed, the monument is intended saving and the development of interventions under extreme urgency, to limit vulnerability and risk, secured castle.

3.5.3. Investigation and restoration of "Grup Şcolar Sportiv nr.2 din Constanța"

Investigation carried out in this case study was based on data aggregation and information collected directly from documents and analyzes made prior concerned. In this phase we analyzed the original technologies and materials, structural design overview, history and state of degradation, ie, the factors that influence the structural behavior and provide useful information on the specific mechanism of damage. In the basement, the floor is made of metal profiles investigated that boltişoare download brick. The floor above the ground floor is made of sawn fir beams 15/10 cm, with a blind floor slats and filling of land between the beams and ceilings (slats, cane and lime mortar plaster), with repairs made after 1977 partly by rabiț .

Fig. 3.80 - Investigation of over ground floor and basement - (photo author)

3.5.4. Investigation and restoration of "Spitalul Sf. Pantelimon din Brăila"

Psychiatric Hospital "St. Panteleimon "is located in Braila, Calarasi no. 59 and serves the entire county for all psychiatric disorders.

The floor above the ground floor is made of wooden beams that download on a belt made of metal tape and a brick weaving corresponding implementation technology practiced important objectives at the end of the nineteenth century (fig.3.89).

Fig. 3.89 - Investigation and diagnosis of floor above the ground floor - (photo author)

In this solution we have proposed the following measures:

- ✓ the top, all the walls will bind with a belt reinforced concrete bearing walls capable of providing collaboration and appropriate conduct at a seismic action. In this belt will anchor nets that strengthen armor bearing walls;

- ✓ replacing rotten wood beams corresponding floor above the ground floor, ceiling restoration, mineral wool insulation bridge.
- ✓ strengthening the casetare floor above ground to reduce deformations, improving the effect of the washer;

The research we made in a complex program in accordance with law 422/2001 in conjunction with experimental results aimed to quantify the parameters for calculating the structural strength and performance monitoring results over time. We have applied measures to maintain existing configuration and function of the building, providing for the works of preservation, restoration and reconstruction, without harmful substance and value historical monument, but mending and building structural and nonstructural degraded to increasing resistance of these elements.

Chapter 4 Studies and experimental research regarding restoration of heritage buildings floors

Experimental studies aimed at quantifying the parameters for calculating the structural strength and performance monitoring results over time in order to propose measures and solutions to restore and strengthen the floors vaulted masonry monuments characteristic.

To maintain and preserve the structural integrity of buildings are required to implement the correct building solutions tailored to each situation.

4.1. Research regarding rehabilitation of floors and masonry in "Pombalina" structures

Structures of "Pombalina" are structures filled with masonry wood frames and designed by the Marquis de Pombal after the earthquake of 1755 in Portugal.

Strengthening masonry and plaster floors by armed should ensure cooperation plaster masonry and achieving very good connections between elements. The use of plaster reinforced with mesh (protected against oxidation), fiberglass, and so on, allow binding of the masonry thereby improving structural function.

I participated in the internship made to achieve consolidation by armed plaster jacketing using stainless steel mesh or glass fiber and mortar. Solutions that apply to both vertical components and floor elements. Rehabilitation did it through incorporation of plaster or polymer mesh (plaster should have a thickness of 5-6cm). Fixed anchors may be used or transverse connectors for better cooperation of masonry with plaster.

4.1.1. Studies regarding the improvement of bearing capacity of floors and masonry by using mesh reinforcement STNB

This process results in structural jacketing of brick with cement mortar brand M100T and using meshes STNB Φ6mm mesh 10x10cm with 6cm thick plaster with cladding role.

The main problem associated with this material, as in elements of reinforced concrete is the presence of moisture, or oxidation that occur within the steel construction element is introduced [60] and a lack of regular maintenance action which must ensure necessary protection of steel.

4.1.2. Experimental works regarding the improvement of bearing capacity of floors and masonry by using nets of galvanized fittings

This solution is taken into account when there is objective necessity of strengthening the resilience of masonry structures. Consists in making a fine plaster (usually between 3 and 8 cm thick) and reinforcement mesh or other material element set properly. Experimental tests we have conducted in the lab frame structures and strength of materials from the Higher Technical Institute - Lisbon / Portugal.

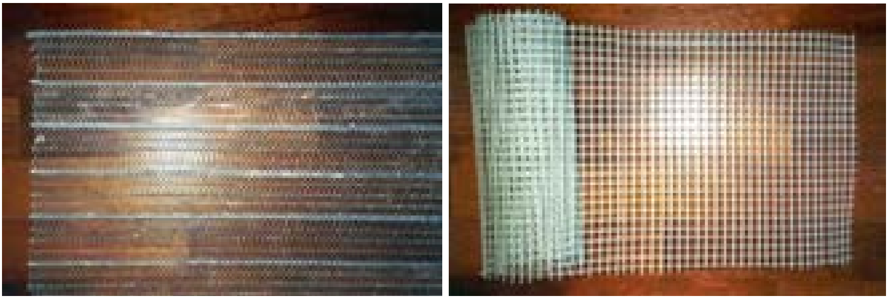


Fig. 4.3 - Galvanized steel reinforcement and fiberglass mesh - (photo João Ferreira)

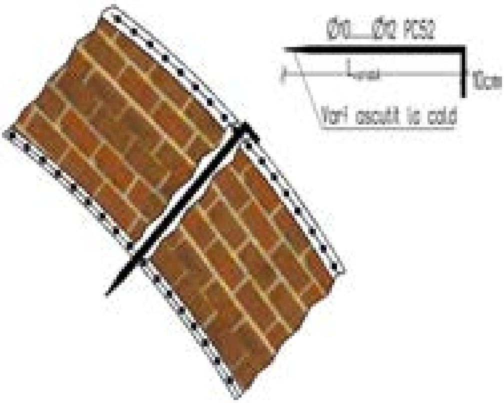


Fig. 4.5 - Jacketing of masonry vaults polymer mesh - (photo João Appleton)
Fig. 4.6 – Layout staples - (photo Grămescu Ana Maria)

Test objectives

The objectives of the experiments were studying and understanding the behavior of timber frame elements, with or without filling masonry, subject to alternating cyclic horizontal actions simulating seismic action and also how the material components work together.

The technology and equipment used

The main equipment for the test was composed of a metal beam in lieu of support embedding metal mounting brackets, a 1000 kN press sample and mounted on a frame to prevent lateral movement of the elements at the top. Technology test test used depended on the type of element attempted (timber frame or timber frame with masonry filler).

Realization of elements necessary for the test

The test consisted in the development and testing of ten samples, each consisting of four modules type wooden cross and brickwork. Wooden structure consists of elements horizontal, vertical and diagonal housed joined by the mid section cut at 45 °. All connections we reinforced steel nails. The wood used in this experimental study was pine is dried to be as homogeneous as possible in order not to differences between trials.

I tried as faithful reproduction of the structures "Pombalina 'original terms of the characteristics and properties of materials.

Test presentation

Testing involves the application of vertical and horizontal load models tested [117]. The items we tested the horizontal displacements applied at the top of the item, using an actuator with a stroke of 400 mm, with a actuator force of 1000 kN.

The test procedure consisted of imposing a horizontal movement at the top of [14], with an average speed of 15 mm / min (uniformly applied). A constant vertical load was transmitted to the top elements to simulate tasks of higher levels by six steel cables tensioned by hydraulic presses, simulating gravity load. Vertical load was considered 60 kN / m

Experimental characterization of the behavior plan we made it through the cycle test, the static shear displacement controlled. This method involves the application of cyclic shift sequences increasing in amplitude during the entire duration of the test, each segment comprises a primary cycle with an amplitude defined as a multiple of the movement reference. Primary followed by a series of cycles with amplitude equal to 75% of primary [146].

Results

Cyclic shifts have been applied to the timber breaking element [133]. The loss of rigidity has been identified in the load-displacement diagram, the movement of more than 60 mm. The analysis is restricted to a range of movement ± 5.5 mm, which results in a deviation of 2.6% of the sample.

Hysteretic behavior of elements subjected to cyclic loading is characterized by nonlinear behavior with a high ductility response [152]. The maximum force is 30 kN for items wooden structure, measured the displacement of 55 mm.

The energy dissipated in each cycle can be measured in the load-displacement curve in each cycle. Energy dissipation / cycle hysteretic behavior associated with the item we determined by measuring cycle diagram large area at each stage of deformation (force-displacement diagram). Increasing deformation leads to greater energy dissipation and lower depreciation associated with the destruction of wooden beams.

In the first cycle, it has substantially a linear behavior up to about 35 kN and 15 mm displacement.

Tabel 4.1 - Energy dissipation and damping coefficient for each cycle

Nr proba	MW1 Ed (kN/m^2)	ζ %	MW2 Ed (kN/m^2)	ζ %
C1	45,31	18,3	52,31	18,4
C2	66,29	12,2	74,82	23,4
C3	95,68	17,5	109,48	15,8
C4	281,67	13,1	308,85	16,2
C5	421,23	1□,2	474,92	16,4
C6	605,29	10,4	658,75□	22,1
C7	1369,75	16,8	1431,24	16,0
C8	2052,84	18,4	1979,76	18,6

Fig. 4.1 – Energy dissipation at each cycle

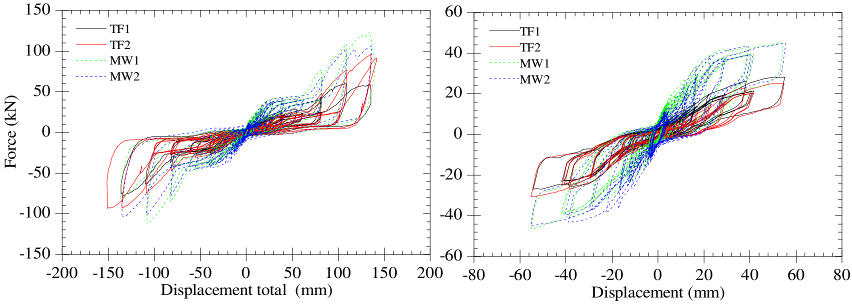


Fig. 4.15 – Force – displacement curve

Conclusions

As expected, masonry wood samples have a higher resistance than those without wood masonry failure occurring at a load of 2000 kN / m to 600kN / m The filling of the masonry is particularly important to the strength and influences the way the entire collapse mode [153], for example, by preventing instability film side of the diagonal. The wood samples masonry energy dissipation capacity and higher damping effect during seismic loadings.

During the tests the basic masonry began to fall off fall and small pieces of mortar after which they began emerging and upper masonry.

The reinforcement steel mesh led to an increase in resistance to a travel of 10 mm, and then begins to fracture at a relatively constant load. Strengthening lead to a significant increase in stiffness and energy dissipation capacity increase.

Force-displacement diagrams shows that a shift of 40 mm requires a force of 60kN and 40 kN armed elements from simple elements. The observed increases resistance to the end of each cycle, but the explanation would be that when touch movement imposed presses that maintain vertical force vertical tie rods extending element so as to give a false resistance. As the element is discharging, the resistance decreases.

4.2. Research regarding masonry specific to vaulted floors subjected to diagonal and vertical compression

4.2.1. Test objectives

The purpose of the diagonal compression test is to determine the tensile strength, shear stress, the breaking mechanism and the force-deformation diagram. Are used to establish a comparison between masonry monuments, techniques and procedures performed after normal and type of masonry reinforced with carbon fiber cover plate; this is achieved by compression of masonry panels diagonally through standardized procedures.

Uniaxial compression test (on the vertical axis direction) was conducted to determine the mechanical characteristics of masonry, without taking into account the influence of structural parameters such as slenderness and eccentricity [147].

We sought to obtain the following data: deformations and resistance in the two cases, highlighting differences in the failure mode comparison with those obtained strains and resistance of masonry reinforcement panels with CFRP blades (carbon fiber reinforced polymer) and obtain data for the design (and calculation) of such solutions.

4.2.2. Technology and equipment used

To achieve the experimental tests we conducted rectangular panels (plan faces) of masonry. The tests were performed on eight samples with 100x80x12cm geometrical dimensions, the thickness of the sample is half a brick-like structure specific "Pombalina". Eight samples were made vertically in the normal style and left walls at runtime, in a warehouse of the IST testing laboratory.

Tests were used brand Enerpac hydraulic presses with a capacity of 600 kN and 800 kN, a force of 600 kN cell and type TML displacement transducers with a 500mm displacement race.

4.2.3. Test presentation

For handling samples we used a crane and some wooden beams. The samples were rotated in the vertical plane at an angle of 450 so that the diagonal measurement of the sample test to be vertically.

In order to be positioned at an angle of 450, the sample was placed at the bottom on a metal support in the form of V [152] and was placed at the top also a V-shaped part, both parts having metal side contact with masonry 125mm sample. The sample was placed between the two metal parts to apply vertical loads (at the top) and transmission to the sample.

Load was applied consistently, with an average speed of 25 MPa / s, manually controlled rupture with the measurement of angular deformation, stress values consistent with slip (main tensile effort).

Fig. 4.21 - Preparation of samples for compression-diagonal (photo Ana Maria Gonçalves)

The uniaxial compression test using an Enerpac hydraulic press mark, with a capacity of 800 kN and 600 kN force cell.

During the test we measured the force applied until disposal, vertical deformation results were obtained using displacement transducers (located on both sides of the sample, the sample equal distance from the center of the face).

4.2.4. Results

I tried four panels masonry compressive diagonal and 4 panels uniaxial compressive masonry. After the completion of the compression test on a diagonal could be seen that the tensile strength of the samples was similar to DT0 and DT1, and to the resistance of the samples DT2 and DT3 that were lower.

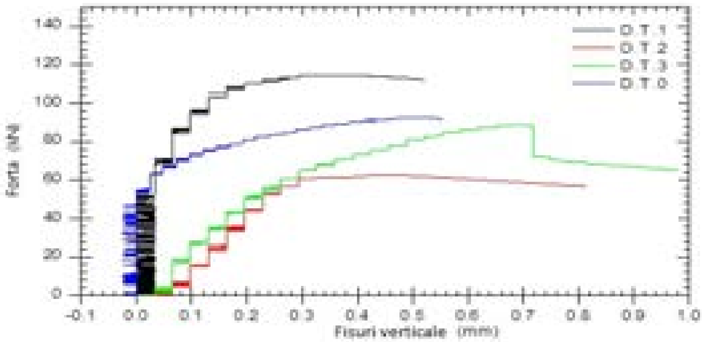


Fig. 4.24 – Vertical Cracks - Strength test rupereRezultatele diagonal compression test - (graphics - João Gomes Ferreira)

Fig. 4.25 - Diagonal compression test results

Fig. 4.27 –Images from the uniaxial compression test - (photo Ana Maria Gonçalves)

4.2.5. Conclusions

Tests carried out at this stage provided information on the behavior of masonry panels made of brick. [151]

Diagonal compression test was performed to determine the bearing capacity of vertical structural components that download vaulted ceilings. Diagonal compression specific request occurs during seismic action when you download items masonry floors are subjected to tensile - compression after the two diagonal length is comparable to request seismic motion during the earthquake. Load-strain diagrams, highlight breaking behavior depending on the size of force and displacement for the four samples considered.

4.3. Research regarding mechanical characteristics of masonry specific to vaulted floors

4.3.1. Test objectives

The main objective of the test is to determine experimentally the mechanical characteristics of the materials it is made the resistance of the heritage building features vaulted floors. The tests we conducted both in situ and in the laboratory of the Faculty of Civil Engineering University "Ovidius" of Constanta.

4.3.2. Technology and equipment used

In establishing rehabilitation solutions is an important element determining the cause that triggered degradation, and physical and mechanical characteristics of the materials it is made structure. Physical and mechanical properties of materials differ depending on the age and physical actions, biological and chemical that have been subject to during operation. Can be quickly determined by non-destructive methods used in numerical modeling is performed to establish the optimal solutions consolidation [158].

Fig. 4.28 - Submission of samples - (photo author)

To verify and validate the results obtained by non-destructive methods, they were compared with the results obtained by destructive methods in the laboratory of the Faculty of Civil Engineering University "Ovidius" of Constanta [159].

4.3.3. Test presentation

The samples used in the tests were taken from the superstructure of building declared a historic monument in Romania. The processing of the samples consisted of surface treatments to be as straight as removal of dust particles, measuring and weighing them. The site chosen for sampling had to meet several requirements: be easy to work in the space and there is severe damage to the area because the evidence is not already cracked.

Fig. 4.29 - Trying destructive compression - (photo author)

Applying the surface hardness

We performed in situ non-destructive testing before each sample. I applied under existing codes, two methods: surface hardness (sclerometer method) and ultrasonic pulse method.

Applying the ultrasonic pulse

For the application of ultrasonic pulse method, we measured the propagation velocity of longitudinal wave through the sample and in situ using experimental data and laboratory analysis of samples we determined coefficient calculation and then the compressive strength on each sample after applying this method.

4.3.4. Results

We have made a comparison between the values of compressive strength and surface hardness measured by the method of compressive strength values determined destructive.

4.3.5. Conclusions

It is noted that the resistance decreases with time intervals chosen according to the age of each sample (from 1650 to 1920) which means lower quality brick manufactured with time [159].

Parameters studied, while explaining the behavior of these structures. The results offer useful information in determining the volume of intervention measures in the work of restoration.

4.4. Research regarding the behavior and evaluation of tensile resistance of metallic tyrants used for vaulted floors consolidation

4.4.1. Test objectives

The research objective was: studying and understanding the behavior of hitch used to strengthen arches, subjected to alternating cyclic horizontal actions simulating seismic action while the vertical forces designed to simulate the weight of the structure and also contribution of masonry and how the components work together materials.

4.4.2. Technology and equipment used

Equipment (Fig. 4.39) for the test consisted of:

- ✓ two reinforced concrete beams with length 2m 35x70cm section that were used to test support;
- ✓ a 2500 kN press which was installed in the basement, below the level where the test was done. Floor, in special places, was introduced and tie rod was fixed release for tensile testing;
- ✓ sample masonry anchoring tie rod was placed on a support consisting of wooden beams 15x15cm;
- ✓ order to obtain load-displacement diagram using a metal frame that was used to support the central displacement transducer;
- ✓ also been used two type of metal I beams, which are fitted two metallic bars at their two hydraulic presses, whereby to act with a force of 100 kN;
- ✓ 30 concrete steel ties PC52 (try successively in different samples) and 5 masonry anchors fastening.

Fig. 4.39 – Test presentation – (author photo)

Their effectiveness depends on the anchor rods anchoring much on their walls. The individual tensioning units, the tension nut is screwed to the threaded ends of the valves, to the contact with the distribution plate anchored in the structure. In the test we used a four displacement transducers measuring range between 25 mm and 500 mm, brand or Apek TML two power cells.

4.4.3. Making samples for tyrants experimental test

Tried to reproduce as faithfully walls, exterior, original in terms of the characteristics and properties of materials. Although old mortars were composed exclusively of lime and sand, cement was added in these cases to ensure faster curing. Making the samples was made formwork melamine chipboard attached to a system of wooden beams.

4.4.4. Test presentation

Tests were performed on models made in the laboratory of Structure and Strength of Materials Strength of Higher Technical Institute. Tests were performed consisting of the application of a tensile force on the anchor plate and the distribution of the tensile force simulating during an earthquake.

After the test was done, it was placed on a wooden frame, which in turn discharges on two reinforced concrete beams. The sample was placed in a horizontal position, although it is tested in a cyclic power level. Horizontal position was chosen because laboratory floor is provided with holes through which you can communicate with the lower level. By such a goal was added and the tie rod has been fixed to the top wall by means of a fastening anchor fixed.

To load the wall with vertical loads, simulating gravity loads, we used two metal profiles type I, located at the ends of the wall. On the side were installed two metal rods pass through metal profiles. At one end of the metal beams have been fixed and the other end was fitted two hydraulic presses, the simulated force of gravity. The wall was equipped with transducers to measure movement in different points. The actuator applied load was also measured using a load cell, and the voltage in the horizontal axis used to simulate the vertical load.

The test procedure consisted of imposing a vertical displacement in the middle: the first test, with an average speed of 25 MPa / s, and in the second test cyclic displacement loading reached up to 110 kN. Horizontal load used to simulate tasks of higher levels was divided by two tensioned steel rods with hydraulic presses, simulating gravity load. Loading was provided to take into account the weight of the wall of a structure that takes part (vertical loading was considered to 100 kN). Simulation of the behavior in the plane of first case was conducted in the constant load and the load in the second cyclical shift control. This method involves the application of cyclic shift sequences increasing in amplitude during the entire duration of the test, each segment comprises a primary cycle with an amplitude defined as a multiple of the movement reference. Primary followed by a series of cycles with amplitude equal to 75% of primary school.

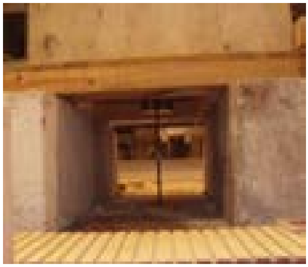


Fig. 4.48 - Sequences during the test - (photo author)

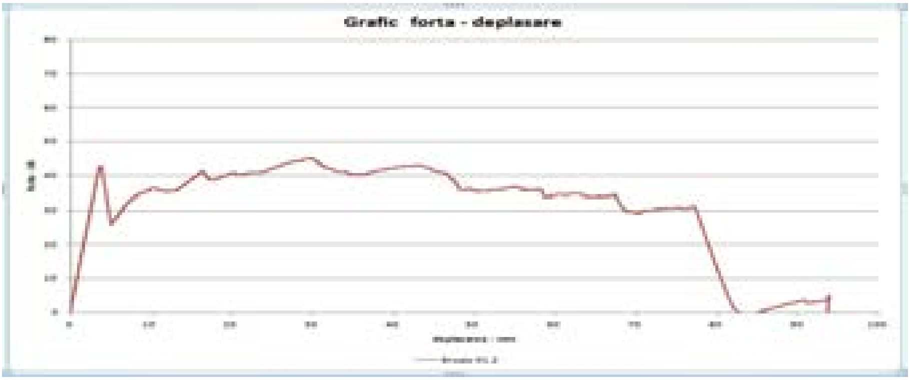


Fig. 4.49 – Force – displacement ratio (author grafic)

4.4.5. Results

Cyclic displacements were applied to the masonry wall rupture. The loss of resistance has been identified in the load-displacement diagram for a displacement of more than 80 mm. The analysis is restricted to a range of movement ± 5 mm, which results in a deviation of 6.25%.

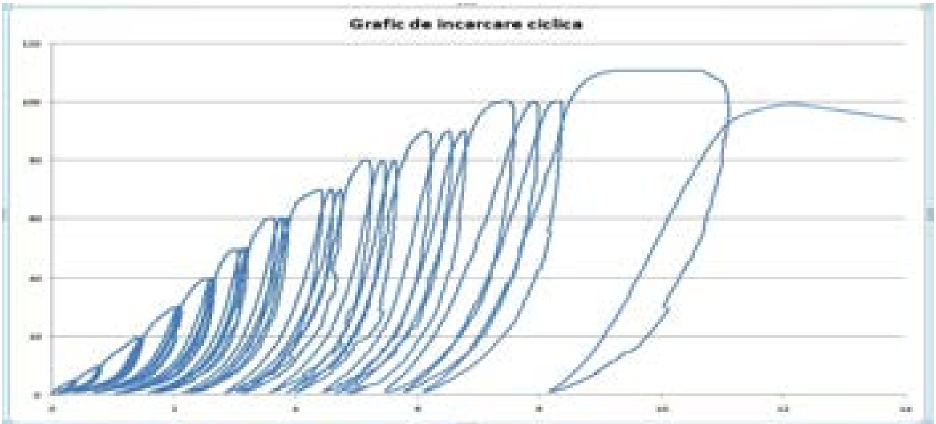


Fig. 4.50 - Graph with cyclic loading - (graphic author)

Hysteretic behavior of walls subjected to cyclic loading is nonlinear, with a high ductility response. The maximum breaking strength was 113 kN. The energy dissipated in each cycle, the surface area can be measured by the load-displacement curve in each cycle. The energy dissipated for cycle (associated with hysteretic behavior of the wall) was determined by measuring cycle broader area. The damping ratio is obtained in each cycle. The deformation increases further increase the energy dissipation resulting in damage to the masonry.

Hysteretic behavior of walls subjected to cyclic loading is nonlinear, with a high ductility response. The maximum breaking strength was 113 kN. The energy dissipated in each cycle, the surface area can be measured by the load-displacement curve in each cycle. The energy dissipated for cycle (associated with

hysteretic behavior of the wall) was determined by measuring cycle broader area. The damping ratio is obtained in each cycle. The deformation increases further increase the energy dissipation resulting in damage to the masonry.

4.4.6. Conclusions

Tests carried out at this stage provided information concerning the behavior of anchorages used to strengthen the ties metal vaults.

The experimental program conducted in this first stage of the reaction revealed some common characteristics walls and thrusts.

Because of its own weight and the geometric shape, vaulted ceilings produce horizontal thrust bearing structure that discharges resulting in cracks in the canopy and displacement component materials. Strengthening ties the pin with the horizontal is effected by means of steel bars anchored at the ends of the vertical walls by means of metal fastened to the masonry anchors or metal plates. Anchors or metal plates will be appropriately sized so as not to produce a concentration of efforts in the areas of attachment and does not lead to breakthrough structure. Strengthening the tensioner with horizontal ties may be permanent or temporary.

4.5. Research regarding improvement of behavior in time by increasing bearing capacity of vaulted floors restored with CFRP fiber stripes

In this research I have conducted a test using carbon fiber reinforcement. The results of the experimental program we used to assess adherence and behavior of brick masonry and strips of carbon fiber reinforced polymer (CFRP) which will be rehabilitation without installing anchors or connectors connected. CFRP reinforcements are increasingly used in civil engineering applications due to their advantages compared to traditional materials such as high strength, low weight and corrosion resistance [44]. The most frequented application involves external bonding [141] strips of CFRP using epoxy resin.

4.5.1. Test objectives

To obtain more clear and sharp, on strengthening the vaults with CFRP strips, we conducted laboratory tests Lerma - lab frame structures and strength of materials from the Higher Technical Institute, Lisbon, several tests: compression tests on several parts of masonry mortar prisms cylinders, the extent of adhesion of the strips and the strips CFRP CFRP and building elements [202], the tests being carried out in several stages. The thesis presents experimental investigations on the behavior of brick vaults strengthened with carbon fiber. The primary objective was to evaluate the effectiveness of different systems cosolidare and assess the viability of their use historical monuments.

4.5.2. Technology and equipment used

Bonding CFRP strips on masonry structures is a technique for rehabilitation, strengthening of historical monuments. In this technique, the adhesion between CFRP and brickwork is crucial, because the effectiveness of the solution depends on how the transfer is made tensions between the two materials, leading to exploitation of omposite section or not.

The strips were rolled trade name S & P laminates CFK 150/2000. They have the cross-section of 20 mm x 1.2 mm. The material consists of unidirectional carbon fibers (70% by weight), embedded in a matrix of epoxy resin.

After preparation of materials, bricks are placed on a stand and secure with two wooden planks and two clamping jaws, so that a distance between them is measured 235mm, then stick strips of CFRP. On their gluing must be careful not too tight as the resin to remain between 1.5-2mm and excess material on the sides, should be removed.

4.5.3. Test presentation

Once all the components were prepared to mount their past. The bricks were placed on a table on a wooden board and melamine as every brick was placed a wooden plank 2cm thick to be able to install other pieces. Between the two bricks to set a hydraulic press and a cell for force measurement and data acquisition, and the left and right inside the CFRP strips were positioned TML displacement transducers. Hydraulic press, power cell, strain gauge sensors and displacement transducers were connected to the control unit.

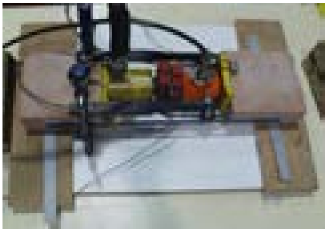


Fig. 4.64 – Preparation of the test -(photo author)

4.5.4. Results

The research aimed to study the adhesion of CFRP blades (used in different configurations), the brickwork.

Test we performed until the lost grip of the building element and CFRP strip and there were separation of the two materials (also called delamination). After testing we could plot the curves characteristic force-strain - displacement of the strips tested (Fig. 4.67).

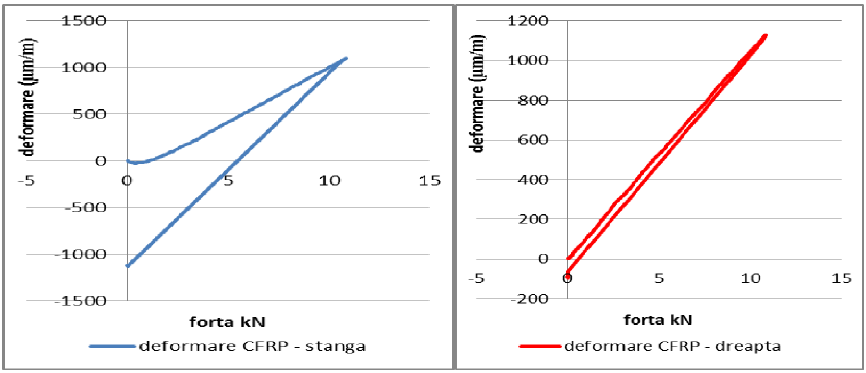


Fig. 4.65 - Graph force - deformation for CFRP strip left and right - (graphic author)

The results of the tests, characterized response elements and enhanced cooperation between the two materials.

Adhesion strips CFRP - brick flexible beam moves in the first stage [23] is followed by a step of loss of adhesion in the final stage of the discharge linear. Adhesion increases in the length and width strips sticking to a limited extent [104], and from this value, the force remains constant. Experimental results have shown a relationship force - displacement significantly nonlinear due exfoliation phenomenon or detachment of CFRP strips (Fig. 4.69).

Fig. 4.67 - Posting CFRP strips of bricks - (photo author)

4.5.5. Conclusions

CFRP laminate strips performance depends heavily on the characteristics of masonry, adhesion, and the physical and geometric structures they belong. Regarding the width of CFRP strips did not identify a major influence on the connection. Instead it was found that the contact surface preparation can significantly affect the increase adherence. Adhesion between the two materials (masonry; CFRP) favors this mode of consolidation.

As a result of observations and analyzes made during the experimental program can conclude the following:

- ✓ cooperation between CFRP strips and masonry is generally good, but stress concentrations occur at the ends of CFRP strips require the adoption of anchoring systems, in addition to bonding with epoxy;
- ✓ strengthening masonry arches on the upper side with CFRP strips are recommended to achieve a surface discontinuous 40% -60% to allow the element to breathe so there is no possibility of condensation on the lower, a vital requirement for monuments whose arches are painted on the inside;
- ✓ where possible in part on certain areas can enter Gaza and the soffit, which was a favorable effect on structural behavior and failure mechanism;
- ✓ use epoxy resin, which has a higher viscosity is suitable for masonry consolidation have a rough surface.

Laminated material made of carbon and epoxy strips have the advantage of being able to be used to strengthen masonry vaults due to high mechanical properties and good cooperation with the masonry.

Chapter 5 Study case: Church “Sf. Great Martyr Gheorghe” from Constanța

Activity, investigations, studies and research conducted during the case study- "St. Great Martyr George" Monastery – were conducted both in situ and laboratories of "Ovidius" University in Constanta County and the "Higher Technical Institute" - Technical University of Lisbon.

The research was conducted within a complex program in accordance with provisions of Law no. 422/2001 in conjunction with experimental results which aimed to quantify the parameters for calculating the resistance structure and behavior over time, in order to propose solutions to restore vaulted floors.

Fig. 5.1 – Images with the Church of St. Great Martyr George - (photo author)

5.1. Description of the place of worship, events and facts

5.1.1. General presentation

Church of St. Great Martyr George was made under Mayor Andronescu Virgil, which, according to the documents from church’s archive, he found in 1915 insufficient church for the community (the document states that in 1915 year there were two churches, namely the Cathedral and Sleeping Saint Mary). In 1922 all work were completed by the support of Mayor Virgil Andronescu, thus in 1st September 1922 began further work and were completed in 1923.

5.1.2. Technical state presentation

Construction of the church (brâncovenesc style) is made of solid brick masonry with cement mortar. Thickness of the walls on ground’s floor height is 96 cm. The foundation is made of stone masonry with cement mortar and the foundation depth is 2.25 m from ground level. The basement is made of stone masonry with brick vaulted ceiling and partially metal profiles that this vaulted brick floors load. A portion was rehabilitated 30 years ago (estimate) by realizing a concrete floor and a ladder access in the basement from concrete.

The ceiling over the nave is designed in cylindrical brick arch and above, the wooden framing falls over the walls. The cafasse has wooden floor which falls over the brick vault and adjacent walls. Above Cafasse, in the bridge area, (it can be assumed that together with the realization of concrete basement floor and a ladder access from the ground floor to the basement), there was board of 12 cm frin concrete whose support on vertical elements is poor. Because of this intervention work which possible was justified at that time though area damaged, there were also produced some masonry unable to take this load.

5.1.3. Mural paintings – decisive factor in consolidation

The church belongs to A class of historical monuments in Romania due to inside painting inside. The painting was executed by Nicolae Tonitza, Constantin Bacalu and Constantin Buiuc (Byzantine style), between 1931-1936, period when the iconostasis and furnishings of church were carved (pulpit, iconostasis and pews) by Anghel Dima sculptor from Bucharest, in yew wood and oak.

5.2. Investigation and diagnosis of building

The investigation action for the diagnosis of resistance structure was based on technical regulations in force, visual observations, the procedures recommended by the guide as technical expert and investigation methodology studied in the PhD program conducted.

The analysis of the overall structural design, analysis on execution technology and impairments identified, has imposed investigative methods and techniques applied. They aimed to establish working hypotheses, continuity model as well as identification of unique elements which constitute a valuable historical material transmitted over time, both in terms of constituent material, technology and overview design of the structure.

By the analysis over time I aimed to identify areas of degradation, their size, direction of crack propagation, their location in the whole structure of the vault, all of which contribute to highlighting areas that no longer ensure structural continuity.

5.2.1. Technology investigations and overall structural conception

In case of vaulted floors, the masonry is made of brick arranged by 28 cm side, at the soffit is seeing a width of 6.5 cm and a length of 28 cm brick. Cylindrical blade thickness is 17 cm.

Masonry mortar layer from masonry is about 1.5 cm and the section is a prism with variable surface (ie the thickness of mortar from 1cm to 2cm). The composition is based on lime mortar and sand. In the channel beam, at the beginning of vault, the structure is more robust, the thickness is 48 cm (1 brick and 1/2 - 28cm +14 cm respectively). In the analysis I found brick in the structure composition with atypical dimensions (15x29.6x5.7cm) without having properties different from standard ones.

Structural investigation was made based on building surveys and outlines a structural sensitivity and structural components: static diagrams, load size, prominent asymmetry, weight distribution and rigidities, structural discontinuities, excessive openings, further intervention.

5.2.2. Investigation of pathological factors and degradation

This investigation was based on information collected directly from documents or analyzes made prior those data. I analyzed information on materials and original technologies, overview structural design, history and state of degradation, namely structural elements that influence behavior and provide useful information on the specific mechanism of damage.

Degradation causes were:

- ✓ degradation due to excessive moisture (from direct infiltration of rainfall, capillary water infiltration through gaps (no leakage), water vapor (moisture).

The water causes masonry and masonry coatings damage (paintings and plaster).

- ✓ the next degradation is mortar and brick element, which can lead to loss of structural strength.
- ✓ material degradation due to aging, lack of regular maintenance and repair;
- ✓ overload structural elements above the design;
- ✓ inappropriate interventions (improvisations of the roof structure, supports of second order, structural components that do not have a proper discharge on structural frame elements, intermediate components which are mounted for taking efforts and deformations and do not download the bearing walls, etc.);
- ✓ seismic actions, which have lowered the carrying capacity;
- ✓ land deformations caused by: the uneven distribution of pressure, unevenness of terrain characteristics, variations in applied loads, variations in humidity ground, rainwater infiltration or seepage water from water plants and sewage.

Graphical representation of observed anomalies is very useful to understand the mechanisms of damage (this is the case of cracks in walls and facades, open cracks, structural inconsistencies and emergence of biological organisms, the occurrence of capillary water, degradation and cracking foundations).

5.2.3. Location investigation

The emplacement significantly influences the behavior of the construction site: morphology and physical - mechanical characteristics of the foundation soil, groundwater depth fluctuations, and seismic characteristics of the site.

5.2.4. Technical state diagnosis

The construction had a good behavior in time. There was no identified serious overall structural damage. Deficiencies are caused by a lack of appropriate technical interventions (eg concrete floor of the bridge) and damage to pipes carrying water. The latter have generated additional subsidence and hence local damage of structural components.

The main faults identified were:

- ✓ in the bridge area: the degradation around the masonry chimney, local catching of wedge strut discharge end is off, crack the vault of brick shaft 5 cracks in the masonry wall and perpendicular to the axis of six local area who poured a concrete floor 30 years ago (he has no appropriate discharge the vertical).
- ✓ ground floor area: crack in the spring shaft key 5, cracks in the floor away and across the entry, vertical cracks in the drain in the washer, on the altar of plaster detachments in the central tower, cracks in the arches of the eardrum cylindrical dome of the nave;
- ✓ in the basement: a rift in the church axis vertical shaft in wall 5 and 6 axis arch key.

5.3. Monitoring the structure and degradation dynamics

The easiest and most accessible method of tracking the dynamics of cracks is to use blank slides in glass, ceramics, paper, etc., which are bonded to one side of the crack. Currently using glass slides with plaster: if the cracks continue to open, the witnesses break or detach.

I placed a sensor registration for crack dynamics in the bridge, on Cafasse wall that makes the transition from the quota share +9.45 to +10.67, wall that is on the shaft 6. The fisurometer was placed 88 cm to access door from Cafasse at the bridge at 46cm from the floor at elevation +9.45 located on the crack in the wall of brick from the shaft 6 (fig.5.38).

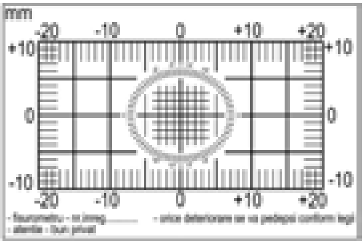


Fig. 5.37 – Fisurometer – (author design) **Fig. 5.38 - Details on emplacement**

Tabel 5.1 - Tracking the dynamics of firusometer's crack – (author design)

Date of investigation Day.month.year	Hour of investigation Hour. Minute. Second	Registration crack evolution [mm]
25.09.2012	10.06.16	0.00
23.10.2012	15.31.04	0.00
20.11.2012	12.54.28	0.00
17.02.2013	11.05.54	0.25
03.04.2013	16.19.41	0.25
11.06.2013	09.11.27	0.50
23.07.2013	17.48.31	0.50
14.08.2013	16.15.30	0.50
18.09.2013	14.19.08	0.50

After investigating the crack, I found a pronounced opening between 02.2013-09.2013, which means that the analyzed structure is still working because interventions conducted improperly and conditions of seasonal rainfall each year, lead to water infiltration and uneven subsidence of the structure. If the cracks continue to open, it will adopt provisional measures to support emergency measures and evacuation damaged portion of the building.

5.4. Analysis of characteristic floors of the church and consolidation measures with TEGOVAKON

As highlighted in previous chapters, an especially important part in the analysis of the existing floors of heritage building includes analysis of materials and their characterization in terms of physical, mechanical and chemical. Following such an analysis, by proposing solutions to restore, you can analyze and assess the impact that the solution adopted has on constituent material regarding modifying the physical, mechanical and chemical or color changes suffered.

5.4.1. The objectives of consolidation treatment by TEGOVAKON

The role of these treatments is to restore studied material - brick, close to its original strength. Treatment should be inexpensive, easy to apply and safe to use. It shall remain effective over time (decades) from a maintenance cycle to another.

Treated material will have about the same moisture, thermal expansion and elastic modulus as the untreated material in order to avoid internal efforts to ensure compatibility (treatment should be invisible).

Consolidantul has the following properties: the ability to penetrate inside the material, low viscosity and property to strengthen when you reach inside, in order to increase resistance of the treated material.

5.4.2. Technology and equipment used

For consolidation treatments, the Tegovakon product was chosen, a commercial product distributed in a version for application. This product is preferably applied on damaged materials, stone, concrete and brick with separation of material and joints affected. The most effective treatment is obtained by applying consolidantului on the surface, until saturation. The product can be applied by brush or by spraying at a distance of 5-10 cm.

Regarding the methodology of the study, although there are international regulations and recommendations for the methodology, I highlight the ones used in RILEM laboratories. Working procedure used must be the same in order to compare the results of different works, and even in this case the comparison becomes difficult due to the diversity of procedures for implementing conservation products. The current state of knowledge, underdeveloped, does not allow a yet normalized study methodology for conservation treatment so as to satisfy all the needs of investigation and conservation practice.

5.4.3. Presentation of experimental tests and consolidation teatment

Physical characterization was carried out by materials testing in order to determine the porosity accessible to water, the bulk density and the absolute maximum percentage of water absorption, coefficient of saturated water absorption, coefficient of the water by capillarity, under pressure low water absorption (Karsten tube method), conductivity coefficient of water vapor and the evaporating curve.

Porosity accesible to water test

Porosity is a fundamental property of materials (brick and mortar) and has a great influence on their durability. Many processes for altering the porosity increase, whereas the decrease porosity impregnation treatment. Therefore, this test is useful for:

- ✓ assessment of the extent of degradation of certain types of bricks and mortar;
- ✓ determining the extent to which the pores were filled with the impregnation treatment;
- ✓ evaluate the success of waterproofing treatments (comparing treated and untreated samples);

sustainability assessment materials treated and untreated [205].

Fig. 5.41 – Equipment necessary for porosity test – (photo author)

Determination of bulk and real density test

Absolute density is the ratio of dry sample weight and volume of solid material (without pores) of the sample and is expressed in kg/m3. Sample volume must be at least 25 cm3.

Absolute and apparent density measurement is a useful laboratory test in the following cases:

- ✓ in evaluating certain brick and mortar degrading;
- ✓ determining in which the pores were filled with an impregnating treatment.

Table 5.2 – Values for porosity on brick samples from the building

	Average values obtained for brick samples
Porosity (%)	34,75%
Real density (kg/m^3)	2603
Bulk density (kg/m^3)	1699

Table 5.3 - Values for porosity on mortar samples from the building

	Average values obtained for mortar samples
Porosity (%)	37,16%
Real density (kg/m^3)	2706
Bulk density (kg/m^3)	1700

Determination of the maximum percentage of absorbed water test

In order to determine the maximum percentage of water absorption, there must be carried out the same steps as in the test for determining porosity; the maximum water absorption percentage (Wmax) is calculated from the equation:

$$W_{max} = \frac{M_3 - M_1}{M_1} \cdot 100 \; [\%]$$

The average value obtained for the specimens analyzed brick is about 20% and the average value obtained mortar analyzed the tests is slightly higher, about 22%.

Determination test for water absorption by capillarity test

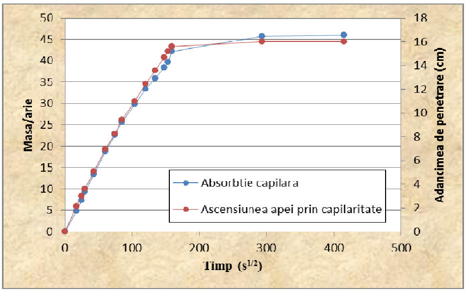
The average value obtained for the specimens analyzed brick is about 20% and the average value obtained mortar analyzed the tests is slightly higher, about 22%.

The test for the determination of water absorption by capillary action

The four side faces of the specimens were waterproof, in order to avoid water evaporation during the test (by applying a resin on the four lateral sides) or it can work without waterproof four sides. The aim is to raise the height of the water on the lateral sides. The test was carried out in an atmosphere saturated achieved by using a cover covering the tray in which the test pieces [283] to prevent evaporation of water from the sides.

Capillary absorption curve is the amount of water absorbed per unit area according to the square root of time (fig.5.44, 5.45). This curve shows generally a straight initial portion tends asymptotically to a maximum and then absorbed.

Fig. 5.43 – Water absorption by capillarity test on mortars and bricks – (photo author)



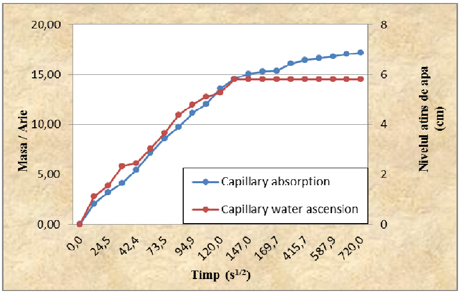


Fig. 5.44 - Graphical representation of the results obtained for specimens of mortar - water absorption coefficient by capillarity - (graphic author) - left image

Fig. 5.25 - Graphical representation of the results obtained for specimens of brick - water absorption coefficient by capillarity - (graphic author) - right image

Determination of water absorption under low pressure test

The test for determining water absorption of a low-pressure

Measurement of water absorption at a low pressure test is useful for:

- ✓ characterize the material intact and, by comparison, to evaluate the changes and alterations which modify the surface water absorption of the surface;

- ✓ analyze the effectiveness of treatment by impregnation of a surface treatment that modifies the permeability (water-repellent sealing products);
- ✓ characterize the effect of the action of climatic elements on the material;
- ✓ to determine the depth of penetration of substances applied during action waterproofing treatment.

This test is used to measure the amount of water absorbed (low pressure) surface of a porous material, after a certain period of time [205].

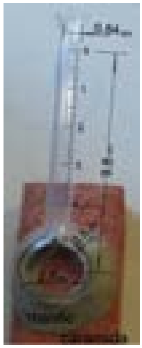


Fig. 5.46 – Karsten tube for water absorption under low pressure – (author drawing)

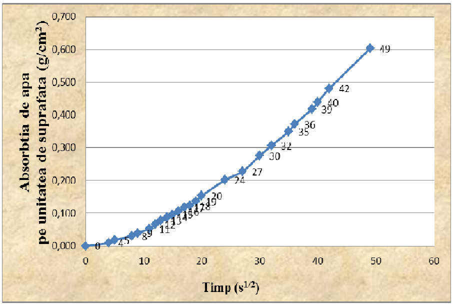


Fig. 5.48 - Determination of water absorption of low pressure in situ - (photo author) – left image

Fig. 5.49 - Average values recorded after the test specimens brick water absorption low pressure - (graphic author) – right image

Determination of water vapor conductivity coefficient test

The test for determining the coefficient of conductivity of the water vapor

The measurement of the conductivity of the water vapor coefficient is a laboratory method used to characterize the material and to analyze the effectiveness of treatment of the sealing material (comparing the untreated to treated samples) or protection against water treatment which allows the diffusion of water vapor (comparing treated to untreated samples).

The procedure consists of weighing successive samples of the cells are fixed to the material by means of an analytical balance with a capacity of 200 g and a sensitivity of 0.1 mg, given the fact that results of the changes made are small.

Fig. 5.50 – Determination of water vapor conductivity

Analysis of mechanical characteristics

Mechanical Characterization of bricks and mortar of this case study was carried out by reference to tests that allow assessment of internal cohesion, such as bending breaking attempt. Other properties, such as speed of propagation of ultrasound gives indirect information on the mechanical properties.

To achieve mechanical characterization were used the following tests:

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

Test for determining the velocity of propagation of longitudinal waves

This technique is particularly suitable for the characterization of those materials of which gaps are in particular due to cracking. If bricks and mortar gaps are mainly due pores and this makes this test can not be used at full capacity, there is a good correlation between the speed of propagation of longitudinal waves and porosity sample.

Test for the determination of mechanical bending strength

The test was based on the recommendations of RILEM III.6 and was conducted on six specimens of prismatic shape 30 x 30 x 120 [mm], a mechanical universal testing machine with a load capacity of 10 kN. Supports that the specimens were positioned and point of application of load were some cylinders with a diameter of 5 mm. The distance between the supports was 80 mm and the rate of application of the load was corresponding to a movement of 2 mm / min.

Fig. 5.52 – Brick samples tested for ultimate bending strength – (photo author)

Test for determination of ultimate compression strength

This test was performed on five specimens cube of side 25 mm faces beforehand on a release for testing compressive load capacity of 200 kN, [284].

Test resistance determined by micro-drilling method

It sends a hole, a drilling diameter, rotational speed, rate of penetration and profundity defined above, according to the material tested. Hardness in Depth is given by the force required distance drill advance brought on rotation speed and predefined by the user. Equipment continuously recorded (every 0.1 mm) drilling profundity and corresponding force required to drill. Acquisition of data and the description of the test are stored in software using a data cable connected to a computer. The software enables, among other things, to calculate the average force required to drill a particular stretch of holes. The equipment allows the use of drills with a diameter between 1 and 8.5 mm (fig.5.56).

The rotational speed of the machine is set in the initial stage of the test from 0 to 1200 rpm and is electronically controlled to guarantee a constant value during the test.

Fig. 5.56 – Testing equipment for microdrilling – (photo author)

Analysis of the chromatic characteristics

The color was achieved using chromaticity coordinates of the reference color system CIE 1931 uniform color space CIE 1976. The color was done using CIELAB system, resulting chromaticity coordinates L, a and b in this system is represented in stimulating colors a three-dimensional space in which the vertical axis Z 0 is recorded by measuring L coordinated to the mean brightness of 0 to 100 to open the dark means, variations in color to give the XY plane [207].

Fig. 5.53 – Equipment used for chromatic testing – (photo author)

5.4.4. Results of modifications registered after the consolidation treatment

The efficacy of treatment was assessed by direct form, evaluating the change in the internal structure and the mechanical characteristics of the material and the indirect form of the products achieved profundity and suffered changes in the capacity of water absorption. Efficacy was determined by comparing the characteristics of the material before and after the treatment, making the following determinations:

- Modification of mechanical resistance to microforare, flexural strength, compressive strength, the speed of propagation of ultrasound;

- Modification of the absorption capacity of the water porosity, water absorption by capillary action, the percentage of water absorbed in 48 hours, water absorption under reduced pressure;

- Profundity penetration resistance to microforare, ultrasound profile, the profile of water vapor permeability, capillarity reverse water absorption 48 hours.

Tabel 5.10 - Consumption values, the amount of product absorption and dry mass resulting from the application of consolidation treatment - average values registered

Brick samples – average values registered	Consuption of product [g/cm^2]	Quantity absorbed [g/cm^2]	Dried mass [%]	No. of samples
	~0.30	~0.10	~ 21%	5

The volatility of the solvent is the main cause of the differences between the values of the registered consumption and the quantity of product consumption will be higher and as the solvents are volatile the time of application is higher.

Tabel 5.11 - Comparison between average values recorded initially obtained after the consolidation treatment applied by brush on brick

Brick samples	Average velocity for propagation of ultrasound [m/s]		Increase [%]
	Non-treated	Treated with consolidant	
	4000 (±80)	4270 (±60)	6,75 (±1)

Microdrilling resistance action as a method of evaluation of consolidation therapy is a great method that provides information, both in the laboratory and in situ, especially on the distribution consolidantului action in profundity material (fig.5.63).

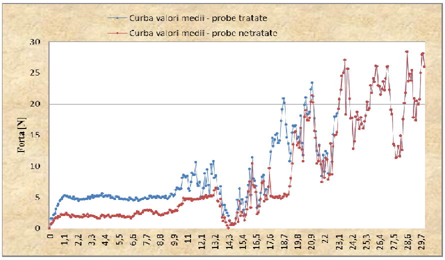


Fig. 5.63 - Consolidation treatment applied by brush. Microdrilling resistence - (graphic author)

Tabel 5.12 – Comparation between average registered values of microdrilling resistance before and after the consolidation treatment applied by brushing on brick samples

Analysed brick samples	Mechanical resistance by microdrilling testing – average values [N] Nontreated	Mechanical resistance by microdriling testing – average values [N] Treated with consolidant	Increase of microdriling mechanical resistance [%]
	18,50	24,30	~30%

The test results of the compressive strength increase provided by treatment of the building are shown in the table below.

Tabel 5.13 - Consolidation treatment. Compressive strength - Comparison of mean values recorded for determining the compressive strength before and those obtained after the consolidation treatment applied by brush on brick specimens

Analysed brick samples	Ultimate compressive strength resistance – average value [MPa]		Increase of compressive strength resistance [%]
	Nontreated	Treated	
	~ 22,6	~ 30,0	32,75%

Compressive strength reflects / certify the conclusions drawn by the results obtained by testing the mechanical strength and highlights microforare consolidantului favorable action.

This product is reinforced building material thickness is reflected by altering the original pore space of the support material and therefore the characteristics of the presence and movement of water within it. These alterations do not allow direct assessment of consolidating action but provides additional information important in the overall assessment of the action of consolidation.

Tabel 5.14 – Values for porosity accesible to water

Brick samples analyzed	Porosity		No. of samples
	Nontreated	Treated	
	~35% (34,75%)	~ 29%	6

The importance of knowing the differences in features reinforced areas and original material for predicting adverse effects introduced by the application of a given consolidation particular product has led to the need to try the most representative material thicknesses possible enhanced.

All treatments were responsible consolidation discounts around 20% of the permeability of different bricks in the table, values that can be considered within acceptable limits.

Tabel 5.16 – Consolidation treatment. Water vapor permeability coeficient

Brick samples analyzed	Water vapor permeability coefficient $\cdot 10^{-9}$ $[kg / m \cdot h \cdot Pa]$		Reduction of water vapor permeability [%]	No. of samples
	Nontreated	Treated		
	28,56 (±3)	23,66 (±2)	20,71%	6

Colorimetric characterization alterations produced by consolidation treatment was performed for all types of brick analyzed.

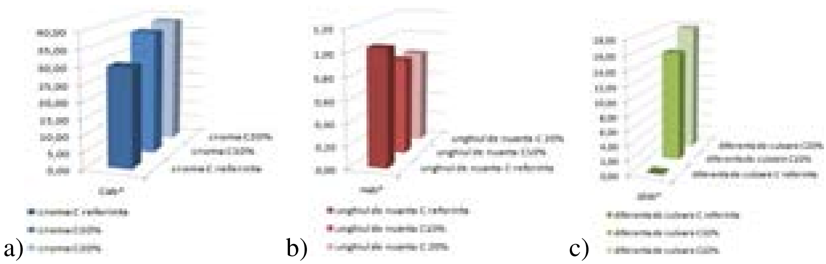


Fig. 5.64 - a)lightness difference, b) hue angle difference, c) chrome difference – (graphic author)

Fig. 5.65 - a) chromatic of the dried sample, b) chromatic of the treated sample with 10% consolidant, c) chromatic of treated sample 20% consolidant – (photo author)

From the readings made, we can infer that the samples used were not homogeneous but could color determines the color of the base material using an average readings taken. Although average values can not illustrate chromatic aspects of a heterogeneous material surface, yet allow quick evaluation and comparison between two different surfaces.

5.4.5. Final considerations and interventions measures proposed for the entire structure

Intervention measures envisaged are likely to eliminate the causes that have led to degradation, improve collaboration structural and restore degraded components in the same design with the initial construction without affecting the value of the monument. Intervention measures on construction analyzed the following criteria: achieving a degree of protection appropriate seismic church construction, removal and degradation is caused by factors other than seismic action and the amount of financial resources.

From the analysis we found that over time the church building underwent degradation caused by water seepage in the foundation soil, the development of intervention works sometimes incompatible with existing materials of the monument that actually damaged the building such as floor concrete from the bridge overhead bell tower mounted right of the main entrance.

Quantified value of the building as a monument, the painting and other components requires special attention in order to operate in optimal conditions, ensuring a very good reaction time. Intervention measures proposed are consistent with the requirements of restoration work that rehabilitation should not affect the substance of the historical monument.

For this reason, the proposed works are:

- ✓ epoxy injection of cracks identified high strength inner arches masonry structure;
- ✓ development of belts reinforced concrete walls in the upper level of the bridge;
- ✓ making a metal or wood flooring (Cases seated height) as a washer at the bridge and anchored in concrete belts (as attached plan) is recommended because wood version has less weight.
- ✓ strengthening tower cracked by arrangement of circular metal clamps on its height and repairing masonry cracked. It will consider and assess all functional bells, the broken proposing to remove from this quota. At the time there were four bells in the presence of a functional one. The proposed measure seeks to reduce load on the share;
- ✓ local Repair a download component of the roof structure (marked by inclination);
- ✓ achieving an adequate acquisition and disposal of rainwater;
- ✓ review all water-bearing plants inside their church and installing protective tube. It is noted that at the time of the investigation there was a very high

humidity of the land on the left - the lumânărar - moisture that comes from existing plants. We will review the adoption of effective solutions air conditioner condensate drainage from the basement;

- ✓ review and where necessary restore the electrical installation in accordance with current technical requirements and rules;
- ✓ are proposed adjacent to a perimeter drain construction, which will drain the lower elevation below the existing foundation will be designed to ensure drainage of excess water;
- ✓ intervention techniques on structural pathologies.

5.5. Mathematical modeling and analysis of behavior in time of vaulted floors

5.5.1. Quantification of mathematical parameters in analysis of structural performance

The structures of old buildings frequently require rehabilitation, repair and / or consolidation. Rehabilitation solutions, consolidation is established following technical expertise that are required to be accurately known physical and mechanical characteristics of the materials it is made structure expertise.

Rapid determination of physical and mechanical characteristics can be made by non-destructive methods in the field or laboratory destructive methods. In the research project we sampled from old buildings of heritage interest and determined the mechanical characteristics of non-destructive methods and finally the results were compared with those obtained by compression at Universal hydraulic press (destructive methods). Samples were processed according to the standards in force both for testing and non-destructive methods for destructive ones. Validation of the results obtained by non-destructive methods has been confirmed in the laboratory by means of destructive, leading to the safety of these mechanical characteristics used for modeling and numerical simulation of the structure.

It is incorrect that these numerical modeling to mechanical characteristics of the materials used as if it were us. Physical and mechanical properties of materials is disrupted while (especially if damaged building requires building intervention, immediate rehabilitation). Moreover, the mechanical properties may vary from one building to another depending on age and causes damages incurred while. In conclusion to establish optimal solutions are needed to strengthen the numerical modeling of the mechanical structure determined for each structure analyzed so as to obtain the numerical simulations real behavior of the structure.

In the following table we made a compilation of the characteristics and properties used for numerical simulations and computational analyzes and literature and studies.

Tabel 5.19 – Characteristics and properties used for analysis and numerical and computational simulations

Notation	Unity measure	Mechanizal characteristics	Value	Studies	Analyzed element
Mortar					

R_t	N/mm^2	Tensile resistance	0.05	Creazza şi alţii 2000	Cross vault
			0.2	Vermeltfoort 2001	Cylindrical vault
			0.1	Foraboschi 2006	Dome
			0.2	Badala 2010	Cylindrical vault
			0.018	Milani 2009	Monastery vault
R_c	N/mm^2	Compressive strength	2.3	Creazza şi alţii 2000	Cross vault
			2.5	Vermeltfoort 2001	Cylindrical vault
			1.8	Foraboschi 2006	Dome
			2.5	Badala 2010	Cylindrical vault
			2.3	Milani 2009	Monastery vault
c		Coesion	1.2 f_t	Creazza şi alţii 2000	Cross vault
			1.2 f_t	Vermeltfoort 2001	Cylindrical vault
			1.2 f_t	Foraboschi 2006	Dome
Φ		Friction angle	25º	Creazza şi alţii 2000	Cross vault
			20º	Vermeltfoort 2001	Cylindrical vault
			20º	Foraboschi 2006	Dome
			20º	Milani 2009	Monastery vault
Brick					
R_c	N/mm^2	Compressive strength	30	Creazza şi alţii 2000	Cross vault
			30	Vermeltfoort 2001	Cylindrical vault
			30	Foraboschi 2006	Dome
			12.6	Badala 2010	Cylindrical vault
			20	Milani 2009	Monastery vault
c	N/mm^2	Coesion	1	Vermeltfoort 2001	Cylindrical vault
			1	Foraboschi 2006	Dome
Φ		Friction angle	45º	Vermeltfoort 2001	Cylindrical vault
			45º	Foraboschi 2006	Dome

5.5.2. Selection of calculation model and behavior in time of vaulted floors

Choosing the calculation model is a complex action and expressing a balance between simplicity and confidence shown in the selected model. In this sense, this chapter presents a brief historical account initially proposed models vaults floors which explains in many situations and principles of composition, but also the intervention.

Although masonry structures have been used over time, only recently constitutive models and computational techniques have become available and can realistically describe the static behavior of structures made of heterogeneous materials whose tensile response is fundamentally different the response of the compressor.

In order to determine the maximum load to failure for masonry structures, many authors have proposed models of rigid blocks with different interfaces and applied these models and vaults study [172], [203].

The elasto-plastic is widely adopted, [176] [177] Some authors even making a comparison between the different models of this type [150] and applied to the study of the dome is set [219].

5.5.3. General principle of vaults mathematic calculation

To drive further and further math to apply the finite element method it is necessary to consider the type of finite element. The literature method was developed based on two established finite element: 8 nodes quadrilateral element type "thin shell" and thickness h and 6 triangular element nodes and thickness h

Exposed the problem mathematically can be solved by appropriate numerical methods. In this section the authors describe the finite element procedure implemented Nosa code static analysis of masonry vaults and domes. Masonry vaults equilibrium problem is solved using a quadrilateral element with eight nodes type "shell" based on the assumption Love - Kirchhoff. Each such element is the corner node three degrees of freedom. The four middle nodes have a degree of freedom (rotation around the side). This rotation is independent nodes movements corner and then the elements are not consistent.

These movements and rotations within the element are given by:

$$u = \sum_{i=1}^{4} \varphi_i \cdot u_i \qquad \text{si} \qquad \theta = \sum_{j=5}^{9} \varphi_j \cdot u_j \tag{33}$$

where :

u_i = displacement vector in node i;

φ_i = bilinear functions i = 1 ... 4;

θ_j = middle node rotations (5 ... 8) and centroid rotations (9);

ψ_j = bicuadric functions j = 5 ... 9

We denote ε_{ij} the total strain component on the local base $\{g_1, g_2\}$. Deformation vector $\varepsilon = (\varepsilon_{11}, \varepsilon_{22}, \varepsilon_{12})^T$ (34) may be expressed as a function of the displacement vector general:

$\tilde{u} = (u_1, u_2, u_3, u_4, \theta_5^S, \theta_6^S, \theta_7^S, \theta_8^S)^T$ (35) where $\theta_5^S, \theta_6^S, \theta_7^S, \theta_8^S$ the middle node rotations around their side through the matrix B containing derivatives of functions of the form $\varepsilon = B \cdot \tilde{u}$ (36). In particular the matrix B can be written as:

$B=\left[B^m+\zeta\cdot B^c \quad \zeta\cdot B^\theta\right]$ (37) where B^m is the matrix membrane deformations and Bθ matrices Bc and changing curvature.

We have developed appropriate numerical techniques based on the Newton method - Raphson solving linear system obtained by the finite element mesh structure. Thus, in this sense, use tangential stiffness matrix whose expression is:

$$K_T = \int_A \int_{-\frac{h}{2}}^{\frac{h}{2}} B^T \cdot D \cdot B \cdot d\zeta \cdot dA \qquad (38)$$

where:

K_T = tangential stiffness matrix (Newton – Raphson)

A = element area

D = matrix of the derivatives components $D_E \hat{T}$ of the effort $\hat{T}(E)$ in relation with deformation E. Taking into account the previous relations, relation (38) becomes:

$$K_T = \int_A \begin{bmatrix} B^{mT} & B^{cT} \\ 0 & B^{\theta T} \end{bmatrix} \begin{bmatrix} D_0 & D_1 \\ D_1 & D_2 \end{bmatrix} \begin{bmatrix} B^m & 0 \\ B^f & B^\theta \end{bmatrix} \cdot dA$$

where $D_i = \int_{-\frac{h}{2}}^{\frac{h}{2}} \zeta_i \cdot D \cdot d\zeta$ i = 0,1,2 (39)

5.5.4. Mathematic calculation example

This example is intended to evaluate and demonstrate the effectiveness of the method originally proposed by Lucchesi and others and implemented in code Nosa Italian and comparison to other methods used in the literature.

In this example I'm numeracy limit state analysis simple masonry structures being studied a spherical dome subjected to loading from its own weight and a concentrated force applied capstone. It will determine the exact solution and then make a comparison with finite element analysis by increasing the variable load until you can find a field of work allowable balance (negative semidefinite field at each point of the structure).

Consider spherical reference system D spherical vault, main radius R and thickness h is recessed canopy supports and subjected to its own weight and load co concentrated force applied capstone. The goal is to determine the value of the multiplier λc collapse / failure.

A quarter dome radius 1 m, thickness of 16 cm and γ = 20 000 N/m3 was meshed with shell elements - 3200 - Nosa coded and analyzed. The coefficient λ loading is increased incrementally until λs value beyond which it is not possible to obtain convergence. For this case, the coefficient multiplier λc = 6230 N load multiplier coefficient determined by Nosa is λs = 6200 N.

Although currently in Romania there is a computer program to quantify realistically improve collaboration by introducing structural elements such diagonals or hardening of ribs, however, studies and research have allowed me to adapt a computer program , used widely in universities in Italy at our floors type canopy, with their geometric characteristics and mechanical parameters and site-specific behavior of SE Romania obtaining results which shows that the measures considered are substantially improved behavior criteria and cooperation of floors and stiffness while increasing importance as part of ensuring a floor washer system.

Chapter 6 Conclusions and future research directions

6.1. Contributions to the development of knowledge in the field of preservation and restoration of heritage buildings

Studies and research conducted in the first stage aimed to identify geometric and mechanical characteristics of vaulted brick floors, a common solution for heritage buildings. This research and identification stage is very important in analyzing structural components, in determining intervention measures for conservation and restoration. I identified structural composition of floors heritage buildings and heritage own values (geometric concepts, traditional technologies, historical materials). I also identified the parameters influencing structural compliance and factors defining vulnerability exploitation, methods and techniques to improve the mechanical behavior of the floors, needed to be considered in the action for restoration and conservation of heritage buildings.

The research was based on construction inspection with these features, their study and consultation a rich material in the field, appeared in the literature, national and international conferences and research results performed in Italy, Germany, Portugal, France, Spain and Turkey testing laboratories. I made a compilation of material characteristics (brick) used and demonstrated in the literature and based on research conducted on the materials coming from South-East area of Romania.

Studies and research conducted in this paper revealed also another important aspect – the one related to the need to increase the bearing capacity of the floors made of brick vaults. In such cases the role of restorer is particularly important, motivated by the fact that the intervention works must not altered historical substance, conformation or element's architecture. Thus, we studied a rich literature, the research were applied in solved case studies and the methods proposed are method and techniques to increase the carrying capacity, increased rigidity.

6.2. Experimental research results and their scientific validation

I performed a classification of vaulted floor characteristic to heritage buildings, the need of such actions related to historical monuments and the presentation of rules and conditions of preservation and rehabilitation, techniques to achieve geometrical characteristics. I set the requirements related to buildings floors, historical evolution of constructive solutions and component materials.

Through documentation and research in situ I gathered information about geometric characteristics on floors, requests and status damage. I presented techniques, methods and equipments for investigation and diagnosis, as well as degradation and failure mechanisms of masonry vaults. I have described also the main causes of component elements and structural analysis of floors in pathological situations.

I researched the target of intervention works: their classification, choice of intervention strategies, interventions and solutions on heritage buildings. I presented techniques to restore both structural and unstructural techniques, restoration techniques with metallic elements, restoration techniques with elements of reinforced concrete, restoration techniques binders or with composite materials. Finally, some restoration techniques were adopted in case studies.

In order to maintain and preserve the structural integrity of the buildings, I tried implementing correct building solutions, tailored to each specific situation. I performed experimental tests on typical floors rehabilitation of heritage buildings that need rehabilitation and restoration because of their degradation and inappropriate interventions that have been checked. Experimentally, I applied techniques and methods for masonry building by jacketing polymer mesh and galvanized mesh.

During this experimental phase I investigated the evolution of deformation characteristics and strenght to uniaxial compressive and diagonal, specific masonry for floors characteristic to historical monuments, highlighting differences in the failure mode, the values on deformation and resistance as well as obtaining information for designing restoration solutions. I achieved the tests objective, thus the results are used to compare the masonry of historical monuments, realized after common techniques and methods and the same type of masonry reinforced with carbon fiber cover plate. By carrying out the experimental program I obtained the following data: evolution of deformation and resistance characteristics, highlighting differences in the failure mode, deformations and resistance values compared to those obtained on the boards of masonry reinforcement with CFRP blades and obtaining data for the design of such solutions.

I conducted experimental tests to determine the physical and mechanical properties of the materials, from which is realized the resistance structure of vaulted floors specific to heritage buildings. I analyzed pathologies related to the physical-mechanical properties of materials (which has a leower or greater level of aging and degradation, with unpredictable behavior and so difficult to parameterized, being away from theoretical linear schemes), pathologies related to typological and morphological characteristics of structural elements that make it difficult to define static simplified schemes.

The results of this analysis were summarized in a database of physical and mechanical characteristics which we can determine the status of efforts in different sections and the whole structure. Parameters studied while explaining the behavior of these structures. The results provide a volume of information valuable in determining intervention measures in the work of restoration.

Intervention technique on both constituent material and used method is dependent on behavioral parameters of each component material, the quality of the material and operating conditions. Qualitative techniques are based on insertion inside the structure of constituent material of materials capable to increase the resistance of the contact surface with the environment, to increase compactness, eliminate brittle and limit possible progressive impairment caused by the environment. Knowing the structure of the material, its composition is particularly important in determining the composition of films or penetrations which are structural components and aimed at limiting degradation, increased wetted surface resistance. I determined the physical and mechanical properties of brick masonry specific to vaulted floors through non-destructive methods for various heritage buildings and to verify and validate the results I compared them with the results determined by destructive methods.

Experimental work carried out to strengthen the ties, the floors vaulted was to assess resilience and behavior during a tensile force, the anchorage for tie rods used to strengthen vaults and assess the effect produced on masonry components. Experimental campaigns have led to studying and understanding the behavior of tie rods used to strengthen arches, subjected to alternating cyclic horizontal actions simulating seismic action while the vertical forces designed to simulate the weight of the structure and also contribution of masonry materials and how components work together. Tests carried out at this stage provided information concerning the behavior of mechanical anchorages fixed to the tie rods used to strengthen metal vaults.

Carbon fiber reinforcements are increasingly used in civil engineering applications due to their advantages compared to traditional materials such as high strength, low weight and corrosion resistance. The most frequented application involves externally bonding carbon fibers using epoxy polymer. In this paper the research we conducted experimental tests to assess adherence and behavior of brickwork and polymer strips that can be used in restorations without installing anchors or connectors connected.

Carbon fiber reinforcements are increasingly used in civil engineering applications due to their advantages compared to traditional materials such as high strength, low weight and corrosion resistance. In this type of solution for consolidate building structures, enhanced material characteristics have an important influence on the ultimate limit state. CFRP laminate strips performance depends heavily on the characteristics of masonry and the physical and geometric structures they belong.

For more efficient use of brick masonry strengthening CFRP strips, I recommend increasing the distance between CFRP strips to ensure flaking and deformation mode.

I investigated the overall structural degradation and the specific components, which are highlighted by the surveys and illustrative inventories on material degradation. We aimed to identify areas of decay, their extent, the direction of crack propagation, their location in the whole structure of the vault, all of which contribute to highlighting areas which no longer have the capacity required to ensure the continuity element.

Structural analysis revealed very interesting elements such as how to download the status of efforts and geometric component. The analysis we performed based on geometric survey of construction and based on finding an overall structural sensitivity and structural components: static diagrams, load size, prominent asymmetry in the distribution of masses and rigidities, structural discontinuities, excessive openings interventions future. I realized plotting the anomalies observed, thus very useful, trying to detect patterns that contain valuable information for understanding the mechanisms of damage.

When examining cracks and damages in order to determine its causes and status of efforts, it is necessary to know if they have stabilized or continue to progress; I watched so if there are signs of enhanced stress state due to the increasing intensity of actions, reduce development section or strains bearing elements.

In the technological investigation we included a description of construction in terms of technological components, namely: type of structural elements, materials and technologies used, the characteristic dimensions of the structural components, such as connections and their functional capacity, any structure defects.

Instrumental investigations through nondestructive methods have provided data on their materials characteristics and damages contents, helping at specifying the causes that led to the damage mechanism and decisively contribute to assess the insurance of the building.

I conducted a study on the different types of vaults, presenting a summary of mechanical parameters related to mortar and brick and I studied the analysis principles of the parameters presented in the works of Creazza, Foraboschi, Milani, Vermeltfoort and Lucchesi.

I adopted an elastic-plastic model from the literature, based on homogeneity principle of the material and a constitutive equation that can be used for modeling the behavior of materials characteristic for vaulted brick floors. In this paper I have studied several such problems in the case studies, through appropriate numerical techniques, showing that although the type masonry material model is not taken into account (at least in its original formulation) features such as material anisotropy allows us to conduct a realistic analysis for large complex structures. Also, it occurs the concept of maximum eccentricity module of the surface in order to permit a concise and effective playback of the results of finite element analysis, as well as evaluating the safety / security level of the vaults. By this method we can analyze any type of arch subjected to any type of static load - a problem that is difficult to solve by traditional methods. Moreover, for different types of loads is possible to determine the appropriate multiplier collapse / failure it.

6.3. Personal contributions and original elements during the research activity done

With the support of Ovidius University, Constanta, Faculty of Construction and Lisbon Higher Technical Institute, we conducted a bilateral cooperation agreement. Under this agreement, we completed a 7 months internship of bibliographic and experimental research on methods and techniques of investigation, diagnosis and rehabilitation of heritage buildings.

Studies and investigations conducted during the research have achieved their ultimate goal related to the development of appropriate intervention methods and techniques of different structural composition floor in order to improve its mechanical behavior supporting the general concerns of specialists in restoration and conservation of historical monuments, being represented by the following own contributions and original elements:

- ✓ making a documentary study on technical and scientific literature on interest of conservation and restoration measures for typical floors for heritage buildings at national and international level;
- ✓ identifying structural composition floors of heritage buildings and own heritage values;
- ✓ identify a significant number of vaulted ceilings and presentation of sub-assemblies;

- ✓ visual analysis and documentation of floors identified in heritage buildings in Romania, Portugal and Italy;
- ✓ thorough documentation and selection of most representative techniques, methods and equipments for investigating and diagnosing floors;
- ✓ selection and investigation of major structural and non-structural techniques and methods needed to be considered in the action for restoration and conservation of heritage buildings;
- ✓ selection of the most representative experimental studies and conducting extensive research in both in situ and laboratory investigation and restoration related to adopted solutions at: "Old Court Braila", "Water Tower in Braila", "High School Sports no. 2 of Constanta" and "Saint Pantelimon Hospital in Braila "
- ✓ experiments on the behavior of masonry load-bearing structures of "Pombalina", specific to heritage buildings in Portugal;
- ✓ research on masonry specific to vaulted floors, subjected to compression in two directions;
- ✓ direct involvement in experiments and research on behavior and the resistance to traction of hitch bolted metal used to strengthen vaulted floors;
- ✓ conducting thorough research both in situ and in laboratory, on the mechanical characteristics of specific masonry for vaulted floors, typical to historical monuments from South-East are of Romania;
- ✓ elaboration of evaluation methodologies of brick adherence and composite materials reinforced with carbon fiber, based on laboratory tests and measurements;
- ✓ conducting experimental research both in situ and laboratory during technical expertise, case study - "St. Great Martyr George" in Constanta, in order to investigate and diagnosis the construction;
- ✓ establish a system of monitoring and diagnosing the condition of failure in the case study;
- ✓ developing its own methodology and restoration for vaulted floors with consolidated product, based on investigations in situ and laboratory tests and measurements, taking into account national and international technical regulations;
- ✓ comparative study on mathematical modeling and analysis of behavior in time of vaulted floors to improve their structural performance;
- ✓ from direct participation in the projects I examined by making behavioral records, inspections, detailing case studies, non-destructive and destructive testing, laboratory studies, for the following construction:

- ➢ restoration, consolidation, enhancement and introduction to the touristic medieval architectural complex of the Monastery Ratesti-Buzau
- ➢ rehabilitation, modernization and equipping specialized outpatient psychiatric hospital of St. Pantelimon-Braila
- ➢ restoration Water Castle – Public Garden – Braila
- ➢ restoration of porch of Antonie Voda – Turnu Monastery – Prahova
- ➢ work of securing limited building No.1 Street Justice - Former court in Braila

- ➢ school sports and restoration group No.1 - Constanta
- ➢ strengthen and restore the church of St. M.Mc.Gheorghe - Constanta

All results lead to new research directions on typical floors behavior specific to heritage buildings and adopted restoration solutions.

6.4. Valorification of the results obtained during the paper elaboration

I expect that the research results will become a valuable database through both their applicability to strength and stability assessment specific to heritage buildings and in elucidating history aspects of construction techniques in reference area.

The material is based on research conducted during the research internship at Higher Technical Institute-Lisbon by the research team of which I was part and in which they occurred experimental research for determining the material used to make arches. The results of research were published in numerous articles on journals from national and international database.

During the research program, the results were used as follows:

- Grămescu Ana Maria, Dragoi Mihaela, **Pericleanu Bucur Dan** – “Research Report No. 1/2009: "Mechanical behavior of slabs made of vaults. Rehabilitation solutions";

- Grămescu Ana Maria, Dragoi Mihaela, **Pericleanu Bucur Dan** - "Contributions to the influence of moisture on the natural stone resistance structure of the patrimony buildings", WATER Conference 2010, published in Annals of “Ovidius” University, year XII Series: Construction, ISSN 1584-5990, Ovidius University Press, pp. 489-496, 2010;

- Grămescu Ana Maria, Mitroi Amedeo, Dragoi Mihaela, **Pericleanu Bucur Dan** - "Influence of environmental factors on mechanical resistance on natural stone buildings and quantification în technical expertise" published in Journal of Enviromental Protection and Ecological, ISSN 1311-50-65 - 2010 Greece – ISI journal;

- Grămescu Ana Maria Popa Mirela Mihaela Dragoi, **Pericleanu Bucur Dan** - Research Report no. 1/2010: "Modeling and computing solutions for cylindrical vaults made of brick";

- Grămescu Ana Maria, Gelmambet Sunai, Drăgoi Mihaela, **Pericleanu Bucur Dan** - Research Report no. 2/2010 "Study and research on mechanical resistance of masonry."

- Grămescu Ana Maria, Gelmambet Sunai, Drăgoi Mihaela, **Pericleanu Bucur Dan** - "Determination of mechanical properties of natural stone and brick masonry elements în heritage buildings” – Internațional Symposium on Nondestructive Testing of Materials and Structures, Istanbul Tehnical University, Istanbul, Turkey, 15 to 18 May 2011, Springer Edition, RILEM Bookseries, ISBN 978-94-007-0722-1, pp. 1173-1178, ISI journal.

- **Bucur Dan Pericleanu**, Mihaela Dragoi - "Accesibility of water în heritage buildings materials" published in Annals of “Ovidius” University, year XIV - No.14 Series: Construction, ISSN 1584-5990, Ovidius University Press, pp. 89 - 94, 2012 under International Water Conference 2012;

- **Bucur Dan Pericleanu**, Mihaela Dragoi - "Water - a key factor in heritage buildings chromatics" published in Annals of “Ovidius” University, year XIV - No.14

Series: Construction, ISSN 1584-5990, Ovidius University Press, pp. 95-100 2012 under International Water Conference 2012;

- **Bucur Dan Pericleanu**, Mihaela Dragoi - "Contributions on realization techniques for vaulted floor decks" published in Annals of "Ovidius" University, year XV - No.15 Series: Construction, ISSN 1584-5990, Ovidius University Press, page 39 -44, 2013;

- Mihaela Dragoi, **Bucur Dan Pericleanu** - "Studies and research on physical and mechanical parameters of building stone used in Fortresses in Dobrogea. Case study: Histria fortress" published in Annals "Ovidius" University, year XV - No.15 Series: Construction, ISSN 1584-5990, Ovidius University Press, pp. 93-100, 2013.

6.5. Future research directions

The results obtained offer the possibility of developing new research themes concerning cooperation between composite and masonry, finding new systems in the current context of protection, conservation and restoration of heritage buildings at national and international level, which leads to superior structural performance of materials .

In the future I intend to study new research themes such as:

- ✓ modeling some types of vaults by mathematical calculation programs, arches subjected to vertical and horizontal loads using actual physical and mechanical characteristics of masonry arch;
- ✓ modeling other types of complex vaults found in the interest area of historical monuments from South-East Romania: a sail vault, vault Romanesque or Gothic in computer programs and comparing their behavior with actual behavior identified on the ground;
- ✓ establishing a methodology for choosing optimal solutions for consolidation;
- ✓ I also intend to elaborate specific technologies such works categories that can be included in a regulatory consolidation / rehabilitation and conservation of strutural components characteristic to heritage buildings;
- ✓ I will track the development of some compatible technologies and materials to achieve a wide range of intervention solutions based on qualitative assessment.

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