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Seismic fragility assessment of superelastic shape memory alloy reinforced concrete shear walls

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ABSTRACT

Mitigation of seismic damage can be achieved through self-centering techniques. One of the potential techniques involves the use of Superelastic Shape Memory Alloy (SE-SMA) bars in Reinforced Concrete (RC) structures. This study explores the use of such bars in the plastic-hinge regions of RC walls. The seismic performance and vulnerability of SE-SMA RC walls of ten- and twenty-story buildings are analytically assessed using fragility curves. The maximum inter-story drift, residual drift, and fragility are evaluated using multi strip analysis. The results clearly demonstrate the superior seismic performance of SE-SMA RC walls as compared to steel RC walls.

1. Introduction

The main function of reinforced concrete (RC) structural walls is to resist lateral loads. Extensive studies have been conducted to explore their behaviour under various load conditions [1–3]. The seismic design philosophy, which aims at preserving life, leaves RC walls vulnerable to damage during strong seismic excitations. This damage was observed following many earthquakes including the 1985 Mexico earthquake [4], the 1999 Chi-Chi earthquake [5], the 2010 Maule earthquake [6], and the 2011 Christchurch earthquake [7].

Residual drift is one of the measures to evaluate the seismic performance of a structure. FEMA P-58-1 [8] introduced four damage states related to residual drift ratios. The limit for repairable structural elements was set at 1% residual inter-story drift [8]. McCormick et al. [9] concluded that the economical limit is 0.5%. To mitigate the residual displacements of RC walls, self-centering methods that rely on unbounded post-tensioned tendons and supplementary energy dissipation devices were proposed [10–12]. Although these methods have resulted in improved seismic performance, researchers are still exploring new techniques.

Superelastic shape memory alloy (SE-SMA) can recover its inelastic deformations upon the removal of the applied load. This unique property has been utilized by many researchers [13–18]. The flag-shaped hysteresis of SE-SMA can eliminate the seismic residual drifts on the cost of lower energy dissipation as compared to steel reinforcement. Also, the lower modulus of elasticity of SE-SMA bars leads to higher seismic deformations. Researchers have addressed these disadvantages by minimizing the amount of SE-SMA material [17,18]. The potential use of SE-SMA bars was extended to RC walls by a number of researchers. Effendy et al. [19] used external diagonal SE-SMA bars to upgrade the seismic performance of existing squat walls. Test results showed a significant reduction in the residual displacements combined with a 16–26% increase in the peak shear strength. Abdulridha [20] experimentally studied the cyclic behaviour of a concrete wall. The boundary elements were reinforced with longitudinal SE-SMA bars at the plastic hinge region [20]. The SE-SMA bars increased the wall ductility and significantly reduced the residual displacements. Abraik and Youssef [21] conducted an analytical study to identify the performance of SE-SMA RC squat and intermediate walls considering different SE-SMA bar locations. The results highlighted that location of the SE-SMA bars have a significant effect on the wall seismic performance.

Research addressing the seismic vulnerability of tall concrete walls reinforced with SE-SMA bars is missing in the literature. The paper addresses this topic. It starts by identifying the plastic hinges for 10 and 20-story steel RC walls that are designed and detailed per CSA A23.3 [22] and NBCC [23]. The influence of using SE-SMA bars is then evaluated. Fragility curves are presented considering various damage states.

2. Numerical model

A multi-story RC wall is shown in Fig. 1a. The walls are modeled using the Shear-Flexural Interaction Multi-Vertical Line Element Model (SFI-MVLEM), Fig. 1b. This model was implemented in the Open System for Earthquake Engineering Simulation software (OpenSees) [24] by Kolozvari [25]. It allows simulating the seismic response of RC

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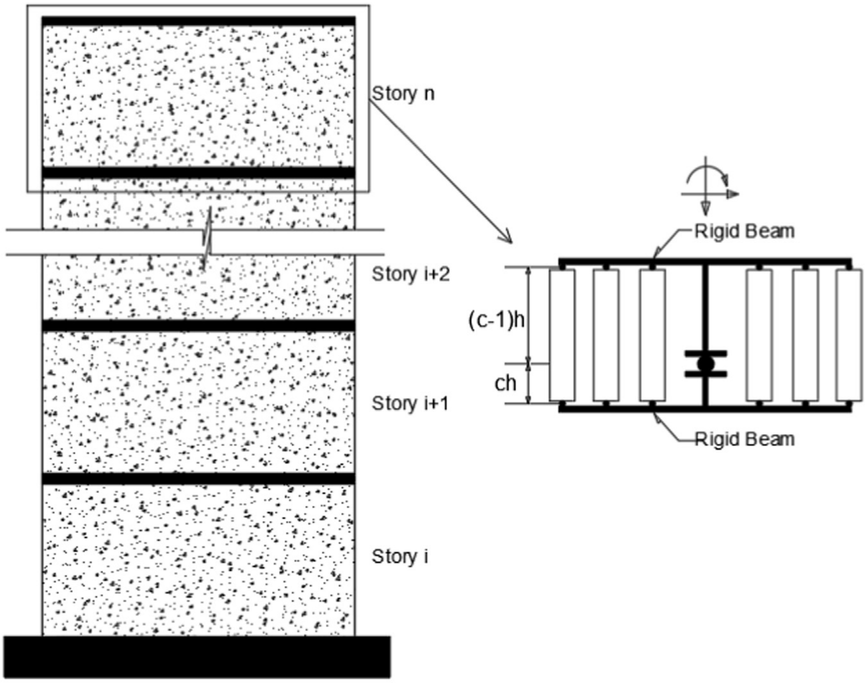
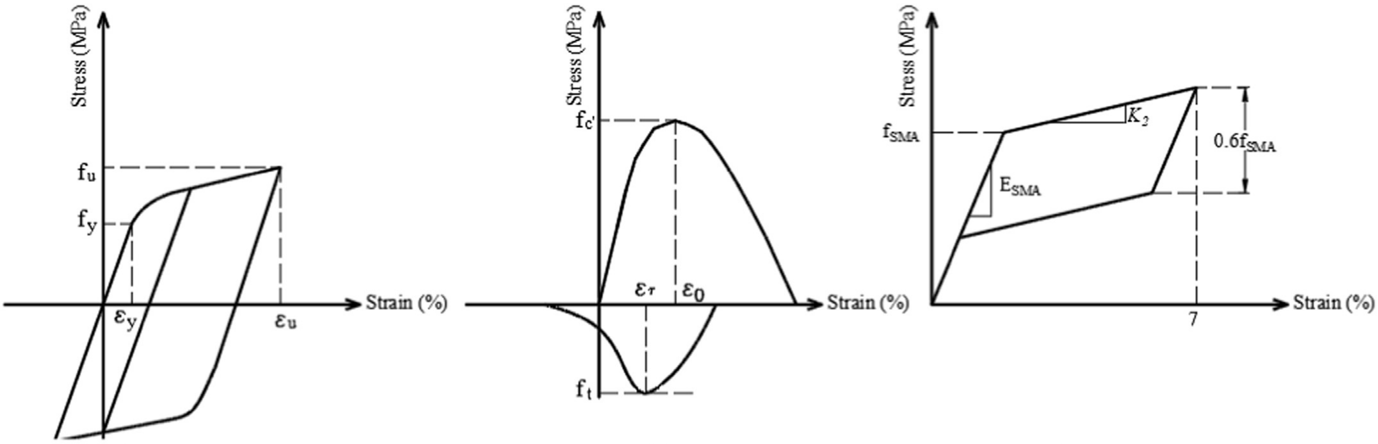
Nomenclature

CMS	Conditional mean spectra
A_g	Cross section area
f_c'	Concrete compressive strength
R_0	Ductility factor
M_f	Factored moment
M_r	Factored moment resistance
l_{bl}	Length of wall boundary element
θ	Median of the fragility function
IM	Ground motion intensity
ρ_{hw}	Horizontal steel ratio in the web
ρ_{hb}	Horizontal steel ratio in the boundaries
ID	Inter-story drift
MSA	Multi strip analysis
P	Probability of exceeding a damage level
RD	Residual displacement ratio
x	Realized condition of the ground motion intensity measure
RC	Reinforced concrete
SE-SMA	Superelastic shape memory alloy
ε_y	Steel yield strain
Φ	Standard normal cumulative distribution
C	Specific damage level
S_a	Spectra acceleration
β	Standard deviation
R_0	Overstrength factor
ρ_{vw}	Vertical steel ratio in the web
ρ_{vb}	Vertical steel ratio in the boundaries
b_w	Wall thickness
l_w	Wall length
H	Wall height



(a) (b)

Fig. 1. MVLE model (a) RC wall; (b) One-story model.



(a) (b) (c)

Fig. 2. Materials model (a) steel bars; (b) concrete; (c) SE-SMA.