Seismic Behavior of T-shape Resistant Frame (TRF) with Different Shapes of Link Beams

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SUMMARY:
Lateral resistant systems should be chosen to resist earthquake lateral forces and dissipate its energy due to their ductility and their adequate lateral stiffness. T-Resistant frame (TRF) is a newly proposed type of lateral resistant system consisting of column steel I-shape that is vertically placed from the lowest level of a building up to the upper stories to which deep I-shape steel beams are horizontally attached. In this paper, several TRFs are chosen and investigated having different shapes of the link beam with nonprismatic shape like fillet shape. Seismic responses of these TRF systems are indagated by push-over method to achieve the best seismic behavior by determining some parameters like response modification.

Keywords: R factor, T-shape resistant frame, nonprismatic link beam.

1. INTRODUCTION

Structures designed to resist moderate and frequently occurring earthquakes must have sufficient stiffness and strength to control deflection and to prevent any possible damage. Selecting a good structural system requires understanding seismic behavior of the systems available. Since stiffness and ductility are generally two opposing properties, it is desirable to devise a structural system that combines these properties in the most effective manner without excessive increase in the cost. Steel structural systems, moment resisting and concentrically braced frames have been widely used to resist earthquake loads. Concentrically braced frames have high stiffness, and are not ductile enough due to the probable buckling of their diagonal members. Versus, moment resisting frames have adequate ductility as their beam sections can undergo elastic deformations, but have low stiffness, thus increase construction cost. To overcome the deficiencies in moment resisting and concentrically braced frames, Roeder and Popov [Roeder, C.W., and Popov, E.P] have proposed the Eccentrically Braced Frame (EBF) system. Subsequently, Aristazabal-Ochoa (Aristizabal-Ochoa, J. D., 1986) have presented Knee braced frames (KBF) and Zahrai-Bruneau (Zahrai, S.M. and Bruneau, M, 1999) have proposed Shear panel systems (SPS). In recent decades, steel shear wall systems have been widely noticed and researches on increasing their performance and design are still in progress. Although these mentioned systems have good seismic behavior, but, to some extent, they limit architectural design. On the other hand, design and construction difficulties have caused a decrease on their usage tendency in our country regions. In 2009, Ashtari proposed TRF configuration for architectural reasons and to provide more energy dissipating capability and Bandehzadeh demonstrated seismic performance advantages of the optimized single-T TRFs. Also, Ashtari and Ghassemi (2011), and Ashtari and Gorzin (2011) introduced single-T and double-T configurations of TRF and investigated some of their seismic characteristics This system is constructed through a deep I-shaped steel beam vertically placed in the middle of span, connected with two other deep I-shaped beams as link beam to the columns at each story level that one on hand is compared with different shapes of the link beam with nonprismatic shape like fillet shape and Seismic responses of these TRF systems are indagated by push-over method to achieve the best seismic behavior by determining parameters response modification, ductility .Section properties of the vertical I-shaped beam have a major effect on the ductility and energy dissipation of the TRF system. It has a sufficient stiffness and decrease structural weight of the moment resisting frames and can be used for retrofitting of existing buildings that architecturally it is not possible to use braced frames as their structural systems. In this paper, seismic behavior of a new structural system (TRF) with nonprismatic and fixed height link beam will be evaluated.

2. BEHAVIOR FACTOR PARAMETERS

In forced-based seismic design procedures, behavior factor, *R (*Eurocode 8, 1998) (or *Rw*) also referred to by other terms including, response modification factor (UBC code (1997; and NEHRP provisions (1997)), is a force reduction factor used to reduce the linear elastic response spectra to the inelastic response spectra. In other words, behavior factor is the ratio of the strength required to maintain the structure elastic to the inelastic design strength of the structure. The behavior factor, *R*, therefore accounts for the inherent ductility and over strength of a structure and the difference in the level of stresses considered in its design. It is generally expressed in the following form taking into account the above three components.

$$R = R_{\mu}.R_{s}.Y \tag{1}$$

where, $R_{\mu}$is the ductility-dependent component also known as the ductility reduction factor, R_s is the over strength factor and Y is termed the allowable stress factor.
With reference to Fig. 1, in which the actual force– displacement response curve is idealized by a bilinear elastic–perfectly plastic response curve, the behavior factor parameters may be defined as:

$$R_{\mu} = \frac{V_e}{V_y} , R_s = \frac{V_y}{V_s} , Y = \frac{V_s}{V_w} \tag{2}$$

$$R(R_w) = (\frac{V_e}{V_y} \times \frac{V_y}{V_s} \times \frac{V_s}{V_w}) = \frac{V_e}{V_w} \tag{3}$$

where, V_e, V_y, V_s and V_w correspond to the structure's elastic response strength, the idealized yield strength, the first significant yield strength and the allowable stress design strength, respectively. For structures designed using an ultimate strength method, the allowable stress factor, *Y*, becomes unity and the behavior factor is reduced to:

$$R = R_{\mu}.R_s = \frac{V_e}{V_s} \tag{4}$$

The structure ductility, μ, is defined in terms of maximum structural drift ($\Delta_{\max}$) and the displacement corresponding to the idealized yield strength (Δ_{y}) as:

$$\mu = \frac{\Delta_{\max}}{\Delta_{y}} \tag{5}$$

Many investigators have discussed the two main components of *R* factor presented in Eq. (4), in particular, the ductility dependent component, R_{μ}, has received considerable attention.

Ductility reduction factor R_{μ} is a function of both the characteristics of the structure including ductility, damping and fundamental period of vibration (*T*), and the characteristics of earthquake ground motion.

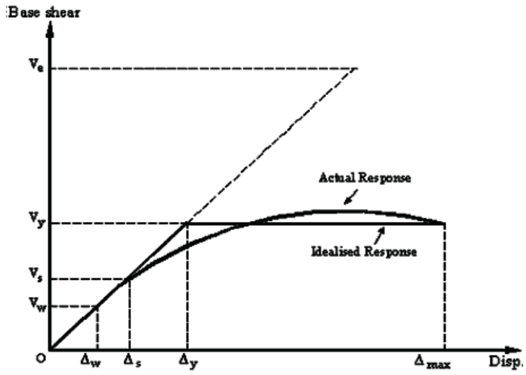

Figure 1. Typical pushover response curve for evaluation of behavior factor, *R*.

Miranda (Miranda, E. and Bertero, V) arrived at a set of equations expressing R_μ in terms of the above characteristics. Their study also showed that magnitude and distance has insignificant results while soil condition has a major effect on the ductility reduction factor. Here Ø is a function of soil condition, μ and $T.T_g$ is defined as the predominant period of the motion.

$$R_\mu = \frac{\mu - 1}{\phi} + 1 \leq \mu \tag{6}$$

Rock Sites:

$$\phi = 1 + \frac{1}{10T - \mu T} - \frac{1}{2T} \exp\left[-\frac{3}{2}\left(\text{In}T - \frac{3}{5}\right)^2\right] \tag{7}$$

Alluvium Sites:

$$\phi = 1 + \frac{1}{12T - \mu T} - \frac{2}{5T} \exp\left[-2\left(\text{In}T - \frac{1}{5}\right)^2\right] \tag{8}$$

Soft Soil Sites:

$$\phi = 1 + \frac{T_g}{3T} - \frac{3T_g}{4T} \exp\left[-3\left(\text{In}\frac{T}{T_g} - \frac{1}{4}\right)^2\right] \tag{9}$$

3. DESIGN, MODELING AND ANALYSIS

In TRF frames under study, behavior factor, R, is dependent on the number of stories and web thickness (t) of the vertical deep I-shaped beams. In this study 2 groups of 1, 3, 5 storey frames that one group having I-shaped beams with fixed height to the columns and other group having different shapes of the link beam with nonprismatic shape, fillet shape are considered, covering low to medium rise buildings, as shown in fig. 3, note that the bold line in the middle of frames span is representing deep I-shaped members of TRF. The original building is a 5 story residential apartment as shown in fig. 2, having concentric braced frames in one direction and frames with TRF at the other (Frames which are hatched). All studied frames have simple connections except in TRF, and are 3-bay wide having TRF in the central bay. Earthquake and Gravity Loads and specification of steel as shown in table 1.

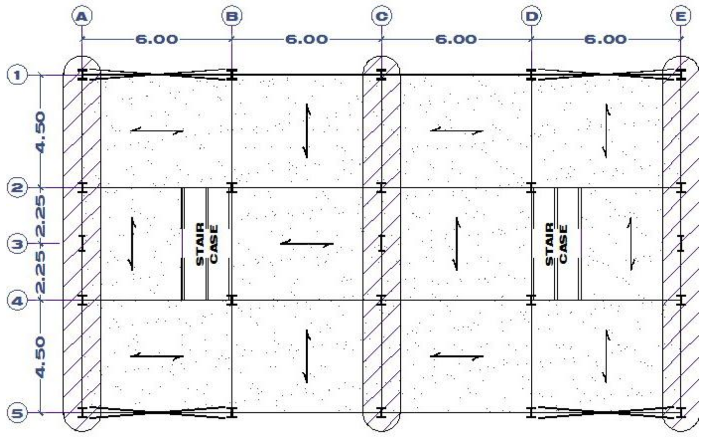

Figure 2. Plan of the original building with TRF in the hatched frames

Table 1. Earthquake and Gravity Loads and specification of steel

Earthquake	
Soil type	
A=0.35	
I=1	
X Dir	Y Dir
R_X=6	R_Y=7
$T_X=0.05(H^{3/4})$	$T_Y=0.07314(H^{3/4})$
B_x=2.33	B_Y=2.75
C_X=0.1359	C_Y=0.1375

Gravity Load	
Dead Load of Surrounding walls	700 Kg/m
Dead Load of Ceiling	700 Kg/m^2
Live Load	200 Kg/m^2

ST-37	
F_y=2400 Kg/cm^2	F_u=3700 Kg/cm^2
E=2100000 Kg/cm^2	Y=0.3

Codes which have been used are:
10th section of Iranian building code for designing steel members.
2800 Standard for seismic provision of Iranian code.
6th section of Iranian building code for loading.
Iranian instruction for seismic rehabilitation of existing buildings.No.360, management and planning organization.

Allowable stress design procedure used for all frames, SAP2000 program was used to carry out nonlinear static pushover analysis for each systems. To compare response factor more accurate, a modifying factor is generated by modeling 1-story, 3-story and 5-story frames with fixed height and variant height link beam in SAP2000 , see fig. 4. The modifying factor is the average ratio of R factor. By multiplying this factor to SAP2000 results, the response factor evaluated for TRF frames will be more accurate. specification of section into designed frames with fixed height link beam and nonprismatic link beam as shown in Table 2.

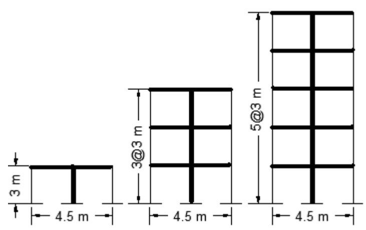

Figure 3. Geometry of frames under study

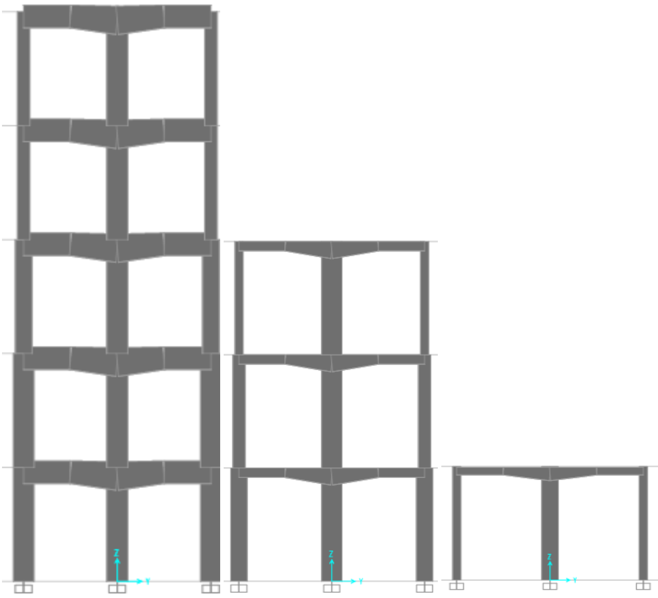

Figure 4. Geometry of frames with nonprismatic link beam under study

Table 2. Specification of section into designed frames with fixed height and nonprismatic link beam

Storey	Side column	Fixed height Link beam	V.P.G
1	IPB200	H=25 B_f=12 t_f=1 t_w=0.4	H=40 B_f=20 t_f=2 T_w=0.4
3	IPB400 IPB300 IPB200	H=30 B_f=15 t_f=1 T_w=0.6	H=50 B_f=20 t_f=2 T_w=0.4
5	IPB500 IPB500 IPB400 IPB300 IPB300	H=60 B_f=20 t_f=2 T_w=0.6	H=50 H=60 B_f=20 B_f=20 t_f=2 t_f=2 t_w=0.4 t_w=0.6

Storey	Side column	Nonprismatic Link beam	V.P.G
1	IPB200	H= 20 to 35 B_f=12 t_f=1 t_w=0.4	H=40 B_f=20 t_f=2 T_w=0.4
3	IPB400 IPB300 IPB200	H= 25 to 45 B_f=15 t_f=1 T_w=0.6	H=50 B_f=20 t_f=2 T_w=0.4
5	IPB500 IPB500 IPB400 IPB300 IPB300	H= 55 to 75 B_f=20 t_f=2 T_w=0.6	H=50 H=60 B_f=20 B_f=20 t_f=2 t_f=2 t_w=0.4 t_w=0.6

To compare SAP2000 results push over curves of frames with different link beams obtained by this program are shown in fig. 5. Behavior factors of 1- storey, 3- storey and 5- storey TRF with fixed beam and variant beam with equal stiffness with 4, 5 millimeter web thickness of the vertical deep I-shaped beam will be evaluated . As shown in figure 6, the difference of behavior factor of frames are between 0.7 for 1- storey TRF (with t= 4 mm) and 0.63 for 3- storey TRF (with t= 4 mm) and 0.73 for 5- storey TRF(with t= 4 mm & 6 mm) and the selected average difference factor between fixed beam and variant beam will be equal to 0.68.

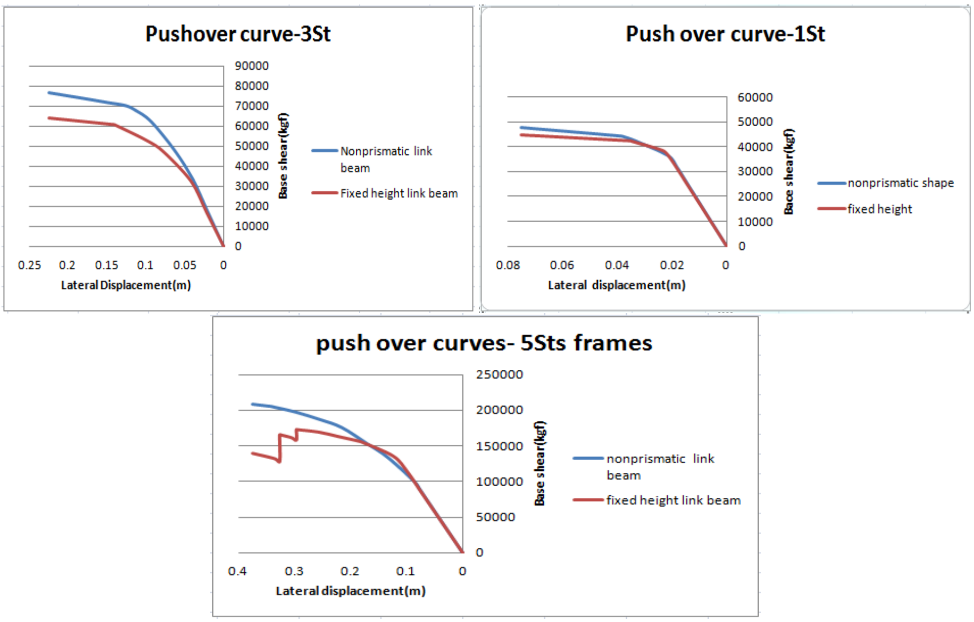

Figure 5. Compare SAP2000 results push over curves of frames with nonprismatic link beam and fixed height link beam for 1-storey , 3-storey, 5-storey TRF frames

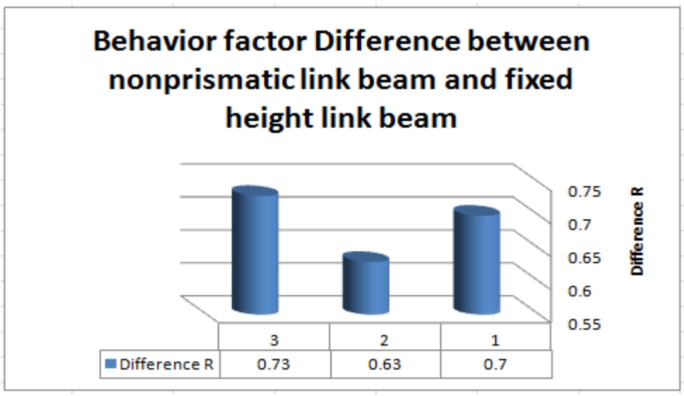

Figure 6. Behaviour Factor difference for 1, 3, 5 storey TRF frames with different link beam
1 : 1 storey, 2 : 3 storey , 3 : 5 storey

Fig. 7. shows push over curves and the for 3-storey TRF frames with fixed link beam and nonprismatic link beam and the idealized bilinear curves. Due attention to the horizontal part of all curves, it can be concluded that the TRF frames with nonprismatic link beam have good ductility and are capable to resist large displacement. Also the second part of bilinear curves have positive slope that shows the system stiffness is not drop down suddenly at large displacement and in comparison with equal stiffness with TRF fixed height, the TRF frames with nonprismatic link beam having better seismic behavior and bearing further base shear and having upper ductility.

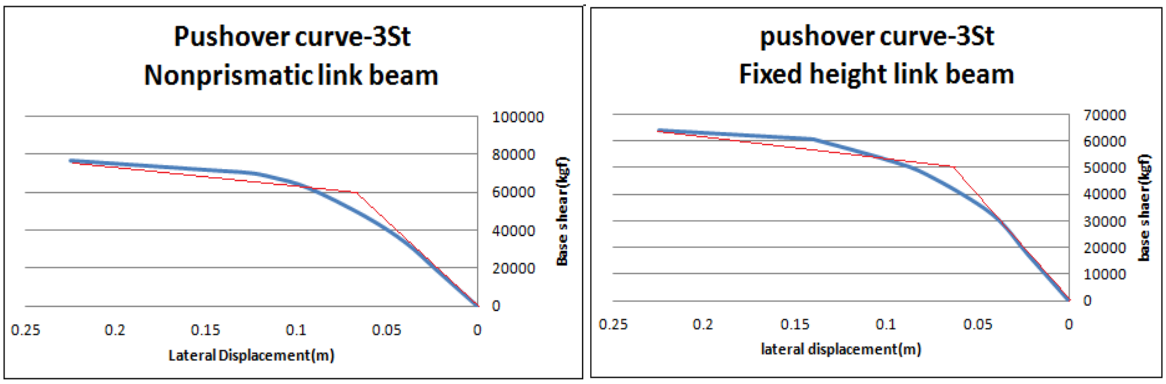

Figure 7. Push- over curves and idealized bilinear curves for 3-storey frames with nonprismatic link beam and fixed height link beam obtained by SAP2000

Table 3. Results of Nonlinear static push-over analysis and R factor parameters

Frame	1St.fixed height link	1St. nonprismatic link	3St.fixed height link	3St. nonprismatic link	5St. fixed height link	5St. nonprismatic link
K_i (kg/cm)	17180	17660	7690	8390	1150	11630
Δ_s (cm)	1.64	1.5	3.217	3.05	8.71	7.9
Δ_{max} (cm)	7.5	7.5	22.5	22.5	37.5	37.5
T (s)	0.31	0.30	0.63	0.60	0.64	0.65
Y	1.44	1.44	1.44	1.44	1.44	1.44
R	7.60	8.30	11.63	12.26	7.16	7.89

Results of push over analysis and R factor parameters of studied frames are shown in table 3. It can be seen that R factor in frame with fixed height link beam increases from 7.60 of 1- storey to 11.63 of 3-storey and then drops down to 7.16 with 5- storey TRF frame. In this manner It can be seen that R factor in frame with nonprismatic link beam increases from 8.30 of 1- storey to 12.26 of 3- storey and then drops down to 7.89 with 5- storey TRF frame. Therefore behavior factor with safety factor consideration is 8.79 whiles Suggested behavior factor frame with nonprismatic link beam with safety factor consideration is 9.48 that is the lowest of the R values range for evaluated T-shape resistant frames.

4. CONCLUSION

In this paper, behavior factor and seismic characteristics of a new Structural system, TRF, with fixed height link beam and nonprismatic link beam have been evaluated. From the analysis results we can draw the following conclusions:

The push- over curves shows adequate ductility of TRF frame with nonprismatic link beam in compare of the TRF frames with fixed height link beam.

The TRF frames with nonprismatic link beam having better seismic behavior and bearing further base shear and having upper ductility and has high response modification factor that will reduce Structure's steel weight and cause economical benefits in construction.

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