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COMPARISON OF RESULTS OBTAINED FROM ANALYTICAL AND EXPERIMENTAL INVESTIGATIONS OF RC BUILDING COLUMNS USING CFRP

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Abstract

The focus of the research in this paper is Quasi-static tests on RC building columns strengthened with CFRP (Carbon Fiber Reinforced Polymers). To present the possibilities and the benefits of use of these materials, laboratory research for definition of the characteristics and experimental investigations of RC columns strengthened by CFRP by variation of concrete class, reinforcement percentage and different technologies of strengthening, are carried out at the Institute of Earthquake Engineering and Engineering Seismology – IZIIS, Skopje. Some recommendations and outcomes regarding the approach and technology of practical application of these materials, will be given.

Selected results from laboratory testing of built-in materials, part of analytical results and part of quasi-static experimental investigations of models designed and constructed by use of CFRP-materials are presented. Based on the analysis of values obtained from nonlinear static and nonlinear time history analyses, it can be concluded that the ductility capacity for displacement of models strengthened with CFRP is greater than 60%, while its strength capacity is greater than 7.7% when compared to the values obtained for the models without CFRP.

It can generally be concluded that CFRP systems are a very practical tool for strengthening and retrofitting RC building structures, as they can extensively improve flexural strengthening, shear strengthening, column confinement and ductility, thus, contributing towards better seismic resilience of the structures.

Keywords: RC columns; quasi-static tests; innovative materials; CFRP; strength; ductility.

1. INTRODUCTION

The field of research in the frames of this paper is application of innovative materials for repair and strengthening of RC buildings in seismic 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.N. Macedonia. Laboratory tests on materials were done at the Institute for Material Testing – ZIM, AD Skopje,R.N. Macedonia. 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 tested.

To contribute to definition of the joint behaviour of concrete, reinforcement and CFRP materials in the nonlinear range and develop a methodology and criteria for application of these materials in seismically active regions, for the needs of this study, an original research program involving experimental investigations on a series of two elements-models (columns) was defined. The main objective of the research programme was to define the strength and deformability of the elements constructed of innovative materials, as a function of a number of selected parameters that were varied in the course of the experiments. Within the frames of the experimental programme realized at UKIM-IZIIS, the percentage of longitudinal and transverse reinforcement was varied. The concrete class and the CFRP type were the same for both models. The behaviour of the models exposed to cyclic loads (quasi-static

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tests) up to failure was investigated by visual monitoring of occurrence of cracks and development of failure mechanism.

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

2. 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), Fig. 1 and Fig. 2 , and presented further are photos and results taken in the process of quasi-static tests on Model M1 and Model M2 with photos of characteristic damage (Fig. 3, Fig.4 and Fig.5) [1].

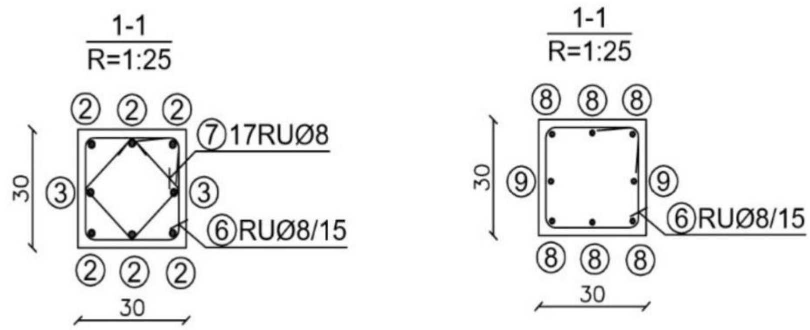

Fig. 1. Construction of the column models (Model M1 and Model M2) for experimental tests.

Fig. 2. Construction of the column models for experimental tests and photos taken during application of CFRP on the models.

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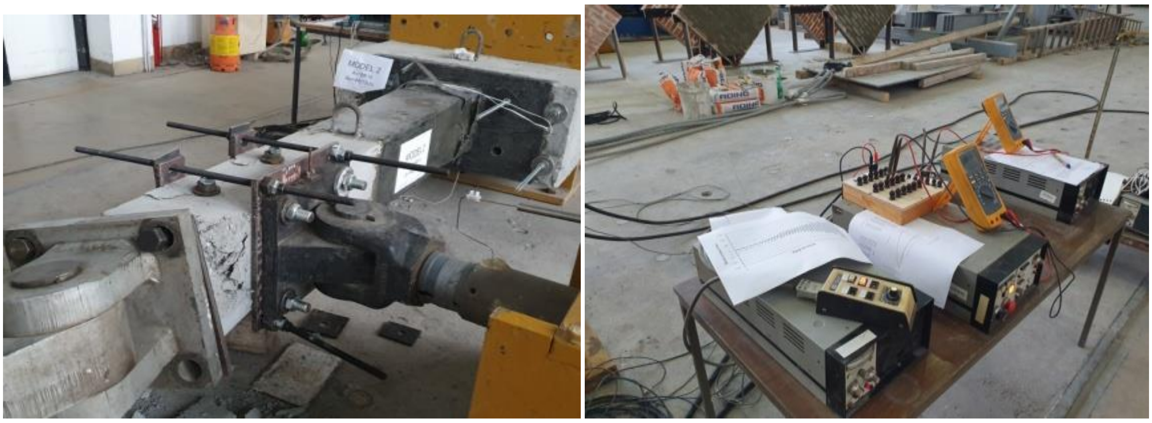

Fig. 3. Photos during the quasi static testing of the column models – Model M1and M2

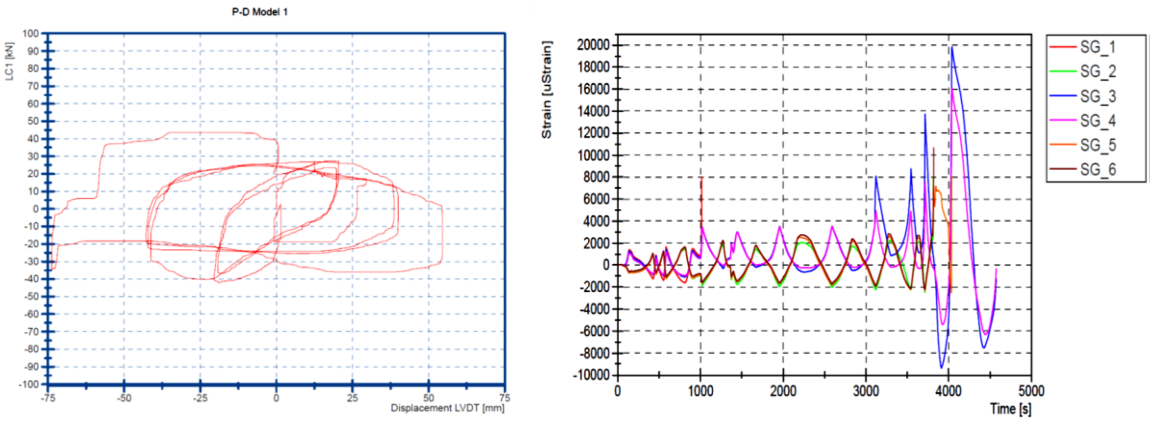

Fig. 4. Force – displacement relationship and time histories of strains for model M1[10]

Fig. 5. Observed damages during the quasi static testing of Model M1 and Model M2.

3. LABORATORY TESTS ON MATERIALS BUILT-IN MODELS FOR EXPERIMENTAL RESEARCH

During concreting of the models for experimental quasi-static tests, two models and 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

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proportioned 15/30 cm (Fig. 6). 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.

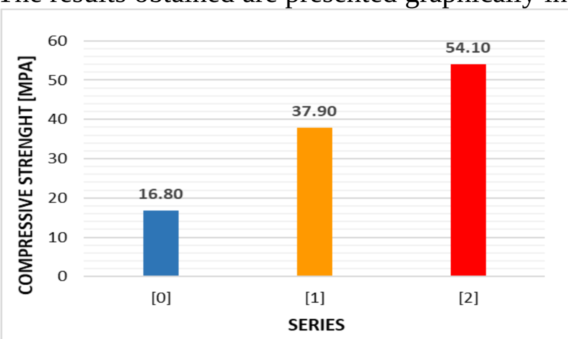
Using the trial concrete specimens – cylinders, three series of tests of compressive strength and tests for definition of the modulus of elasticity of the built-in concrete were carried out as follows:

- 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 and Modulus of elasticity of concrete and for the three series. 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.

Fig. 6. Testing of the Compressive strength and modulus of elasticity of all three series.

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, and static modulus of elasticity are 28200.Mpa, 33000.Mpa And 43500.Mpa respectively.
The results obtained are presented graphically in Fig. 7.



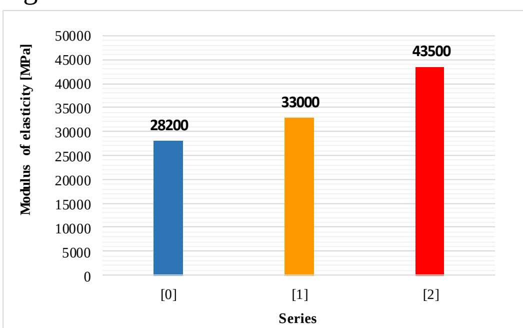


Fig. 7. Diagram of compressive strength and static modulus of elasticity for each series.

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

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3.1 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 real M-N diagrams, and then, based on the obtained M-Φ diagrams, the strength and deformability capacity of each model was defined [1].
The strength and deformability characteristics (M-N) and (M-Φ) at cross-section level, and Nonlinear Static Pushover Analysis and Nonlinear Time-History Analysis were analytically defined by use of the SAP2000 computer software. The following analyses were carried out:

(1) For Model M1, definition of the M-Φ diagram for Nv = 500 kN and M-N diagram (Fig. 8) 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.

(2) For Model M2, definition of the M-Φ diagram for Nv = 300 kN and M-N diagram (Fig. 9) 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.

Presented further are the results obtained from these analyses for Model M1 and Model M2.

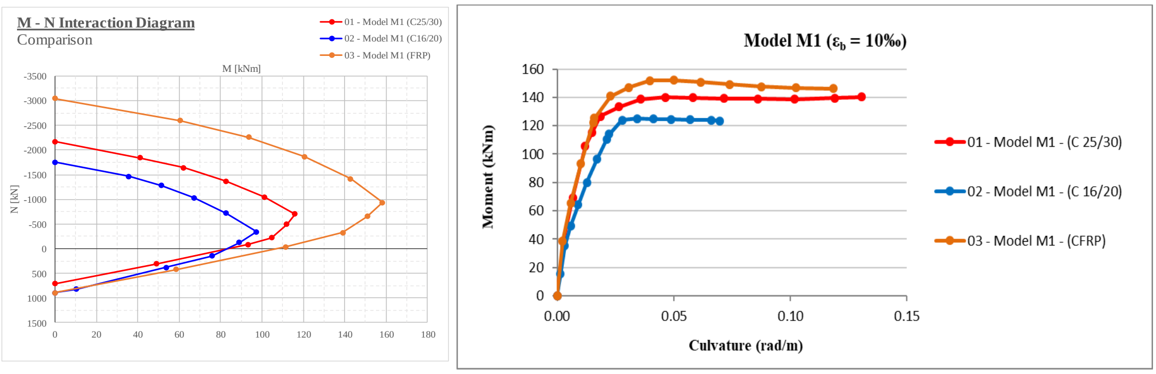

Fig. 8. M-N and M-Φ Diagrams for Model M1 - Comparison

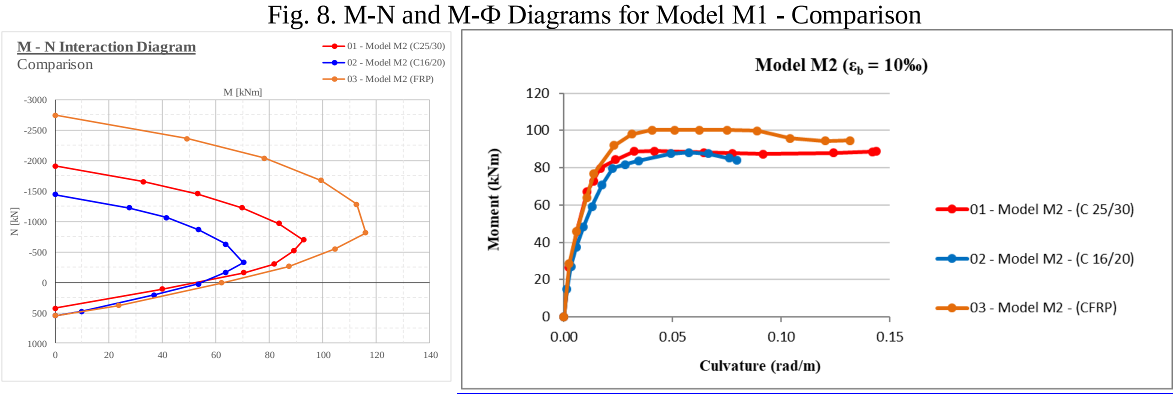

Fig. 9. M-N and M-Φ Diagrams for Model M2 – Comparison

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Based on this analyses (Fig. 8 and Fig.9) and 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 displacementt 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
	Φy [rad/m]	Φu [rad/m]	DΦ	dy [cm]	du [cm]	Dd
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

From the Nonlinear Static Pushover Analysis and Nonlinear Time-History Analysis analysis of the values obtained, it can be concluded that the ductility capacity of Model M1 strengthened with CFRP is greater for 64.6% and for Model M2 is greater for 60% , while the strength capacity for Model M1 is greater for 21.1% and for Model M2 is greater for 7.7% compared to the model without CFRP (Fig.10 and Fig.11 and Table 2 and Table 3).

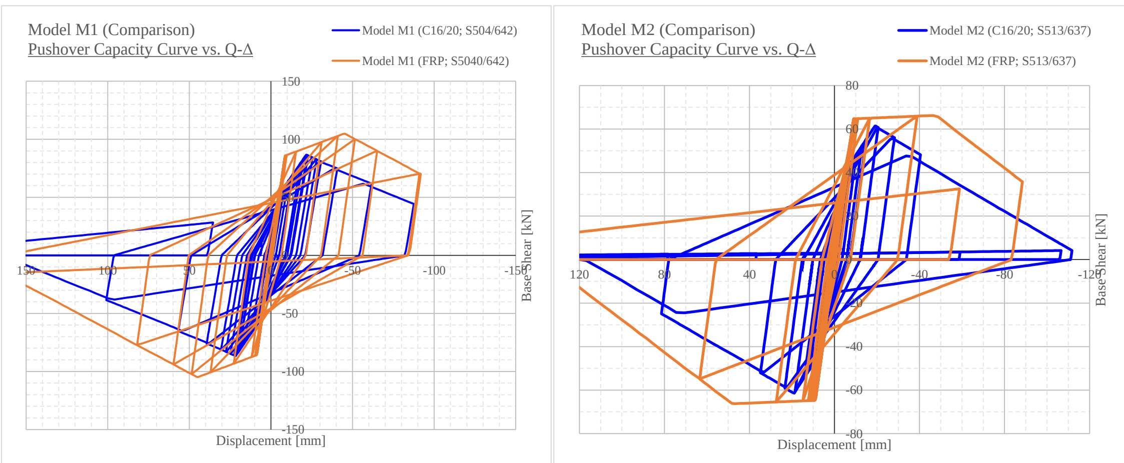

Fig. 10. Q – d diagram for Model M1 and Model M2 – comparison for series 02 and 03.

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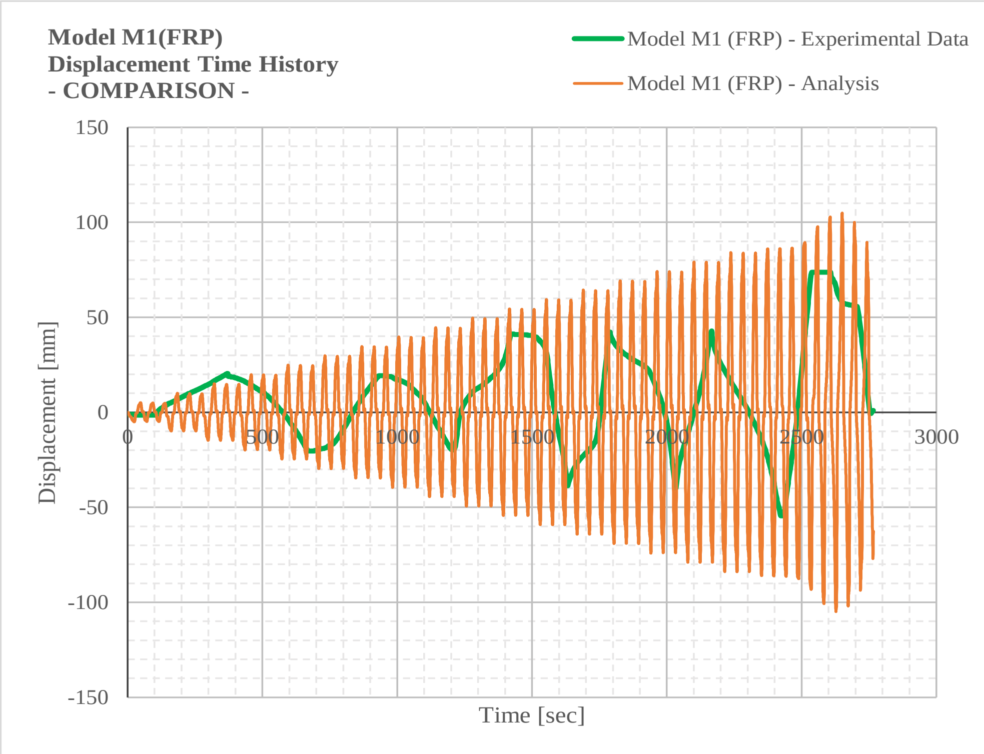

Fig. 11. Time history of displacements for Model M1- comparison between experimental and analytical results.

Table 2. Forces and displacements capacities, obtained from Pushover analysis for Model M1

Specimen	Displacement		Ductility	Shear force	
	dy [cm]	du [cm]	D_d	Qy [kN]	Qu [kN]
Model M1-01	0.864	3.564	4.125	81.41	99.01
Model M1-02	0.676	2.164	3.20	56.54	87.07
Model M1-03	0.855	4.506	5.27	86.15	105.39

Table 3. Forces and displacements capacities, obtained from Pushover analysis for Model M2

Specimen	Displacement		Ductility	Shear force	
	dy [cm]	du [cm]	D_d	Qy [kN]	Qu [kN]
Model M2-01	0.637	3.633	5.70	51.65	62.77
Model M2-02	0.578	1.916	3.31	41.96	61.88
Model M2-03	0.904	4.803	5.31	65.10	66.70

4. CONCLUSION

As a result of the comprehensive laboratory tests on concrete cylinders for: 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; It can be concluded that the compressive strength and Modulus of Elasticity becomes higher with the increase of the number of FRP layers.

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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 programme. Based on the obtained M-Φ diagrams, the strength and ductility capacity of each model was defined.

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

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.

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