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

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ABSTRACT :

12 eccentrically braced steel frames are designed according to LRFD (1999) and ASCE 7-05. Capacity-based design principles are based on AISC Seismic Provisions (2005). Some of the model frames have different link lengths along the height. Inelastic dynamic analyses of each of model frames are performed under 20 SAC ground motions with DRAIN-2DX. Each earthquake record for each frame is scaled by a coded program by modifying the DRAIN input files in an automated manner until one of the links reaches the code-based limit rotation angle, and the resultant scale factors are used for assessment of the frames' inelastic behaviours. Effects of the different link lengths along the frame height on the frames' seismic behaviours and weights are investigated. Push-over analyses of the designed frames are also performed with DRAIN-2DX in order to compare their displacement ductilities.

KEYWORDS: Eccentrically braced steel frame, link length, inelastic analysis, ductility.

1. INTRODUCTION

Characteristics of EBFs with variable link lengths along the frame height have not been investigated so far, known to the writers. Hence, in this research, 3-, 6- and 9-storey EBFs with variable link lengths are designed in addition to the frames with constant link lengths. The frames with variable link lengths are found out to be lighter because of the capacity based design principles. Reducing the link lengths along the height affects the ductility and lateral resistance of those frames. These effects are investigated by the scale factors of the earthquakes acceleration records under which frames reach their limit states. Mean scale factors and the material weights of the frames with variable and constant link lengths are compared. When the mean scale factors are same for both design cases, one with variable link length and the other one with constant link length, material weights are compared. For the completeness of the study displacement ductilities of the frames are also investigated by pushover analyses.

2. MODEL FRAMES

12 EBFs with shear yielding links are designed according to AISC Seismic Provisions (2005) and LRFD (1999). The loads and load combinations are taken from ASCE 7-05. Although, the frames are the components of symmetrical buildings in plan the effect of the accidental torsion is added. All the EBFs of one building are assumed to be identical. It is assumed that there are four EBFs in each building, two of which resist the earthquake loads together, while the other two resist the earthquake loads coming from the perpendicular direction. The seismic effective mass of each frame is calculated by using the half of the building area.

A992 steel is used for the beams and the columns, A500-Grade B steel is used for the braces. The entire AISC wide-flange section database is assumed available for beams. Column and brace sections are chosen from W14 series and from rectangular hollow sections with equal depth and width values, respectively. The chosen sections are the minimums, which satisfy the necessary conditions. This was achieved by a coded design program. The reader is referred to (Özhendekci and Özhendekci, 2008) basic characteristics and the algorithm of the program. The basic properties of the designed frames are given in Figure 1 and Table 2.1.

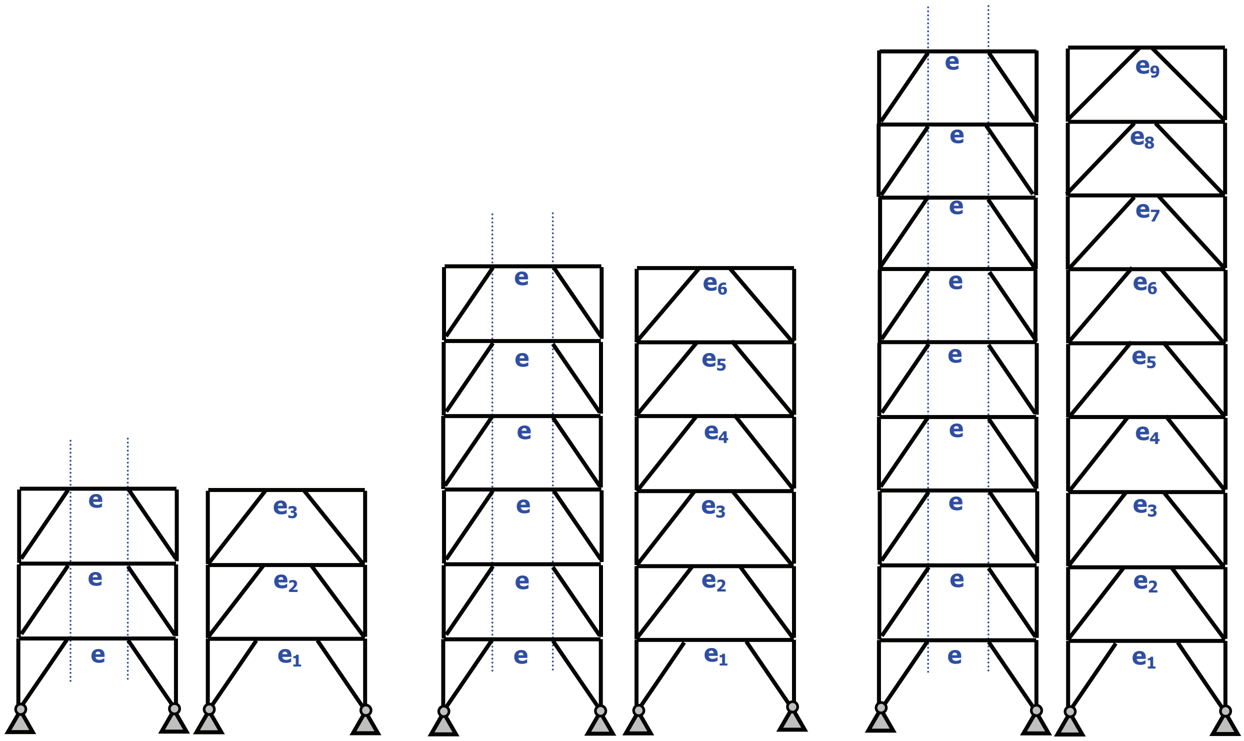

Figure 1 Geometric properties of the model frames

Table 2.1 Properties of the model frames

Link Floor	Frame Name / Link Name	FR3-1	FR3-2	FR3-3	FR6-1	FR6-2	FR6-3	FR9-1	FR9-2	FR9-3	FR9-4	FR9-5	FR9-6
1th	e_1 (cm)	110	110	110	110	110	110	110	110	110	110	110	110
2nd	e_2 (cm)	110	105	100	110	105	110	110	110	110	110	110	105
3rd	e_3 (cm)	110	100	90	110	100	100	110	100	100	100	100	100
4th	e_4 (cm)				110	95	100	110	100	100	100	100	95
5th	e_5 (cm)				110	90	90	110	100	100	100	90	90
6th	e_6 (cm)				110	85	90	110	100	100	100	90	85
7th	e_7 (cm)							110	110	100	90	80	80
8th	e_8 (cm)							110	110	100	90	80	75
9th	e_9 (cm)							110	100	90	80	70	70

	ALL OF THE MODEL FRAMES
Plan Area	750 m^2
Span Length	8 m
Storey Height	3.5 m
Link Yielding Type	Shear

Richards and Uang's link element model (2004) is used for inelastic analyses.

2.1. Link Plastic Rotation

The design procedure involves some final checks (Özhendekci and Özhendekci, 2008), including the link plastic rotation angle. The link rotation angle is the primary variable used to describe inelastic link deformation and can be estimated by assuming that the EBF bay will deform in a rigid-plastic mechanism as illustrated in Fig.2 . AISC (2005) gives this rotation as the following:

$$\gamma_p = \theta_p \times \frac{L}{e} \tag{2.1}$$

Here, $\theta_p = \frac{\Delta_p}{h}$, γ_p = the link rotation angle, θ_p = the column rotation angle, Δ_p = the storey drift, h = storey height. During design process, above equation is adopted. However, Eqn. 2.1 does not consider the vertical displacements of the column ends (Δy) which are cumulative and especially important for the upper stories of high rise frames. During inelastic analyses modified link rotation equation (Eqn. 2.2) is used (Özhendekci and Özhendekci, 2008):

$$\gamma_{pv} = \gamma_p - \frac{2\Delta y}{e} \tag{2.2}$$

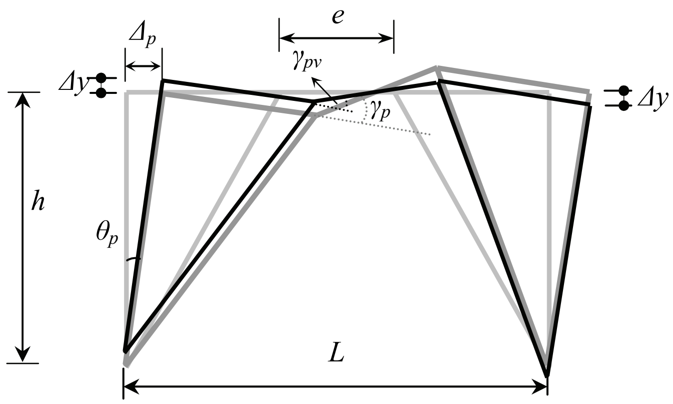

Figure 2 Rigid-plastic mechanism of an EBF bay (Özhendekci and Özhendekci, 2008)

3. COMPARISON OF THE SCALE FACTORS

Lateral capacity of a frame is reached when the link of a storey reaches its capacity during an inelastic dynamic analysis. Maximum rotations of the remaining links are smaller than the rotation limit of the code. Since the full capacities are not used, smaller lengths can be selected for those links during the design stage of the frame and lighter frame weight can be obtained, in turn. However, these selections should not be under a certain limit since decreasing the link length causes an increase in the link rotation angle (Eqn. 2.1, 2.2) and to reach the frame capacity in an early stage of the inelastic action.

Inelastic dynamic analyses of the modeled frames are performed by DRAIN-2DX program under 20 SAC ground motions. Each earthquake record is scaled by modifying the DRAIN input file by the coded program until the frame reaches its capacity. The earthquake properties are given in Table 3.1 This procedure is repeated for each frame and for each earthquake record and obtained scale factors of the earthquakes are used for comparisons. Scale factors of each frame with variable link lengths are normalized by that of the frame with the same geometry but with constant link lengths. Similar normalization is applied for the material weights of the frames.

Considering the 3-storey frames, scale factor ratios are given in Fig.3. Mean values of them are 1.02 and 0.98 for FR3-2 and FR3-3, respectively. Corresponding material weight ratios are 0.89 and 0.85. Similar results are obtained for 6-storey frames (Fig.4). Mean values of the scale factor ratios are 0.99 and 1.00 while the material weight ratios are 0.93 and 0.93 for the frames FR6-2 and FR6-3, respectively. For generalization, it can be said that reducing the link lengths along the height of the frame does not change the mean scale factor much however 11% and 7% lighter frames obtained for 3- and 6-storey frames (FR3-2, FR6-2).

Table 3.1 Properties of the earthquake records

Given Name	Record Name	Magnitude	Distance (km)	Duration (s)	PGA (cm/s^2)
EQ01	1995 Kobe	6.9	3.4	59.98	1258.00
EQ02	1995 Kobe	6.9	3.4	59.98	902.705
EQ03	1989 Loma Prieta	7	3.5	24.99	409.95
EQ04	1989 Loma Prieta	7	3.5	24.99	463.76
EQ05	1994 Northridge	6.7	7.5	14.945	851.62
EQ06	1994 Northridge	6.7	7.5	14.945	925.29
EQ07	1994 Northridge	6.7	6.4	59.98	908.70
EQ08	1994 Northridge	6.7	6.4	59.98	1304.10
EQ09	1974 Tabas	7.4	1.2	49.98	793.45
EQ10	1974 Tabas	7.4	1.2	49.98	972.58
EQ11	Elysian Park (simulated)	7.1	17.5	29.99	1271.20
EQ12	Elysian Park (simulated)	7.1	17.5	29.99	1163.50
EQ13	Elysian Park (simulated)	7.1	10.7	29.99	767.26
EQ14	Elysian Park (simulated)	7.1	10.7	29.99	667.59
EQ15	Elysian Park (simulated)	7.1	11.2	29.99	973.16
EQ16	Elysian Park (simulated)	7.1	11.2	29.99	1079.30
EQ17	Palos Verde (simulated)	7.1	1.5	59.98	697.84
EQ18	Palos Verde (simulated)	7.1	1.5	59.98	761.31
EQ19	Palos Verde (simulated)	7.1	1.5	59.98	490.58
EQ20	Palos Verde (simulated)	7.1	1.5	59.98	613.28

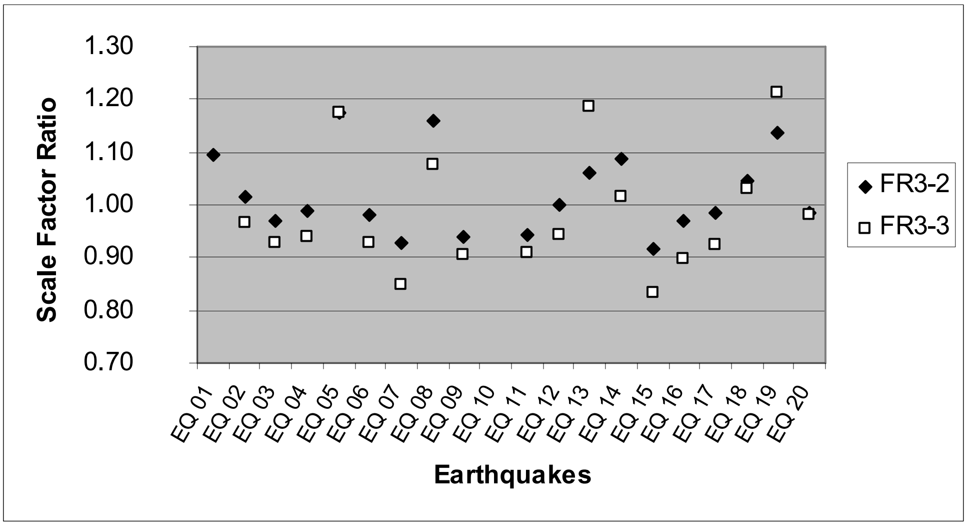

Figure 3 Scale factors for 3-storey EBFs

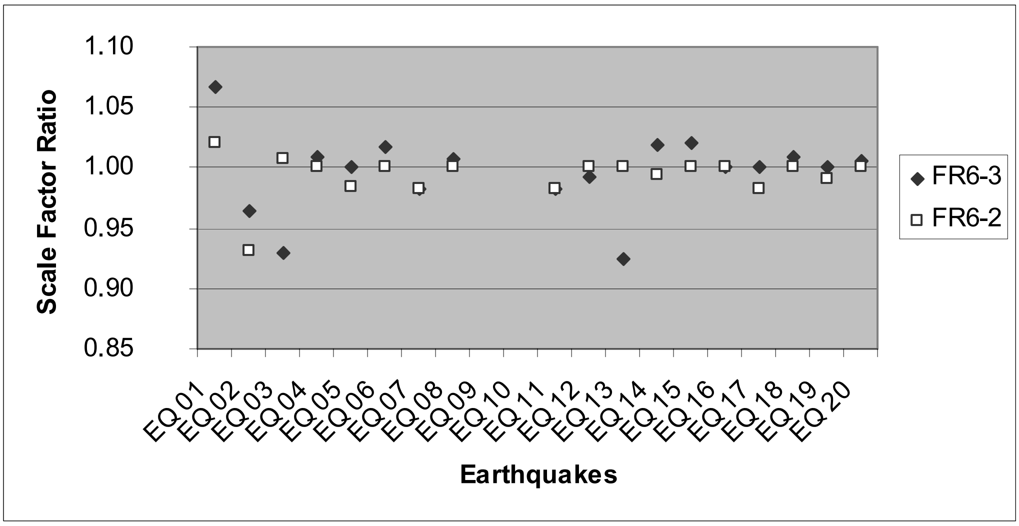

Figure 4 Scale factors for 6-storey EBFs

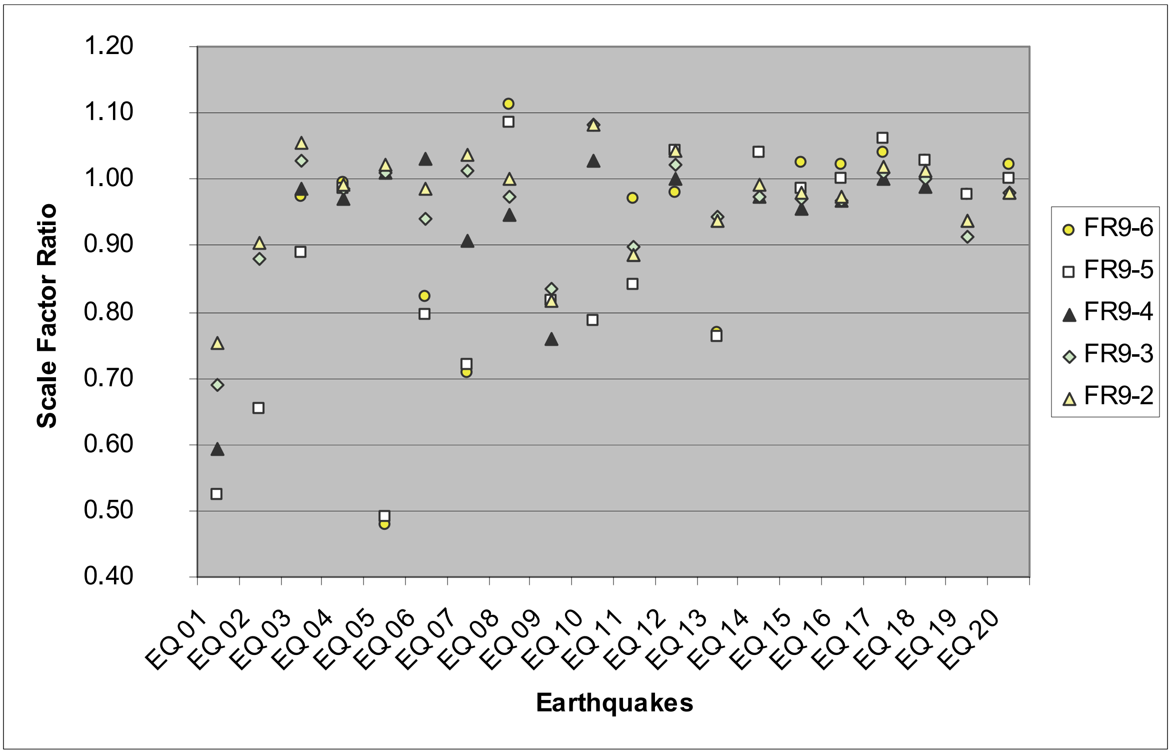

Figure 5 Scale factors for 9-storey EBFs

Scale factor ratios are given for the 9-storey frames in Fig.5. Mean values of them are 0.97, 0.96, 0.99, 0.87 and 0.93 while the material weight ratios are 0.92, 0.91, 0.89, 0.87 and 0.91 for the frames FR9-2, FR9-3, FR9-4, FR9-5 and FR9-6, respectively. Inappropriate distribution of the link lengths along the height, like FR9-5 and FR9-6 had, did not give better results because of the reason mentioned above. This implies that sufficient ductility should also be provided for upper stories. FR9-4 having mean scale factor ratio 0.99 and being lighter 11% is a good choice regarding the link lengths.

3. COMPARISON OF THE DISPLACEMENT DUCTILITIES BY PUSHOVER ANALYSES

Although pushover analysis may not predict the collapse mode of the frames well, it is used to compare the displacement ductilities of the frames for the completeness of the study. Pushover curves of 3-storey, 6-storey and 9-storey model frames are given for the ratio of inelastic base shear to seismic effective weight of the frame (V/W) versus lateral top displacement (δ) of it (Figs.6-8). Considering the 3- and 6-storey frames, obtained displacement ductilities are 3.57, 3.42 and 3.19 for FR3-1, FR3-2 and FR3-3; and are 3.22, 3.19 and 3.07 for FR6-1, FR6-2 and FR6-3, respectively. Considering the 9-storey frames, they are 2.77, 2.59, 2.52, 2.58, 2.35 and 2.38 for the frames FR9-1, FR9-2, FR9-3, FR9-4, FR9-5 and FR9-6, respectively. Hence selection of the reduced link lengths along the frame height did not change the displacement ductilities much, especially for the frames FR3-2, FR6-2 and FR9-4.

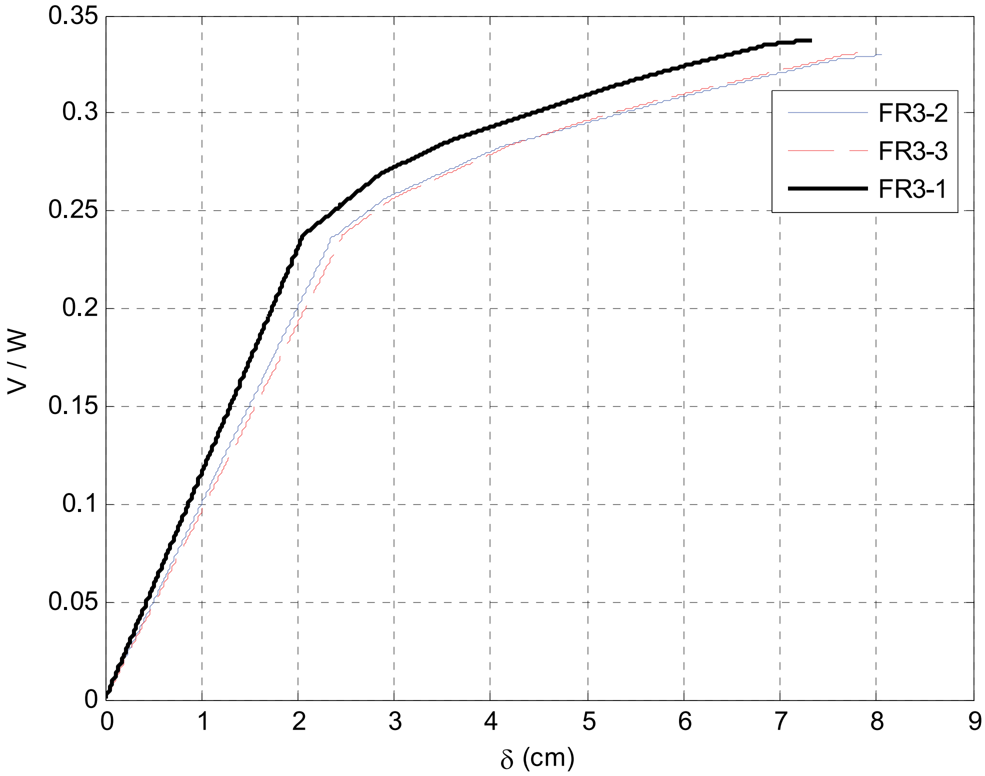

Figure 6 Pushover curves of 3-storey EBFs

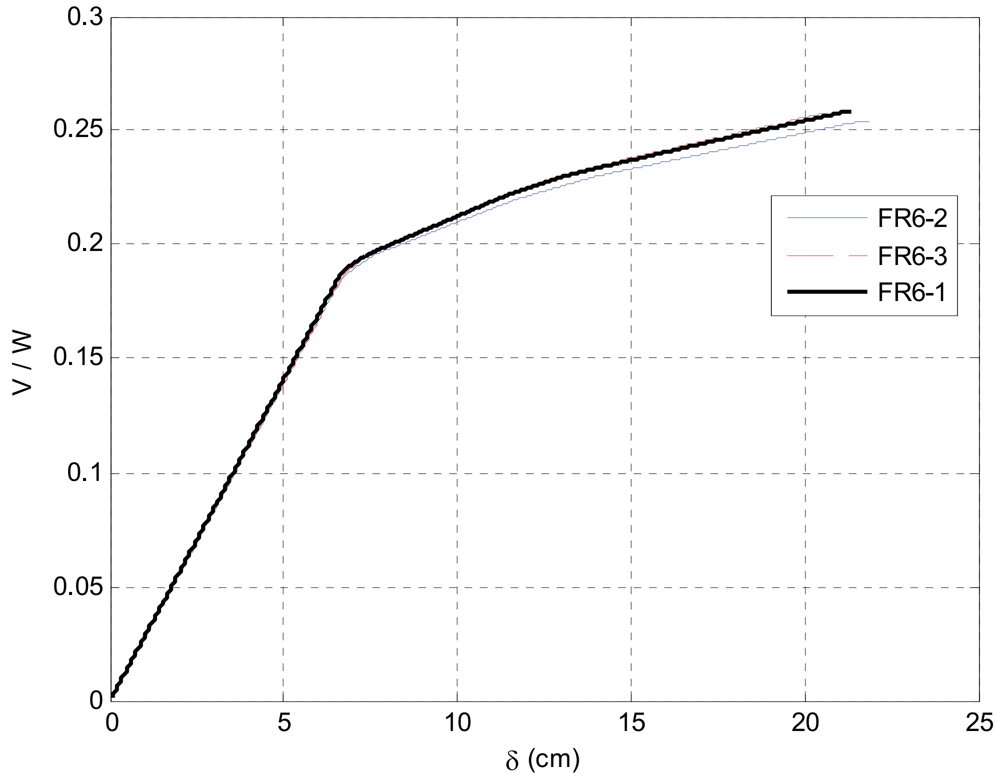

Figure 7 Pushover curves of 6-storey EBFs

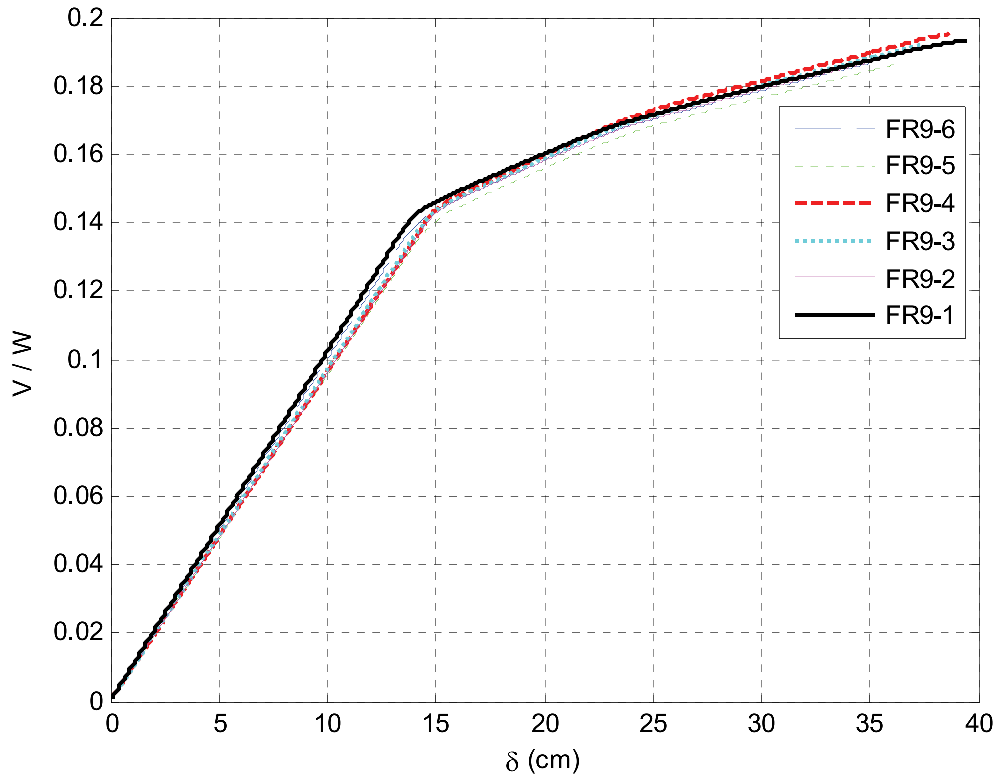

Figure 8 Pushover curves of 9-storey EBFs

3. CONCLUSIONS

During an inelastic dynamic analysis, which is continued until the frame reaches its capacity, maximum rotations of most of the links of the EBF does not reach to the limit rotation of the code. Increasing the maximum rotations and reducing the unused capacities of the links is achieved by selecting smaller lengths for these links. Decreasing the link lengths along the height of the frame, in turn, results in lighter designs according to the capacity based design principles.

Model frames FR3-2, FR6-2 and FR9-4 designed with smaller link lengths along the height of the frame are 11%, 7% and 11% lighter, respectively, than the ones designed with constant link lengths. Mean scale factors of the earthquakes under which these frames reach their limit states are retained nearly same with that of the frames with same geometry but with constant link lengths. However selecting link lengths under a certain limit (FR9-2) may cause the frame to reach its limit state in an early stage of the inelastic action. Sufficient ductility should also be provided for upper stories of higher frames.

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