NUMERICAL SIMULATION OF SMA DAMPERS IN SEISMIC DESIGN

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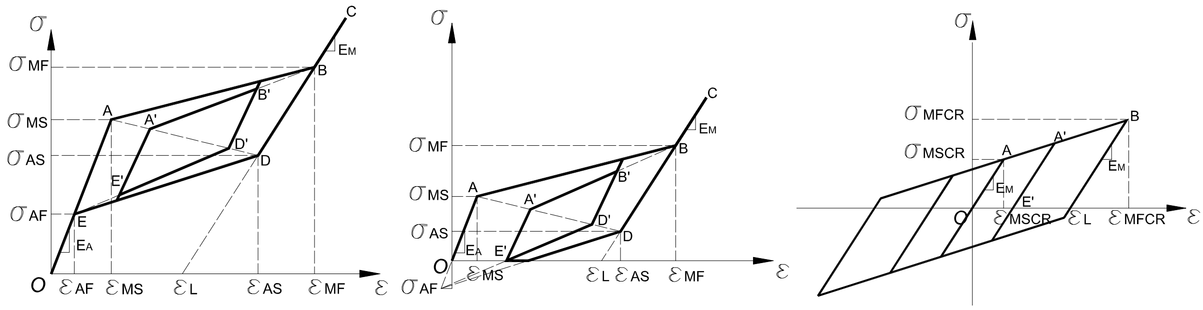
Introduction

Shape memory alloys (SMAs) are smart metallic materials that can undergo large deformations over 10% and return to their original shape without residual deformations through heat process or removal of load for their fairly high characteristics such as re-centering, energy dissipating, damping and so on, which obtained by reversible phase transformation between martensite and austenite. Here, a kind of SMA damper developed for seismic upgrading is proposed, and its effectiveness is verified under detailed analysis and comparisons.

Constitutive Models of SMAs

In order to simulate the material behavior of SMAs numerically, microscopic methodology and macroscopic methodology are two approaches which focus on molecular level and phenomenological features of SMAs, respectively (Paiva, A., 2006). Here in Fig.1(a)-(c), a simple multi-linear one dimensional constitutive model is formulated in 3 cases with different metallographic phase fractions to simulate mainly characteristics of SMAs' axial-type damping devices for seismic upgrading in bridge engineering. The constitutive curve could be described by 4 stress transition points mentioned as σ_{MS}, σ_{MF}, σ_{AS}, σ_{AF}.

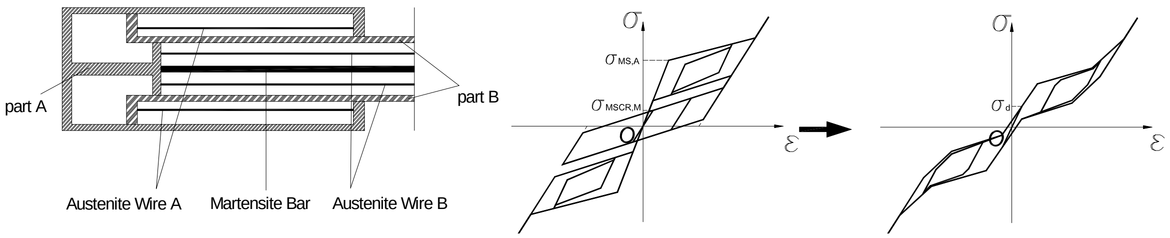


(a) General model (b) Model of partial transformation (c) Model of martensite detwining

Fig. 1 Constitutive model for SMA

Numerical Model of Axial-type SMA Damper

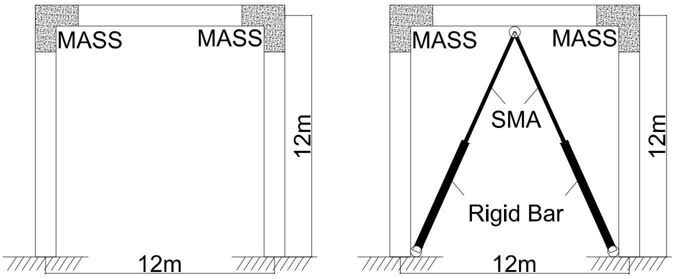
An axial-type SMA damper is shown in Fig.2(a) that two blocks part A and part B made of steel can slide past each other and two sets of austenite wire systems and one martensite bar are kernel materials in the damper that the martensite bar can afford tension and compression without undergoing buckling and two sets of austenite wire are tension only and react in reverse directions. The corresponding analytical model of the damper is shown in Fig.2(b) that combined by 3 separate schematic plots acted as austenite wires in positive direction, austenite wires in reverse direction and martensite bar, respectively.



(a) SMA damper prototype (b) Damper constitutive law

Fig.2 Prototype of SMA damper and stress-strain relationship of SMA damper

Examples and Results



(a) Bare frame (b) Frame with dampers (L_{SMA}=0.5L_{BRACE})

Fig. 3 Bare portal frame and frame with dampers

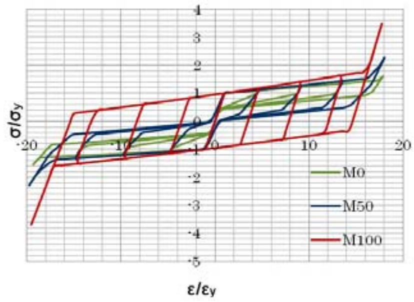
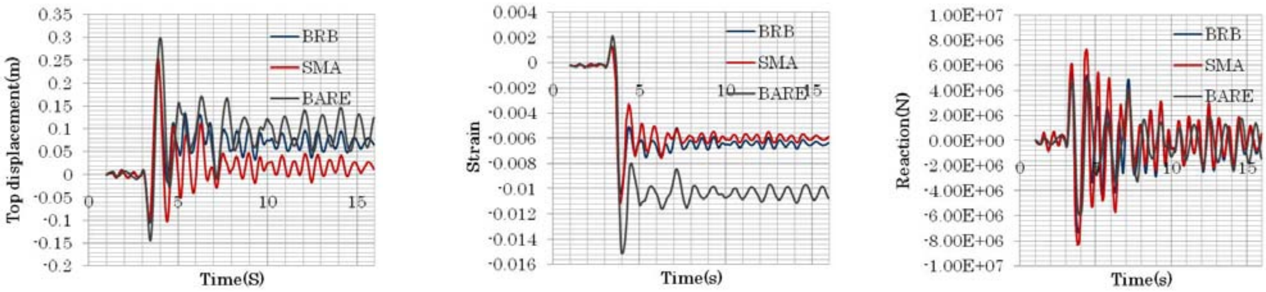
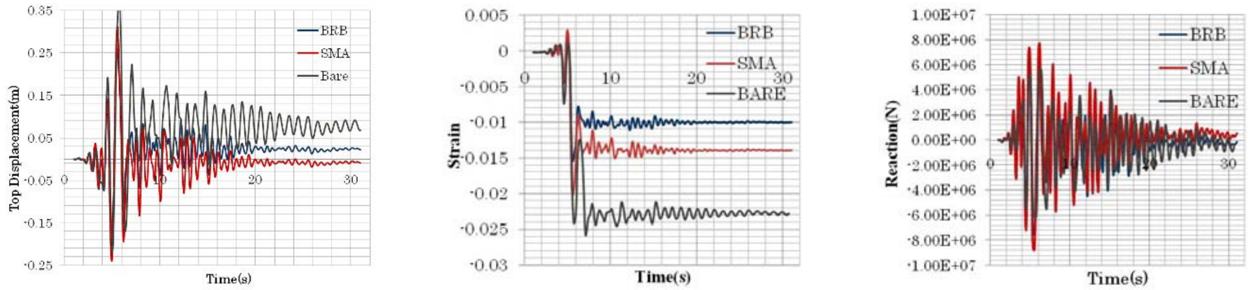


Fig.4 Stress-strain relationship of damper



(a) Top displacement(LA-16) (b) Strain at column conner(LA-16) (c) Base reaction(LA-16)



(d) Top displacement(Fukiai-M) (e) Strain at column conner(Fukiai-M) (f) Base reaction(Fukiai-M)

Fig. 5 Time histories with different ground motion inputs

A portal frame FA shown in Fig. 3 is a 12×12m square-shaped plane frame (bare frame in (a) and frame with dampers in (b)). A brace system with SMA dampers is set under the conditions of K_{SMA}/K_F=0.5, L_{SMA}=0.5L_{BRACE}. Here, K_{SMA} and K_F are stiffness of the brace system and the bare frame; L_{SMA}, L_{BRACE} are length of the SMA damper and the whole brace.

Cyclic analysis is carried out on frame with SMA dampers considering one of influence factors,e.g., martensite fraction,which is varied at 3 levels: 0, 50%,100%. The results shown in Fig.4 illustrate that dampers having more martensite composition show more energy dissipating abilities but less re-centering characteristcs.

The performance of SMA damper is also verified by time history analysis results comparison among bare frame,frame with SMA dampers and the equivelent BRB dampers. Fukiai-M and SAC designed LA16 are two ground motion inputs with different frequcency characteristcs. As shown in Fig. 5, both SMA frame and BRB frame induce amplified reactions at the base and reduced average strain in frame columns. The time histories of top displacement shown in Fig. 5(a) and 5(d) verify that although a little larger maximum displacement amplitute would ocurr, frame with SMA dampers have shown much better recentering ability than BRB's and the performance is also relevant to characteristcs of ground motion inputs.

Conclusion

Using the proposed model, seismic upgrading characteristics of a frame with SMA dampers are evaluated that the damper has good re-centering and energy absorbing abilities and the performance is relevant to its own components formation and inputs.

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Reference: 1) Paiva, A., et.al. (2006). An Overview of Constitutive Models for Shape Memory Alloys. *Math. Pro. in Eng.*, 2006,1-30.