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Smart Structures with Pseudoelastic and Pseudoplastic Shape Memory Alloy: a critical review of their prospective, feasibility and current trends.

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Abstract. This paper provides a critical review of the feasibility to construct smart structures using pseudoelastic and pseudoplastic shape memory alloy for rehabilitation, seismic resistant, retrofit or repair of structural elements and prestress application. Recent developments have been rapid, making the SMA promising a viable solution for numerous situations in buildings and infrastructure. Owing to their distinctive properties including pseudoelastic, pseudoplastic, hysteretic damping due their ability to undergo large deformations and return to their undeformed shape through stress removal (pseudoelastic) or heating (pseudoplastict) and the superior energy dissipation capacity which led to the use of shape-memory alloys to mitigate natural disasters, repair of structural elements, prestress application to enhance structural performance and safety are reviewed, discussed and explains in different alternatives for its application, which should motivate researchers and practicing engineers to extend its use in novel and emerging applications This paper also examines the fundamental characteristics of SMAs, its constitutive material models and the factors influencing its engineering properties. Also stated is the contrast between reinforcement material properties of steel and SMAs and the type of SMA used by the previous researchers.A review of current studies show that the pseudoelastic SMA, pseudoplastic and high-damping characteristics of SMAs result in applications in bridges and buildings that show significant promise.

1. Introduction

To deal with the problems of the integrity of the reinforced concrete structure, research on smart material such as Shape Memory Alloy (SMA) is essential to develop a durable, robust and high performance construction. In addition, the inspection and maintenance techniques for rehabilitation become the focus of increasing attention despite of the cost of construction and maintenance is difficult.

SMA is a novel functional material and has caught the interest across many research disciplines recently [1]. Owing to wide properties of shape memory alloy, originated from reversible austenite to martensite phase transformation this alloy has been used widely in many applications from medical, aerospace and civil application [1] due to fatigue resistance, solid state actuation high density, high damping capacity, durability, excellent properties of corrosion resistance and are non-magnetic in nature [2]. Although SMAs have many applications in different fields, they are considered relatively new in the civil engineering field.

Shape memory alloy (SMA) exhibits stable superelasticity above a reverse transformation finish temperature, and therefore can adequately work as a superelastic material to handle macro-size cracks for structural use in buildings so that Shape memory alloy (SMA) exhibits stable superelasticity above a reverse transformation finish temperature, and therefore can adequately work as a superelastic material to handle macro-size cracks for structural use in buildings so that these structures can exhibit sufficient resistant against earthquake. These properties could be effectively utilized to substantially enhance the performance and safety of various structures.

The current paper presents, in a systematic manner, a summary of the fundamental characteristics of SMAs, some useful tables on summary and definition of various SMA properties and their effects, type of shape memory alloy, Prospectives, Feasibility and Current Trends of Shape Memory Alloy Application, Comparison of NiTi and steel, their mechanical properties, and a critical review of the state-of-art of their possible seismic and non-seismic applications along with their future expected trends in civil engineering. This paper also provides a general description on the modelling aspects of SMAs in addition to useful information for practicing engineers on built-in SMA models available in some FE packages. Over the last two decades, a substantial amount of research has been done on the material science and possible uses of SMAs in structural applications. It is being realized that SMAs possess a substantial potential to replace or complement conventional materials, while achieving great gains in performance and safety.

2. Fundamental of Shape Memory Alloy

Shape Memory Alloys have two different phases, characterized by three different crystal structures, and six possible transformations as shown in the Figure 1. Figure 2 describes the stress-strain-temperature diagram of a typical Shape Memory Alloy, including all the possible transformations and phases namely Shape memory effect and Pseudoelasticity. Practically, SMAs can exist in two different phases with three different crystal structures (i.e. twinned martensite, detwinned martensite and austenite) and six possible transformations (see Fig. 1). While Figure 2 shows the typical stress–strain curve of superelastic shape memory alloy under cyclic axial, shear, and torsion stresses of NiTi. For NiTi of cyclic the number of cycle and dissipation of energy during pseudo-elastic response hysteresis is determine for their response and the performance for the seismic material properties.

The austenite structure is stable at high temperature, and the martensite structure is stable at lower temperatures. When a SMA is heated, it begins to transform from martensite into the austenite phase. The austenite-start-temperature (A_s) is the temperature where this transformation starts and the austenite-finish-temperature (A_f) is the temperature where this transformation is complete. Once a SMA is heated beyond. As it begins to contract and transform into the austenite structure, i.e. to recover into its original form. This transformation is possible even under high applied loads, and therefore, results in high actuation energy densities.

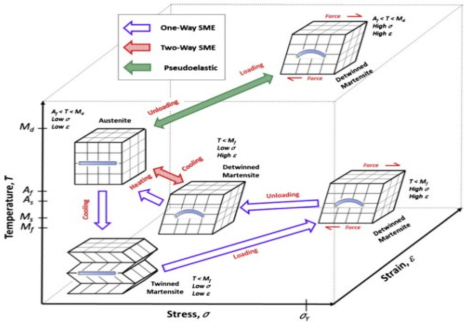


Figure 1. SMA phases and crystal structures [3]

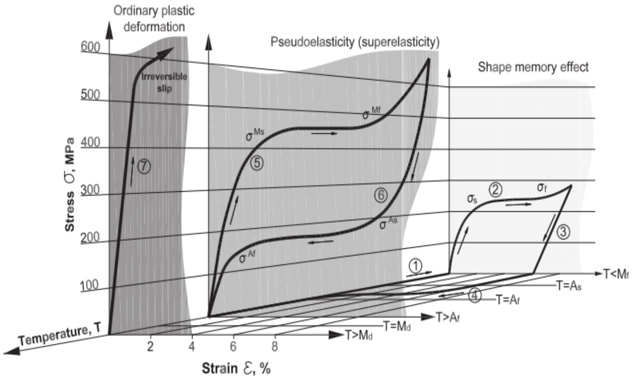
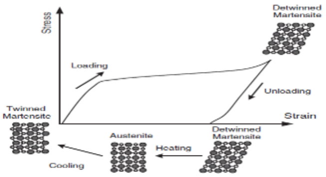
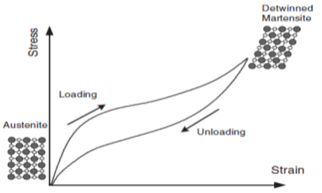
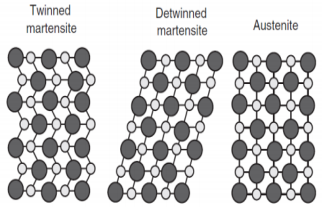
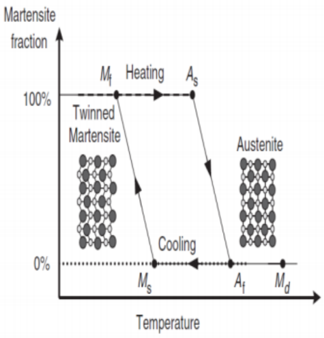


Figure 2. Typical stress–strain curve of superelastic shape memory alloy under cyclic axial, shear, and torsion stresses of NiTi. Adapted from .[37]

During the cooling process, the transformation starts to revert to the martensite at martensite- start-temperature (M_s) and is complete when it reaches the martensite-finish-temperature (M_f) (see Fig. 2). The highest temperature at which martensite can no longer be stress induced is called M_d, and above this temperature the SMA is permanently deformed like any ordinary metallic material. These shape change effects, which are known as the SME and pseudoelasticity (or superelasticity), can be categorised into three shape memory characteristics as follows that can be classified into One-way shape memory effect (OWSME), Two-way shape memory effect (TWSME) or reversible SME and Pseudoelasticity (PE) or Superelasticity (SE) which is summarized the terms and the definition in the Table 1.

Table 1. Summary and definition of various SMA properties and their effects

Ref	SMA traits	Graphics	Practical consequences
Clareda et al., 2014 Janke et al., 2005	Shape memory effect or pseudoplastic $T < M_f$		• Occurs due to the reversible phase transformation between the two crystalline structures – Martensite and Austenite • Damping capacity or two-way shape memory effects •Isothermal stress-induced martensitic phase transformation.
Dureig et al., 1990	Pseudoelasticity $T < A_f$		• The ability to undergo significant inelastic deformation under stress, and revert to their original shapes upon unloading • Material can be stressed to provide large, recoverable deformations at relatively constant stress levels • Stress–strain relationship of the martensitic SMAs (T < Mf)
Dureig et al., 1990	Austenite		• Stronger and stable at higher temperatures • Having a body-centered cubic crystal structure and single orientation, has increased resistance to external stress
Song et al., 2006	Martensitic		• Asymmetric parallelogram structure (with 24 variations) • Martensite phase is weaker, being easily deformed
Jani et al	One-way shape memory effect	•Retains a deformed state after the removal of an external force, and then recovers of its original shape upon heating.	
	Two-way shape memory effect (TWSME)	•Can remember its shape at both high and low temperatures. •Less applied commercially due to the 'training' requirements and usually produces about half of the recovery strain provided by OWSMA for the same material and it strain tends to deteriorate quickly, especially at high temperatures •OWSMA provides more reliable and economical solution but need to be train either by spontaneous and external load-assisted induction	
O. E. Ozbulut, S. Hurlebaus and R. Desroches (2011)	Martensite and Austenite temperature fraction		• As (Austenite start temperature): material starts to transform from twinned Martensite to Austenite. • Af (Austenite finish temperature): material is completely transformed into Austenite. • Ms (Martensite start temperature):material starts to transform from Austenite to twinned Martensite. • Mf (Martensite finish temperature): Martensite transformation is completed. • Md (Martensite desist): the maximum temperature at which SMAs phase transformation can no longer be stress induced, after this temperature the material will be permanently deformed.

3. Type and Mechanical Properties of SMA

Table 2 shows the Comparison of Mechanical properties of Shape Memory Alloy and Steel and classification of SMA used by the previous researcher. Most of the researcher use the NiTi as shown in the reference because of this alloy is the most promising for seismic design. Other type of SMAs are Cu-Al-Mn, Fe–Mn–Si, Cu-Zn-Al, NiTi-Nb, Ti-Ni-Cu, Cu-Al-Be and Ti-Ni-Hf.

Table 2. Comparison of Mechanical properties of Shape Memory Alloy and Steel and classification of SMA used by the previous researcher

Property		Unit	NiTi	Steel	Fe–Mn Si-Cr
Young’s modulus $8.7x10^4$ (A), $1.^{4x104}$(M)	Austenitic	MPa	70-98	2.07×10^5	140(1)[d]
	Martensitic		28-41	@200GPa	
Yield strength	Austenitic	MPa	195-690	248	~200(1)
	Martensitic		70-140		
Ultimate Tensile strength	Austenitic	MPa	800-1500	500	650(1)
	Martensitic		700-2000		
Recovery strain		%	8	0.2%	3.4(3)
Max recovery stress	MPa	MPa	600-900		400(3)
Elongation at failure	Austenitic		15-20	20%	29(1)
	Martensitic		20-60		
Fatigue strength $N=10^6$			350		-
Specific damping capacity(SDC)[a]		%	15-20		-
Superelastic energy storage		Joule/g	6.5	non	non
Poison ratio			0.33	0.27-0.3	
Corrossion performance			Excellent	Failure	
Reference: (1)Measurements with Fe-27%Mn-6Si-5Cr at 22^0C (2) Data given by the material supplier (3) From [21] for the Fe-28%Mn-6Si-5Cr-1.5VN (mass%)					
[a] dependent on frequency and amplitude [b] varies for martensite and austenite		[c] varies greatly with shape, required quantities etc [d] higher values was given by the material supplier			

Classification of SMA

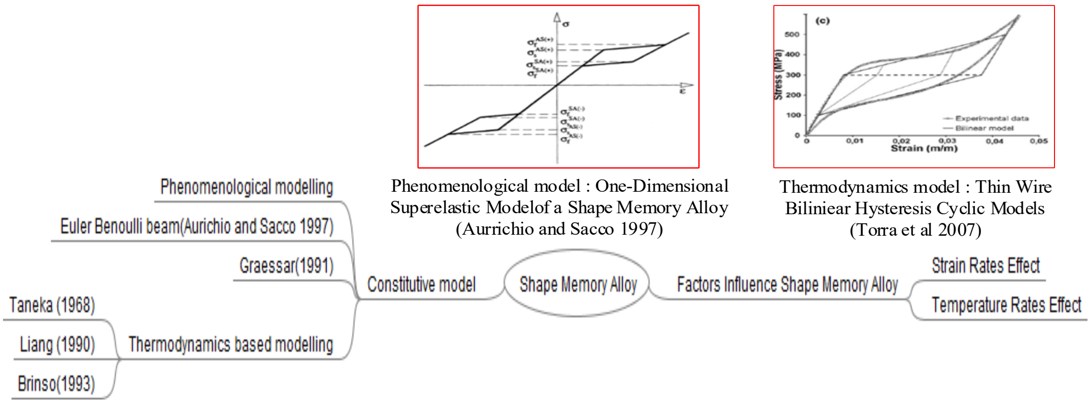
Author	SMA Type
Refer to [1]-[66]	NiTi
Araki, Shrestha (2013)	Cu-Al-Mn
Czaderski	Fe–Mn–Si
Otsuka and Wayman, 1999	Cu-Zn-Al
Eunsoo Choi, Osman E	NiTi-Nb
Liu 2003	Ti-Ni-Cu
Rejzner et al 2002	Cu-Al-Be
Wang et al	Ti-Ni-Hf

SMAs are a unique class of materials that have the ability to spontaneously recover strain of up to 8%. In order to evaluate the material for structural application, a number of researches have focused on mechanical properties and mechanical characterization.

Mechanical behaviour of Shape Memory Alloys for seismic applications for Martensite and Austenite NiTi bars subjected to torsion and Austenite NiTi wires subjected to tension can be referred to [38] and [39] respectively. While the experimental study of Shape Memory Alloy stress-strain property towards application of self-restoration for structural members can be obtained from [14]. To establish the understanding of the relation between the SMAs mechanical properties and cyclic deformation mechanism and correlation between engineering stress-strain and true stress-strain curve, paper by [15] and [16] also were referred.

4. Factors influence Shape Memory Alloy and Constitutive Model

Factors influence Shape Memory Alloy and constitutive modelling is summarized in the Figure 3.



Phenomenological model : One-Dimensional Superelastic Modelof a Shape Memory Alloy (Aurrichio and Sacco 1997)

Thermodynamics model : Thin Wire Biliniear Hysteresis Cyclic Models (Torra et al 2007)

Figure 3 : Factors influence Shape Memory Alloy and Constitutive Model

Figure 3 shows the influence factors of Shape Memory Alloy (SMA) and the constitutive model. The two main influence factors are the strain rates effect and temperature effect. The phenomenological constitutive constitutive model for superelastic SMAs can be discuss by using one dimensional superelastic model by Aurrichio and Sacco 1997 or Graessar (1991). While the thermodynamics based constitutive modelling by using Taneka (1968), Liang (1990) and Brinso (1993).

5. Prospectives, Feasibility and Current Trends of Shape Memory Alloy Application

Prospective, Feasibility and Current Trends Smart Structures with Pseudoelastic and Pseudoplastic Shape Memory Alloy were described as the following:-

5.1 Prestressing

The shape memory effect (pseudoplastic) and superelasticity or pseudoelasticity is unique properties that distinguish SMAs from other metals and alloys [2] that make them beneficial for the structural performance in civil infrastructure for reinforcement in concrete structures, self-rehabilitation, structure control which can be classified into passive structural control, semi active control and active damage control, retrofitting of existing structures, prestressing, post-tensioning, restrainer, sensor, bolt joint, beam to column joint and health monitoring as reported by [13 -16]. Feasibility of Self-Post-Tensioned Concrete Bridge Girders Using SMA were studied by Osman E et al[19]. This study investigates self-post-tensioned (SPT) bridge girders by activating the SME of NiTiNb, a class of wide-hysteresis SMAs, using the heat of hydration of grout. The use of self post-tensioned SMA tendons in concrete girders will increase overall sustainability of bridge structures by (i) minimizing the susceptibility of post-tensioning tendons to corrosion; (ii) enabling the adjustment of prestressing force during service life; and (iii) simplifying the tendon installation.

5.2 Bridge Restrainer

Other related review on Shape Memory Alloy base smart RC bridge and potential of existing Shape Memory Alloy for bridges can be adopted from Alam 2007, Junhui Dong 2011[17] and [18]. The feasibility of using superelastic shape memory alloys in the retrofit of multiple frame bridges was investigated by [22]. From the study two conclusion here can be drawn.The effect of temperature shows that a reduction in the ambient temperature tends to negatively affect the hinge opening while an increase in temperature results in a slight improvement and the superelastic shape memory alloys are superior in their effectiveness compared to other devices in the case of bridges with moderate period ratios and high level of ductility, especially when subjected to strong earthquakes.

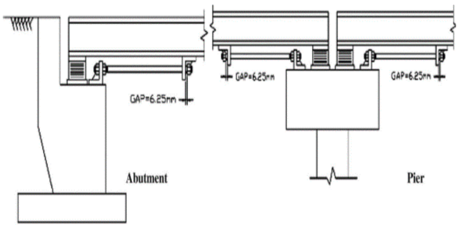


Figure 4. General layout of the bridge restrainer [23]

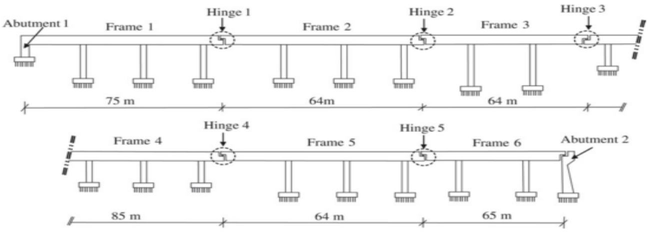


Figure 5. Shape memory alloy restrainer bar used in multi-span simply supported bridge at abutments and intermediate piers. [22]

5.3 Structure Damage Repair

Research in SMA is gradually gaining recognition in civil engineering application [24] because it can undergo large inelastic deformations and revert back to their original undeformed shape by stress removal in order to mitigate the problem of permanent deformation [25] or through their shape memory effect with the application of heat [4]. The distinct and unique properties of SMAs make them intelligent materials with the potential to respond and adapt changes in environment and condition as smart structures. Due to these properties, researches have been carried on martensite SMA wires and strands for rehabilitation and crack closure of reinforced concrete beam by [26],[27],[28],[29],[30][31] and [32] which requires an external power source to deliver a large current to deliver a large current to induce the shape memory effect and enable the phase transformation and shape restoration.

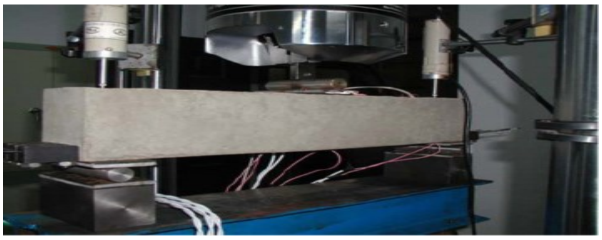


Figure 6. Reinforced concrete beams strengthened using SMA wires with carbon-fiber-reinforced polymer plates

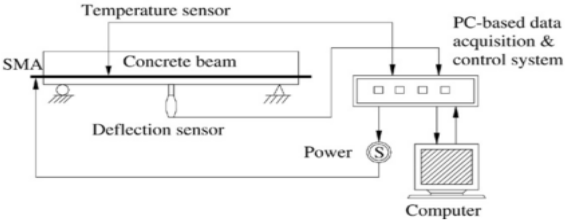


Figure 7. The deflection control system for a beam with SMA ([27]

However, currently, pseudoelastic wire has attracted much attention instead of pseudoplastic for reinforced concrete structure which also enables the shape restoration regardless no external heating is required [33]. Furthermore, this Pseudoelastic Shape Memory Alloy (PE) exhibits stable superelasticity above a reverse transformation finish temperature, and therefore can adequately work as a superelastic material to handle macro-size cracks for structural use in buildings so that these structures can exhibit sufficient resistant against earthquake [34], demonstrated self-rehabilitation capacity of intelligent reinforced concrete structures to reduce crack induced by the removal of load with Pseudoelastic wires. Experiment conducted by [35], shows that the mortar beam with pseudoelastic SMA at 30 ^{0}C above Af (reverse transformation finish temperature) can return about one-tenth of maximum deflection; and the deflection of mortar beam using pseudoelastic is more than seven times of beam with steel.

5.4 Recentering System and Seismic Resisting Devices

In effort to mitigate the structural damage; the SMAs can be integrated into structural systems for recentering system and seismic devices. With proper placement in a structural system, SMAs can also act as pseudoelastic which is able to absorb large deformations, hysteretic energy dissipation, durability, high fatigue resistance, excellent corrosion resistance, high damping capacity, and extraordinary recentering the structure after the removal of the load [4].

For instances, C.Fang *et el* [36] introduced recentering systems using nickel titanium (NiTi) helical spring and Belleville washers to reduce residual deformations instead of using traditional system (elastoplastic) by using base isolator. [37] explored the potential of superelastic NiTi shape memory alloy (SMA) Belleville washers for the applications of seismic resisting devices. A numerical study were employed by adopted a superelastic-plastic constitutive model for NiTi SMA to scrutinize the self-recovery and damping properties of NiTi SMA Belleville washers under the cyclic compression. The design recommendation for the NiTi SMA Belleville washers were proposed based on the parametric study results obtained from the geometric spectrum configuration that consider the effects of varying cone angles, thicknesses and the friction when two or more washers are stacked in parallel were also studied. Further developments to facilitate numerical model for a viable re-centring and energy dissipating seismic resisting devices such as base isolations and dampers were anticipate.

An experimental study of the cyclic performance of extended end-plate connections connected using SMA bolts were experimentally studied by [37] and compare with the conventional connection using the high strength bolts where eight full-scale tests were conducted including seven extended end-plate connections with SMA bolts and one conventional extended end-plate connection with normal high strength bolts. As the result, moderate energy dissipation capability with an equivalent viscous damping up to 17.5% were formed via the elongation of the SMA bolts due to the ‘superelastic’ response that absorb the earthquake-induced deformation into the plastic hinge of the connection. In comparison, the conventional bolt exhibit a compatible energy dissipation capability and ductility and limited until their permanent deformation. Ductility of the connection were govern by the SMA bolt rupture where the stiffness and strength of these connections can be classified into the semi-rigid and partial-strength categories, respectively. In addition, SMA connection specimens exhibit excellent recentring abilities and the experiments results were used to validated the establish numerical models.Other studies reviewed from [20], [21], [38]–[42] also show a siginificant promise.

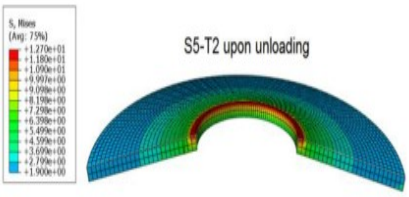


Figure 8. Typical Mises stress distributions of washer ([43]

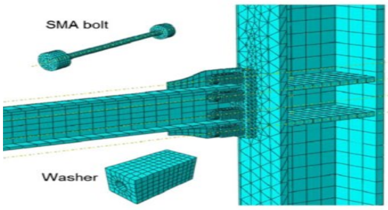


Figure 9. FE model and properties of SMA [37]

Figure 10. Detailed connection deformation ([37]

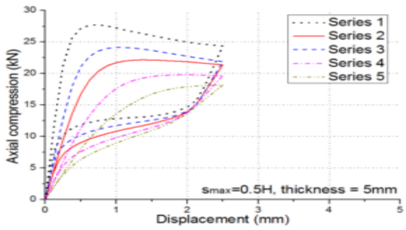


Figure 11. Load-displacement responses of selected SMA washers.[43]

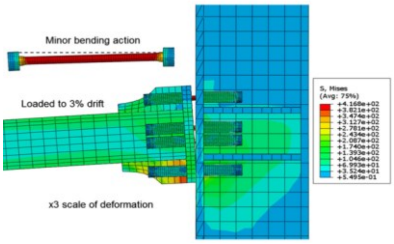


Figure 12. Deformed shape and vonMises stress contour for SMA bolt ([37]

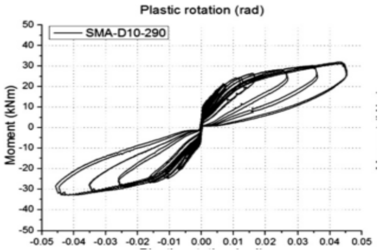


Figure 13. Moment plastic response of the specimen [37]

5.5 Seismic reinforcement for reinforced concrete frame structure

The discoveries of SMA in lieu of steel reinforcement currently become the sparked research to be addressed. The distinctive properties of SMAs make it ideal contender to be incorporated in reinforced concrete structure as reinforcement to address some of the shortcomings of steel rebar and mitigate the problem of deformation [44] explicitly by controlling permanent strains [45]. Furthermore, it was exhibited can remarkably recover and sustained minimum residual deformations after earthquakes [46], dissipate seismic energy through hysteric damping [49]–[51] and can be heat-treated to attained comparable strength to conventional deformed reinforcement [45].

Afrin Hossain, 2013. In this study, superelastic shape memory alloy (SMA) rebar was used as reinforcement in the plastic hinge regions of reinforced concrete beams. Twenty different reinforced concrete (RC) moment resisting frames of three different heights (3, 6, and 8-storys) were used in this study where SMA is gradually introduced from level 1 to the top most floor. The seismic performance of the SMA RC frames was evaluated where the acceptability of a trial value of the response modification coefficient, factor was assessed and appropriate values of system overstrength factor, and the deflection amplification factor, were determined. Steel-SMA-RC frames experienced 4%-17% lower probability of collapse compared to the steel-RC frames. Recent experimental and numerical investigations have demonstrated on numerous feasibility of manipulating SMAs as reinforcement bar in reinforced concrete structures. Previous studies have concentrated on SMA as reinforcement in full reinforced concrete frame structures.[eg [5],[53]–[57].

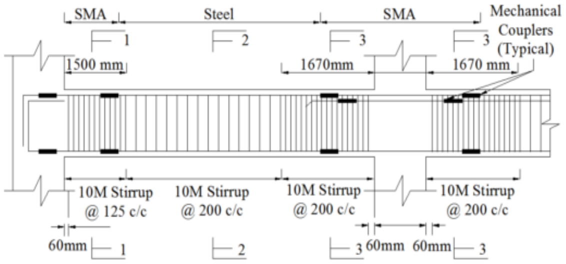


Figure 14. Longitudinal section of beam reinforcement [48]

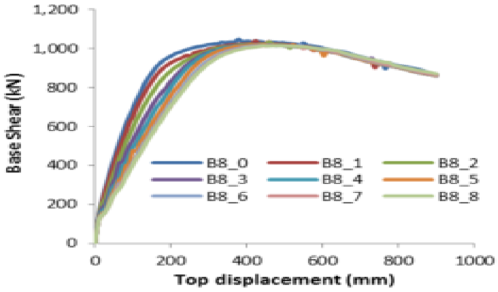


Figure 15. Pushover response curves for 8 storey beam [48]

5.6 Seismic retrofit structure

Billah *et al* [44] performed analytical investigations the development of hybrid columns with SMA bars and fiber reinforced polymer (FRP) to compare with stainless steel rebar for corrosion resistant. A hybrid reinforced concrete (RC) column configuration is presented in order to reduce permanent damages, and enhance its corrosion resistance capacity where the plastic hinge region will be reinforced with SMA or stainless steel and the remaining regions with FRP or stainless steel rebar. An analytical investigation has been carried out to develop such hybrid RC columns and analyze them under seismic loadings. The results are compared in terms of base shear-tip displacement, base shear demand/capacity ratio, ductility, residual displacement, and energy dissipation capacity to those of a similar RC column reinforced with stainless steel. As a result, the corrosion resistant hybridized column can substantially reduce the residual displacement with adequate energy dissipation capacity during earthquakes.

Figure 16. Specimen SMAC-1 after Run 11 [46]

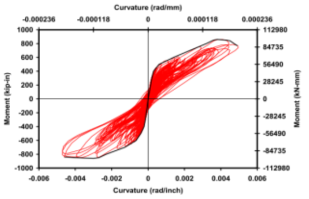


Figure 17. Moment Curvature Histeresis for the Lower Two Segments in SMAC-1 [46]

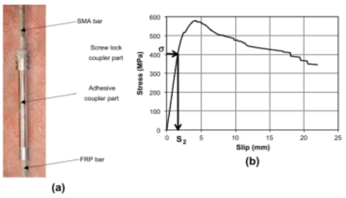


Figure 18. Mechanical–adhesive type coupler for splicing SMA/SS with FRP bar, (b) test setup of coupler in a universal testing machine for determining slippage.[54]

Other research works related to the applications of pseudoelastic SMA in in concrete frame are also reported in the literature [e.g., [15–20]]. It has been conclusively been shown that RC columns were able to recover nearly all of their post-yield deformation by using SMA rebar with engineering cementitious composites (ECC) has been reviewed from research work by [46].

The shake table data showed that SMA RC columns were able to recover nearly all of post-yield deformation and that the use of ECC reduced the concrete damage substantially, thus requiring minimal repair even after very large earthquake. A significant amount of experimental study extensively on the pseudoelastic SMA-FRP composite reinforcement for concrete structure was conducted by Nicholas, [55], Zafar and Andrawes.[56]–[59].

5.7 Post tensioned Bridge

Researchers also studies the application of pseudoelastic bar for bridge application. Hwasung Roh [60] studied the hysteretic behaviour of precast segmental with superelastic shape memory alloy bars by analytical to ensure the SMA model developed provides a good agreement with experimental result. Nonlinear static analysis conducted on seismic performance of self-centering precast post-tensioned bridge column with SMA bar designated the self-centering precast bridge column with SMA bar have superior performance in term of energy dissipation and residual displacement.

As a new alternative, in this paper, the use of superelastic shape memory alloy (SMA) bars is suggested in order to improve the hysteretic performance including the energy dissipation capacity of the bridge columns. The use of SMA bars ensures a self-centering capacity to the PT column system. SMA model developed provides a good cyclic performance. Considering a segmental bridge pier with 7.5 slenderness, a quasi-static cyclic analysis is carried out to investigate the hysteretic response. The results show that stable energy dissipation, self-centering, and high ductile behavior are achieved with the PT column system.

5.8 Beam to Column Reinforcement

Alam *et al* [61] discovered that SMA RC beam-column joints exhibited better performance despite of large inelastic displacements, due to their recentering capability compared of steel-RC beam-column joints. The predicted load–displacement, moment–rotation relationships and energy dissipation capacities have been found to be in good agreement with experimental results. Other scope corresponding with the application of pseudoelastic bar for beam-column joints including the research work by [60]–[65]. There also also several attempts have been made to feasibility study on a self-centering beam-to-column connection by using the pseudoelastic behavior of SMAs by Hongwei, 2007 [65]. The connection deformations are recoverable upon unloading. Latest, feasibility study of utilizing pseudoelastic shape memory alloy not only for reinforced concrete bar but also plates in steel beam-column for improved seismic by S Moradi, 2014[65]. As a resut, the new self-centering connections exhibit a good energy dissipation capability. Based on the numerical results, the recentering properties of superelastic shape memory alloy plates were found to be effective in reducing the residual drifts of a flange plate beam–column connection, while displaying an excellent ductility. In addition, shape memory alloy plates could prevent the occurrence of local buckling and damage in structural members.

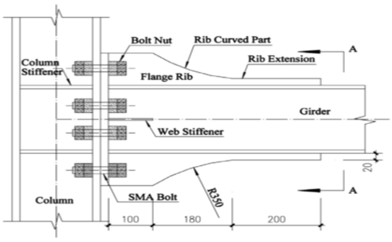


Figure 19. The SMA connection diagram (Ma et al., 2007)

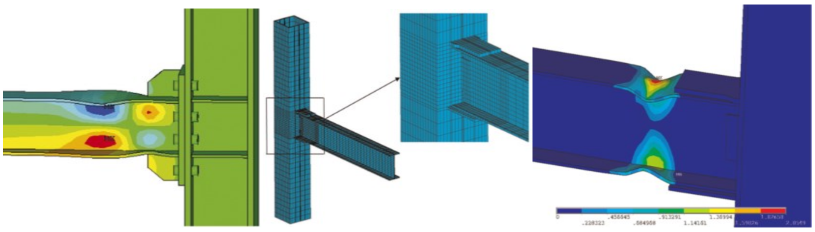


Figure 20. (a) Finite element model of the connection. (b) Equivalent plastic strain from FE analysis ([65]

6. Concluding Remarks and Conclusion

This paper presents the distinctive properties and several applications of shape memory alloys in the proposed smart structure using NiTi (Nickel Titanium) SMAs which are recognized due to their promising prospective in providing recentering capabilities, in increasing damping capacity. The SMAs' unique properties make it an ideal contender to be used for the development of numerous smart RC building and bridge and appealing as devices and new material for seismic resistant design and retrofit.

From the review, the conclusion can be drawn that the Shape-memory alloys (SMAs) is promising smart material to be integrated in the numerous RC building and bridge for seismic resistant design and devices by using the NiTi due to their excellent properties. From the reviews, NiTi SMAs have been successfully used in number of experimental and analytical studies on the applications of SMA and its devices (dampers and base isolators) in RC structures proved them to be effective in improving the response of smart structures of bridges and building to earthquake loading due to their distinctive properties of superelasticity, shape-memory effect and high damping.

In particular, the recentering capability of SMA can be very efficient in reducing the cost of repairing and retrofitting bridges even after severe earthquakes. Other than that, SMA has been proposed to be used as reinforcement at critical regions of the smart RC bridge piers along with conventional steel, where the SMA is expected to yield under strains caused by seismic loads but potentially recover deformations at the end of the earthquake event.

Thus, it is expected that SMAs will emerge as an essential material in the construction industry with the new ideas of using it with other smart materials and in new applications where the current extensive research work still needs to be done. This is because of Shape-memory alloys are a rapidly developing material that will become a good option for tackling the challenges that society is now facing, such as natural disaster resilience and demand for high performance. It is essential that engineers and researchers work together to promote this innovative material's use in bridge and building infrastructure.

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