COMPARING RESPONSE MODIFICATIONFACTORS OF T-SHAPE RESISTANT FRAMEWITH ECCENTRICALLY BRACED FRAME

Mostafa GHASSEMI
MSc. Graduated in structural engineering, University of Zanajn, Zanajn, Iran
m_ghassemi@znu.ac.ir

Mahdi GORZIN
MSc. Graduated in structural engineering, University of Zanajn, Zanajn, Iran
mahdigorzin@yahoo.com

Hossein TAJMIR RIAHI
Assistant professor, University of Isfahan, Isfahan, Iran
tajmir@eng.ui.ac.ir

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ABSTRACT

Response modification factor is one of the seismic design parameters which considers nonlinear performance of structures during strong earthquakes. This parameter is widely used in linear desing of structural members of buildings. Design codes are proposed response modification factors for common structural systems. Comparing on these values of lateral resistant systems gives a general information about their nonlinear behaviour in earthquakes and helps designers to select the best system for the under design structure. The present paper tries to evaluate response modification factors of a new structural lateral resistant system called ‘T-shape resistant frame’ (TRF) and compares its performance with eccentrically braced frames (EBF). in order to comparing the two systems, two dimensional steel frames with 3, 5, 8 and 12 stories and one bay are studied. These frames have been designed with TRF and EBF systems in the same condition to achieve a resonable analogy. The TRF and EBF parameters such as response modification, ductilityandover strength have been evaluated for all the frames. Response modification factors obtained from analysis of TRF frames illustrates that this system have high values. Results show that these factors of TRF are more than EBF ones. TRF’s ductility factor is increased with height so that 8 and 12 stories frames with TRFs are more than the EBF frames. It can be inferred that ductility factor of the TRF frames are significant. Morever, overstrength factors obtained from analyzing the TRF frames are more than the EBF frames in all models. Using TRF system in structures causes an optimum design because of its great response modification factor.

INTRODUCTION

Past earthquakes show the importance of using proper seismic resistant systems. There are many parameters affecting on lateral resistant systems selection such as strength, stiffness, ductility, energy dissipation capability and architectural limitations. Moment resisting frame (MRF), concentrically brace frame (CBF) and eccentrically brace frame (EBF) can be mentioned as prevalent lateral resisting systems. MRFs consist of only beams and columns which are connected to each other by fixed connections. This system stands against ground motions by its bending strength and stiffness of its members. MRFs have high ductility but their lateral stiffness islow in comparison with the other systems so that to limit their lateral displacement especially in higher buildings, columns and beams should have large cross sections. It leads to an uneconomical project. Concentrically braced frames consist of diagonal steel elements and have pinned connections. Lateral stiffness and strength of this system are significant but their ductility and energy dissipation are low according to the other systems. Eccentrically braced system has MRF and CBF advantages. It has not only appropriate lateral stiffness and strength due to its diagonal members but also high ductility and energy dissipation due to its link beams. Link beam opperates like a fuse which prevents other members entering nonlinear zone. Another lateral resistant system which hasbeen proposed recently is T-shaped resisting frame (TRF). This new form of framing system is constructed through a deep I-shaped steel beam which is vertically placed in the middle of span, connected with two other deep I-shaped beams at each story level. The TRF system has been proposed primarily by Ashtari and associates (Ashtari and Bandehzadeh, 2010). Past researches are shown that this system has ductile behaviour, high capability of energy dissipation and appropriate response modification factor under severearthquakes (Ashtari and Gorzin, 2011), (Ashtari and Ghassemi, 2011). Most of energy are dissipated due to yielding of the web of the TRF vertical members. Response modification factor is an important parameter in linear design of structures. This parameter shows earthquake loads reduction due to nonlinear behaviour of structural elements which is widely used in design of structures in linear range. So, determining this parameter for each structural system is necessary. Morever, comparing this parameter for different systems in the same condition can helps designers to select the best system. In this paper, response modification factor and its parameters of TRF and EBF are compared in the same condition.

MODELLING

In the present paper, response modification factor of T-shaped resisting frame (TRF) is compared with eccentrically brace frame (EBF) one. Frames with 3, 5, 8 and 12 stories are consideredwhich are representative of short through high buildings. The frames have been designed using TRF and EBF systems which are placed in buildings with regular plan and elevation. All connections in buildings with TRF systems are pinned except connections between TRF elements. Iranian National Building Code (INBC) section 6 has been used for building loading and section 10 has been used for steel design of the structures. Allowable stress design (ASD) method has been used for designing of steel elements. Plan of the buildings which the frames extracted from them are shown in Figure 1. Hatched frames determined in this figure are the location of the lateral resistant frames. In this paper, the frame which is located on the C gridlineaxis, is selected to analyze in both systems. This frame hasbeen modelled as a two dimensional frame. Loads applied to the frame from other elements and roofs are considered as external loads on the frame.

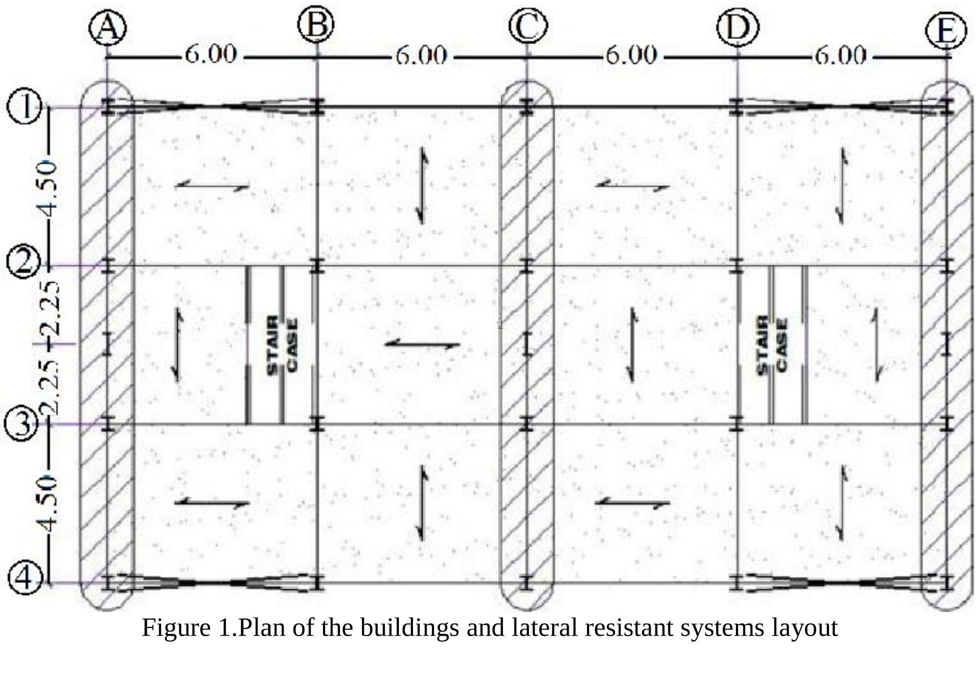

Figure 1.Plan of the buildings and lateral resistant systems layout

Analysing and designing of the frames have been performed with sap2000 software. Steel material properties which is used in the models has 2400 kg/cm^2 yielding stress, 3700 kg/cm^2 ultimate stress, 2.1×10^6 kg/cm^2 modules of elasticity and 0.3 Poisson ration. Figures 2 shows 3-story frames with EBF and TRF lateral resisting system. As can be seen in this figure, dimensions and conditions are the same for both systems. So, bay width is 4.5 and story heights are 3.00 meter.

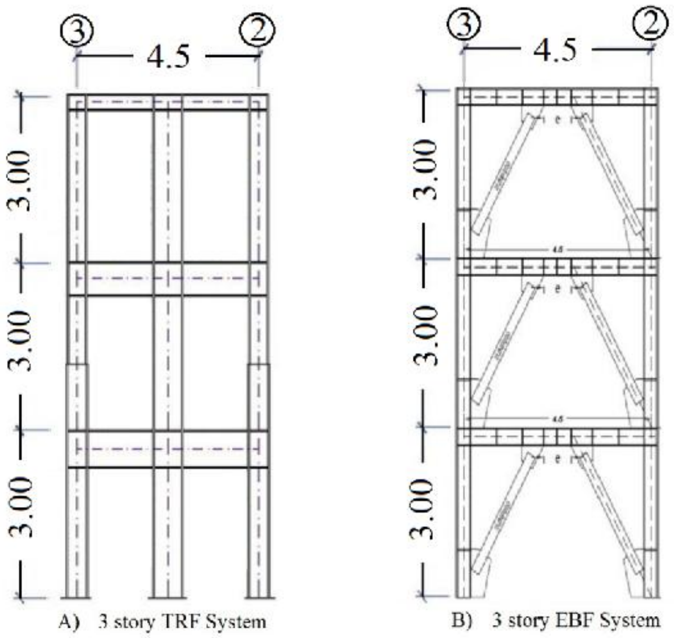

Figure 2. TRF and EBF frames: A) 3-story TRF system, B) 3-story EBF system

According to Iranian seismic code (ISC), a concentric brace frame with intermediate ductility has response modification factor equal to 7. With respect to past investigations on TRF, response modification factorof this system is considered equal to 9. So, mentioned values are used to calculate earthquake factors in equivalent static analysis method, consequently designing of the frames. Earthquake factors obtained according to ISC code for the frames are shown in Table 1.

Table 1.Earthquake factors of the frames in equivalent static analysis

Number of story	3-story		5-story		8-story		12-story	
Structural system	TRF	EBF	TRF	EBF	TRF	EBF	TRF	EBF
Earthquake factor	0.107	0.137	0.107	0.137	0.1	0.119	0.075	0.097

RESPONSE MODIFICATION FACTOR

Mazzolani and Piluso(1996) addressed various theoretical approaches in order to computing the response modification factor. These approaches are the maximum plastic deformation approach, the energy approach, and the low-cycle fatigue approach. ATC-19 proposed a simplified procedure to estimate the response modification factors. In this procedure, the response modification factor, R, is calculated as the result of the three parameters that extremely influence the seismic response of structures (equation 1).

$$R=R_oR_\mu R_r \quad (1)$$

Where R_o is the overstrength factor.Analyzing structures in elastic zone under earthquakes can creates base shear forces in structures which are so noticeably bigger than real structural responses (Jinkoo Kim and Hyunhoon Choi, 2005). Structures can dissipate lots of earthquake energy and behave in inelastic range of deformation. In fact, maximum lateral strength of structures generally exceeds its design strength. This fact is known as overstrength which its value shows by a factor called “overstrength” factor. R_μ is ductility factor which is a measure of the global nonlinear response of a structure. Also, R_r is redundancy factor to specify the improved reliability of seismic framing systems constructed with multiple lines of strength.

Figure 3 shows relationship between base shear and roof displacement of a structure. There are three types response of structuresin this figure. Corresponding elastic response is a response in which elastic strength of the structure is more than earthquake loads and the structure behave in elastic range during earthquake. This behavior occurs in very strong structures which are usually non-economic and almost are not considered in structural design. Actual inelastic response is the real response of general structures which are designed for forces less than earthquake. A bilinear elastic-perfectly plastic behavior (idealized bilinear response) is usually used instead of actual inelastic response of structures in order to simplicity of structural analysis and assessment.

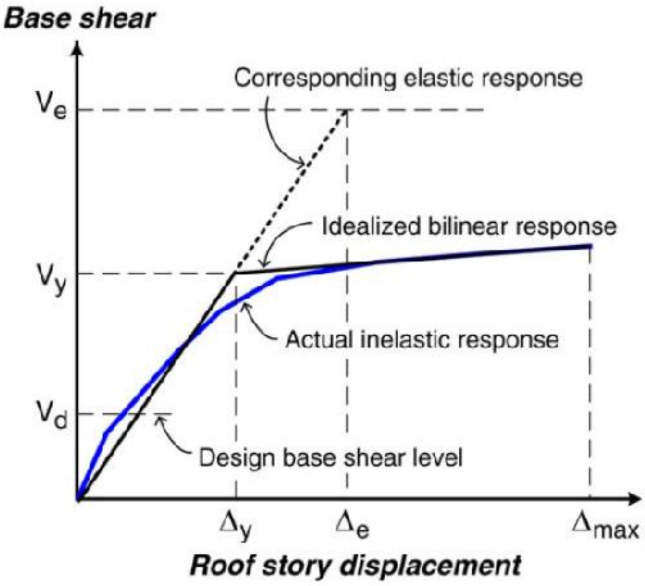

Figure 3. Lateral load-roof displacement relationship of a structure

With respect to Figure 3, overstrength factor and ductility factor can be calculated according to equation 2.

$$R_{\mu}=V_e/V_y \text{ , } R_o=V_y/V_d \quad (2)$$

Where R_{μ} is ductility factor, R_o is overstrength factor, V_e is maxinmum seismic demand for elastic response, V_y is corresponsing to the maximum inelastic displacement and V_d is design base shear.

COMPARATIVE STUDY

An important parameter that is used in structural design in linear range is response modification factor. Values of this parameter can help engineers to select the optimum and the best system and compare alternatives in their projects rapidly. So, in this section, this parameter for TRF and EBF systems with various stories are examined and compared to help selecting and finding the better systems with considering their advantages and disadvangages. Response modification factors of the frames are illustrated in Figure 4. As can be seen in this Figure, in the 3-story frames of TRF and EBF, response modification factors are obtained 9.83 and 7.34 respectively. On the other word, for 3-story frames, this parameter for the frame with TRF system is about 34 percent more than the EBF one. This difference is decreased in the 5-story frames which the TRF responce modification factor is about 20 percent more than the EBF. The factor for the TRF frame is 11.12 and for the EBF frame is 7.76 in 8-story frames. The defference between the two systems is more than the shorter frames. The most discrepancy between response modification factors of the two systems is happened in 12 stories frame, so that, the factor of TRF have been obtained 8.44 and achieved 3.73 for the EBF frame. Obtained response modification factor for TRF is 126 percent more than of the EBF frame. It can be concluded that in all of the frames, the TRF frames have more response modification factor than EBFs. The deference between the two system parameters increases with increasing in story height except in the 5-story frame. The least values among the frames studied in this paper is happened in 12-story frames for both systems. It can be concluded that considered base shear in linear structural design for TRF system is less than those of EBF. So, structures which are designed using TRF system are more optimum than EBF. The values shown in Figure 4 for TRF system are more than the response modification factors of the other structural systems. It shows that TRF system is an appropriate lateral resistant system which dissipates earthquake energy properly.

One of the parameters that affects on response modification factor is ductility factor. Figure 5 shows the system ductility factor of the TRF and EBF frames. It can be observed that their trends are different.

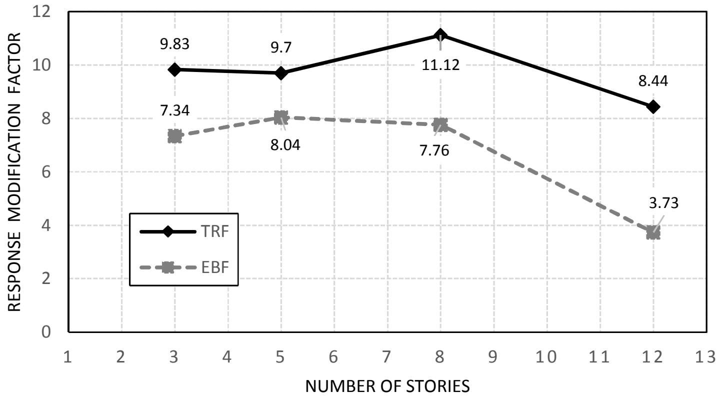

Figure 4. Comparison Response modification factor of TRF and EBF

Ductility factor of the EBF frames is decreased with increasing in story height. This reduction isapproximately linear. This factor of EBF frames becomesminimum in the 12-story frame which is equal to 2.15. As mentioned before, minimum response modification factor is happened in 12-story frame too. So, this parameter is an important parameter to reduction of the response modification factor of the EBF frames. In according to Figure 5, ductility factors of the TRF frames are less than EBF in the 8-story and 12-story frames and more than EBF in 3-story and 5-story. The values of TRF frames except in the 8-story frame are close to each other. Ductility factor of the 8-story TRF frame in more than the other TRF frames like its response modification factor.

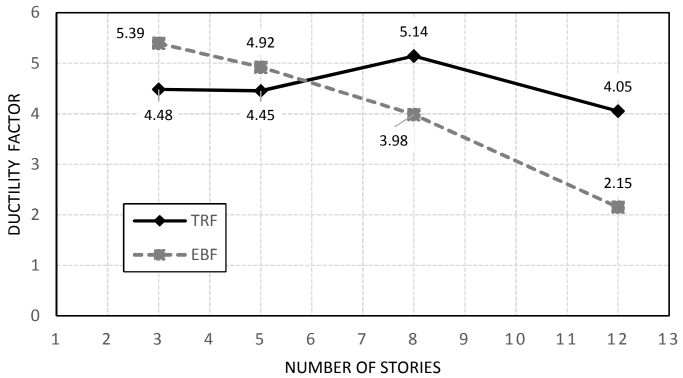

Figure 5. Comparison ductility factor of TRF and EBF

Figure 6 shows overstrength factors of the TRF and EBF frames. As can be seen in this figure, there is not significan different between values of the EBF frames. It is observed in the TRF frames especially in 8-story and 12-story frames. Overstrength factor of TRF in taller buildings are less than shorter ones. So, increasing in number of story reduces overstrength factor in both systems except a neglegible increasing in the 5-story EBF frame. Comparing the results shows that overstrength factor of TRF system is more than EBF ones in the same condition and loading. It is true for all frames with different number of story.

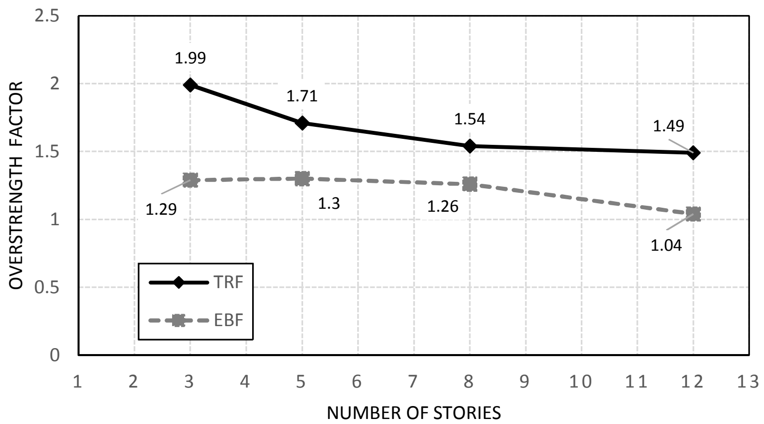

Figure 6. Comparison Over strength Factor of TRF and EBF

CONCLUSIONS

Since response modification factor is used in common structural design methods, in this paper, this parameter for TRF and EBF systems in the same condition are obtained and compared. On the basis of the results,response modification factors of TRF systems have been obtained 9.8, 9.7, 11.1 and 8.4 for 3, 5, 8 and 12 story frames respectively, which are more than of EBF's in all models. This parameter for TRF frames alteres from 20 to 126 percent more than EBF's. Maximum and minimum response modification farctor for TRF are accured in 8 and 12 story frames, although it is obtained from 5 and 12 story of EBF frames respectively. Moreover, ductility factors of TRF system except in 3 and 5 storyframes, are further comparing to EBF's. Ductility farctor decreases uniformely with increasing in number of stories in EBF frames. But there is not a considerable change in TRF frames except in 8 story frame. Furthermore, Overstrength factors of taller buildings of TRF are less than shorter ones. Its decrease is reduced with increasing in number of stories. This parameter for EBF system does not have a considrable change from 3 to 8 stories, but in 12 stories frame it is decreased 17 percent in accordance with 8 stories frame.

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