DESIGNING ECCENTRICALLY BRACED STEEL FRAMES WITH DIFFERENT LINK LENGTHS ALONG THE FRAME HEIGHT

N. Özhendekci[1] and D. Özhendekci[2]

[1] *Research Assistant, Dept. of Civil Engineering , Yildiz Technical University, Istanbul, Turkey*
[2] *Research Assistant, Dept. of Civil Engineering , Yildiz Technical University, Istanbul, Turkey*
Email: nuriozhendekci@yahoo.com, devrimozhen@yahoo.com

ABSTRACT :

At present, inelastic static pushover analysis is widely used in engineering practice to predict seismic capacity of building structures because of its simplicity compared to the inelastic dynamic analysis. In this paper, the maximum displacements of 9 eccentrically braced steel frames with various geometries are obtained with inelastic static pushover analyses based on FEMA-356 load patterns. Model frames are designed according to LRFD (1999) and the capacity based design principles are based on AISC-Seismic Provisions for Structural Steel Buildings (2005). Loads and load combinations are compatible with ASCE 7-05. Inelastic dynamic analyses of these frames are also conducted under 20 SAC ground motions. Both static and dynamic inelastic analyses are carried out with the DRAIN-2DX program. During inelastic dynamic analyses each earthquake record for each frame is scaled by a coded program by modifying the DRAIN input files in an automated manner until the frames reach their limit states and the resultant scaled earthquake records are used for obtaining the frames' maximum displacements. The maximum displacements obtained by these methods are utilized in order to assess the validity of the pushover analyses.

KEYWORDS: Eccentrically braced steel frame, pushover analysis, lateral load pattern, inelastic dynamic analysis.

1. INTRODUCTION

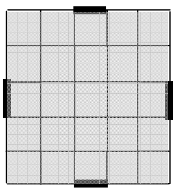
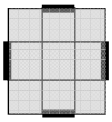
In this study validity of the pushover analysis is investigated. Special attention is given to the distribution of the maximum link rotations along the frame height. To this aim both inelastic dynamic analyses and pushover analyses are performed till the target link rotation is reached, which is 0.08 rad. for shear yielding links and 0.02 rad. for flexural yielding links. Four different load patterns from FEMA-356 are used for pushover analyses. The resultant maximum link rotation distributions obtained from different analyses are compared. Obtained distributions are considerably different for model frames with shear yielding links and flexural yielding links. Apart from that it seems that the link length is also an effective parameter as well as the frame height.

2. MODEL FRAMES

9 eccentrically braced frames (EBFs) are designed according to LRFD (1999) and seismic design of these frames are based on Seismic Provisions for Structural Steel Buildings (AISC, 2005). The loads and load combinations are taken from ASCE 7-05. A computer program is coded for optimum design of EBFs, the algorithm and brief description of which are given in a recent paper (Özhendekci and Özhendekci, 2008). Material and cross section types chosen are also given in the referred paper. The basic characteristics of the model frames are given in Table 2.1

For inelastic analyses, columns and braces are modeled as beam-columns capable of developing strain-hardening plastic hinges. Moment-axial force interaction surface is determined for each element based on the section properties and plastic design principles. Uang and Richard's link element model is utilised. The details of the model can be found in (Richards, 2004).

Table 2.1 Characteristics of the model frames

Plan view and area (m^2)	Link yielding type	Number of stories	Link length (cm)	Frame Name	EBF Span length (m)	h (m)
 EBF — Simple Frame **750**	**SHEAR**	3	70	**FR-01**	**8**	**3.5**
		3	120	**FR-02**		
		6	70	**FR-03**		
		6	120	**FR-04**		
		9	70	**FR-05**		
		9	120	**FR-06**		
 **250**	**FLEXURAL**	3	280	**FR-07**		
		6	280	**FR-08**		
		9	280	**FR-09**		

3. INELASTIC ANALYSES

Inelastic analyses of model frames are performed with DRAIN-2DX. During pushover analyses the scale of the lateral loads and during dynamic analyses scale factor of each ground motion acceleration record is increased till each frame reaches its limit state. The limit state is reached, when one of the links of a frame reaches its plastic rotation capacity. Generally, the 1st storey links reach their capacities first, but in rare occasions the upper storey links can reach their capacities first. The plastic rotation capacity of shear yielding links is given as 0.08 rad. in the code and it is given as 0.02 rad. for flexural yielding links (AISC, 2005).

3.1.Pushover Analyses

Pushover analysis is expected to represent the inertia forces under the considered earthquake. The distribution of lateral inertia forces determines the relative magnitudes of link rotations along the frame height. Four different load patterns are used for the analyses. These patterns are explained below:

(1) Vertical distribution proportional to the values of F_x given in Eqn. 3.1.

$$F_x = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_x^k} V_0 \qquad (3.1)$$

Here, w_x is the portion of the total effective frame weight assigned to floor level *x* and h_x is the height from the base to the same floor level. V_0 is a constant force value to use in the pushover analyses, initially. Exponent *k* is determined by linear interpolation between 1 and 2 with the corresponding period values of 0.5 s and 2.5 s. It should be noted that ASCE7-05 allows using the constant value of 2 where the interpolation is required, thus 2 is used for the design of model frames.

(2) A vertical distribution proportional to the shape of the fundamental mode and denoted as F_1.

(3) A vertical distribution proportional to the story shear distribution calculated by combining modal responses

using CQC rule including all the modes of the frame. This distribution is denoted as F_V .

(4) A vertical distribution proportional to the total mass at each level which is nearly uniform and denoted as F_M .

3.2.Inelastic Dynamic Analyses

Inelastic dynamic analyses of each model frame are performed under 20 SAC ground motions. During inelastic dynamic analyses each earthquake record for each frame is scaled by a coded program by modifying the DRAIN input files in an automated manner until the frames reach their limit states and the resultant scaled earthquake records are used for obtaining the frames' maximum link rotations.

Table 3.1 provides detailed information on the 20 SAC ground motion records generated for Los Angeles having probabilities of exceedence of 2% in 50 years. These acceleration time histories include records from historic earthquakes as well as artificially-generated time histories based on modeling of the rupture process and wave propagation through the soil strata (Somerville et. al., 1997).

Table 3.1 Properties of the earthquake records

Record Name	Magnitude	Distance (km)	Duration (s)	PGA (cm/s^2)
1995 Kobe	6.9	3.4	59.98	1258.00
1995 Kobe	6.9	3.4	59.98	902.705
1989 Loma Prieta	7	3.5	24.99	409.95
1989 Loma Prieta	7	3.5	24.99	463.76
1994 Northridge	6.7	7.5	14.945	851.62
1994 Northridge	6.7	7.5	14.945	925.29
1994 Northridge	6.7	6.4	59.98	908.70
1994 Northridge	6.7	6.4	59.98	1304.10
1974 Tabas	7.4	1.2	49.98	793.45
1974 Tabas	7.4	1.2	49.98	972.58
Elysian Park (simulated)	7.1	17.5	29.99	1271.20
Elysian Park (simulated)	7.1	17.5	29.99	1163.50
Elysian Park (simulated)	7.1	10.7	29.99	767.26
Elysian Park (simulated)	7.1	10.7	29.99	667.59
Elysian Park (simulated)	7.1	11.2	29.99	973.16
Elysian Park (simulated)	7.1	11.2	29.99	1079.30
Palos Verde (simulated)	7.1	1.5	59.98	697.84
Palos Verde (simulated)	7.1	1.5	59.98	761.31
Palos Verde (simulated)	7.1	1.5	59.98	490.58
Palos Verde (simulated)	7.1	1.5	59.98	613.28

6.RESULTS

The values and the distributions of maximum link rotation angles along the frames' heights, evaluated according to the inelastic dynamic analyses and the pushover analyses with various lateral load patterns, are given in Figures 1, 2 and 3. According to the results, for nearly all of the analysis types the limit rotation angles occur at first storey levels. Except for the pushover analyses of FR-01 and FR-03 with $\mathbf{F_1}$ load pattern, and for inelastic dynamic analyses of FR-03 under 2 records, FR-05 under 5 records, FR-06 under 2 records and FR-09 under 1 record.

For all of the model frames the distribution of the maximum link rotation angles along the heights under the pushover lateral load patterns of $\mathbf{F_V}$ and $\mathbf{F_M}$ are similar. Furthermore, for nearly all of the frames the distributions are similar for $\mathbf{F_1}$ and $\mathbf{F_X}$ load patterns, except for some storey levels of the frames with short shear links, namely top stories of FR-03 and FR-05, and all the stories of FR-01. The distributions evaluated by $\mathbf{F_1}$ and $\mathbf{F_X}$ load patterns are very similar for the high frames with flexural yielding links, namely FR-08 and FR-09.

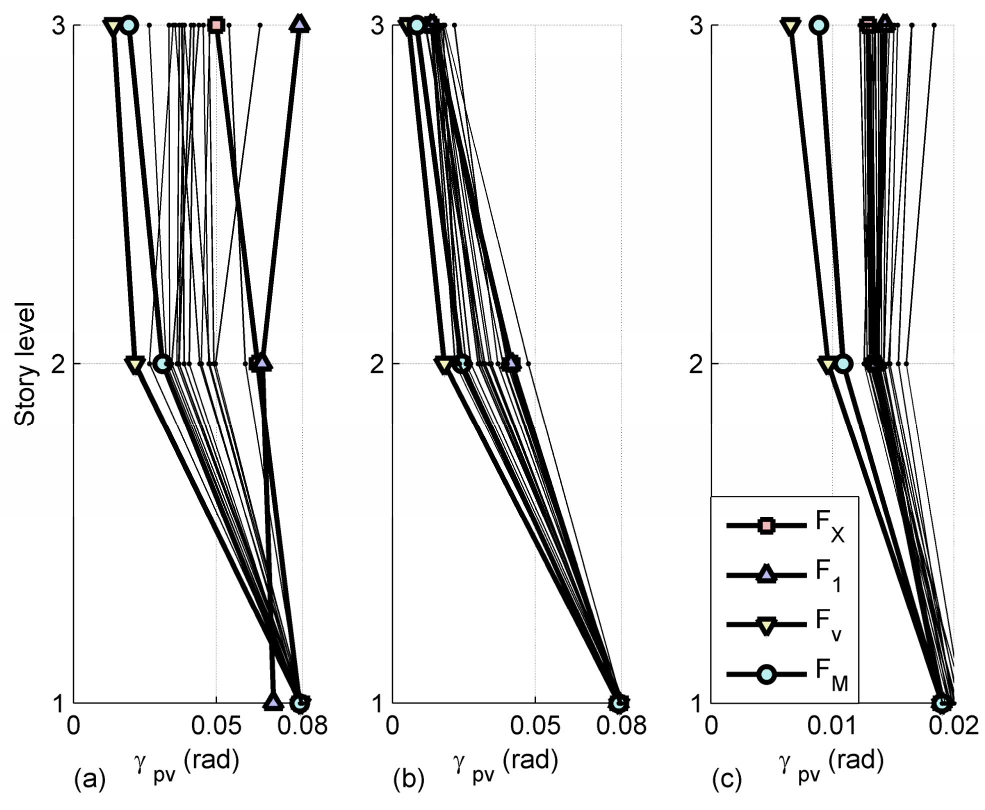


Figure 1 Distribution of maximum link rotations along the frame height (a) FR-01 (b) FR-02 (c) FR-07

Among all of the procedures, pushover analyses with $\mathbf{F_V}$ load pattern give the minimum values of maximum link rotations except for a few situations where the limit rotations do not develop at the first storeys. The displacement values evaluated by the $\mathbf{F_M}$ load patterns are generally close to the values obtained by $\mathbf{F_V}$ load pattern.

For the frames with short shear links, among all of the procedures, the maximum link rotations obtained by the pushover analyses with the load pattern of $\mathbf{F_1}$ give generally the maximum values. Namely, for FR-01 except for the 1st storey $\mathbf{F_1}$ gives the maximums, and the values obtained by $\mathbf{F_X}$ are close to the maximums; for FR-03 except for 3rd and 6th storeys $\mathbf{F_1}$ gives the maximums, and the values obtained by $\mathbf{F_X}$ are not close to the maximums; for FR-05 except for the 8th storey $\mathbf{F_1}$ gives the maximums, and the values obtained by $\mathbf{F_X}$ are far from the maximums.

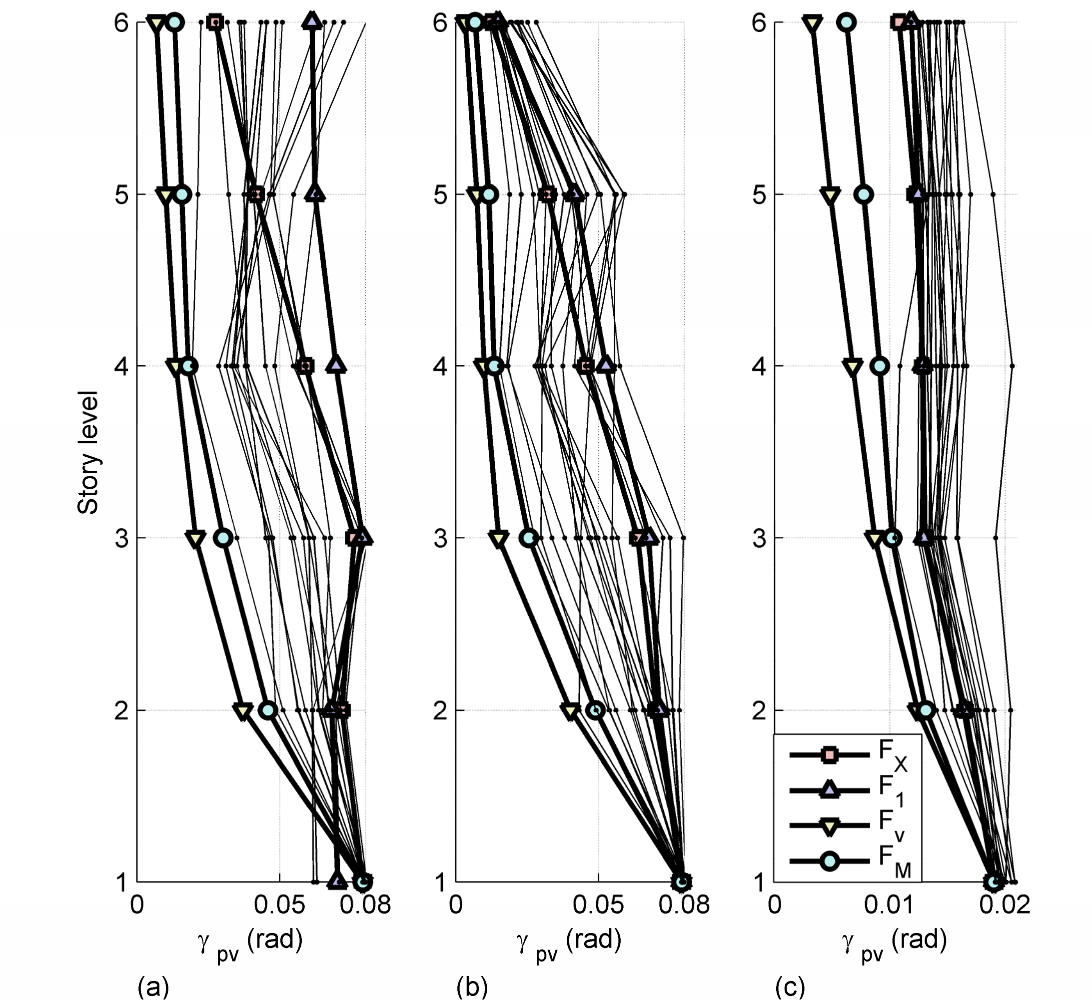


Figure 2 Distribution of maximum link rotations along the frame height (a) FR-03 (b) FR-04 (c) FR-08

Among all of the procedures, for the frames with long shear link lengths, the rotation values obtained by the load patterns of $\mathbf{F_1}$ and $\mathbf{F_X}$ are generally similar and in some occasions they are close to the maximum values for 3 and 6 storey frames. Namely, these load patterns give the maximums for 1st and 2nd storeys of FR-02, close to maximums for FR-04 except for the 5th and 6th storeys.

For the frames with flexural yielding links, the rotation values obtained by the load patterns of $\mathbf{F_1}$ and $\mathbf{F_X}$ are generally similar, but they are not close to the maximums, in fact they are almost close to the minimums for especially the 6 and 9 storey frames.

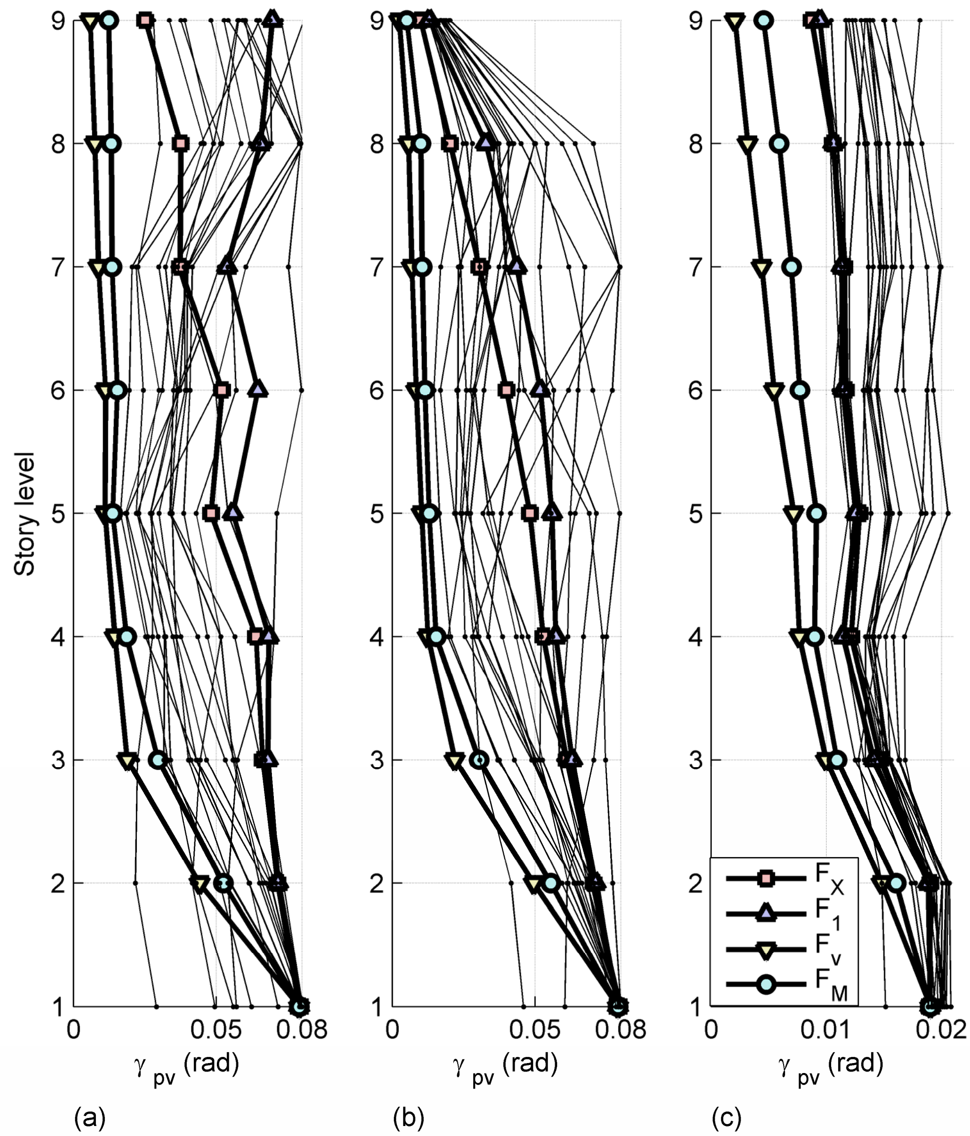


Figure 3 Distribution of maximum link rotations along the frame height (a) FR-05 (b) FR-06 (c) FR-09

7.CONCLUSIONS

The maximum link rotation distribution patterns of pushover analyses are not generally similar to the distribution patterns obtained with inelastic dynamic analyses for the EBFs with shear links and the rotations obtained by the load patterns of $\mathbf{F_V}$ and $\mathbf{F_M}$ are similar and may be accepted as lower limit. The rotations obtained by $\mathbf{F_1}$ load pattern may be accepted as upper limit for the EBFs with short shear links, but this is not valid for the EBFs with long shear links.

The maximum link rotation distribution patterns of pushover analyses are similar to the distribution patterns obtained with inelastic dynamic analyses for the EBFs with flexural yielding links. None of the lateral load patterns is proper for the purpose of evaluating upper limit for the EBFs with flexural yielding links.

Furthermore, the lower limit obtained by the $\mathbf{F_V}$ (or $\mathbf{F_M}$) load patterns is below the findings of the dynamic analyses.

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