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Seismic Vulnerability Assessment of Reinforced Concrete Structures Equipped with Eccentrically Braced Frames Having Vertical Link

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ABSTRACT: Nowadays, there are various types of existing buildings with poor seismic detailing so they cannot cover the seismic code provisions. Accordingly, seismic rehabilitation technics should be implemented for these structures. Eccentrically Braced Frame having a vertical link is a new strategy for retrofitting existing RC buildings. In this article, three types of reinforced concrete structures with the same architectural plan having 3, 5, and 8 stories are retrofitted with Eccentrically Braced Frames having vertical links, and the seismic fragility curves are developed based on Incremental Dynamic Analysis (IDA) in OpenSEES. The demand statistics in terms of maximum inter-story drift ratio are obtained for 20 sets of ground motion records, the capacity is determined according to the HAZUS-MH limit states, and finally, the corresponding seismic fragility curves are developed. The results represent the effect of the implemented retrofit strategy on the seismic vulnerability of this subclass of structures. The median seismic fragility for 3, 5, and 8 story models are increased 35%, 90%, and 146 % accordingly, at the complete damage state.

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1. INTRODUCTION

Increasing damage to structures in severe earthquakes such as Northridge of California (1994), Kobe of Japan (1995), Central Western of India (2001), and Bam (2005) have brought about an extensive loss in the structures. Today, with the advancement of science in the field of the construction industry, numerous methods have been proposed in the retrofitting of reinforced concrete (RC) structures including the application of metal bracings to increase the stiffness. However, the use of metal bracing along with a vertical link has been less examined. The aim in the retrofitting of structures is not only to provide adequate structural stiffness against ground motions caused by the earthquake but also to bolster the ability to dissipate the energy generated by such vibrations. In a bracing system retrofitted with a vertical link beam, the bracings deliver the necessary stiffness and the vertical link is responsible for absorbing and dissipating the energy. In the present research, vulnerability assessment and plotting of fragility curves of RC structures having construction faults, yet strengthened by eccentric steel bracing coupled with the vertical link, have been investigated.

2. 3D MODEL OF THE STRUCTURE

To evaluate the seismic performance of moment-resisting framed concrete structures subjected to earthquakes, three types of low-rise, medium-rise, and high-rise concrete buildings respectively with 3, 5, and 8 stories were considered.

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The proposed structure is located in Mazandaran, which according to the Iranian Standard No. 2800 Code is sited in a region with a high seismic risk. Conforming to this code, soil type III is considered at the site.

A) The structure has 4 spans of 5 *m* along the X direction, and 3 spans of 5 *m* in the Y direction. The height of each floor is 3.2 *m*.

B) Longitudinal reinforcements embedded in concrete are of type AIII with a yield stress Fy= 4000 $\frac{Kg}{cm^2}$.

C) The structure has intermediate concrete moment-resisting frames in both directions, which are then strengthened by eccentric bracing shown in Fig. 1.

D) The design concrete in beams and columns has a 28-day compressive strength of fc= 250 $\frac{Kg}{cm^2}$. Based on the field studies conducted by the authors in 1391, carrying out destructive and non-destructive tests on 350 specimens of RC buildings in the city of Babolsar, supported by the Construction Engineering Organization, it was observed that among the investigated buildings with intermediate moment-resisting frame systems, a considerable number of existing structures (over 50%) suffered low concrete strength, with compressive strengths of 120 to 180 $\frac{Kg}{cm^2}$.

In this study, by calculating mean values and dispersion of the measured strengths, to take the concrete strength uncertainty (of columns) into account, the average concrete strength was considered to be $f_c^{'}=150$ with a standard

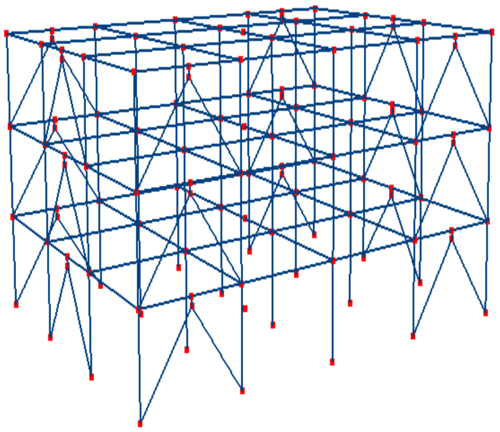

Fig. 1. Elevation of the 3-story structure strengthened by eccentric bracing.

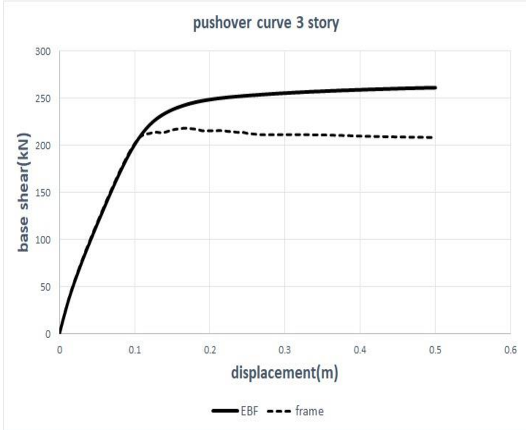

Fig. 2. Comparison of the three-story building capacity curve before and after strengthening.

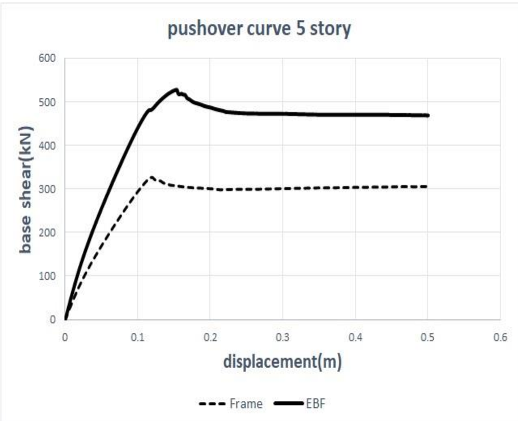

Fig. 3. Comparison of the five-story building capacity curve before and after strengthening.

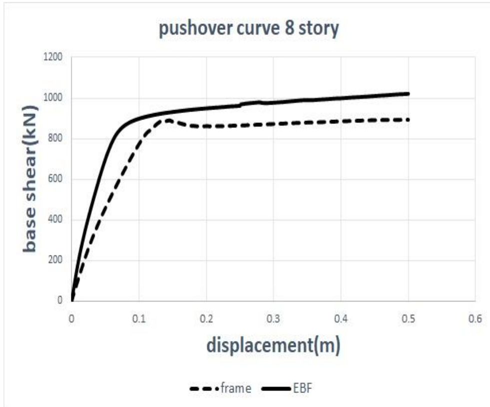

Fig. 4. Comparison of the eight-story building capacity curve before and after strengthening.

deviation of 30 $\frac{Kg}{cm^2}$ [1]. Since lap splice lengths may essentially be underestimated owing to various reasons encompassing the lack of construction drawings or incorrect implementations, another structural weakness considered in this study is then the insufficient lap splice length of longitudinal reinforcements in columns. To reflect such drawback, it was assumed that the splice length of rebar is half the length required. Hence, following clause 5-3-6 of the Iranian Seismic Retrofit Code No. 360 [2], stresses in the longitudinal reinforcements of columns were considered half the design value.

The OpenSEES software [3] was utilized to model the structures, and all members were defined as to be completely non-linear. To define steel as the rebar in beams and columns, *Steel02* material was used. Likewise, *Concrete01* material was employed to define concrete in the beam and column sections.

The shear link beam was defined as *Steel02* to simulate the bending behavior, and as Multi Linear Material to model the shear behavior. Furthermore, to define beam and column elements, a nonlinear Beam-Column was used, and to define the bracing element, an equivalent diagonal element was implemented, which was modeled as pinned at both ends. This element is attached to the two ends of the beam and column in the form of a single strut, defined as an element truss.

3. NONLINEAR STATIC ANALYSIS AND CALCULATION OF STRUCTURE CAPACITY CURVE

By performing a nonlinear static analysis subjected to modal lateral loading pattern, the capacity curve (pushover) is depicted for the three types of structures in Figs. 2 to 4, both before and after strengthening.

4. INCREMENTAL NONLINEAR DYNAMIC ANALYSIS

Incremental nonlinear dynamic analyses were performed on both strengthened and non- strengthened structures and their IDA curves were plotted. The IDA curves of an 8-story structure under 20 earthquake records, conforming to FEMA P695 [4], are illustrated in Figures and 10, respectively before and after strengthening. Furthermore, brief IDA curves have been compared through Fig. 5 to 9.

5. ANALYSIS OF FRAGILITY CURVES

When the structure capacity and seismic demand are two variables that follow the normal or lognormal distribution,

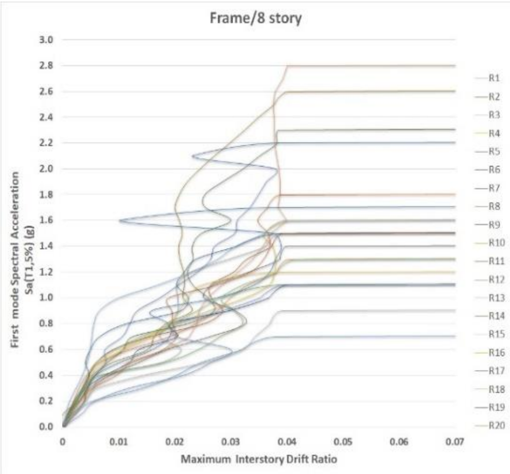

Fig. 5. The IDA curve of a 5-story structure without eccentric bracing.

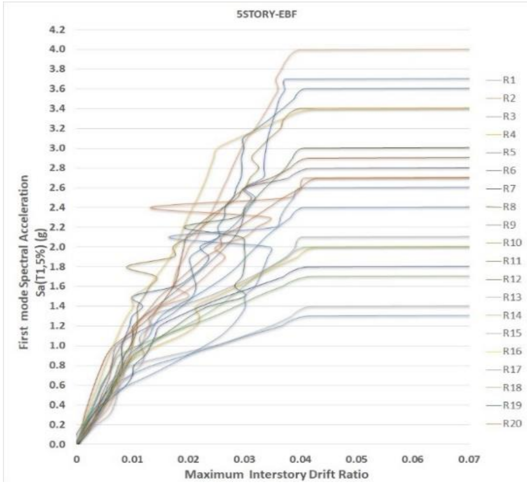

Fig. 6. The IDA curve of a 5-story structure with eccentric bracing.

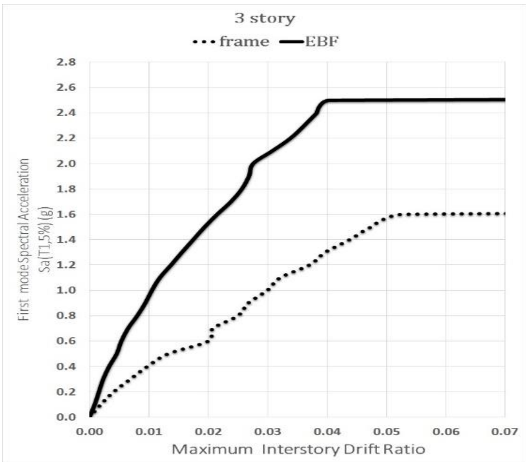

Fig. 7. Comparison of the dynamic capacity of a 3-story structure with and without eccentric bracing.

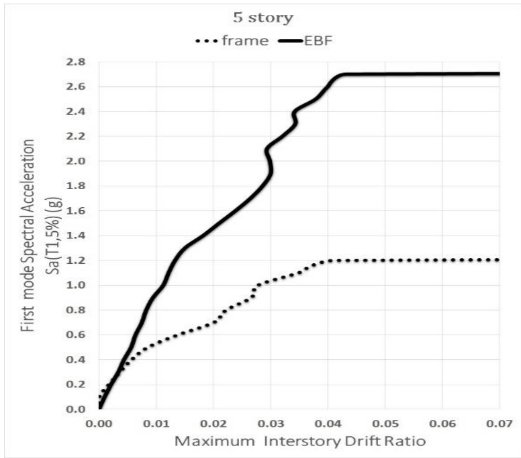

Fig. 8. Comparison of the dynamic capacity of a 5-story structure with and without eccentric bracing.

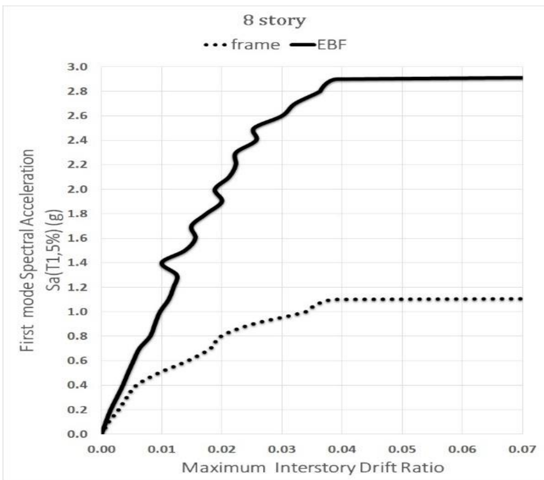

Fig. 9. Comparison of the dynamic capacity of an 8-story structure with and without eccentric bracing.

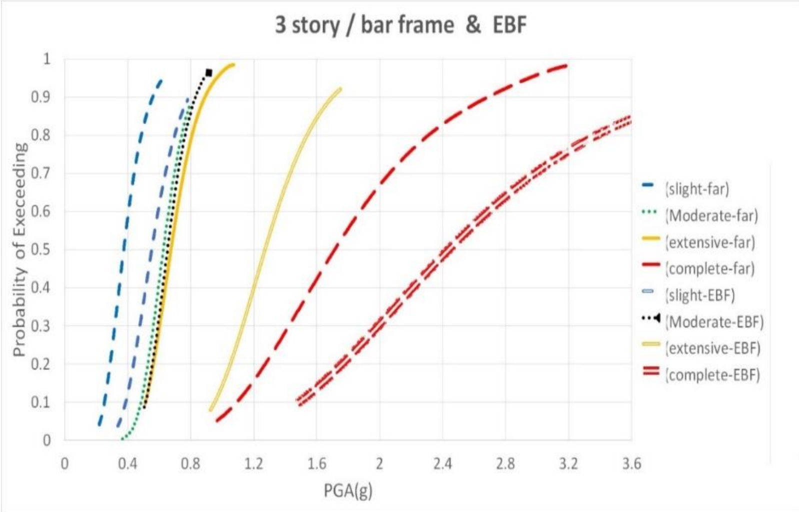

Fig. 10. The failure curve of the 3-story structure before and after strengthening in the four states of damage.

it can be shown via central limit theory that the combined function yields a lognormal distribution. Therefore, the fragility curve can be demonstrated as a lognormal cumulative distribution function according to Eq. (1) [5-7].

$$p(: \leq D) = \Phi[(\frac{1}{\beta_{sd}} \ln \left(\frac{S_d}{S_c}\right)] \quad (1)$$

in which, p is the probability of reaching or exceeding damage state D (in this research, maximum inter-story drift), B_{sd} the lognormal standard deviation, S_d the mean of seismic demand, S_c the mean value of allowable limit state presented in HAZUS-MH MR-5 guideline for various building types and different damage states. Table 1 reports the mean value of allowable limit state (*Sc*) for concrete moment-resistant framed structures in various damage states.

The value of *Sd* is also obtained thru Eq. (2).

$$\ln(S_d) = a\ln(x) + b \quad (2)$$

In this relationship, X is the ground motion intensity (*PGA*) parameter, and *a, b* are regression coefficients obtained through logarithmic regression analysis, maximum inter-story drift, versus different *PGA*s.

The examined fragility curves are indeed the probabilistic representation of the vulnerability or the risk of structures which have been sketched in Figures 15 to 17, based on previously mentioned concepts.

6. CONCLUSIONS

- According to the results of base shear values, the structure without bracing has a larger seismic response coefficient when compared to the brace structure. This is attributed to the lower weight and coefficient of the behavior of the former, leading to a larger base shear of the non-braced structure. Base shear of the 3-, 5-, and 8-story strengthened structures respectively decreased by about 17, 9, and 13% compared to the non-strengthened structure.

Table 1. The mean value of allowable limit state in HAZUS-MH MR-5 guideline for various damage states [8]

Type Building	Inter Story Drift at Threshold of Damage State			
	Slight	Moderate	Extensive	Complete
C1L	0.005	0.0087	0.0233	0.06
C1M	0.0033	0.0058	0.0156	0.04
C1H	0.0025	0.0043	0.0117	0.03

- In the 3-story structure before strengthening, the median of fragility (50% failure probability) in the slight, moderate, extensive and complete fragility states is equal to 0.25, 0.51, 0.68, and 1.28 respectively; whereas the corresponding values after strengthening are respectively 0.48, 0.67, 1.22 and 2.44. As it was witnessed, before strengthening, the structure reaches the median of the failure border earlier than the strengthened structure. In other words, the four damage limit states occur earlier with lower PGA in this structure, while the structure strengthened by bracing requires larger PGA to reach the four mentioned damage states.

- The effect of eccentric bracing has further increased the structural capacity so that the ratio of structure capacity strengthened by bracing to the structure alone escalates by increasing the number of stories in the structure. Moreover, increasing the number of stories leads to reduced structure capacity. As previously stated, such an issue is less observed in frames with bracing. The structure capacity is 35, 90, and 146% respectively for structures of 3 to 8 stories. A significant increase in the high-rise building is associated with an increase in ductility.

- In the modeling of eccentric bracing through the current study, it was revealed that the behavior of short link beam is of shear type. It is also advantageous to simultaneously contribute both shear and bending factors in the modeling of the beam. Modeling shear behavior with Multi Linear material serves high accuracy, the point which is confirmed in the present study.

REFERENCES

[1] H. Pahlavan, A. Naseri, A. Einolahi, Probabilistic Seismic Vulnerability assessment of RC Frame Structures Retrofitted with Steel Jacketing, Amirkabir Journal of Civil Engineering, (2018).

[2] Code No. 360, 2007. The Islamic Republic of Iran, Management and Planning Organization, Instruction for Seismic Rehabilitation of Existing Buildings.

[3] Mazzoni, S., McKenna, F. and Fenves, G.L., 2005. "OpenSEES command language manual". Pacific Earthquake Engineering Research (PEER) Center, 264.

[4] FEMA. Quantification of building seismic performance factors. FEMA P695. 2009. Federal Emergency Management Agency, Washington, DC.

[5] A. Naseri, H. Pahlavan, G. Ghodrati Amiri, Probabilistic seismic assessment of RC frame structures in North of Iran using fragility curves, Journal of Structural and Construction Engineering, 4(4) (2017) 58-78.

[6] Earthquake damage evaluation data for California, Applied Technology Council (ATC). 1985.

[7] H. Pahlavan, A. Naseri, S. Rafiei, H. Bagheri, The Effect of Columns Height and Span Number on the Vulnerability of Horizontally Curved Multiframe RC Box-Girder Highway Bridges, Amirkabir Journal of Civil Engineering, (2017).

[8] HAZUS-MH MR5, 2003. "Multi-Hazard Loss Estimation Methodology, Earthquake Model." Washington, DC, USA: Federal Emergency Management Agency.

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