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Analysis of an RC beam with super-elastic reinforcement

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Abstract: Shape Memory Alloy (SMA) is a novel purposeful material and has found increasing applications in many areas. Nickel-titanium alloys are largely used SMAs. Recently, research efforts have been extended to use SMA for the management of civil structures. SMAs exhibit unique characteristics, most importantly, recovery of large dead deformations upon unloading or heating counting on the crystal structure of the metal. As a result, SMAs are extensively studied and enforced for varied applications. Nickel-Titanium alloy is widely for its superior mechanical and thermal performance over completely different compositions. The shape memory effect and pseudoelasticity, two major properties of SMA associated with the thermal-induced or stress-induced reversible hysteretic section transformation between austenite and primary solid solution, are reviewed. In this paper the response of Simply Supported reinforced concrete beams with smart rebars in static loading has been studied numerically, using Finite element technique.

I. INTRODUCTION:

Concrete structures subjected to rare loading events, including blasts, impacts, and earthquakes, are expected, in many things, to respond within the inelastic range and suffer permanent damage

As an example, the primary objective in seismic design is to substantiate life safety and forestall structural collapse throughout a major earthquake. For concrete structures located in high unstable regions, this is typically achieved through the formation of well-defined plastic hinges, resulting in injury owing to permanent straining inside the reinforcement and permanent deformations inside the structural members. While the main objective is additionally achieved, the sustained damage would possibly forestall the structure from being serviceable and proscribe post-earthquake repairs.

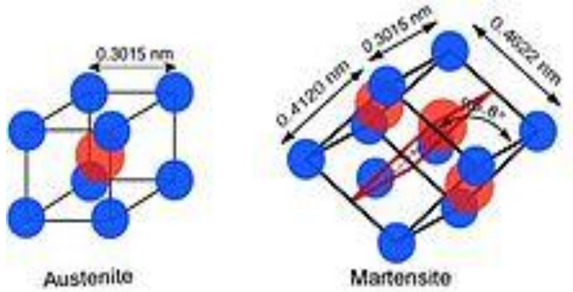
Shape memory alloys have the ability to sustain large deformations; but, they return to their original undeformed shape upon removal of stress (superelastic SMA) or with the application of heat (shape memory effect). The objective of this study is to analyze the structural performance of super elastic SMA reinforced concrete and to develop a preliminary constitutive model applicable to nonlinear finite element algorithms.

II. SHAPE MEMORY ALLOYS -BEHAVIOURS

A. Crystalline Structures

SMA has two crystalline structures or phases i.e. martensite and austenite. In martensite section (i.e. stable at lower temperatures and higher stresses), SMA can be distorted into any form.

Fig. 2.1 3-D model of SMA Phase Transformation

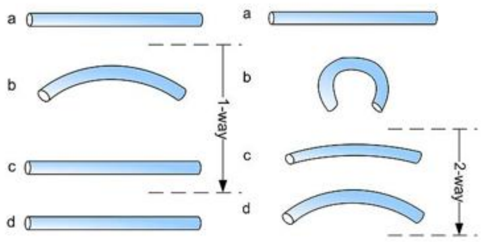


SMA undergoes a transformation from martensite to austenite once heated. In austenite section (i.e. constant at higher temperatures and lower stresses), SMA can "remember" shape it had before it was distorted. However, martensite becomes stable at a critical stress level that causes stress plateau and yielding shown in Fig.1. Martensite may be constant as a result of stress applied, however, the original undeformed form will be regained by making austenite structure stable upon unloading.

B. Shape Memory Effect (Sme)

The SME is described as the method by which SMA will revert to their preset shapes upon heating. The shape changes with temperature variation are primarily attributed to martensite phase transformation.

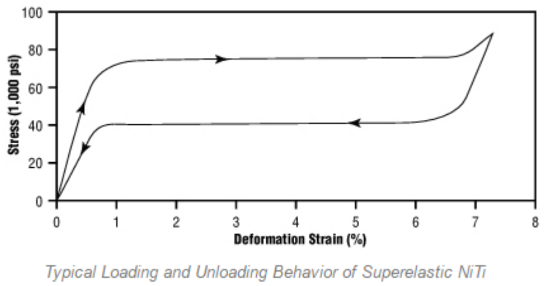
Fig.2.2 One way and Two way shape memory effect



C. Superelasticity

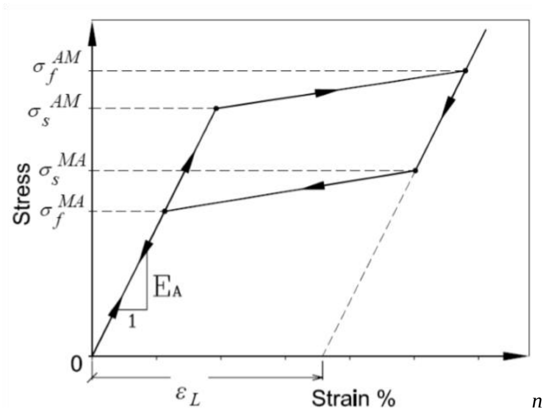
Superelasticity sometimes known as Pseudoelasticity, is an elastic (reversible) response to an applied stress, caused by a phase transformation between the austenitic and martensitic phases of a crystal.

Fig 2.3 Superelastic Effect



Superelasticity is from the reversible motion of domain boundaries during the phase transformation, rather than just bond stretching or the introduction of defects within the space lattice (thus it is not true superelasticity but rather a pseudoelasticity). Even if the domain boundaries do become pinned, they may be reversed through heating. Thus, a pseudoelastic material may come back to its previous shape (hence, shape memory) when the removal of even comparatively high applied strains.

Fig 2.4 Response of SMA to Temperature Variatio



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One special case of pseudoelasticity is called the Bain Correspondence. This involves the austenite or the martensite phase transformation between a face-centered crystal lattice (FCC) and a body-centered tetragonal crystal structure (BCT).

SMAs can recover their shape once unloading even it endures large inelastic deformation.

D. NI-TI based SMA

Among many alloy families primarily based upon nickel- Ti composition, Nitinol, is mostly used for activating and sensing devices in structural control systems.

Ti-Ni alloys behavior changes deeply with temperature, at ambient temperature, the microstructure is totally martensitic, stress–strain behavior displays large hysteresis loop identical to that of traditional steels and don't show any recovery. The superelastic effect seems once materials are absolutely austenite at a higher temperature.

Nickel-titanium alloys are usually utilized in cold drawn wire or as bar stock. The SME can be “programmed” into SMA alloys with the appropriate thermal method.

III. CHARACTERISTICS OF MATERIALS

A. Concrete: The modeling of concrete considers cracking, crushing failure modes and nonlinear behavior. The compressive strength of concrete is 30 MPa and its tensile strength is 3.5 MPa. Also, the elastic modulus and Poisson’s ratio are 20 GPA and 0.2, respectively. The concrete material model in the ANSYS software predicts the failure of brittle materials by using the model of Willam and Warnke.

Willam-Warnke yield criterion - Function that is accustomed predict once failure can occur in concrete and different cohesive-frictional materials like rock, soil, and ceramics.
B. Steel: Linear stress-strain curve has been used for the modeling of steel behavior. The values of elastic modulus and Poisson’s ratio of steel ar 200 GPA and 0.3, respectively. The model, which introduces the behavior of steel in nonlinear type, is based on the model of bilinear Kinematic Hardening. The steel is assumed to have the yield strength of 400 MPa.

C. Nickel Titanium Alloy: Composition: Nickel–Titanium (NiTi), consisting of approximately 56% nickel and 44% Ti alloy, is the commonest kind of SMA investigated for structural applications.

Titanium– nickel, can bear strains up to 8% and can be strained up to 6% by regaining fully the undeformed shape once heated on the far side activation temperature.

1. Physical Properties:

a) *Appearance*: This is a bright silvery metal.
b) *Density:* The density of this alloy is 6.45 gm/ cm3
c) *Melting Point*: Its melting point is around 1310 °C.
d) *Resistivity*: It has a resistivity of 82 ohm-cm in higher temperatures and 76 ohm-cm in lower temperatures.
e) Thermal *Conductivity*: The thermal conductivity of this metal is 0.1W/cm-°C.
f) *Heat Capacity:* Its heat capacity is 0.077 cal/ gm-°C.
   Latent Heat: this material has a latent heat of 5.78 cal/ gm.
g) *Magnetic Susceptibility*: Its magnetic susceptibility is 3.8 emu- gm in high temperatures and two.5 in low temperatures.

2. Mechanical Properties:

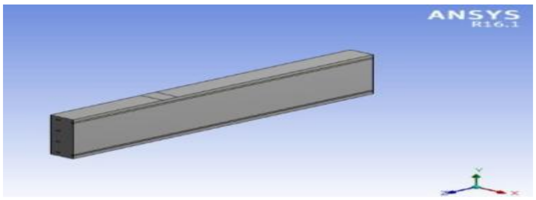
a) *Ultimate Tensile Strength*: The ultimate tensile strength of this material ranges between 754 and 960 MPa.
b) *Typical Elongation to Fracture:* 15.5 percent Typical Yield Strength: 560 MPa in high temperature; 100 MPa in low temperature.
c) *Approximate Elastic Modulus:* 75 GPa in higher temperature; 28 GPa in low temperature
d) *Approximate Poisson's Ratio:* 0.3.

IV. MODELLING OF BEAMS IN ANSYS:

This chapter is going to contend with the size of the beam, its reinforcement details, the support conditions and the characteristics of the finite element model in ANSYS.

A. Geometrical Modelling:

Fig 4.1 ANSYS Model



The concrete beam has a length of 1 m and is rectangular in cross section with dimensions of 200 mm by 300 mm.

1. Characteristics Of Finite Element Model:

Regarding concrete model meshes, it is noticeable that by using SOLID 65 component the nonlinear behavior and also the potential of cracking and crushing of the concrete are thought-about. In ANSYS software, SMAs can be fixed for the subsequent elements: PLANE182, PLANE183, SOLID185, SOLID186, SOLID187, and SOLSH190. The most suitable elements for 3D rebar modeling are SOLID elements. Besides, the number of node and order are identical in each elements SOLID185 and SOLID 65; both SOLID185 and LINK8 will be accustomed 3D modeling. Since the details of both SMA and steel reinforcement should be modified oftentimes, using SOLID185 component for the entire reinforcements provides high speed throughout modeling method.LINK8 element has been used here for stirrups modeling of the concrete beam. Hexahedral-shaped elements have been accustomed mesh the model. Each part has the dimensions of 10x10x10 cm^3.

2. Details Of Reinforcement:

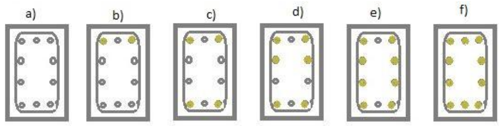
Assuming 3.5% reinforcement ratio roughly, 10 rebars with 10 mm diameter is used to reinforce the beam. This amount of ratio and varied arrangements of reinforcement build it attainable to compare the impact of smart rebars to that of steel rebars in the behavior of concrete beam. The ratio of smart rebars to total bars for 5 different arrangements of reinforcement are shown in table 1.

Beam	*Percentage of niti rebars*
a	*0*
b	*20*
c	*40*
d	*60*
e	*80*
f	*100*

Table 1.

The section of beam for each arrangement is also shown in figure 4.2.

Fig 4.2 Arrangement of Rebars



The width and the effective depth of the beam section were set to 200 mm and 250 mm, respectively. The 6 mm diameter bars with 100 mm centers are provided as stirrups.

B. Loading And Boundary Conditions:

In this paper, the response of a Simply Supported beam is studied in axial loading. The vertical load was applied to the beam at the center in the Y direction.

V. ANALYSIS OF BEAMS AND RESULTS

In this section, the results of the numerical study of the concrete beam models have been presented. The results due to the varied details of smart rebars are compared further.

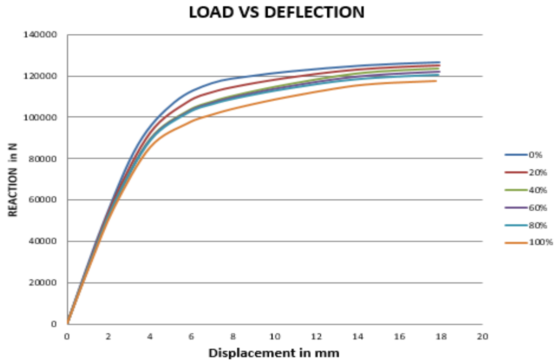
A. Analysis Of Beams:

The behavior of beam has been studied here by the use of nonlinear static analysis in large displacement condition. Due to controlling the convergence at each performance of study at each sub-step, both force and displacement convergence criteria have been performed by using the tolerance value of 0.01. Due to the compressive response of concrete, there is less compressive strain in SMA.

B. Load-Displacement Variation:

The figure 5.1 shows the variation of shear force vs. displacement for the concrete beam for the various proportion of SMA. The displacement of the models is measured at the midpoint of the concrete beam. This figure indicates that the increase in the ratio of the smart rebar reduces the deflection within the curves. The Smart rebars cut back the residual displacement. For the higher ratio of smart rebars, higher the reduction in residual displacement. Therefore, they create recovery forces that lead into both closings of concrete cracks and reduction of residual displacement.

Fig 6.1 Variation of Displacement With Respect To Load



VI. CONCLUSIONS

The response of RC beams using smart rebars in static lateral loading is numerically studied using the finite element methodology. The 3-D model of the concrete beam has been generated by ANSYS software; SOLID85 and SOLID185 have been used for the modeling of concrete and longitudinal reinforcement, respectively. Based on the study presented, the following conclusions are summarized:

a) Replacing steel bars with SMA bars reduces the deflection of the beam.
b) Using smart rebar reduces the residual displacement of the beams post the loading.
c) Even though SMA reduces residual displacements in RC beams due to its recoverability, it reduces energy absorption capacity of the structure.

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