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EXPERIMENTAL ANALYSIS OF SLENDER HPC COLUMNS AT THE STABILITY FAILURE

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Abstract: *The European standard for design of compressed concrete members allows the use of non-linear calculations. The required reliability within design of slender members subjected to axial force and bending moment is not yet satisfyingly verified and confirmed for cases when the buckling failure precedes the breach in the critical cross-section. In order to verify and compare the reliability of the standard design methods, a comparison with experiment results is necessary. In cooperation with STRABAG Bratislava LTD, the Faculty of Civil Engineering at the Slovak University of Technology in Bratislava, carried out an applied research covering an experimental verification of slender high-performance concrete columns. In the following paper, the authors present the preparation and progress of the third series of experimental verifications for six slender high-performance concrete columns of the concrete strength class C80/95. The reinforcement and shape of the columns together with the initial eccentricity of axial force were designed so that the columns fail due to stability loss before reaching the resistance in the critical cross-section.*

Keywords: Slender columns, concrete, stability failure, experiment, reliability

1. Introduction

Within the design of concrete members which are subjected to axial force and bending moment, it is often important to take the second order effects into account. Current European standard (EN 1992-1-1, 2004) offers three methods of second order analysis. Namely, a general method, based on non-linear analysis, and two simplified methods: Method based on nominal stiffness and Method based on nominal curvature.

The increase of total bending moment within the critical cross-section is markedly influenced by slenderness of the column (Koenig et al., 1997; Koteš & Vičan 2013; Pfeiffer & Quast, 2003). The increase of total eccentricity due to increase of axial force may be so significant, that the buckling failure of compressed concrete members occurs inside the domain of the cross-section's design interaction diagram M-N, considerably earlier before the design resistance in the critical cross-section is reached (Benko et al., 2015; Fillo et al., 2013). In such cases, the partial factors of materials cannot apply and do not contribute to the overall reliability. Therefore, defining a partial reliability factor for buckling failure of compressed concrete members is appropriate.

2. Geometry, reinforcement, fabrication and materials of the tested columns

The tested columns were of a rectangular cross-section with dimensions of 240 x 150 mm. Total length of the columns, including spread steel plates and steel heads, was 3890 mm. Both ends of the columns were inserted into a press with a hinged connection. Steel heads, 25 mm thick, ensured the initial eccentricity $e_1 = 40$ mm (Fig. 1).

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Fig. 1: Steel head for ensuring of initial eccentricity

The columns were reinforced with four bars with diameter of 14 mm. In the critical places, the longitudinal reinforcement was supplemented with additional bars of 14 mm in diameter and 600 mm in length, which were at each end welded to spread steel plates with thickness of 20 mm. The amount of stirrups with diameter of 6 mm was doubled for the places with additional longitudinal reinforcement in order to increase the resistance of ending parts in the columns, as a local failure in these locations can precede the buckling failure (Fig. 2). The concrete cover of stirrups was 20 mm.

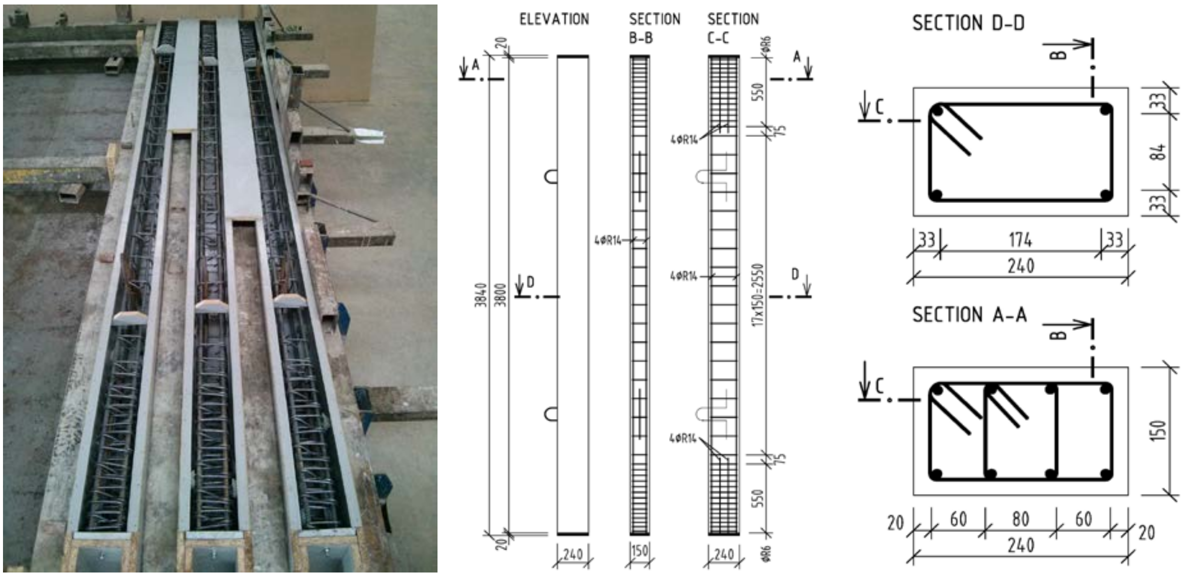

Fig. 2: The shape and reinforcement of columns for S3 series (λ=89)

Thirty testing samples were made during the production of columns - cylinders, cubes and prisms were to be checked for the standard concrete characteristics both after 28 days and at the actual time of testing of columns. After completing the tests of columns, core samples for testing concrete material characteristics were taken (Fig. 3). The evaluation of the material tests proved the concrete strength class C80/95.

Fig. 3: The core samples for testing of concrete material characteristics

3. Experimental verification

The slender concrete columns were tested in the laboratory of Faculty of Civil Engineering SUT in Bratislava (Fig. 4). The diagrams of tested columns within S3 series and calculated columns by non-linear methods are shown in Fig. 5. Diagram on the left shows the relation between axial force and bending moment while taking the second order effects into account. Curves “S3-1” – “S3-6” show M-N relation of tested columns, curves “Stab2D-NL” and “NL Method” show M-N relation of calculated columns, while first column (red curve) was calculated in non-linear software Stab2D-NL and second column (green curve) was calculated in one's of the authors own software based on non-linear calculations. The diagram on the right side shows ε - N relation on both sides of cross-section.

Fig. 4: Column testing (on the left), column after failure (on the right)

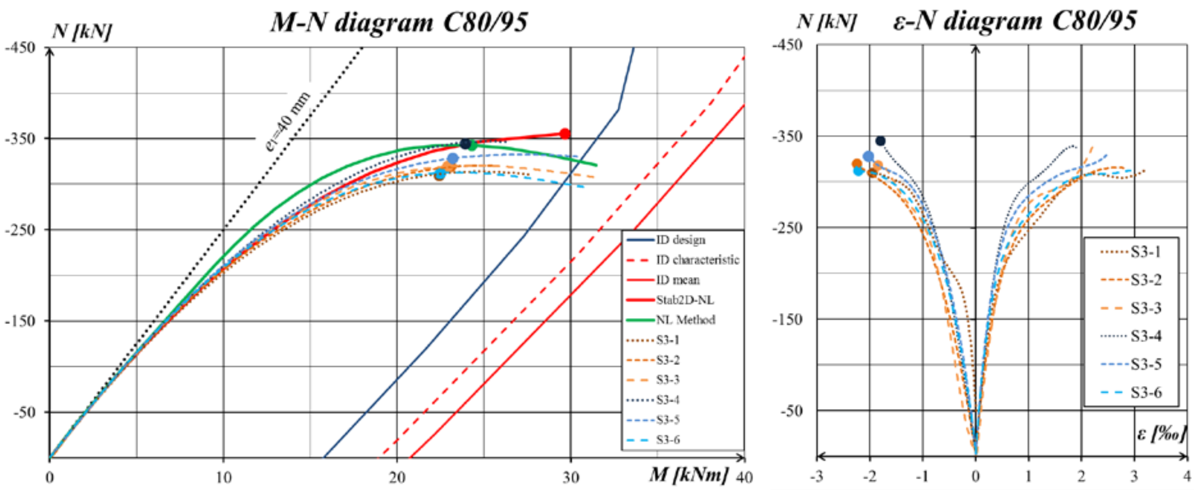

Fig. 5: Bending moment – axial force diagram (on the left), b) strain – axial force diagram (on the right)

4. Summary

The experimental analysis confirmed the predictions of the authors. The buckling failure of slender concrete columns occurred in the domain of the design interaction diagram of the column cross-section much earlier than the designed resistance of critical cross-section was reached. The compressive strain at the collapse of the columns was around 2 ‰ (Fig. 5). In such cases the definition of partial reliability factor for stability failure would be appropriate, as the partial factors of materials could not be put into effect. The importance of right definition of partial reliability factor for stability failure of compressed members is increased by the fact that the buckling failure occurs without warning. It is a brittle failure which requires higher overall reliability than the signalized failures.

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