„OVIDIUS" UNIVERSITY CONSTANT
Doctoral School of Applied Sciences
Civil Engineering PhD Field

Summary of PhD thesis

PhD coordinator

Prof. dr. ing. Romeo CIORTAN

PhD student

Ing. Daniel VLĂESCU

- CONSTANȚA 2020 -

TECHNICAL - ECONOMIC ASPECTS IN MODERN CONSOLIDATION WITH COMPOSITE SYSTEMS FOR CONSTRUCTION ON STRUCTURES OF REINFORCED CONCRETE FRAMES

SUMMARY

ABSTRACT OF THE DOCTORAL THESIS

1. CONTENT OF THE DOCTORAL THESIS

2. KEYWORDS

Rehabilitation, consolidation, consolidation of nodes, composite materials, consolidation of historical monuments, consolidation of port hydrotechnical constructions, structural rehabilitation, fibre-reinforced polymer composites.

3. INTRODUCTION

Strengthening reinforced concrete frame constructions using fibre reinforced composite materials is a relatively new approach to structural rehabilitation. Lately, this modern method of rehabilitation is widely applied in a wider way on constructive components. Due to the fact that some traditional building materials have suffered degradation over the life span and at the same time have certain structural limitations, it has become necessary to look for alternative constructive solutions. A viable solution came from the area of aeronautical materials which, applied in close connection with traditional construction materials, allowed us to achieve higher structural capability

The applicability of composite materials reinforced with fibres in order to improve the structural performances is analysed from two different perspectives: the reinforcement applied to the outside of the concrete face or embedded in concrete. The exterior reinforcement is the most used and consists in reinforcing the timber beams or reinforced concrete structural elements by bonding of composite boards or by lining, confining concrete columns, reinforcing masonry or structural floors. The embedded reinforcements are used in concrete as simple, pre and post reinforcements.

Within the doctoral thesis, a research program was initiated in order to analyse the modern systems of consolidation with composite materials.

Researching the studies performed so far on the various structural elements of reinforced concrete, it became obvious that a study to detail the junction area of the beams in the nodes of the structural frames that require consolidation was not properly researched. Some of the experimental tests performed are unique to the materials researched in the national and international literature.

In order to carry out the experimental investigations, a load bearing frame in natural size (1: 1) was created, which was assimilated within an existing construction, where there were a series of dimensional and reinforcement constraints to the current design norms.

The doctoral thesis with the title "Technical-economic aspects in the modern consolidation with composite systems for constructions with structures of reinforced concrete frames" has as a priority objective an analysis of the solutions offered following the use of fibre-reinforced polymeric composite systems for the rehabilitation and consolidation of the structures from reinforced concrete frames and, in particular, the reinforcement of reinforced concrete frames with composite systems.

The accomplishment of a sector from the vast research-development program, started in this field, is found in this doctoral thesis following the collaborations with the research teams, with Mr. Professor Univ. Dr. Eng. Ciortan Romeo, with Mr. Professor Univ. Dr. Eng. Breabăn Virgil and others in this field.

4. SYNTHETIC PRESENTATION OF THE CHAPTERS OF THE DOCTORAL THESIS

Chapter 1 represents the introductory part and defines the objectives and content of the doctoral thesis by chapters.

Chapter 2 (MODERN COMPOSITE MATERIALS USED FOR ENGINEERING STRUCTURES), defines the main types of composite materials used in the rehabilitation of structural structures, as well as their physical-mechanical properties. The main procedures for obtaining the composite systems were analysed when consolidating the structural elements.

Taking into account the particularities and the different characteristics of the materials, depending on their nature, the production making aspects, as well as the need to determine the characteristics of the maximum use, leads us to a more detailed study of the composite materials and the ways of consolidation with these type of materials.

Composite materials are multi-phase system elements obtained by joining at least two chemically distinct materials with a clear interface between components, and the result is a composite material created for the purpose of obtaining properties that cannot be obtained by any of the components working individually. Given the fact that these materials are artificially obtained, it is possible to order the reinforcement orientation, depending on the desired performance.

The composites comprise of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase, usually more rigid and more resistant is called reinforcement, and the continuous phase is defined as matrix or, basic mass - figure 4.1 [20].

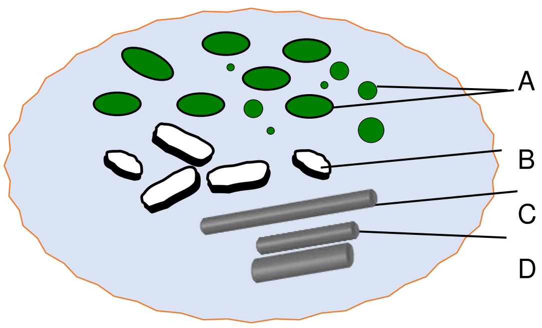

Figure. 4.1 Component phases of composite materials:
A - particle; B - sheets; C - fibres; D - matrix.

In order to establish the property of the composite as a multi-phase system, the interface region must be delimited. The general interface idea defines the common boundary of two phases and represents a surface of separation of the components of an existing mixture as a distinct phase [4, 12, 16, 18].

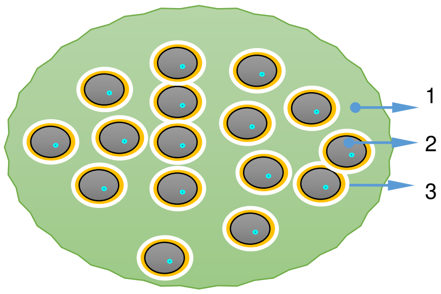

Figure. 4.2 Phases of the composite system [1, 2, 4, 5, 6, 9, 10, 13, 15]:
1 - continuous phase (matrix); 2 - the dispersed phase (armature); 3 - the interface

Since there are more manufacturers of composite systems on the market and more manufacturing technologies, the mechanical properties of the fibres can vary in high value ranges. In practical applications and in research, glass, carbon and aramid fibres are most commonly used because they exhibit a linear elastic behaviour until breaking, unlike steel. Figure 4.3 shows the characteristic stress-strain-specific curves of fibres versus steel.

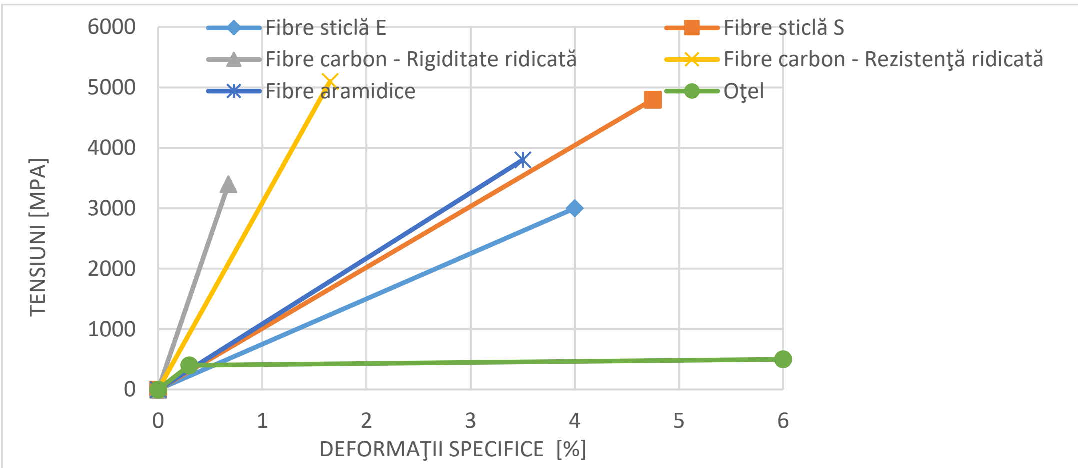

Figure 4.3 Characteristic stress-strain curves specific to fibres and steel

Starting from the simplest fibre found in most composite products, the industry has developed several types of materials that underpin modern consolidations. From classical engineering, several bars or flat bands have been assimilated into composite materials. The linear elements are used mainly as interior reinforcements for concrete structures but also as elements applied to the outside of the constructions in the form of flat strips, working on the same foundation as the conventional steel structures.

Manual handling is the cheapest and simplest process for creating composite products. The fibres are in the form of mattresses or fabrics and are placed on a mould or on a flat surface to be impregnated with resin and pressed using a roller [8].

In the spraying process, the reinforcement material and the resin are impregnated at the same time on a mould. Spray moulding is most commonly used in glass fibre reinforced materials [7].

Vacuum formation is based on the method of manual handling, using in addition a vacuum film, which is disposed at the top of the surface of the composite element. The foil is fixed by means of a sealing gasket, followed by the vacuuming of the air between the foil and the mould.

Continuous lamination formation is accomplished by a more complex technological process which consists of a first step in the introduction of a material or fabric that is protected on both sides with a protective foil and immersed in an impregnated resin container.

Pultruding is a continuous process of automatic manufacturing that allows the production of long elements, with constant sections in various forms from fibre reinforced composite materials [18].

Pressure formation derives from the pre-impregnation formation method. A thin film of rubber is applied over the fibres impregnated with resin. The air pressure of about 0.35 MPa is applied through the tube of the pressure plate and then through the rubber bag.

Vacuum impregnation of fibres is similar to the method of pre-impregnation forming and is used to reinforce concrete elements.

Chapter 3 (TYPES OF STRUCTURAL CONCRETE FRAMES), presents practical solutions and application technologies used in the structural rehabilitation of structural reinforced concrete frames constructions. This chapter presents several case studies on the current methods of consolidation.

By rehabilitation is meant the whole of the works that are being carried out in order to increase the load bearing capacity of a structure or for the purpose of consolidation.

The necessity of the rehabilitation measures is established by a series of elements: the aging process of the constituent materials, damage due to the aggressive chemical working environment, the change of functional requirements, the appearance of new functional loads, poor design or execution, the end of the operating life, the maintenance and the exploitation. inappropriate, vandalism, modification of the requirements stipulated by standards [20].

The reinforcement of reinforced concrete structures is based on a simple conceptual solution and the greatest challenge is given by the ability of the concrete area - composite to take over and transfer the stress states between the elements.

The reinforcement of reinforced concrete beams is done with composite systems to increase the load bearing capacity (the fibres are disposed in the direction of the longitudinal axis applied to the soffit of the beams) or for the purpose of increasing the shear load capacity (the fibres are arranged perpendicularly to the longitudinal axis for the additional view. transverse interior).

Figure. 4.4 Final repairs with composite systems to damaged elements (personal archive photo - Maritime University of Constanța)

The design of composite materials applied to the outside of reinforced concrete floors is based on the principle of steel bars used in reinforcing concrete slabs. The application of the composite strips to the soffit of the floors follows the same paths, and the distance between them is determined by a calculation of the bent plates [4,13].

Figure. 4.5 Consolidation of the floor with composite strips (personal archive photo - Maritime University of Constanța - building Nautical Base)

In order to reinforce the reinforced concrete walls, the narrow composite strips applied on the main stress directions are used most of the time. They are also used for reinforcement and continuous fabrics covering concrete walls [4]. The fibres of the composite can be arranged horizontally, vertically or in the directions of the diagonals depending on the direction of the requests in relation to the median plane of the wall.

Structural reinforcement of reinforced concrete pillars aims to increase the compression bearing capacity by creating an external confining system. The evolution of extension in the transverse direction of the requests is held instead of the external system that shows a confining pressure on the concrete [4,16]

Figure. 4.6 Final repairs with composite systems at the columns (personal archive photo - Maritime University of Constanța)

Since seismic risk is an increasingly important factor determining the conditions in the process of structural design, the framework nodes become of interest. The intersections between the horizontal and vertical elements create a series of areas that require a special approach, considering the transfer of loads under optimal conditions and without influencing the directions of the loads to the foundation system [3, 19].

Figure. 4.7 Experimental node 1 - left (zone 1) and right (test area 2)

Figure. 4.8 Experimental node 2 - right (test area 3)

Chapter 4 (EXPERIMENTAL INVESTIGATION ON THE BEHAVIOR OF CONSOLIDATED REINFORCED CONCRETE STRUCTURES WITH COMPOSITE MATERIALS) presents the experimental results obtained on the consolidated and non-consolidated loading elements with composite systems. Four tests were performed on four distinct areas for two frame nodes (left and right). Three test areas were consolidated with composite systems in separate hypotheses, and one area was not consolidated in order to establish the basic characteristics related to the unconsolidated structure. The test areas were subjected to individually controlled loads in order to establish the mechanical characteristics under request conditions.

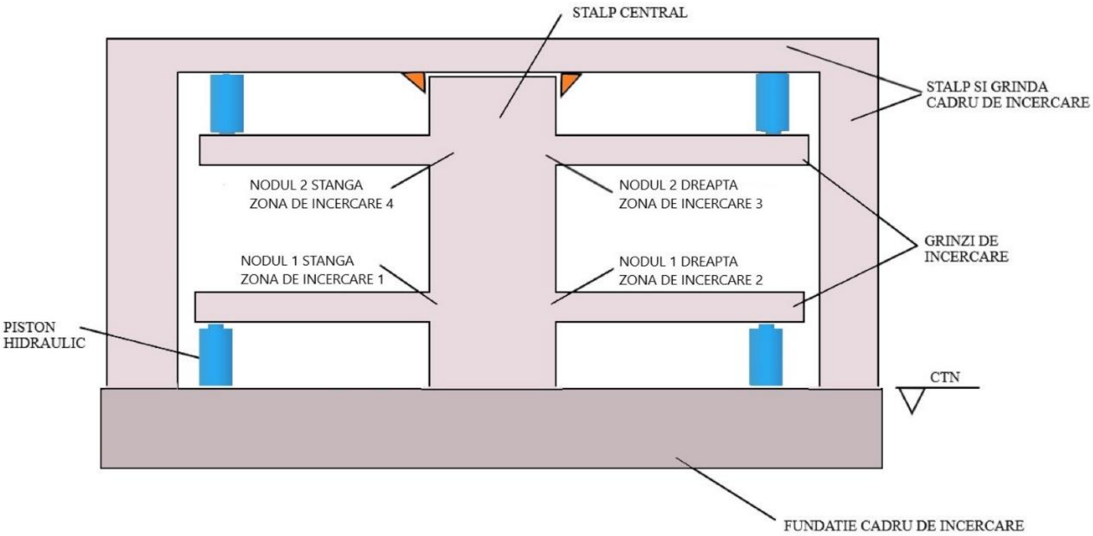

Figure. 4.9 Test assembly

For the evaluation of the structural response of reinforced concrete nodes reinforced with fibre reinforced polymeric composites (CPAF), as an experimental program has been established to allow obtaining conclusive experimental data and results that reflect as accurately as possible the studied phenomenon. Another important aspect that has been considered is the recording and interpretation of the behaviour of the nodes.

Within the experimental program, the areas of embedding of the beam in the node on one side and on the other were analysed in a framework structure of reinforced concrete.

The experimental program required the execution of an auxiliary construction in the form of a reinforced concrete frame that was made in order to fix the hydraulic loading piston. Inside the auxiliary frame, an assembly consisting of a central pole and two beams disposed in the console symmetrically to the central pole was build, calculated so that the hydraulic piston can be installed. From the way the construction was designed four test zones resulted, numbered from 1 to 4 and which were subjected to individual tests. The structural calculation of the experimental assembly was idealized in order to optimize the method of application of Polymer Composites Armed with Fibres (CPAF).

In order to carry out the experimental program, a series of working stages were set according to the complexity of the proposed objectives, in order to obtain the desired quality parameters.

Thus, the following working steps have been established and considered:

a) achievement of the helper test framework (foundation, pillars and beam)

b) reinforcement of the experimental elements - the central pillar and the beams disposed in the console symmetrically to the central column

c) formwork of the experimental elements of reinforced concrete

d) casting and vibration of the experimental elements of reinforced concrete

e) shuttering removal of the experimental assembly

f) the processing of surfaces and edges related to the areas subject to consolidation

g) achievement of the composite system for consolidating the nodes (test areas 1, 2 and 3)

h) preparation and calibration of the system consisting of the hydraulic pump, hydraulic piston, manometer, microcomputers and connection elements

i) performing the test of the unconsolidated zone (zone 4), recording and acquiring the data

j) carrying out the experimental study on the consolidated nodes (test areas 1, 2 and 3) and data acquisition

k) data processing and observations on the experimental program

Test zones 1, 2 and 3 (as shown in Figure 4.9 - test assembly) were reinforced with Fiber Reinforced Polymer Composites (CPAF) in three distinct hypotheses resulting in three different modes of consolidation:

- Test area 1 (left node 1) has been reinforced with carbon fiber fabrics arranged in several directions. A reinforcement direction was provided by a Sika Wrap fabric that was fixed 70 cm from the node to the beam soffit and extended by 40 cm to the vertical side of the column. A second direction of consolidation was ensured by the most intimate wrapping and fixing of nodess of Sika Wrap fabrics in order to ensure the consolidation elements applied to the beam and to the vertical of the column. Test area 1 was further strengthened by applying a fabric of Sika Wrap on the diagonal which is perpendicular to the bisector of the node;

- Test area 2 (right node 1), required the execution of a cold-pressed sheet metal construction on the inner corner of the node. In front of this auxiliary construction, a series of anchors made of split carbon fiber fabrics were provided at the end. Composite anchors made of Sika Wrap fabric were fastened into holes drilled on both sides of the node (pole and beam) and reinforced with Sika Wrap fabric placed on the diagonal that is perpendicular to the test node bisector;

- Test area 3 (right knot 2), was provided with a composite corner profile fixed at the bottom with the help of epoxy resins and with the help of composite anchors made from Sika Wrap fabric. The composite anchors were in turn fixed by the angle bisector of the node, and their visible part was distributed uniformly on both the column and the beam. All this assembly was fixed by the structural elements of concrete using Sika Wrap fabrics which were wrapped perimeter with fiber arranged perpendicular to the beam axis.

The type of consolidation applied in zone 2 and in zone 3 respectively are different from the current practice due to the fact that they required as a novelty element the so-called composite anchors. The technology for fixing the anchors was achieved by drilling 25 mm diameter concrete, injecting holes in the epoxy resin and forcing holes in holes made of carbon fiber fabrics impregnated with epoxy resins and split at the end. The length of these anchors is between 20 and 30 cm.

Figure. 4.10 Consolidation of zone 2 with composite anchors

In order to establish the basic characteristics of the nodes related to the unconsolidated structure, the test area 4 wasn't subject to consolidation. This node was considered as a witness to establish a pattern of response compared to the consolidated components.

The analysis of the assignment criteria found in the experimental data leads to the following conclusions:

- the practical scientific research on the natural scale (1: 1) create the premises for obtaining accurate and faithful results
- visual observations showed depletion of bearing capacity
- by recording the force / displacement relationship, the efficiency of the type of consolidation was highlighted
- the experiments allowed the analysis of the various systems and ways of consolidation

Chapter 5 (THEORETICAL INTERPRETATION OF EXPERIMENTAL TESTS) provides a theoretical analysis of the experimental tests as well as a processed analysis of the experimental loads. The response modes of the reinforced concrete nodes were evaluated. An analysis was also made of the possible modes of disposal identified by Triantafillou.

Prior to any execution process, a rigorous analysis and design is required that will consider all aspects including the nature of the materials, their interaction with the composite systems, the working conditions to which they will be subjected, as well as the existing and subsequent loads.

In the graphical representation below, a comparative analysis of the 4 experimental tests was performed, from which it can be observed that the test area no. 2 recorded the best behaviour and the best response compared to the other areas. As expected, zone 4 (unconsolidated) recorded the lowest values.

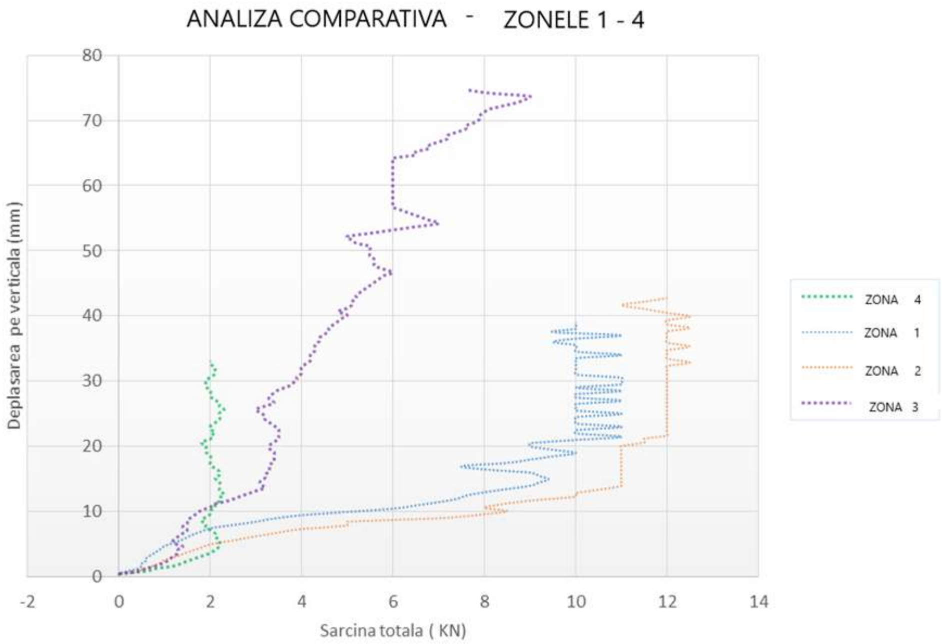

Figure. 4.11 Comparative analysis of loading areas. Characteristic force-displacement curve

In the literature there are four general requirements that must be met by composite systems [11].

- identifying the risks to which the structures can be subjected
- the rehabilitation will consider the identified risks
- the structure must not be endangered by the possible local damage accepted
- the possible failure of the composite systems should not take place without any predictive signals.

The maximum confinement efficiency in the case of reinforced concrete columns is given by the structures with circular section. Individual elements related to the geometry of the reinforced concrete element determined to carry out further studies in order to increase the efficiency of the composite system by establishing calculation relationships between the required final resistances and the quality of the composite.

The reinforcement of the reinforced concrete beam with flatbed from composite systems is carried out like the calculation of a bent beam with a non-homogeneous section. Both the concrete and the flat band of the composite are perfectly bonded together by the epoxy adhesive layer and the shading on the separation plane is prevented [13].

The frame nodes must be able to retrieve and transmit the shear forces acting on them horizontally and vertically. The calculation shear forces that can act on a frame node are determined by the equilibrium condition of the maximum efforts that result in the concurrent elements of the node (column and beam).

By reinforcing reinforced concrete structures with composite systems, a stretching effort is made from the reinforced concrete structure to the confinement system [14, 23]. The characteristic behaviour of the concrete (loading-deformation) changes due to the confinement system. Above the concrete, a so-called confining pressure is exerted which turns into a spatial state of stresses and deformations.

Triantafillou has established through analytical studies an analytical model that describes the maximum level of pretension that can be achieved in the strips of fibre-reinforced polymeric composites.

The analytical model was developed based on the following hypotheses:

- the materials used are linear elastic
- shear deformation plays a decisive role in the adhesive layer.

The theoretical model can determine the maximum prestressing level, so that the prestressed composite system will not yield near the anchorage areas.

Triantafillou graphically represented the possible ways of giving up, as shown in figure 4.12.

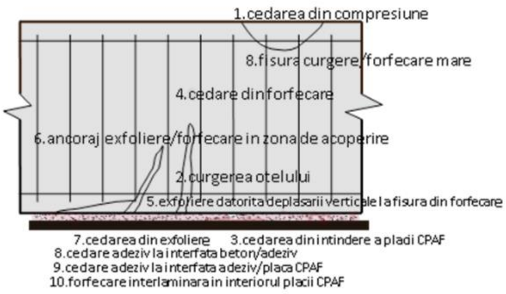

Figure. 4.12 Possible ways of giving up

Chapter 6 (SEISMIC CONSOLIDATION OF REINFORCE CONCRETE ELEMENTS OF USING COMPOSITE SYSTEMS) analyses seismic consolidation and various processes used in structural rehabilitation.

Due to the important seismic activity, it is necessary to address the problems regarding the structural rehabilitation of buildings with deficiencies.

Currently, several causes are known to influence the occurrence of structural degradation caused by earthquakes:

- improper design
- improper exploitation
- improper execution of the works
- extraordinary external effects.

Depending on the type of the structural element of reinforced concrete and the damage suffered, a classification of the most important types of damage can be achieved:

A. Damage to reinforced concrete beams
B. Damage to reinforced concrete columns
C. Damage to reinforced concrete floors
D. Damage to the reinforced concrete supporting walls.

The methods used in the projects of interventions on structures are of two types: repair or consolidation works. The investigation of the existing constructions in order to determine the material characteristics must follow the following steps:

- identification of materials and characteristics through non-destructive tests and visual examination

- correlating the age of the construction with the existing regulations during the execution period

- collecting data on its design, execution and history

- taking samples and performing tests to determine the characteristics of the materials

- determination of material characteristics.

Composite systems have begun to be used in the rehabilitation of structures in situations where traditional consolidation solutions have proved to be dysfunctional under certain aspects. Although consolidation solutions based on polymeric composites are relatively new, in the last period a large volume of studies has been accumulated, allowing realistic assessments regarding the viability of these solutions in structural rehabilitation projects.

The disadvantages of the steel plate cladding system led to the introduction of strip compositions made of polymeric composites, a solution with obvious advantages. Another traditional method (covering the elements to be consolidated) has been shown to be effective in terms of increasing strength and ensuring ductility, but inefficient due to costs, sometimes stiffness and interruption of operation over a certain period.

Following the researches carried out for the seismic rehabilitation, in addition to the classic methods of consolidation that are already widely used, over the last 30 years, several new seismic protection processes have been highlighted, such as:

a) seismic isolation of the base
b) increasing the energy dissipation capacity.

Chapter 7 (ECONOMIC ASPECTS IN STRENGTHENING CONSTRUCTIONS WITH THE COMPOSITE SYSTEM) contains an economic analysis of the value of consolidating structures with composite systems.

Fibre-reinforced polymer composites have several advantages over traditional materials, such as:

- fire resistance due to the reduced thermal conductivity
- due to the reduced weight the composite systems can be applied to constructions where the foundation can no longer be loaded
- reduced execution time
- low maintenance cost
- possibility of pretensioning by increasing the shear stress
- superior strength
- lower transport cost due to lower fibre weight
- easier preparation of contact surfaces
- easier and easier fixing of composites
- the durability of the composite system
- low risk of freeze-thaw
- flexibility in the design of the composite system
- composite materials are not magnetic.

Fibre-reinforced polymeric composites have the disadvantage that qualified personnel are required for application, and special resins are required for some resins with a high degree of toxicity.

From highlighting the advantages of using composite systems, as well as their disadvantages we can conclude that the application of composite materials in the rehabilitation of buildings is economically viable given the final cost of consolidation and the possibility of execution of works while construction is in operation without there are losses caused by the interruption of its use.

In order to establish a value on a construction that needs consolidation, the assessment must be carried out in such a way that the appropriate identification and description of the construction and relevant comparisons in the assessment can be made.

The information provided by the market showed that a rehabilitation with composite materials of a severely damaged building costs between 200 and 600 euros per square meter built, while if classical methods are used the cost varies between 700 and 1000 euros per square meter.

Chapter 8 (OTHER FIELDS OF APPLICATION OF COMPOSITE CONSOLIDATION SOLUTIONS) describes the rehabilitation and restoration of the historical buildings and a description of the consolidation of the hydrotechnical constructions. Solutions for consolidating heritage structures are presented.

When it is found that a historical heritage building requires consolidation, rehabilitation and repair work, in the majority of cases, it is recommended to use materials that have characteristics close to those of the original traditional materials, such as: carved or cast stone, timber , tile, cast iron, iron, concrete, etc. In cases where the need to replace portions or elements of the building with historical value is observed, the material to be replaced should have similar characteristics related to appearance, structure, colour or other similar features.

Taking into account the technological advancement of the last decades and due to the non-invasive interventions of the composite elements, in the protection, preservation and maintenance of the historical monuments, the materials obtained synthetically from the type of epoxy resins, polymers and polymers have started to be used more and more.

To protect and maintain the historical monuments and heritage buildings, there are several classical methods applied, such as: repairing concrete walls of load-bearing masonry walls, repairing through recess the masonry areas with cracks and cracks, repairing by redoing the joints between elements, repair by replacing damaged elements, repair by inserting steel clips in the masonry fixing, repairs with steel rods for consolidation, repairs by injection of cement mortar at the masonry, reinforcing the masonry walls with pebbles and reinforced concrete belts and repair by coating with reinforced concrete.

To repair historical monuments, current consolidation procedures are used by coating with fibre-reinforced polymeric composites. The main methods applied are pre-tensioning and post-tensioning with flat systems of polymeric composites, confinement with polymeric composites reinforced with fibres, bars embedded in composites and anchoring with polymeric composites reinforced with fibres.

Most fibre-reinforced polymer composite products are compatible with traditional materials such as timber, steel, concrete or aluminium. Composite materials can be used to consolidate and repair the constituent elements of traditional materials or even to replace them.

The solution of consolidating a historical monument or heritage building is chosen based on a rigorous analysis, and the favourable result from the end of the project is given by the involvement and professionalism of the team of architects, engineers, builders, manufacturers, etc., but also by compliance with the laws and regulations in force.

It is well known that for more than two decades concrete structures can be reinforced with composite systems. Due to the wide scope of application, composite systems were introduced to protect and maintain historic monuments and heritage buildings with concrete structures.

Due to the remarkable results obtained from the use of composite systems for the consolidation of masonry, the solution of consolidating the heritage structures with fibre reinforced composites has been implemented in a much wider context.

The notion of timber consolidation with composite systems is relatively new and is based on the technique of structural consolidation. As concrete columns and beams are reinforced with composite systems, the same method can be applied to timber columns and beams in order to increase the structural capacities.

The port hydrotechnical constructions are distinguished from other engineering constructions mainly by the following aspects:

- the execution of most of the structure is performed below the water level and sometimes under difficult conditions caused by waves, currents, etc.
- large prefabricated elements, used with specialized naval equipment, are used to the maximum

- constructions are requests, both vertical and horizontal, with important values and dynamic character

- the construction materials are subject to the aggressive action of the aquatic environment and especially the marine one.

In most cases, the infrastructure of the port constructions is made of reinforced concrete piles, pre-compressed or metallic.

The methods of reinforcing the superstructure of the reinforced concrete port stacks with composite systems are similar to those presented in the thesis and consist of: epoxy resin injections, carbon fibre flat bands, carbon fibre fabrics, anchors, etc. It should be kept in mind that the degradation can occur on the outside as well as inside the reinforced concrete elements.

Due to the specificity of the port constructions, some of the elements that need repairs are below the water level.

For the piles that are practically below the water level, a series of execution technologies have been developed that allow the work to be carried out in dry conditions. On the affected pile, there is a sealed room in which people can act in order to carry out the repair work in safe conditions.

In **Chapter 9 (GENERAL CONCLUSIONS. PERSONAL CONTRIBUTIONS AND ORIGINAL ELEMENTS OF THE DOCTORAL THESIS)**, the final conclusions are drawn following the completion of the doctoral program, the use of the results and the original contributions from the thesis.

The structures that require rehabilitation and consolidation are based on several specific methods developed on each structural element separately. These methods analyse the role played in the structure of which it belongs, the relative and absolute position in the context of the structure, the state of stresses and deformations, the degree of exposure to the action of the environmental factors, the connections with the neighbouring elements, the aesthetic aspect, the functionality, the economic parameters and not lastly, the physical possibility of doing the job at hand.

Traditional rehabilitation and consolidation practices involve the use of the same constituent materials (concrete, steel, wood) which, although present with a high degree of efficiency, take on the shortcomings of the initial materials.

The main arguments underlying the consolidation of reinforced concrete structures with fibre-reinforced polymeric composites are given by:

- arrangement of reinforcement made of fibre-reinforced polymeric composites on the lateral faces with fibres oriented following the direction of the main tensile stresses to increase the shear strength
- adding reinforcement from fibre-reinforced polymeric composites to the extended face of the beams and plates to increase the load bearing capacity
- confining with composite membranes in order to improve the loads capable of axial loads, shearing or in order to increase the ductility of the posts.

5. FINAL CONCLUSIONS AND RECOMMENDATIONS

Through this doctoral thesis I wanted to make a synthesis of the ways of using fibre-reinforced polymeric composite products in the rehabilitation and structural consolidation of reinforced concrete elements in general and frame nodes in particular.

Without understanding the phenomena and processes that take place in the matrix-fibre interface region, it is not possible to perform an analysis of the properties and behaviour of a fibre-reinforced polymeric composite material. Only in the case of intimate molecular contact between the components can an adequate transfer of the efforts be made to the interface.

The solutions and methods of reinforcing structures in reinforced concrete frames using fibre-reinforced polymeric composite materials have a wide scope and can be used to consolidate all structural elements.

The distribution of stresses around fibres can be obtained by finite elements or finite differences (analytically) or experimentally.

After achieving the objectives set, the study of the doctoral thesis stopped at a certain research stage, following that the data obtained up to this moment will be used for further study in the vast field provided by the composite materials.

The doctoral thesis can be used as a starting point for further consolidation studies with fibre-reinforced polymeric composite materials.

The experimental consolidation modes with composite systems provided for zone two and zone three are unique not found in the specialized literature.

The study of composite materials used in the consolidation of constructions is a relatively new field, which requires a volume of experimental data and the development of applied research. The main directions for further research are:

- durability of composite materials and systems
- the collaboration between concrete and composite
- possibility of pretensioning of composite materials
- anchoring of composite materials
- new ways to consolidate the knots
- the breaking character of the assignment of the structural elements.

The results of the research carried out during the doctoral studies were the basis of engineering works that were capitalized by publication in journals and specialized volumes.

The World Bank, in partnership with the City of Constanța City Hall, has developed a "Guide for urban regeneration of Constanța block neighbourhoods", in which the undersigned contributed as co-author (2019).

Within "OVIDIUS" UNIVERSITY ANNALS CONSTANTZA (OUAC) - Series Civil Engineering, Year XXI (2019), Issue XXI - I published as Author the paper entitled: "The specific use of composite materials in consolidation of historical monuments"- http://revista-constructii.univ-ovidius.ro/doc/editii/2019.pdf.

Within "OVIDIUS" UNIVERSITY ANNALS CONSTANTZA (OUAC) - Series Civil Engineering, Year XXI (2019), Issue XXI - I published as Co-Author the paper entitled: "Proper infrastructure design at high vertical loads, nearby waterfront structures" - http://revista-constructii.univ-ovidius.ro/doc/editii/2019.pdf.

Also, as an Author, I published and gave oral presentations on the occasion of the Doctoral School Conference in Iași (May 23-24, 2018), in order to communicate research results, exchange ideas and initiate new collaborations (www.tuiasi.ro).

5. SELECTIVE BIBLIOGRAPHY

1. *** (1997) "Engineering and design: Composite materials for civil engineering structures", Technical Letter no. 1110-2-548, Department of the army – US Army Corps of Engineers, Washington, DC.
2. *** (2005) „Normativ privind Consolidarea cu Fibre a Elementelor Structurale de Beton"; Institutul National de Cercetare-Dezvoltare în Construcţii şi Economia Construcţiilor
3. *** (2006) "FRP reinforcement for RC structures", Technical report on the Design and use of fibre reinforced polymer reinforcement (FRP) for reinforced concrete structures, Federation International du Beton (fib)
4. *** fib Bulletin 14 (2001), "Externally bonded FRP reinforcement for RC structures. Technical report on the Design and use of externally bonded fibre reinforced polymer reinforcement (FRP EBR) for reinforced concrete structures" International Federation for Structural Concrete. Lausanne
5. Bakis C. E., Bank L. C., Brown V. L., Cosenza E., Davalos J. F., Lesko J. J., Machida A., Rizkalla S. H., Triantafillou T. C. (2002). "Fiber-Reinforced Polymer Composites for Construction-State-of-the-Art Review", Journal of Composites for Construction, May. 16
6. Department of Defense Handbook (1997). "Polymer Matrix Composites", Materials Sciences Corporation, Fort Washington, PA
7. Emmons P.H., Vaysburd A. M., Thomas J. - "Strengthening Concrete Structures, Part I", Concrete International, Vol.20, Issue 3, March 1, 1998
8. Extern Design Manual (1995). Marisson Molded Figerglass Co., Bristol

9. Fukuyama H., Tumialan G., Nanni A. (2001). "Japanese design and construction guidelines for seismic retrofit of building structure with FRP composites", *FRP composites in Civil Engineering*
10. Head, P. R., Maunsell, G. (1996). "Advanced composites in civil engineering - A critical overview at this high interest, low use stage of development"-Advanced composite materials in bridges and structures, Quebec, Ed. El-Badry
11. ISIS Canada (2001). " Strengthening Reinforced Concrete Structures with Externally Bonded Fibre Reinforced Composites", Design Manual No. 4
12. Matthys, S. (2000). "Structural behaviour and design of concrete members strengthened with externally bonded FRP reinforcement", PhD Thesis, Ghent University, Faculty of Applied Sciences, Department of Structural Engineering
13. Oprisan G., (2002). „Soluţii moderne de consolidare a structurilor pentru construcţii industriale", Univ. Tehnică Gh. Asachi Iaşi, Facultatea de Construcţii şi Arhitectură - Teza de doctorat
14. Oprisan, G., Taranu, N., Munteanu, V. (2007). "Experimental and numerical analysis of compressed concrete elements confined with FRP composites", Computational Civil Engineering - International Symposium Iaşi, România, May 25
15. Peters S.T. (1998). "Handbook of composites – Second Edition", Chapman&Hall, London, UK
16. Stoian, V., Tamas, N. G., Dan, D., Gergely, J., Daescu, C. (2004). „Materiale compozite pentru constructii", Editura Politehnica, Timisoara
17. Täljsten, B., Elfgren, L. (2000). "Strengthening concrete beams for shear using CFRP materials Evaluation of different application methods. Journal of Composites, Part B, Accepted for publication."
18. Taranu, N., Bejan, Liliana. (2005). Mecanica mediilor compozite armate cu fibre. Ed. Cermi, Iaşi.
19. Triantafillou T.C., Matthys S. (2001). "fib report on design of concrete members strengthened with Externally Bonded Reinforcement", FRP composites in Civil Engineering
20. Ţăranu, N., Isopescu, D., Secu, A., Decher, E., Groll, L., Entuc, I., Oprişan, G., Saftiuc, C. (1999). "Modernizarea structurilor inginereşti prin utilizarea materialelor compozite armate cu fibre. Îmbinarea elementelor."
21. Xiao Y., Wu H. (2003). "Compressive Behaviour of Concrete Confined by Various Types of FRP Composite Jackets", Journal of Reinforced Plastics and Composites