

Rehabilitation of Buildings and Bridges by Using Shape Memory Alloys (SMA)

Rameshwar S. Ingalkar

Department of Civil Engineering, PRMCEAM-Badnera.

Abstract

Shape-memory alloys (SMA) are a class of alloys that display several unique characteristics, including Young's modulus-temperature relations, shape memory effects, and high damping characteristics. In most current applications, the temperature-induced phase change characteristic of shape-memory alloys is used. Shape Memory Alloy (SMA) materials are widely used in different disciplines and it has substantial potential for civil engineering applications. A review of rehabilitation techniques of building and bridges by using shape memory alloy are presented in the present work.

Keywords: Shape Memory Alloy, SME, Martensite, Austenite, Dampers.

1. Introduction

Shape memory alloys are a class of materials that can recover from large strains through the application of heat (known as the shape memory effect) or removal of stress (known as the superelastic effect). This results in several unique characteristics, including Young's modulus-temperature relations, shape memory effects, superelastic effects, high damping characteristics, and recentering capabilities.

Over the past 10 to 15 years, several studies have provided a better understanding of the behavior of shape memory alloys, and illustrated their potential use in practical applications. Additionally, the cost has decreased significantly, and is no longer considered prohibitively expensive. This has led to the use of SMAs in a number of medical and commercial products. The unique properties that make SMAs useful for commercial and biomedical applications can also be utilized in seismic resistant design and retrofit applications. SMAs have demonstrated energy dissipation capabilities,

large elastic strain capacity, hysteretic damping, excellent high/low-cycle fatigue resistance, re-centering capabilities and excellent corrosion resistance. All of these characteristics give SMAs great potential for use within seismic resistant design and retrofit applications.

2. Shape Memory and Super Elastic Effect

Memory: When a shape memory alloy is in its martensitic form, it is easily deformed to a new shape. However, when the alloy is heated through its transformation temperatures, it reverts to austenite and recovers its previous shape with great force. This process is known as Shape Memory.

The SME occurs due to a temperature and stress dependent shift in the material's crystalline structure between two different phases, martensite (low temperature phase) and austenite (high temperature phase). The temperature, where the phase transformation occurs, is called the transformation temperature. Figure 1 is a simplified representation of material's crystalline arrangement during different phases.

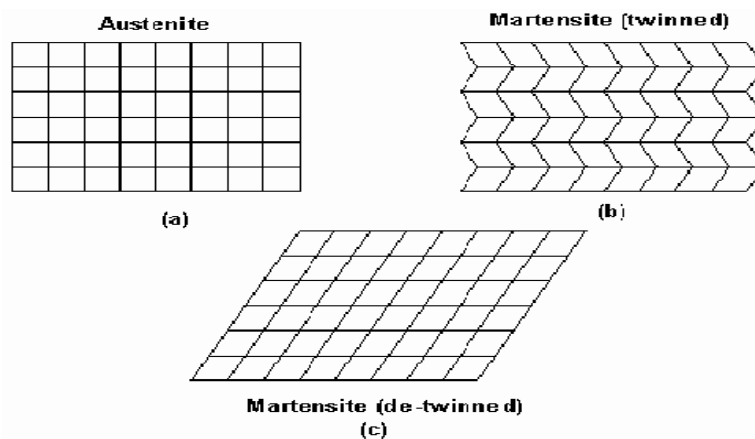


Fig. 1: Crystalline arrangement of SMA in different phases.

In austenite phase, the structure of the material is symmetrical; each “grain” of material is a cube with right angles (a). When the alloy cools, it forms the martensite phase and collapses to a structure with different shape (b). If an external stress is applied, the alloy will yield and deform to an alternate state (c). Now, if the alloy is heated again above the transformation temperature, the austenite phase will be formed and the structure of the material returns to the original “cubic” form (a), generating force/stress.

3. Rehabilitation of Bridge Using SMA

In this study using SMAs devices in bridges, Adachi and Unjoh [1999] created an energy dissipation device out of a Nitinol SMA plate, designed to take the load only in bending. The proof-of-concept study is performed by xing, one end of the plate to the shake table and the other to a large mass (representing the deck). Shake table tests and

numerical models were used to confirm the feasibility of such a device. The SMA damper systems reduced the seismic response of the bridge, and were found to be more effective in the martensite form than the austenite form. This is due to the improved damping properties when in the martensitic phase, as compared to the austenite phase.

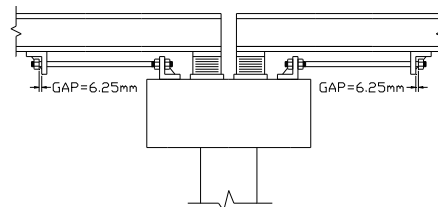


Fig. 2: SMA restrainer used at intermediate hinges of Bridge.

3.1 Seismic Dampers.

By using shape memory alloys in seismic dampers one may reduce plastic deformation in the structure and at the same time dissipate energy. Here are various seismic dampers.

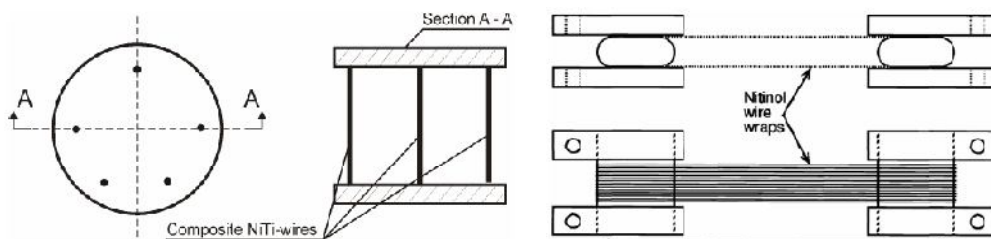


Fig. 3: (Left) Seismic damper with composite NiTi-wires and (Right) Seismic dampers with wrapped NiTi-wires.

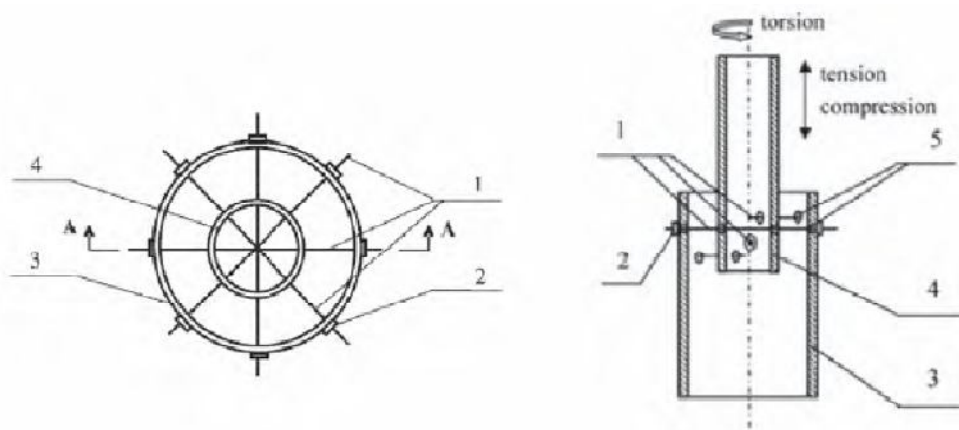


Fig. 4: NiTi damper for damper of tension, compression and torsion: 1. NiTi-wires, 2 Chuck, 3. Outer tube, 4 Inner tube.

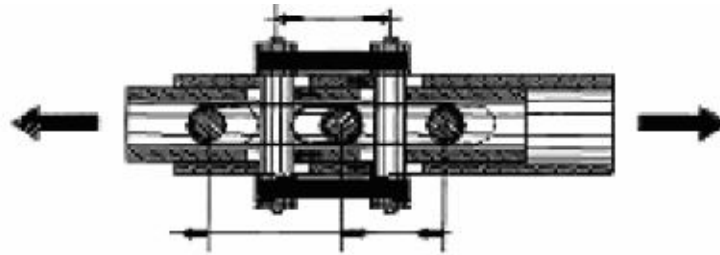


Fig. 5: The MANSIDE damper.

4. Rehabilitation of Buildings Using SMA

4.1 Retrofitting Of the Basilica of San Francesco at Assisi, Italy

The Basilica of San Francesco was restored after being strongly damaged by an earthquake of 1997 Umbria-March earthquake (Castellano 2000). The seismic upgrade was carried out under the framework of the ISTECH project. The gable was completely disconnected from the roof and was then linked to the roof again by means of Shape Memory Alloy Devices (SMAD's). Each SMAD is designed to take both tension and compression forces, while consisting of SMA wires which are only subjected to tension. The main challenge of the restoration was to obtain an adequate safety level, while maintaining the original concept of the structure. In order to reduce the seismic forces transferred to the tympanum, a connection between it and the roof was created using superelastic SMAs. The SMA device demonstrates different structural properties for different horizontal forces. Under extremely intense horizontal loads, the SMA stiffness increases to prevent collapse. Figure 6 shows the SMAs used in the retrofit.



Fig. 6: SMA Devices in the Basilica of St Francesco of Assisi [Castellano et al., 2000].

4.2 Retrofitting of the Bell Tower of the Church of San Giorgio at Trignano, Italy

The S. Giorgio Church, located in Trignano, Italy, was struck by a 4.8 Richter magnitude earthquake on October 15, 1996, resulting in significant damage to the bell tower within the church. Following the earthquake, the tower was rehabilitated using SMAs Indirliet al. [2001]. Retrofit design of the 17 meters tall masonry tower was carried out under the framework of the ISTECH project. The upgrade was carried out linking top and bottom of the tower by means of hybrid tendons. Four vertical

prestressing steel tie bars with SMA devices were placed in the internal corners of the bell tower to increase the flexural resistance of the structure.

5. Conclusions

In India a number of historical buildings and monuments, such as Taj Mahal, Victoria Memorial, Kutub-Minar, Lal-Kella, Nizam-Palace etc. were established in different era. And SMA Devices can play major role to prevent these building from earthquakes. So if such buildings are retrofitted by using SMA devices, can be prevented in future earthquakes.

References

- [1] A Nilendu Krishna Paul and B R.P.Nanda[2013] "Shape Memory Alloy As Retrofitting Application In Historical Buildings And Monuments – A Review In Indian Perspective": International Journal of Civil Engineering and Technology (IJCIET),
- [2] A Adachi, Y. and B Unjoh, S. [1999] "Development of Shape Memory Alloy Damper for Intelligent Bridge Systems," Proceedings of SPIE, Smart Structures and Materials.
- [3] A Buehler, W. and B Wiley, R.[1961] "The Properties of TiNi and Associated Phases," Rept. NOLTR 61-5 [AD 266607], U.S. Naval Ordnance Laboratory.
- [4] A CZADERSKI, C., B. HAHNEBACH, et al. (2006). "RC beam with variable stiffness and strength." *Journal of Construction and Building Materials* **20**(9): 824-833.
- [5] A Castellano, M., B Indirli, M. and C Martelli, A [2001] "Progress of Application, Research and Development and Design Guidelines for Shape Memory Alloy Devices for Cultural Heritage Structures in Italy," Proceedings of SPIE, Smart Structures and Materials.

