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EXPERIMENTAL STUDIES ON THE BEHAVIOUR OF STEEL COLUMN BASE CONNECTIONS

BY

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Abstract. The present design regulations require that the structural strength requirements should not prevail to the ductile behavior of structures in a design process. In case of steel columns bases, brittle failures (failure of holding-down bolts, concrete crushing in compressive zone) should be avoided. In this context, ductility or the rotational capacity should be determined mainly by the flexibility of baseplates. Experimental research studies may reveal specific local phenomena otherwise “invisible” (by numerical simulations, failure theories or other analysis methods). The main objective of this paper is to describe the overall structural behavior and evaluate the parameters involved in the connection design of the exposed rigid baseplate analysed in the laboratory test. The performed full-scale tests lead to failure modes validated by the maximum equivalent stress distributions numerically obtained.

Key words: base column joint; base plate; ductility.

1. Introduction

The column bases represent one of the most important zones of steel structures having the role of load transfer from the superstructure to the

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foundation system. When laterally loaded, exposed baseplate solutions for steel columns bases deform – under bending moments and (associated) shear forces – mainly by rotations. Behaviour of connections in these regions is of major importance in the overall structural behavior under lateral loading conditions. Previous research studies, (Grauvilardell *et al.*, 2005; Hamizi & Hamachi, 2007; Stamatopoulos & Ermopoulos, 2011), showed that connections between columns and foundation elements behave in a semi-rigid manner and, in most of the cases, heavily influence the overall structural system.

As stated above, experimental research studies may reveal specific local phenomena otherwise "invisible". In this order, an experimental program involving full-scaled models of columns with exposed baseplates seconded a numerical simulation. The experimental tests analysed the behavior of exposed baseplated steel columns connections under cyclic loading conditions with the aim of validating the numerically obtained results. Evaluation of parameters not possible to quantify by the conducted numerical simulations was also of interest.

Nonlinear elastic–plastic numerical analyses of the later on tested models were performed by the Finite Elements Method based ANSYS Workbench 12 software package (Ansys, 2009; Melenciuc, 2011).

2. Experimental Program and Test Set-Up

The experimental tests were performed in the dynamic and seismic test laboratory of the Structural Mechanics Department from the Faculty of Civil Engineering and Building Services of Iaşi.

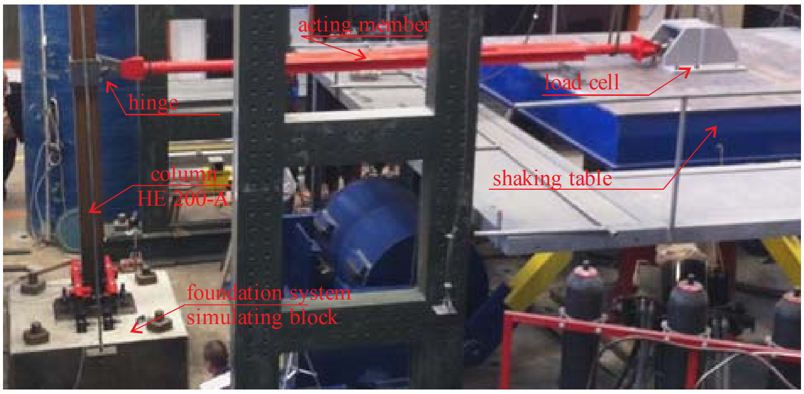

Fig. 1 – Experimiental stand; load transmition system.

For testing the column base ends connections, a specially designed stand completing the ANCO shaking table was used (Fig. 1). The test set-up consisted in: the stiff concrete slab supporting the shaking table, foundation system simulating block, held-down through four M80 bolts anchored in the laboratory ground slab. The shaking table acting member was equipped with a 200 kN load cell.

The tests peformed on the steel columns were under lateral horizontal load conditions only, not involving any axial components (excepting the column dead load). In this manner, the column base behavior under extreme conditions was observed. It may be stated that this reflects a rather common situation of real structures, especially in case of perimetral columns in slender steel structures under seismic actions when the axial components may be neglected. The horizontal action transmitted by the shaking table was applied at a 2.10 m height with respect to the column base.

A "sinus beat" type action was applied under displacement control, with maximum amplitudes (Δ) of 10, 20, 40, 60, 80 and 100 mm (Fig. 2).

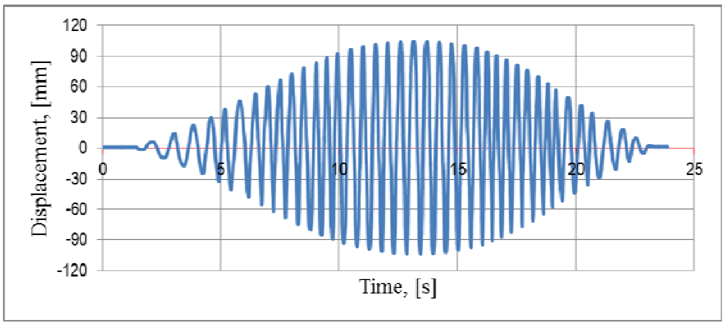

Fig. 2 – Imposed displacements; maximum amplitudes (Δ) 100 mm.

The action was indirectly applied by imposing successive displacements for the shaking table platform. The actual load transmitted to the steel column was monitored using a load cell placed at the end of the acting member, connected on the platform.

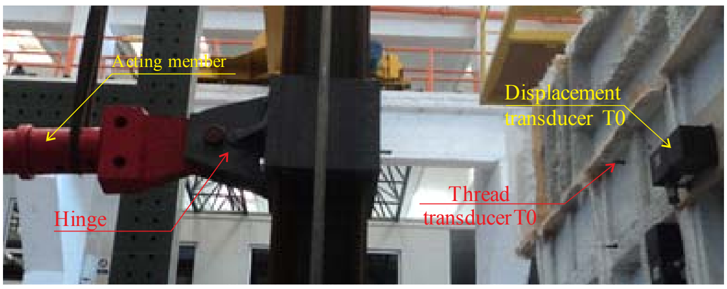

Fig. 3 – Horizontally placed displacement transducer (*T*0).

300 mV/V/inch sensitivity, CELESCO thread type displacement transducers (*T*) were used in order to determine the structural response of the column models. The load *vs.* displacement curve at the level of load application (acting member level) was obtained using the readings of the *T*0 (Fig. 3).

The other transducers were placed at the base level by connecting them to the steel column and measuring the relative displacements between the baseplate elements and the foundation system. The transducers were fixed on the column, at a 250 mm span from the bottom face of the baseplate, in order to monitor the potential plastic hinge formation region (Stamatopoulos & Ermopoulos, 2011).

Relative column base-foundation system displacements, in case of baseplated models, were monitored using *T*1 to *T*4 transducers; displacements of the baseplates were accounted using the *T*5 to *T*8 transducers (Fig. 4), (Stamatopoulos & Ermopoulos, 2011).

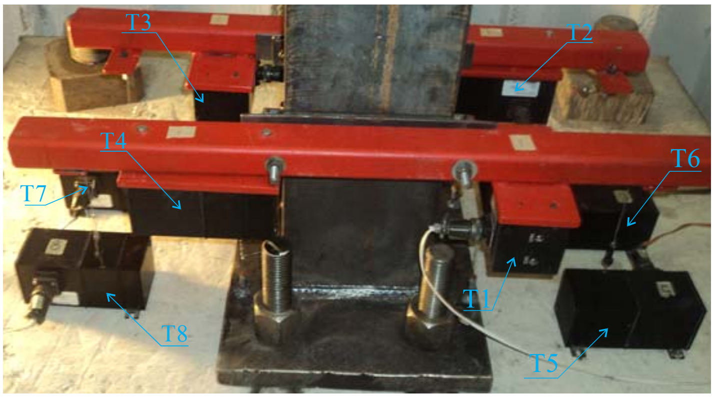

Fig. 4 – Baseplate tranducers location.

3. Test Specimen

The tested specimen consisted in the 2.10 m high, HE 200-A cross-sectioned steel column and the baseplate anchored in the reinforced concrete foundation block by four M36 hold-down bolts (Fig. 5). The hold-down bolts were fixed in the foundation block with a clear deformation span of 360 mm. The column and the baseplate were made of S355 steel while the concrete used for the foundation was of C20/25 class.

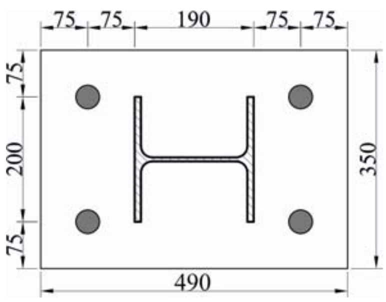

Fig. 5 – 350 × 490 mm steel column base plate.

The connections rotations were determined based on the vertical displacements of the baseplate at the level of column section flanges, using the following relation, (Hamizi and Hamachi, 2007):

$$\theta = \frac{a-b}{x}, \tag{1}$$

where: θ is the rotation of the column baseplate; a, b – vertical displacements of the column baseplate; x – span between the displacement measuring points.

4. Test Results

For each of the loading cycles curves were ploted unsing the load readings of the load cell and the displacements given by the $T0$ transducer, loacated at the level of the acting member.

The specimen behaved in a linear elastic manner up to loading cycle of maximum amplitude of displacement of 40 mm, (Fig. 6). The base plate presented a rigid behavior and presented no plastic deformations.

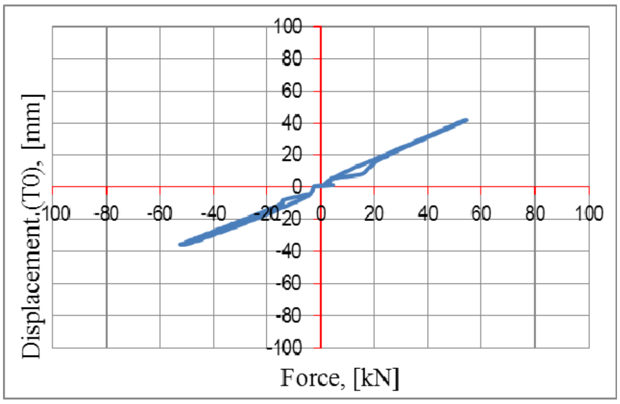

Fig. 6 – Relaţia forţă-deplasare din timpul ciclului cu amplitudinea maximă 40 mm.

Starting with the load cycle of displacement maximum amplitude of 60 mm, the behavior of the model became elastic–plastic, due to occurrence of plastic hinges at the column base level (Fig. 7).

The bending moment *vs.* rotation curve of the connection is depicted in Fig. 8. The shape of the curve is not uniform; this fact may be attributed to the lossening of nuts. The bending moment capacity of the connection was evaluated at 156.6 kNm, corresponding to a maximum baseplate rotation of 0.011 rad. The vertical displacements of the column baseplate were determined as arithmetic mean values given by the displacement transducers, when the amplitude of the action was of $\Delta = 80$ mm.

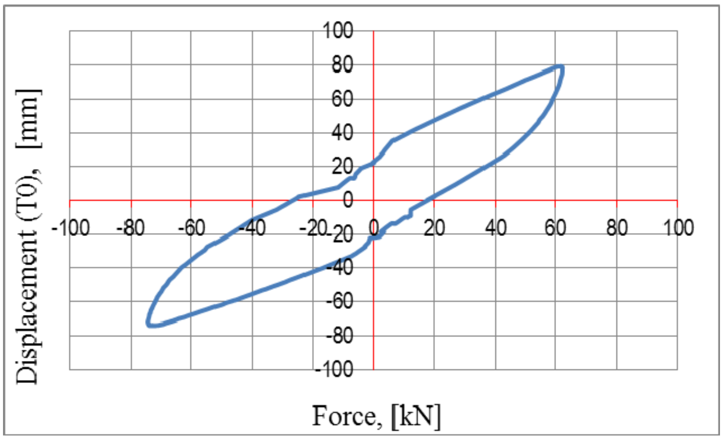

Fig. 7 – Load *vs.* displacement curve for the connection, Δ = 80 mm.

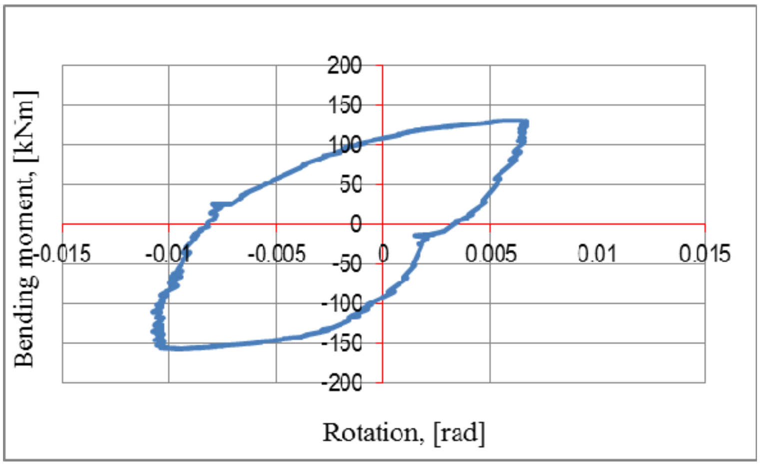

Fig. 8 – Bending moment vs. rotation curve for the connection, Δ = 80 mm.

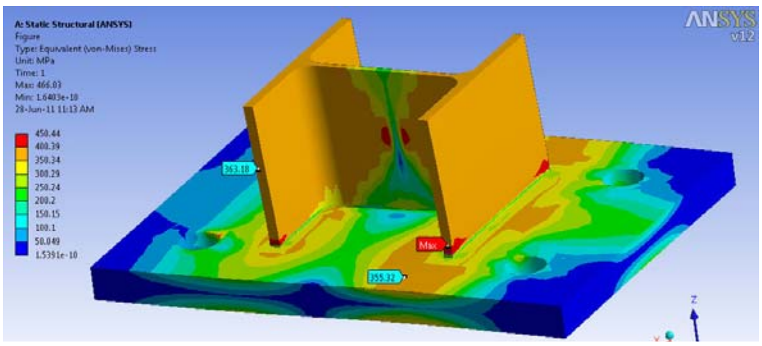

Fig. 9 – Von-Mises equivalent stresses distributions, Δ = 100 mm.

The connection failed by formation of the plastic hinge in the column, that is the loss of the local stability of compressed flanges (Fig. 10). The failure occurred at a load level corresponding to the maximum displacement of 80 mm. The failure manner was also described by the numerical simulations, as the maximum von Mises equivalent stresses shown in Fig. 9 (Melenciuc, 2011).

Fig. 10 –Plastic hinge formation in the column.

5. Conclusions

The behavior of exposed baseplate located connections for steel columns is highly influenced by the thickness of the base plate. When using rigid baseplates, there may be obtained design parameters characteristic to the full capacity connections.

As a direct consequence of the increased stiffness of the baseplate – given by the large thickness and short outstands – the joint rotation was significantly influenced by the holding-down bolts deformation. This aspect should be avoided in case of seismic actions exposed structures.

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STUDII EXPERIMENTALE ASUPRA COMPORTĂRII ÎMBINĂRILOR STÂLPILOR METALICI DE LA NIVELUL INFRASTRUCTURII

(Rezumat)

Prevederile impuse de normele actuale de calcul şi în concluziile cercetărilor în domeniu este ca rezistenţa să nu fie prioritară în faţa comportamentului ductil. În cazul îmbinărilor de la baza stâlpilor metalici trebuie evitate modurile de rupere casante (ruperea şuruburilor de ancoraj, cedarea betonului în zona comprimată). Ductilitatea, capacitatea de rotire, trebuie determinată în principal de flexibilitatea plăcii de bază. Cercetarea experimentală poate demonstra unele fenomene greu de surprins prin analize numerice. Lucrarea de faţă are ca scop determinarea comportamentului valorilor de calcul ale îmbinărilor cu placa de bază expusă rigid, pe cale experimentală. În urma încercărilor experimentale a fost determinat modul de cedare ce a validat distribuţia tensiunilor maxime echivalente obţinută pe cale experimentală.