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ANALYSIS OF ULTIMATE LOAD CAPACITY OF SHORT RC AND COMPOSITE COLUMNS

A. LANDOVIĆ[1] **M. BEŠEVIĆ**[2]

Abstract: *This paper gives an overview of comparative experimental-theoretical analysis of ultimate load capacity for centrically compressed reinforced concrete columns and composite steel and concrete columns. The aim of this research was to experimentally determine ultimate load bearing capacities (failure forces) and to make subsequent comparisons with European standards. Analysis of obtained experimental results gave necessary guidelines for better understanding and application of Eurocodes.*

Key words: *Short columns, reinforced concrete, composite section.*

1. Introduction

This paper gives an overview of comparative experimental – theoretical analysis of ultimate load capacity for centrically compressed reinforced short concrete columns and short composite steel and concrete columns.

Reinforced concrete columns with squared cross section represent one of the oldest types of structural elements. Aims of presented experiments were to provide better understanding of column behaviour under ultimate load state and to compare effects of different cross section size and reinforcement ratio on ultimate load capacity.

Composite columns made from steel tubes filled with concrete represent one of the first types of composite structures. Round steel pipes with concrete infill have many structural advantages compared to classical reinforced concrete columns. A composite column shows great performance in terms of rigidity, strength, ductility and resistance to fire. The main advantage of steel tubes filled with concrete is better interaction between two materials [5],[6].

Outer shell or steel tube enables that, due to coupling effect with concrete, a hoop stress state forms what increases significantly the composite action and load bearing capacity. Hoop stress effects cause biaxial stress state within steel and triaxial stress state within concrete core, while the concrete core itself local buckling of steel tube inwards. Effect of increased load capacity in columns made of concrete filled steel pipes is more pronounced in short axially compressed columns. Ultimate load capacity of composite columns depends on mechanical properties of its materials, concrete compressive strength and steel tensile strength [7].

The dimensions of columns in conducted

[1] Aleksandar Landović, Ms, BsCE, Prof. Miroslav Bešević, Phd, BsCE
[2] University of Novi Sad, Faculty of Civil Engineering Subotica, Kozaracka 2a, Serbia

experiments were selected so that they correspond to real structure with a ratio 1:3,3. Model represented a typical real RC structure with squared concrete columns with dimension 30÷40 cm, height of around 280 cm and reinforcements consisting of Ø19mm and stirrups of Ø10mm spaced 10cm and 20cm. Column with composite section correspond to steel tube with outer diameter of D=525mm and wall thickens of t=6.6mm with concrete infill. This experiment was prepared with respect to exact geometric similarity.

All experiments were conducted in hydraulical testing machine by direct application of force on column models. Columns were loaded in steps until ultimate load capacity was achieved and recorded.

2. Reinforced concrete columns

Experimental analysis was performed on a model of reinforced concrete column with square cross section. The testing was conducted with centrically applied load on columns constant cross section and hinges on both ends. Experimental research included eight short reinforced concrete columns divided into two groups. First group of three samples consisted of reinforced concrete columns that had square cross section with dimensions 10×10 cm and length of 85 cm. Columns were made of concrete with cube mean strength of f_{ck}=57.2MPa and module of elasticity E_{cm}=30Gpa.

Second group of five samples had square cross section with dimensions 12×12 cm, length of 90 cm and were made of concrete f_{ck}=50.7MPa, E_{cm}=30.7GPa.

Main reinforcements of first group were 4Ø5mm and second group were 8Ø6mm as it was shown on figure 1. Stirrups of both group of Ø4mm were spaced 3cm at the top and the bottom 20cm of the column length and spaced 6cm in the middle. Steel tensile strength of reinforcement bars were f_y=500MPa.

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

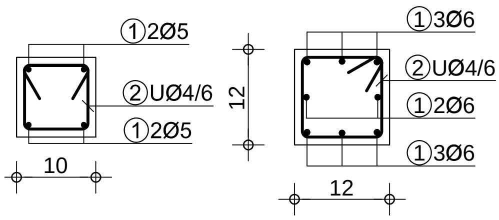

Fig. 1. *Cross sections with reinforcement bars and stirrups*

For all 8 samples acquired and analyzed results included: changes in the stress and strain state, ultimate load bearing capacity, shape of the global deformations at failure, load carrying engagement of each material within cross section. Local deformations (strains) were measured at the middle of the column's height with strain gauge on each model.

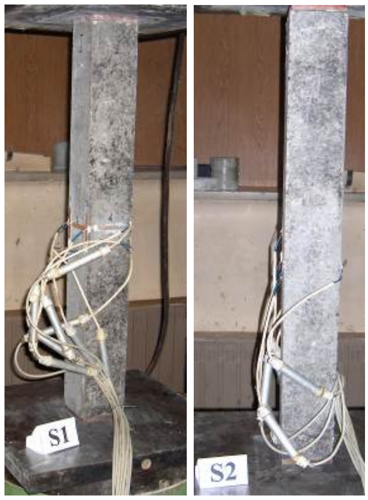

Fig. 2. C*olumn samples of the first group before testing*

Reinforcement ratio of the first group was μ=1.0%, while second group had μ=1.6%.

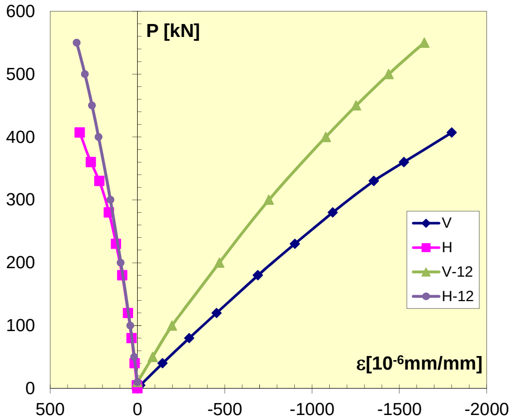

Fig. 3. *Characteristic deformation response of RC columns*

Fig. 4. *Column samples of the first group after testing*

Reinforced concrete columns of the both group showed linear behavior during whole loading process until failure (Figure 3). This behavior corresponds fully to one described in other literature, proving that axially compressed columns and high grade concrete columns show that their stress/strain diagram does not deviate much from the straight line [3].

Fig. 5. *Column samples of the second group after testing*

Comparison of ultimate load forces for tested RC columns Table 1

Nu [kN]	10×10cm	12×12cm
Experimental value	368	592

3. Composite steel and concrete columns

The composite columns were made from circular welded steel tube with outer diameter of D=159mm and wall thickness of t=2mm with length of 850mm. Yield strength of the steel taken from steel tube was experimentally determined to be f_y=250Mpa with module of elasticity E_s=207Gpa. Infill was made of concrete f_{ck}=60MPa and E_{cm}=34GPa.

Tubes were formed with cold forming

process and low-carbon welding process. Ratio of outer diameter and wall thickness was D/t=79.5 and it was chosen so that limit conditions for circular tubes filled with concrete are met as defined by EC4, ACI 318-08 and AISC 360-08 [12-14].

Fig. 6. C*olumn samples of the first group before testing*

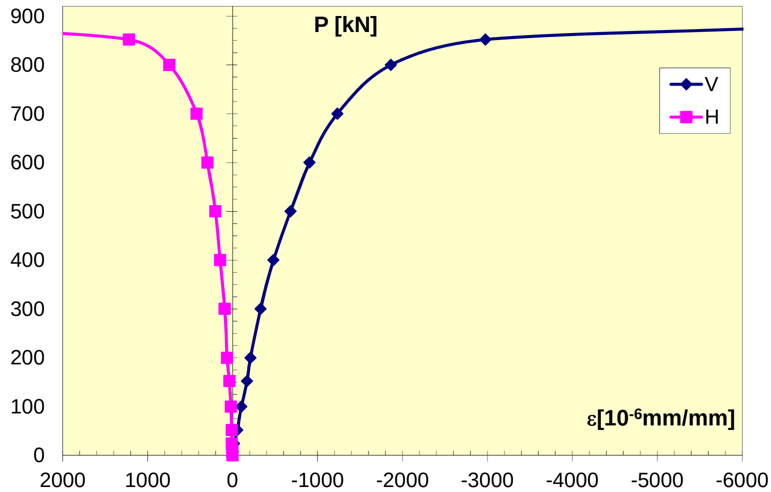

Fig. 7. *Characteristic deformation response of the composite column*

Experimental testing was conducted on three column models which were loaded across of all parts of the cross section. Measuring points for the registration of specific strains are located in the middle of the length of the column, and placed symmetrically relative to the longitudinal axis.

Mean value of ultimate load force for composite columns were Nu =876.0 kN.

Comparison of strains shows that composite columns had somewhat larger strains relative to RC column what is to expect regarding higher ductility of composite cross sections. Ration of main strains of the steel tube remained constant all the way up to failure and stresses within middle height cross section do not reach a steel yielding limit [8], [9].

Stress state analysis for each sample was conducted for cross section positioned at middle height for the load which is equivalent to maximum exploitation load. For evaluation of stress state within steel tube plane stress state assumptions were used. Measured strains were used then to determine stress state. Compression stresses were registered for the longitudinal axes of the column, while tangential stresses were tension stresses. Obtained stressed yield a conclusion that certain load distribution appeared between the tube and the core column as well as hoop stress effect within the tube itself. Transfer of load between materials within the composite cross section was a result of friction forces at the adjacent surfaces of the cross section, i.e. steel and concrete

Ultimate bearing capacity of the column with composite steel-concrete section under regulations Eurocode 4 [14] was determined by the expression (1), taking into account the increase of the strength of concrete due to triaxial effect:

$$N_{pl,Rd} = \eta_a \cdot \frac{A_a \cdot f_y}{\gamma_a} + \frac{A_c \cdot f_{ck}}{\gamma_c}\left[1 + \eta_c \frac{t}{d}\frac{f_y}{f_{ck}}\right] \quad (1)$$

$$N_{pl,Rd} = 858.32kN$$

Reduced capacity for the appropriate buckling model is:

$$\chi N_{pl,Rd} = 846.40kN$$

Comparing ultimate bearing load of composite column obtained from experiment and calculated value using EC4 it can be seen that difference is around 4%. This suggests that these regulations, with appropriate partial safety coefficients, provide very good approximation of the ultimate bearing capacity of the composite columns [11], [4].

4. Conclusion

This paper gives a short comparative presentation of experimental and numerical analysis of ultimate limit failure forces of centrically compressed RC and composite columns. 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 [10],[1] and [2].

Experimental results largely depend on assumptions made prior to design and forming of test samples what implies that conclusions refer to exactly defined boundaries. According to results obtained through experimental-theoretical analysis of samples following conclusion are made:

- RC columns from the control group have almost linear stress/strain relationship all the way to the failure.
- Columns made from steel tubes filled with concrete show considerably more ductile behavior and are capable of withstanding larger deformations relative to classical RC columns.
- Failure of the control RC columns occurred as a result of cracking and crushing of the concrete at the location of load application, while failure of composite columns occurred as a result of the combination of concrete crushing and local buckling of the steel tube at the location of the load application at the top of the column.

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