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Original Scientific Paper

SEISMIC PERFORMANCE OF RC BUILDING COLUMNS CONFINED WITH CFRP*

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Abstract. *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.*
In the paper part of the laboratory and quasi-static experimental investigations of designed models of RC columns confined with CFRP will be presented. Particular attention will be paid to behavior of these columns under quasi-static 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 will be given as to the approach and technology of practical application of these materials, particularly in seismically active regions.

Key words: *seismic strengthening, innovative materials, CFRP, quasi-static test.*

1. INTRODUCTION

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

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the designed concrete class and/or buildings that cannot satisfy the required strength, stiffness and deformation characteristics particularly in earthquake conditions, [1]. In these cases, it is necessary to take measures for repair and strengthening of both individual structural elements and whole structures, [2], [3].

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, [4], [5] and [6].

In this paper, some of the laboratory and quasi-static experimental investigations of designed models of RC columns are presented.

2. 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, Figure 1. 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[1].

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

Figure 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 Construction of the column models for experimental tests and Photos taken during application of FRP on the mode

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 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

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 photos and results taken during laboratory tests for definition of compressive strength of concrete for the three series Figure 3. 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 FRP. This was particularly pronounced in Series 2 where concrete was wrapped with two CFRP layers.

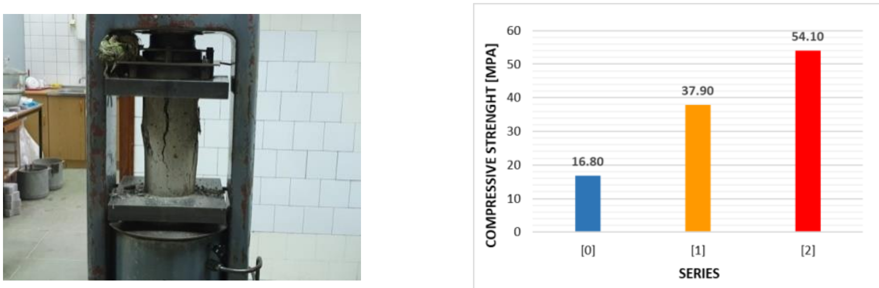

Fig. 3 Testing and results: a) Testing of compressive strength for the first series, b) Diagram of compressive strength for each series

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

3. Experimental Program

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 the FRP was same for both models. The elements were designed to the geometrical scale of 1:1.

Presented further are photos taken during construction of the models (Model M1 and Model M2), Figure 4.

Fig. 4 Construction of the models: a) Model M1 and Model M2; b) Construction of the column models for experimental tests.

To define the real bearing and deformability capacity of the built column models, the values on quality of built-in concrete and reinforcement obtained for both vertical and transverse reinforcement, as well as the type of used CFRP were used. In the first phase, the real M-Φ (moment – curvature) relationships of the column cross-sections were computed by applying axial force, the real M-N diagrams, and then, based on the obtained M-Φ diagrams, the strength and deformability capacity of each model was defined.

The strength and deformability characteristics (M-N) and (M-Φ) at cross-section level were analytically defined by use of the SAP2000 computer software. All analyses were done by taking into consideration confinement of the cross-section of transverse reinforcement. Selected results are given in chapter 4.

4. Results from Experimental Investigations at UKIM-IZIIS

Presented further are photos and results from the process of quasi-static tests on Model M1 and Model M2 with photos of characteristic damage Figure 5 and Figure 6, respectively. Figure 7 and Figure 8 represent results from the testing in terms of Moment – curvature diagrams for the two models and series of testing.

Fig. 5 Quasi-static tests of Model M1: a) Shot during the quasi-static testing of column Model M1; b) Damage from quasi static testing of column Model M1

Fig. 6 Experimental set-up quasi static testing of column Model M2

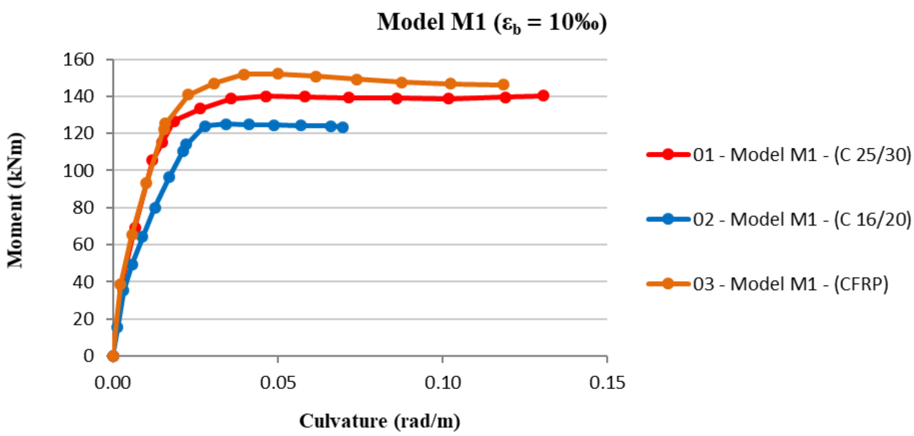

Fig. 7 M-φ Interaction Diagram for Model M1 – Comparison

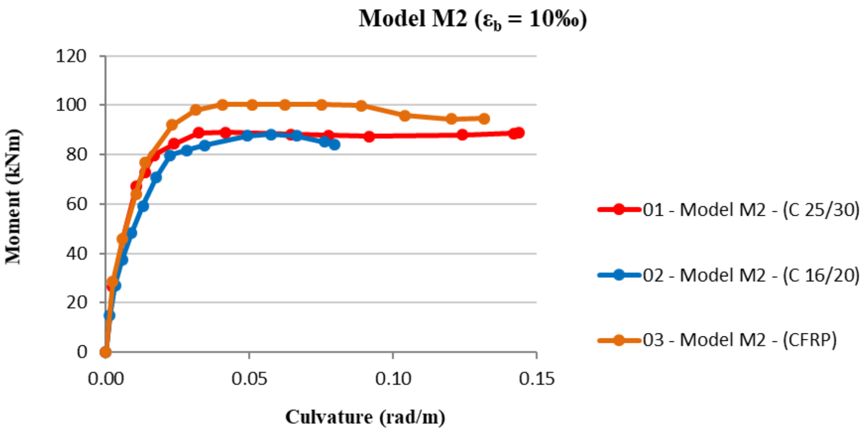

Fig. 8 M-φ Interaction Diagram for Model M2 – Comparison

The interaction diagrams clearly show the difference among the all series of analyses. The moment capacity for the 03 series (cross-section with CFRP) is higher than that of cross-section 02 (series with built-in concrete class of 16/20).

Based on the analyses of the results from Table 1, it can be concluded that the ductility to rotation for Model M1 is 2.049 greater for the model with CFRP, while the ductility to displacement is greater in respect to the ductility of Model M1 without CFRP for 76.7%.

In the case of Model M2, the ductility to rotation is higher in the case of the Model with CFRP for 64 %, while the ductility to displacements is higher compared to the ductility of the Model M2 without CFRP for 46.1%.

Table 1 Rotation and displacement capacity for Model M1 and Model M2

Specimen	Rotation		Ductility	Displacement		Ductility
	φ_y [rad/m]	φ_u [rad/m]	D_φ	d_y [cm]	d_u [cm]	D_d
Model M1-02	0.0127	0.0696	5.48	1.056	2.626	2.487
Model M1-03	0.0154	0.1730	11.23	1.281	5.631	4.306
Model M2-02	0.0128	0.0663	5.18	1.065	2.542	2.387
Model M2-03	0.0231	0.1963	8.50	1.922	6.702	3.487

5. CONCLUSIONS

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

- In general, it can be concluded that the compressive strength and modulus of elasticity is higher with the number of CFRP layers (Figure 3b).
- 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 (Figure 7).
- These tests are good basis for further analytical and numerical investigations, which can provide additional conclusions.

REFERENCES

1. Roshi, A., (2020). Application of innovative buildings materials for repair and strengthening of rc columns in seismically active regions, Doctoral dissertations, Ukim Iziis Skopje, Macedonia
2. Sarafraz, M., & Danesh, F. (2008, October). Flexural enhancement of RC columns with FRP. In The 14th World Conference on Earthquake Engineering (pp. 1-7).
3. Chapragoski Goran, Nechevska-Cvetanovska Golubka. (2019). Strengthening Of Existing Building Using Cfrp Wrapping System, 18th International Symposium of Macedonian Association of Structural Engineers (MASE), Ohrid, Macedonia.
4. Roshi Artur, Nechevska-Cvetanovska Golubka Repair And Strengthening Of RC Buildings Using Traditional And Innovative Materials, 18th International Symposium of Macedonian Association of Structural Engineers (MASE), Ohrid, Macedonia.
5. Nechevska-Cvetanovska, G., & Roshi, A. (2019). Rehabilitation of RC buildings in seismically active regions using traditional and innovative materials. Građevinski materijali i konstrukcije, 62(3), 19-30.
6. Nechevska-Cvetanovska, G., Roshi, A., & Bojadjieva, J. (2019). Seismic strengthening of existing rc buildings structures using concrete jacketing and FRP materials. E-GFOS, 10(19), 68-80.

SEIZMIČKA OTPORNOST AB STUBOVA ZGRADA UTEGNUTIH UPOTREBOM CFRP

Uobičajena je praksa da se za popravku i ojačavanje konstrukcija koriste tradicionalne metode sa tradicionalnim materijalima (najčešće oblaganje elemenata). Međutim, u poslednje vreme, posebno u poslednje dve decenije, pojavljuju se novi građevinski materijali namenjeni za ojačavanje i dizajn koji se nazivaju kompoziti ojačani polimernim vlaknima (FRP). Ovi materijali imaju posebna mehanička svojstva i posebna svojstva.

U radu će biti prikazana laboratorijska i kvazistatička eksperimentalna istraživanja projektovanih modela RC stubova utegnutih CFRP-om. Posebna pažnja će biti posvećena ponašanju ovih stubova pod kvazistatičkim opterećenjima, pri čemu će se izvršiti niz uporednih analiza niza parametara dobijenih eksperimentalnim ispitivanjem testiranih modela. Daće se neke preporuke i rezultati u vezi sa pristupom i tehnologijom praktične primene ovih materijala, posebno u seizmički aktivnim regionima.

Ključne reči: *seizmičko ojačavanje, inovativni materijali, CFRP, kvazi-statičko ispitivanje.*