Investigating the Seismic Performance of Strong Back and Buckling Restrained Brace Systems for High-rise Structures in Far-Field Earthquakes

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ABSTRACT

Earthquakes are currently considered a serious threat to structures, particularly steel-braced structures, underscoring the need for systems that are capable of maintaining functionality and serviceability after seismic events. In this regard, the StrongBack Structural System (SBS) has been introduced as a combination of elastic and plastic truss elements, which, by ensuring a uniform distribution of forces along the height of the structure, prevents the development of a soft-story mechanism. In this study, through a detailed investigation of the conventional configuration of this structural system, a new configuration is proposed with the aim of achieving improved seismic performance.

KEYWORDS

Seismic Performance, High-rise Structures, Far-Field, StrongBack Structural System

1. Introduction

Seismic design codes have been developed with the primary objective of preventing building collapse; however, they do not adequately address structural performance in terms of post-earthquake serviceability and economic consequences. Although steel-braced frames provide life safety, they are susceptible to the formation of a soft-story mechanism due to brace buckling, a phenomenon that can lead to increased structural damage. Post-earthquake observations demonstrated that braced frames often exhibit unsatisfactory performance because of buckling of compression members, resulting in a reduction in their capacity under cyclic loading [1–3]. To mitigate the probabilistic formation of soft-story mechanisms, the StrongBack Bracing System (SBS) has been introduced. Numerous studies have shown that the presence of an elastic truss component in this structural system improves the uniform distribution of interstory drift along the height of the structure [4,5]. Furthermore, experimental and numerical investigations indicate that the strong-back system is capable of maintaining stiffness and reducing damage concentration, even after the failure of inelastic bracing elements [6,7,8]. In this study, by examining the conventional configurations of the strong-back structural system, a new configuration is proposed to enhance the seismic performance of the strong-back system during earthquakes.

2. Methodology

In this study, to investigate the seismic performance of the strong-back system in high-rise structures, buildings with a square plan layout consisting of four bays of 5 m each and heights of 8, 12, and 16 stories were examined (Fig1). The story height was taken as 2.9 m, and gravity loads were applied in accordance with the specified values. The structures were designed using ST37 structural steel, in compliance with ANSI/AISC 341-16 and the fourth edition of Standard 2800 [9,10].

To evaluate the performance of the modelled frames, a set of 22 pairs of far-field earthquake acceleration records with moment magnitudes ranging from 6.5 to 7.6 on the Richter scale was employed. These ground motion records were recorded at distances ranging from 11.1 km to 26.4 km from the seismic source [11].

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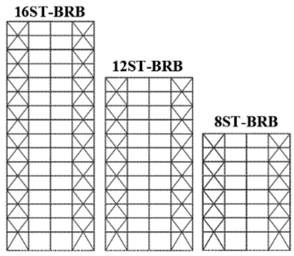

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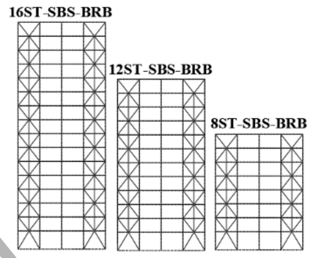

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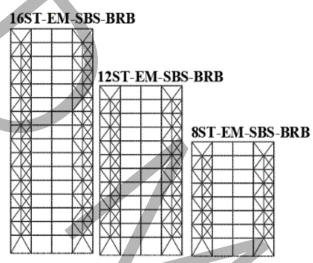

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Fig.1.View of the structures modelled in the OpenSees software (a) BRB, (b) SBS-BRB, (c) EM-SBS-BRB

3. Results and Discussion

Based on the curves presented in Fig.2, it can be observed that BRB structures experience a degradation in seismic performance as the number of stories increases. Comparison of the spectral acceleration values for the 8-story models indicates that no significant improvement in seismic performance is observed. Similarly, for the 12-story structures, comparison of the spectral acceleration values between the 12ST-BRB and 12ST-EM-SBS-BRB models shows an improvement of 27.2%. However, when comparing the 16ST-BRB and 16ST-EM-SBS-BRB analytical models, a 279.7% improvement in seismic performance is observed, representing a substantial enhancement in seismic behavior.

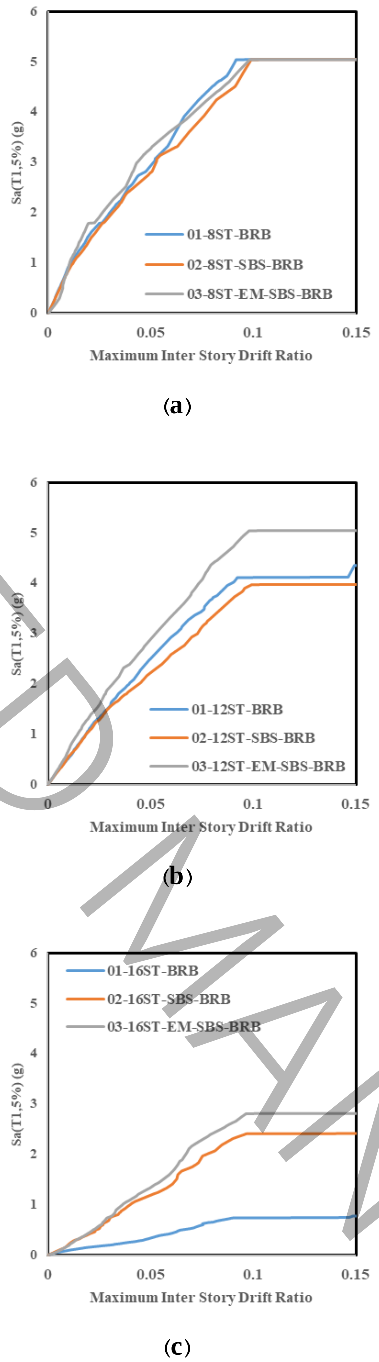
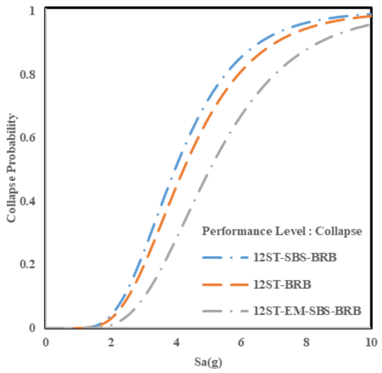


Fig.2. Median IDA curves for (a) 8-story, (b) 12-story, (c) 16-story

By comparing the fragility curves shown in Fig.3, it can be observed that, in general, the probability of collapse increases with increasing structural height, since high-rise structures experience larger lateral displacements at the story levels. As can be seen, in the 12- and 16-story structures, the proposed model of this study was able to improve the inter-story drift.



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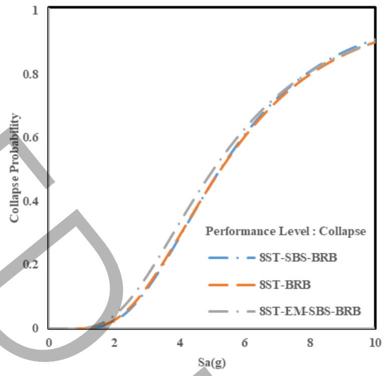

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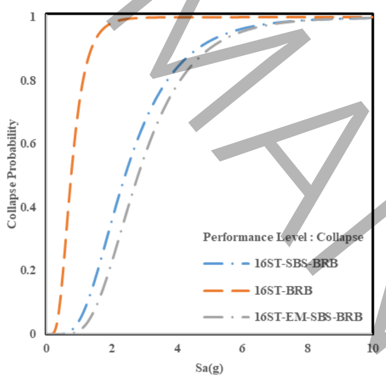

(c)

Fig.3. Fragility curves corresponding to a 10% drift limit for (a) 8-story models, (b) 12-story models, (c) 16-story models.

4. Conclusion

An examination of the structural models indicates ing height has a significant influence on the results. In the 8- and 12-story structures employing only the buckling-restrained bracing (BRB) system, the collapse demand in the 8-story structure exhibited lower values; however, as the height increased to 12 stories, this demand gradually increased, and ultimately, in the 16-story structure, very poor seismic performance was observed. This trend clearly demonstrates the adverse effect of building height on the seismic performance of BRB systems. It further indicates that combining the buckling-restrained bracing system with the strong-back system can effectively enhance the seismic performance of BRB-based structural systems. Across all analyses, the proposed model of this study exhibited the highest seismic performance in the 12- and 16-story structures. In addition, the fragility curves of these structures show significantly lower probabilities of damage and collapse compared to the conventional BRB structural system.

5. References

[1]. F. Khatib, S. A. Mahin, K. S. Pister, Seismic behavior of concentrically braced steel frames, Earthquake Engineering Research Center, University of California Berkeley , 1988.

[2] - R. Tremblay, Achieving a stable inelastic seismic response for multi-story concentrically braced steel frames, Engineering Journal, 40(2) (2003) 111-129.

[3]- J. -W. Lai, Experimental and analytical studies on the seismic behavior of conventional and hybrid braced frames, UC Berkeley, 2012.

[4]- S. Merzoug, R. Tremblay, Sismic Design of Dual Concentrically Braced Steel Frames for Stable Sismic Performance for Multi-Storey Buildings, (2006).

[5]- R. Hooft, S. Mahin, J. Lai, Preliminary study of the strongback system: preventing the soft story mechanism, in, 2010.

[6]- B. Simpson, S. Mahin, J. Lai, Experimental investigation of the behavior of vintage and retrofit concentrically braced steel frames under cyclic loading, University of California, Berkeley, CA: Pacific Earthquake Engineering Research Center, (2017).

[7]- B. G. Simpson, S. A. Mahin, Experimental and numerical investigation of strongback braced frame system to mitigate weak story behavior, Journal of Structural Engineering, 144(2) (2018) 04017211.

[8]- B. G. Simpson, Higher-mode force response in multi-story strongback-braced frames, Earthquake Engineering & Structural Dynamics, 49(14) (2020) 1406-1427.

[9]- A.I.o.S. Construction, Seismic provisions for structural steel buildings, American Institute of Steel Construction, 2016..

[10]- Permanent Committee for Revising the Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800, fourth ed., Road, Housing and Urban Development Research Center, Tehran, Iran, 2014.(In Persian)

[11]- ATC. Quantification of building seismic performance factors. US Department of Homeland Security, FEMA; 2009.