Bulletin of the *Transilvania* University of Braşov • Vol. 9 (58) - 2016
Series I: Engineering Sciences

# PUSHOVER ANALYSIS ON STEEL-CONCRETE COMPOSITE FRAMES

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***Abstract:*** *The paper presents a case study performed on five types of similar steel-concrete composite frames, with different height: two, six, eight, ten and twelve levels. The composite frames are made with fully encased steel-concrete composite columns and steel beams. For every type of composite structure were design three types of composite columns, using different structural steel ratios: low, medium and high. To study the seismic performances of studied frames pushover analysis were performed on the chosen structures. Some conclusions extracted from performed analysis were drawn in the end of the paper.*

***Key words:*** *steel-concrete composite frames, fully encased steel-concrete columns, pushover analysis.*

## 1. Introduction

The paper proposes to study the seismic performances of steel-concrete composite frames, made with fully encased composite columns and steel beams, using pushover analysis: pushover curve, evolution of displacement of interstorey drift at all levels, rotation capacity. The chosen structures had the same floor plan, but different height: two, six, eight, ten and twelve levels. For each type of structure three types of steel-concrete composite columns were designed, using different steel ratios: low, medium and high.

## 2. Case Study

### 2.1. Numerical Model

The numerical model used for all analysis was developed in 2013 at Technical University of Cluj-Napoca [2], using five experimental programs taken from the international literature [3], [4], [5], [6], [7]. The model was validated supplementary in 2015 [1] using different experimental results [8]. The finite element used was a classic beam element for concrete plane frames with steel reinforcement and embedded beams, as shown in Figure 1. The total number of degrees of freedom corresponds to: one rotational and two translational degrees of freedom for each two nodes located at beam element ends and one relative translational degree of freedom for the node situated at the mid-length of the beam element, as shown in Figure 1.

The numerical laws used in all performed analysis for the materials are presented in Figure 2 for concrete and Figure 3 for steel.

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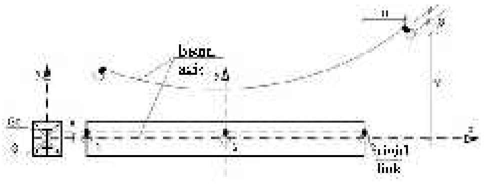

Fig. 1. *Numerical model*

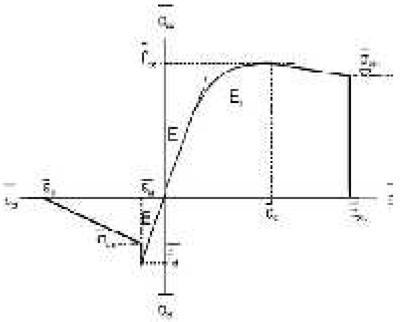

Fig. 2. *Material law for concrete*

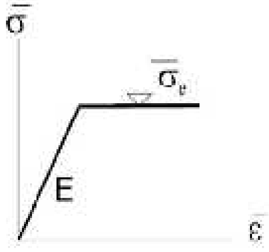

Fig. 3. *Material law for steel*

## 2.2. Steel-concrete Composite Frames

The composite frames chosen for the case study had two opening of 7.00 m in transversal direction and five openings of 6.00 m in longitudinal direction (see Figure 4). The structures have different height: two, six, eight, ten and twelve levels of 3.20 m/level (see Figure 5). The structures had two, six, eight, ten and twelve levels. For each structure three types of composite columns were designed, using different structural steel ratios: low, medium and high. The considered loads were the same for all levels: permanent load 6.50 kN/m$^2$ and live load 3.00 kN/m$^2$. The chosen seismic zone had a peak ground acceleration of 0.32 g and corner period of 1.60 s [9].

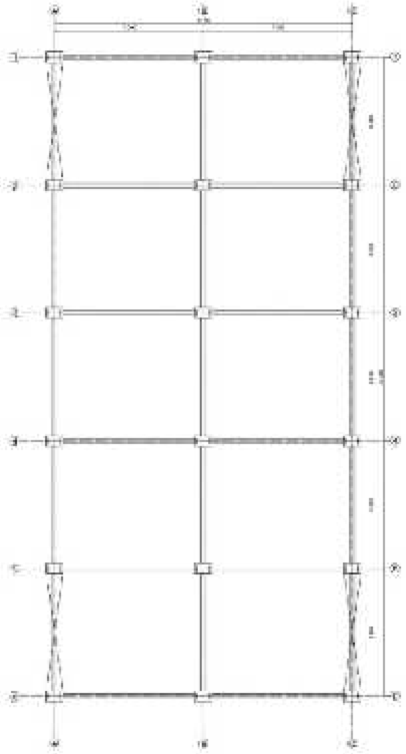

Fig. 4. *Floor level for all structures*

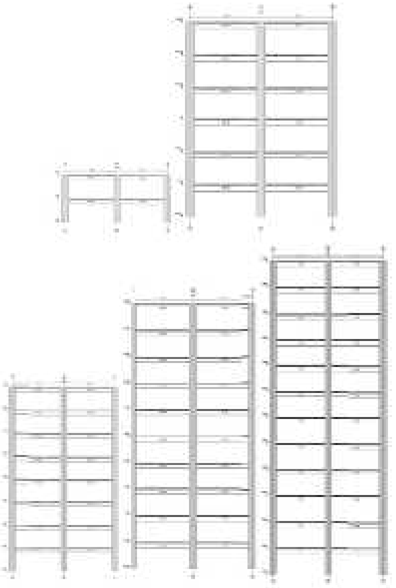

Fig. 5. *Transversal frames*

The materials chosen in the design of the structures were: C40/50 concrete class, S500 for reinforcing steel and S355 for structural steel. The beams resulted IPE 550 profile.

There are presented the cross-sections for all types of columns, the embedded profile, longitudinal reinforcement and the structural steel ratio (δ). The structures were noted as following: the first number represents the height of the structure, L is from level and the last number represents the structural steel ratio, 1 for low, 2 for medium and 3 for high. So, the structure called 6L2 means: structure with six levels and medium structural steel ratio. For the two and six storeys structures the columns had the same section at all levels. The columns of the eight level structures vary by height as follows: the first four storeys had one type of section and last four another type of section. The chosen sections for the columns had closed values of structural steel ratios. In the similar way two types of columns were designed for the ten level structures and three types for the twelve level structures. In the design stage, all recommendations from P100-1/2006 [2] were considered. The ductility class chosen was H, with a q behaviour factor equal to 6.5 for the transversal frames and 4 for the longitudinal ones.

*Cross-section properties for all structures* Table 1

| **Structure** | Column section [mmxmm] | Embedded profile | Longitudinal reinforcement | δ |
|---|---|---|---|---|
| 2L1 | 390x400 | HEA 200 | 16Ø16 | 0.288 |
| 2L2 | 350x360 | HEM 140 | 16Ø14 | 0.439 |
| 2L3 | 350x360 | 160x150x18x28 | 16Ø14 | 0.506 |
| 6L1 | 500x590 | HEA 400 | 14Ø22 | 0.320 |
| 6L2 | 490x510 | HEM 260 | 14Ø20 | 0.544 |
| 6L3 | 450x460 | 260x250x25x40 | 14Ø18 | 0.610 |
| 8L1 | 520x900 | HEAA 500 | 20Ø25 | 0.253 |
| | 520x670 | HEAA 400 | 20Ø20 | 0.291 |
| 8L2 | 520x770 | HEA 450 | 20Ø22 | 0.249 |
| | 520x570 | HEA 360 | 20Ø18 | 0.368 |
| 8L3 | 510x580 | HEM 340 | 16Ø22 | 0.582 |
| | 470x490 | HEM 260 | 16Ø18 | 0.550 |
| 10L1 | 500x980 | HEAA 700 | 20Ø25 | 0.315 |
| | 500x670 | HEAA 400 | 20Ø20 | 0.291 |
| 10L2 | 500x840 | HEA 650 | 20Ø22 | 0.415 |
| | 500x550 | HEA 360 | 20Ø18 | 0.389 |
| 10L3 | 510x680 | HEM 340 | 16Ø22 | 0.553 |
| | 470x490 | HEM 260 | 16Ø18 | 0.550 |
| 12L1 | 600x2000 | HEAA 1000 | 30Ø32 | 0.215 |
| | 500x1600 | HEAA 700 | 30Ø28 | 0.209 |
| | 500x670 | HEA 400 | 20Ø22 | 0.291 |
| 12L2 | 520x1650 | HEB 1000 | 26Ø28 | 0.361 |
| | 520x1200 | HEB 700 | 26Ø25 | 0.370 |
| | 500x550 | HEA 360 | 20Ø18 | 0.389 |
| 12L3 | 520x1150 | HE 900x466 | 22Ø25 | 0.559 |
| | 520x850 | HE 600x399 | 22Ø22 | 0.595 |
| | 470x490 | HEM 260 | 16Ø18 | 0.550 |

*Results of pushover analysis on studied frames* Table 2

| **Structure** | 0.008h/v | 2.50% | Concrete failure | 35 mrad corresponding force [kN] |
|---|---|---|---|---|
| | Fb [kN] | dc [m] | Fb [kN] | dc [m] |
| 2L1 | 676 | 0.046 | 804 | 0.112 |
| 2L2 | 610 | 0.049 | 804 | 0.121 |
| 2L3 | 616 | 0.050 | 891 | 0.131 |
| 6L1 | 744 | 0.112 | 1443 | 0.307 |
| 6L2 | 733 | 0.115 | 1267 | 0.314 |
| 6L3 | 660 | 0.116 | 1193 | 0.324 |
| 8L1 | 859 | 0.151 | 1531 | 0.375 |
| 8L2 | 773 | 0.155 | 1329 | 0.385 |
| 8L3 | 739 | 0.158 | 1252 | 0.411 |
| 10L1 | 724 | 0.155 | 1355 | 0.464 |
| 10L2 | 711 | 0.175 | 1330 | 0.482 |
| 10L3 | 753 | 0.195 | 1281 | 0.549 |
| 12L1 | 678 | 0.198 | 1400 | 0.541 |
| 12L2 | 672 | 0.213 | 1284 | 0.578 |
| 12L3 | 653 | 0.219 | 1221 | 0.623 |

To investigate the seismic performances of the studied frames pushover analysis were performed. The monitored parameters were: the global pushover curve, the evolution of interstorey drift at all levels, rotation capacity. Table 2 presents the displacement and corresponding force for 0.008h criteria [9], 2.5% drift limitation according to FEMA 356-2000 [10] and the values at concrete failure, when εcu2 reaches 3.5‰ value. The last column of Table 2 presents the corresponding force when θp reaches 35mrad value [9], where θp represents the rotation capacity of the plastic hinge. The 0.008 value corresponds to buildings having non-structural elements or brittle materials attached to the structure, according to the seismic norm P100/1-2006 [9]. As can be seen in Table 2 the two and six level structures did not achieve a minimum rotation capacity of the plastic hinge region of 35 mrad, necessary to design the structure in class H. From the eight level structures the analysed frames reached a superior rotation capacity of the plastic hinge region, 37 mrad for 8L1 structure to 69 mrad for 12L3 structure.

In Figures 6, 7, 8, 9 and 10 are presented the beams rotations at each level, at concrete failure, for all studied frames. For every type of structure are presented three values of achieved rotations at each node. The three values represent: with blue are presented the achieved rotations for frames with low structural steel ratio (2L1, 6L1, 8L1, 10L1 and 12L1), with red the achieved rotations for frames with medium structural steel ratio (2L2, 6L2, 8L2, 10L2 and 12L2) and with green the achieved rotations for frames with high structural steel ratio (2L3, 6L3, 8L3, 10L3 and 12L3).

For the two level frames (see Figure 6) the rotation increases with 10% by choosing a medium structural steel ratio and about 12% in case of high structural steel ratio.

The maximum rotations were obtained at first level, exterior column.

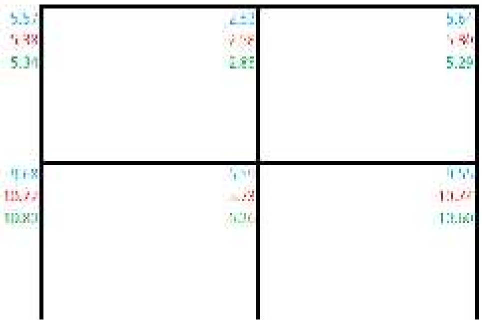

Fig. 6. *Rotations for two level structures [mrad]*

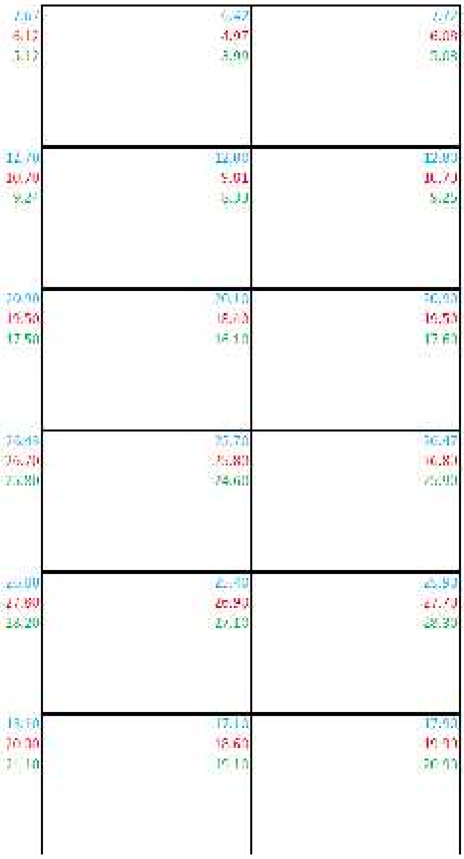

Fig. 7. *Rotations for six level structures [mrad]*

The rotations at second level, for the exterior column decreases with 4% for medium structural steel ration and 5% for high structural steel ratio. All comparison were made by comparing with frames with low structural steel ratio. The rotation besides interior column at second level increases with 2% for medium structural steel ratio and with 12% for high.

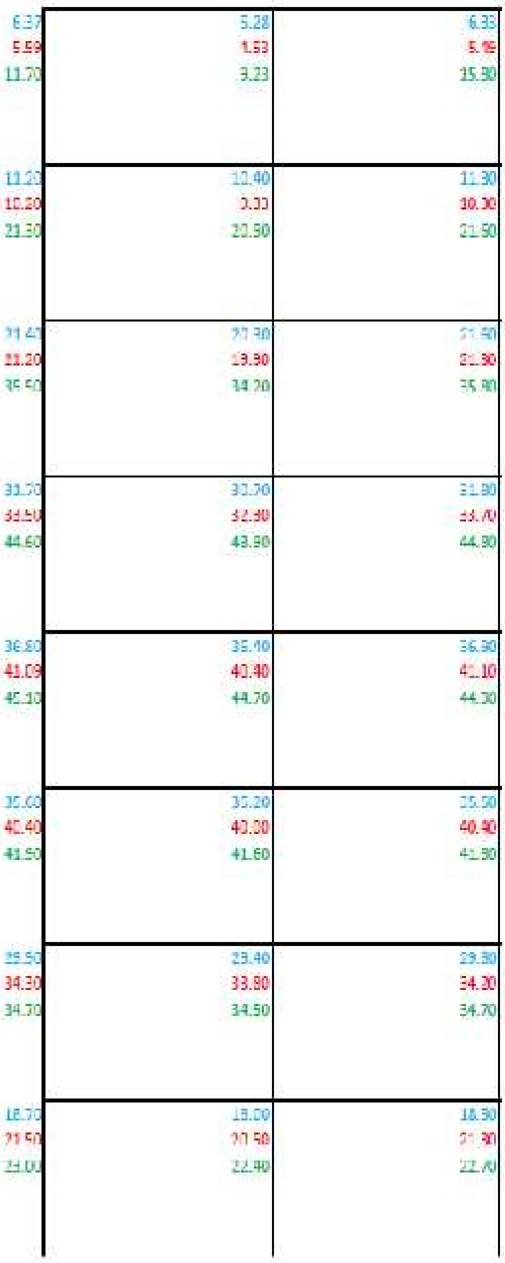

Fig. 8. *Rotations for eight level structures [mrad]*

For the six level frames (see Figure 7) the rotation increases with 5% by choosing a medium structural steel ratio and about 7% in case of high structural steel ratio.

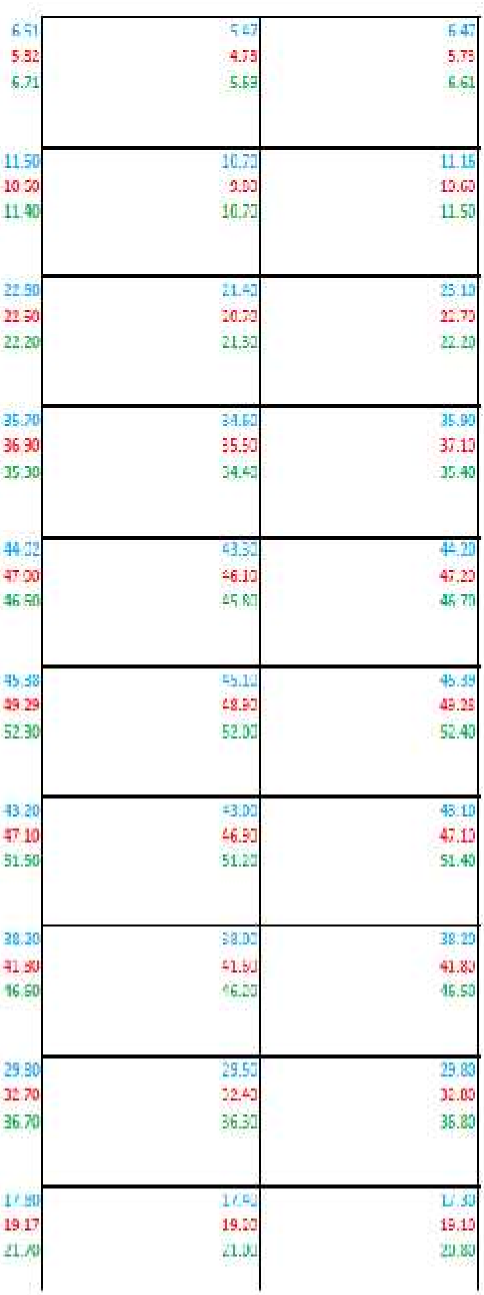

Fig. 9. *Rotations for ten level structures [mrad]*

The maximum rotations were obtained besides exterior column, at third level for 6L1 structure and second level for 6L2 and 6L3 structures. Same as for the two level frames, the rotations at last floor decrease with increasing the structural steel ratio, for both exterior and interior columns. The rotations increase for the first three levels and decrease for the last ones. The maximum increase achieved was at first floor with 10% by choosing a medium structural steel ratio and about 15% in case of high structural steel ratio.

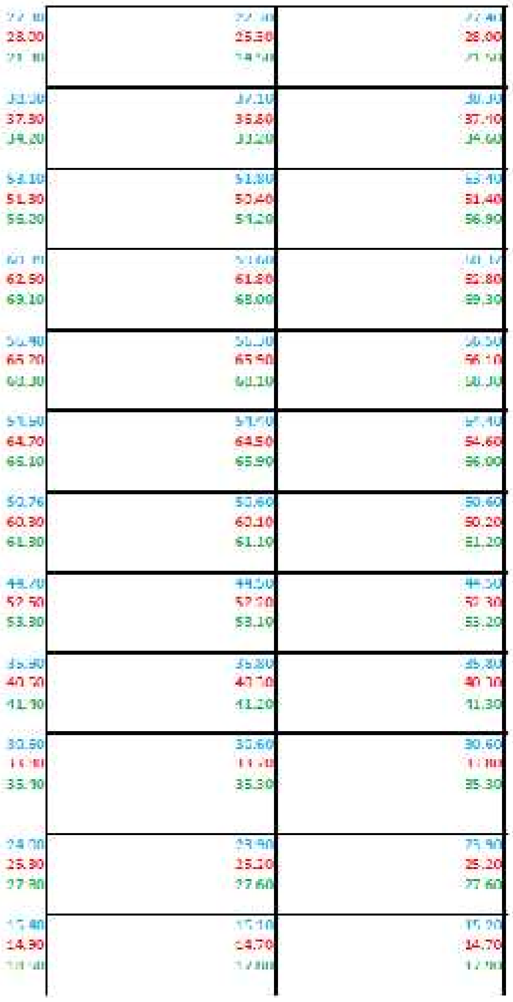

Fig. 10. *Rotations for twelve level structures [mrad]*

For the eight level frames (see Figure 8) the rotation increases with 11% by choosing a medium structural steel ratio and about 22% in case of high structural steel ratio. In contrast with two and six level structures, the rotation capacity increase while increasing the structural steel ratio from medium to high is more substantial for the eight level structures (10% in comparison with 1% for two level structures and 2% for six two level structures).

For the ten level frames (see Figure 9) the rotation increases with 8% by choosing a medium structural steel ratio and about 15% in case of high structural steel ratio. The maximum rotations were obtained besides exterior column, at fifth level. The maximum increase of rotation capacity was from low to medium structural steel ratio at the two first floors (approximately 21% for first level and 23% for the second one).

For the twelve level frames (see Figure 10) the rotation increases with 9% by choosing a medium structural steel ratio and about 15% in case of high structural steel ratio.

If we compare results it can be observed an important increase of maximum rotation capacity, due to increase ductility by contribution of structural steel in case of comparing columns with low and medium structural ratio and a more modest one when comparing columns with medium and high structural steel ratio, for small buildings (with two and six levels).

For taller buildings (with eight, ten and twelve levels) the increase of maximum rotation capacity, due to increase ductility by contribution of structural steel is more substantial in comparison with smaller buildings.

The values of the chosen structural steel ratios for all frames were as follows: for low structural steel ratio between 0.209÷0.32 (medium 0.276), for medium structural steel ratio between 0.349÷0.543 (medium 0.403) and for high between 0.506÷0.610 (medium value 0.562).

## 3. Conclusions

Some important conclusions can be drawn from the performed analysis regarding frame structures made with fully encased steel-concrete composite columns, using different types of structural steel ratios.

For smaller structures, up to approximately six-seven levels, it is recommended that the structures to be designed in medium class of ductility. The design for high ductility class requires very special attention in terms of achieving the required ductility for all structural elements.

Taller structures (with at least eight levels) presented sufficient rotation capacity to be designed for both medium and high ductility class. The choice made by the design engineer will take into account many aspects as: architectural restrictions, seismic zone, fire and corrosive protection, and of course perhaps the most important factor, the costs.

The increase of structural steel ratio in fully encased steel-concrete composite columns lead to major increase of structure ductility. This increase is more substantial when comparing low structural steel ratio with medium and more moderate when comparing medium structural steel ratio with high.

Due to many advantages, frames designed with fully encased steel-concrete composite columns can be utilized with great results in medium and high seismicity zones.

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