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SEISMIC STRENGTHENING AND REHABILITATION OF EXISTING RC BUILDINGS USING INNOVATIVE MATERIALS

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Abstract

The focus of the research in this paper is application of innovative materials for repair and strengthening of RC columns of Buildings in seismically active regions. The need for repair and strengthening of RC buildings and their structural elements occurs when their elements do not possess sufficient strength, stiffness and/or ductility out of different reasons or due to slighter or more severe damages that are most frequently caused by earthquakes. 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 and/or buildings that cannot satisfy the required strength, stiffness and deformation characteristics particularly in earthquake conditions due to built additional storeys or enlargements. In these cases, it is necessary to take measures for repair and strengthening of both individual structural elements and whole structures.

It is a usual practice that traditional methods with traditional materials (most frequently jacketing of elements) are used for repair and strengthening of structures. However, lately, particularly in the last two decades, there have occurred new construction materials intended for strengthening and design referred to as composites strengthened by polymer fibers (FRP). These materials have special mechanical properties and special properties.

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 and experimental investigations of RC columns strengthened by CFRP by variation of concrete class, reinforcement percentage and different technologies of strengthening by CFRP (Fiber Reinforced Polymers) materials are carried out at the Institute of earthquake Engineering and Engineering Seismology – IZIIS, Skopje.

In this paper, some of the analytical, laboratory and quasi-static experimental investigations of designed models of RC columns will be presented. Particular attention will be paid to behavior of these columns under cyclic loads, whereat a number of comparative analyses of a number of parameters obtained from the experimental investigations of the tested models will be carried out. Some recommendations and outcomes regarding the approach and technology of practical application of these materials, particularly in seismically active regions, will be given.

Keywords: Seismic strengthening; innovative materials; CFRP; quasi-static tests, experimental study.

1. Introduction

Behaviour of existing building structures constructed and built of reinforced concrete during their serviceability period as well as during earthquakes depends on many factors. On one hand, there are external factors, i.e., loads acting upon the structures (in addition to the main loads, there are also additional loads as well as effects caused by possible explosions, fires, earthquakes…), while on the other hand, there are factors that directly depend on the very structure of the buildings (structural system, type, quality and quantity of material used for construction of the structure, number of storeys, mode of foundation,….). All these factors directly affect the strength and deformation capacity of the individual structural elements and the structural system as a whole.

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 [1], [2], [3]. 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 [4].

In this paper, selected results from laboratory testing of built-in materials and quasi-static experimental investigations of models designed and constructed by use of FRP-materials are presented.

2. Laboratory Tests on Materials Built-in Models for Experimental Research Carried out at UKIM-IZIIS

2.1 Preparation of Trial Concrete Cylinders for Testing

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 30/30/200cm), constructed to the scale of 1:1. The concrete class was the same wherefore the models were concreted simultaneously. The mode and the technology of placement of FRP was also the same, while the percentage of vertical and transversal reinforcement in the models and the constant vertical axial force in the columns were varied. Since a relatively small amount of concrete was at stake, Sintek-Specific decided to use self-compacting concrete “SIBET”.

For the purpose of easier incorporation of the FRP materials, it was decided to build the models in vertical position.

Fig. 1 shows photos taken during concreting of the foundation-beam and the columns of both models. In the first phase, concreting of the supports – foundations was done, while in the second phase, both columns were concreted.

Fig. 1 - Photos taken during concreting of models.

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 (Fig. 2). 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.

Fig. 2 - Photos of taken trial concrete specimens (cubes and 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 FRP- plain concrete
- Series 1- concrete cylinders wrapped with 1 (one) FRP layer
- Series 2- concrete cylinders wrapped with 2 (two) FRP layers

Presented further are some of the photos taken during the preparation of the concrete cylinders for further tests (Fig. 3 and Fig. 4).

Fig. 3 - Preparation of trial concrete cylinders for testing.

2.2. Results from Tests on Trial Specimens of Built-in Concrete Classes

For all three series of concrete trial specimens – cylinders, laboratory tests of compressive strength and elasticity modulus of the concrete built-in the models were done. The laboratory tests were realized by the Institute for Testing Materials and Development of New Technologies “, ZIM “Skopje” AD Skopje.

Presented further are the results from the tests on three series of concrete trial cylinders.

2.2.1. Results from Tests for Obtaining the Compressive Strength of Concrete Cylinders

The compressive strength of concrete was defined from tests on trial specimens – cylinders proportioned 15/30 cm and exposed to monotonously increasing compressive force up to failure.

Presented further are photos taken during laboratory tests for definition of compressive strength of concrete for the three series (Fig. 4). It must be pointed out that the collapse of the models from the first and the second series was explosive, with extensive crushing of concrete wrapped with FRP. This was particularly pronounced in Series 2 where concrete was wrapped with two FRP layers. Therefore, while applying the force, the part with the cylinder had to be protected by a steel plate in order to prevent unwanted consequences.

Fig. 4 - Testing of compressive strength for the three series.

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).

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

Date of concreting: 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 [t]	Compressive strength [MPa]
Specimens		Cylinders without FRP	30/15	12200	29,6	16,8
		Cylinders with one FRP layer	30/15	12700	67,0	37,9
		Cylinders with two FRP layers	30/15	12800	95,5	54,1

From the results obtained, it can be concluded that 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.

2.2.2. 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 (Fig. 5).

Fig. 5 - Testing of the static modulus of elasticity of all three series.

All the results obtained for all three series of concrete cylinders are presented in a tabular form (Table 2).

Table 2 - Modulus of elasticity of three series of concrete cylinders.

Date of concreting: 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 [t]	Elasticity Modulus [MPa]
Specimens		Cylinders without FRP	30/15	12200	29,6	28200.
		Cylinders with one FRP layer	30/15	12700	67	33000.
		Cylinders with two FRP layers	30/15	12800	95,5	43500.

In general, it can be concluded that the Modulus of Elasticity becomes higher with the increase of the number of FRP layers.

3. Experimental Program

3.1. Design of Column Models

For the needs of own experimental investigations, two column elements were designed. The column models were designed as fixed cantilever girders with a constant length of both models of 200 cm (the column was treated only up to the inflection point, i.e., half of the total height) and cross-section of 30/30 cm. In both models, the varying parameters were the percentage of longitudinal and transverse reinforcement and the axial forces. The concrete class, i.e., the compressive strength of concrete and the type of FRP were the same for both models. The elements were designed to the geometrical scale of 1:1. The axial force for simulation of the gravity load was 500. KN for Model1, while for Model2, it was 300 kN.

In designing the column models, the mode of simulation of the fixation of the column elements was also designed. The fixation of the models was done in the same way. Designed was an RC column with proportions b/h equal to 50/50 cm and length of 116 cm, reinforced in such a way as to provide complete fixation of the model. The main longitudinal reinforcement of the column model was anchored to the column in such a way as to avoid loss of adhesion in the course of the experiment. The column models were screwed through the fixation column to a steel support by means of eight prestressed steel screws (four on each side). The total weight of the entire composition (column + column for fixation of the model) amounted to 1.2 tons.

3.2. Characteristics of FRP Material Used for Construction of Models

Carbon fiber was used to wrap the models (Model M1 and Model M2) and the cylinders.

S&P C-Sheet 240 with technical data 300 g/m^2 was used. This material was available at Sintek-Specific and was used in repair and strengthening of RC columns in RC buildings in the territory of Skopje city R.Macedonia.

3.3. Construction of Models for Experimental Investigations

The construction of models MODEL M1 and MODEL M2 as well as the placement of FRP by use of the corresponding technology were done by the construction firm SINTEK-SPECIFIC DOO Skopje. The entire process of preparation and construction of the models for experimental tests was carried out in the UKIM-

IZIIS' laboratory by experienced workers from Sintek-Specific DOO. To wrap the models (Model M1 and Model M2) and the cylinders, carbon fiber with the subsequently presented characteristics was used.

S&P C-Sheet 240 with technical data 300 g/m^2. This material was available at Sintek-Specific and was used in repair and strengthening of RC columns in RC buildings in the territory of Skopje city R. Macedonia.

During their construction, the models were placed vertically for the purpose of easier placement of FRP materials. Concreting of the models was done in two phases. First of all, the foundations (the column supports) of both models were concreted, while in the second phase, the columns of both models were concreted. Concreting was done by use of self-compacting concrete –SIBET. Presented further are photos taken during construction of the models (Model M1 and Model M2), Fig. 6**.**

Fig. 6 - Construction of the column models (Model M1 and Model M2) for experimental tests.

Once the models were concreted and following 28 days of curing, there started the process of application of carbón fabric S&P C-Sheet 240, 300 gr/m^2 in accordance with the following procedure:

(1) Removal of cement slurry by a diamond drilling machine

(2) Formation of rounded edges of the column and the connection with the support - foundation

(3) Application of a base consisting of epoxy composite material Sikarbon H

(4) Application of glue for carbon fiber by means of a spiral roller

(5) Application of a new layer of Sikarbon B after 24 hours

Parallel with the process of application of carbon fabric on the models, the same procedure was also applied for wrapping the trial concrete specimens – cylinders 15/30. It should be mentioned that, prior to application of the epoxy composite base, strain gauges were glued to the models and the concrete specimens – cylinders as necessary for further laboratory and quasi-static tests on both cylinders and models.

Presented further are several photos taken during the entire process of application of carbon fabric (Fig. 7).

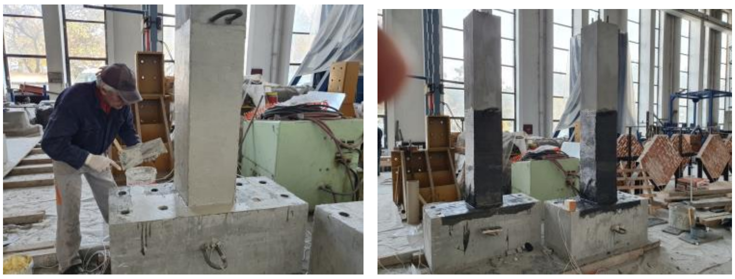

Fig. 7 – Photos taken during application of FRP on the models.

3.4. Preparation of Models for Experimental Tests

The process of testing of the column models started with mounting and instrumentation of the model, control of functioning of the entire system for performance of quasi-static tests and finally the loading programme.

Shown further are some of the photos taken during assemblage of the supports, models, placement of steel joints for transfer of cyclic and axial forces on the models as well as equipment for quasi-static tests (Fig. 8).

Fig. 8 – Assemblage of steel joints for application of forces and equipment for experimental tests.

4. Results from Experimental Investigations at IZIIS

Tested were two different models of columns (Model M1 and Model M2) that were exposed to cyclic horizontal forces with an increasing intensity and constant axial force (N = 500 kN for Model M1 and N=300 kn for Model M2) applied to the front side of the column. The experiments were conducted through the displacement that was applied on the free end of the models.

It should be mentioned that, during the experiments, the loading process was not interrupted for marking the cracks in the carbon since these were negligible and could not bee seen with a naked eye. Prior to total failure and cracking of carbon, quite loud snapping could be heard. This was the result of failure of the FRP carbon fibers after which explosive failure took place in the zone of occurrence of plastic hinges by tearing of the carbon fabric and total crushing of the concrete below it. This manifestation was identical in both models.

The results from the experimental tests are presented in the form of hysteretic relationships between force-displacement, force-deformation (in concrete or reinforcement in selected channels) and history of displacement at the free end of the model [2], [3]. Presented are also some of the photos (taken during the tests) that provide a visual presentation of the occurrence and the extent of damage.

Presented further are some of the photos taken during the experiments as well as some of the results obtained from the experimental tests on both models, MODEL M1 and MODEL M2.

4.1 Model of RC Column – MODEL M1

Model M1 (Fig. 9) was exposed to cyclic horizontal forces with increasing intensities and constant axial force of N=500 kN applied on the column front side. The experiment was conducted through control of displacement, controlling at the same time the level of horizontal force that was applied on the free end of the model through the steel plates at distance of 158 cm from the column support.

The experiment started by application of vertical force on the column starting from 0.0 to 500 kN. When value of 500 kN was achieved, the recorded strains in concrete and reinforcement were read from the strain gauges.

Fig. 9 - Quasi-static testing of the column models-MODEL M1.

. After reading these initial values from the strain gauges in concrete and reinforcement, there started the application of horizontal force, whereat the displacement value was controlled for the entire period of time. Then, there sarted the application of three cycles of displacement of 2 mm at the free end of the column by increasing the applied displacement to higher values further in the experiment.

During the entire experiment, values for all channels and a total of 4023 points were recorded.

Presented further are photos taken in the process of quasi-static tests on MODEL M1 along with photos of characteristic damage (Fig. 10) as well as some of the obtained results (Fig. 11).

Fig. 10 shows some of the photos shot during quasi static testing of column Model M1.

From the results, it can be observed that the model exhibited a nonlinear behavior, by occurrence of cracks near the fixation. It must be emphasized that tearing of the carbon fabric was explosive, with extensive crushing of concrete at that place, as evident from the presented photos.

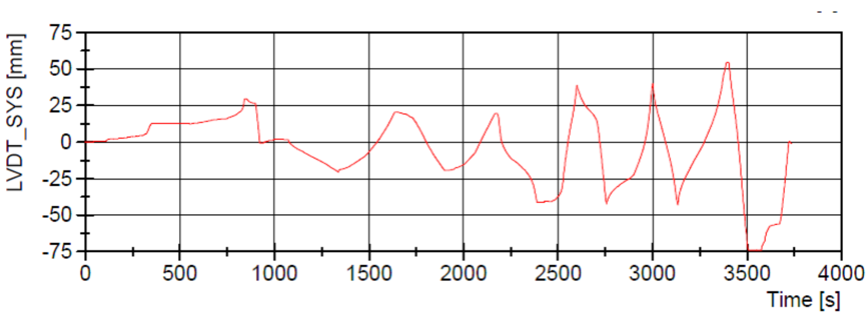

Fig. 11 - Time histories of displacement during the test, Model M1 [4].

4.2 Model of RC Columns-MODEL M2

After finishing the tests on model 1, this model was dismantled and there started the assemblage of Model M2 with all necessary steel joints and testing equipment. Parallelly, the values obtained for model 1 were explored. Considering that, during the collapse of model 1, extensive crushing of concrete under the carbon fabric was evident, it was confirmed that the quality of the built-in concrete was very low and corresponded to the values obtained by ZIM – "Skopje" – Skopje. Therefore, it was decided to reduce the vertical axial force in the column. From these reasons, a force of max. 300 kN was applied on Model M2. The loading programme was the same as for Model M1. During the experiment, 3734 points with all data were recorded. The maximum displacements reached 75 mm when total tearing of the carbon fabric and crushing of concrete took place. In addition to crushing of concrete, extensive buckling of reinforcement was also evident (Fig 12).

Presented further are photos taken in the process of quasi-static tests on Model M1 along with photos of characteristic damages (Fig. 12), as part of the obtained results (Fig. 13).

Fig. 12 shows some of the photos shot during the quasi static testing of column l Model M2.

From the performed measurements and observation of the level of damage to the elements during the test (Fig. 13), it can be concluded that Model M2 showed also a pronounced nonlinear behavior through formation of cracks in the vicinity of the fixation as Model M1. Model M2 exhibited larger capacity than Model M1. It must be pointed out that tearing of the carbon fabric was explosive also in this model and was accompanied by extensive crushing of concrete at that place, which is evident from the presented photos.

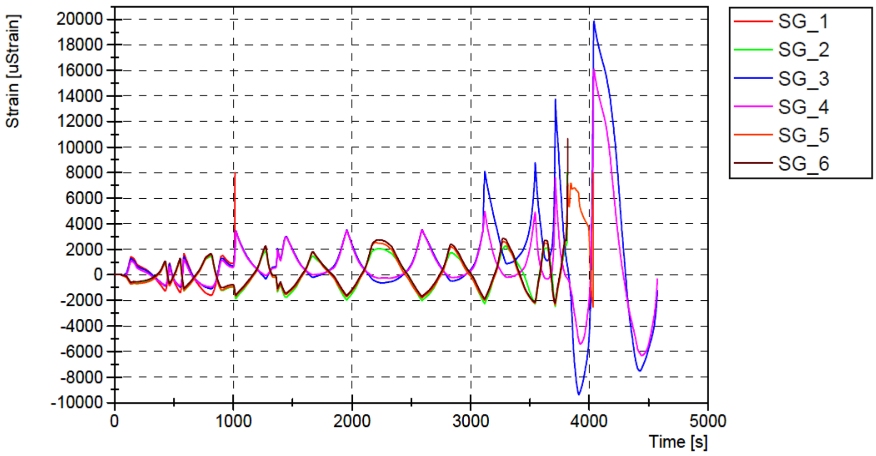

Fig. 13 - Time histories of strains during the test, Model M2 [4].

5. Conclusions

This paper shows some of the analytical, laboratory and quasi-static experimental investigations of designed models of RC columns strengthened with FRP. Based on the experimental investigations, the following conclusions can be outlined:

- The force inducing failure of concrete cylinders without FRP amounted to 29.6 t, i.e., 296. KN. For the cylinder with one FRP layer, it amounted to 67.0 t , i.e., 670. KN, while for the cylinder with two FRP layers, it amounted to 95.5, i.e., 955. KN. The compressive strength amounted to 16.8 Mpa, 37.0 Mpa and 54.1 Mpa, for all three series, respectively.
- From the behavior of the tested elements, it can be concluded that, in both Models, the failure was sudden and explosive, but with sufficient ductility capacity.
- These tests are a good basis for further analytical and numerical investigations which can provide additional conclusions.

6. References

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