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# Evaluation of buckling-restrained braced frame seismic performance considering reserve strength

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ABSTRACT

Buckling-restrained braced frame (BRBF) systems are used extensively for resisting lateral forces in high seismic regions of the United States. Numerical and large-scale experimental studies of BRBFs have shown predictable seismic performance with robust ductility and energy dissipation capacity. However, the low post-yield stiffness of buckling-restrained braces (BRBs) may cause BRBFs to exhibit large maximum and residual drifts and allow the formation of soft stories. Thus, reserve strength provided by other elements in the lateral-force-resisting system is critical to improving seismic performance of BRBFs. This reserve strength can be provided in two primary ways: (1) moment-resisting connections within the BRBF and (2) a steel special moment-resisting frame (SMRF) in parallel with the BRBF to create a dual system configuration. These two approaches to providing reserve strength can be used together or separately, leading to a variety of potential system configurations. In addition, special attention must be given to the connections within the BRBF since moment-resisting connections have been observed experimentally to limit drift capacity due to undesirable connection-related failure modes. This paper presents nonlinear dynamic analysis results and evaluates performance of BRBF and BRBF–SMRF systems using moment-resisting and non-moment-resisting beam–column connections within the BRBF. Reserve strength is shown to play a critical role in seismic behavior and performance of BRBFs.



## 1. Introduction

### 1.1. Background

Tests of buckling-restrained braces (BRBs) have consistently demonstrated stable and robust behavior under cyclic loading [1,2]. Since the steel core of a BRB cannot buckle, it yields in compression as well as in tension and develops significant inelastic deformation and energy dissipation. These characteristics have made BRBs an attractive alternative to conventional steel braces in high seismic regions of the United States. In response to the widespread interest in concentrically braced frames (CBFs) with BRBs, which are called buckling-restrained braced frames (BRBFs), BRBF design provisions are now included in *Minimum Design Loads for Buildings and Other Structures: SEI/ASCE* 7-05 [3] and the American Institute of Steel Construction (AISC) *Seismic Provisions for Structural Steel Buildings* [4].

Although these provisions were developed to be both practical and sufficiently rigorous to provide a level of reliability equivalent to that of other earthquake-resistant structural systems [5], they do not explicitly address the low post-yield stiffness of BRBs and the resulting effect on residual drift and soft story formation. After the BRBs in a given story have yielded under seismic excitation, their low post-yield stiffness provides minimal restoring force and drift can easily concentrate in the story. As a result, residual drift is inherently unpredictable and highly dependent on the ground motion characteristics. Numerical studies of BRBFs have shown residual drift with a mean value greater than 0.005 rad for the design basis earthquake (DBE), which corresponds approximately to a seismic hazard with 10% probability of exceedance in 50 years, and greater than 0.01 rad for the maximum considered earthquake (MCE), which corresponds to a seismic hazard with 2% probability of exceedance in 50 years [6,7]. Large-scale hybrid earthquake simulations of BRBFs produced residual story drifts of 0.013 and 0.027 rad for the DBE and MCE, respectively [8]. Although limits on residual drift are not clearly established, it is typically expected that residual drift less than 0.005 rad would be tolerable and would permit a building to be returned to service with little difficulty (e.g., doors, windows and elevators would still be functional). Given that BRBF residual drift after a DBE could exceed this threshold, post-earthquake repair costs arising from residual drift may make BRBFs less attractive.

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