Study on the Seismic Importance Factor in the Iranian Seismic Design Code

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SUMMARY:
According to the Iranian seismic code, structures are classified to four categories in view of their importance. The highest value of the importance coefficient (I) is assigned to the special structures which their damages subsequently cause a great number of casualties or their serviceability after a catastrophic event is necessary. For instance hospitals, power plants, etc are considered as very important structures and according to the code, (I) is equal to 1.4 for these types of structures. While the Iranian seismic code is strength based, it is not clear whether the designed structure behaves satisfactorily and the level of its real performance is desired.

In this study, the performance of 2 samples of important structures, in earthquake loads have been evaluated by performing linear and nonlinear static analysis. The results showed that the performance levels of the sample structures were not acceptable. In the simplest way, for the strength based design method of Iranian seismic code using the importance factor equal to the 1.6 has proposed.

Key words: Seismic codes, Strength base design, Performance base design, Importance factor

1. INTRODUCTION

Strength based design (SBD) codes are gradually replaced by performance based (PBD) codes but, the use of PBD codes are not mandatory yet and in many cases important structures are designed based on a SBD code. While the Iranian seismic code is strength based, it is not clear whether the designed structure behaves satisfactorily and the level of its real performance is desired. As it is mentioned before, this problem is more important when an engineer wants to design an important structure.

In general, static and linear method is used to analyze the structures in SBD procedure and elastic earthquake base shear is reduced according to the predefined Reduction factor (R), based on the typical inelastic response of the structural system (Ucar T., Duzgun M., 2007). Then, the calculated base shear is magnified by multiplying the Importance factor (I) to increase the base shear for designing the important structures. Although, there is no guarantee of high performance level in important structures by using SBD procedure, it is better to define and use a more reliable Importance factor for such structures to increase the probability of achieving the higher performance level. Iranian seismic design code (3rd ed., 2005) is strength based and Guideline for the Seismic Rehabilitation of Existing Buildings (2006) is used for performance assessment of existing buildings.

Elastic analysis gives good information of the elastic capacity of the structures and indicates where the first yielding occurs, but generally it cannot predict the failure mechanism of structures and redistribution of forces during the progressive yielding. The performance-based seismic design process explicitly evaluates how a building is likely to perform; given the potential hazard it is likely to experience, considering uncertainties inherent in the quantification of potential hazard and uncertainties in assessment of the actual building response (FEMA 356, 2000). In PBD approach it is necessary to determine the nonlinear behavior of structures. Both nonlinear time history and nonlinear static analysis may be used for this objective (Ucar T., Duzgun M., 2007). Nonlinear static analysis gives good estimation of the behavior of short and medium raise structures.

Figure 1-1 shows a flowchart that presents the key steps in the performance-based design process. It is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design, an assessment as to whether or not the design meets the performance objectives, and finally redesign and reassessment, if required, until the desired performance level is achieved (FEMA 445-B, 2006).

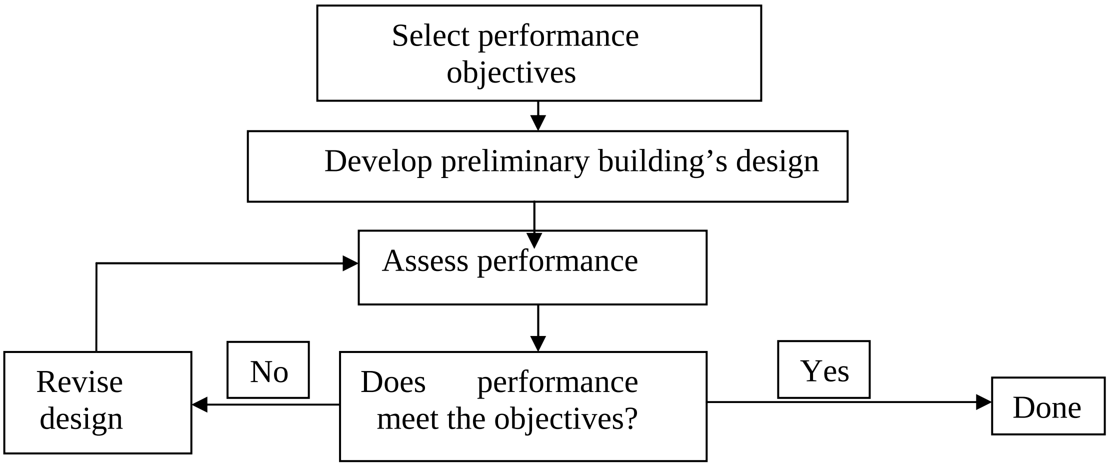


Figure1.1 Performance-based design flowchart (FEMA 445-B, 2006)

In this study, two symmetric buildings with 6 and 9 stories which have designed as important structures based on the SBD code of Iran (3rd ed., 2005), have been reanalyzed by the nonlinear procedures to realize their performance level. These analyses have been repeated several times to determine which value of the (I) factor in SDB method may leads the structures to achieve the desired performance level.

2. STRUCTURES

Sample structures are 6 and 9 stories high, special moment resisting steel frames in both direction of X and Y. These structures were analyzed and designed according to the SBD code of Iran (3rd ed., 2005). Table 2.1 shows the basic parameters for analysis and design of the structures. Fig. 2.1 illustrates the configuration of the frames.

Table2.1. Basic parameters for analysis and design of the structures

structure specifications and Code coefficients		**Specifications of the material**		**loadings**	
Height of story	3.2m	Yield stress (F_y)	2400kg/cm^2	Dead load	650kg/m^2
Length of spans	5m	Ultimate stress (F_u)	3700kg/cm^2	Live load	300 kg/m^2
Design base acceleration	A=0.35g	Maximum predictable stress (F_{ye})	2640kg/cm^2	Exterior walls	610kg/m
Type of site soil	175 m/s <Vs < 375 m/s				
Behavior coefficient	R =10*				
Importance factor	I=1.4				

* According to the Iranian seismic code the value of R have proposed for the ASD method

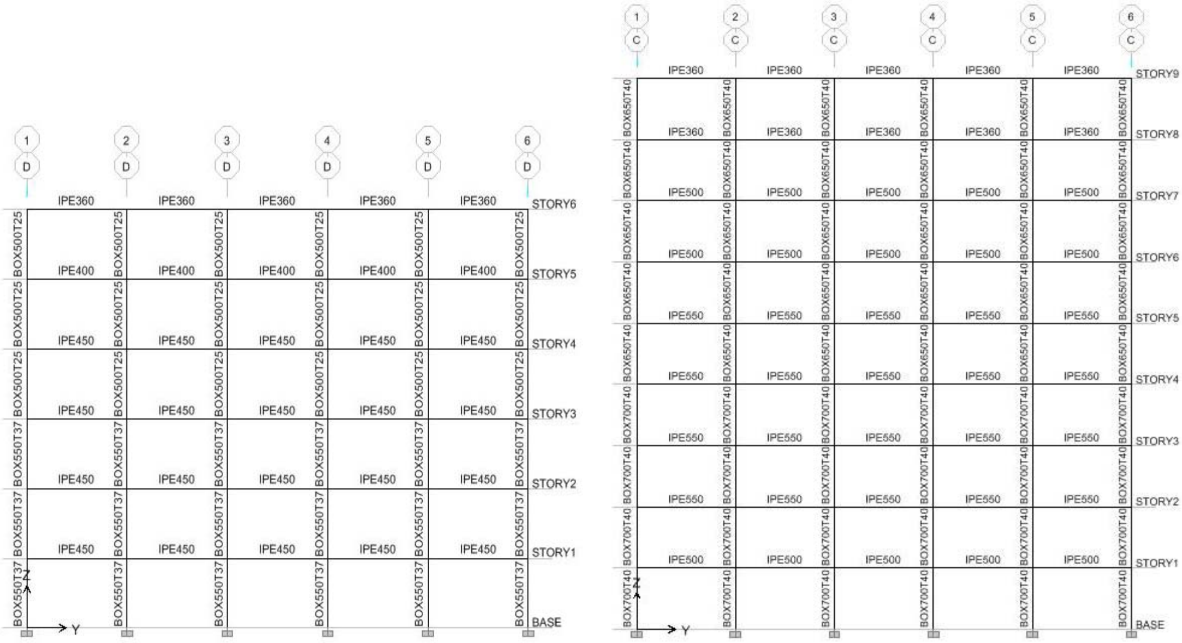


Figure 2.1. Typical frames of structures in both directions of X and Y

3. LINEAR STATIC ANALYSIS

According to the seismic design code of Iran, the structures with high seismic importance should be stay in the performance level of immediate occupancy with no significant damage against sever earthquakes. To control such an objective in a structure, it is necessary to control the drift angle in every story against the magnified earthquake load. The results of the drift control have illustrated in Fig. 3-1.

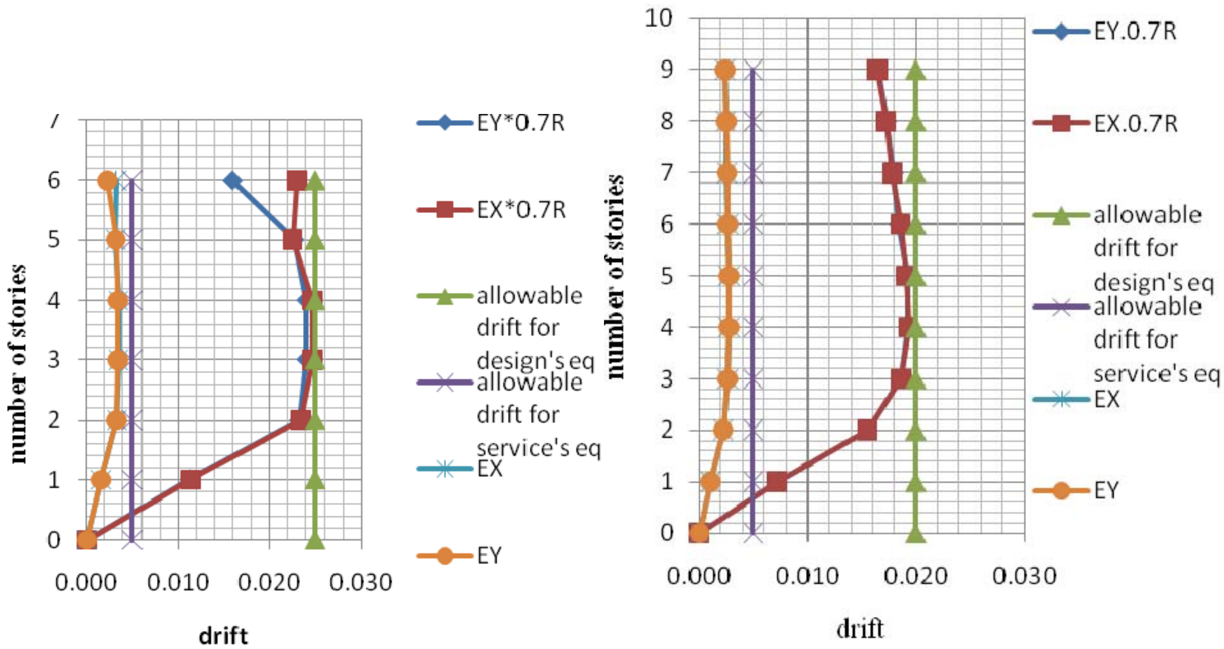


Figure 3.1- Drift angle of the structures against the service and the design level earthquakes

4. NONLINEAR STATIC ANALYSIS (PERFORMANCE LEVEL CONTROL)

The structures which introduced and designed in the previous section were modeled and analyzed by nonlinear static method (pushover). The performance level of these structures in the Hazard level 1 (earthquake with 10% probability of exceedence in 50 years) according to the Iranian code (2006) and FEMA (2000) performance level of B-1, have been assessed.

4.1. Assigning Plastic Hinges to the Elements

Two kinds of plastic hinges should be defined for the elements. Moment nonlinear hinge for beams and nonlinear interaction of axial force and moments hinges for columns.

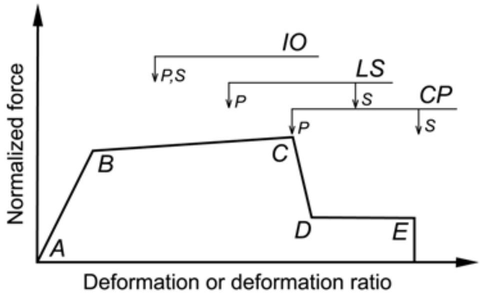


Figure 4.1- Behavior and performance limits in a typical hinge (FEMA 356, 2000)

Schematic illustrations of elastic-plastic behavior and performance limits in a typical hinge have shown in Fig. 4.1, also the acceptance criteria for deformation or deformation ratios for primary members (P) and secondary members (S) corresponding to the target Building Performance Levels of Collapse Prevention (CP), Life Safety (LS), and Immediate Occupancy (IO) have shown in Figure 4.1 [4]. Table 4.1 and Table 4.2 present the basic criteria for inelastic hinges of beams and columns.

Table4.1.Parametric modeling and acceptance criteria for compact beam element (FEMA 356 & ISREB, 2006)

Parametric modeling			Acceptance criteria		
a	b	c	IO	LS	CP
$9\theta_y$	$11\theta_y$	0.6	θ_y	$6\theta_y$	$8\theta_y$

Table 4.2. Parametric modeling and acceptance criteria for compact column element (FEMA 356 & ISREB, 2006)

Parametric modeling			Acceptance criteria		
a	b	c	CP	LS	IO
$10(1-1.7 P/P_{CL})\theta_y$	$10(1-1.7 P/P_{CL})\theta_y$	0.2	$10(1-1.7 P/P_{CL})\theta_y$	$7(1-1.7 P/P_{CL})\theta_y$	$0.25\theta_y$

4.2. Determination of Target Displacement

Target displacement should be calculated considering the efficient period. When the parametric modelings are defined to the software, the target displacements would be calculated. The calculated target displacements have shown in Table 4.3.

Table 4.3. Target displacement for both triangle and rectangular lateral loading

Type of lateral loading	Target displacement of x-direction(δ_{Tx})	Target displacement of y-direction(δ_{Ty})
Triangular	18.8 cm	18.8 Cm
Rectangular	15.4 cm	15.5 Cm

4.3. Study of the 6 storey Structure

The expected performance level is IO and no plastic deformation criteria corresponding to the IO level should occur before reaching the control point (roof) to the target displacement. It has demonstrated in Fig. 4.2 and 4.3 that the structure could not satisfy the expected performance levels.

As shown in the Table 4.4, it is clear that the plastic hinges have formed before the target displacement is reached.

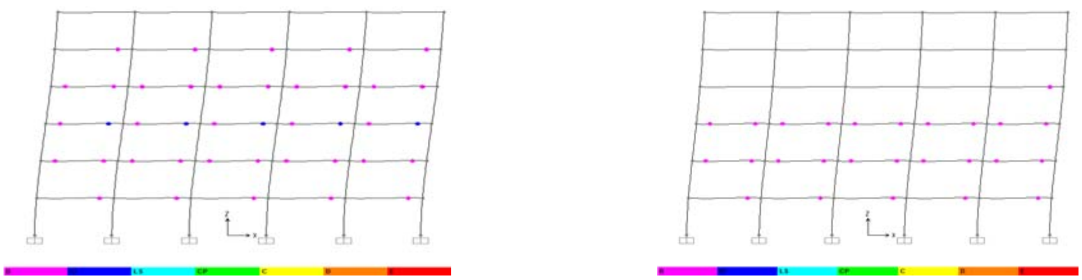
Table 4.4. The target displacements and the displacement due to first plastic hinge in the x and y direction

(a) x direction

The status of structure	**lateral loading**	Δx	**V_x(ton)**
Forming of the first plastic hinge	triangular	16.54cm	1769.7
IO performance level	triangular	18.8 cm	1851.038
Forming of the first plastic hinge	rectangular	17.2 cm	2449.87
IO performance level	rectangular	15.4 cm	2239.4

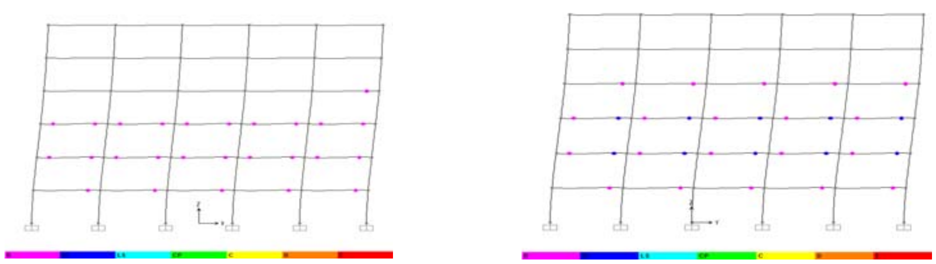
(b) y direction

The status of structure	**lateral loading**	Δ_Y	**V_y (ton)**
Forming of the first plastic hinge	triangular	18.4cm	1843.6
IO performance level	triangular	18.8cm	1854.9
Forming of the first plastic hinge	rectangular	15.5cm	2330.1
IO performance level	rectangular	15.5cm	2330.1



(a) x direction (b) y direction

Figure 4.2. Status of plastic hinges of the 6 storey structure at the end of the pushover analysis under the triangular loading



(a) x direction (b) y direction

Figure 4.3. Status of plastic hinges of the 6 storey structure at the end of the pushover analysis under the rectangular loading

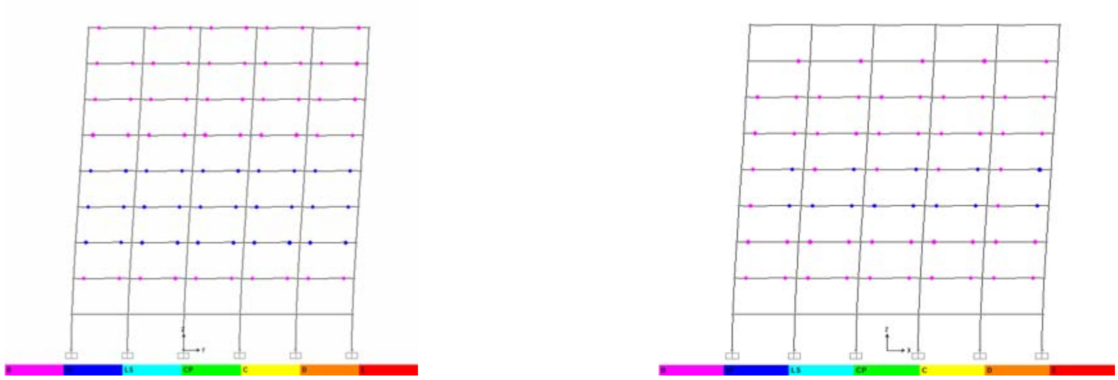
4.4. Study of the 9 storey Structure

Similar description to the previous section but for the 9 storey structure led to Fig. 4.4, 4.5 and Table 4.5. It is clear that the plastic hinges have formed before the target displacement is reached.

Table 4.5. The target displacements and the displacement due to first plastic hinge in the x and y direction

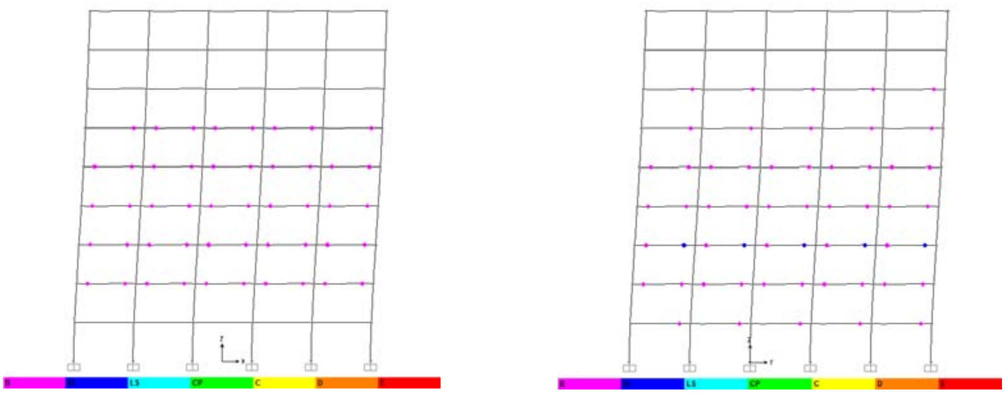
The status of structure	**lateral loading**	Δx	**V_x(ton)**
Forming of the first plastic hinge	triangular	23.8cm	2327.8
IO performance level	triangular	25.8 cm	2361.3
Forming of the first plastic hinge	rectangular	21.6 cm	3211
IO performance level	rectangular	20.6 cm	3128.5

The status of structure	**lateral loading**	Δ_Y	**V_y (ton)**
Forming of the first plastic hinge	triangular	23.96cm	2340.8
IO performance level	triangular	25.8cm	2367.5
Forming of the first plastic hinge	rectangular	20.1cm	3113.8
IO performance level	rectangular	20. 6cm	3120.8



(a) x direction (b) y direction

Figure 4.4. Status of plastic hinges of the 9 storey structure at the end of the pushover analysis under the triangular loading



(a) x direction (b) y direction

Figure 4.5. Status of plastic hinges of the 9 storey structure at the end of the pushover analysis under the rectangular loading

5. PROPOSING THE MODIFICATION IN IMPORTANCE FACTOR

It has shown that the important structures which have designed based on the SBD method, could not meet the defined criteria of the high performance. Another researches by Sadeghazar and Keyvani Boroujeni (2008) has shown the same results for the structures which have designed based on the SBD method with I=1.

To define a suitable Importance factor (I) for designing of an important structure to present the desired performance level, other values of (I) have selected and the above procedure have repeated several times. Finally, both of the 6 and 9 storey structures which have designed based on the Importance factor of I=1.6 present the IO performance in the nonlinear analysis. Table 5.1 and Fig. 5.1 illustrate the results of the nonlinear static analysis of the structure.

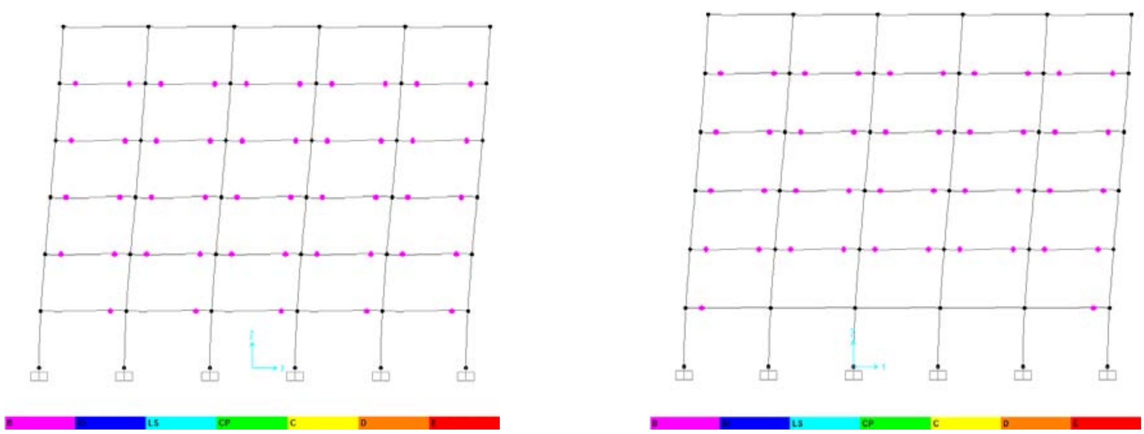
Table 5.1. The target displacements and the displacement due to first plastic hinge in the x-direction and y-direction associate with I=1.6 for 6 storey building

(a) x direction

The status of structure	**lateral loading**	Δx	**V_x(ton)**
Forming of the first plastic hinge	trangular	16.48cm	2546
IO performance level	trangular	15.63cm	2343.4
Forming of the first plastic hinge	rectangular	15.15 cm	2950
IO performance level	rectangular	12.34 cm	2867

(b) y direction

The status of structure	**lateral loading**	Δ_Y	**V_y (ton)**
Forming of the first plastic hinge	trangular	18.32cm	2495
IO performance level	trangular	15.64cm	2341
Forming of the first plastic hinge	rectangular	15.15cm	2921
IO performance level	rectangular	12.38cm	2870



(a) x direction (b) y direction

Figure 5.1. Status of plastic hinges of the 6 storey structure at the end of the pushover analysis under the triangular loading

Table 5.2. The target displacements and the displacement due to first plastic hinge in the x-direction and y-direction associate with I=1.6 for 9 story

(a) x direction

The status of structure	**lateral loading**	Δx	**V_x(ton)**
Forming of the first plastic hinge	triangular	24.4cm	3256.2
IO performance level	triangular	22 cm	3033.6
Forming of the first plastic hinge	rectangular	20.1 cm	3956.5
IO performance level	rectangular	17.8 cm	3876

(b) y direction

The status of structure	**lateral loading**	Δ_Y	**V_y (ton)**
Forming of the first plastic hinge	triangular	25cm	3156.4
IO performance level	triangular	22cm	3042
Forming of the first plastic hinge	rectangular	18.8cm	3975.6
IO performance level	rectangular	17.8cm	3855.9

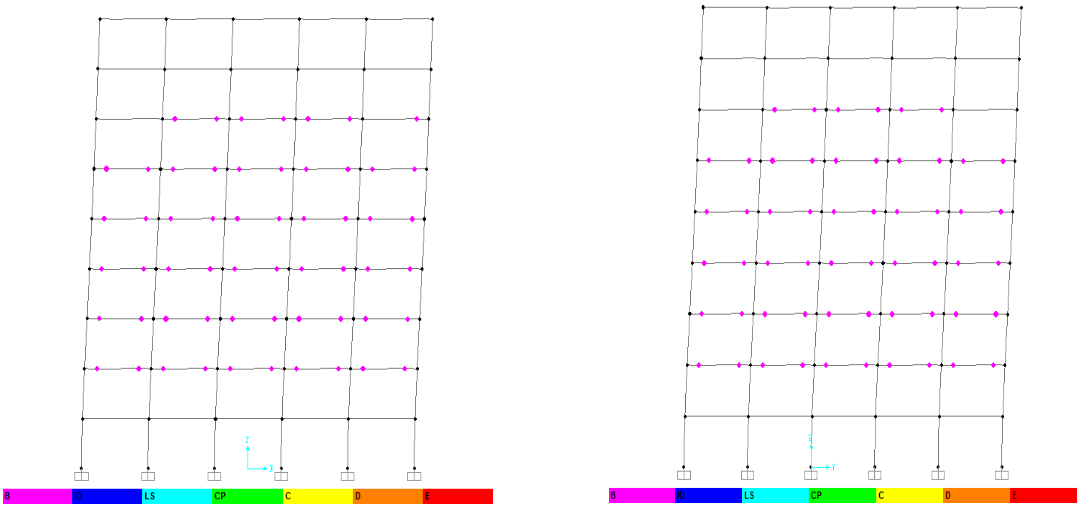


Figure 5.5. Status of plastic hinges of the 9 storey structure at the end of the pushover analysis under the triangular loading

6. CONCLUSION

In this study, the seismic performance of 2 steel moment resisting frame structures with 6 and 9 storeys, have evaluated by performing linear and nonlinear static analysis. The results showed that the performance levels of the sample structures were not acceptable when it is designed based on the SBD method with Importance Factor of I=1.4. To improve the expected performance level of the structures in SBD method, it is necessary to revise the Importance Factor in the Code. The results of this paper showed that the Importance Factor of I=1.6, led the structure to the desired performance level. So, for the strength based design method of Iranian seismic code the modification of the Importance Factor is recommended.

It should be mentioned that the method which has been used in this paper is a simplistic way to assess the Importance Factor of the Iranian seismic code, while it is assumed that the other factors in the Code such as R factor remains the same as before. The complementary researches are recommended to address the true aspects that may influence the value of the Importance Factor.

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