LABORATORY STUDY OF CONCRETE CYLINDERS CONFINED WITH CFRP

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The field of research in the frames of this paper will be Application of Innovative Materials for Repair and Strengthening of RC Buildings in seismic active regions. Within the frames of this paper, special emphasis will be put on RC buildings where, during construction, the built-in concrete has not achieved the designed concrete class. In these cases, it is necessary to take measures for repair and strengthening of both individual structural elements and whole structures using traditional and Innovative Materials.

To present the possibilities and the benefits of use of these innovative construction materials in strengthening of structural elements of buildings and integral building structures, ample laboratory research for definition of the characteristics of these materials with different technologies of strengthening by CFRP (Carbon Fiber Reinforced Polymers) materials are carried out at the Institute of earthquake Engineering and Engineering Seismology – IZIIS, Skopje and Institute of Material Testing-ZIM-AD Skopje.

In this paper, technology of strengthening of RC columns with traditional materials as well as characteristics and types of innovative materials are introduced. Results from laboratory research of RC concrete specimens-cylinders with different technologies of strengthening by CFRP are presented.

Keywords: repair and strengthening, seismically active regions, traditional and innovative materials, concrete jacketing, compressive strength, elasticity module, CFRP

1. INTRODUCTION

Seismic strengthening of reinforced concrete structural elements represents one of the methods to increase the earthquake resistance of damaged or undamaged buildings. The strength of the structures can be moderately or significantly increased and the ductility can be improved, or in other words, it can be said that the concept of strengthening involves: a) increase in strength; b) increase in strength and ductility; and c) increase in ductility.

It has been a usual practice to perform repair, strengthening and rehabilitation of existing RC buildings structures by application of traditional methods (most frequently, jacketing of elements), but lately, new innovative materials with a special technology of construction and repair have increasingly been applied. The application of these materials is still the subject of a large number of investigations worldwide, particularly in the field of application of these materials in seismically active regions.

In order to make a contribution towards development and application of new innovative materials in engineering practice, experimental, quasi-static tests were carried out in the Dynamic Testing Laboratory at UKIM-IZIIS – Skopje, R. Macedonia, and laboratory tests on materials were done at the Institute for Material Testing – ZIM, AD Skopje, R. Macedonia .

In this paper, at first traditional methods for strengthening of RC columns with jacketing, followed by detailed explanation of characteristics and types of innovative materials for strengthening of RC columns. At last, results are given from laboratory research and experimental investigations of RC concrete specimens-cylinders strengthened by CFRP with different technologies of strengthening by CFRP (Carbon Fiber Reinforced Polymers) materials.

2. REPAIR AND STRENGTHENING OF BUILDINGS USING TRADITIONAL MATERIALS

R/C jackets are applied in the case of serious damage or inadequate seismic resistance of the column (including here failure of quality of concrete used on the site during construction). Depending on the existing local conditions, jackets are applied along the perimeter of the column, which is the ideal case, or sometimes on one or more sides.

In case where the jacket is limited to the storey height, an increase in the axial and shear strength of the column is achieved with no increase in flexural capacity at the joints. Therefore, it is recommended that the jackets protrude through the ceiling and the floor slabs of the storey where column strengthening is necessary (Figure 1) [2].

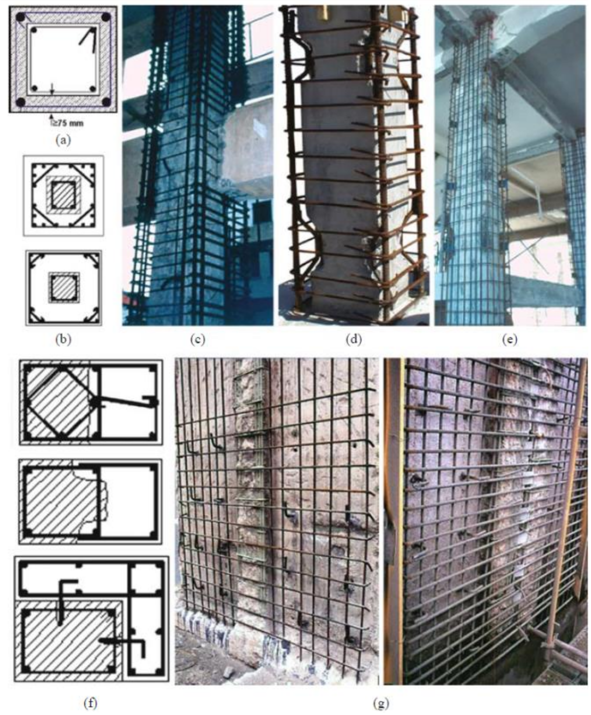


Figure 1. Concrete jackets in columns: a) simplest case b) jacket bars bundled near corners, engaged by cross-ties or orthogonal tie c) jacket bars bundled at corners, dowels at interface with old column d) U-bars welded to corner bars e) steel plates welded to corner bars f) one-or two-sided jackets g) one-sided concrete overlay with single curtain of two way reinforcement at exterior face of perimeter walls [2]

3. REPAIR AND STRENGTHENING OF BUILDINGS USING INNOVATIVE MATERIALS

3.1 FIBER REINFORCED POLYMERS (FRP)

FRP composites comprise fibers of high tensile strength within a polymer matrix. The fibers are generally carbon or glass, in a matrix such as vinylester or epoxy. These materials are manufactured to form plates under factory conditions, generally by a pultrusion process.

Reinforcement fibers are qualified in three main families of glass, aramid and carbon. There are other fibers, but they are relatively insignificant. The most important property of the fibers is their elastic modulus, and the fibres must be significantly stiffer than the matrix which allows them to carry most of the stress. Consequently, they must also be of high strength. Reinforcements are available in a variety of configurations of which there are three main categories:

- unidirectional, in which all the fibers lie in one direction.
- bidirectional, in which the fibres lie at 90° to one another. This is achieved either by use of woven fabric, non-woven fabric or by use of separate layers of fibres each unidirectionally, but successively laid at 90°.
- random, in which the fibers are randomly distributed and are in-plane.

Stress-strain fiber behaviour is different for every type of fiber (Figure 2) and different FRP shapes (Figure 3).

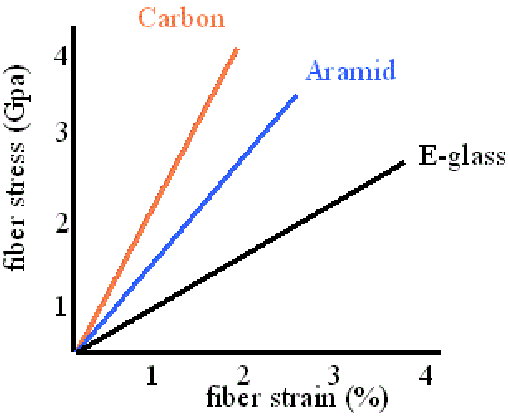


Figure 2. Stress- strain fiber behaviour [12]

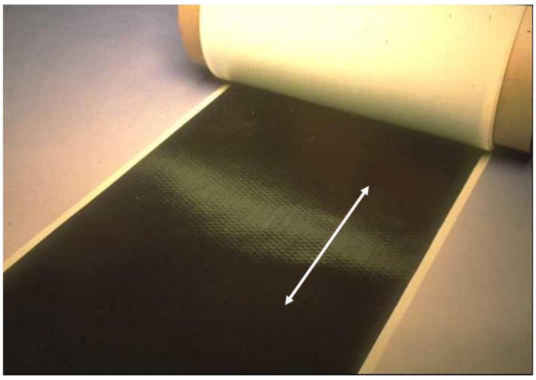
3.2 CONFINEMENT STRENGTHENING

Confinement strengthening (Figure 4) consists of:

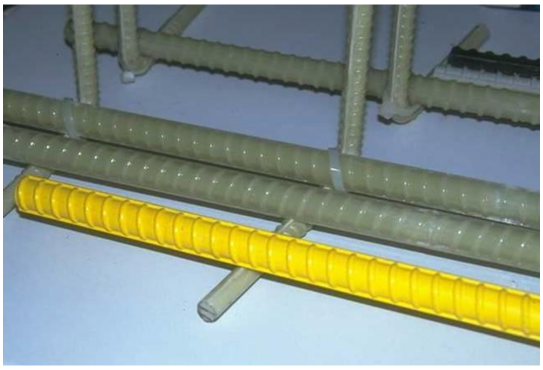
(1) Cleaning and repair
(2) Primer
(3) Adhesive
(4) FRP strips
(5) Last adhesive layer

Fiber polymer fabrics that can be used to improve bending, shear and axial capacities of the columns and beams may be manufactured from various materials such as carbon, glass and aramid without an increase in the volume of the strengthened member, significant improvements can be achieved in the capacity and ductility characteristics of the element.

These materials may practically be used for numerous purposes such as enhancement of the flexural capacity of floor slabs and improvement of shear capacity of beams, columns, joints and shear walls.



a)



b)

Figure 3. Different FRP shapes a) sheet b) bars [12]

Figure 4. Confinement strengthening [5]

4. LABORATORY TESTS ON MATERIALS BUILT-IN MODELS FOR EXPERIMENTAL RESEARCH CARRIED OUT AT UKIM-IZIIS

To realize the experimental quasi-static tests, two models were designed and constructed, namely Model M1 and Model M2. The models were with identical proportions (supporting beam proportioned 50/50/116 cm and a column proportioned 30/30/200 cm), constructed to the scale of 1:1[13].

For the purpose of easier incorporation of the CFRP materials, it was decided to build the models in vertical position [3].

During concreting of the models, three trial specimens- concrete cubes proportioned 15/15/15 were taken from the supports - beams and three trial cubes proportioned 15/15/15 were taken from the columns, in addition to the nine (9) cylinders proportioned 15/30 cm (Figure 5). To define compressive strength and concrete class, laboratory tests were performed at stock holding company-GIM-Skopje (for the cubes) and ZIM –Skopje (for the cylinders), while the tests for definition of the modulus of elasticity of the built-in concrete were done at ZIM – Skopje, Macedonia [13].

Figure 5. Photos of taken trial concrete specimens (cylinders)

Using the trial concrete specimens – cylinders, three series of tests of compressive strength and tests for definition of the modulus of elasticity of the built-in concrete were carried out as follows:

- Series 0- concrete cylinders without CFRP- plain concrete
- Series 1- concrete cylinders wrapped with 1 (one) CFRP layer
- Series 2- concrete cylinders wrapped with 2 (two) CFRP layers

Presented further are photos and results taken during laboratory tests for definition of compressive strength of concrete for the three series (Figure 6 and Figure 7). It must be pointed out that the collapse of the models from the first and the second series was explosive, with big crushing of concrete wrapped with CFRP. This was particularly pronounced in Series 2 where concrete was wrapped with two CFRP layers.

4.1 RESULTS FROM TESTS FOR OBTAINING THE COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS

Parallel with the performed tests on the three series, the obtained results on failure forces and the results from computation of compressive strength of all three series of concrete cylinders were recorded in special tables (Table 1).

Figure 6. Preparation of strain gauges on concrete cylinders.

From the results obtained, it can be concluded that the force inducing failure of concrete cylinders without CFRP amounts to 296.0 kN. For the cylinder with one CFRP layer, it amounts to 670.0 kN., while for the cylinder with two CFRP layers, it amounts to 955.0 kN. The compressive strength amounts to 16.8 MPa, 37.0 MPa and 54.1 MPa, for all three series, respectively.

Figure 7. Testing of compressive strength of concrete wrapped with two CFRP layers- the 2nd series.

Table 1. Compressive strength of three series of concrete cylinders.

Date of casting: 04.10.2019 Date of testing: 15.11.2019 Concrete cylinders CC (3 series) 15/30 cm					
Series		**Proportions H/D [cm]**	**Weight (g)**	Failure force [kN]	**Compressive strength [MPa]**
Specimens	**0**	30/15	12200	296.0	16.8
	1	30/15	12700	670.0	37.9
	2	30/15	12800	955.0	54.1

In general, it can be concluded that the compressive strength is higher with the number of CFRP layers.

4.2. RESULTS FROM TESTS FOR OBTAINING THE ELASTICITY MODULUS

Testing of the static modulus of elasticity for each series (0, 1, 2) of built-in concrete was also done in the laboratory of the Institute for Testing Materials – ZIM – Skopje AD. The tests for obtaining the static modulus of elasticity under pressure were performed according to MKS U.M1.025. The most relevant for estimation of the static modulus of elasticity was the mean value of the recorded entries of the strain gages, after dissolution in the last cycle.

Presented further are some of the photos taken during the tests on the three series of concrete cylinders (Figure 8).

Figure 8. Testing of the static modulus of elasticity of all three series.

Generally, it can be concluded that the obtained values for the concrete cylinders with one and two CFRP layers are higher than the values obtained for the concrete cylinders without CFRP.

5. CONCLUSIONS

In the paper part of the analytical, laboratory and experimental investigations of designed

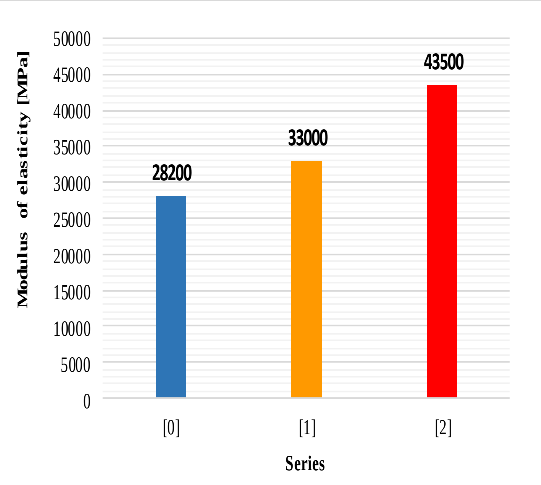


Figure 9. Testing of the static modulus of elasticity of all three series.

models of RC columns strengthened with CFRP were presented. Based on the experimental investigations the following conclusions can be outlined:

- The force inducing failure of concrete cylinders without FRP amounts to 29.6 t, i.e., 296 KN. For the cylinder with one FRP layer, it amounts to 67.0 t, i.e., 670 KN, while for the cylinder with two FRP layers; it amounts to 95.5, i.e., 955 KN. The compressive strength amounts to 16.8 MPa, 37.0 MPa and 54.1 MPa, for all three series, respectively.

- In general it can be concluded that the compressive strength and Module of elasticity is higher with the number of FRP layers.

- Obtained values for the concrete cylinders with one and two CFRP layers are higher than the values obtained for the concrete cylinders without CFRP.

- These tests are good basis for further analytical and numerical investigations that can provide additional conclusions.

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