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SEISMIC PERFORMANCE EVALUATION OF PLAN IRREGULAR STEEL STRUCTURES WITH BUCKLING RESTRAINED BRACE (BRB) AND ECCENTRICALLY BRACED FRAME (EBF) UNDER NEAR-FAULT EARTHQUAKE

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ABSTRACT

Analyses on braced frames show that bracing is a suitable, fast and cost effective system for strengthening of existing structures or structures damaged by earthquake. Use of this system for strengthening structures enables designer to distribute forces optimally with respect to situation. Regarding different common types of bracing systems used for steel structures, the present study tries to evaluate seismic performance of buckling restrained brace (BRB) instead of using eccentrically braced frame (EBF) for plan irregular steel structures under near-fault earthquake. Both of structures equipped with BRB and EBF were designed and then PERFORM-3D was used to nonlinear dynamic analysis and both structures have shown very good performance under near-fault earthquakes.

Keywords: Seismic performance of steel structures, BRB, EBF, nonlinear dynamic analysis

INTRODUCTION

Earthquake Vulnerability Reduction always has been one of the most important challenges facing structural engineers. Evidences from the past two decades destructive earthquake indicate weakness of force based design approach in predicting the behavior of structural elements under earthquake. Therefore, extensive researches have been done on the review of criteria for *earthquake* resistant *design of structures.*

Vision 2000 offers a definition for performance-based design as follows: "performance-based design includes all engineering functions which could use to design a structure with a specified seismic performance that these functions can include setting design objectives, seismicity studies, seismic analysis and design of structural and non-structural elements, control of the construction and maintenance of structures" [1]. However, the definition of typical design codes such as standard 2800 for seismic performance of buildings is quite vague and inaccurate, because the performance targets such as the ability to fix structure, limiting damage and lateral displacement have been not accurately specified in these codes. The main difference between performance-based design and other usual design approaches is replacing the concept of "performance" rather than "resistance". In fact the objective of performance-based design is to enable engineers to design structures with predictable performances. Several guidelines have been presented for performance-based designing which among them FEMA237 [2], FEMA356 [3] and ATC40 [4] provide more comprehensive recommendations with regard to structural and non-structural details. Since bracing is the most suitable system to strengthen existing or damaged structures, so evaluating these lateral load resisting systems from minimum requirements point of view using performance evaluation methods seems to be important. In the present study, seismic performance of plan irregular steel structures has been evaluated by replacing BRB instead of EBF under near-fault earthquake designed to create nonlinear performance evaluating model as input data for PERFORM-3D. Three records of near-fault ground motion have been selected as nonlinear model dynamic loading and have been scaled to desired design range using Seismosignal software. Effects of near-fault earthquakes on the parameters which determine performance levels of accelerographs at each moment have been studied using functionalities of Prform-3D nonlinear software.

Design link beams in eccentrically braced structures

Designing eccentrically frames with lateral beams is done based on "capacity based design approach". The objective of this approach is focusing all nonlinear deformations only in link in the way that all objects outside the bonds remain elastic at the time of earthquake. To achieve this goal, other objects must be designed for forces corresponding shear capacity of link and applying required confidence coefficient. The link length has a major effect on the stiffness and ductility of these frames. Several studies have shown that shear and flexural hinges are formed in short links and long links, respectively. In the length between short and long, the formation of both hinges at the same time is possible. The results of studies indicate that formation of shear hinge has more stability and better performance in terms of stiffness and ductility compared to flexural hinges [5]. To achieve shear behavior in link beam, the link length (e) has been considered as 1m in all desired structures with respect to frame openings (5 and 6 m).

Buckling restrained bracing

This type of bracing *consists of* a slender steel core, surrounded by a concrete-filled steel casing. In this bracing, steel core carries axial load and surrounding case provides the lateral support against buckling of the steel core by filling concrete [6]. Steel core surfaces are covered by a thin layer of a viscous material to prevent shear transmission from concrete to steel core during deformation of steel core and also make it possible to contain radial deformations caused by Poisson's effect when the member is under pressure. Existing conditions enables steel core to freely have axial deformation in the concrete-filled case [7].

Case study buildings

Two 6-storey residential buildings have been designed using ETABS based on third edition 2800 [8] of AISC code [9], and analyzed using PERFORM-3D. Floor heights are equal to 2.3m and floor area of each one is equal to 600 m^2. Structural system of these buildings are shown in figure 1 as hinge frames with BRB of EBF braces in both directions, locations of the braces, roof joists in which joists have been installed on a checkered form and floor diaphragm has been considered as semi-rigid. Figure 1 shows general floor plan view and properties of materials, and gravity loading are presented in table 1 and 2, respectively.

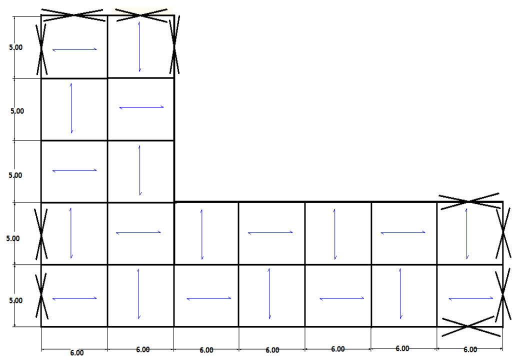

Figure 1: General floor plan view

Table1: Properties of material

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

Table2: Gravity loads on the building

Situation	Dead loadKg/m	Live loadKg/m
Floor	620	200
Roof	470	150
Lateral walls	215	----

Performance levels of entire building

Based on performance level improvement guideline, structural components consist of four main performance levels and two intermediate performance level. Main performance levels include: [10]

1- Performance level 1: immediate occupancy (IO)

Immediate occupancy performance level refers to the performance level which is predicted that resistance and stiffness of structural elements would not significantly change during earthquake and immediate (continuous) occupancy of it is possible.

2- Performance level 2: life safety (LS)

Life safety performance level refers to the performance level which is predicted that earthquake would cause structural damage by but damages levels not to be such extent which led to loss of life.

3- Performance level 3: collapse prevention (CP)

Collapse prevention performance level refers the performance level which is predicted that earthquake would cause extensive structural damage but the building does not collapse and to minimize loss of life.

Plan irregularity

Structural responses (torsion) in the irregular structures depend on structural characteristics and ground motion parameters. Study the twisting effect in plan irregular structures is a complex issue. Due to the effect of torsion in these structures, non-linear time history analyses are run using three earthquake records. Torsional movements cause displacements and additional forces in some structural members of irregular buildings in comparison with the corresponding regular buildings and torsion effect is a major cause of damage buildings affected by seismic forces.

One of the conditions of plan irregular structures is that the distance between the center of mass and the center of rigidity be more than 20% of building dimension [8]. In structures used in the present study the distance between center of mass and center of rigidity is more than 20% of building dimension. In addition to irregularity of the center of mass and the center of rigidity, they are still irregular in terms of asymmetry cross two x and y axes. In such structures, to apply maximum effect of earthquake, hundred percent of earthquake force of each direction combines to 30% of earthquake force perpendicular to it to apply maximum earthquake effect to the structure.

Analysis type

To evaluate the performance of buildings during an earthquake needs to run nonlinear analysis and displacements; location of plastic hinges and their distribution must be specified. One important step in seismic performance-based design is estimation of nonlinear seismic response of structures. According to objective, the present study used non-linear dynamic analysis to analyze.

Nonlinear time history analysis

In the present study 3 near-fault earthquake records have been used to nonlinear time history analysis. It has been attempted to select records with good consistency. This means that soil type of records must be in the range of $375 \leq V \leq 750$ (m/s) according to their shear wave velocity. Based on Iran earthquake code 2800 this soil type is soil type II [8]. Also all records have been selected from a constant reference, so in terms of issues such as processing records, etc. we can almost ensure that there is uniformity and consistency. table 3 presents the information of records.

Elements behavior curve

In PERFORM 3D software, Fema-Beam and Fema-Column have been used to model non-linear behavior of beams and columns, and Brace/Other element has been used to model non-linear behavior of EBF brace, and Buckl Rest Brace has been used to model non-linear behavior of BRB braces. Behavior curve used in PERFORM 3D for non-linear behavior of elements is presented in figure 2.

Table 3: Accelerographs used to nonlinear dynamic analysis

Number of pairs	Event name	Station	Year	Component	PGA(g)	Maximum velocity (cm/s)	Maximum displacement (cm)
1	Loma prieta	57007 Corrolitos	1989	0° 90°	0.644 0.479	55.2 45.2	10.88 11.37
2	Kobe	KJMA	1995	0° 90°	0.821 0.599	81.3 74.3	17.68 19.95
3	Chi chi	TCU084	1999	N W	0.417 1.157	45.6 114.7	21.27 31.43

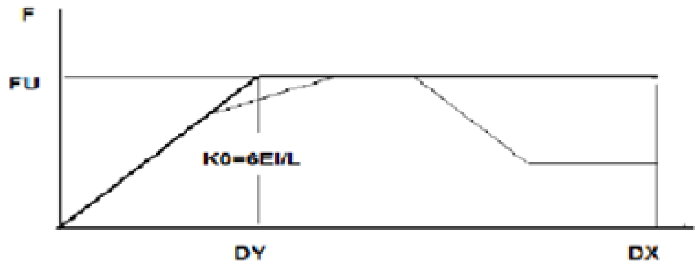

Figure 2: behavior curve used in PERFORM 3D

To model compound in link beam the pair of moment hinge rotation type at the beginning and end of the link and the pair of shear hinge displacement type in the middle of the link were considered. To model compound in BRB braces the following equation is used:

Basic Components=Buckling Restrained Brace + Elastic Bar

RESULTS

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

Relative displacement of floors in non-linear dynamic analysis (Drift)

Maximum relative displacement of floors is one of perceptible and measurable parameters for vulnerability assessment of structures. Most earthquake codes consider it as control parameter for buildings damages. Generally, limitation of elative displacement of floors depends on factors such as seismicity of the area, number of floors and the degree of structure importance. To determine relative displacement in non-linear dynamic analysis, history of response of a point from each floor obtains as the floor representative for each earthquake. By subtracting the response history of this point from the response history of upper floor, the history of relative displacement (drift) of upper floor is determined. Relative replacement quantities have been shown in figure 3.

As it can be seen in figure 3, using BRB bracing instead of EBF bracing in plan irregular structure in near-fault area increases relative displacement in structure floors. Maximum quantities of relative displacement for BRB and EBF braces structure have been presented.

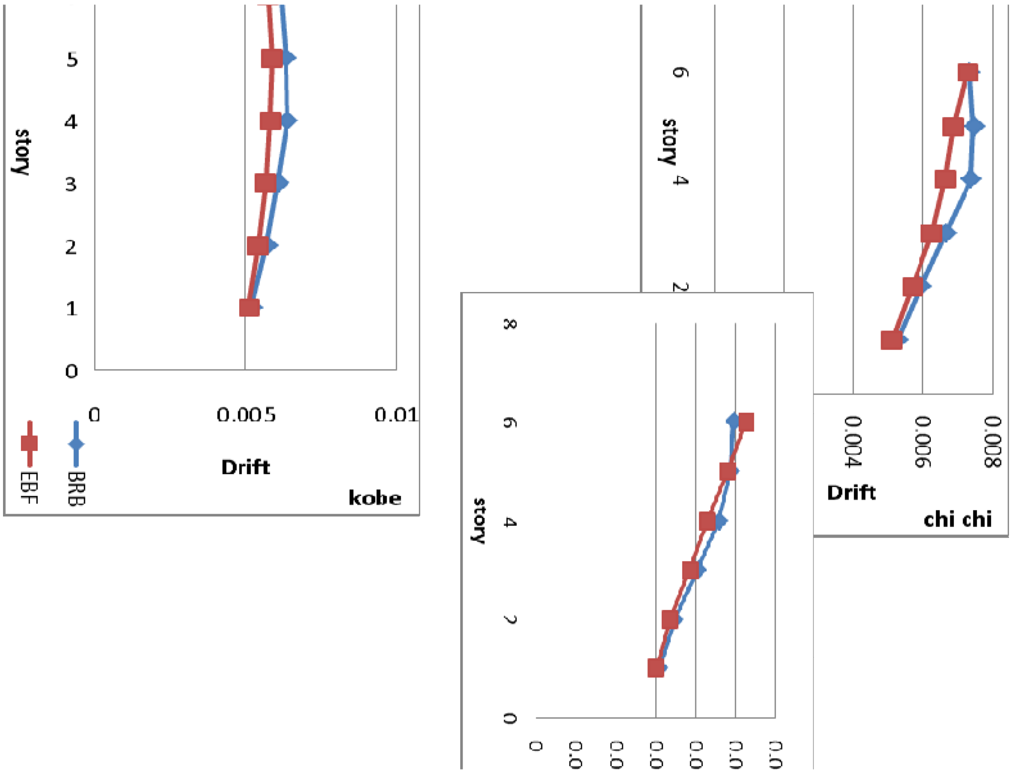

Figure 3: relative displacement under 3 accelerographs

Table 4: Maximum quantity of relative displacement for each earthquake and each structure

Earthquake / Structure type	Kobe	LomaPrieta	ChiChi
BRB structure	0.006367	0.004945	0.007456
EBF structure	0.005871	0.00526	0.007279

Evaluating structures performances

According to existing tables in the interpretation of the instructions for seismic performance of braced steel building, relative displacement of floors which are presented in both steady and transient states must be considered. Transient lateral displacement refers to maximum relative lateral displacement of floors that are predicted to cause the building during the project earthquake. Steady lateral displacement refers to maximum relative lateral displacement of floors that remain in the structure after the earthquake due to plastic of cracking behavior. In tables, relative transient displacement of 0.5% for immediate occupancy (IO) performance level, relative transient displacement of 1.5% for life safety (LS) performance level and finally relative transient displacement of 2% for collapse prevention performance level have been suggested. Now, according to non-linear dynamic analysis of time history we can evaluate performances of models. With regard to maximum relative displacement of floors in non-linear dynamic analysis, performance levels of samples are evaluated in the following. Table 5 shows the performance levels of desired structure in the present study.

Type and number of hinges formed in structures

Table 6 shows the number of plastic hinges in structural elements of two desired structures under influence of 3 accelerographs. As you see in table 6, by using BRB instead of EBF fewer number of plastic hinges forms in structure.

Table 5: determining performance level of samples in non-linear dynamic analysis using 3 accelerographs

Structure type	BRB braced structure	EBF braced structure
Maximum drift of 3 accelerographs	0.74	0.72
control	0.5 << 1.5	<0.5
Structure performance	LS	LS

Table6: hinges formed in two desired structures under influence of 3 accelerographs

Structure	BRB			EBF		
Earthquake	chi ch	kobe	loma	chi ch	kobe	loma
B-IO	17	5	0	51	26	39
IO-LS	2	0	0	14	3	6
LS-CP	2	0	0	0	0	1
TOTAL	21	5	0	65	29	46

CONCLUSION

THE present study compared buckling restrained brace (BRB) and eccentrically braced frame (EBF) in plan irregular steel structures and hinges joints based on non-linear dynamic analysis. To this purpose at first all sections of desired structures have been designed using ETABS, and then desired structures have been analyzed using PERFORM-3D under influence of 3 accelerographs. Results of analysis are as follows:

As it seen in results section both structures with BRB and EBF bracing systems shown very good performance under near-fault earthquake and met life safety performance level (LS) which indicated high ability of these systems when earthquake occurs. It should be noted that near-fault records have been used to this evaluation which applies very strong pulses to structures. According to the comparison, relative displacement in structure with BRB brace is about 3% more than structure with EBF brace, and also use of BRB in such structures decreases plastic hinges rather than EBF.

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