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EVALUATION OF SEISMIC BEHAVIOR OF IRREGULAR STEEL STRUCTURES IN PLAN WITH BRB AND EBF BRACES UNDER NEAR-FAULT EARTHQUAKE

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ABSTRACT

Building structures under earthquake loads are suffered from displacement. The most common methods of displacements' control for steel structures are braces which are implemented in various forms which are usually lateral. Buckling Restrained Braces (BRB) and Eccentrically Braced Frame (EBF) are kinds of braces that combine "lateral suitable stiffness" and "absorption of energy" to each other and apply BRBs to resist the structure against earthquake due to their resistance to buckling and the high plasticity. Eccentrically Braced Frame (EBF) leads to the emergence of large bending moments and shear forces in the beam area near to brace. In this way, the tensions in this area enter from the beam into the inelastic range and lead to energy loss caused by the earthquake. In order to the seismic retrofitting of steel buildings with the braced frames BRB system instead of EBF is assessed in irregular plan in the area near the fault. Dynamic analysis is used due to the structure over 5 floors, proximity faults and irregularity in the plan; and for dynamic analyses and modeling of braces, especially BRB, PERFORM-3D software is applied. After analysis, the results show that applying BRB instead EBF reduces structural weight, shear base, and absorbed energy.

Keywords: Steel structures, braces of BRB and EBF, nonlinear dynamic analysis.

1. INTRODUCTION

Recently, the topics of the control of the inactive structures in earthquake-prone areas have been concerned by structural engineers. During the earthquake, a lot of energy is applied in the form of strain and kinematic to the structure. The most common design methods based on inelastic deformation of certain parts of the structure, it is assumed that the input energy is amortized a lot. But in the 1994 Northridge earthquake and the 1995 Kobe earthquake, it was seen that structures which were designed and implemented properly suffered from destruction or severe damages because of damage to the main members. To reduce structural damages was considered in the main members after production and manufacturing of inactive energy absorptive systems to restrict the damages in sub-members and interchangeable members. Inactive control of the structure is a method whereby it can reduce the severe damages caused by the earthquake; and the damages are noticed some of secondary replaceable members. With proper design and precise placement of damper parts in structures, it can be allocated a large part of the energy loss to these components, followed by reducing incurred damages to the original members. In addition, the replacement of the fuses will be easy and low cost after the earthquake. So far, various types of energy absorbing systems from earthquake are presented by the researchers. Here, according to the fact that the steel frames with joint connections are the only robust and secure system against lateral forces of braces, seismic behavior of irregular steel structures in plan is assessed with BRB and EBF braces under the near fault earthquake. Near the fault, the torsional and irregular effects in the plan are the main factors of vulnerability of steel buildings. During the earthquakes, also, a lot of energy enters in the building that in the common design of structures, inelastic deformation of members in certain areas of the beam, column, and other members lead to waste energy. Permanent damage is often so high in these members that is required the high cost to rebuild. With proper design of energy dampers of BRBs or EBFs in the structure, the plenty rate of energy is transmitted to the dampers that lead to reduce damage to the structure. Here 3 earthquake records near faults were selected to load the dynamic non-linear model and using the Seismosignal software to scale the design spectrum. Various applicable softwares have been developed for dynamical analyses of nonlinear model and each one has characteristics and limitations. Some of them such as PERFORM-3D software provide the possibility of building the non-linear model directly and in some software such as SAP and ETABS must be used approximate and equivalent methods. One of the very strong softwares for nonlinear and complete analyses to model Buckling Restrained braces (BRB) and linked beam in Eccentrically Braced Frame (EBF) braces is PERFORM-3D software that this software was also used in this study.

2. Design of binder beams in eccentrically braced structures:

Design of eccentric frame with horizontal link is carried out based on the "design in the capacity method". The purpose of this design approach is focusing all non-linear deformations only in linked part, so that all organs outside the bond at the time of the earthquake remain in elastic mode. To achieve this goal, the other members must be designed for the corresponding forces associated with linked shear capacity and for the application of needed confidence coefficient. Meanwhile, the effect of the bond length influences on the hardness and plasticity of these frames. Numerous researches have shown that in bonds with short length and long length, it is formed shear hinge and bending hinge, respectively. Between the long and short lengths, there is the possibility of forming both mentioned hinges at the same time. The results suggested that the formation of the shear hinge in comparison with bending hinge has better stability and performance in terms of hardness and plasticity [1]. To access the shear behavior in the link beam, bond length (e) has been considered one meter for all of the desired structures with respect to the opening of the frames 5 and 6 meters.

3. **Buckling Restrained Brace**:

This kind of brace consists of a yielding steel core which is located within a steel container filled with a special concrete. The brace can withstand against any kind of buckling mode and reach to the yield strength. In this brace, the steel core bears exerted axial force and the outer container provides lateral restraining supports by filling concrete for steel core to prevent its buckling [2]. The steel core surfaces of the brace is covered by a thin layer of a viscous material, so that it can prevent the transfer of shear from concrete to the steel core during deformations of the steel core, and also it provides the possibility to accommodate radial deformations caused by Poisson's effect as long as the member is under pressure. The present conditions enable the steel core to freely give axial deformations inside the container, which is filled with concrete [3].

4. Introducing the studied structures

Two 6-story building structures with residential application were designed by ETABS software based on the third edition 2800 [4], AISC-regulation [5] and were analyzed by PERFORM-3D software. The stories' height is 2.3 m and underpin of every story is 600 m^2; structural system of the buildings as hinge frames with BRB or EBF braces in both directions and the location of braces are shown in Figure 1, and the stories' roof is joist covering that joists have been placed checker and the bottom diagram is considered semi-rigid. Figure 1 shows a view of the general plan of stories. For properties of used materials and gravity load refer to table 1 and table 2, respectively.

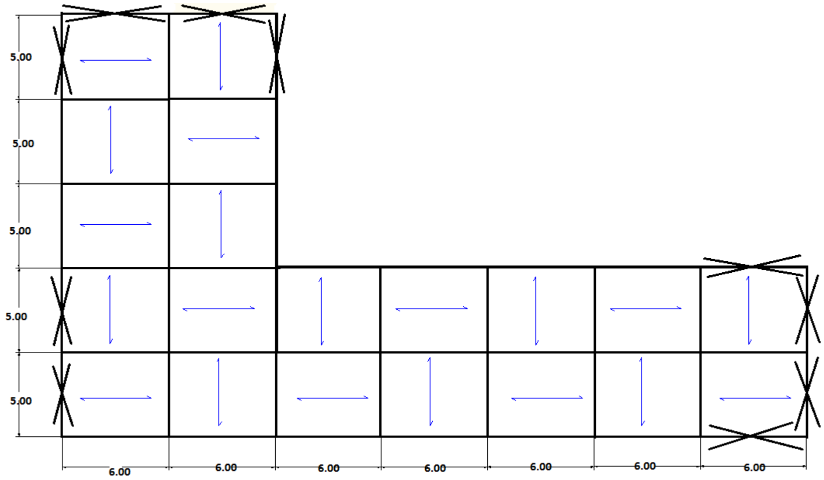

Fig1. The general plan view of the stories

Table1. Used material properties

E_c (k g/cm^2)	F_y (kg/cm^2)	F_U (kg/cm^2)
2.1E6	2400	3700

Table2. The summary of the gravity loads on the building:

Situation	Dead load (Kg/m)	Live load (Kg/m)
Bottom stories	620	200
Bottom rooftop	470	150
Lateral walls	215	-

5. Irregularity in the plan

Structural responses (torsional) in the irregular buildings depend on the structural characteristics as well as ground motion parameters. The evaluation of the effect of torsion in irregular buildings in the plan is a complex issue. Due to the effect of the torsion in the mentioned structures, non-linear time history analyses are implemented using three earthquake records. Torsional movement cause deflections and additional forces in some structural members in irregular buildings in comparison with the corresponding regular structures that torsional effect has been one of the most important reasons of damage to structures under seismic forces.

One of the conditions of being irregular structure in the plan is the distance of the center of the mass with the center of the stiffness that is more than 20% of the building dimension [4]. The distance of the center of the mass with the center of the stiffness in the desired structures in this research is more than 20% of the building dimension, in addition to the irregularity in terms of the center of mass and the center of stiffness, in terms of being asymmetric, they are also irregular towards the axes x and y. In such structures in order to provide the greatest effect of the earthquake, a hundred percent of the earthquake force of each direction is combined with 30 percent of the earthquake force perpendicular to it to be applied the greatest effect of the earthquake to the structure.

6. Nonlinear time history analysis

6-1. Selected records for performing nonlinear time history analysis

In this study, 3 records of the earthquake near fault have been used for nonlinear time history analysis. In the selection of the records, it has been tried to be a good consistency between them. This means that soil type of the records is according to their shear wave velocity in the range of 375 (m/s) ≤ V ≤ 750 (m/s). The soil type is the soil type II in the earthquake regulations 2800 in Iran [4]. As well as all the records were selected from a fixed reference; therefore, in terms of issues such as processing records and so on, it can mostly ensure that there is uniformity and consistency. Information on records can be seen in table 3.

6-2. modifying the selected records:

For the purposes of the performance designing and controlling through the non-linear time history analysis, it is necessary that Accelerographs are modified as their spectrum were consistent with the plan spectrum. For example, the acceleration-time scale couple of Accelerograph of Chi Chi earthquake are shown in figures 2 and 3.

Table3. The used Accelerographs in nonlinear dynamic analysis

The number of pair	The name of event	Station	Year	Component	PGA(g)	The highest acceleration	The most ground displacement
1	Loma Prieta	57007 Corrolitos	1989	0°	0.644	55.2	10.88
				90°	0.479	45.2	11.37
2	Kobe	KJMA	1995	0°	0.821	81.3	17.68
				90°	0.599	74.3	19.95
3	Chi Chi	TCU084	1999	N	0.417	45.6	21.27
				W	1.157	114.7	31.43

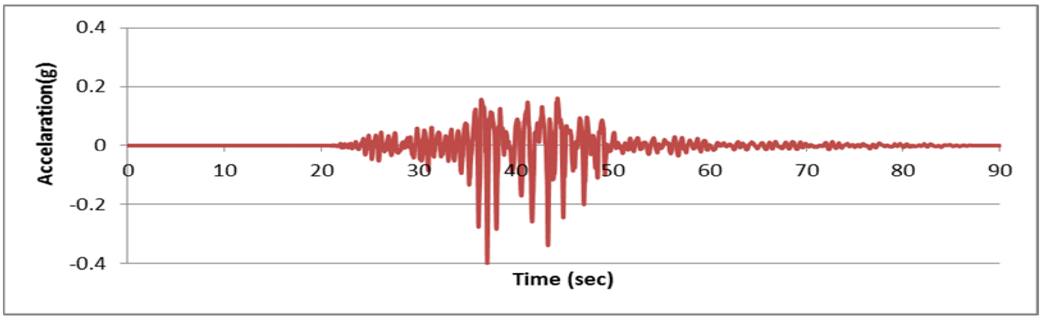

Fig2. Diagram of the acceleration-time scale couple of Accelerograph of Chi Chi-X earthquake (near fault)

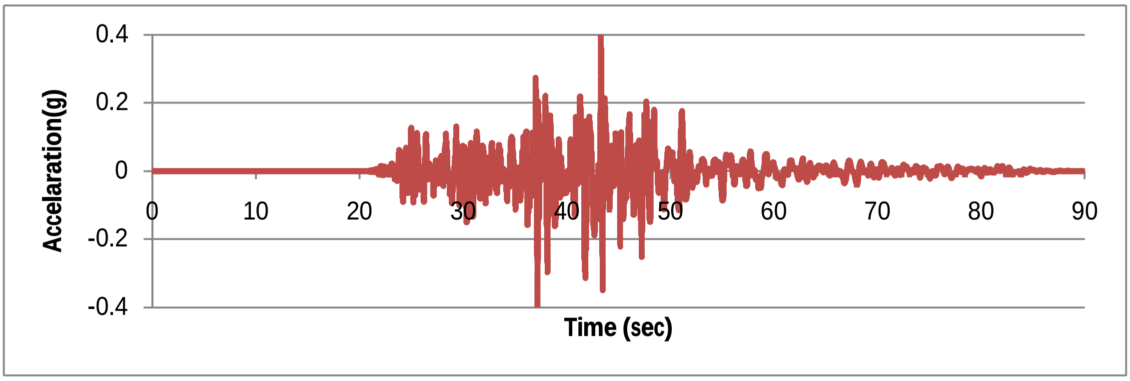

Fig3. Diagram of the acceleration-time scale couple of Accelerograph of Chi Chi-Y earthquake (near fault)

Now, response spectra of both Accelerographs for an earthquake are combined using the square root of the sum of squares (SRSS), and a single hybrid spectrum for both Accelerographs can be obtained as it is shown in Figure 4.

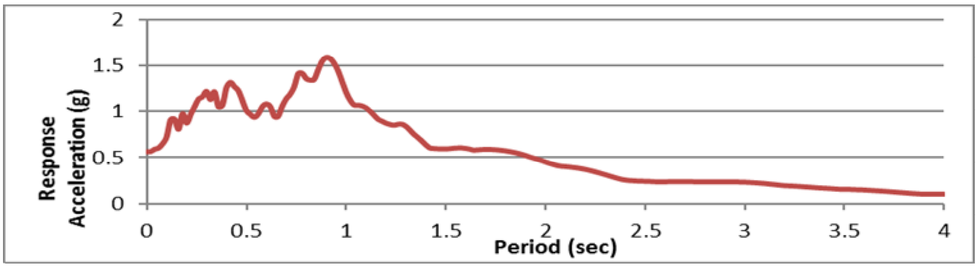

Fig4. The acceleration spectrum from the combined SRSS of scaled acceleration spectrum in two directions 0° and 90° Chi Chi earthquake

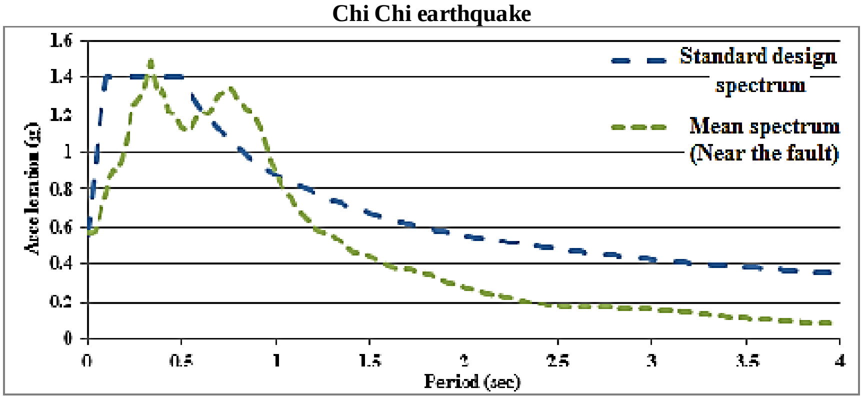

Fig5. Comparing the mean square root of the sum of squares of modified response spectra by Regulation

7. Output results

In this section, output results of the nonlinear time history analysis of two structures have been studied.

7.1. The comparison of the structures based on weight:

Economic discussion of the project is very important that it cannot be ignored indifferently. Here, the pillars of desired structures with wide flange shapes as over design and beams with IPE sections, eccentric braces with moment and Buckling Restrained braces with rectangular core are selected. The sections are made of steel ST37 and after designing with the ETABS software, results from two structures from weight is given in table 4.

7.2. Absorbed and wasted energy by the structural components:

One of the very important goals in this research is the topic of absorbed energies by structural components. Buckling restrained braces (BRB) resist against buckling and high plasticity of structure against earthquake and cause energy loss from the earthquake. Eccentric braces (EBF) lead to the emergence of bending moments and large shear forces in the area closed to brace. Thus, the tensions in the area of the beam enter into the inelastic range and lead to energy loss caused by the earthquake. Here, it is evaluated the utilization which brace in structure is more effective for energy absorption in structures with irregular plan and in the area near the fault. In Figure 6, the amount of each type of energy during vibration time is shown, in Figure 7, the total amount of absorbed energy under the effect of Accelerograph in shown and in Figure 8, the strain energy of the two structures under dynamic analysis is shown.

Table4. The weight values of structural components

Structure with EBF brace	Structure with BRB brace	Structural components	
11.7876	12.2922	COLUM	SUM
30.3158	16.5772	BEAM	SUM
9.5612	7.2227	BRACE	SUM
51.66	36.0922	ALL	TOTAL

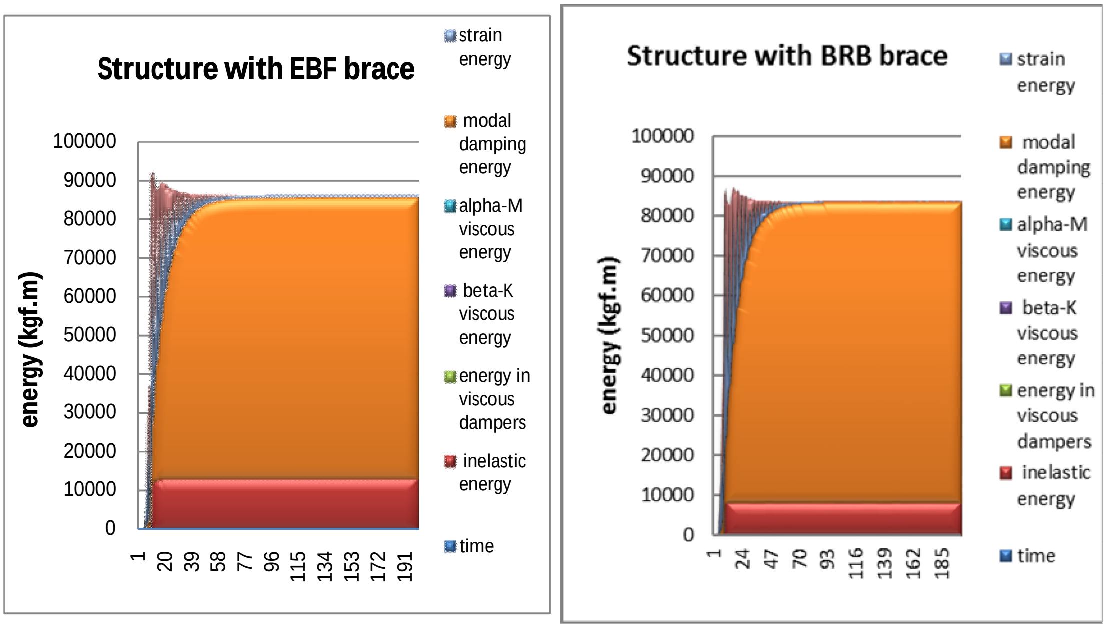

Fig6. Energy changes during the vibration time

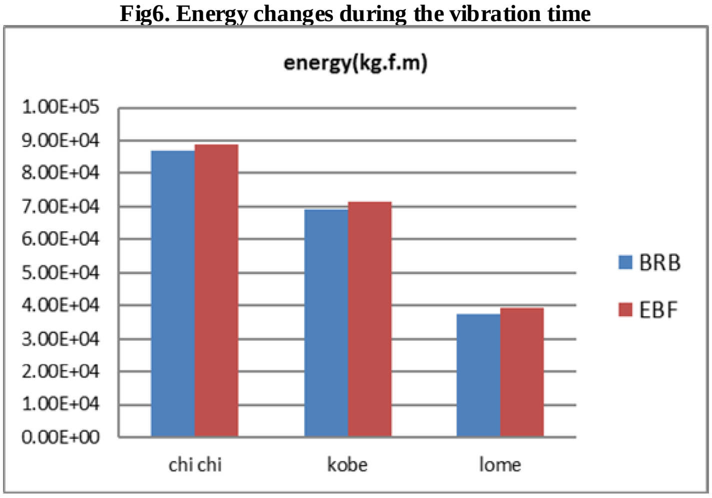

Fig7. Total energy of the structures under three Accelerographs

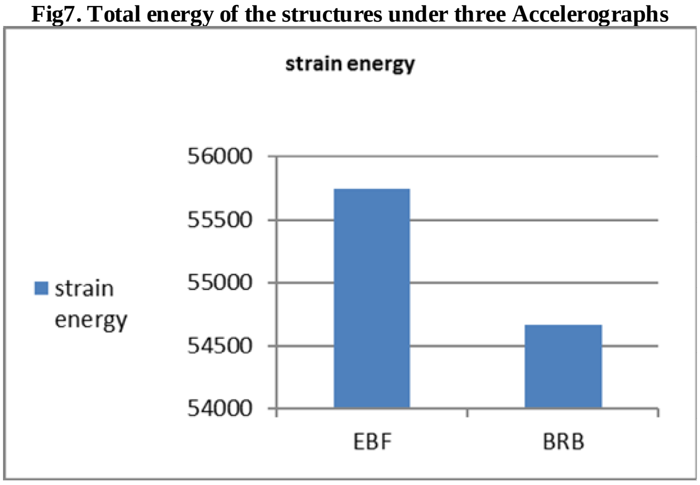

Fig8. Strain energy of the two structures under dynamic analysis

7.3. Base shear force

The amount of base shear of two structures is given in Figure 9 under the effect of three Accelerographs.

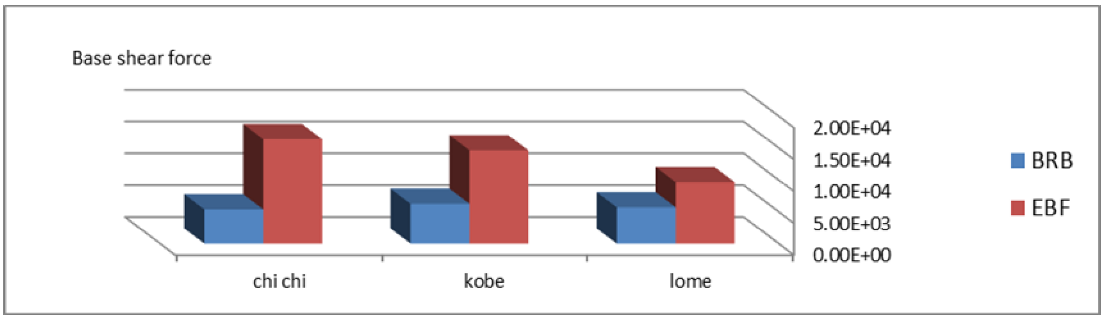

Fig9. Base shear force under the effect of three Accelerographs

8. CONCLUSION

In this study, comparing buckling restrained braces with eccentric braces in steel structures with irregular plan and the hinge joints based on nonlinear dynamic analysis was investigated. For this purpose, first, sections in the structures were designed using the ETABS software and then the structures were analyzed in the PERFORM-3D software under the effect of three Accelerographs that finally, after analysis, the results is as follows:

As shown in Table 4, columns' and braces' elements in both structures, with both braces in terms of weight are nearly the same, but in terms of beams' sections, the structure with EBF brace has more weight. In general, using BRB brace instead of EBF brace leads to the 16% reduction of structural weight in all the structure. According to the applied comparison, the structure with the BRB brace more reduce total energy and strain energy than the structure with the EBF brace. As well as using the BRB brace rather EBF in both directions (X and Y) causes to reduce the base shear in structures with irregular plan.

9. REFERENCES

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