Seismic Performance of Building Frames with Buckling Resistance Braces Under Far and Near Field with and without Pulse Earthquakes

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ABSTRACT

Buckling Resistance braces are known as elements which resistant to axial loads in tension and compression. The present study is focused on the seismic behavior of low to medium height of braced building frame, which equipped with non-buckling braces under far and near fault with and without pulse earthquakes. In this research, building frames with pinned beam-to-column connections in 4 stories have been studied. Incremental dynamic analysis has been performed for 14 earthquake records from all three domains. The results obtained from the incremental dynamic analysis for the studied frames under the selected earthquake records with the conditions and characteristics affected by the distance from the earthquake site, has shown the vulnerability of 4 and 8-story frames with pinned beam-to-column joints against ground movements in all three areas distance from location of the fault and for the damage parameter of inter story drift ratio. Also, the results have shown that the bracing members are the most vulnerable members of this frame. The median acceleration that obtained to a 4-story structure and for the performance levels of immediate occupancy, life safety and collapse threshold to meet the functional conditions of the inter story drift ratio as damage parameter in far-field earthquakes are 0.30 g, 0. 85 g and 1.05 g, and 0.40 g, 0.75 g, and 0.95 g were obtained for the near field with pulse, and 0.30 g, 0.80 g, and 1.00 g for the near field without pulse, respectively.

KEYWORDS

Buckling-Resistant Brace, Fragility Curve, Progressive Seismic Analysis, Seismic Performance Levels, Far and Near Field Earthquakes

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1. Introduction

Lateral force resisting systems are used in buildings to increase lateral strength, stiffness, ductility, and energy dissipation potential under seismic loading. Buckling resistance braces (BRBs) as one of these lateral force-resistant elements which have shown almost equal resistance in tension and compression, higher ductility, and better energy dissipation capability [1]. Experimental and numerical studies have shown that frames equipped with buckling resistance braces may have relatively higher residual deformations when exposed to severe earthquakes [2, 3]. Also, it has been shown that buckling-resistance braced frames can be used to overcome several potential problems related with conventional concentrically braced steel frames (CBFs), such as sudden reductions in strength and stiffness, reduced energy dissipation capacity and limited plasticity [4]. After the recent earthquakes and the large damage of the structures designed with the seismic codes, it has been proven for researchers that the nonlinear response of the structures which are exposed to far and near field earthquakes is different and therefore the codes should be modified [5-6]. One of the such resistant systems that has recently received much attention for use in high seismically area is the building frame system with buckling resistance braces.

2. Methodology

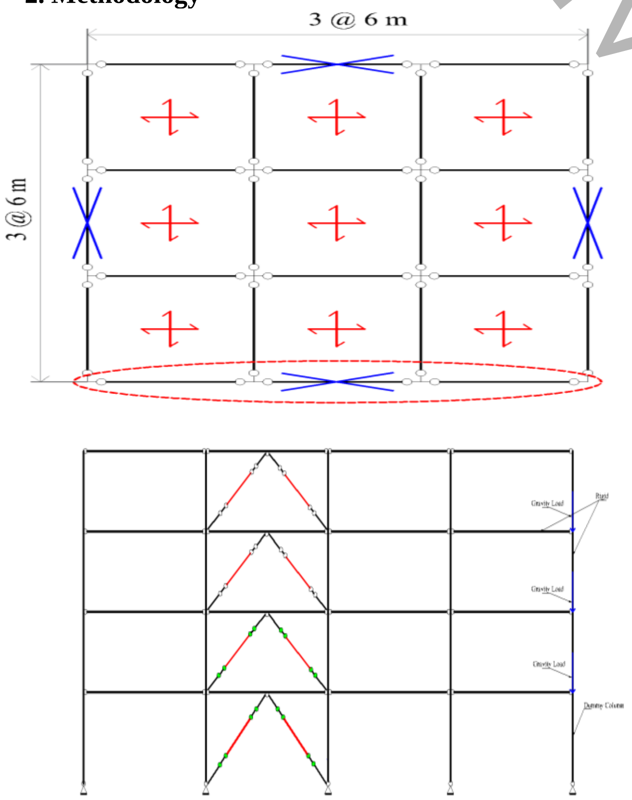


Figure 1. Plan and side view of two-dimensional frame extracted from three-dimensional frame of 4 story

A building, 4 story, is considered for seismic evaluation in this study. This building represents low rise structures. The plan dimensions and elevation views of this buildings are shown in Figure 1. The floor plan dimensions of the buildings are 18 (m) x 18 (m) with three beams 6 (m) length in one direction and three beams 6 (m) length in the other direction. The total height of the 4-story building is 12.50 (m) and the height of the first story is 3.50 (m). As shown in Figure 1, all beam-to-column connections are considered non-earthquake-resistant connection (or hinge connection).

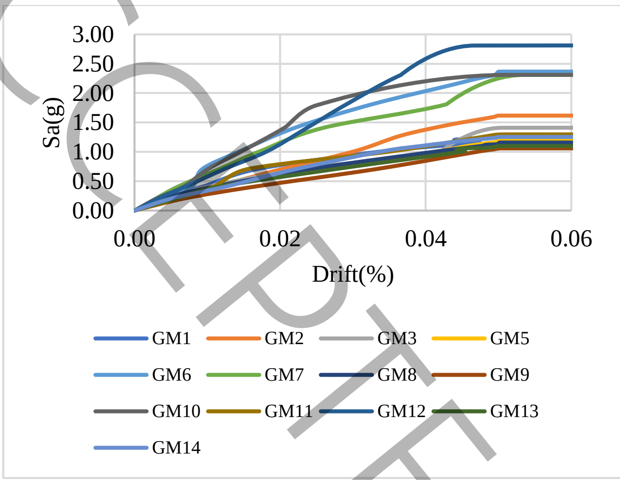
The computational models of the frame were developed in Python software version 8.3 and using the OpenSeesPy library [7], and the members were individually calibrated by comparing the hysteresis response of the components used with the results of the past test. Then, the analysis of progressive nonlinear dynamic of frame has been done. Finally, by drawing the overall fragility curves of the frame (based on story relative displacement) and the fragility of frame members (brace axial deformation and column rotation), the seismic response of frames with buckling resistance braces investigated in this article, have been evaluated for the required performance at different risk levels.

14 records were used to perform incremental dynamic analysis for each investigated seismic field. According to the guidelines for the evaluation of seismic performance coefficients of structures (FEMA P-695) [8], all records after scaling to their maximum acceleration at period of the main mode of the analyzed structure, scaled up to the target design spectrum with incremental step (0.01g) until collapse criteria is achieved. In the process of modeling, in each structure, one of the side frames is modeled as a two dimensions frame, which brace is located in the middle bays. Incremental nonlinear dynamic analysis under 14 earthquake records for all three domains have been done in this research based on proposed FEMA P-695 guidelines. In this method, each structure was subjected to incremental dynamic analysis 42 times, and a collapse capacity was obtained for each analysis, and their results were used to evaluate the collapse probability of the frame.

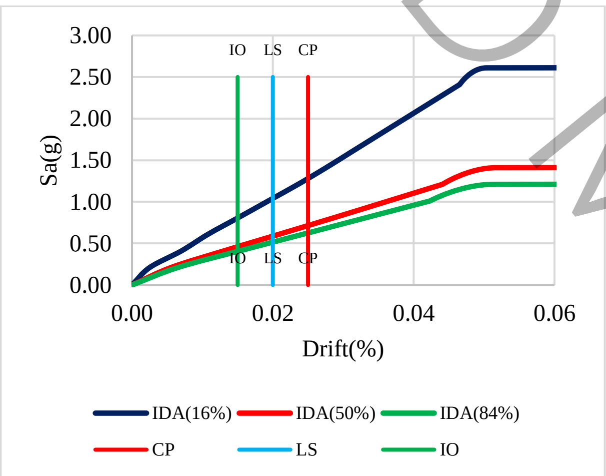
3. Result and Discussion

Figure 2(a) shows the maximum variation of 4-story frame relative displacement response for near-field earthquakes with pulse. It has been observed that the maximum value of spectral acceleration response is 2.81g. In Figure 2(b), the spectral acceleration in maximum story relative displacement of 4-story frame, in quantiles of 84%, 50%, and 16% (respectively), is

1.21, 1.41, and 2.61g have been achieved. In addition, for the three main performance levels of IO, LS, and CP, the mean spectral acceleration values (respectively) are calculated 0.48, 0.61, and 0.70g.



(a) Analysis results under different earthquake records

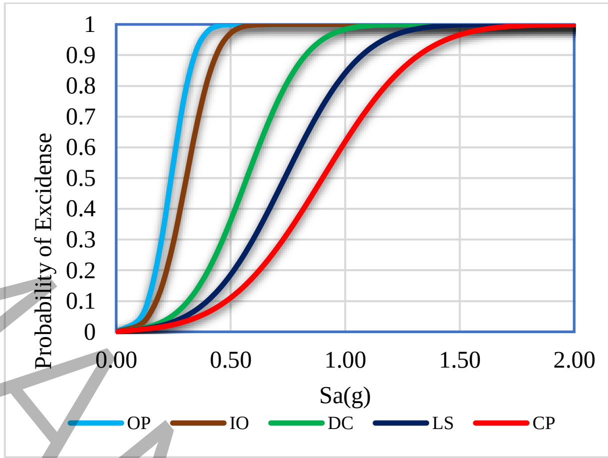


(b) Summary of analysis results

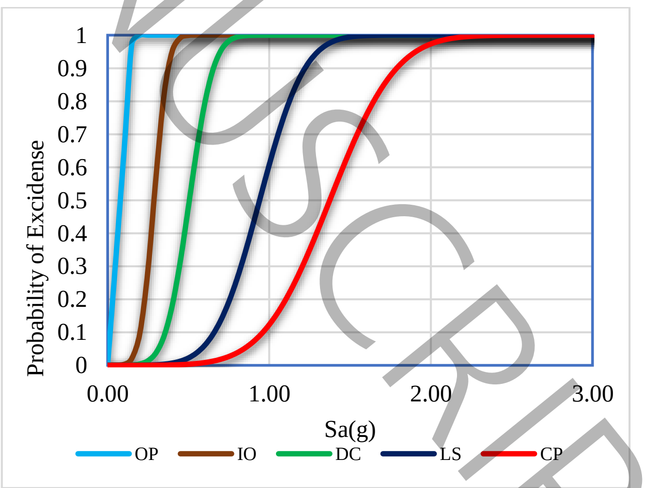
Figure 2. Results of incremental dynamic analysis of 4-story braced steel building frame for near field records with pulse.

Figure 3(a) shows the maximum variation of story relative displacement response of 4-story frame for far-field earthquakes. It has been observed that the maximum value for response of spectral acceleration is 3.45g and the maximum displacement is obtained in first story. In Figure 3(b), the spectral acceleration in maximum story relative displacement of 4-story frame, in the quantiles of 84%, 50%, and 16% (respectively), is obtained 1.41, 1.81, and 2.61g. In addition, for three main performance levels of IO, LS, and CP, the median spectral acceleration values are obtained 0.50, 0.69, and 0.90g, respectively.

As have been mentioned previously, the response of the structures was obtained according to the type of earthquake records in terms of the distance from record released field, magnitude, and presence of pulse for the selected records. Therefore, probabilistic evaluation by considering the uncertainties in the design of engineering structures, is inevitable, and it can be provided better express the functional behavior of structures for obtained result. From incremental non-linear dynamic analysis, the response of structural elements such as braces deformation and columns rotation have been also extracted. In this research, these responses were used as other damage parameters in addition to the relative story displacement (i.e., brace axial deformation, and columns plastic hinge rotation) to evaluate the structural performance. Also, the summary of results is presented in Tables 1.



(a) Relative displacement of the story in the field with pulse



(b) Axial deformation of the brace in the field with pulse

Figure 3. Fragility curves of 4-story braced steel building frame at performance level

Table 1. The values of 4-story frame maximum spectral acceleration result from incremental dynamic analysis and the median spectral acceleration from fragility analysis

CP	LS	DC	IO	OP	Damage parameter	IDA-50%	Seismic field
0.90g	0.75g	0.60g	0.35g	0.25g	Story relative displacement	1.41 g	Near field with pulse
1.40g	0.95g	0.50g	0.30g	0.10g	Brace axial deformation		
1.80g	1.50g	0.85g	0.35g	0.10g	Column rotation		
1.00g	0.80g	0.60g	0.35g	0.25g	Story relative displacement	2.01 g	Near field without pulse
1.60g	1.05g	0.60g	0.30g	0.10g	Brace axial deformation		
1.90g	1.55g	0.90g	0.30g	0.10g	Column rotation		
1.05g	0.85g	0.65g	0.35g	0.25g	Story relative displacement	1.81 g	Far field
1.30g	0.90g	0.50g	0.30g	0.10g	Brace axial deformation		
1.95g	1.60g	0.95g	0.55g	0.30g	Column rotation		

4. Conclusions

1-There is a significant gap between story relative displacement damage criterion and two other damage criteria, column plastic hinge rotation and brace axial deformation, for the 4-story structure. So, it can indicate that the failure criteria must be used which consider maximum capacity of the structure according to the general regulation’s restrictions (such as story relative displacement) and the limitations of structural components (such as column rotation and brace axial deformation), and it seems that more optimal structural designs can be achieved by providing conditions that help bring these control criteria being closer.

2- Earthquakes in the area near to the fault have a higher destructive effect for relative displacement response for 4-story frames, which braced with buckling resistance brace, so that in the middle of the spectral acceleration, more damages were imposed to the structure compared to earthquakes in the far field records.

3- Using the obtained results, it can be stated that the functional response of the structures will have a significant impact on the number of stories, and the location of the building in relation to the location of probable earthquake, and need for more investigation and research in this field to change parameters. Such as width and height of the braced bays, and the type of bracing arrangement can be suggested for future research.

5. References

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