Comparison of seismic responses of T Resistant Frame (TRF) with shear or bending yielding in link beams

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SUMMERY:

Eccentric and concentric braced frames hysteretic behavior is asymmetric in tension and compression, other limitations such as, energy dissipation and ductility or providing opening and stiffeners position in those frames, are also appeared. Consequently, the concept of T Resistant Frame (TRF) has been introduced to overcome this deficiency. The configuration of TRF system fabricated in this study is a deep I-shaped steel beam (V.P.G) that vertically placed within the span, connected with two other deep link beams (H.P.G) to the side columns at each story level, improvement of system by utilization of rigid connection in link beams is also provided. The bending or shear yielding of link beam could have a significant effect on its overall behavior since it directly influences the energy dissipation of the member. In this paper, analytical study such as push over method is used for illustration of the seismic parameter of link beam with shear or moment yielding with different configurations that are rested in frame and it is seemed the (TRF) system with shear performance of the link beams have efficient behavior and appropriate response modification factor (R_W). Furthermore, by developing nonlinear Finite Element model of a TRF system, other properties are properly investigated.

Keywords: T resistant frame, Seismic behavior, Link beams, Shear and bending yielding, Response modification factor

1. INTRODUCTION

As respect to development of construction industry especially in manufacturing of resistant structures against earthquake load and optimization of materials with modern lateral porter systems chiefly in under the risk of earth quake arena, structure with sufficient stiffness and strength to control deflection and to prevent any possible damage. 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, lateral porter system TRF with primary idea of suitable quake operation especially in shear yielding in its elements is explained by Ashtari. This system consists of vertical beam-column (Vertical Plate Girder (V.P.G)) with high depth, that is located at the middle of span and are jointed to surrounding piles by two link beams (Horizontal Plate Girder(H.P.G)). The idea of high depth plate girder and low thickness of its web for usage of post buckling resistant with respect of tension field theory and also rigid connection link beam to vertical plate girder and surrounding piles even rigid based connection of them to earth are improved the operation and optimum system and the earthquake force would be merged specially by running of link beam. Firstly the bending yielding approach has been considered an investigation of V.P.G connection method and the number of middle beam-column that is located at the middle of span, suitable quake operation of systems are deducted (P.Ashtari, M.Bandehzadeh 2009 and P.Ashtari, A.A.Abbasi 2010), also this lateral retrofit system was checked by performing Endurance Time method(ET) analyze and obtaining of plasticity and confirmation of prior studying of suitable bending behavior system with different span's length and alternate height(P.Ashtari,M.Gorzin 2011). In this paper,



regarding history of studies and investigation and also first aim of producing this system, the study progressed its structure operation like Eccentric braced frame (EBF) and shear wall and a coordinating of this matter that previous researchers proceed just to moment yielding specially in link beam, and demand for optimization of system behavior is felt. According to definition of running condition at elements in moment frame, Eccentric Bracing Frame (EBF) and shear wall in this paper, seismic behavior of a new structural system (TRF) with bending or shear yielding will be evaluated. Section properties of the vertical I-shaped beam and link beams have a major effect on the ductility and energy dissipation of the TRF system. The condition of bending or shear yielding specially in link beam has been studied by SAP 2000 and finite elements software ABAQUS. The effect of running on methods to behavior and quake parameters on non-linear static analysis has been used to estimate of site, position and kind of yielding and control of running condition through usage of finite elements software.

2. MODELING

2.1. THE GENERAL ASSUMPTIONS

In this study 1 storey frames, 3m high are considered, for covering structure behavior three model both of them with similar span and the last with similar plane and different length in the span that TRF are located Fig.2.1.1span length is4.5m, 2.25m,and the similar length and width plan in Fig.2.1.2,note that the bold line in the middle of frames span is representing V.P.G members of TRF, behavior factor, R, is dependent on the shear or moment yielding of I-shaped beams as these called link-beams. The building is a residential apartment as shown in figure 2, having concentric braced frames in one direction(x dir) and frames with TRF at the other (Y dir)(Frames which are hatched). All studied frames have simple connections except in link beam connection to TRF and side column; also have rigid connection to base. The properties of modeling, analysis and design are shown in table. 2.1.1. Allowable stress design procedure used for all frames to carry out the analysis. The modeling, design and analysis are performed in SAP2000 and the outcomes are checked by Finite Element modeling in ABAQUS. These models are performed:

Frame 1: Link beams with bending yielding (Span length: 4.5m) (e=195 cm) Frame 2: Link beams with shear yielding (Span length: 4.5m) (e=195 cm) Frame 3: Link beams with shear yielding (Span length: 2.25m) (e=83.5 cm)



Figure. 2.1.1.section of one span with TRF

Codes which have been used are: Uniform Building Code.ASD. (UBC97) 2800 Standard for seismic provision of Iranian code (RERDB2800) 6th section of Iranian building code for loading. (6th IBR) Iranian instruction for seismic rehabilitation of existing buildings.No.360, management and planning organization.



Figure. 2.1.2. Plan of the original building with TRF in the hatched frames

Table. 2.1.1. Assumptions of Loading and specification of steel

| Earthquake | | | | |
|------------------------|------------------------------|--|--|--|
| Soil type | | | | |
| A=0.35 | | | | |
| I=1 | | | | |
| X Dir | Y Dir | | | |
| R _X =6 | $R_{Y}=7$ | | | |
| $T_X = 0.05(3^{3/4})$ | $T_{\rm Y}=0.07314(3^{3/4})$ | | | |
| 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 | | | | |
|------------------------------|----------------------------|--|--|--|
| $F_y=2400 \text{ Kg/cm}^2$ | $F_u=3700 \text{ Kg/cm}^2$ | | | |
| E=2100000 Kg/cm ² | Y=0.3 | | | |

2.2. MODELING AND DESIGN IN SAP2000

The design of the structures with shear and bending yielding is accomplished in SAP 2000 and, The yielding criteria for H.P.G in all frames is expressed as EBF link beams, V.P.G such as shear wall and in this manner like side column moment frame terms. The specifications of appropriates sections that are deduced are shown in table. 2.2.1

| SIDE COLUMN | V.P.G | H.P.G | |
|----------------|------------------------|------------------------|---------|
| HE200B | t _f =2 cm | t _f =1 cm | Frame 1 |
| | b _f =20 cm | $b_f=12 \text{ cm}$ | |
| | t _w =0.4 cm | t _w =0.4 cm | |
| | h=40 cm | h=25 cm | |
| HE200B | t _f =1.5 cm | t _f =2 cm | Frame 2 |
| | b _f =20 cm | b _f =15 cm | |
| | t _w =0.4 cm | t _w =0.4 cm | |
| | h=40 cm | h=25 cm | |
| HE180B | t _f =1.5 cm | t _f =1 cm | Frame 3 |
| | b _f =15 cm | $b_f=12 \text{ cm}$ | |
| | t _w =0.4 cm | t _w =0.4 cm | |
| | h=40 cm | h=25 cm | |

Table 2.2.1 The specifications of appropriates sections

2.3. FINITE ELEMENT MODEL IN ABAQUS

To evaluate other seismic behavior of TRF, such as energy dissipation characteristics or R factor finite element models of the span that TRF are located in, are generated using ABAQUS software. The elements which have been used are four nodes shell elements with 6 degrees of freedom at each node. The material is introduced as Isotropic with elastic plastic strain hardening behavior (hardening slope: 3%) the VON-MISES criteria and large displacement for illustration local buckling and post bulking strength are used. Loading protocol for investigation in gravity and lateral loading of TRF models according to codes that are introduced below and one direction displacement in higher and corner of the frames have been considered, which have identical distance between stiffeners at vertical plate beam(V.P.G) web as listed:

Middle: 47 cm End (base):40 cm End (near by H.P.G):25 cm

3. SEISMIC NON-LINEAR AND BEHAVIOR PARAMETERS

3.1.YIELDING PARAMETERS

Non-linear analysis such as push-over method is exact process to illustrate the system behavior in seismic loading, the response of system are assumed as one degree of freedom and otherwise cause the time history response along the analysis are constant and these two supposition have no accuracy but it seems have perfect anticipation by using one mode shape of multi degrees of freedom to evaluated the maximum response. This analysis and its parameters should be calculated for approaching the push-over curve for evaluation of behavior such as energy dissipation, ductility, strength and computing the seismic parameters such as R factor, etc. One of the important data that could be export from this approach is the non-linear hinges that assess the bending or shear yielding and performance point and the step of yielding that cause the limitation of analyses procedure.

The edge of plastic rotation and performance point for bending or shear yielding for components of moment frame, link beam of EBF and shear wall is shown in Table5-3 of Iranian instruction for seismic rehabilitation of existing buildings. No 60.for the yielding property the below formulas are used that θ_y is the yield rotation and K_e is the equvilant stiffness for link beam and G, E ,K_S ,K_b ,Q_{CE},e, I_b , F_{ye} , Z correspond to the shear module , elastic module , shear and bending stiffnes , demand strength that depends on bending or shear performance of link beam of TRF ,length of shear beam, effective yield stress and plastic modules.

$$\theta_{y} = \frac{ZF_{ye}I_{b}}{6EI_{b}}$$
(3.1.1)

$$K_e = \frac{K_S K_b}{K_S + K_b}$$
(3.1.2)

$$K_{s} = \frac{GA_{W}}{e}$$
(3.1.3)

$$K_b = \frac{12EI_b}{e^3}$$
(3.1.4)

$$\theta_{y} = \frac{Q_{CE}}{K_{e}e}$$
(3.1.5)

3.2. BEHAVIOR FACTOR PARAMETERS

Behavior factor R (R_w), (EC 8) is the ratio of the strength required to maintain the structure elastic to the inelastic design strength of the structure, therefore accounts for the inherent ductility and over strength of a structure and the difference in the level of stresses considered in its design (UBC67,NEHRD Provision). It is generally expressed by Youang's assessment, and the following parameters are calculated to access the ductility of this system in allowable strength design (ASD). The Fig 3.2.1 is illustrated the actual system behavior in state of elastic-plastic and bilinear behavior and their parameters in push-over analysis.

$$R_{w} = \frac{C_{eu}}{C_{w}} = \frac{C_{eu}}{C_{y}} \cdot \frac{C_{y}}{C_{s}} \cdot \frac{C_{s}}{C_{w}} = R_{\mu} \Omega y$$
(3.2.1)



Figure 3.2.1 Typical pushover response curve for evaluation of behavior factor, *R*.

The structure ductility, μ_s , is defined in terms of maximum structural drift (Δ_{max}), idealized yield strength (Δ_v)

$$\mu_s = \mu = \frac{\Delta_{\max}}{\Delta_y} \tag{3.2.2}$$

ductility dependent component, 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. The equations expressing R_{μ} in terms of the above characteristics (Miranda and Bertero). Here \emptyset is a function of soil condition, μ and $T.T_g$ is defined as the predominant period of the motion.

$$R_{\mu} = \frac{\mu - 1}{\phi} + 1 \le \mu \tag{3.2.2}$$

Rock Sites:

$$\phi = 1 + \frac{1}{10T - \mu T} - \frac{1}{2T} \exp\left[-\frac{3}{2}\left(\ln T - \frac{3}{5}\right)^2\right]$$
(3.2.3)

Alluvium Sites:
$$\phi = 1 + \frac{1}{12T - \mu T} - \frac{2}{5T} \exp \left[-2 \left(\ln T - \frac{1}{5} \right)^2 \right]$$
 (3.2.4)

Soft Soil Sites:
$$\phi = 1 + \frac{T_{g}}{3T} - \frac{3T_{g}}{4T} \exp\left[-3\left(\ln\frac{T}{T_{g}} - \frac{1}{4}\right)^{2}\right]$$
(3.2.5)

 C_e , C_y , C_s And C_w correspond to the structure's elastic response strength factor, the idealized yield strength factor, the first significant yield strength factor and the allowable stress design strength factor. Ω_o is the over strength factor that is appear as a result of strain hardening, redistribution of load and etc.

$$\Omega_0 = \frac{C_y}{C_s} \tag{3.2.6}$$

 Ω the actual over strength including the accurate factors ,Y is termed the allowable stress factor:

$$\Omega = 1.05 \times 1.1 \times \Omega_{\circ} \tag{3.2.7}$$

$$y = \frac{C_s}{C_w} = \frac{M_p}{M_w}$$
(3.2.8)

4. NON LINEAR PARAMETERS AND ANALYSIS

4.1. ANALYSIS IN SAP2000

The non-linear analysis of the structures with shear and bending yielding is accomplished in SAP 2000 and the push-over curves, locations and specifications of hinge in H.P.G and V.P.G were considered. Allowable stress design procedure used for all frames to carry out the analysis. Some of the parameters that were used to modeling: $C_0=1$, $C_1=1$, C_2 , C3 are calculated by SAP2000 in analysis proceeding. T $\leq 0.5 \rightarrow$ K=1It shows the load distribution method of earthquake is in triangle pattern.

4.2. FINITE ELEMENT ANALYSIS IN ABAQUS

The Von-Mises stress countors are illustrateded in Fig. 4.2.1 in 7.5cm displacement of pick point of frames. In frame1 the bending yielding is appeared in V.P.G and also the shear yielding in H.P.G web with $3.418 \times 10^{3} \text{ Kg/cm}^{2}$ in beam and $3.139 \times 10^{3} \text{ Kg/cm}^{2}$ in H.P.G, furthermore in frame 2 the stress

in V.P.G web is occurred more sooner than its flange but in last increment both of them have high Von-Mises stress and also shear yielding in H.P.G are took place with 2.728 $\times 10^{3}$ Kg/cm² in beam nearby H.P.G and 3.322 $\times 10^{3}$ Kg/cm² in its, at last in frame 3 have shear yielding first in V.P.G and then in H.P.G web 3.4 $\times 10^{3}$ Kg/cm² in beam and 3.3 $\times 10^{3}$ Kg/cm² in H.P.G. The consequences is indicated and proved the assumptions especially strain hardening (slope: 3%). The yielding is took place otherwise in flange of H.P.G at base and its web in connection field at top.



 Image: State of the state

Figure 4.2.1.countor of Von-Mises stress (a)frame 1.(b)frame 2,(c)frame 3

4.3. COMPARISION OF SEISMIC NON-LINEAR CONSEQUENCES IN SAP2000 AND ABAQUS

To compare ABAQUS and SAP2000 results, frames pushes-over curves obtained by these two programs are shown in Fig. 4.3.1. Behavior factor of three frames with similar web thickness of the V.P.G and different performance of links beam would be evaluated. The push-over curves of ABAQUS are illustrated that the distances of stiffeners don't allow the local buckling are took place.

Fig. 4.3.2 shows push- over curves and the idealized bilinear curves for frame 3 that have shear yielding in link beams and highest R factor. Due to attention to the all curves, it could be concluded that the TRF frame 3 have good ductility and are capable to resist large displacement and dissipate the energy and the earthquake load is not remanded in the system. Also the second part of bilinear curves have positive slope that shows the system stiffness is not drop down suddenly at large displacement.



Figure. 4.3.1. Comparison of push-over curves obtained by SAP2000 and ABAQUS. (a)frame 1,(b)frame 2,(c)frame 3.



Figure.4.3.2. bilinear push-over curves for frame 3,(a)SAP2000,(b)ABAQUS.

Results of push-over analysis and R factor parameters of studied frames are shown in table. 4.3.1 and are compared in Fig. 4.3.3. It could be seen that R factor increases from frame1 and then drops down in frame2 and then increases in frame3. In this study, Suggested behavior of link beams in yielding condition factor consideration is 8.08 that is the highest R values range for evaluated T-shape resistant frames.

| Frame | Frame 1 | Frame 1 | Frame 2 | Frame 2 | Frame 3 | Frame 3 |
|------------------------|-----------|----------|-----------|----------|-----------|----------|
| | (SAP2000) | (ABAQUS) | (SAP2000) | (ABAQUS) | (SAP2000) | (ABAQUS) |
| K _i (kg/cm) | 17180.157 | 17430.52 | 18597.532 | 14175 | 13884.32 | 13884.32 |
| $\Delta_{\rm S}$ (cm) | 1.698 | 1.585 | 1.719 | 1.653 | 1.613 | 1.543 |
| Δ_{\max} (cm) | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| T (s) | 0.31 | 0.319 | 0.2978 | 0.282 | 0.278 | 0.278 |
| Y | 1.44 | 1.44 | 1.44 | 1.44 | 1.44 | 1.44 |
| R _w | 7.34624 | 7.87 | 7.255 | 7.98 | 7.73 | 8.08 |

Table. 4. 3.1. result of Nonlinear static push-over analysis and R factor parameters

R Factor Ratio



Figure.4.3.3. R Ratio Factor (1:R₂/R₁, 2: R₃/R₁, 3: R₃/R₂)

CONCLUSION

In this paper, from the analysis results we could draw the following conclusions: The push- over curves shows adequate ductility and high response modification factor which is shown its good energy dissipation characteristics even better than EBF behavior.

The T Resistant Frame have a appropriate performance in lateral loading by initiate shear yielding specially in link beams(V.P.G) by decreasing of their length.

TRF have not enough sufficient behavior in plastic region with bending yielding or inclined behavior to shear performance by increasing the flange area of its link beams with same proportionately stiffness and length in comparison with absolute shear yielding in this system.

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