Artur Roshi
PhD
Metropolitan University of Tirana, Albania
artur.roshi@yahoo.com

Golubka Nechevska-Cvetanovska
PhD, Full Professor
UKIM-IZIIS
Ss. Cyril and Methodius University-Skopje, Republic of North Macedonia

Jordan Bojadjiev
Ass. Professor
International Balkan University, Skopje, Republic of North Macedonia

EXPERIMENTAL TESTS AND ANALYTICAL INVESTIGATION OF RC BUILDING COLUMNS STRENGTHENED BY CFRP

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 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 using traditional or Innovative Materials. In this paper, focus will be given on technology of strengthening of RC columns with innovative materials as well as characteristics and types of these material will be introduced.

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. Selected results of experimental and analytical investigations of RC column models with different technologies of strengthening by CFRP are presented.

Keywords: quasi-static tests; innovative materials; CFRP; repair and strengthening; strength; ductility

1. INTRODUCTION

Behaviour of structures constructed and built of reinforced concrete during their serviceability period as well as during earthquakes depends on many factors. On

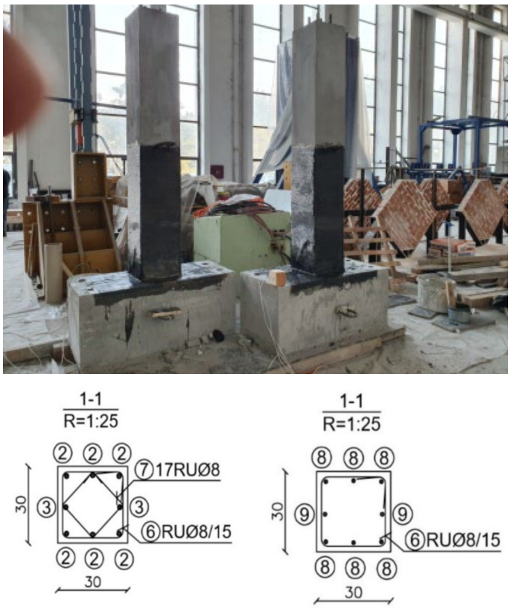

Figure 1. Construction of the column models (Model M1 and Model M2) for experimental tests.

one hand, there are the 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 the factors that directly depend on the very structure of the buildings (structural system, type, quality and quantity of material used for the construction of the structure, the number of storeys, the mode of foundation etc.). All these factors directly affect the strength and deformation characteristics of the individual structural elements and the structural system as a whole.

It has been a usual practice to perform repair and strengthening of 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 this paper, there are some parts of the results from quasi-static experimental investigation of two RC column models and some part of analytical investigation for Definition of Real Strength and Deformability Capacity of Column Models strengthening with CFRP.

Figure 2a. Construction of the column models for experimental tests

Figure 2b. Construction of the column models for experimental tests and instrumentation

2. EXPERIMENTAL PROGRAM FOR QUASI-STATIC TESTS PERFORMED AT UKIM-IZIIS

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 CFRP was same for both models. The elements were designed to the geometrical scale of 1:1(Figure 1) [10].

Model M1 has 8∅18 as longitudinal reinforcement and stirrups ∅8 at a distance of 15/7.5 cm. and Model 2 has 8∅14 as

Figure 3. Test set-up

longitudinal reinforcement and stirrups ∅8 at a distance of 15 cm.

Photos taken during construction of the models (Model M1 and Model M2), are presented in Figure 1, Figure 2a and Figure 2b., Photos and results obtained in the process of quasi-static tests on Model M1 and Model M2 (Figure 3) are presented further.

The models were instrumented with 6 strain gages, out of which 2 were placed outside on the concrete and 4 were on the longitudinal reinforcement, placed and protected before concreting of models.

For performing the tests, quasi-static equipment available in the Laboratory for dynamic testing in IZIIS, was set in appropriate position [1].

Before starting with application of the alternative horizontal force (LC 1), axial force of 500 kN was applied in the column – Model 1, i.e. axial force of 300 kN in the column – Model 2, simulating the gravity load (LC 2).

The process was controlled by the displacement, in several repeated cycles, up to reaching heavy damage of the models.

The testing was performed by application of increasing displacement steps up to failure of the models.

The following sections contain the processed results from the quasi-static tests of model M1 and model M2 along with conclusions.

2.1. RESULTS OF MODEL M1

During the tests, a vertical force of 500 kN was first applied on the column (LC2 (Figure 4). During application of the horizontal force (LC1), the values of strain (in both concrete and reinforcement) as well as the displacements at the point of application of the horizontal force (LVDT) were

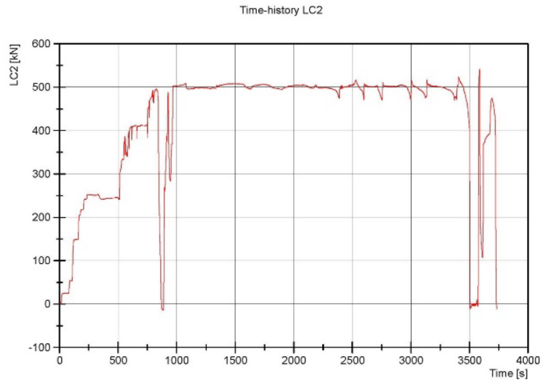

Figure 4. Time histories of applied vertical force LC2 and strains (SG) during the test of Model M1.

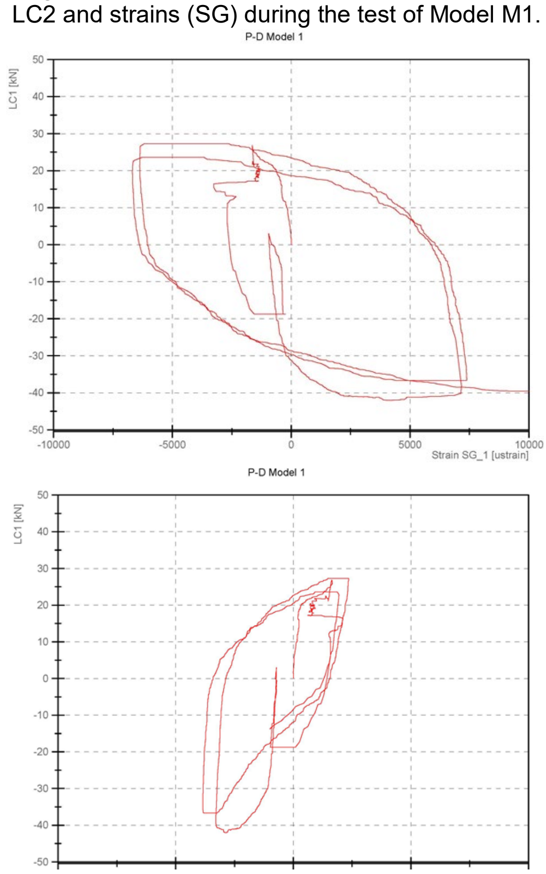

Figure 5. Force LC1 – strain relationship (SG_1) and (SG_3) for Model M1 .

measured. Channels SG_1 and SG_2 measured the strains in the concrete, while SG_3, SG-4, SG-5 I SG_6 measured strains in reinforcement in both directions (Figure 5).

Based on the data obtained, hysteretic curves LC1 were obtained with SG_1, and SG-3 presented in Figure 5, it can be concluded that the model exhibits an excellent hysteretic behaviour. This points to the fact that Model M1 in this period has a high capacity for energy absorption, i.e., it exhibits a good hysteretic behavior with obtained high capacity for displacement.

For a value of ε_s = 1.94 ‰ in steel (the yielding point of reinforcement), displacement of 10.065 mm and force of 38.39 KN were achieved.

The maximum measured displacement at the free end of the model M1 in positive direction was 55.3 mm, while during the last test, the displacement was already very high. The maximum achieved horizontal force was 47.5 KN.

2.2. RESULTS OF MODEL M2

During the tests, vertical force of 300 kN was first applied upon the column (LC2). During the application of horizontal force (LC1), the values of strains (epsilon in both concrete and reinforcement) as well as displacements at the point of application of force were measured (LVDT). At channels SG_1 and SG_2, strains in concrete were measured, while at SG_3, SG-4, SG-5 I SG_6, strains in reinforcement were measured in both directions (Figure 6, Figure 7 and Figure 8).

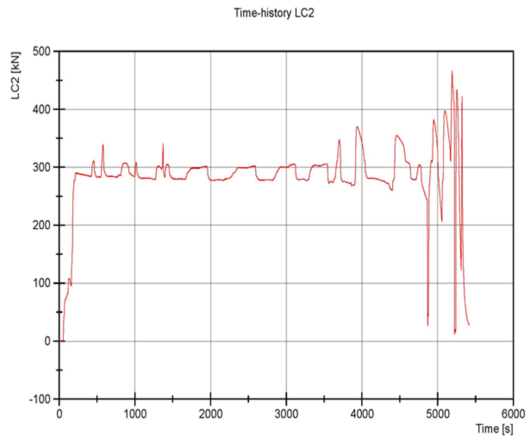

Figure 6. Time histories of applied vertical force LC2 during the test for Model M2

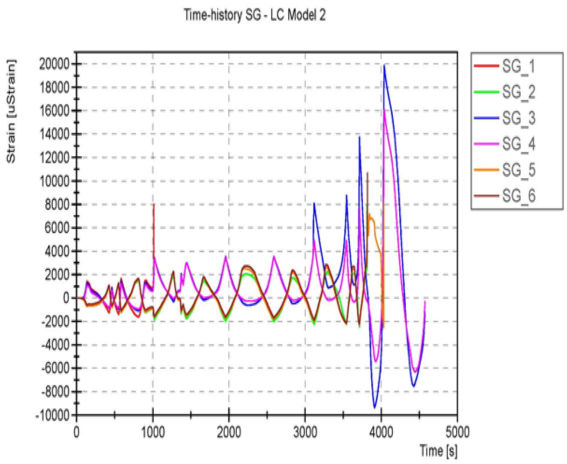

Figure 7. Time histories of strains (SG), during the test, Model M2, up to 5000 points.

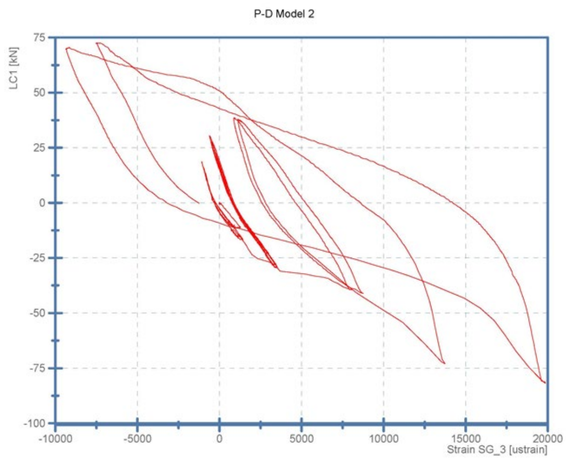

Figure 8. Relationship force – SG_3 for model M2

Based on the data obtained, the best hysteretic behavior, with regular hysteretic curves, was obtained at SG_3 and SG_4, which points to the fact that this model also exhibits hysteretic behavior, but with a lower capacity for energy absorption compared to Model M1.

The maximum measured displacement at the free end of the model M2 in positive direction was 69.28 mm. The maximum achieved horizontal force was 68.5 KN.

The observed damages during the quasi-static testing of Model M1 are presented in Figure 9.

Figure 9. Observed damages during the quasi-static testing of Model M1

Figure 10. Observed damages during the quasi-static testing of Model M2.

The observed damages during the quasi-static testing of Model M2 are presented in Figure 10.

The following comments can be mentioned regarding the models' behavior during the testing:

- The failure of the CFRP was sudden followed by specific sound and by crashing of concrete.
- The concrete quality was not good enough and it was easy to remove the particles after cutting of the CFRP.
- There was visible bending of the longitudinal reinforcement after test accomplishment.

3. DEFINITION OF REAL STRENGTH AND DEFORMABILITY CAPACITY OF COLUMN MODELS

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

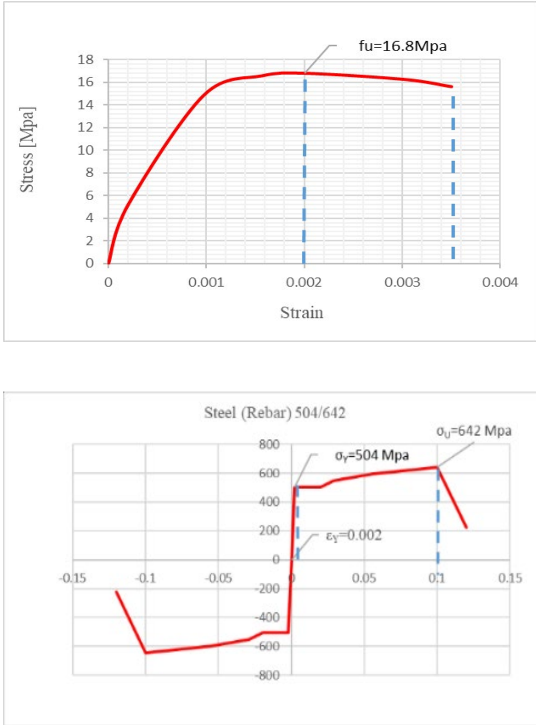

Figure 11. Stress-strain relation for non-linear structural analysis for concrete C16/20 and for rebar RA 504/642

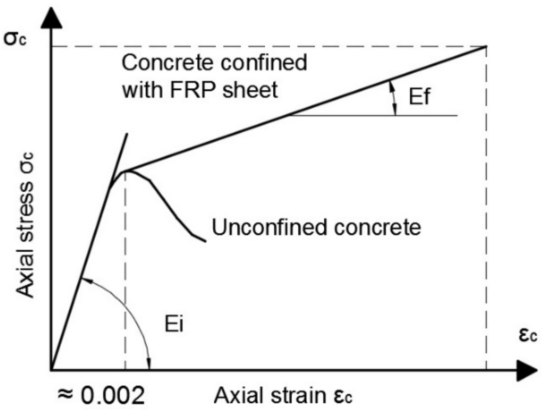

Figure 12. Ideal axial stress-strain diagram σc-εc for concrete confined with a CFRP sheet

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. The following analyses were carried out:

For Model M1, definition of the M-Φ diagram for Nv = 500 kN and M-N diagram (Figure 13) for the following values for 0.1, 0.2, 0.3 series:

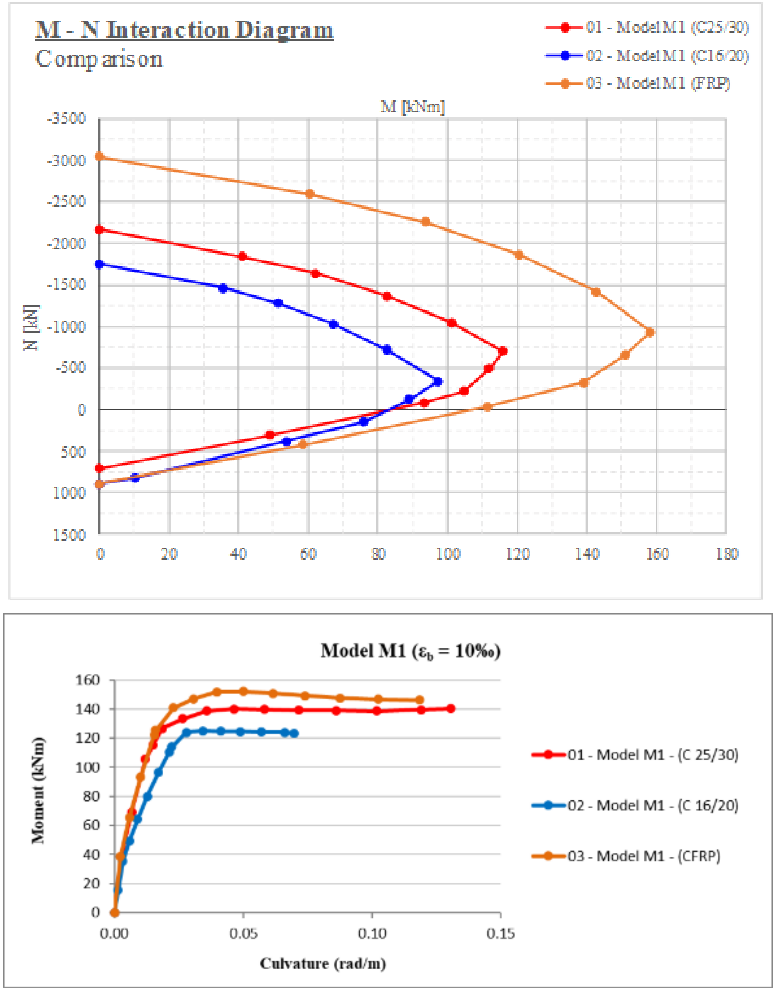

Figure 13. M-N and M-Φ Diagrams for Model M1 - Comparison

- For the designed concrete class (DC) (EC-25/30) with quality and quantity of reinforcement.
- For the built-in concrete class (CC) (EC-16/20) with quantity and quality of reinforcement.
- For the built-in concrete class with one layer of CFRP (CC-FRP) (38/46) with quantity and quality of reinforcement.

For Model M2, definition of the M-Φ diagram for Nv = 300 kN and M-N diagram (Figure 14) for the following values for 0.1, 0.2, 0.3 series:

- For the designed concrete class (DC) (EC-25/30) with quality and quantity of reinforcement.
- For the built-in concrete class (CC) (EC-16/20) with quantity and quality of reinforcement.
- For the built-in concrete class with one layer of CFRP (CC-FRP) (38/46) with quantity and quality of reinforcement.
- For all analyses of RC cross-sections without CFRP, the working diagrams (σ-ε) for concrete and the working diagram of steel shown in Figure 11 were used. All analyses were done by taking into consideration confinement of the cross-section of transverse reinforcement.

For the concrete wrapped with CFRP, the working diagram shown in Figure 12 was used [3].

The results obtained from these analyses are presented in the following sections.

3.1 M-N AND M-Φ RELATIONSHIP FOR MODEL M1

Presented for Model M1 are the results from three series of analyses (0.1, 0.2, 0.3 series) performed for definition of M-N and three series for M-Φ diagrams. All of the presented diagrams have been obtained by use of the SAP2000 program. The M-N interaction diagrams are displayed in Figure 13, which clearly shows the difference among all three series of analyses.

The M-N and M-Φ comparative diagrams for Model M1 are presented in Figure 13.

3.2 M-N AND M-Φ RELATIONSHIP FOR MODEL M2

Presented for model M2 are the results from three series of analyses (0.1, 0.2, 0.3 series) for definition of M-N and M-Φ diagrams (Figure 14). All of the presented diagrams have been obtained by use of the SAP2000 program. 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) for 63%. The capacity of axial forces for the 03 series (cross-section with CFRP) is higher in respect to that of cross-section 02 (series with built-in concrete class of 16/20) for 59.5%.

The M-N and M-Φ comparative diagrams for Model M2 are presented in Figure 14.

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%.

4. CONCLUSION

The following analyses were carried out: The moment capacity obtained for cross-section of Model M1 with CFRP is greater for 21.07 % than that of cross-section without CFRP and the ductility to rotation is higher in the case of the model with CFRP for 98 %. The moment capacity obtained for cross-section of Model M2 with CFRP is greater for 7.7 % than that

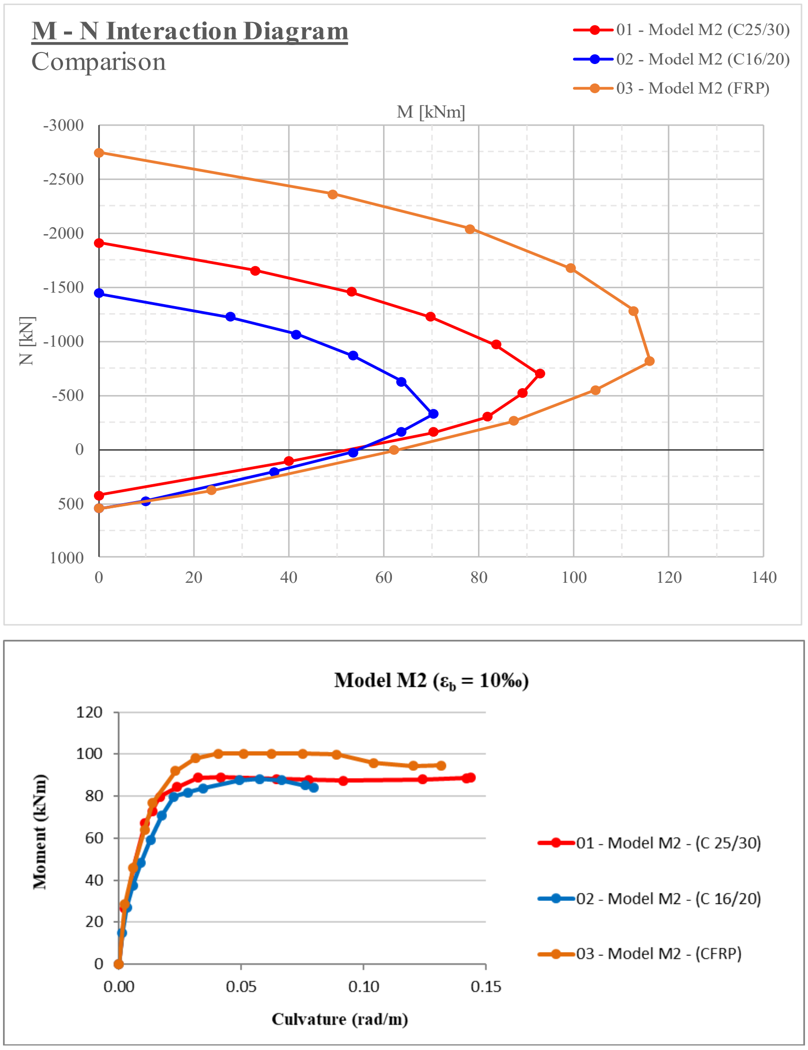

Figure 14. M-N and M-Φ Interaction Diagrams for Model M2 - Comparison

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

Specimen	Rotation		Displacement		Ductility
	Φy [rad/m]	Φu [rad/m]	dy [cm]	du [cm]	Dd
Model M1-02	0.0127	0.0696	1.056	2.626	2.487
Model M1-03	0.0154	0.1730	1.281	5.631	4.306
Model M2-02	0.0128	0.0663	1.065	2.542	2.387
Model M2-03	0.0231	0.1963	1.922	6.702	3.487

of cross-section without CFRP and the ductility to rotation is higher in the case of the model with CFRP for 64 %.

Sample analytical analyses were carried out to define the strength and deformability capacity (M-N) and (M-Φ) at cross-section level were analytically defined by use of the SAP2000 computer program. Based on the obtained M-Φ diagrams, the strength and ductility capacity of each model was defined. The rotation and ductility capacity for model M1 and model M2 are greater than the models without CFRP.

Generally, it can be concluded that FRP systems represent a very practical tool for strengthening and retrofitting of concrete structures and are appropriate for flexural strengthening, shear strengthening and column confinement and ductility improvement.

REFERENCES

[1] Krstevska, L., Nechevska- Cvetanovska, G. (2019), Quasi-static testing of column models strengthened by FRP, UKIM-IZIIS, IZIIS Report 2019-75.

[2] CNR-DT 200/2004. Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening, 2004 (Downloaded free from: http://www.cnr.it/sitocnr/IlCNR/Attivita/NormazioneeCertificazione/NormazioneeCertificazione file/IstruzioniCNR DT200 2004 eng.pdf).

[3] M. DI Ludovico, A. Prora, G.Manfredi and E.Gosenza, "Seismic Strengthening of an Under-design RC Structure with FRP", Department of Structural Engineering, University of Naples Federico II, Naples, Italy, Published online 24 August 2007 in Wiley InterScience;

[4] G. Necevska-Cvetanovska and R. Petrushevska (2000). " Methodology for Seismic Design of R/C Building Structures ". 12WCEE, New Zeland

[5] Necevska-Cvetanovska, G., Apostolska, R. (2012). Methodology for Seismic Assessment and Retrofitting of RC Building Structures, Proc. of 15 World Conference on Earthquake Engineering (Paper ID 2149), 24-28 September 2012, Lisbon, Portugal.

[6] Necevska – Cvetanovska, G., Roshi, A. "Rehabilitation of RC Buildings in Seismically Active Regions Using Traditional and Innovative Materials", Journal Building Materials and Structures, Novi Sad, Serbia, 62 (2019) 3 (19-30).

[7] 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.

[8] 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.

[9] Roshi, A., Nechevska- Cvetanovska, G. (2019). Repair and Strengthening of RC Buildings using Traditional and Innovative Materials, 18th International Symposium organized by Macedonian Association of Structural Engineers (MASE), October 4-7, 2019, Ohrid, Macedonia

[10] 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