ANALYTICAL STUDY OF IRON-BASED SHAPE MEMORY ALLOY TO SUSTAIN SERVICEABILITY IN CIVIL STRUCTURES

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Abstract: This paper discuss the behavior of shape memory alloy. In recent years the deterioration of reinforced concrete is widely increased. To improve the life span and strength of reinforced concrete structures the several materials has been used like shape memory alloy. SMA material has a property to regain its original shape and ability to withstand the large deformation. SMA were used to replace the steel bars at the critical region of beam. The conventional reinforcement bars and Fe-SMA reinforcement bars is studied by analytical results The beam size of 150x150x700mm with #2-10mm diameter is reinforced in tension side while #2-10mm in compression side and 2- legged 8mm diameter stirrups at 150 mm c/c used as shear reinforcement.

The analysis of beam is done by ANSYS 2021R1. By non –linear finite element modeling, the deformation in RC beam with conventional reinforcement bars and Fe-SMA reinforcement bars are calculated. A comparison between Fe-SMA and conventional reinforcement is done in ANSYS 2021R1 for evaluating deflection of RC beam to obtain more durability between them.

***Index Terms* –** Shape Memory Alloy, Fe-SMA, Steel, ANSYS

1. INTRODUCTION

Reinforced concrete is heavily used in the civil industries. Reinforced concrete is composite material that achieve its strength from the concrete in compression and the reinforcing bars in tension. Durability is the main factor for all the civil structures. Due to the damaged and deteriorating conditions of the concrete, infrastructure maintenance has become a common crisis. So, to overcome these and to increase the life span of structures, the present study focuses on the use of advanced material as Shape Memory alloy as alternative of conventional reinforcement. Shape memory alloy can undergo large inelastic deformation and have ability to return in their original shape by removal of stress or by heating. This study presents the performance of iron based SMAs with conventional reinforcement in concrete beam. SMA is capable of undergoing large recoverable strains of the 8%. [2]

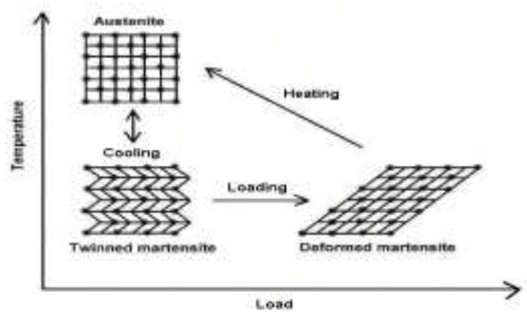


Fig. 1 Phase Transformation of SMA [5]

In 1932, the gold-cadmium shape memory alloy was first discovered by Ame Olande. [2] Later in 1938, Greninger and Mooradian first observed the SME for copper-zinc (Cu-Zn) alloys and copper-tin (Cu-Sn) alloys. [2] William Buehler and Frederick Wang were first developed the nickel-titanium alloy in 1962-1963 and gave trade name as Nitinol alloy. Fe-SMA was first discovered in 1982.[1] . Iron based shape memory alloy has better workability, corrosion resistance properties. [2] Temperature and external stresses define the phases of SMA. [5] Figure 1 shows the phase transformation of SMA. Martensite structure is stable at lower temperature phase and austenite structure is stable at higher temperature phase. [1,8] In martensite phase SMAs is weaker and in austenite phase they are stronger. [3,4,6,7]

2.FINITE ELEMENT MODELING

The finite element analysis includes a modeling of concrete beam with properties and dimensions. To prepare finite element model, ANSYS Mechanical APDL 2021 was used. The various steps were followed to run the model properly.

2.1 METHODOLOGY

These are the steps shown in Figure 2 to be carried while analyzing the deflection of the beam.

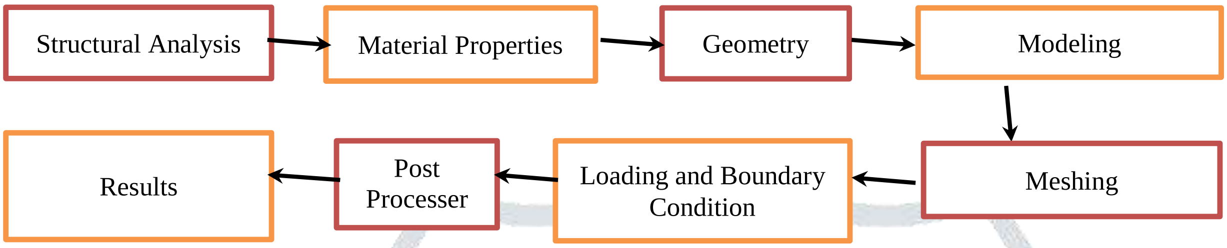


Fig. 2 Flow chart representing steps to be performed in ANSYS.

2.2 MATERIALS

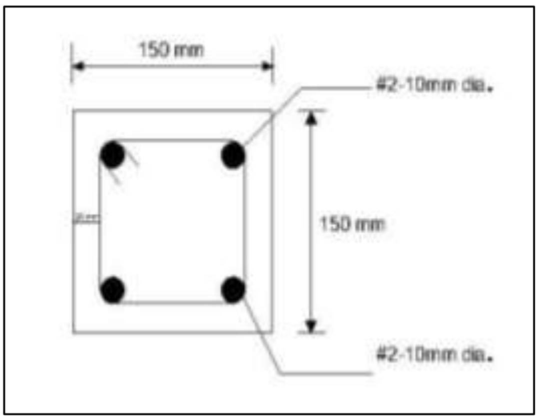
The properties of materials used while analyzing the deflection of the beam is tabulated in Table 1.

Table 1 Material Properties input data for analytical study in ANSYS R21

Properties	Concrete	Steel	Fe-SMA
Ansys elements	Solid 65	Solid 185	Solid 185
Young's Modulus (MPa)	30000	$2x10^5$	$2.08x10^5$
Poisson's ratio	0.2	0.3	0.358
Grade	M30	Fe500	-
Yield strength (MPa)	5	500	868

2.3 GEOMETRY OF RC BEAM

A RC beam of size 150 x 150x 700 mm with 2- 10mm dia. bars in tension and #2-10mm dia. bars in compression was prepared. For shear reinforcement 2-legged 8 mm diameter bars were used. The two-point loading case was taken for analysis as shown in Figure 3(a) and 3(b)



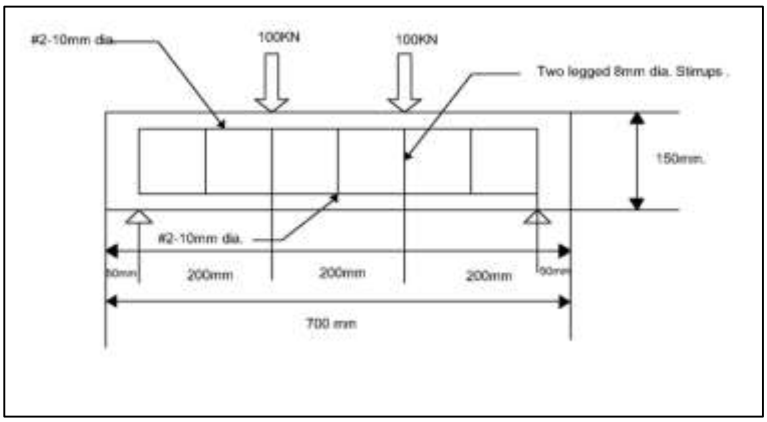


Fig 3(a) Cross-section of the beam.

Fig. 3(b) Loding and Reinforcement details of the beam.

2.4 MESH, LOADING AND SUPPORT CONDITIONS

A mesh splits the domain into the discrete number of the elements. RC beams with conventional reinforcement bars and Fe-SMA reinforcement bars were meshed in proper sizing in such the way that good results are obtained from the elements. The boundary conditions of the model is one end is roller support and another end is hinged support. The load of 100 kN were applied at one third distance of the beam. Figure 4(a) shows the placing of reinforcement bars and stirrups & Figure 4(b) shows the meshing, loading & support conditions of the beam.

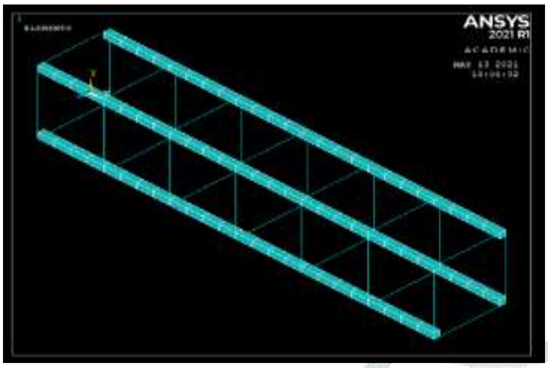


Fig. 4(a) Placement of reinforcement bars & stirrups.

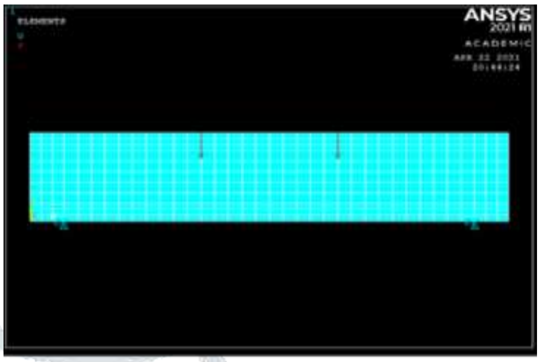


Fig. 4(b) Meshing, loading and support conditions of beam

3. RESULT & DISCSSION

3.1 DEFLECTION

The deflection of the RC beam with conventional reinforcement bars. Fe-SMA reinforcement bars and Fe-SMA at critical is determine analytically. The results shows that the deformation of RC beam with conventional reinforcement in Figure 5(a) & Fe-SMA at critical section along with conventional reinforcement bars Figure 5(d) have almost same values that is 0.635mm & 0.640mm respectively. The deflection of the Fe-SMA reinforcement as shown in Figure 5(b) is 0.707mm which is greater than other beam type. The deflection of combination of Fe-SMA reinforcement in tension side and steel reinforcement in compression side is 0.558mm as shown in Figure 5(c).

As per Is 456:2000, the deflection of flexural member should not exceed the permissible value that its span by 250. The permissible deflection of 700mm size of beam is 2.8mm.

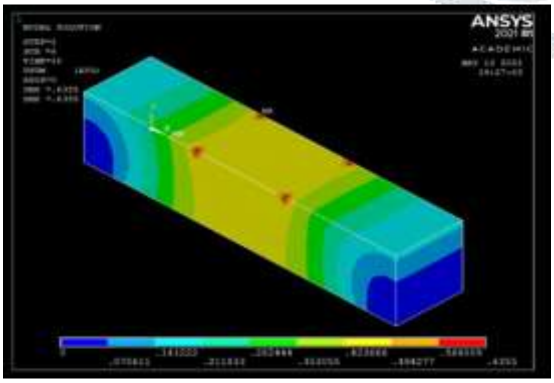


Fig. 5(a) Beam with Conventional Reinforcement bars

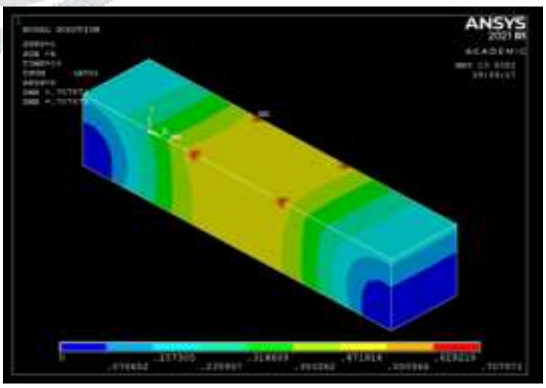
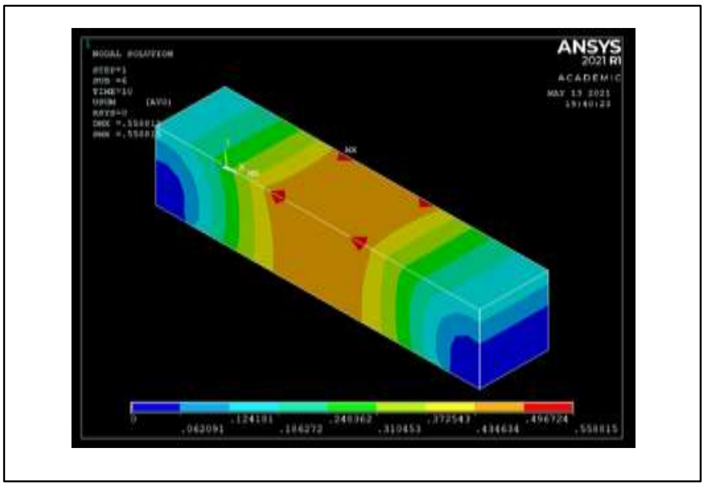


Fig. 5(b) Fe-SMA Reinforcement bars



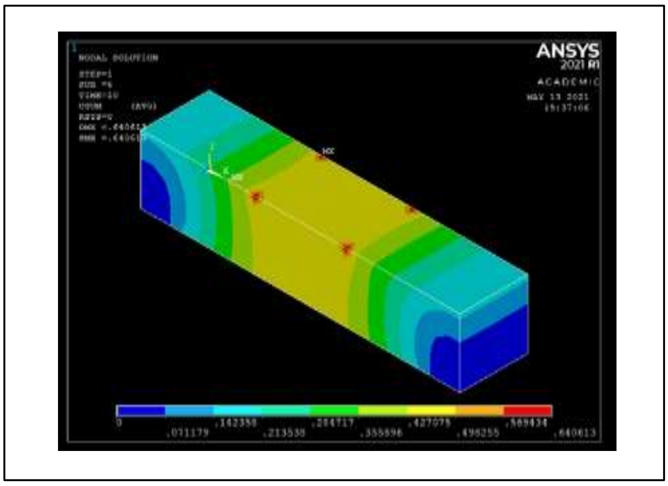


Fig. 5(c) Fe-SMA reinforcement at tension side & Conventional Reinforcement at compression side

Fig. 5(d) Fe- SMA reinforcement bars at Critical Section

The load v/s deflection graph shown in Figure 6 gives a brief information of how the variation takes place in deflection with respect to corresponding loads.

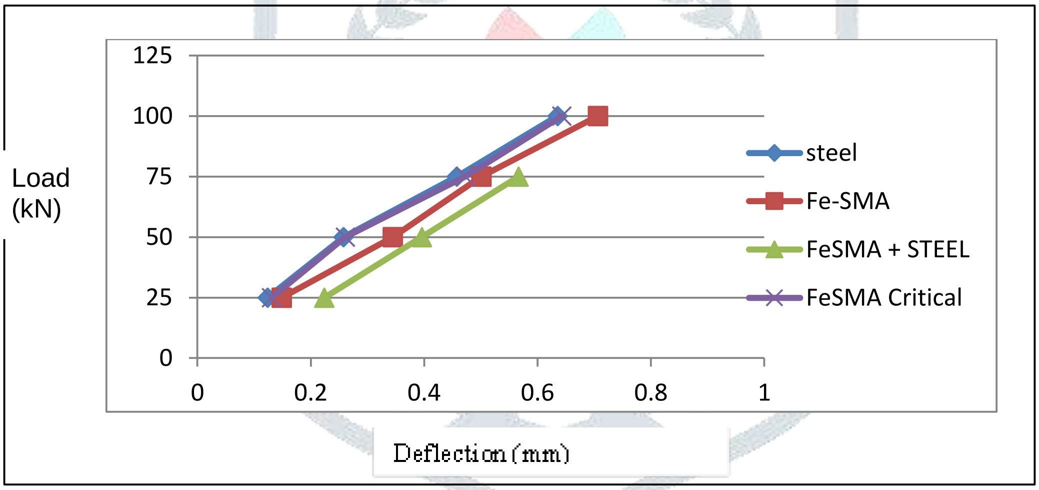


Fig. 6 Load v/s Deflection Graph

The load and deflection of each beam type is tabulated in Table 2.

Table 2. Deflection of different beam type.

Sr. No	Beam Type	Load (KN)	Deflection (mm)
1.	Steel Reinforcement Bars (#2-10mm dia. tension side) (#2-10mm dia. compression side)	100	0.635
2.	Fe-SMA Reinforcement Bars (#2-10mm dia. tension side) (#2-10mm dia. compression side)	100	0.707

3.	Fe- SMA reinforcement (#2-10mm dia. tension side) Steel Reinforcement (#2-10mm dia. compression side)	100	0.558
4.	Fe- SMA reinforcement at L/3 of beam (critical location) Combined with Steel Reinforcement.	100	0.640

3.2 COST ANALYSIS

Cost analysis of steel, NiTi, Fe-SMA reinforcement bars was carried out and compared with each reinforcement bars. In various research paper we have seen that the Fe-SMA reinforcement is less costly than NiTi SMA reinforcement bars. Figure 7 shows the graphically representation of cost of various types of reinforcement bars. It was observed that Fe-SMA reinforcement bars are costly as compared to conventional reinforcement.

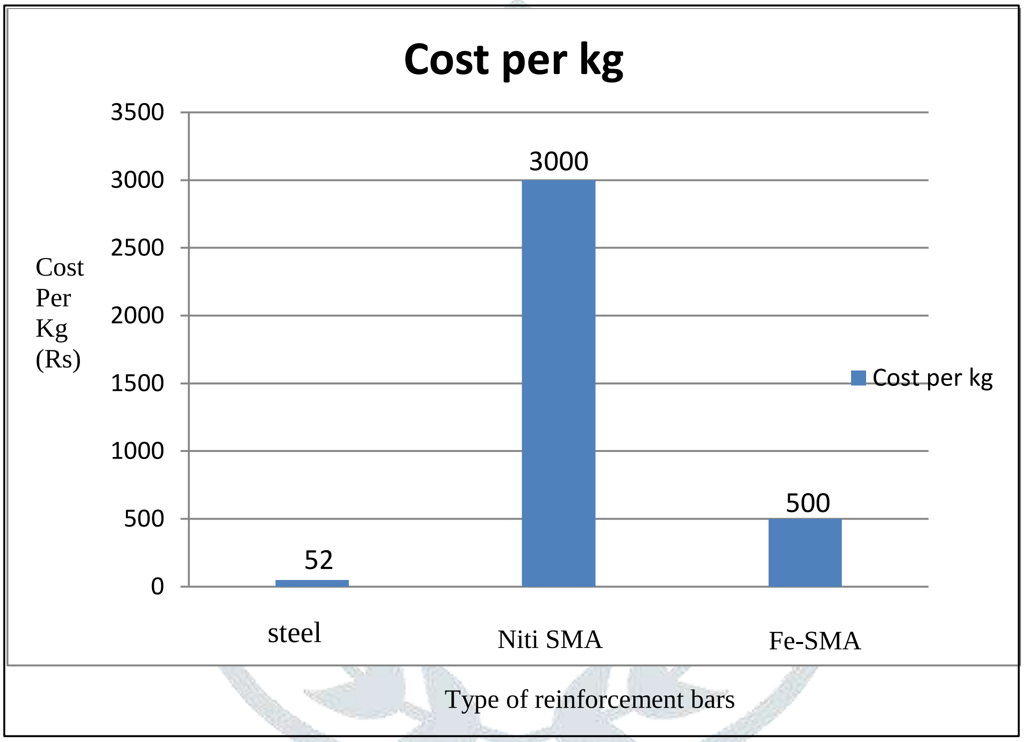


Fig. 7 Cost Analysis of reinforcement bars

4. CONCLUSION

1. By using Fe-SMA reinforcement in the beam the deflection by analytical means comes out to be 0.707mm which is greater as compared to other beam types. In addition, the cost of Fe-SMA is also high. So, it is not economical.
2. By using Fe-SMA Reinforcement in tension side and conventional reinforcement in compression side the deflection is 0.535mm which is less than other beam types.
3. The deflection of conventional reinforcement and Fe-SMA reinforcement at critical section is 0.635mm and 0.640mm respectively which is almost same. But by using Fe-SMA at critical location the durability of the structure will be increased and it will be sustained for longer period of time.

So, by using Fe-SMA at critical section with combination of conventional reinforcement gives strength as well as durability to the civil structures.

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