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Seismic evaluation of reinforced concrete moment frames retrofitted with steel braces using IDA and Pushover methods in the near-fault field

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ABSTRACT: One of the methods for seismic retrofitting in reinforced concrete structures is the use of steel braces. In this paper, the effect of concentric and eccentric bracing systems on the seismic performance of dual reinforced concrete building systems was investigated under seven near-fault earthquake records. Following this, two reinforced concrete frames with 10-story and five spans were designed and analyzed using the incremental dynamical analysis (IDA) method, where the braces were placed in the 1st and 5th spans. The results indicated that the bearing capacity of the reinforced concrete frame by using CBF and EBF braces increases up to 2.3 and 2 times, respectively. The use of EBF brace in a reinforced concrete frame reduces the amount of the base shear applied to the structure up to 7 times compared with the CBF frame. Approximately, the displacement of the roof in the EBF frame is less than the CBF frame. Furthermore, the ductility of the EBF frame against earthquake records causes an increase in the performance level of structure to the immediate occupancy (IO).

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1. INTRODUCTION

In 1990, Gould and Lee investigated the seismic strength of reinforced concrete retrofitted by concrete ductile steel braces [1]. In this study, a two-story reinforced concrete frame damaged by the Mexican earthquake of 1985 was reinforced and constructed by steel braces and tested under reciprocating loads. The most important result of this experiment was the stability, the widespread hysteresis loop, and the high formability of the frame.

In 1994, Nateghi Elahi conducted a study on the seismic reinforcement of an eight-story reinforced concrete structure with steel braces. In this research, information was provided on reinforcement methods and considerations used to strengthen the building for lateral and vertical loads [2].

In 1995, Maheri and Sahebi experimentally investigated the reinforced concrete frames with steel brace. For this study, four samples of the frame were fabricated with one forth scale and tested for cyclic loading. The results of this study showed that the final failure of the frame and the destruction of the stretched bracing are dominant on the frame behavior [2, 3].

In 1997, Haji Ghaffari studied the interaction of steel frame and brace in reinforced concrete structures to withstand lateral forces. In this research, the effect of X and K shaped steel braces was investigated on retrofitting the bending frame of reinforced concrete without a shear wall. The results of this study showed that when using steel bracing in a reinforced concrete frame, 0.1Fy allowable stress should be used to design steel braces, whereby braces can absorb 75% of the lateral force [4].

In 2000, kheyroddin studied the mixed-use of two shear-wall and steel-bracing systems to retrofit existing reinforced concrete structures. The results of this study showed that the increase in the area of braces is effective to a certain extent on the behavior of the structure, and after a certain limit, it will not play a specific role in the behavior of the structure and shear absorption. The use of a combination of bracing and shear walls also indicated better system behavior [5].

2. METHODOLOGY

In this study, two 10-story reinforced concrete frames with five spans of 4 meters and a height of 3 meters are considered to be retrofitted by concentric (CBF) and eccentric (EBF) steel bracing in the first and last spans. Figure 1 shows the overall view of reinforced concrete frames retrofitted with steel braces. Due to the applicability of the design, the dimensions and spans are real and structures are considered symmetrical. The use of the residential building and dead floor load, the partition equivalent load and the living load of floors and the ceiling are considered to be 650, 150, and 200 kg/m^2, respectively.

The compressive strength of the concrete frame 280 kg/cm^2 and the yield strength of the main and rebar are 3000 and 2400 kg/cm^2, respectively. The fourth edition of Iranian seismic code 2800 has been used for loading and a quasi-static method for earthquake load, and first, the total base shear is calculated and then distributed in the floors in proportion to weight. For the design of reinforced concrete members, the ACI Code, and

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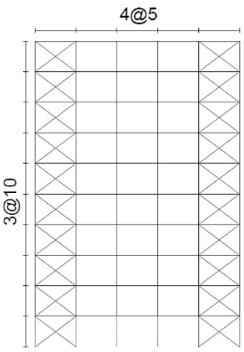
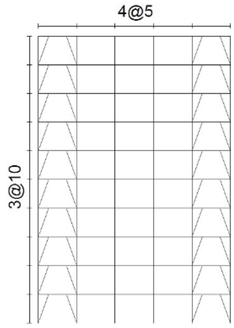


a) Overview of concrete frame with a concentric brace (CBF)



b) Overview of concrete frame with an eccentric brace (EBF)

Fig. 1. Overview of the studied frames

Table 1. The details of sections used in the design of frames

Story Number	Column Section	Beam Section	Brace Section	
			EBF	CBF
1-2-3	80×80	80×70	2UNP160	2UNP180
4-5-6	70×70	70×60	2UNP140	2UNP140
7-8-9-10	60×60	60×50	2UNP120	2UNP120

the AISC Code for steel members have been used, respectively. The soil considered in this study is of type II.

For design, all frames were first designed in ETABS 2015 software, and after determining the sections of the beams, the columns were analyzed and evaluated in OpenSees software using a brace (UNP section type).

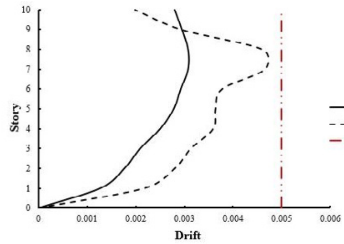
The details of the sections used in the design of frames are shown in Table 1.

3. RESULTS AND DISCUSSION

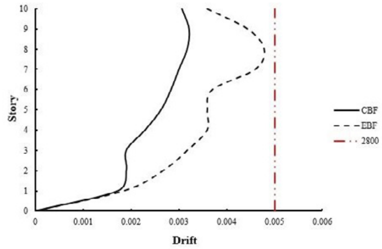
After analyzing the structure in the OpenSees software, the drift curve for each earthquake record is shown in Figures 2a to g.

The comparison of lateral drift with maximum allowable drift based on Iranian seismic code 2800 where is equal to 0.02 H (height of structure) for buildings with 5-story or more, as indicated in Figure 2. As shown in this Figure, by using the bracing system in reinforced concrete building all drifts were placed within the allowable range.

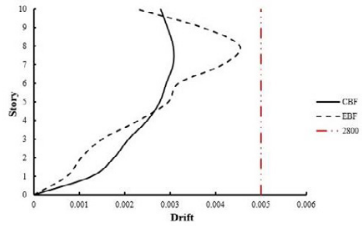
As shown in Figure 2a, in general, under the earthquake record of chuetsuoki0909g, the drift of the frame with an



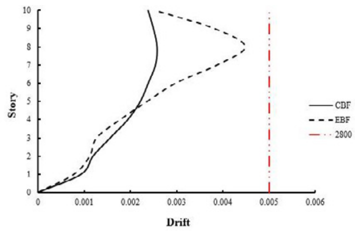
a) Floors drift curve under the chuetsuoki0909g record



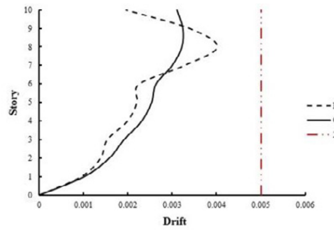
b) Floors drift curve under the elmayorcucapah0538g record



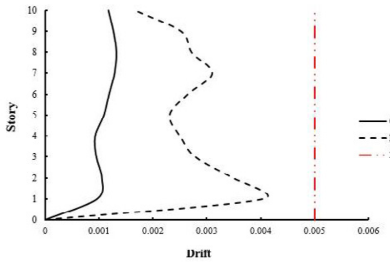
c) Floors drift curve under the elmayorcucapahcerroprieto0288g record



d) Floors drift curve under the elmayorcucapahriito039g record

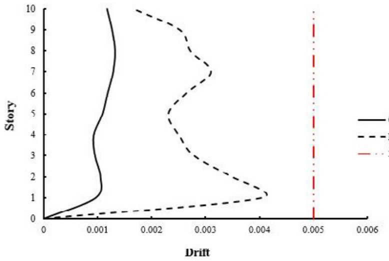


e) Floors drift curve under the lomaprietagilroyarray0419g record



f) Floors drift curve under the morganhillgilroyarray0349g record

Fig. 2. Floors drift curve under various earthquake records



f) Floors drift curve under the morganhillgilroyarray0349g record

Fig. 2. Floors drift curve under various earthquake records

EBF brace on all floors was more than the drift of the frame with a CBF brace, so that the largest drift has occurred on the seventh floor. The seventh-floor drift of the EBF frame is approximately 1.6 times the size of the CBF frame. Thus, in the earthquake record of the chuetsuoki0909g, the EBF frame is more ductile. In both frames from the seventh to tenth floors, the amount of drift is reduced, which this value is much higher in the EBF frame.

As shown in Figure 2b, under the record of the earthquake elmayorcucapah0538g, the first-floor drift in both frames was approximately equal, but from the second floor, it grew up and then in the EBF and CBF frames of the seventh and ninth floors afterward, the trend is decreasing. The largest amount of drift in the EBF frame is roughly 1.45 times the largest amount of drift on the CBF frame. On the tenth floor, the amount of drift in the CBF frame is less than the EBF frame, although this is the opposite in the earthquake record of chuetsuoki0909g. As can be seen in Figure 2c, the results of the earthquake record of elmayorcucapahcerroprieto0288g are slightly different from the two previous records. The CBF frame drift is more than the EBF frame up to the fourth floor and is reversed from the fifth to ninth floors, and again on the tenth floor, the drift of the CBF frame has become more than the EBF frame. Maximum drift occurred in CBF and EBF frames in the seventh floors, so that this value in the EBF frame is approximately 1.5 times of the CBF frame.

As shown in Figure 2d, under the earthquake record of elmayorcucapahriito039g, to the fifth floor, almost the drifts of the CBF and EBF frames are equal, but in the upper floors, the EBF frame drift is larger so that it reaches its maximum value on the eighth floor. The maximum drift of the EBF frame is about 1.5 times the maximum drift of the CBF frame, but they do not differ much on the tenth floor.

According to Figure 2e, under the lomaprietagilroyarray0419g earthquake record to the sixth floor, the drift of the frames is equal. The maximum drift occurred in the frames on the eighth floor and the drift of the EBF frame is about 1.3 times the CBF frame.

According to Figure 2f, under the record of the morganhillgilroyarray0349g earthquake in the CBF frame, with increasing floors, the drift does not change much and rises upright. However, in the EBF frame, the maximum drift occurred on the first floor, which is about four times the size of the CBF frame. Also, the drift of the EBF frame is more on all floors.

According to Figure 2g, the northwestchina3jiashi03g earthquake record has the largest drift of frames on the 9th floor, which this value in EBF frame is approximately 1.1 times the value of the CBF frame.

4. CONCLUSIONS

- The maximum drift of EBF and CBF frames was 0.025 and 0.007, respectively. Also, the minimum roof drift was 0.01 and 0.008 for these frames, respectively.
- On the eighth floor, each CBF and EBF frames reached its maximum. So the eighth floor was sensitive and important.
- The roof displacement of the CBF and EBF frames is the same to 0.5 g earthquake intensity and displaces up to about 0.35 meters. But in higher earthquake intensities, there was not much change in the displacement of frame roofs, but the EBF frame showed a more smooth behavior.
- The use of steel bracing in the reinforced concrete moment frame reduces the base shear value up to 7 times when used with CBF steel braces.

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