BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LXI (LXV), Fasc. 2, 2015
Secţia
CONSTRUCŢII. ARHITECTURĂ

BEHAVIOUR OF STEEL COLUMN BASE CONNECTIONS UNDER CYCLING LOADING CONDITIONS

BY

SILVIU CRISTIAN MELENCIUC*, MIHAI BUDESCU, VLAD MUNTEANU and VICTORIA ELENA ROŞCA

“Gheorghe Asachi” Technical University of Iaşi
Faculty of Civil Engineering and Building Services

Received: May 14, 2015
Accepted for publication: May 29, 2015

Abstract. The high complexity of the load transfer mechanism at the steel column base connection yields for special care in both analysis/ design as well as in the actual errection stage of frame steel structures. Describing the real behaviour of the joint represents a key aspect in the overall structural analysis. The fully rigid or fully pinned assumptions on the column base joint behaviour have already been surpassed by more complex approaches in the analysis. As the dissipative capacity assessement is still under debate among specialists, the paper aims at delivering additional data to the problem. Laboratory tests, backed-up by numerical modeling investigations were performed on two natural scale steel columns base connection configurations under cyclic lateral loading conditions. Results of in terms of load - displacement and moment - rotation diagrams are hereinafter advanced for further studies purposes.

Key words: steel column; base plate; dissipative capacity; structural behaviour; cyclic loading.

1. Introduction

The key role played by steel column bases within the overall structural behaviour of steel frames rises a wide range of problems in both analysis and design of these structural zones. In this context, the dissipative capacity as well

*Corresponding author: *e-mail*: melenciucsilviu@ce.tuiasi.ro

as the brittle failures are of current debate among specialists. The uncertain dissipative capacity of joints at this level is generally addressed by ensuring conservative overstrength factors. At the same time, in order to avoid the brittle failure mechanism of the joint, detailing of these joints should not use both bolts and welds for undertaking the same force component.

As regards the the connection rotational capacity, both theoretical and empirical approaches are generally used to evaluate the structural behaviour of studied joints as close as possible to the real neither fully pinned nor fixed situation. Connection rotational capacity becomes a sounder grounds defined component within the overall structural analysis (Stamatopoulos & Ermopoulos, 2011).

In a previous work the authours mentioned that the connection between the columns and the infrastructure system behaves in a semi-rigid manner, heavily influencing the overall structural behaviour (Melenciuc *et al.*, 2011). The reffered paper also advanced – as partial results of an extensive research program – obtained data upon the behaviour of an exposed-type steel column baseplate connection.

Along with the laboratory tests, a finite element method based numerical modeling was performed using the ANSYS software capabilities in order to study its suitability for the stated problem. A special attention is paid to identifying the components (bolts/ steel base plate) contribution in the overall rotational capacity, within the frame of the component method based code design approach.

The present work aims to provide additional information by advancing comparative experimental and numerical modeling results regarding the overall behaviour of the steel column exposed base plate connections. Results expressed in *load vs. displacement* and *moment vs. rotation* curves are considered to be useful in further calibrating joint design parameters.

2. Steel Column Base Behaviour Assessement

The steel column base behaviour assessement was performed on two joint configurations for natural scale columns subjected to a lateral cycling load. The dead load of the column represented the single axial compressive force component. Although this situation does not necessarily reflect the case of all real structures columns, the adopted loading conditions may be representative for marginal columns in slender steel structures. Under seismic actions, these marginal columns are facing minor axial force components and the column base connections are experiencing an extreme loading session.

The research program involved two full-scaled models of HE200A columns with exposed base-plates. The horizontal force was applied at a 2.10 m distance with respect to the column base.

2.1. Joint Configurations

The tests were performed on a rigid base-plate column connection and a more flexible base-plate. As described in Fig. 1 (dimensions in mm), the variance in flexibilities for the two base-plate configurations were ensured by varying the distance between the bolt rows.

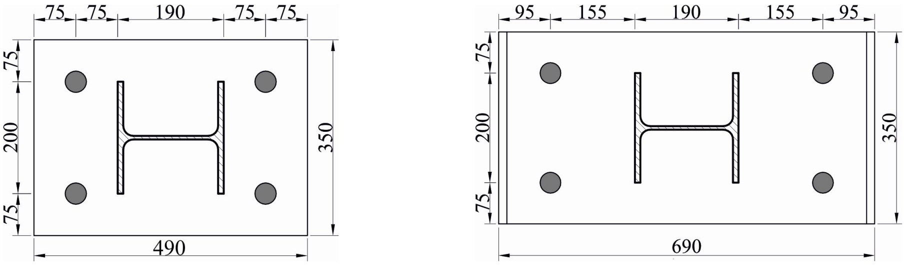


Fig. 1 – 33mm thick plates configurations: *a* – rigid *vs.* *b* – flexible.

2.2. Experimental Work

The experimental program was conducted in the Dynamic and Seismic Test Laboratory of the Structural Mechanics Department from the Faculty of Civil Engineering and Building Services of Iaşi. The test set-up (Fig. 2, dimensions in mm) consists in the laboratory shaking table inducing the load, the rigid loading arm and the foundation block/ base plate/ HE-200A column assembly.

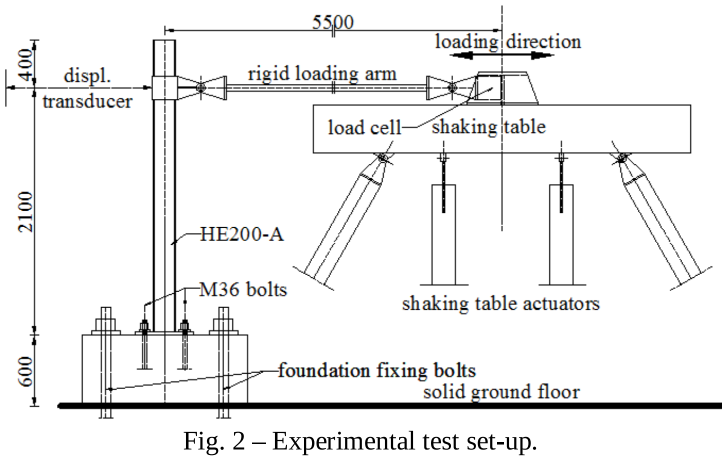


Fig. 2 – Experimental test set-up.

The horizontal cycling action was indirectly applied by assigning different displacement levels (with maximum amplitudes (Δ) of 10, 20, 40, 60, 80 and 100 mm, following a constant 0.5 Hz frequency sinus shape loading curve) to the shaking table platform.

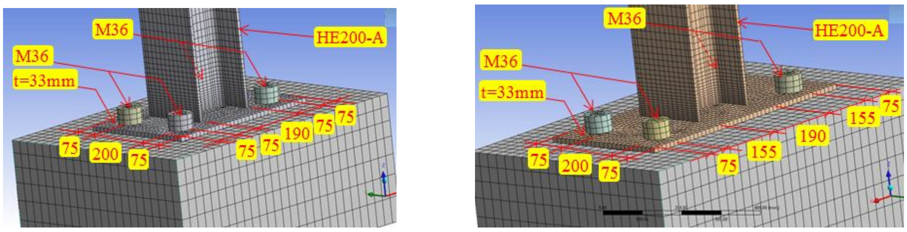
The actual load affecting the steel column was monitored using a load cell placed at the end of the rigid loading arm. A horizontally oriented displacement transducer was accompanying the load cell to obtain data for plotting load vs. displacement curves at the loading arm level. Displacement transducers monitoring the potential plastic hinge formation region were also used to measure relative displacements between the base-plate joint components and the foundation block.

Additional information upon the components of the experimental set-up and the loading protocol may be found by Melenciuc *et al*., (2011).

2.3 Numerical Modeling

The numerical modeling based behaviour assessement for the studied elements was developed using the ANSYS software capabilities. The analysis was performed on models meshed with SOLID95, 3-D 8-node solid elements able to undertake irregular shapes without important loss of accuracy.

As connection components were expected to experience contact and sliding phenomena, the CONTA174 elements were found suiting the purpose since they are designed to cover 3-D structural and coupled field contact problems (ANSYS Inc., 2009). The detailed models for the two joint configurations are covered in Fig. 3, while in Table 1 the material model parameters for the considered base plates components are presented.



a *b*

Fig. 3 – Joint models: *a* – rigid plate *vs*. *b* – flexible plate.

Table 1

Material Properties for Modeled Column Base Plate Connection Components

Joint component	Property			
	Yield/ ultimate strength f_y / f_u, [MPa]	Yield/ ultimate strain $\varepsilon_y / \varepsilon_u$, [mm/mm]	Young's modulus E, [MPa]	Poisson's ratio ν
Steel column	355/510	1.7e-3/25.4e-3	2.1E5	0.3
Base plate	355/510	1.7e-3/25.4e-3	2.1E5	0.3
Hold-down bolts	900/1,000	4.3e-3/64.3e-3	2.1E5	0.3
Welds	450/580	2.1e-3/32.1e-3	2.1E5	0.3

3. Results

3.1. Moment *vs.* Rotation Curves

For comparison purposes, *Load vs. Displacement* curves are given along with the previously reported results (Melenciuc *et al*., 2011). The plots were obtained after the completion of 15 and 12 cycles for the rigid and flexible base plate configurations, respectively, Fig. 4. These curves were later on used in order to draw the *Moment vs. Rotation* curves.

As presented in Fig. 5, the flexible base plate configuration revealed an increase in the rotational capacity of 227%.

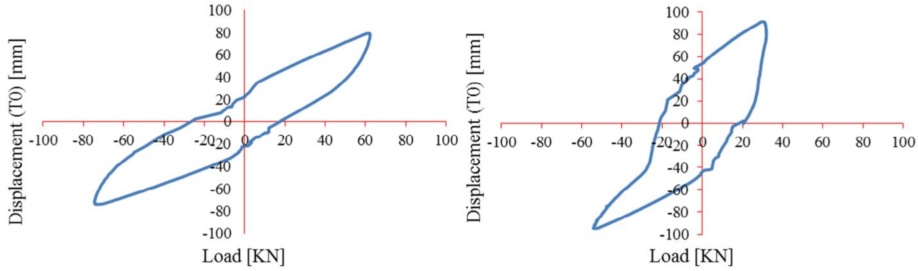


Fig. 4 – *Load vs. displacement curves* for *a* – rigid plate configuration; *b* – flexible plate configuration.

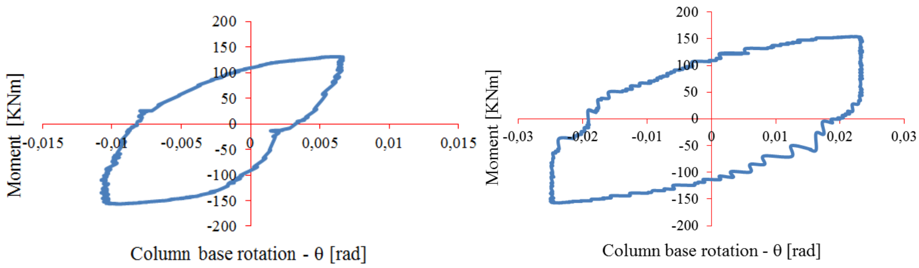


Fig. 5 – *Moment vs. rotation curves* for *a* – rigid plate configuration; *b* – flexible plate configuration.

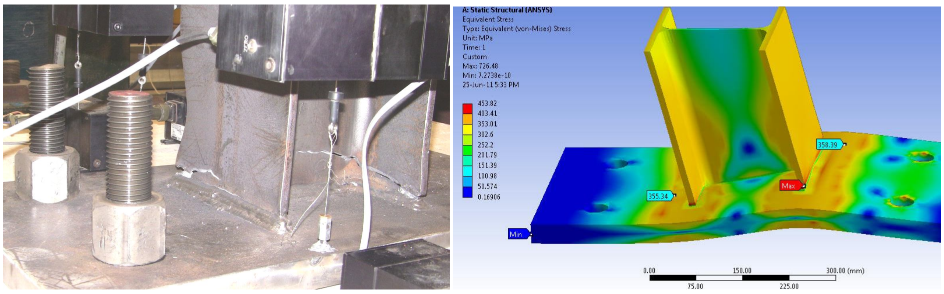
3.2. Overall Behaviour and Failure Mechanisms

The rigid base-plate model presented a ductile overall behaviour. The dissipative process consisted in plastic hinge formation within the steel column region. The plastic hinge occurred during the fourth loading stage, without any signs of base plate plasticization. As reported, the connection failure occurred after completing 15 loading cycles, with Δ = 80 mm displacement amplitude, as the column flanges buckled (Melenciuc *et al*., 2011).

By contrast, the flexible base-plate configuration behaviour was mainly determined by the base-plate bending. At Δ = 60 mm imposed displacement level plastic deformations were observed at the level of the base-plate. The nonlinear character of the behaviour accelerated as the imposed displacement reached Δ = 80 mm in amplitude.

The base plate connection failure was of brittle character and produced by column web fracturing after completing 12 loading cycles – 100mm displacement amplitude), Fig. 6 *a*. At this load level, a crack was initiated in the heat affected zone at the tensioned column flange and quickly passed the column web.

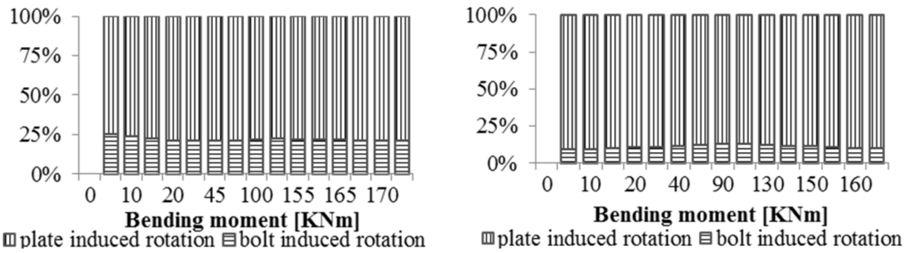
Prior to connection failure, a redistribution of stresses from the column flanges to the bend base-plate was noticed and successfully captured by the ANSYS model (Fig. 6 *b*).



a *b*

Fig. 6 – Failure of the flexible base plate connection.

The FEM modeling was used also to analyze the components contribution in the overall rotational capacity of the joint. As the base plate stiffness and anchoring bolts stiffness are governing the rotational behaviour, the comparative diagrams in Fig. 7 depict the differences within the two joint configurations.



rigid base-plate joint flexible base-platejoint

Fig. 7 – Components influence upon the total rotation of the column base connection.

The computation of components contributions in the overall column base plate connection rotation involve several geometrical parameters that are detailed by Melenciuc, (2011). Vertical displacements of both tensioned and compressed column flanges, the horizontal distance between the column faces, the vertical displacements of bolt rows and horizontal distance between bolt shank axes and the inflection point of the base plate in the compression zone are included.

4. Conclusions

The expected full strength, rigid overall behaviour in the case of high stiffness base-plate model was experimentally obtained results confirmed. The rotational capacity governed by the column plastic deformation as well as by the bolt shank elongation.

The decreasing within the base-plate stiffness lead to semi-rigid behaviour of the column base-plate connections. The higher ductility of the flexible base-plate joint configuration base-plate model was also marked by the significantly increased number of loading cycles (130 loading cycles after the plastic hinge formation at the column flanges level). The rather brittle character of the failure mechanism requires special attention when detailing and yields for additional research.

The advanced results presented in this work are intended to calibrate numerical models of steel column base connections of the studied configurations.

A secondary potential use of the work may be within overall steel frame analysis and design projects, by directly addressing the neither fully pinned nor fully fixed connection behaviour. The obtained moment relative – rotation behavioral curves reflect the semi-rigid real behaviour of these connections.

REFERENCES

Melenciuc S., *Contributions to Steel Structures Connections Behaviour Improvement in Seismic Hazard Conditions.* Ph.D. Diss., Politehnium, Iaşi, 2011.

Melenciuc S.C., Ştefancu A.I., Budescu M., *Experimental Studies on the Behaviour of Steel Column Base Connections*. Bul. Inst. Politehnic, Iaşi, **LVII (LXI)**, *3*, s. Constr., Arhit., 149-156 (2011).

Stamatopoulos G.N., Ermopoulos J.Ch., *Experimental and analytical investigation of steel column bases*, Journal of Constr. Steel Research, **67**, *9*, 1341-1357 (2011).

* * * *ANSYS Workbench 2.0 Framework Version: 12.0.1.* ANSYS Inc. (2009).

COMPORTAREA BAZEI STÂLPILOR METALICI LA ACŢIUNI CICLICE

(Rezumat)

Gradul ridicat de complexitate al mecanismului de transfer al solicitărilor în îmbinările de la baza stâlpilor metalici impune o atenție sporită atât în faza de analiză structurală/ proiectare cât şi în faza de execuție a structurilor metalice. Un factor critic în faza de analiză structurală este reprezentat de asimilarea corectă a parametrilor specifici îmbinărilor. Într-o abordare modernă a procesului de analiză structurală, nu se mai consideră suficient asocierea îmbinărilor cu noduri perfect rigide sau perfect articulate. Lucrarea îşi propune să participe cu date experimentale şi numerice privind comportarea îmbinărilor studiate în contextul în care, capacitatea de disipare a îmbinărilor reprezintă un subiect deschis în comunitatea stiințifică. În acest sens, au fost analizate două configurații de îmbinări la nivelul bazelor de stâlpi metalici, studiile experimentale şi numerice vizând modele la scară naturală. Lucrarea prezintă, cu scopul unor posibile utilizări ulterioare, rezultate obținute în termeni de forță – deplasare, moment – rotire.