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Investigating the effect of infill walls on the behavior of building with eccentrically braced frame in the Sarpol-e Zahab earthquake through nonlinear analysis

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ABSTRACT: The most important goal in designing an eccentrically braced frame (EBF) is that only link beam yields during the earthquake and other structural members remain elastic. Field survey after the Sarpol-e Zahab earthquake shows that despite several defects in the structural design and construction of EBFs, due to the positive effects of infill walls, they have remained stable. In this study, one of the buildings damaged in the Sarpol-e Zahab earthquake as a three-story four-bay frame with and without infill walls, was analyzed. In the condition that infill walls are not connected to the structure, three cases including case one: design of braces and link beams according to the code, case two: only design of link beams according to the code, and case three: neither design of braces nor design of link beams according to the code were studied. In the condition that infill walls are connected to the structure, the existing structure, in which neither the braces nor the link beams are designed according to the code, was considered as case four. Based on the pushover diagram of all four cases, it can be concluded that connecting the infill walls to the structure causes an increase in stiffness, strength, and energy absorption and it almost compensates the weakness of link beams and braces. In this condition, if there were not infill walls, there would be a possibility of structural collapse.

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1- Introduction

The most important concept in designing eccentrically braced frame (EBF) against earthquake is that yielding is concentrated only at link segments and all other members of the frame remain essentially elastic [1, 2]. The proportion between stiffness and ductility has always been a major concern for engineers. Moment resisting frames have high ductility and low stiffness, while concentrically braced frames have high stiffness and low ductility. Eccentrically braced frames have the advantages of both moment-resisting frames and concentrically braced frames simultaneously [1-5].

Unlike the concentrically braced frame, the interaction of the eccentrically braced frame with the infill wall is very important because the equivalent strut of the infill wall causes the lateral force to be transmitted axially and the shear performance of the link beam to be reduced. In such a system, the wall must be completely separated from the frame [6]. Although many studies have been done on the concentrically braced frame with infill walls, there are a few studies about the eccentrically braced frame with infill walls. The purpose of this research is to study one of the damaged buildings with an eccentrically braced frame system in the Sarpol-e Zahab earthquake.

2- Models' specifications

The studied building is a three-story steel building with an eccentrically braced frame system that was damaged in the Sarpol-e Zahab earthquake (Figure 1). The building has three four-bay frames perpendicular to the street that there are eccentric braces in the first and last bays.

In this building, although the length of the link beam is short, the stiffness is not sufficient due to construction defects. Figure 2 shows that the braces buckled under the seismic force and experienced a large out-of-plane deformation, also the link beams do not have stiffeners. In this building, the infill walls have made a significant contribution to the overall stability of the structure due to the formation of the equivalent diagonal struts under the lateral load (Figure 3).

Fig. 1. Damaged three-story building with EBF system in the Sarpol-e Zahab earthquake (Authors)

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Fig. 2. (Top) buckling of brace iin out-of-plane, (Bottom) lack of stiffness in link beam (Authors)

For numerical analysis of building behavior, a two-dimensional model in the form of a three-story four-bay frame was made in Etabs software, taking into account three-dimensional effects. The columns are made of 2IPE160 with a distance of 20 cm from the axis to the axis which are connected with PL200 × 10. The beams in braced bays are IPE 200 and in other bays are IPE 180 and the braces are IPE 140. Design forces were determined based on provisions of the Iranian national building code-part 6 [7] and seismic forces were calculated based on the 3th Edition of Iranian standard No. 2800 [8]. To model the infill walls, a compression diagonal strut with a width of 0.2 times of the diagonal length of the wall was considered that in braced bays, the width of the strut was reduced to 50% of this value [6]. As the walls have been constructed with the moderate strength hollow clay blocks, considering the effect of interior and exterior plaster, the equivalent modulus of elasticity was considered 3927 MPa and the equivalent thickness of walls, 16 cm [9].

In nonlinear models, the specifications of the plastic hinges for the compression strut of the infill wall, the braces as well as the two ends of the link beam were defined based on the instruction No. 360 [10]. Nonlinear models include the following four cases:

Case 1: Infill walls are not connected to the structure, braces and link beams are designed according to the code.

Case 2: Infill walls are not connected to the structure, only link beams are designed according to the code.

Case 3: Infill walls are not connected to the structure, neither braces nor link beams are designed according to the code.

Case 4: Infill walls are connected to the structure, neither braces nor link beams are designed according to the code, the conditions of the existing structure.

Fig. 3. Tolerate part of the lateral load by the formation of the compression diagonal struts of infill walls (Authors)

3- Results and Discussion

Shear force diagrams of the eccentrically braced frame with and without infill walls under seismic force are presented in Figures 4 and 5. The fundamental period of the bare frame is 0.46 seconds and the fundamental period of the infilled frame is 0.17 seconds. In order to calculate the story stiffness, the method of triangular force distribution similar to the seismic force distribution and calculating the resulting displacement of each story was used [11], the results are presented in Table 1.

The results of the pushover analysis are demonstrated in Figure 6. As can be seen, connecting the infill walls to the structural system has led to a significant increase in the stiffness, strength, and energy absorption and it almost compensates for the weakness of link beams and braces. In case 3 that the infill walls are separated from the structure, the seismic behavior of the structure is much weaker than the existing structure and the amount of seismic energy absorption is less than one-third.

The analysis shows that the presence of the diagonal strut of the infill wall causes the shear force in the link beam to experience a reduction of 7 to 8.5 times. The infill wall also reduces the lateral displacement by 6.7 to 7.7 times, the lateral stiffness of the stories increases by 6.7 to 8.5 times, and thus the fundamental period decreases by 2.7 times. According to the pushover analysis, in cases one and two, the formation of plastic hinges began from the link beams of the second story and in the next steps, it was formed in the link beams of the first story. This is expected based on shear force diagram, so the results of the linear and nonlinear analysis are matched. In case four, first, the axial plastic hinges were formed in the infill walls of the first story, after removing the infill walls from the lateral resisting system, plastic hinges were formed in the braces of the first story and then by developing plastic hinges in the braces of the first story, this story became a mechanism. The axial and shear force diagrams in this case, before and after the brittle failure of infill walls show that most of the lateral force was tolerated by infill walls and after the brittle failure of infills

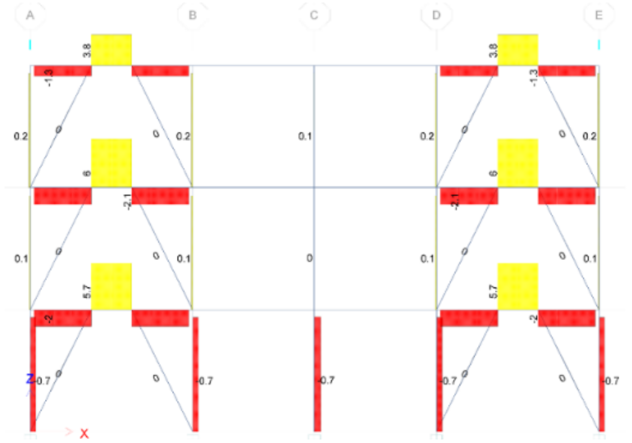

Fig. 4. Shear force diagram of EBF without infill walls (tonf)

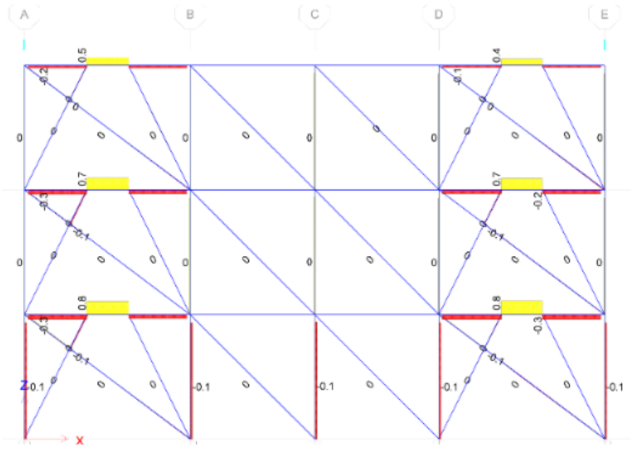

Fig. 5. Shear force diagram of EBF with infill walls (tonf)

Table 1. Story stiffness of EBF with and without infill walls

	First Story			Second Story			Third Story		
	Δ	F	K	Δ	F	K	Δ	F	K
	cm	tonf	tonf/cm	cm	tonf	tonf/cm	cm	tonf	tonf/cm
EBF	0.61	18.9	31	0.66	15.7	24	0.43	9.4	22
Infilled EBF	0.09	18.9	210	0.08	15.7	196	0.05	9.4	188

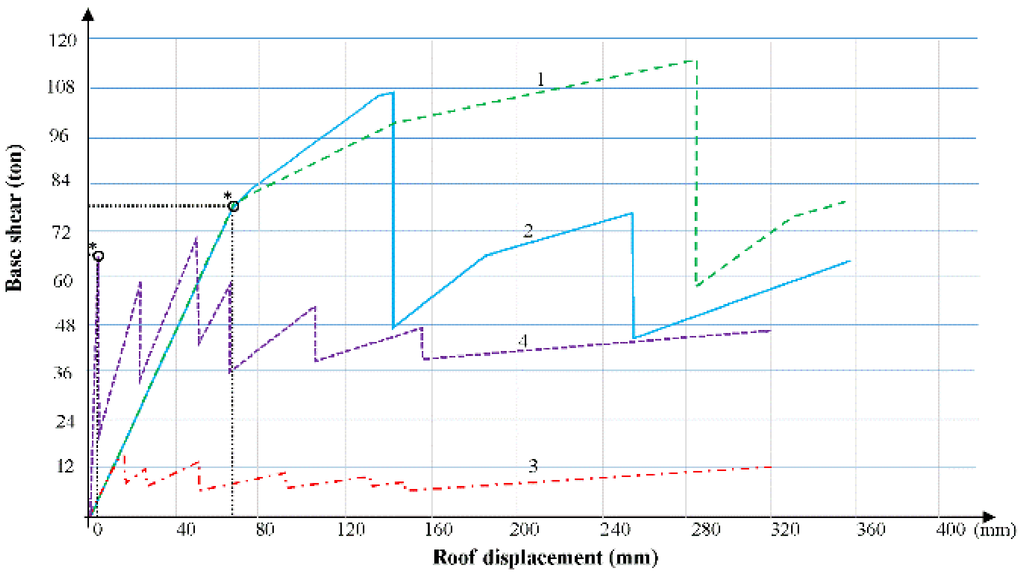

Fig. 6. Pushover diagram of EBF and infill wall for four cases

in the first story, this force was transmitted to the braces. Accordingly, in the initial earthquake cycles, defects of the braces are not a problem for the structure due to the participation of infill walls. The shear force diagram before failure of the infill walls shows that shear force in link beams is low and this is contrary to the philosophy of the eccentrically braced frame design. By removing the infill walls, the shear force in link beams increases about three times.

4- Conclusion

- The results of linear and nonlinear analyses are in good agreement with the behavior of the damaged building in the Sarpol-e-Zahab earthquake.
- In addition to moment frames, the infill wall also has a significant effect on the seismic behavior of eccentrically braced frames.
- In the condition that there are several defects in the design and construction of the eccentrically braced frame, connecting the infill walls to the structure is desirable.
- For the eccentrically braced frame that is designed and constructed well, connecting the infill walls to the structure disrupts the desirable ductile behavior of the system.

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