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Investigation the Sidesway Collapse and Seismic Fragility Analysis of Frames with BRB Equipped with SMAs

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ABSTRACT: Although Buckling-Restrained Braces (BRBs) can dissipate a large amount of the seismic input energy. However, they need to be repaired or replaced due to large permanent deformation after a severe earthquake. To overcome this issue, the use of Shape Memory Alloys (SMAs) in the braces has recently received attention. These alloys are able to return to their original state after loading. The present study aims to analyze the fragility curves and to investigate the sideway collapse of the BRB frames equipped with SMA during near-field earthquakes in comparison with those given for the case without SMA. For the purposes, two 5 and 15-story BRB and BRB-SMA frames subjected to 7-pair of near-fault earthquake records are studied. Nonlinear Incremental Dynamic Analyses (IDAs) are carried out using OpenSees software. On average, the simulation results showed that the collapse capacity and collapse duration of the BRB-SMA frames are about 30% and 35% more than those given for the BRB frames, respectively. For instance, a collapse probability of 38% for the 5-story BRB-SMA frame and a collapse probability of 60% for the BRB frame is given for 3g spectral acceleration. Furthermore, at the performance level of 50% for the 15-story frame, the collapse duration of the BRB-SMA frame is obtained 25.6 seconds, while it is given about 10 seconds for the BRB frame. In addition, the use of a memory alloy for spectral accelerations of 1 to 4 g resulted in a reduction of 50% to reach the collapse performance level of the frames.

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1- Introduction

Today, frames with buckling restrained brace (BRB) are considered as a lateral load-resistant system. Due to the lack of buckling in the compression, their hysteresis curve is stable, but these braces also have disadvantages. These disadvantages include permanent deformation of the structure after loading, as well as the cost of replacing these members after failure and leakage of the steel core of these braces. To fix these defects, shape memory alloy (SMA) is used. Its two important properties are the shape memory effect and their super-elastic properties. Shape memory alloys are a type of intelligent material that have significant potential for controlling the responses of structures with BRB [1-4]. Nowadays, it is important to study the sidesway collapse of structures and the development of fragility curves to evaluate the seismic behavior of structures. Researchers have presented some research in the field of steel moment frame structures [5-7], but limited research has been done on structures equipped with bracing systems. Considering that the implementation of steel structures with various bracing systems is common in our country, the study and compare the probability of their behavior by considering appropriate earthquakes can give a new perspective on the behavior of these systems. Therefore, in this study, considering 5 and 15-story steel structures with BRB system, expect a more accurate assessment of the role of using shape memory alloy in the collapse potential of structures under 7 pairs of near fault earthquakes. In addition, investigating the role of shape memory alloys in the collapse capacity of steel frames, probabilistic evaluation and comparison of frame behavior with the development of fragility curves at different performance levels of FEMA P695 [8] has been performed. Also, by examining the collapse duration of structures in both cases with and without shape memory alloy, the effectiveness of shape memory alloys in improving the collapse duration and seismic system resilience can be studied.

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2- Methodology

The step-by-step research method is presented as follows:

1- Design of regular steel frames with BRB with and without shape memory alloy.

2- Preparing nonlinear models of the studied frames and selecting 7 pairs of near fault earthquakes based on FEMA P695 instruction.

3- Performing incremental nonlinear dynamic analyses of the studied frames under selected earthquakes.

4- Estimation of sidesway collapse capacity and collapse duration of steel frames with BRB with and without shape memory alloy.

5- Development of seismic fragility curves at the collapse performance level.

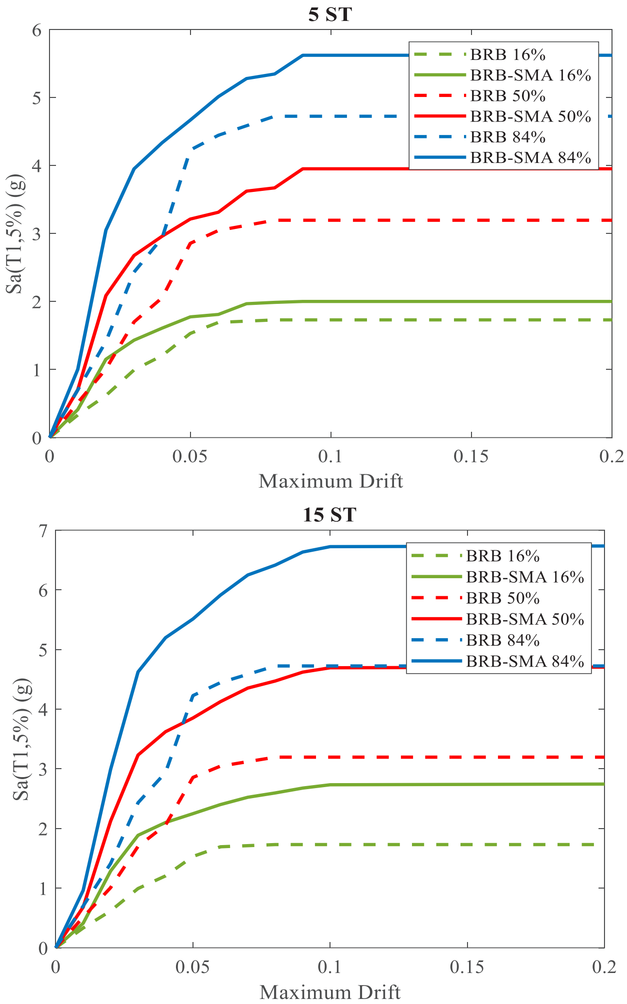

Fig. 1. The summarized results of incremental dynamic analysis of 5 and 15-story frames with BRB in two modes with and without SMA

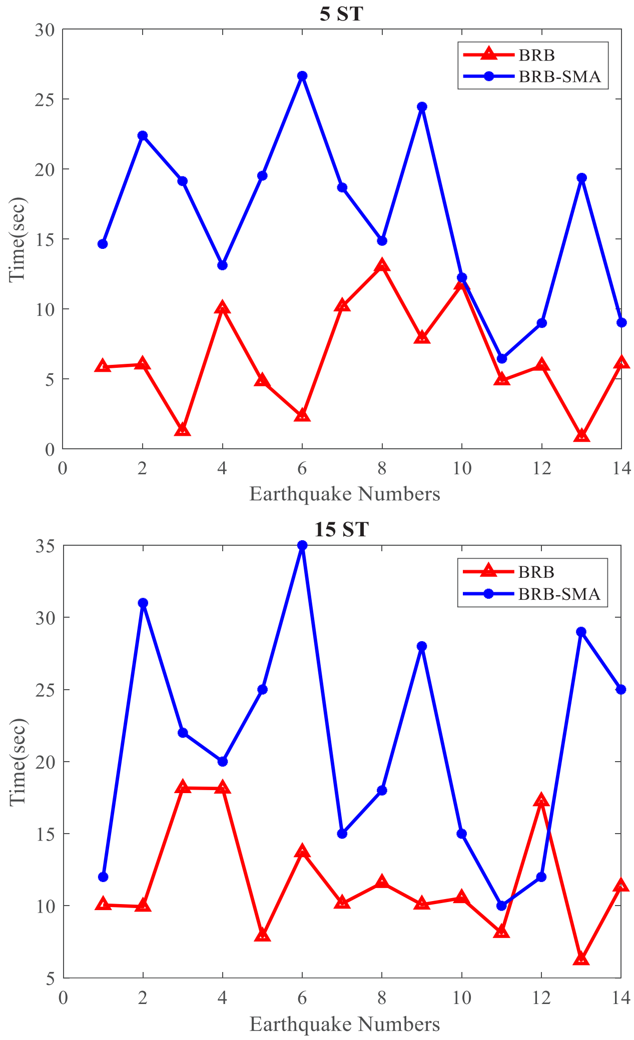

Fig. 2. Comparison of the collapse duration of the studied frames due to near fault earthquakes

3- Results and Discussion

In this study, in order to evaluate the performance of steel frames with BRBs equipped with shape memory alloys, nonlinear incremental dynamic analysis (IDA) has been used under 7 pairs of near fault earthquakes. The outputs of this analysis include IDA and fragility curves. Fragility curves can be summarized for 16, 50 and 84% probability levels in terms of the probability distribution of the normal log, which is also presented in the PEER report [9]. In this study, based on code 361 [10], drift values of 0.7, 2.5 and 5% have been considered as performance levels of immediate occupancy (IO), life safety (LS) and collapse prevention (CP). Nonlinear incremental dynamic analysis is applied to each record with spectral acceleration steps of 0.1 g. The collapse capacity of each frame is the largest spectral acceleration that the frame has withstood.

In this study, IDA curves were summarized at three levels of 16%, 50% and 84%. As shown in Figure 1, the summarized curves of the IDA analyses correspond to both frame modes. It is clear that the sidesway collapse capacity of the BRB-SMA frame is higher than other frames. According to this figure, as an example, in a 5-story frame, the level of 84% of the BRB frame corresponds well with the level of 50% of the BRB-SMA frame with the level of 16% of the BRB-SMA frame.

According to Figure 2, a comparison of the collapse duration of the considered frames under the effects of the studied earthquakes is presented. It is known that the collapse duration is maximum under the second component of the Irpinia earthquake and minimum during the first component of the Cape Mendocino earthquake. The reason for this difference is due to the nature of near fault earthquakes. It is also observed that the collapse duration of the BRB-SMA frame is longer than the time required for the BRB frame collapse for most earthquakes. The BRB frame provides the minimum time required for sidesway collapse. As shown in Figure 3, the BRB-SMA frame has shown a longer collapse duration than other frames. In a 15-story frame, for example, at the level of 16% of the input

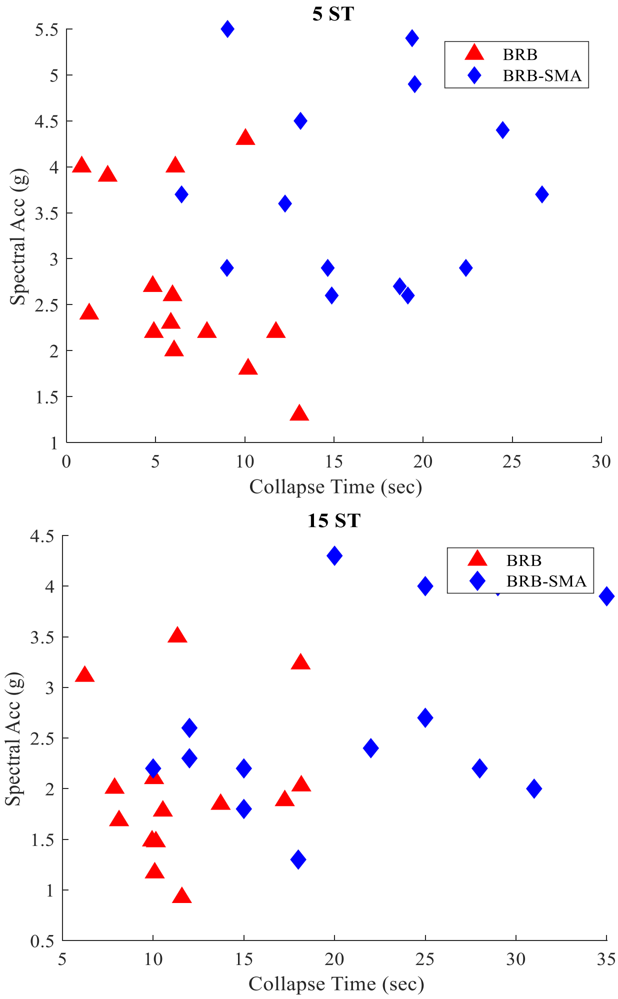

Fig. 3. The collapse capacity of the studied frames under 7 pairs of earthquakes

records, the collapse duration of the BRB-SMA frame is 17 seconds and that of the BRB frame is 5 seconds. Also, at the level of 50% of the input records, the collapse duration of the BRB-SMA frame is 25.6 seconds and the BRB frame is 10 seconds, and at the level of 84% of the input records, the collapse duration of the BRB-SMA and BRB frame are 32 and 18 seconds, respectively.

4- Conclusions

In this study, the role of shape memory alloy was investigated in increasing the duration of collapse and sidesway collapse capacity of BRB frames under near fault earthquakes. The following results can be mentioned below:

1. Based on the results of incremental dynamic analysis, a frame with BRB-SMA showed the highest collapse capacity and a frame with BRB indicated the lowest collapse capacity. Also, the rate of spectral acceleration has enhanced by increasing the height of the specimens with shape memory alloy.

2. Based on fragility curves, performance levels of immediate occupancy (IO), life safety (LS) and collapse prevention (CP) of frames were compared. The results showed that the use of shape memory alloy in the BRB has significantly increased the collapse capacity of mid-rise and high-rise structures. For example, at the 84% probability level, the collapse capacity of a 15-story frame with the BRB-SMA increased in comparison with 16% probability level of BRB frame.

3. The sidesway collapse duration in BRB frames with shape memory alloy has increased compared to the state without it. Also, the results related to the collapse duration showed that at high spectral accelerations, the sidesway collapse duration of the frames decreased

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