EXPERIMENTAL AND THEORETICAL ANALYSIS OF ULTIMATE LOAD CAPACITY FOR STRENGTHENED RC COLUMNS AND SHORT STEEL COLUMNS

LJ. VLAJIĆ[1] A. LANDOVIĆ M. BEŠEVIĆ D. KUKARAS[2]

Abstract: *This paper gives an overview of comparative experimental-theoretical analysis of ultimate load capacity for rei nforced concrete, centrically compressed, columns that were strengthened with carbon fiber reinforced polymer (CFRP) fabrics and laminates and strengthened with steel tubes. The aim of this research was to experimentally determine ultimate load bearing capacities (failure forces) and to make subsequent comparisons.*
Second part of the paper shows results of testing on short, cold formed, steel columns.

Key words: *Short steel columns, reinforced concrete, strengthening, CFRP.*

1. EXPERIMENTAL ANALYSIS OF RC COLUMNS

1.2. Description of the problem and test samples

During restorations and reconstructions it is very often necessary to strengthen RC structures what is usually achieved with Carbon Fiber Polymer (CFRP) fabrics or strips. Motivation for this research came from an effort to find ultimate failure force for centrically compressed columns that were strengthened by means of „classical“ methods such as steel tube encasing, as well as strengthening with CFRP fabrics and strips. Comparative analysis of ultimate failure forces was conducted following experimental testing of the various column samples. This paper presents five groups of column samples:

- Group I: RC columns without strengthening with cross section 10×10cm,
- Group II: RC columns strengthened with steel tube encasing,
- Group III: RC columns without strengthening with cross section 13×13cm,
- Group IV: RC columns strengthened with CFRP strips,
- Group V: RC columns strengthened with CFRP fabric.

Shape and sample dimensions were

---

[1] Prof. Ljubomir Vlajić, PhD, Transportation institute CIP, Nemanjna 6/4 Beograd, Serbia.
[2] Aleksandar Landović, MSc, Prof. Miroslav Bešević, PhD, Danijel Kukaras, PhD, Faculty of Civil Engineering Subotica, Kozaracka 2a, Serbia.

determined so that they are in close proportion with realistic columns that can be found in practice, in other words, tested samples can be considered as prototypes for real structures.

* Columns of the Group I and II:

Concrete columns had square cross section with dimensions 10/10 cm and height of 85 cm. Properties of concrete were as follows: fc=30MPa, modulus of elasticity Ec=30Gpa. Main reinforcements were ±2Ø5mm and stirrups of Ø4mm with spacing of 3cm at the top and the bottom region (20cm) of the column length and 6cm spacing in the middle region. Tensile strength of steel was fy=500MPa. Strengthening of the columns was achieved with circular welded tube with outer diameter of D=159mm and wall thickness of t=2mm. Yield strength of the steel taken from steel tube was experimentally determined to be fy=250Mpa with modulus of elasticity Es=207Gpa. Infill concrete had same characteristics as columns core concrete.

* Columns of the Group III, IV and V:

Cross section was b/h=13/13cm, height was 100cm. Core cross section for all samples was reinforced with ±2Ø8mm bars and stirrups of Ø6mm with spacing of e=9 cm. Compressive strength of representative concrete cube was fp=50 MPa.

All RC columns were designed with slenderness ratio of approx. λ=25, in order to eliminate buckling effects.

1.3. Testing of samples and obtained results

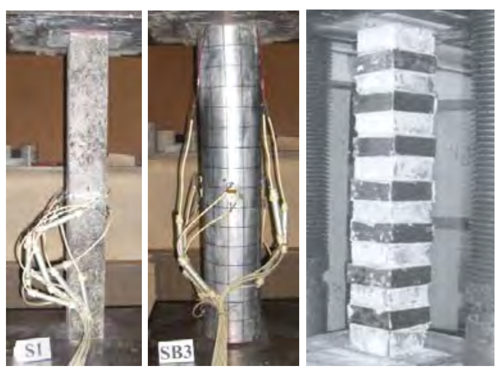

Fig. 1. *Samples before testing*

Overview of the obtained ultimate failure forces Table 1

Specimen	Ultimate load forces [kN]				
	Group I	Group II	Group III	Group IV	Group V
1	305	888	668	808	672
2	391	1052	660	824	656
3	407	1064	672	-	-
Mean value	369	1001	666	816	664
Strength increase percentage	-	271%	-	22.52%	0%

Fig. 1 presents following samples: left-RC column without strengthening, middle-column with steel tube encasing, right-RC column strengthened with CFRP strips. Table 1 shows an overview of testing results for all columns and strength increase percentage for each group compared to Group I.

1.4. Short description of numerical model and results of numerical analysis

Numerical analysis of RC columns was conducted by means of finite element modeling. The analysis was focused on centrically compressed RC columns behavior for ultimate load bearing state. Structural elements such as columns treated in this research have a brittle failure so linear stress-strain relations was assumed. It was also assumed that the bonding between concrete and steel remains intact during loading and strain for concrete and steel in this region is the same. In geometrical sense, numerical model was shaped to be of the same properties as the actual column.

Concrete part of the cross section and steel encasing were modeled with „3D solid" elements. The size of concrete elem. was 10×10×10 mm. Reinforcement bars were modeled with „3D beam" elements 10mm long.

Due to length limitations for this paper, the authors presented only a fraction of the numerical analysis that served as a support for conducted experimental analysis in order to describe/explain different behavior of differently strengthened columns in relations to reference columns without strengthening.

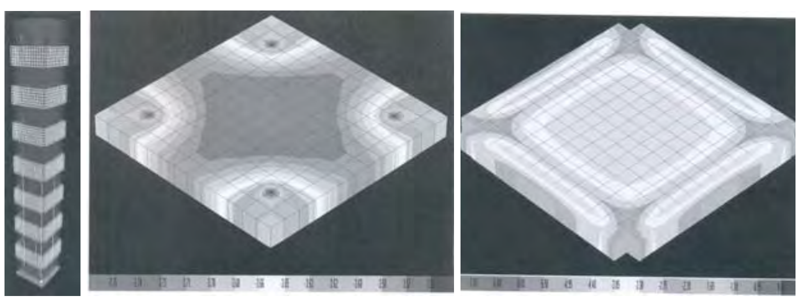

Fig. 2. *a) one numerical model, b) RC column without strengthening, c) RC column strengthened with CFRP strips*

Numerical model of column strength-ened with CFRP strips is given in Fig. 2a. Fig. 2b. gives a visual presentation of the stress distribution in concrete for reference column without strengthening and Fig. 2c. Represent stress distribution for column strengthened with CFRP strips.

Compression stress distribution in concrete given in Fig. 2. clearly shows different behavior within cross section. Stresses in central region of the reference column are slightly increased and reinforcement relieved some of the con-crete stresses in the corners of the cross section. Figures 2b and 2c show different stress distribution over the cross section for the same vertical load level. Stress distribution in concrete is in both, 2b and 2c, cases more even what, to certain extend, explain the strength increase in these cases.

2.TESTING OF SHORT STEEL COLUMNS

2.1. Description of the problem and test samples

Steel columns that were tested in this research consist of two profiles that form a unique complex cross section (Figure 3).

Profiles that form columns cross section were made by a cold forming process. This production method demands an investigation such as the one performed in this research, especially because cold forming production changes mechanical properties and causes residual stresses within cross section. Ultimate yield limit, tensile strength, modulus of elasticity and elongation percentage obtained from standardized samples can not represent the whole cross section or stress strain relations. In cases like this, yield limits are determined by compression tests on short columns. Short column samples, tested within this research, were designed so that they are short enough to eliminate buckling effects but also long enough to preserve initial distribution and values of residual stresses. Testing of short columns also shows the effects of local buckling as well as the effects of cold forming on load bearing capacity of columns. Height of tested column samples was 366.3 mm or approx. 15λ. Centric position of the introduced force was ensured by spherical supports and carefully positioning of the samples all of which was electronically monitored.

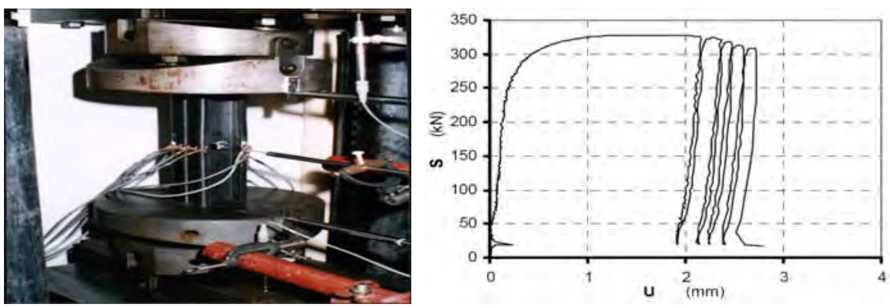

Fig. 3. S*hort steel column during testing and Force (S) / Deflection (U) diagram under cyclic loading*

Two samples were tested for strains, with 12 strain gauges, maximum force and deflection, with electronic force and deflection sensors, while remaining 4 were measured for maximum force and deflection. Deflection was measured in two orthogonal directions. Stress-strain and force-deflection diagrams were obtained electronically. Figure 3. shows short steel column testing with measuring equipment.

Test also yielded a modulus of elasticity. Cyclic loading was conducted on two samples. One force-deflection diagram is given in Fig. 3b.

Table 2. shows differences of experimentally determined ultimate limits that were obtained by compression tests and by standard tension tests performed on the strips of base material (Rel).

Experimentally determined ultimate limits Table 2

Base steel strip stresses and short steel column stresses	U11	U12	U13	U14	U15	U16	Mean value
Base strip R_{el} (kN/cm2)	27.2	26.4	29.9	28.1	27.2	-	27.76
Short column σ_T (kN/cm2)	32.14	32.30	32.47	33.00	32.62	32.90	32.57
Difference σ_T - R_{el} (kN/cm2)	4.94	5.90	2.57	4.90	5.42	-	4.81
Difference σ_T - R_{el} (%)	15.36	18.27	7.92	14.86	16.61	-	14.77

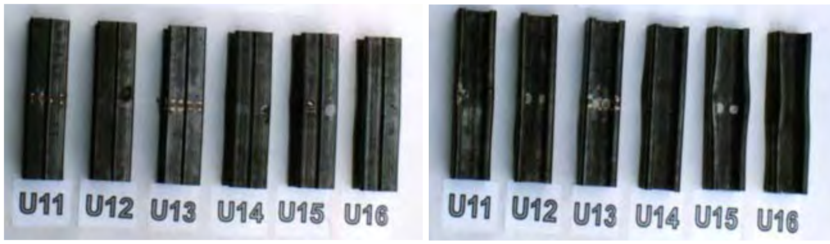

Fig. 4. *Short steel column samples after testing*

3. COMPARATIVE ANALYSIS OF ULTIMATE LIMIT FORCES FOR TESTED SAMPLES

Table 3. gives an overview of ultimate limit forces obtained within this research. Due to different geometrical and material characteristics all of the cross sections of tested RC columns were numerically reduced to idealized homogenous concrete material. For the comparison purposes this was also performed for steel columns. Numerical reduction was conducted by means of experimentally determined modulus of elasticity rations of steel and concrete. This was followed by ultimate forces (P) and idealized cross section area (A*).

Comparison of mean values of ultimate limit failure forces Table 3

Specimen group	I	II	III	IV	V	Steel
Ultimate load forces [kN]	368	1001	666	816	664	332
$\sigma = P / A^*$ [kN/cm^2]	3.50	3.92	3.72	4.56	3.71	5.50

Maximal value of ultimate limit failure force, according to the Table 3, was recorded for short steel columns. Compared to ultimate force determined on strengthened RC columns it can be concluded that RC columns without strengthening reach 67% of the force determined on steel columns while strengthened columns reach 82.5% of the same force. This confirms the effectiveness of measures applied for strengthening RC columns, especially when it is taken into consideration that the strengthening elements were positioned perpendicularly to the direction of the introduced load.

4. CONCLUSION REGARDING TESTING RC COLUMNS WITH AND WITHOUT STRENGTHENING

This paper gives a short comparative presentation of experimental and numerical analysis of ultimate limit failure forces of centrically compressed RC columns that were strengthened by steel tube encasing, CFRP strips and fabrics. The aim of this research was to experimentally determine the values of ultimate limit failure forces and to make comparisons. Detailed analysis of obtained results gave necessary guidelines for future, more extensive, research related to optimal and most efficient methodology for RC column strengthening.

Best results were obtained for columns

strengthened with CFRP strips where strength increase is 22.5%. This type of strengthening causes effects similar to ones of the spiral reinforcement within concrete columns. CFRP fabric yielded no strength increase what could be expected since the fabric, applied like this, does little to prevent transverse strains. Presented results, along with other research conducted under guidance of prof. Vlajić, previous to this research show that the use of CFRP strips and steel tube encasing is possible, economically sound and technically justified, all of which gives further motivation for similar future research.

5. CONCLUSION RELATED TO SHORT STEEL COLUMN TESTING

Results obtained by testing of short cold formed steel columns represent initial data for numerical analysis of centrically compressed columns made of cold formed profiles which includes geometrical and material nonlinearities. The shape of the stress-strain diagram obtained by short steel column tests is usually similar to the one obtained by standard tensile tests but only in cases where short columns have unique cross section where material strengthening effects take place due to lack of local buckling.

This research yielded a global yielding limit for short column with complex cross section which was compared to ultimate elongation limit Rel obtained by standard tensile tests. Real modulus of elasticity was also determined. Mean value of compressive yielding limit increase relative to the tensile yielding limit from standard tensile tests (Series 1) is 14.77%.

References

1. Vlajić, Lj., Kovačević, T.: *Investigation of composite action effects of concrete-exmal-steel in case of axially compressed columns*. SDGK Symposium '89, Yugoslavia, 1989, p. 296-303.
2. Vlajić, Lj., Landović, A.: *Analysis of methods for strengthening reinforced concrete columns coupled with steel tubes*. 13th Congress of Serbian society of structural engineer, Zlatibor-Cigota, Serbia, 2010, p. 433-438.
3. Landović, A.: *Experimental-theoretical model analysis of possibility for strengthening axially compressed RC columns with steel tubes*. Master's Thesis, Faculty of civil engineering, Subotica, Serbia, 2010, p. 110.
4. Vlajić, Lj., Bešević, M., Landović, A., Kukaras, D.: *Experimental analysis of reinforced concrete columns strengthened with steel tubes*. The 5th PSU-UNS International Conference on Engineering and Technology, Phuket, Thailand, 2011.
5. Vlajić, Lj., Bešević, M., Landović, A., Kukaras, D.: *Numerical analysis of steel-concrete composite columns under axial load*. Serbian journal Izgradnja 64, Serbia, 2010, p. 513-520.
6. Bešević, M.: *Contribution to the analysis of compressed steel columns with complex cross section made from cold formed profiles.* PhD Thesis, Faculty of civil engineering Belgrade, Serbia, 1999.
7. Ostojić, M.: *Comparative experimental analysis of the ultimate limit force for centrically compressed columns.* Diploma Thesis, Faculty of civil engineering Subotica, Serbia, 2005.