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# Seismic collapse evaluation of steel moment resisting frames with superelastic viscous damper

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ABSTRACT

This study investigates the seismic collapse resistance of steel moment resisting frames equipped with superelastic viscous dampers (SVD) through incremental dynamic analysis (IDA). The SVD is a hybrid passive control device that strategically combines a viscoelastic device and shape memory alloy cables in parallel. The hybrid device exhibits improved re-centering and energy dissipating capabilities compared to only viscoelastic or only SMA-based devices. First, the design and mechanical behavior of SVDs are described. A nine-story steel frame building is selected for the numerical analyses. The building is first designed as a conventional special moment resisting frame (SMRF) to meet the strength and stiffness requirements of the design codes. Then, a reduced strength version of the fully code compliant frame is developed and upgraded with either SVDs or buckling restrained brace (BRB) system. Analytical models of the steel building for each configuration are developed to simulate global frame behavior by considering both geometric nonlinearities and cyclic strength and stiffness deterioration of structural steel components under dynamic loads. Incremental dynamic analysis is employed to assess the seismic resistance of steel frame structures up to collapse using 44 ground motion records. A sensitivity analysis is also performed to evaluate the influence of SVD design parameters on the seismic response of the frame. The results indicate that the steel frame designed with SVDs has the largest median collapse capacity and minimal residual drifts under various seismic hazard levels.

## 1. Introduction

Conventional seismic design approaches rely on the ability of structures to dissipate the input earthquake energy through inelastic deformations in designed regions of the steel frames, implying substantial structural damage and potential residual drifts after a major earthquake [1]. Peak response quantities such as peak story drifts and peak floor acceleration are typically considered to evaluate performance of different structural systems under seismic loads. However, several studies have shown that residual drifts, which occur due to the nonlinear behavior of yielding components of a structural system, can have an important role in defining the performance of a structure after a seismic event and in evaluation of potential damage [2,3]. McCormick et al. [4] studied the effects of residual drifts on occupants and concluded that residual drifts >0.5% in buildings may suggest a complete loss of the structure from an economic point of view. In another study, Erochko et al. [5] examined the residual drift response of special moment resisting frames (SMRFs) and buckling restrained braced frames (BRBFs). It was found that both types of building systems experience significant residual drifts, with values between 0.8–1.5% for the SMRFs and 0.8–2.0% for the BRBFs under design-based excitations. Ramirez and Miranda [6] found that considering residual drifts in building earthquake loss estimation significantly increases the expected economic losses. By reducing residual drifts of a structure subjected to a seismic event, structural engineers can maximize post-event functionality, reduce the cost to repair the structures, and increase the public safety.

To enhance the seismic performance of structural systems, structural systems that can provide stable energy dissipation with full self-centering capabilities are desirable. These systems, known as self-centering or re-centering, exhibit flag-shaped hysteric response with the ability to return to small or zero deformation after each cycle. The self-centering system can control structural damages while minimizing residual drifts. A wide variety of self-centering systems have been developed over the past two decades including post-tensioned systems, rocking wall systems, and self-centering brace systems [7–12]. An extensive review of self-centering systems can be found in [13].

Shape memory alloys (SMAs) are a class of smart materials that exhibit unique properties such as excellent re-centering ability, high corrosion and fatigue resistance, and good energy dissipation capacity. These distinct properties of SMA have broadly attracted the attention of researchers to develop SMA-based seismic control systems [14]. A number of studies investigated the use of SMAs in developing an effective energy dissipation device with self-centering capabilities [15–20].

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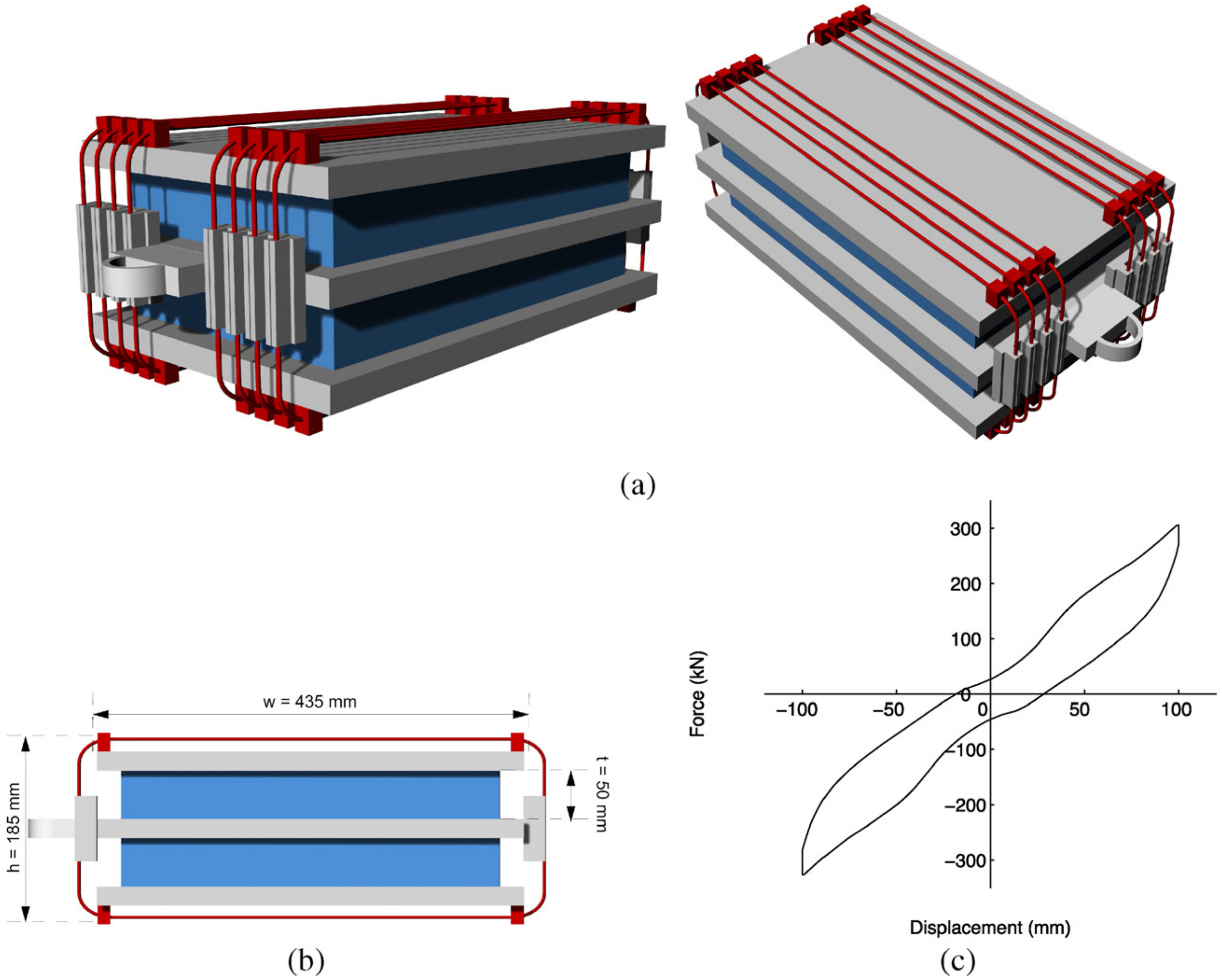

**Fig. 1.** (a) 3D renderings of SVD, (b) design parameters for SVD and (c) force-displacement curve of SVD.

However, the previous studies indicate that superelastic SMA wires or bars employed as the sole damping device can provide only limited quantity of equivalent viscous damping under dynamic loading [21, 22]. Therefore, several researchers have explored ways to add supplemental energy dissipation capabilities to SMA-based control devices [23–26]. Recently, Silwal et al. [27] proposed an SMA-based passive seismic control device, named as superelastic viscous damper (SVD), and conducted experimental and numerical studies to evaluate its effectiveness in mitigating response of steel frames. The SVD combines SMA cables and a viscoelastic element in parallel for improved re-centering and

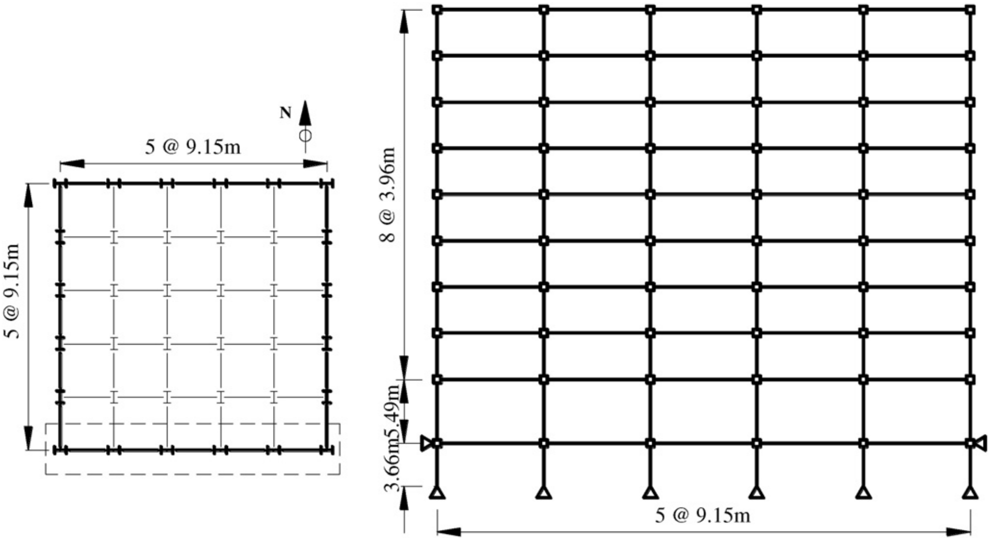

**Fig. 2.** Plan and elevation of nine-story steel special moment resisting frame.