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Evaluation of behaviour factors of steel moment-resisting frames using standard pushover method

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Abstract

The structural performance limit (SPL) is an important parameter in the qualification of the behaviour factor (BF), because this factor is involved in the selection failure mode of the structure. EC8 does not indicate accurately criteria for define the failure mode or quantitative definition of the ultimate limit state corresponding to which values of BF frames are recommended. Moreover, the evaluation of the seismic strength of structures of buildings is usually carried out by the capacity design approach taking into account the nonlinear response of structure through the BF and in seismic design codes actual seismic load is reduced by this factor that takes into account several parameters including the capacity to dissipate energy, reserve strength and redundancy. Thus, the need for identifying BF in relation to its importance in the seismic design of frames seems indispensable. In this study, results of standard nonlinear static pushover analysis (NSPA) using SAP2000 program for steel moment-resisting frames (SMRFs) of different stories and bays were analyzed and compared and conclusions regard the effect of the structural performance limits and the capacity factor and other parameters on BF and its components are presented. It is found that the height and the capacity factor of frame have a profound effect on the BF and the value of this factor recommended by the EC8 is underestimated, mostly for low-rise frames.

Keywords: behaviour; ductility; redundancy; pushover; steel; frame; code.

1. Introduction

Currently, many seismic design codes, such as EC8 [1] and ASCE-7 [2], permit a reduction in design base shear force, taking advantage of the fact that the building structures possess significant reserve strength, redundancy,

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damping and capacity to dissipate energy, which are incorporated in structural design through a reduction factor called behaviour factor (q-factor) in EC8 and response modification factor (R-factor) in the American codes. EC8 specifies a single value of behaviour factor for all building structures of a given framing type, irrespective of building dimensions (storie height and width bay). This approach, however, under certain circumstances may lead to values of the behaviour factor not always appropriate as compared with the actual dissipative features of the building structure [3-5]. The main aim of this study is to investigate the performance of medium ductile regular SMRFs designed in accordance with the provisions given in the European Codes EC3 [6] and EC8. In this context reserve strength, redundancy and ductility reduction factors are evaluated.

2. Methodology for computation of behaviour factor

The formula proposed by American codes for determining the BF is given by :

$$R = R_{\Omega} R_{\mu} R_{\rho} \tag{1}$$

where: R_{Ω}, R_{μ}, and R_{ρ}, are the strength reduction factor, the ductility reduction factor, and the redundancy reduction factor, respectively. The evaluation of these factors can be obtained from the capacity curve (Fig. 1).

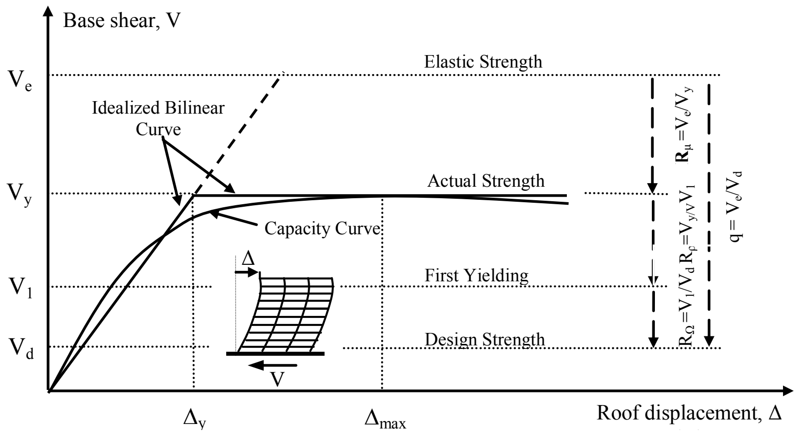

Fig. 1. capacity curve of a building structure (base shear versus roof displacement relationship).

In EC8 the BF for building structures is defined as follows:

$$q = q_0 \frac{\alpha_u}{\alpha_1} \tag{2}$$

where: q_0 is the basic value of the BF, α_u represents the horizontal force multiplier corresponding to the maximum lateral strength, and α_1 is the multiplier corresponding to the first yielding in the structure. From the comparison of equations (1) and (2), it follows that $\alpha_u/\alpha_1 = R_\rho$ and $q_0 = R_\mu R_\Omega$ [4].

3. Considered parameters

Several parameters, such as the number of stories and bays, the structural performance limits and the capacity factor "Column/Beam (a_i)", are considered to see how they affect the BF and its components. The capacity factor, α_i, is given by :

$$a_i = M_{RC,1,av} / M_{RB,av} \quad (3)$$

where: $M_{RC,1,av}$ is the average of the plastic moments of the columns of the first storey, and $M_{RB,av}$ is the average of the plastic moments of the beams of all the stories. As a reminder, the plastic axial capacity $N_{pl} = A.f_y$ is defined as the compression strength of the column at the yielding limit state (A and f_y are area and elastic limit stress of steel column respectively).

4. Numerical analysis

4.1. Frames characteristics

SMRFs buildings were designed according to the requirements of EC3 and EC8 for the medium ductility class (Fig. 2) with the following characteristics: number of stories n_s with values 3, 6, 9 and 12; number of bays n_b with values 3 and 6. So, each frame is designated by the notation: n_sSn_bB, where S = Storey, B = Bay (table 1 [7]). The design seismic action has been defined assuming soil class B, damping ratio ξ=5%, PGA=0.35g, and q-factor = 4.0.

Table 1. Characteristics of steel moment-resisting frames.

Storey level	i	α_i	Columns: HEB- Beams: IPE (N° of stories)
3-storey frame	1	1.30	240-330(1-3)
	2	1.60	260-330(1-3)
	3	1.90	280-330(1-3)
6-storey frame	1	1.60	280-360(1-4) + 260-330(5-6)
	2	1.97	300-360(1-4) + 280-330(5-6)
	3	2.27	320-360(1-4) + 300-330(5-6
9-storey frame	1	2.19	340-360(1) + 340-400(2-5) + 320-360(6-7) + 300-330(8-9)
	2	2.43	360-360(1) + 360-400(2-5) + 340-360(6-7) + 320-330(8-9)
	3	2.93	400-360(1) + 400-400(2-5) + 360-360(6-7) + 340-330(8-9)
12-storey frame	1	2.60	400-360(1) + 400-400(2-3) + 400-450(4-5) + 360-400(6-7) 340-400(8-9) + 340-360(10) + 340-330(11-12)
	2	3.00	450-360(1) + 450-400(2-3) + 450-450(4-5) + 400-450(6-7) 360-400(8-9) + 360-360(10) + 360-330(11-12)
	3	3 .63	500-360(1) + 500-400(2-3) + 500-450(4-5) + 450-450(6-7) 400-400(8-9) + 400-360(10-11) + 400-330(12)

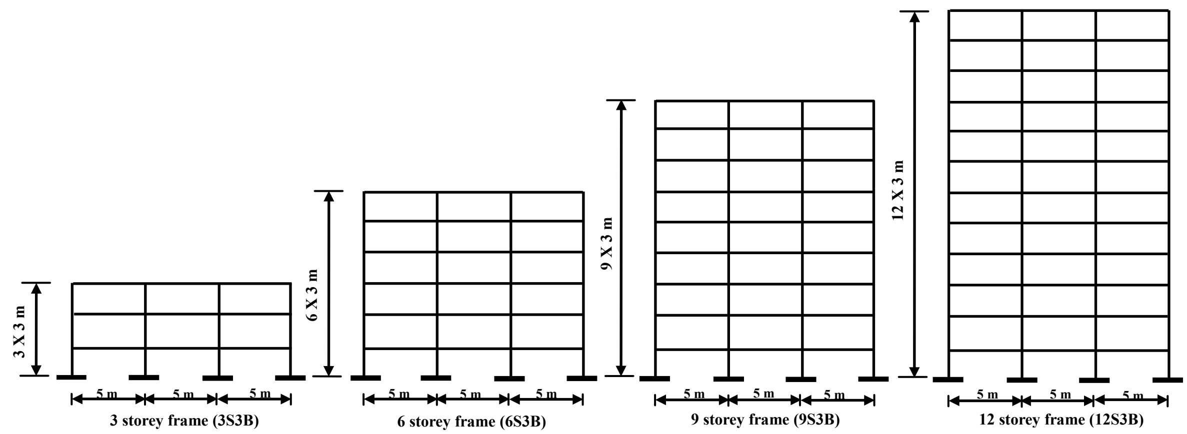

Fig. 2. geometrical configuration of SMRFs.

4.2. Modeling approach for nonlinear static analyses

NSPA was performed using the well-known SAP2000 computer code [8] in which is incorporated a two dimensional mathematical model of each frame where bilinear moment-rotation relationships are assigned [9, 10].

4.3. The performance limit states of the structure

The EC8 does not specify drift criteria to define the failure mode. Of this fact, three SPL are used in this study to define the failure mode. These are: performance limit, “PL1”, including an upper limit of the inter-story drift ratio “ID” equal to 3% of the inter-storey height “h_s”, performance limit, “PL2”, which is associated with the global ultimate capacity “GUC” of the frame (maximum base shear or ultimate plastic rotation at the base of the first-storey columns), and performance limit PL3 related to the first column to reach ultimate load capacity “ULC”.

5. Results and discussion

In figure 3 the SPL are observed. It can be seen that a small difference between the capacities curves whatever the value of the capacity factor (a_i), especially for 9-storey frame.

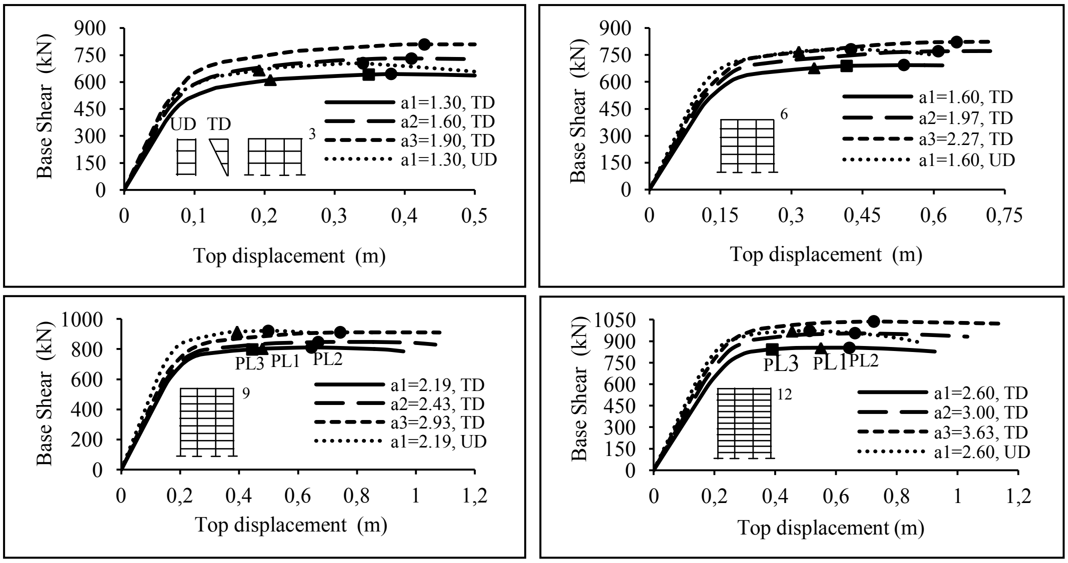

Fig. 3.Comparison between pushover curves of the studied frames for uniform (UD) and triangular (TD) load distributions.

In figure 4 the three factors (R_Ω, R_ρ and R_μ) are plotted. It can be noticed that:

1- The greatest values of R_Ω factor are obtained under uniform lateral force distribution regardless of the performance limit (PL1 or PL2). Moreover, the number of bays apparently had no effect on the R_Ω factor, but relative to the number of story the greatest values are obtained for low-rise frames.

2- The mean value of redundancy factor (R_ρ= 1.62) is greater than that of EC8 (α_u/α_1= 1.3). But, the highest values of R_μ factor are obtained for low-rise frames under the performance limit PL2. Also, those calculated with the triangular load are generally higher than those of the uniform load.

In Fig. 5, taking into account the two SPL (PL1 and PL2), the global behavior factors are plotted. It can be observed that the greatest values of q-factor are obtained for low-rise frames and are greatest than the EC8 value. The q-factor depends on the structural performance limits contrary to EC8. In figure 6 the q-factor and its components, obtained under the "Column/Beam" capacity factor, ai, are plotted. It can be observed that, although" the Column/Beam" capacity factor values of low-rise frame are smaller than those of high-rise frames, the q-factor values of low-rise frames are greater than those of high-rise frames.

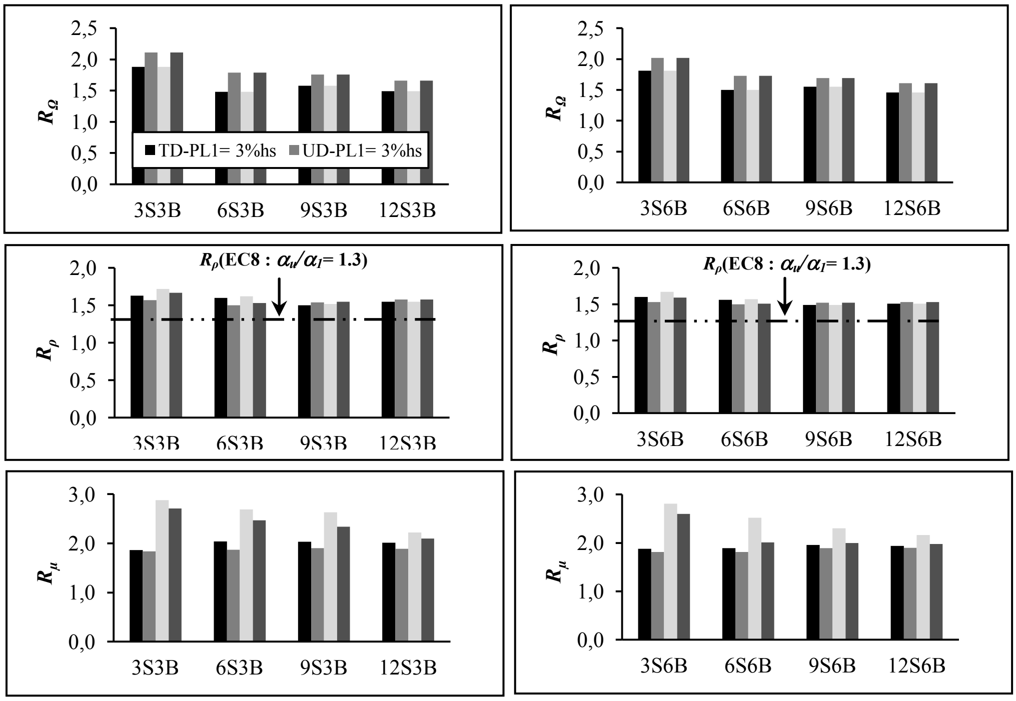

Fig. 4. comparison of behaviour factor components of the studied frames .

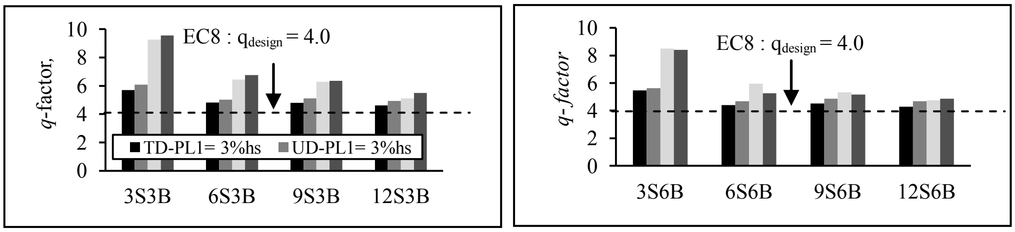

Fig. 5. Comparaison of behaviour factors of the studied frames.

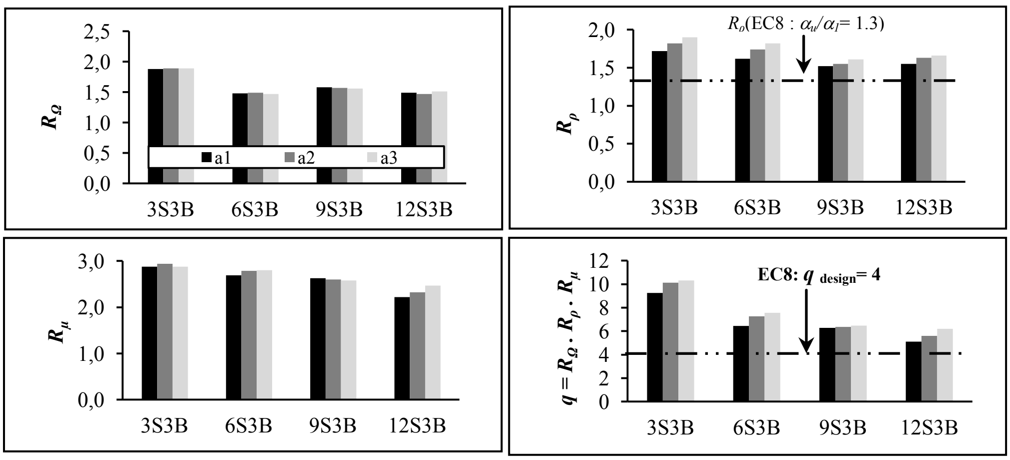

Fig. 6.comparison of behaviour factors and its components of the studied frames at PL2.

Figure 7a shows the variation of the q-factor as a function of "Column/Beam" capacity factor, a_i, and the ratio of the axial force N to the plastic axial capacity N_{pl} of the first column sections that reach their ultimate load capacity PL3. According to Fig. 7a, it is clear that the q-factor value decrease as the axial force increase. According to figure 7b, as the number of stories increases the axial force increases; it leads to limiting the ductility of frame. For this reason, a criterion related to the local ductility of column section ($N/N_{pl} < 0.40$) has been proposed. This limit is higher (1.6 times) than that proposed by EC3 which is 0.25.

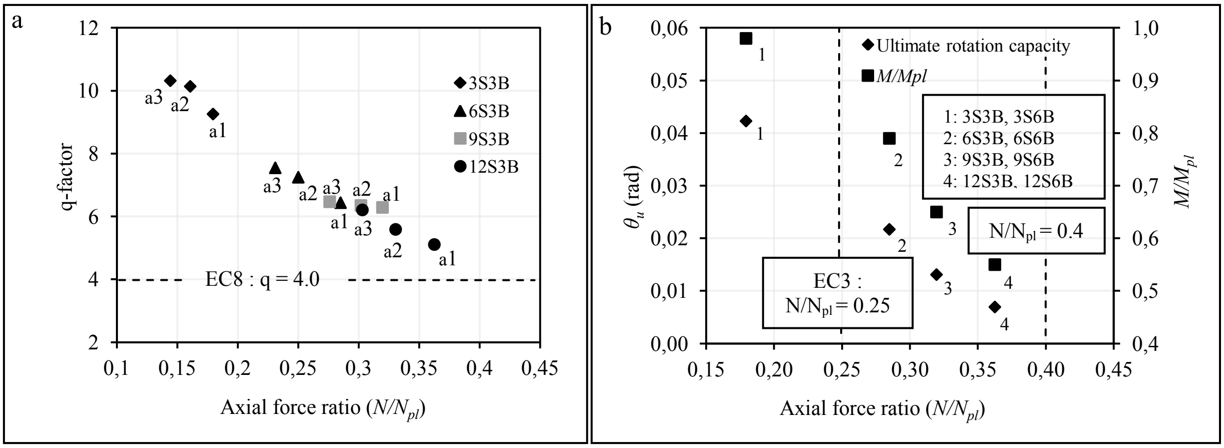

Fig. 7. effect of axial force ratio on: 1) behaviour factor; 2) ultimate plastic rotation, θ_u, and 3) moment capacity ratio, M/M_{pl}.

6. Conclusion

This paper evaluates the seismic q-factor and its components stipulated in EC8. SMRFs are considered. It is shown that: (1) the structural lateral capacity of the frames studied increases as the capacity factor increases and the structural performance limit is influenced by the increase in the number of stories causing an increase in the risk of instability; (2) Neither the number of bays nor the lateral load patterns influenced the reserve strength factor except the stories number; (3) Regardless of the number of stories and bays all the frames analyzed have similar redundancy whose average value is higher than that recommended by EC8; (4) The highest values of the ductility factor, calculate with the triangular load, are obtained for low-rise frames under the global ultimate capacity; (5) The greatest values of the q-factor are obtained for low-rise frames and are higher than those of EC8. Therefore a criterion related to the local ductility of column section ($N/N_{pl} < 0.40$) is proposed

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