



Potentially Plastic Zones Details in Bottom Storey Columns of Concentrically Braced Frames

Helmuth Köber^(✉), Ramona Marcu, and Marina Stoian

Technical University of Civil Engineering Bucharest,
Bulevardul Lacul Tei nr. 124, 020396 Bucharest, Romania
koberhelmuth@yahoo.de

Abstract. The present paper is intended to illustrate the advantages and disadvantages of different structural details for the potentially plastic zones located near the bottom end of the first storey columns in concentrically braced frames. Several structural details were analysed, considering: reduced flanges cross-sections and/or transversal and longitudinal stiffeners for the bottom zone of the columns.

The features of the proposed alternative details are analysed for four concentrically braced frames. The considered frames had six and respectively ten storey and were located in Bucharest, Romania. The frames had two spans of 6.0 m and the storey height was 3.5 m. Built-up I-shaped cross-sections were used for all types of structural members: braces, columns and girders. All connections among different kind of structural members, as well as the connections to the foundation were considered as fixed.

Dynamic nonlinear analyses were performed for each structural configuration using acceleration records of three Vrancea earthquakes, calibrated all to a peak ground acceleration value of 0.3 times the acceleration of gravity.

The maximum values of the bending moments, the axial forces and the plastic deformations in the potentially plastic zones at the bottom end of the first-storey columns were compared.

The buckling resistance of first-storey columns was compared for the most unfavourable loading states recorded during dynamic nonlinear analyses.

Keywords: Potentially plastic zones · Joint reactions · Plastic hinge rotations · Column stability · Plastic failure mechanism

1 Introduction

Generally, in steel frames subjected to strong seismic actions, inelastic deformations appear also near the bottom of first storey columns. The present paper intends to illustrate the advantages and disadvantages of different structural details for the potentially plastic zones located near the bottom end of first storey columns in concentrically braced frames. Several structural details were analysed considering: reduced flanges cross-sections and/or transversal and longitudinal stiffeners for the bottom zone of first storey columns [1]. Four concentrically braced frames were taken into

consideration, having six and respectively ten storey of 3.5 m and two spans of 6.0 m (see Fig. 1). Built-up I-shaped cross-sections were used for all types of structural members: braces, columns and girders. All connections among different kind of structural members, as well as the connections to the foundation were considered as fixed. The frames were dimensioned according to the provisions of the in charge European [2] and Romanian [3] seismic design codes.

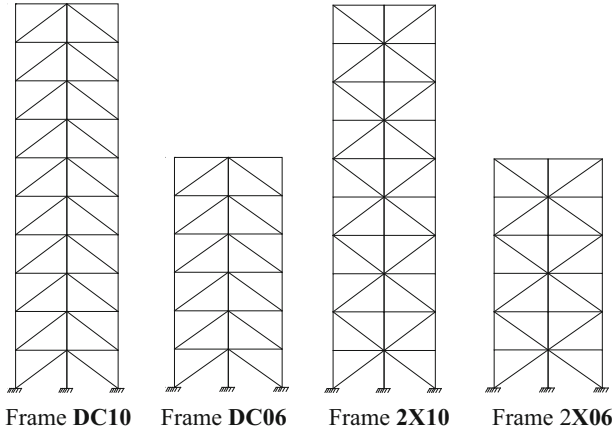


Fig. 1. Analysed concentrically brace frames.

Dynamic nonlinear analyses were performed for each structural configuration using acceleration records of three Vrancea earthquakes, all recorded in and around Bucharest at 04.03.1977, 31.08.1986 and 30.05.1990 and calibrated to a peak ground acceleration value of 0.3 times the acceleration of gravity [4]. Rayleigh damping was taken into consideration. Mass and stiffness proportional damping factors were considered for the first and third modal periods [5]. The considered critical damping fraction values were 2.5% for the first eigenmode and 5.0% for the third eigenmode. Drain 2D+ was used to perform the dynamic nonlinear analyses [5].

The maximum values of the bending moments, the axial forces and the plastic deformations in the potentially plastic zones at the bottom end of the first storey columns were compared. The buckling resistance of first storey columns was compared for the most unfavourable loading states recorded during dynamic nonlinear analyses.

2 Considered Bottom Column Details

Four different constructive details were considered. Configuration 1 is the reference analysis detail (see Fig. 2a). The column has the same cross-section on the entire height of the first storey column. Pairs of transverse web stiffeners (P3) were used to avoid early local buckling in the potentially plastic zone [1].

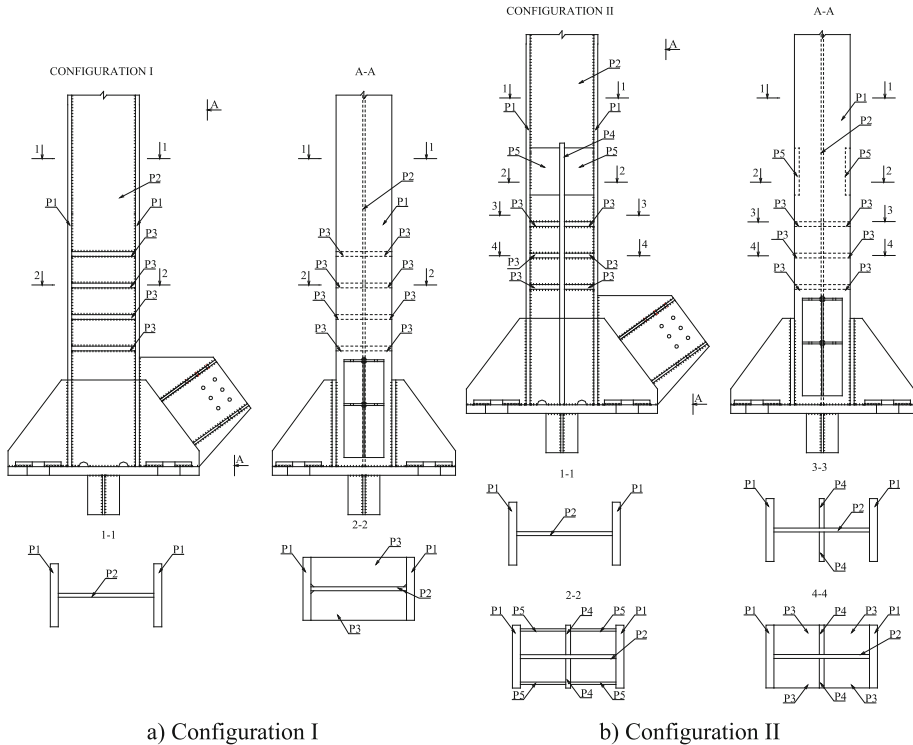


Fig. 2. Considered bottom column details.

Compared to configuration 1, in the second considered detail, an additional pair of longitudinal stiffener (P4) was placed on the web (see Fig. 2b). This pair of stiffeners was used to reduce the axial loading level in the flanges, to make room for stresses generated by bending moment. Plates P5 were provided to facilitate the axial load transfer from the column flanges (P1) to the longitudinal web stiffener (P4) reducing at the same time load concentrating effects. Transverse web stiffeners (P3) are kept in all considered configurations, in order to reduce the risk of local buckling in the potentially plastic zone [1].

The third configuration has a reduced flange cross-section in the potentially plastic zone (resembling to dog-bone detail) [1, 4]. The pair of longitudinal web stiffeners from configuration 2 is kept to ensure about the same axial capacity all along the first-storey column height (see Fig. 3a). In configuration 3 the reduced width of the flanges in the potentially plastic zone is about 20–25% smaller than the flanges width in the rest of the first-storey column (see the values in Table 1, 2, 3 and 4).

In the fourth considered detail, the first configuration column cross-section was kept for the potentially plastic zone, whereas the rest of the column has larger flanges cross-sections in order to increase the buckling capacity of the first storey column [1]. The reduced flange width in the potentially plastic zone is also about 20–25% smaller than the flange width in the rest of the first storey column (see Fig. 3b).

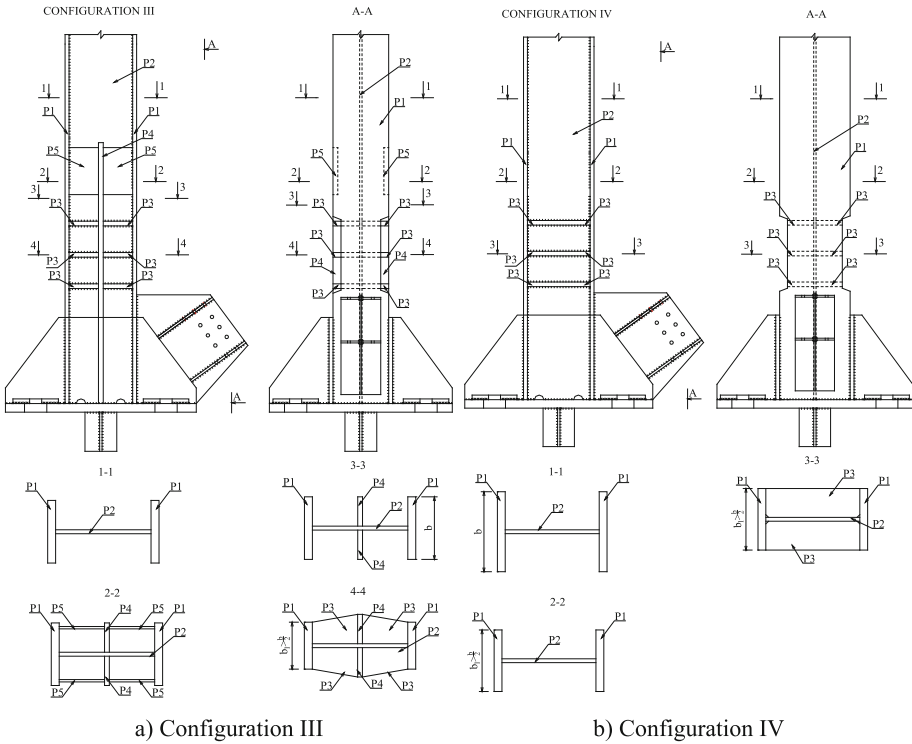


Fig. 3. Considered bottom column details.

In the models for the dynamic nonlinear analyses, the first story column was divided into several segments: the rigid zone at the bottom, the potentially plastic zone (with transverse web stiffeners) and the current zone. In case of configuration 2 and 3, the current zone was divided into two segments (with and without the plates P5). All these segments were modelled to plastify at their ends under the combined effects of bending moments and axial forces. For all considered configurations, plastic hinges were observed along the first story columns only in the potentially plastic zones.

The following tables contain the dimensions of the different steel plates in the considered configurations of the first storey columns.

Table 1. Frame DC06 - lateral column, dimensions of steel plates [mm].

Configuration	Steel plate of the first-story column			
	Flange current zone (P1)	Flange potentially plastic zone (P1)	Web (P2)	Longitudinal web stiffener (P4)
1	400 × 30	400 × 30	500 × 16	–
2	400 × 30	400 × 30	500 × 16	192 × 16
3	400 × 30	300 × 30	500 × 16	192 × 16
4	520 × 30	400 × 30	500 × 16	–

Table 2. Frame DC06 - central column, dimensions of steel plates [mm].

Configuration	Steel plate of the first-story column			
	Flange current zone (P1)	Flange potentially plastic zone (P1)	Web (P2)	Longitudinal web stiffener (P4)
1	400 × 25	400 × 25	450 × 14	–
2	400 × 25	400 × 25	450 × 14	193 × 14
3	400 × 25	300 × 25	450 × 14	193 × 14
4	500 × 25	400 × 25	450 × 14	–

Table 3. Frame 2 × 10 - lateral column, dimensions of steel plates [mm].

Configuration	Steel plate of the first-story column			
	Flange current zone (P1)	Flange potentially plastic zone (P1)	Web (P2)	Longitudinal web stiffener (P4)
1	600 × 40	600 × 40	750 × 22	–
2	600 × 40	600 × 40	750 × 22	290 × 20
3	600 × 40	450 × 40	750 × 22	290 × 20
4	750 × 40	600 × 40	750 × 22	–

Table 4. Frame 2 × 10 - central column dimensions of steel plates [mm].

Configuration	Steel plate of the first-story column			
	Flange current zone (P1)	Flange potentially plastic zone (P1)	Web (P2)	Longitudinal web stiffener (P4)
1	600 × 40	600 × 40	700 × 20	–
2	600 × 40	600 × 40	700 × 20	290 × 20
3	600 × 40	450 × 40	700 × 20	290 × 20
4	750 × 40	600 × 40	700 × 20	–

3 Results and Comments

3.1 Maximum Values for Bending Moments and Axial Forces at the Bottom of First Storey Columns

Configuration 3 (with reduced column flanges in the potentially plastic zones) leads to the smallest bending moment values at the bottom end of all first storey columns. The maximum bending moments, noticed during dynamic nonlinear analyses at the bottom end of the columns, in the other three considered configurations are nearly the same (see Fig. 4). Compared to these values, the maximum bending moments recorded for configuration 3 are 13–28% lower (see Fig. 4).

The maximum axial forces recorded in the first storey columns during dynamic nonlinear analyses are quite the same, for all considered configurations. The maximum differences are less than 1.4% (see the values in Table 5). It seems that the considered

constructive details do not have a significant influence on the maximum axial force values, noticed in the first storey columns.

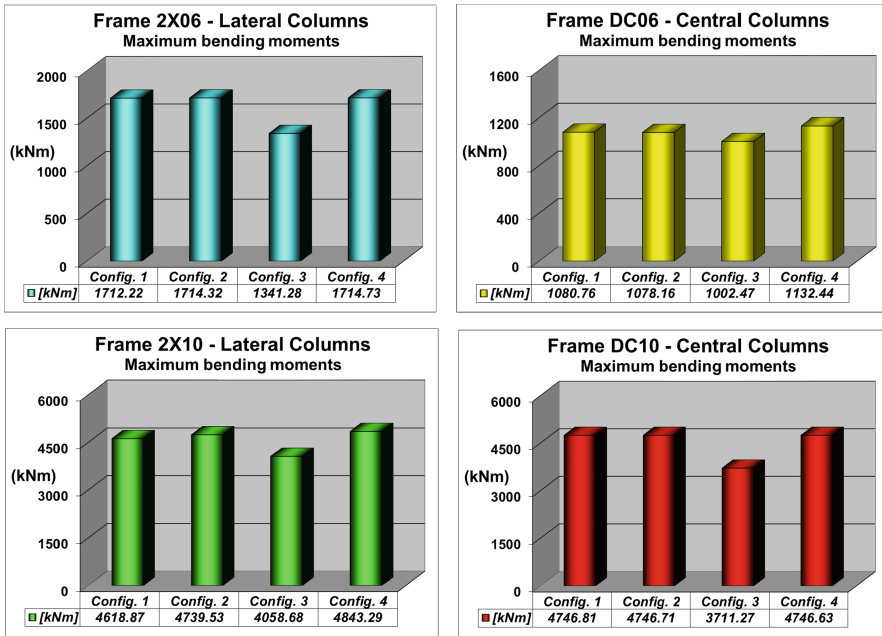


Fig. 4. Maximum bending moments at the bottom of first storey columns.

Table 5. Maximum axial force values recorded in first storey columns [kN].

Structure	Column	Configuration 1	Configuration 2	Configuration 3	Configuration 4
Frame DC06	Lateral	3012.40	3015.72	3010.99	3012.06
	Central	2756.96	2757.17	2755.37	2764.09
Frame 2X06	Lateral	3214.69	3215.07	3185.85	3211.26
	Central	922.30	924.15	935.47	926.25
Frame DC10	Lateral	7934.90	7949.39	7924.48	7935.13
	Central	4715.94	4728.99	4714.69	4717.32
Frame 2X10	Lateral	8436.77	8437.29	8438.25	8440.72
	Central	1652.92	1650.80	1677.21	1665.64

3.2 Inelastic Deformations in the Potentially Plastic Zones

During dynamic nonlinear analyses, the largest plastic hinge rotations in the potentially plastic zones of first storey columns were always noticed in case of configuration 3. The values of the maximum plastic hinge rotations at the bottom of the columns for the other considered configurations were in the same range. Compared to these values, the plastic rotations for configuration 3 were about 37–45% greater (see Fig. 5).

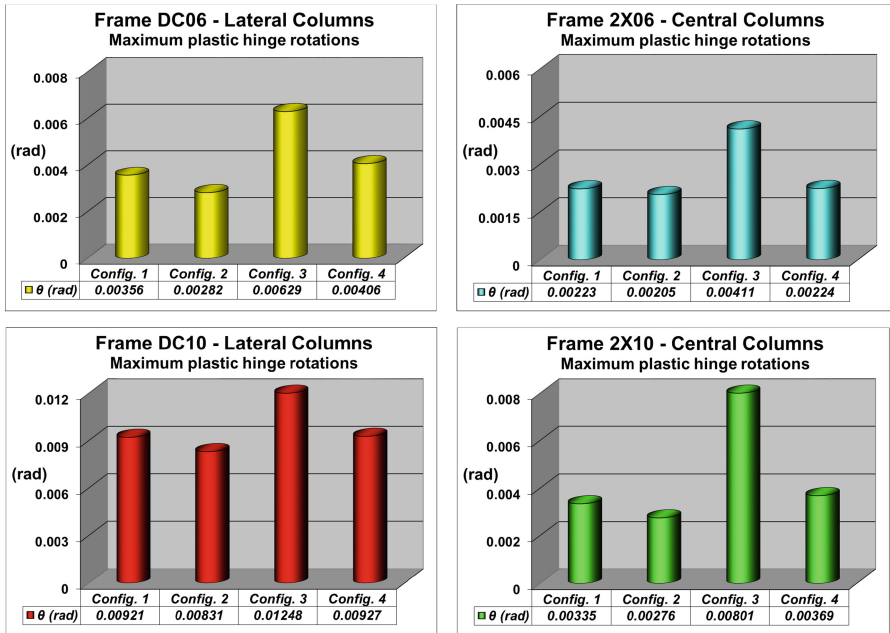


Fig. 5. Maximum plastic hinge rotations at the bottom of first storey columns.

3.3 Buckling Resistance of First Storey Columns

The buckling resistance of first storey columns was evaluated using relations (6.61), (6.62) and annex B from EN 1993-1-1:2005 [6].

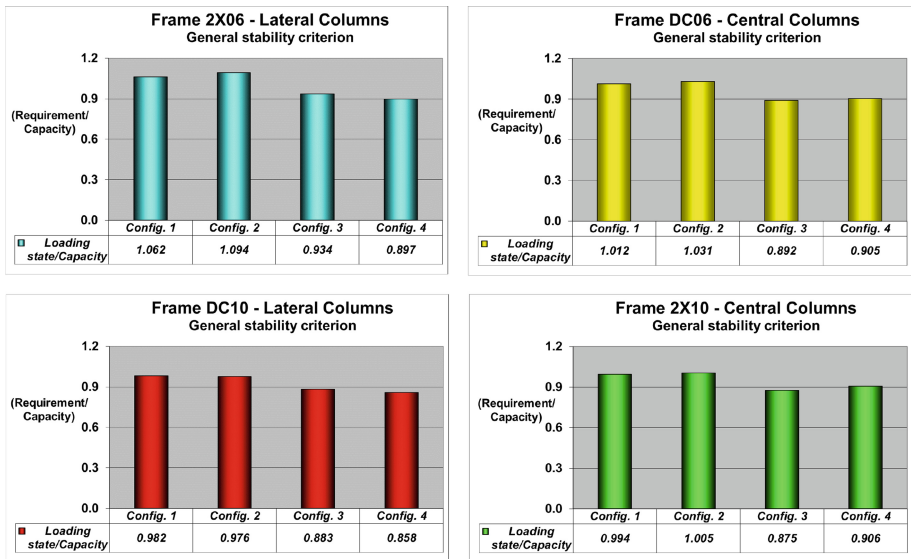


Fig. 6. Buckling resistance of first storey columns.

The most unfavourable loading states noticed during dynamic nonlinear analyses were taken into consideration (compressive axial forces combined with pairs of bending moments at the columns ends, recorded all at the same time during the same dynamic nonlinear analysis).

It can be observed from the graphics in Fig. 6, that configurations 3 and 4 provide the greatest buckling resistance for the situations, when inelastic deformations appear in the potentially plastic zones at the bottom of the columns. The general stability criterion [6] was always satisfied in case of configuration 3 and 4!

In case of configuration 1 and configuration 2, it can be noticed that the general stability check [6] is not satisfied in same situations! The general stability criterion was exceeded in same cases by up to 10% for configuration 1 and 2!

4 Conclusions

In configuration 3 and 4, the distribution of plastic deformations along the first storey columns is better controlled. The inelastic deformations along the first storey column are concentrated mainly in the column segments with reduced flanges width.

Compared to the other considered constructive details, configuration 3 leads to smaller bending moments and greater plastic hinges rotations near the bottom of the columns. The smaller bending moment values conduct to smaller anchor bolts for the columns.

Configurations 3 and 4 appear to be the safest from the point of view of ensuring the general stability of the first storey column, in the situation when plastic deformations occur in the potentially plastic zone near the column bottom.

These arguments lead to the conclusion that configuration 3 or 4 bottom end details should be used for first storey columns in concentrically braced frames subjected to severe seismic actions.

References

1. Köber H, Stefănescu B (2009) Potentially plastic zone details in columns in eccentrically braced frames. In: Proceedings of 6th STESSA conference - behaviour of steel structures in seismic areas. CRC Press/Balkema, Taylor & Francis Group, Philadelphia, pp 629–634
2. EN 1998-1:2004 (2004) Eurocode 8: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings
3. Ministry of Regional Development and Public Administration (2013) Seismic design code - Part 1 - Design rules for buildings, indicative P100-1/2013, Bucharest, Romania
4. Marcu R, Köber H (2021) Seismic behaviour of ten storeyed concentrically braced frames. In: IOP conference series: earth and environmental science, vol 664, no 1. IOP Publishing, Bristol, p 012083
5. Tsai KC, Li JW (1994) Drain2D+ a general purpose computer program for static and dynamic analyses of inelastic 2D structures. Taipei, Taiwan
6. EN 1993-1-1: 2005 (2005) Eurocode 3: Design of steel structures, Part 1-1: General rules and rules for buildings