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THE STEEL CORE COVERED BY REINFORCED CONCRETE IN THE COMPOSITE STEEL-CONCRETE COLUMNS

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Abstract: *Design of the composite steel concrete columns with the massive solid steel profiles, called steel cores, is not covered in Eurocode 4 by using of simplified design method. Reasons are related to the problems about the residual stresses arising during the fabrication process of the solid steel profile and strain limitation in concrete section of the column. The available results of German research gives recommendations to design the composite steel concrete columns with the section of the concrete filled tubes with the central steel core according to Eurocode 4. Studies of the composite steel-concrete columns with the section of the steel core covered by reinforced concrete have not been covered in this research. This paper deals with the experimental and numerical analysis of this type unverified columns. 6 columns were tested with column lengths of 3.85 m and 3.0 m. Description and results of the experimental analysis are given. Numerical analysis consists of calibrated 3D models in the FEM program ATENA 3D with the conformity to the results of the experimental study. Presently these calibrated models are used as a background for the analysis of the columns with the variable geometrical and material modifications.*

Keywords: Composite steel-concrete column, steel core, experimental study, resistance, imperfection

1. Introduction

The solid steel profile, called steel core too, can increase the plastic axial stiffness significantly of the section of the composite steel-concrete column. Column with the steel core reaches higher resistance by higher slenderness. High resistance and high slenderness are the most required structural and architectural attributes for the columns of high-rise buildings. In general, there are two basic section-types of the composite steel-concrete columns with steel core:

- concrete filled steel tube with central steel core (Fig.1a),
- steel core covered by the reinforced concrete (Fig.1b).

Fig. 1: Section-types of composite steel-concrete columns with steel core.

Design of the composite steel-concrete columns with steel core is not covered in actual standard Eurocode 4 by using of simplified method because of two reasons. Residual stresses in the section of the steel core, which arise during its fabrication process (Roik, 1980) and strain limitation in concrete. German research has given recommendations for design of the steel-concrete columns with the section of concrete filled steel tubes with central steel core (Fig.1a) according to Eurocode 4. These recommendations are based on close experimental and numerical analysis, where the main studied parts are reduction factor of the plastic bending resistance α_M, initial bow imperfection and buckling curve (Lippes, 2008). This paper deals with experimental and numerical analysis on the composite steel-concrete columns with the section of the steel core covered by reinforced concrete (Fig.1b). Our research should lead to recommendation for safe and economical design of the columns with section according to Fig.1b by using the simplified design method of the Eurocode 4.

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2. Experimental analysis

2.1. Description of experimental tests

Experimental analysis included fabrication and tests of 6 specimens of columns divided into 2 length series. S1-serie consisted of 3 columns by length of 3.85 m with the relative slenderness $\overline{\lambda}$ =1.37. S2-serie consisted of 3 columns by length of 3.0 m with the relative slenderness $\overline{\lambda}$ =1.06. The assumed resistances and cross-section of columns are shown in Fig.2. Columns were concreted in vertical position.

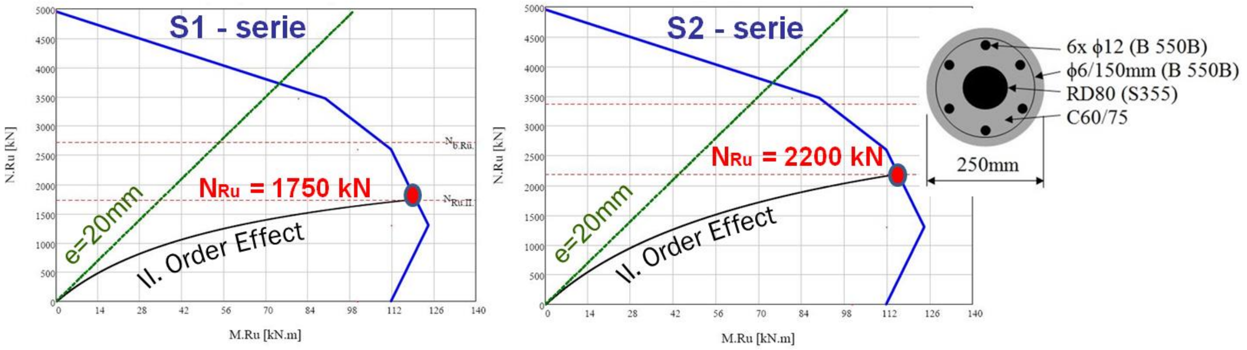


Fig. 2: The assumed ultimate resistances and cross-section of columns series S1 and S2.

First of all geometrical imperfection were measured and material tests were performed before load tests of columns. Measured geometrical imperfections were from 0.15 mm to 2.51 mm. The concrete cylinder strength was 63.9 MPa, the yield strength of reinforcement was 548.7 MPa and the yield strength of steel cores was 327.3 MPa. Measuring system of columns consisted of strain gauges on the steel core, strain gauges on concrete, mechanical strain measuring on concrete, measuring of deflections and measuring of depression of testing system between top and bottom of column. Force was received from the hydraulic cylinder machine. The columns were hinge-supported in the hydraulic cylinder machine with axial eccentricity of 20 mm. The columns were subjected to short-term load tests. Each test was performed by increasing and decreasing load steps with taking into account stabilizing deformation between individual load steps. This loading process should take into account slight influence of long-term loads, negative influence of irreversible effects like irreversible deflection and it should lead to earlier failure of column.

2.2. Results of experimental study

All columns failed approximately in middle of the length (Fig. 3) during the holding constant load by uncontrollable increasing of deflection, known as second order effect. Measurement results suggest that all failures were caused by run out of the concrete capacity. Before each failure the strain was about 3.5‰ in compression zone of concrete cross-section. Strains of column cross-section in the middle of the length are shown in Fig. 4b. Ultimate resistance of each column is shown in Tab. 1.

Fig. 3: a) The column before test; b) the column after failure; c), d) the detail of column failure

Tab. 1: Measured geometrical imperfections, experimental resistances and deflections of columns.

	Length L [m]	Relative slender-ness $\bar{\lambda}$ [-]	Measured geometrical imperfection w_0 [mm]	Eccentricity of axial force e_0 [mm]	Assumed axial resistance N_{Ra} [kN]	Ultimate axial resistance N_{Ru} [kN]	Ultimate deflection w_u [mm]	Accuracy N_{Ra} / N_{Ru}
S1.1	3.85	1.37	1.09	20	**1 734**	**1 829**	**34.7**	**95%**
S1.2			0.15		**1 756**	**1 811**	**41.1**	**97%**
S1.3			2.51		**1 703**	**1 777**	**40.4**	**96%**
S2.2	3.0	1.06	1.04		**2 207**	**2 294**	**23.5**	**96%**
S2.3			0.99		**2 209**	**2 292**	**24.8**	**96%**

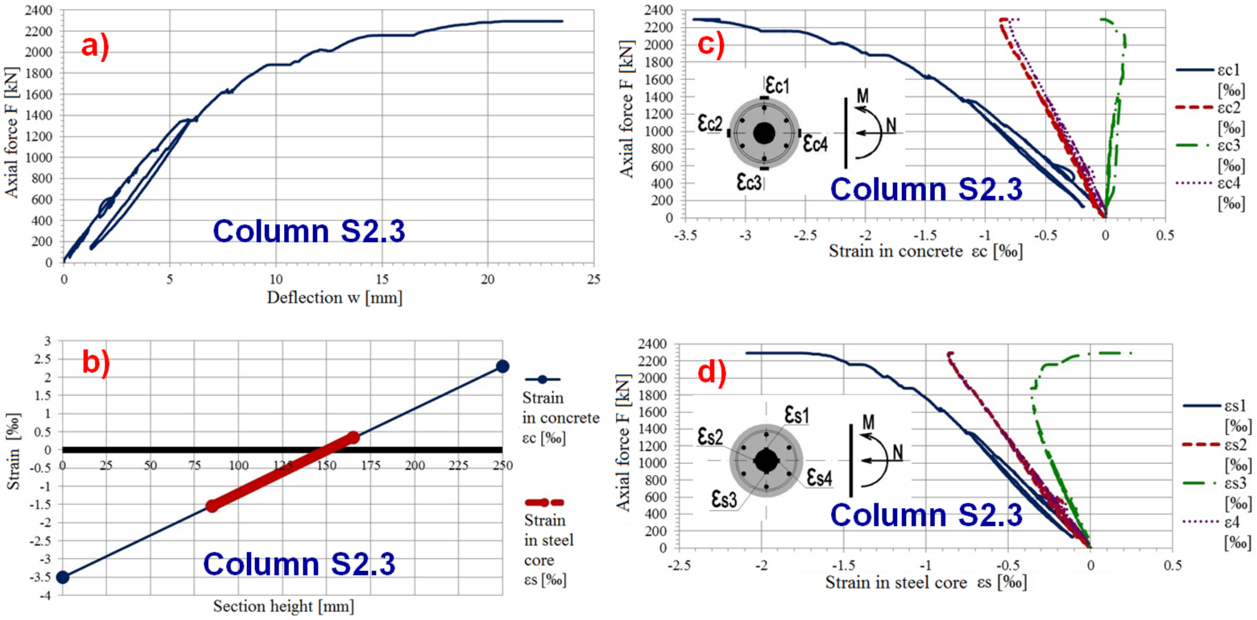


Fig. 4: Recordings during the test of column S2.3: a) deflection; b) strain in the section before failure; c) strain on the concrete surface; d) strain on the steel core surface.

3. Numerical analysis

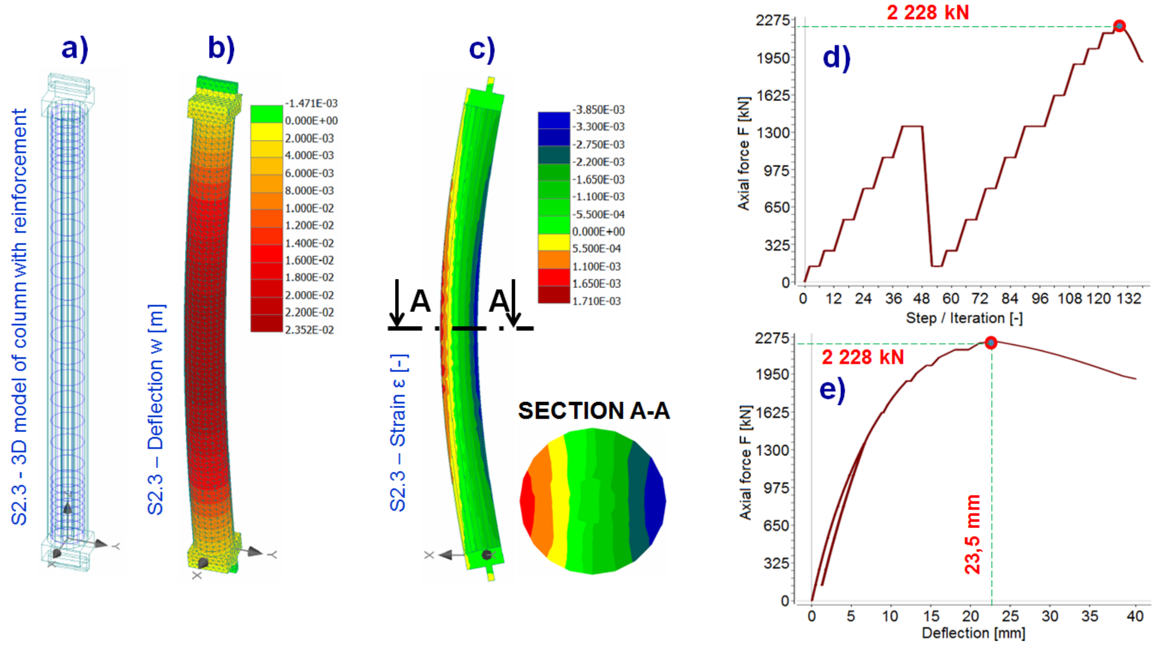


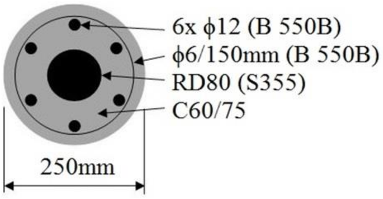
Fig. 5: Column S2.3 in ANTENA 3D: a) 3D model with reinforcement; b) deformed 3D model; c) strain in the column before failure; d) load steps, e) deflection during the load steps.

Numerical analysis was performed by nonlinear FEM calculation with 3D models by software ATENA 3D. Each column was modeled with same geometrical dimensions, material properties and boundary conditions as columns in experimental part. Geometrical imperfection was taken into account by additional eccentricity w_0 to basic eccentricity e_0. Load steps were defined the same as load steps in experimental tests. Model calibrations were based on optimizing the mash of 3D elements in order to reach the closest results to experimental results. Results comparison between experimental and numerical analysis is shown in Tab. 2. Calibrated models are presently used as a background for further analysis of the columns with various geometrical and material modifications. Columns with variable relative slenderness have been calculated yet. These columns are of the same material and section properties and boundary conditions as columns S1.1-S2.3.

Tab. 2: Results comparison between experimental and numerical analysis.

	L [m]	w_0 [mm]	e_0 [mm]	Experiment. ultimate axial resistance $N_{Ru,EPX}$ [kN]	Numerical ultimate axial resistance $N_{Ru,NUM}$ [kN]	Accuracy $N_{Ru,NUM}$ / $N_{Ru,EXP}$	Experiment. ultimate deflection $w_{u,EXP}$ [mm]	Numerical ultimate deflection $w_{u,NUM}$ [mm]	Accuracy $w_{u,NUM}$ / $w_{u,EXP}$
S1.1	3.85	1.09	20	**1 829**	**1 754**	**96%**	**34.7**	**31.1**	**90%**
S1.2		0.15		**1 811**	**1 797**	**99%**	**41.1**	**30.4**	**74%**
S1.3		2.51		**1 777**	**1 686**	**95%**	**40.4**	**33.8**	**84%**
S2.2	3.0	1.04		**2 294**	**2 226**	**97%**	**23.5**	**23.3**	**99%**
S2.3		0.99		**2 292**	**2 228**	**97%**	**24.8**	**23.5**	**95%**

Tab. 3: Results of numerical analyzed columns with variable relative slenderness.

	Relative slenderness $\overline{\lambda}$ [-]	Buckling length L_{cr} [m]	Basic eccentricity of axial force e_0[mm]	Ultimate axial resistance N_{Ru} [kN]	Ultimate deflection w_u [mm]
	0.2	0.66	20	**4 217**	**1.72**
	0.5	1.65		**3 323**	**6.70**
	1.0	3.29		**2 277**	**17.60**
	1.5	4.93		**1 361**	**33.61**
	2.0	6.58		**880**	**37.48**

4. Conclusion

Experimental tests have been performed and numerical 3D models have been calibrated in research of the composite steel-concrete columns with the steel core covered by reinforced concrete. Presently columns with variable material and geometrical modification are investigated. The columns with steel cores of dimension size over 100 mm will be investigated with the influence of residual stresses in the section of massive steel profile. From new available evaluated research we conclude the necessary adjustment for tested and analyzed type of composite steel-concrete columns for design them according to Eurocode 4 by using the simplified design method.

Acknowledgement

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