The 2016 World Congress on
The 2016 Structures Congress (Structures16)
Jeju Island, Korea, August 28-September 1, 2016

Analytical Investigation on the Behavior of Smart recentering T-stub Components with Superelastic Shape Memory Alloy (SMA) Bolts and Performance-Based Optimal Design

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ABSTRACT

This study suggests optimal design for smart recentering T-stub components with respect to recentering and energy dissipation after observing the FE analysis results. Instead of the full-scale T-stub connection under bending moment, simplified T-stub components subjected to axial force are designed on the basis of basic equilibrium theory that bending moment transferred from beam to column can be converted into equivalent couple forces acting on the beam flange. Superelastic shape memory alloy (SMA) bolts which have the recentering capability upon unloading are intended to be fabricated so as to solve these drawbacks, and utilized by replacing conventional steel bolts in the PR bolted T-stub connection.

1. INTRODUCTION

After 1994 North-ridge (USA) and 1995 Kobe (Japan) earthquakes, partially-restrained (PR) bolted connections have been utilized as the alternatives of fully-restrained (FR) welded connections which exhibit brittle failure within the allowable deformation limit. In these PR bolted connections, beam members are connected by fastening connection components (i.e., end-plate, T-stub, and clip angle components) to column members with tension bolts, and thus bending moments transferred from beams are delivered to connections, including shear forces. The PR bolted connections can accommodate a rotation angle greater than the allowable limit (i.e., typically 0.03 radian for plastic deformation) before structural beam members reach full plastic moment. It is because tension bolts where plastic deformation may concentrate are fabricated with carbon steel materials, which are rich in ductility. Contrary to the FR welded connections, the PR bolted connections cope flexibly with axial couple forces converted from bending moment, and simultaneously possess excellent energy dissipation capacity without rapid strength degradation. When structural beam

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Note: Paper to be submitted to "Computers and Concrete, An International Journal" for the purpose of Special Issue.

members are subjected to either initial yielding or local buckling as preliminary collapse, the typical PR bolted connections exhibit delayed deterioration to withstand additional force until tension bolts installed arrive at ultimate strength.

Although the PR bolted connections have been highlighted to substitute themselves for the existing FE welded connections, they are restricted to be applied to modern structures which are becoming massive and higher, in the same way as before, and thus it is necessary to improve their performance. The tension bolts made by ductile carbon steel prevent breaking out brittle failure by permitting the concentration of plastic deformation, but immoderate residual deformation may occur at the PR bolted connection. The extra cost is required to recover to original condition after strong excitation. For this motivation, this study suggests new PR bolted connections that are integrated with superelastic shape memory alloy (SMA) bolts replaced for conventional steel bolts in an effort to reduce residual deformation at the connection behavior, as enhancing recentering capability. Unless other connection members are prone to generate plastic yielding, superelastic SMA-bolted connections can recover to initial shape without any permanent displacement after the removal of the applied load.

2. SUPERELASTIC SMA MATERIALS

The temperature-dependent stress and strain curves for SMA materials are presented in Fig. 1. At the martensite phase transformation temperature, SMA materials are susceptible to residual deformation upon unloading, and exhibit shape memory effect where additional heat treatment is required to revert to original shape. The crystallographic conversion from martensite phase to austenite phase, which provide recentering capability to the SMA material, takes place during this heat treatment. The superelastic effect that can automatically recover to original condition without heat treatment may be observed at the austenite phase transformation temperature above the martensite one, and thus superelastic SMA materials behave as the flag-shaped hysteresis loop as shown in the figure . Due to the improvement of manufacturing technology, SMA materials have been feasible to generate the superelastic effect at the room temperature about 30 years ago. In addition to medical, mechanical, and electronic instruments, superelastic SMA materials have been utilized as dampers, passive control devices, and fasteners in the civil engineering field since the early 2000s.

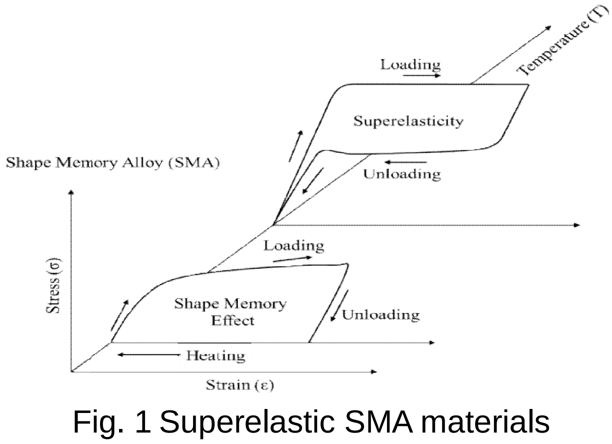

Fig. 1 Superelastic SMA materials

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