 Online ISSN: 2456-1495
CODEN (USA): JSLOBJ

JOURNAL OF SCIENTIFIC LETTERS
www.jslsci.com

# INNOVATIVE APPLICATIONS OF SHAPE MEMORY ALLOYS IN CIVIL ENGINEERING AND SEISMIC PROTECTION

**Oza Jyoti Omprakash**

Research Scholar, Department of Civil Engineering, Vikrant University, Gwalior, M.P

**Dr. Manoj Sharma**

Research Supervisor, Department of Civil Engineering, Vikrant University, Gwalior, M.P

**ABSTRACT**

Materials known as shape memory alloys (SMAs) have piqued the curiosity of researchers and businesses alike. So-called "shape memory alloys" (SMAs) are materials that, despite appearances to the contrary, may be deformed and then deformed again. As soon as it is heated below its transition temperature, this alloy will bend into whatever shape it can maintain, and its yield strength is minimal. These days, many are starting to question whether or not civic institutions will last. Although they are widely used, modern procedures such as fixing structural parts, prestressing, and external post-tensioning, as well as creating kernel components for seismic devices such as actuators, dampers, and isolators, are still rather expensive. In addition to calming fears about building longevity, this report will provide the construction sector a much-needed boost. A comprehensive analysis of the method and its practical implementations will form the basis of our endeavour.

**Keywords:** Phases, Temperature, Magnetic Field, Shape Memory, Cubic



*E-mail: editor.jslsci888@gmail.com*

Online ISSN: 2456-1495
CODEN (USA): JSLOBJ

## I. INTRODUCTION

Metallic alloys with shape-memory properties (SMAs) can return to their initial form when subjected to certain environmental conditions, such as changes in temperature, loads, or magnetic fields. There are two stages of metamorphosis that SMAs go through. SMAs are characterised by two fundamental properties: super elasticity (SE) and the shape memory effect (SME). The most important use of these materials is in their malleability; they can be bent with little to no effort, and they will snap back into shape when subjected to heat above a certain point, either from the outside or inside (Joule heating) or other related stimuli (like a magnetic field for MSMAs). The two crystal phases of SMAs are austenite (the parent phase) and martensite (the product phase), with austenite being stable at high temperatures and martensite at low temperatures. During the martensite phase, the SMA is very malleable due to its relative pliability. The cubic structure of the austenite phase is well-ordered and has one variant. A number of configurations (monoclinic, orthorhombic, and rhombohedra structures) are possible for the martensite phase, which has reduced symmetry and is affected by the kind of phase shift. Atoms in materials lacking diffusion-less properties undergo the martensitic transformation, a thermos-elastic first-order crystalline displacive mechanical process that often involves a shear mechanism, during which they move together.

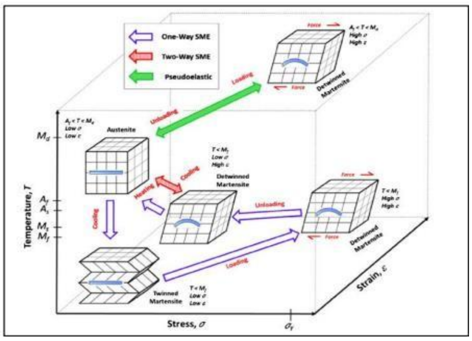


**Figure 1: Crystal structure and phases of shape memory alloys (SMAs).**

The transformation of austenite from a cubic structure with a body center to a compact packed hexagonal structure with a monoclinic or orthorhombic configuration results in twinned martensite (Figure 1). This change in solid state enables one-way, two-way, and three-way SME.

## II. FUNDAMENTALS OF SHAPE MEMORY ALLOY

You may modify the elements ratios to adjust the SMA's characteristic melting point, which


E-mail: editor.jslsci888@gmail.com

is the temperature at which it changes crystallographic structure. The transition from austenite to martensite begins at a certain temperature, Ms, and is complete at a certain temperature, M f, when the structure cools. So, As is the starting temperature for the reverse change from martensite to austenite, and A f is the finishing temperature. A stress-strain temperature diagram is used to depict the majority of the SMA-related effects in Figure 2. Metallurgical considerations lead to these effects because of the reversible phase transition between austenite and martensite, two phases that exist at different temperatures. Here is a summary of the most important behaviour displayed by SMAs: The SMA remains at room temperature when no external heat or cold is applied. The alloy's stability in the absence of thermal actuation and the likelihood of phase transitions in response to thermal actuation and mechanical stress are both defined by this temperature. The substance becomes completely martensite below M f. Its deformation behaviour is exhibiting characteristics of a pseudoplastic material. and may experience significant pseudoplastic deformation of up to 8% (e.g., NiTi alloy). During heating, the transformation begins at As and ends at A f. At this point, the pseudoplastic deformation is almost entirely restored, and the phase transition from martensite to austenite is complete.

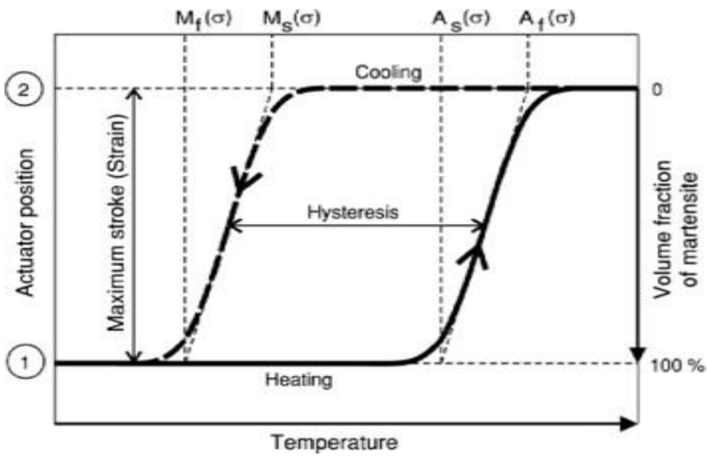


**Figure 2: Temperature – induced phase transformation**



*E-mail: editor.jslsci888@gmail.com*

**Online ISSN: 2456-1495**
**CODEN (USA): JSLOBJ**

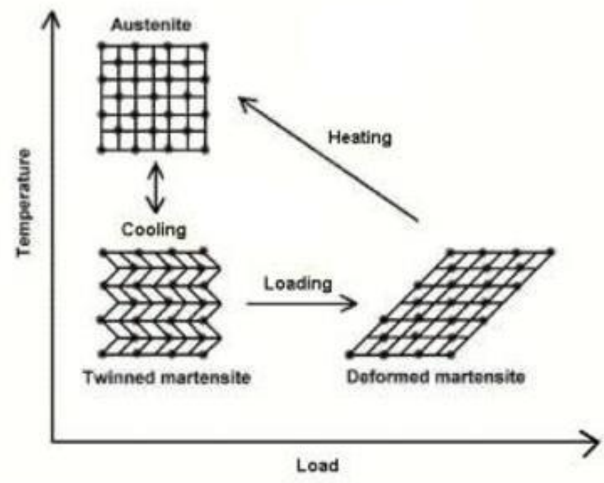


**Figure 3: Material Phenomena**

### Crystal Structure

The shape memory effect is not present in most metals, despite the fact that many metals exhibit many crystal forms at the same composition. Because their crystal change is completely reversible, shape-memory alloys have the unique ability to return to their initial shape when heated. Even though the metal is composed of the same atoms throughout, the composition might change locally due to atomic diffusion in most crystal transitions. Instead of atoms diffusing through a material, in a reversible transformation they all move in unison to create a new structure, like pushing on opposite corners of a square to make a parallelogram. When a structure is chilled below its transition temperature, it transforms from its austenitic phase into the martensite structure, which is favoured at certain temperatures.

## III. APPLICATION OF SHAPE MEMORY ALLOY IN CIVIL ENGINEERING

### A) Pre-Stressing

Another option is to pre-stress masonry and concrete constructions using SMA strands wires. The use of SMAs allows for both pre- and post-tensioning. One advantage of pre-stressing using SMAs is that they:

- Active regulation of pre-stressing with enhanced extra load-bearing capability.
- Neither jacking nor strand-cutting is involved.
- Eliminating anchoring losses and elastic shortening friction.


*E-mail: editor.jslsci888@gmail.com*

**Online ISSN: 2456-1495**
**CODEN (USA): JSLOBJ**

**Pre-Tensioning**

After being embedded in concrete, pre-tensioned SMA strands-wires in their martensite state are electrically heated to change the material's phase from martensite to austenite. As a result, the material undergoes large shrinkage strains and, if constrained, generates a substantial pre-stressing force in the concrete. The end of the girders cracks when the pre-stressing strands are released and jacked during conventional prestressing using pre-tensioning wires. Prestressing with SMA eliminates the need for jacking or strand-cutting.

**Post-Tensioning**

After the concrete is placed, post-tensioning conduits are used to transmit pre-stretched martensite phase SMA strands and tendons through. Post-tensioning may be easily induced by heating the tendons. While jacking isn't necessary for post-tensioning, anchoring SMA bars is, and strand-cutting reduces the likelihood of friction and anchorage losses. Pre-stressing losses due to elastic shrinkage, creep, and shortening are minimal and can be recouped by heating SMA bars to induce post-tensioning when necessary. Beams underwent substantial pre-stressing as confirmed by four-point bending tests.

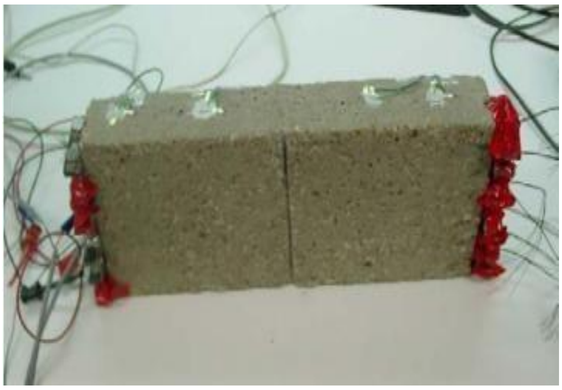

**Figure 4: A small concrete block post-tensioned with SMA wires**

**B) Self-Sensing and Repairing Capabilities**

The weakest part of most buildings are the bolted joints. Worn, leaking, slipping, or torn, they might fall apart. By utilising SMA's super elastic property, the preload drop in bolted joints can be recovered, and the clamping force needed to maintain the joined members together can be supplied. recover from preload. Self-sensing and bolted joint repair are accomplished with the help of piezoelectric and SMA elements. In the event of damage, the SMA washers


*E-mail: editor.jslsci888@gmail.com*

may restore lost torque automatically, enabling the structure to keep running.

### C) Intelligent Reinforced Concrete Structure

Song et al. created an IRCS, or intelligent reinforced concrete structure, by combining SMAs with piezoceramics. The IRCS could self-repair, self-dampen vibrations, and self-monitor structural health, among its many other duties. By reinforcing the IRCS using post-tensioned martensite SMA cables, the damping performance and impact resistance of the concrete were greatly enhanced. In order to identify the presence of cracks, piezocermaic patches were embedded in concrete. It is possible to assess the fracture breadth by tracking the change in electric resistance of the SMA cables.


**Figure 5: During loading**

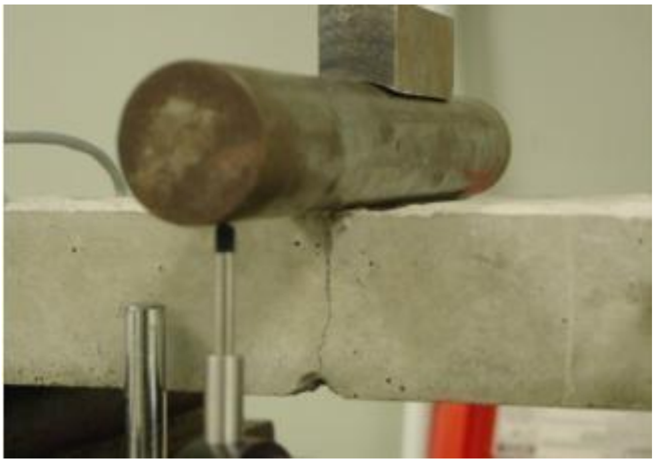

**Figure 6: After heating**


*E-mail: editor.jslsci888@gmail.com*

## D) SMA In Earthquake Resistant Techniques

### Seismic Retrofitting with SMA Bracings

The use of SMA diagonal bracing wires as passive devices to control vibrations in a one-story structure model was investigated in a feasibility study by Salichs et al. In comparison to steel bracing of the same rigidity, SMA super elastic hysteresis reduced peak lateral drift. Bracing members made of large-diameter super elastic SMA bars perform well according to an analytical assessment. Compared to steel bracing, SMA bracing members reduced inter-story drift and column rotation in RC frames more effectively.

### SMA Based Dampers

An SMA plate damping device is used to absorb seismic energy and reduce seismic force through its pseudo-yield effect in bridge structures. The efficiency of the system was confirmed by a battery of shaking table experiments that demonstrated a substantial decrease in the seismic reactions of bridge structures when subjected to earthquake-type excitations.

Through a variety of strain amplitudes, loading frequencies, and temperatures, two distinct types of reduced-scale dampers were tested using SMA wires. The analytical study's practical application was demonstrated in a six-story steel frame, where it effectively reduced structural displacements when subjected to earthquake excitation.

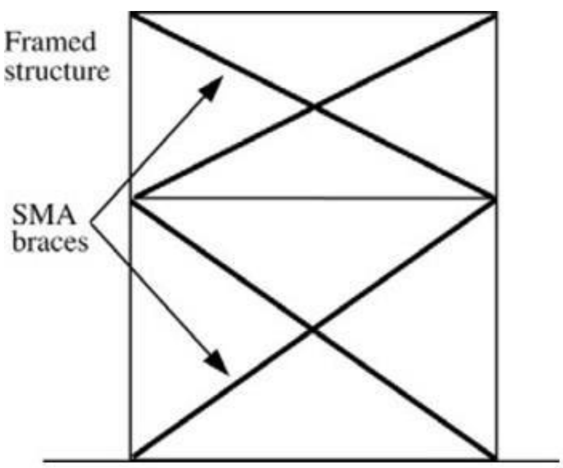


**Figure 7: SMA braces for a two-story steel frame**

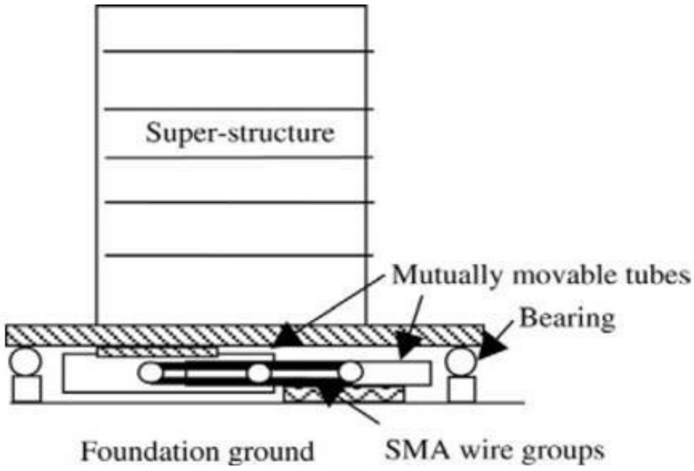


**Figure 8: SMA isolation system for buildings**

**SMA Based Isolation Devices**

Analytical research was conducted on a bridge pier/superstructure system with a single SMA device fitted between the pier and the superstructure. The model used two degrees of freedom to lump the masses together. Results showed that SMA devices may minimise seismic accelerations by 90% with almost no residual displacements due to the super elastic device's self-centering properties.

**E) Bolted Joints**

In the case of an earthquake, the weakest points of a building are often the beam-column and column-foundation connections. The use of super elastic shape alloy material in a joint allows for the dissipation of significant amounts of energy via plastic deformation, leading to a reduction in damages and subsequent recovery.

## IV. PROCESSING OF SHAPE MEMORY ALLOYS

For each given material, there are a plethora of processing options in today's cutting-edge, competitive technology. Manufacturing, applications, economics, efficiency, etc., all have a role in the different processing pathways. A wide variety of processing processes are also at your disposal when it comes to making shape memory alloys. Because thermal and mechanical treatments impact the chemical reactions and phase transformation of shape memory alloys, processing these materials can lead to variations in mechanical properties, microstructural changes, the formation of intermetallic compounds and precipitates, and the retention of the shape memory effect. Melting route, powder metallurgy, mechanical, and thermomechanical processing are all methods used to work with shape memory alloys. For accurate and efficient production, SMAs undergo pre-processing steps before being processed through various routes. Gathering the necessary raw materials, washing them thoroughly, cutting and sizing them to the proper proportions, cleaning them again, and finally creating a powder form of the material are all necessary pre-processing procedures for shape memory alloys. This is done in preparation for powder metallurgical processing.

**Melting Route**

The four distinct methods for treating shape memory alloys by melting them are vacuum induction melting, selective laser melting, electron beam melting, and plasma melting. A number of manufacturing procedures are used to manufacture Ni-Ti alloys, one of which is vacuum induction melting. This method's technology in graphite crucibles is the current standard for preparation. Achieving very fine compositional tolerances, perfect temperature control, and an environmentally benign process all play a significant role in the rapid expansion of metal production with this approach. Some shape memory alloys have been found to be made via Selective Laser Melting, including Ni-Ti, Cu-Al-Ni-Mn, Fe-Mn-Al-Ni, and Al-Fe-V-Si. Fabricating porous shape memory alloys using this method yields materials with superior shape memory capabilities. The scanning pattern of f-theta lenses is advantageous because it reduces distortion when scanning.

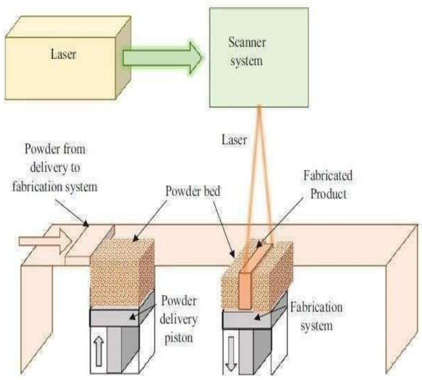


**Figure 9: Selective Laser Melting Process**

Electron beam melting is a manufacturing technique that uses electron beams to add material layer by layer. The method requires a vacuum chamber to run since an electron beam is involved. It outperforms Vacuum Induction Melting in terms of chemical homogeneity and



*E-mail: editor.jslsci888@gmail.com*

Online ISSN: 2456-1495
CODEN (USA): JSLOBJ

oxygen and carbon contamination reduction, leading to superior NiTi material. The Plasma Melting technique was born out of a need to prevent graphite contamination of melted materials caused by used electrodes, as well as a combination of a high energy concentration, a high plasma flow velocity, and very rapid heat transmission. In this technology, plasma burners are employed in place of electrodes, and the furnace is outfitted with a specific soil electrode that charges the system.

**Powder Metallurgy Processing**

One common approach to processing materials is powder metallurgy, which involves working with metal powder to get a finished product with little material loss. Different powder metallurgy processes, including traditional sintering, hotisostatic pressing, and metal injection moulding, are used to process and study shape memory alloys composed of Ni-Ti, Cu-Al-Ni-Mn, and Fe-Mn-Si-Cr-Ni.

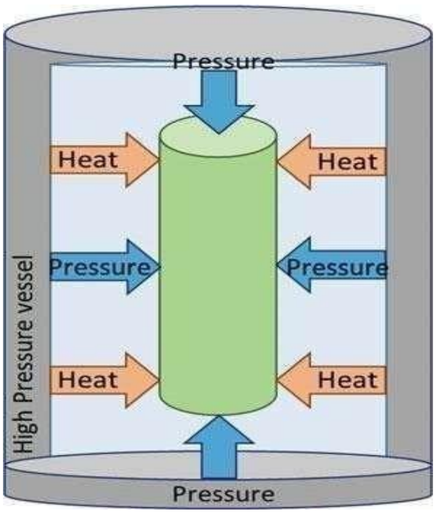


**Figure 10: Hot Isostatic Process**

One solution to the problem with traditional sintering methods for shape memory alloys is hot isostatic pressing, which is another name for pressure assisted sintering. This method boosts density and decreases porosity. By applying heat or pressure and compacting and shaping the material, sintering creates a solid mass of material without melting it to a liquid state. Its primary use is with Nitinol. In typical sintering of Nitinol, the creation of porosity is governed by a few parameters, including applied pressure, an imbalance in the diffusion of Ni into Ti and Ti into Ni, shrinkage during sintering, and capillary forces. The principle of plastic injection moulding is applied to metal injection moulding. Feedstock manufacture,


*E-mail: editor.jslsci888@gmail.com*

injection moulding, rebinding, and sintering are the four phases that make up the procedure. The process's main benefits are its cheap cost, high production value, and geometrically precise pieces. This process is commonly used to create NiTi materials, which have many potentials uses in the medical field.

**Thermo-mechanical Processing**

A subset of manufacturing procedures known as thermo-mechanical processing involves plastic or mechanical deformation in addition to the effects of thermal processing. In the realm of thermo-mechanical processing, you'll find techniques like friction stir processing, hot forging, and hot rolling. The idea of solid-state processing is the basis of friction stir processing. By carefully regulating the process conditions, it was feasible to fabricate an aluminum-nickel composite with a NiTi powder distribution that was uniform throughout the matrix and excellent bonding. As a thermo-mechanical manufacturing technique, hot forging involves heating and pressing the material to create the desired shape. A hot forging investigation on a Ni-Mn-Ga shape memory alloy is underway. A complicated shape memory alloy component with outstanding shape memory properties and no significant flaws may be produced using optimal hot forging conditions. As a processing method, hot rolling involves heating the material and then pressing it using rollers. Controlling the shape memory effect and other mechanical qualities requires critical process factors such heating temperature, pulling tension applied to the material, kind of lubricant, and number of passes.

## V. CONCLUSION

The fundamental characteristics and civil engineering uses of Nitinol shape memory alloys (SMA) are reviewed in this article. Various methods exist for controlling civil constructions using shape memory alloys. Various forms of SMAs, such as bars, wires, plates, etc., are available for usage. Researchers are increasingly interested in SMAs because of its unusual features, such as shape memory effect and super elasticity. Several investigations, both theoretical and practical, into SMA devices have shown promising results in enhancing the resilience of civil engineering projects to seismic loads. Thanks to its remarkable ability to mend itself, SMA has created new possibilities and become a building material for the future.

**REFERENCES**

[1] J. Sohn, J. D. Ruth, D.-G. Yuk, and S. Choi, “Application of shape memory alloy actuators to vibration and motion control of structural systems: A review,” *Applied Sciences*, vol. 13, no. 2, pp. 1–24, 2023.

[2] O. Er-Remyly, M. Ben Zohra, A. Riad, and A. Alhamany, “New smart actuator based on shape memory alloys for avoiding overheating and preventing fire in electronic devices,” *Metallurgical and Materials Engineering*, vol. 29, no. 1, pp. 129–141, 2023.

[3] M. Kim, J.-K. Heo, H. Rodrigue, H.-T. Lee, S. Pané, M.-W. Han, and S.-H. Ahn, “Shape memory alloy (SMA) actuators: The role of material, form, and scaling effects,” *Advanced Materials*, vol. 35, no. 33, pp. 1–22, 2023.

[4] Z.-X. Zhang, J. Zhang, H. Wu, Y. Ji, and D. Kumar, “Iron-based shape memory alloys in construction: Research, applications and opportunities,” *Materials*, vol. 15, no. 5, pp. 1–26, 2022.

[5] M. Ghassemieh, M. Mostafazadeh, and M. S. Sadeh, "Seismic control of concrete shear wall using shape memory alloys," *Journal of Intelligent Material Systems and Structures*, vol. 23, no. 5, pp. 535–543, 2012.

[6] J. Dong, C. S. Cai, and A. M. Okeil, "Overview of potential and existing applications of shape memory alloys in bridges," *Journal of Bridge Engineering*, vol. 16, no. 2, pp. 305–315, 2011.

[7] R. A. Hawileh, J. A. Abdalla, F. Oudah, *et al.*, "Low-cycle fatigue life behaviour of BS 460B and BS B500B steel reinforcing bars," *Fatigue & Fracture of Engineering Materials & Structures*, vol. 33, no. 7, pp. 397–407, 2010.

[8] L. M. Massone and D. Moroder, "Buckling modeling of reinforcing bars with imperfections," *Engineering Structures*, vol. 31, no. 3, pp. 758–767, 2009.

[9] M. S. Alam, M. A. Youssef, and M. Nehdi, "Utilizing shape-memory alloys to enhance the performance and safety of civil infrastructure: A review," *Canadian Journal of Civil Engineering*, vol. 34, no. 9, pp. 1075–1086, 2007.

**Online ISSN: 2456-1495**
**CODEN (USA): JSLOBJ**

[10] J. McCormick, J. Tyber, R. DesRoches, *et al*., "Structural engineering with NiTi. II: Mechanical behavior and scaling," *Journal of Engineering Mechanics*, vol. 133, no. 9, pp. 1019–1029, 2007.

[11] M. S. Saiidi and H. Wang, "Exploratory study of seismic response of concrete columns with shape memory alloys reinforcement," *ACI Materials Journal*, vol. 103, no. 3, pp. 436–443, 2006.

[12] R. DesRoches, J. McCormick, and M. Delemont, "Cyclic properties of superelastic shape memory alloy wires and bars," *Journal of Structural Engineering*, vol. 130, no. 1, pp. 38–46, 2004.

[13] R. DesRoches and B. Smith, "Shape memory alloys in seismic resistant design and retrofit: A critical review of their potential and limitations," *Journal of Earthquake Engineering*, vol. 8, no. 3, pp. 415–429, 2004.

[14] T. Hesse, M. Ghorashi, and D. J. Inman, "Shape memory alloy in tension and compression and its application as clamping-force actuator in a bolted joint: Part 1—Experimentation," *Journal of Intelligent Material Systems and Structures*, vol. 15, no. 8, pp. 577–587, 2004.

[15] T. Ikeda, F. A. Nae, H. Naito, *et al*., "Constitutive model of shape memory alloys for unidirectional loading considering inner hysteresis loops," *Smart Materials and Structures*, vol. 13, no. 4, pp. 916–925, 2004.


***E-mail:* *editor.jslsci888@gmail.com***