Journal of Civil Engineering Researchers

J-Researchers

JOURNAL OF CIVIL ENGINEERING RESEARCHERS

Investigating the behavior of two story steel structure reinforced by X-bracing using pushover analysis

Mehdi Tourchi Roudsari [a] *

[a] *Islamic Azad University, Chaloos, Iran*

Abstract

In most regulations, the reduction coefficient for seismic force is only dependent to the lateral bearing system. However, researches has shown that this coefficient is a function of many factors such as period and modal properties of structure, height, and especially the building plane shape. Regarding the complexities of nonlinear dynamic analysis methods, nowadays, the nonlinear static analysis named Pushover method has been developed in performance-based earthquake engineering as an appropriate practical tool. Considering the simplicity, performance speed, and ease of results interpretation compared to the dynamic analysis methods that are as the most accurate methods of seismic analysis, the nonlinear static analysis (pushover) methods are quickly developed and welcomed. These methods are very applicable in performance-based design as well as retrofitting of structures due to their less computational cost relative to nonlinear time history dynamic analysis methods. Thus, in this study, the way of applying the pushover nonlinear static analysis method in the seismic retrofitting of structures is taken into investigation. The results are presented in the form of capacity diagrams.

Keywords: Nonlinear Static Analysis, Pushover Analysis, Performance-Based Design, Seismic Retrofitting, X-Bracing

1. Introduction

In order to increase seismic resistance of concrete structure, steel bracings or shear walls are often used. It is common to use shear walls in RC frame structures, and steel bracings in steel frame structures. For several years, steel bracings are used in order to increase the lateral stiffness and shear strength of concrete frames. Over the past thirty years, a large number of concrete frames have been seriously suffered or destroyed caused by strong ground motions. For instance, the earthquakes of

* Corresponding author. e-mail: mehditourchi@gmail.com.

Mexico city in 195 and Turkey in 1999 can be mentioned [1].

In the case of braced RC frames, there is not any behavior factor provided in the regulations and guidelines and the use of this system is limited in conventional structures [2].

In the present paper, it is attempted to investigate the influence of x-bracing in steel frames having a number of 2 stories on their behavior factors. In order to study the behavior factor, it is used from nonlinear analysis of median braced steel structures by the help of ETABS software.

2. Introducing Specifications of the Project

2.1. The building general specifications

- 2-story steel building
- Building with therapeutic usage – very much seismicity – the soil of the project site is of type III (first edition of standard 2800)
- Lateral bearing system: having special centroid x-bracing in both *x* and *y* directions

2.2. Regulations and references used

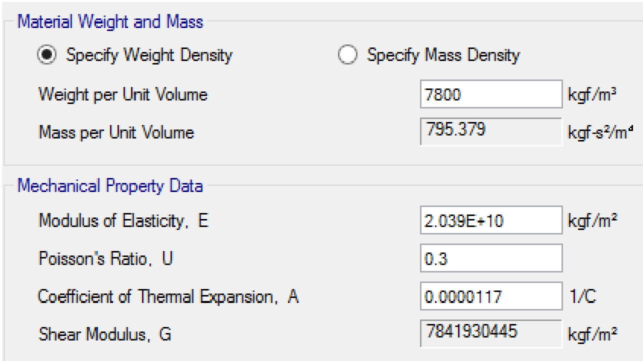
- Standard 2800 (Iranian standard for seismic resistant design of buildings), first edition, for design
- The sixth topic of Iranian Building National Regulations
- The tenth topic of Iranian Building National Regulations
- Retrofitting instructions (publication no. 360)
- Standard FEMA356

2.3. Software used

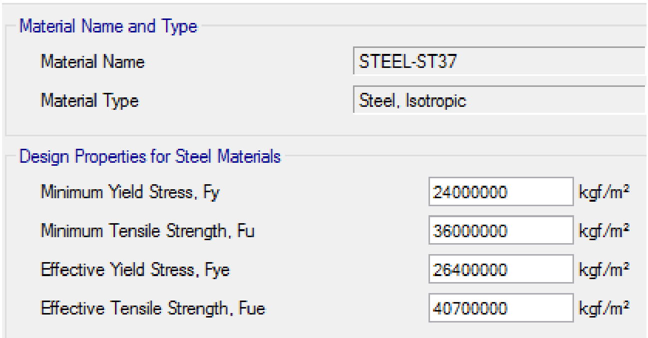
- ETABS V.13.1.1

2.4. Martials properties

Building steel of type ST37 with the following charachteristics has been defined in the software, as shown in Fig. 1.



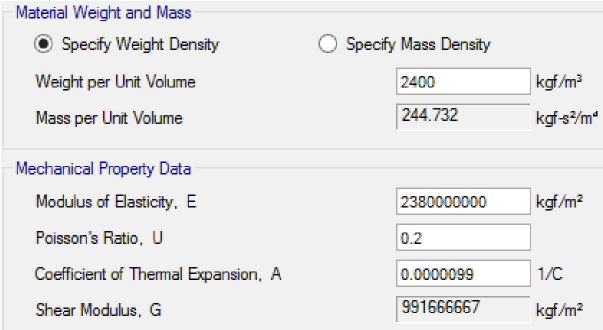
(a)



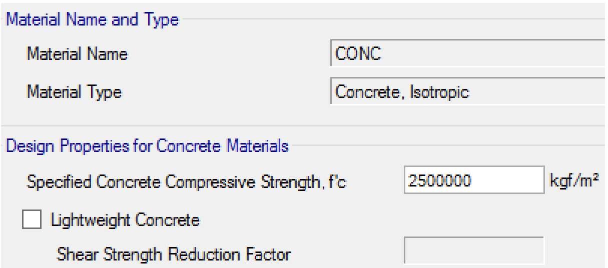
(b)

Fig 1. Characteristics of the steel materials

The foundation concrete defined for the software has a specific strength of 250 kg/cm^2 and the steel is of type AIII having the characteristics shown in figure 2.



(a)



(b)

Fig 2. Characteristics of the foundation concrete

3. Design of the structure

The structure is designed in accordance with the criteria of the tenth topic of Iranian Building National Regulations by using ETABS software and the members sections are specified, accordingly. In the designing procedure, it is used from standard UBC97-ASD in the software. In this section, the details of loading, sections geometrical characteristics, and a brief description of the configurations applied in the software and the regulation criteria are presented.

3.1. Design of the structure

3.1.1. Geometry of the building plan

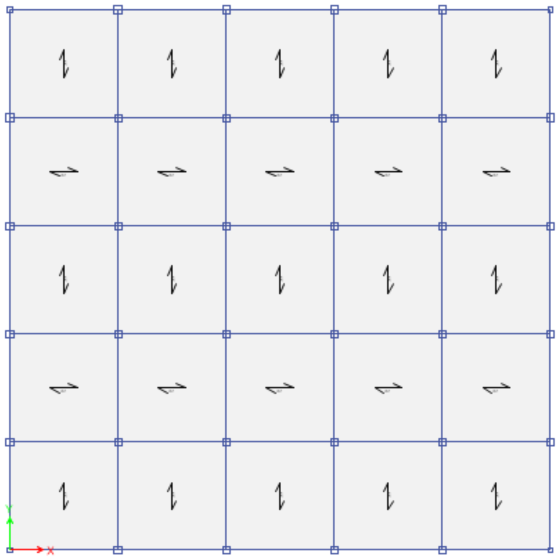


Fig 3. Type plan of stories

3.1.2. Loading

3.1.2.1. Gravity loading

The amounts of dead and live loadings are summarized in the following table:

Table 1. Gravity loading

unit	content	Type of load
Kg/m²	550	Dead – Floor floors load
Kg/m²	200	live load - Floor floors
Kg/m²	700	Dead load - Roof
Kg/m²	150	Live - Roof
Kg/m²	100	Equivalent blades load
Kg/m²	50	Installations Dead load

3.1.2.2. Earthquake lateral laoding

The seismic loading is applied on the building based on the fourth edition of the standard 2800.

The building main time period:

The main time period is obtained using the following empirical equation:

$$A = 0.3 \quad I = 1.2 \quad R_x = R_y = 5$$

soil type: $III \rightarrow T_0 = 0.15 \;\; , T_s = 0.7 \;\; , S = 1.75 \;\; , \;\; S_0 = 1.1$

$$T = \left(0.05H^{\frac{3}{4}}\right) = \left(0.05 \times 6.8^{\frac{3}{4}}\right) = 0.21 \; sec$$

$$B_1 = (S+1)\left(\frac{T_s}{T}\right) = (1.75+1) = 2.75$$

$$N = 1$$

$$B = B_1 N = 2.75$$

$$C = \frac{ABI}{R} = \frac{0.35 \times 2.75 \times 1.2}{5} = 0.21$$

3.1.3. Designing of the building and determining the characteristics pf profiles and the structure components:

It is used from I-shaped sections and box-sections for the beams and columns of the structure, respectively. The sections of the braces are also defined as doubled trough section.

In the following pages, the structure geometry as well as the type of the profile designed for each member are presented in figures 4(a) to 4(b)

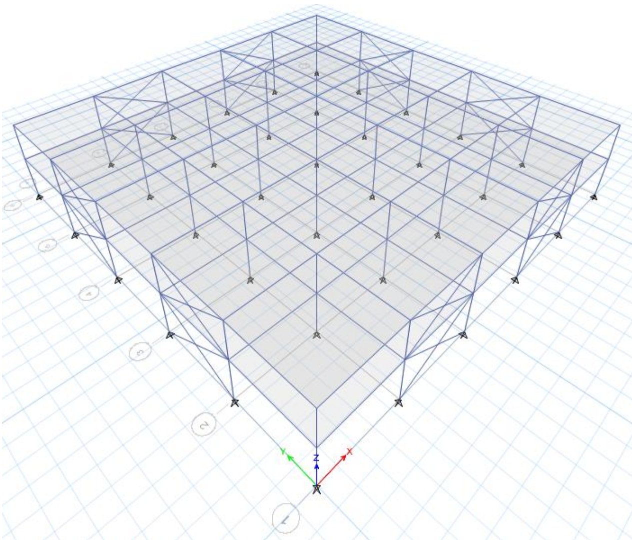


Fig 4. (a) Three-dimensional view of the structure

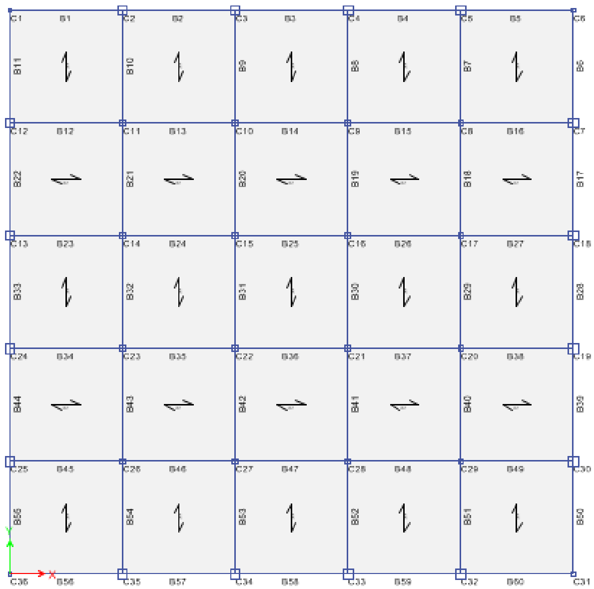


Fig 4. (b) Type plan of stories along with members' number

Fig 4. (c) Plan of columns' number

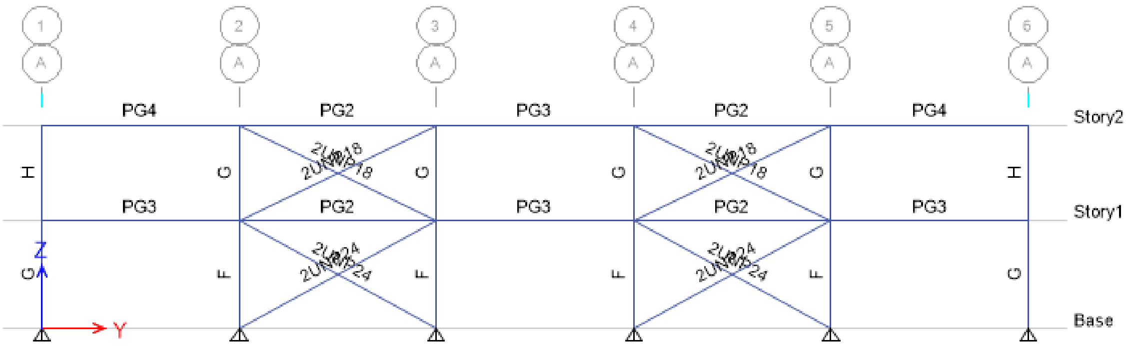


Fig 4. (d) View A

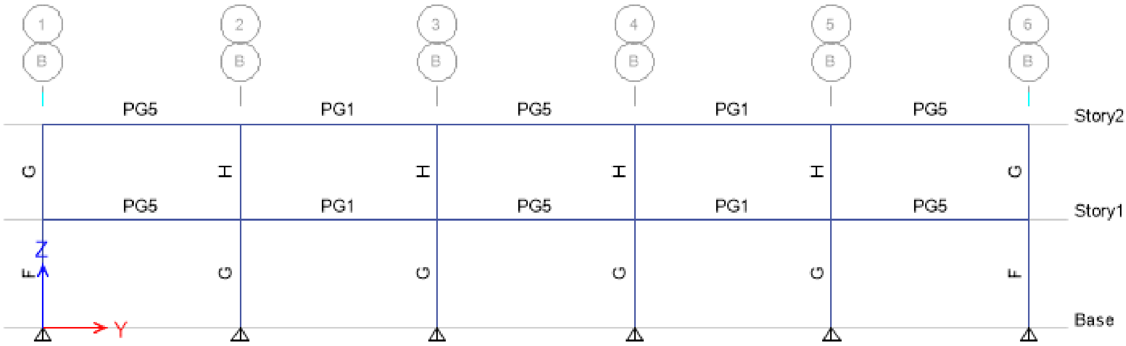


Fig 4. (e) View B

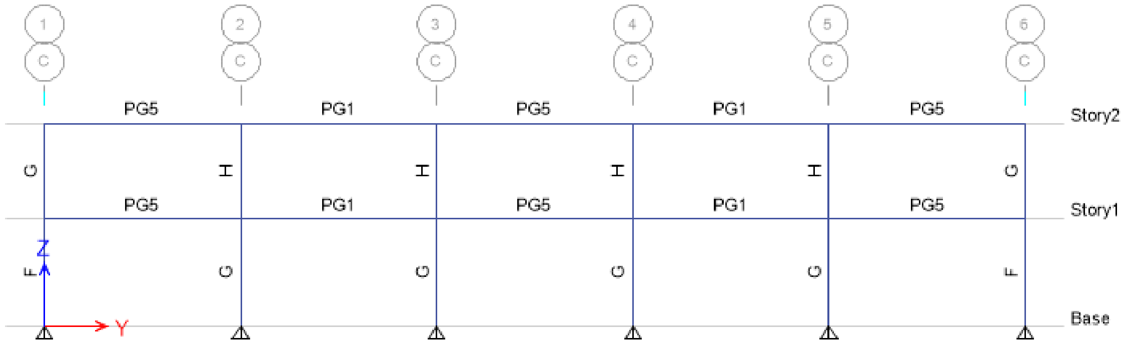


Fig 4. (f) View C

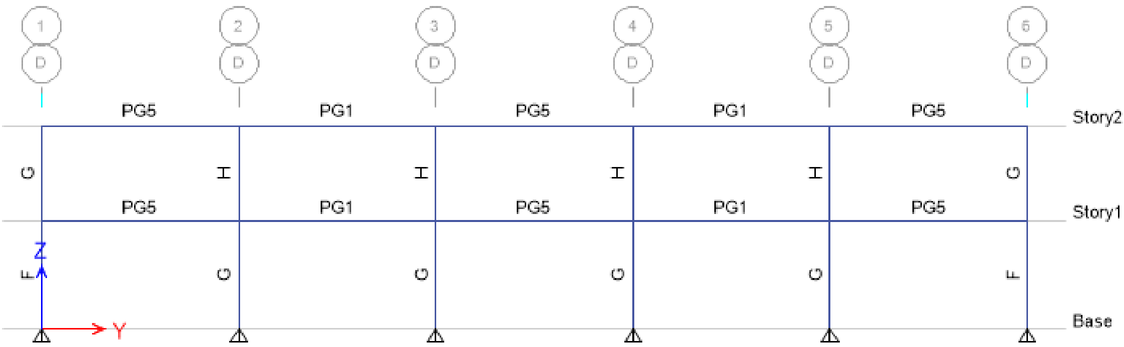


Fig 4. (g) View D

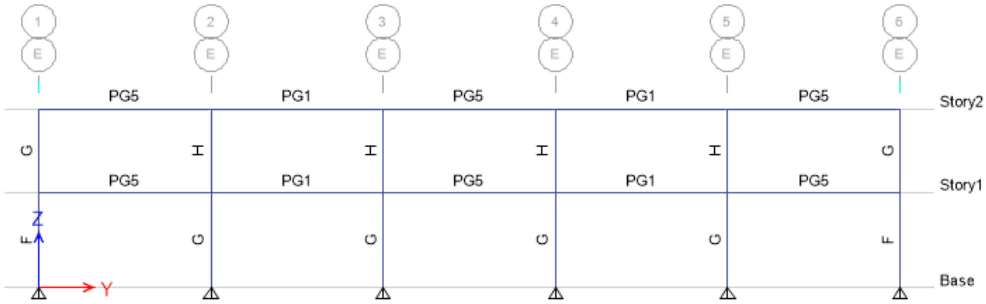


Fig 4. (h) View E

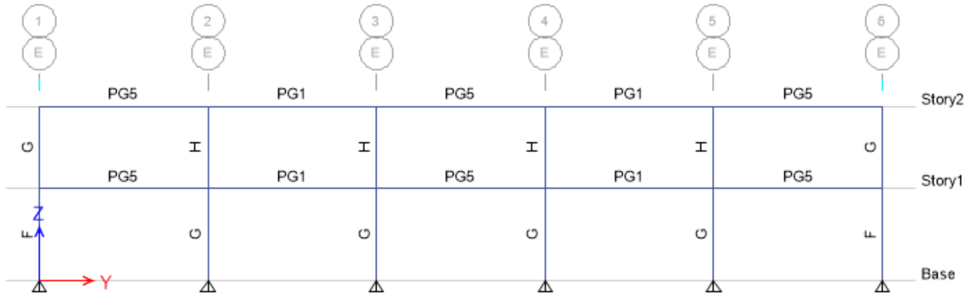


Fig 4. (i) View F

Table 2. Beams characteristics

section	h(cm)	b_f(cm)	t_f(cm)	t_w(cm)
PG1	43	25	2	1.5
PG2	35	18	2	1.5
PG3	32	16	2	1.5
PG4	20	10	0.85	0.56
PG5	16	8.2	0.74	0.5

Table 3. Columns characteristics

section	steel	b(cm)	t(cm)
F	ST37	25	1.5
G	ST37	20	1
H	ST37	15	1

Table 4. Bracings characteristics

section	steel	h(cm)	tf(cm)	ts(cm)
2UPN18	ST37	18	1.1	0.8
2UPN20	ST37	20	1.15	0.85

Table 5. Beams classification characteristics

Label	Section	Label	Section	Label	Section	Label	Section
B1	PG2	**B16**	PG3	**B31**	PG5	**B46**	PG3
B2	PG2	**B17**	PG2	**B32**	PG5	**B47**	PG3
B3	PG2	**B18**	PG1	**B33**	PG3	**B48**	PG3
B4	PG2	**B19**	PG1	**B34**	PG3	**B49**	PG3
B5	PG2	**B20**	PG1	**B35**	PG3	**B50**	PG4
B6	PG4	**B21**	PG1	**B36**	PG3	**B51**	PG5
B7	PG5	**B22**	PG2	**B37**	PG3	**B52**	PG5
B8	PG5	**B23**	PG3	**B38**	PG3	**B53**	PG5
B9	PG5	**B24**	PG3	**B39**	PG2	**B54**	PG5
B10	PG5	**B25**	PG3	**B40**	PG1	**B55**	PG4
B11	PG4	**B26**	PG3	**B41**	PG1	**B56**	PG2
B12	PG3	**B27**	PG3	**B42**	PG1	**B57**	PG2
B13	PG3	**B28**	PG3	**B43**	PG1	**B58**	PG2
B14	PG3	**B29**	PG5	**B44**	PG2	**B59**	PG2
B15	PG3	**B30**	PG5	**B45**	PG3	**B60**	PG2

Table 6. Columns classification characteristics

story	Brigade 1	Brigade 2	Brigade 3
STORY 1	A	F	D
STORY 2	B	F	D

Table 7. Bracings classification characteristics

story	section
STORY 1	2UPN18
STORY 2	2UPN20

4. Nonlinear elastic analysis (Pushover)

4.1. Selecting the loading pattern

According to article 3-4-3-1-3 of publication no 360 (first edition, 2003), the distribution of the lateral load on the structure model must be as similar as possible to what happens during earthquake and must create the critical modes of deformation and internal forces in the members. for this reason, at least two types of lateral loadings must be exerted on the structure:

(a) Distribution type I

Distribution proportional to the first mode shape of vibration in the intended direction

(b) Distribution type II

Uniform distribution, in which lateral load is calculated proportional to the weight of each floor

Determining the initial objective displacement:

$$\Delta_T = C_0 C_1 C_2 S_a \left(\frac{T_e}{2\pi}\right)^2 g \xrightarrow{T_e=T}$$

Loading type I:

$C_0=1.3$

Loading type II:

$C_0=1.2$

$C_1=1$

$C_2=1$

$T=0.33$ S

$S_a=0.9625$

$$\Delta_T = C_0 C_1 C_2 S_a \left(\frac{T_e}{2\pi}\right)^2 g \xrightarrow{T_e=T} \Delta_T = 1.3 \times 1 \times 1 \times 0.9625 \times \left(\frac{0.33}{2\pi}\right)^2 \times 981 = 3.4cm$$

Table 8. loading pattern

Objective displacement ΔT	Type of loading
5.1	First mode
4.7	Uniform

4.2. Determining the characteristics of plastic joints

(a) Column Joints

The definition of column joints characteristic is done automatically by the software

(b) Beams Joints

The flexural behaviour of beams is controlled by deformation. All beams in the direction of the moment-resisting frame meet the criteria of part (a) of table (5-3). Is worth noting that the amounts of yielding rotation and yielding moment are calculated automatically by the software, in accordance with the relations of standard FEMA356, which is based on the criteria of instructions for retrofitting of publication no. 360.

(c) Bracings Joints

According to article 5-5-2-4-1 of the instruction for retrofitting (publication no. 360), axial tension and compression in the bracings are of deformation controlled behaviour. Therefore, plastic joints for them are calculated based on the criteria of table (5-4).

4.3. Objective displacements obtained from the software

Table 9. displacements

Objective displacement ΔT	Type of loading
15	First mode
13.4	Uniform

PUSHL 1	1.1x(QD+QL)+EXT
PUSHL2	1.1x(QD+QL)-EXT
PUSHL 5	1.1x(QD+QL)+EXU
PUSHL 6	1.1x(QD+QL)-EXU
PUSHL 9	0.9QD+EXT
PUSHL 10	0.9QD-EXT
PUSHL 13	0.9QD+EXU
PUSHL 14	0.9QD-EXU

4.4. The amount of seismic demand using nonlinear static method

4.4.1. Displacement of stories:

The displacements of stories subjected to the nonlinear static loading are calculated at the final step and presented in the following table:

Nonlinear static loading in *x* direction:

Table 10. Displacement of stories subjected to nonlinear static loading at the final step

STORY	PUSHL1	PUSHL2	PUSHL5	PUSHL6	PUSHL9	PUSHL10	PUSHL13	PUSHL14
2	11.98	-11.99	10.53	-10.78	11.99	-11.99	10.54	-10.54
1	6.53	-6.53	5.93	-6.07	6.53	-6.53	5.93	-5.93

Table 11. Relative displacement of stories (cm)

STORY	PUSHL1	PUSHL2	PUSHL5	PUSHL6	PUSHL9	PUSHL10	PUSHL13	PUSHL14
2	5.45	-5.46	4.6	-4.71	5.46	-5.46	4.61	-4.61
1	6.53	-6.53	5.93	-6.07	6.53	-6.53	5.93	-5.93

4.4.2. Relative displacement of stories

4.4.3. Shear and forces exerted to stories

The shear forces exerted on the stories subjected to the nonlinear static load are calculated at the final step and presented in the following table:

Table 12. The shear and forces exerted on the stories (TONf)

STORY	PUSHL1	PUSHL2	PUSHL5	PUSHL6	PUSHL9	PUSHL10	PUSHL13	PUSHL14
2	-256.14	249.06	-174.38	174.01	-249.14	249.14	-173.91	-173.91
1	-510.86	496.73	-348.77	348.02	-496.89	496.89	-347.82	-347.82

4.4.4. Location of plastic joints

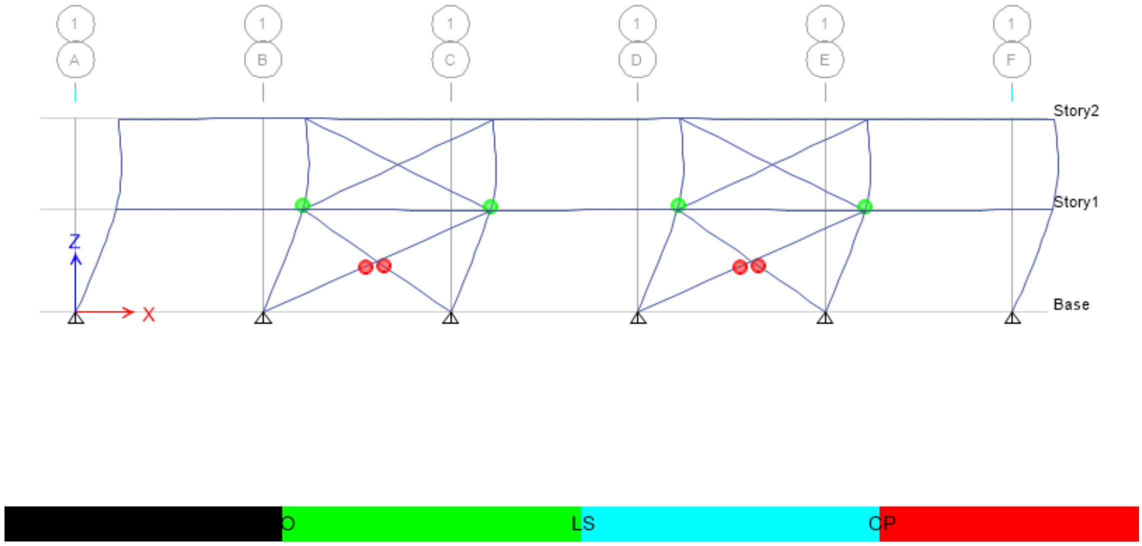


Fig 5. (a) Location of plastic joints along axis 1 – PUSHL1

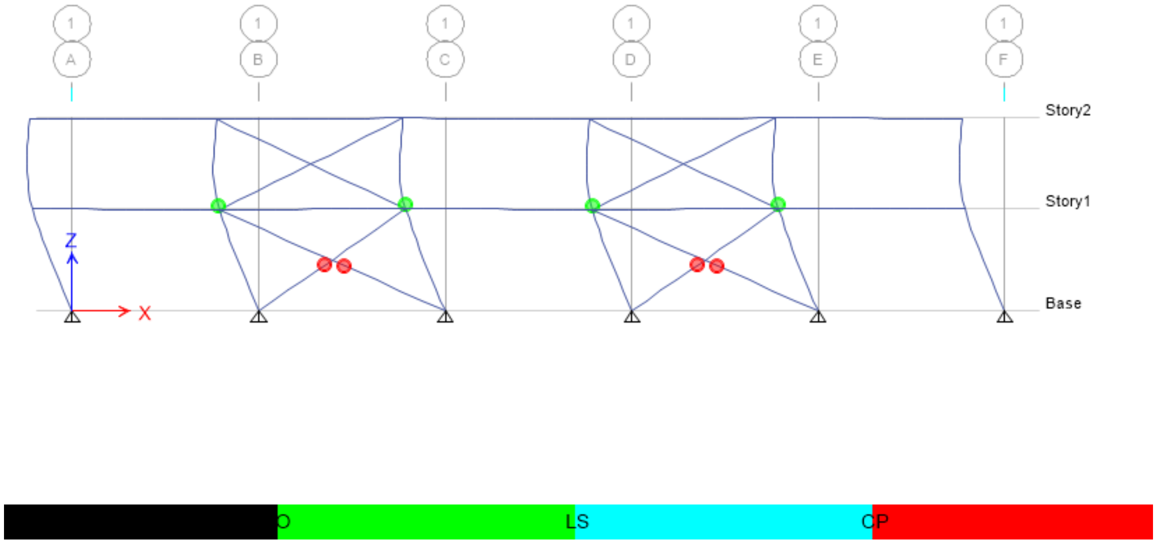


Fig 5. (b) Location of plastic joints along axis 1 – PUSHL2

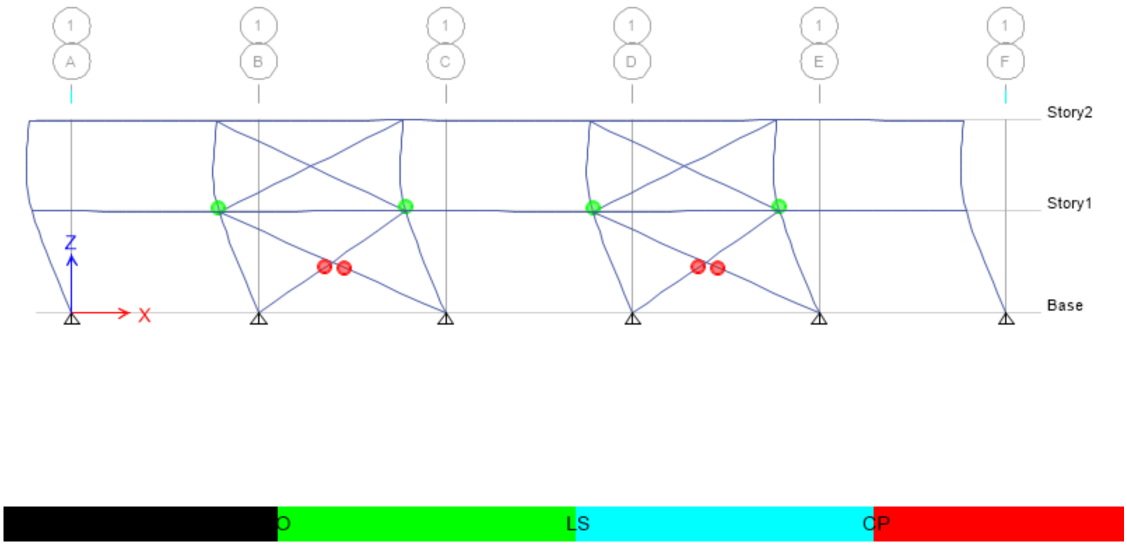


Fig 5. (c) Location of plastic joints along axis 1 – PUSHMODE-E1

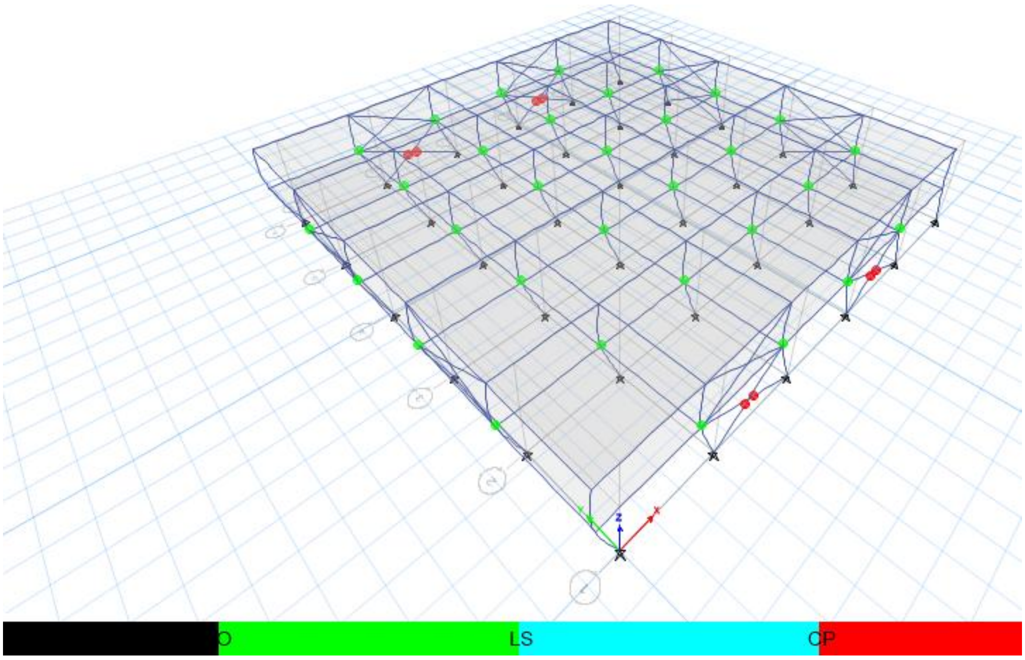


Fig 5. (d) Location of plastic in three-dimensional mode – PUSHMODE-E1

4.5. Pushover Curves

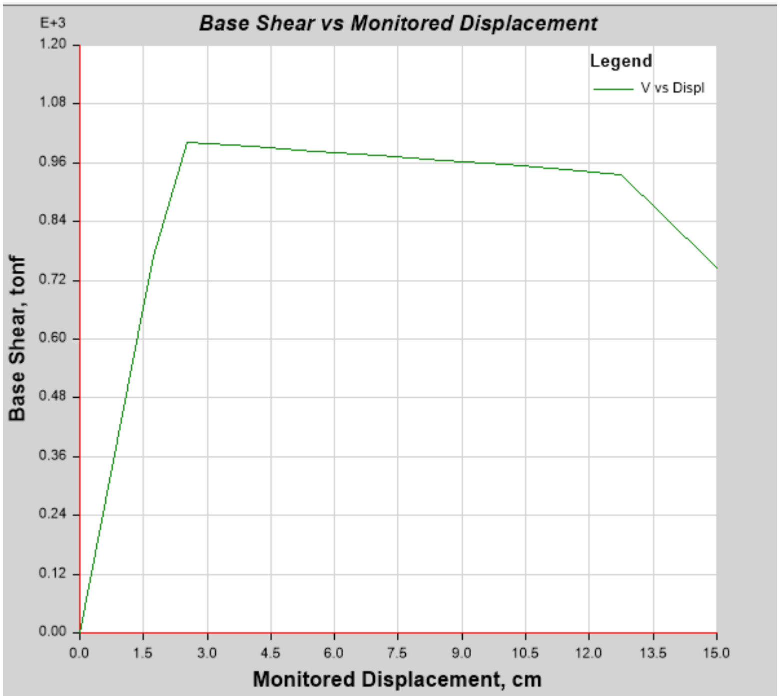


diagram 1.Pushover diagram subjected to loading PUSHL1

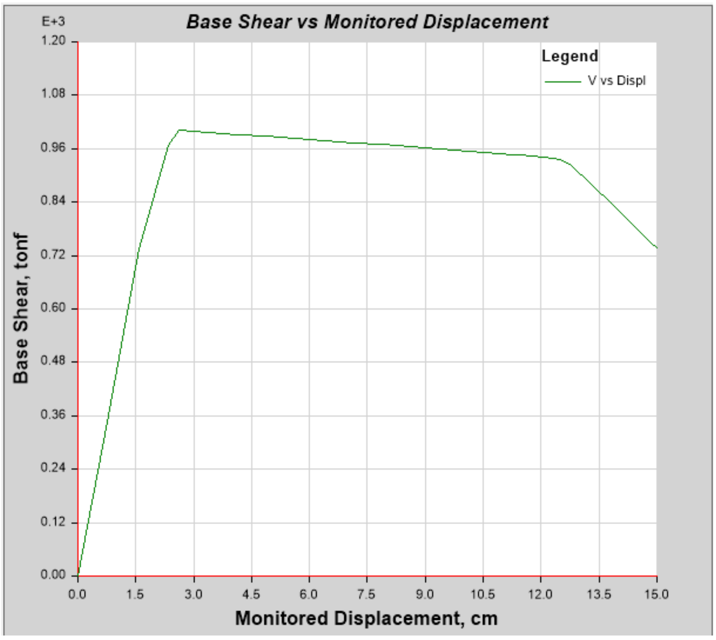


diagram 2. Pushover diagram subjected to loading PUSHL5

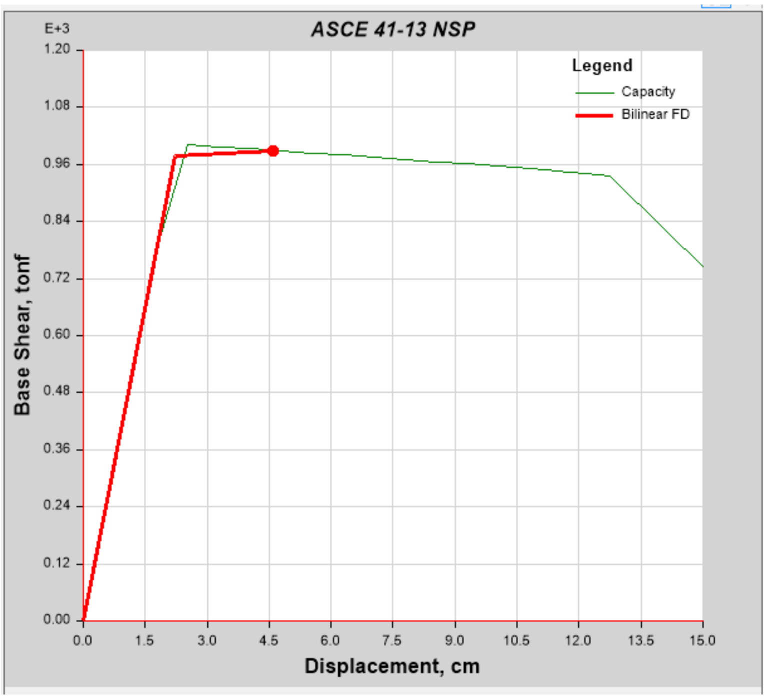


diagram 3.Pushover and bilinear diagrams subjected to loading PUSHL1

5. Conclusion

Pushover analysis is a useful tool of performance based seismic engineering to study post-yield behavior of a structure. It is more complex than traditional linear analysis. Pushover analysis was performed on a two story steel structure reinforced by X-bracing. Utilizing the results from this analysis, some modifications were made to the original code-based design so that the design objective of life safety performance is expected to be achieved under design earthquake.

References

[1] Maheri, M. R.,andAkbari,R.,"Seismic behavior factor ,R, for X-steel braced and knee braced RC buildings", Engineering Structures, No 25, pp. 1505-1513, (2003).

[2] Maheri, M. R., and Sahebi, A.,"Use of steel bracing in reinforced concret frames", Engineering Structures,PP. 0141-0296, (1996).

[3] GhobarahA.,andAbouElfath H.,"Rehabilitation of reinforced concrete frame using eccentric steel bracing", Engineering Structures, No23, pp. 745-755, (2000).

[4] Maheri, M. R., and Kousari R., Pushover test on steel X-braced and knee braced RC frames", Engineering Structures, No 25, pp. 1697-1705, (2003) .

[5] Youssef,M.A., and GHaffarzadeh, H.,"Seismic performance of RC frames with concentric internal steel bracing", Engineering Structures, No 29, pp. 1561-1568, (2006).

[6] Federal Emergency Management Agency (FEMA). NEHRP provisions for Seismic rehabilitation of buildings. Rep FEMA 356 and 273, Washington DC,1997.

[7] ACI Committee 318. Building code requirements for reinforced concrete (ACI 318-02). American Institute, Detroit, MI, 2002.

[8] AISC Manual of steel construction: load and resistance factor design. 3rded. Chicago (IL): American Institute of steel Construction; 2001.