NUMERICAL INVESTIGATION ON THE PERFORMANCE OF REINFORCED CONCRETE T-BEAMS USING SHAPE MEMORY ALLOYS

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Abstract - *This research paper is about recent works have shown the feasibility of using shape memory alloys (SMA) in structural rehabilitation projects, especially for flexural strengthening. SMA is an alloy that can be deformed when cold but returns to its pre-deformed shape when heated. This paper presents a numerical investigation on the performance of reinforced concrete T-beam using SMA, considering an existing reinforced concrete T-beam bridge. Internal strengthening has been done using Nickel-Titanium (Ni-Ti) SMA as reinforcement numerical analysis done with ANSYS 18.1 workbench. External strengthening of T-beam bridge with Ni-Ti, and copper-nickel (Cu-Ni) as U-shaped clips, it connected to the weakest portion of the existing bridge. Determined the external and internal strengthening of reinforced concrete T-beam with various types of SMA.*

Key Words: Shape memory alloys (SMA), Super elasticity, Ni-Ti SMA, SMA U clips

1.INTRODUCTION

Reinforced concrete buildings represent one of the most popular structures in developing countries.[1] The design of a reinforced concrete building takes into account safety considerations under service loads but does not include seismic considerations in particular. Furthermore, reinforced concrete buildings require regular monitoring, evaluation, maintenance and repair at regular interval due to ageing and deterioration. Lack of proper detailing, poor construction practice, and proper maintenance has caused devastation in many cases, including permanent damage and failure of many buildings and structures during an earthquake. Seismic hazards and their associated damage following earthquake events often render the structure economically not possible to repair.

To mitigate these sorts of problems, designers often use a performance based approach which allows designing structural members with enhanced deformation capacity, ductility, energy dissipation capacity, and reduced permanent deformation. This performance based approach ensures that following major earthquake events, the structure can be restored to a serviceable state with minimum repairs.

[2]The rehabilitation of civil engineering structures and structural strengthening is a strategic field in the construction sector due to the ageing of existing infrastructures (including bridges, buildings and others). Many research works have been carried out in the last few decades on different strengthening systems to control the failure mechanisms of existing structures by increasing their safety and lifetime. One of the most critical failures in concrete structures is shear failure given its fragile instantaneous nature and the general inability to warn users before collapse occurs. For this reason, it is sometimes necessary to strengthen existing structures to avoid shear failures especially when the structure may be subjected to significant seismic actions.

However, most strengthening systems used to increase shear strength are passive; that is, strengthening elements do not start to collaborate with resistant actions until there is a change in the structure's balance new loads or deformations.

Among them, super elastic Shape Memory Alloy (SMA) is one of the promising solutions, and it has ushered in a new era in terms of overall performance of the structure. The novelty of this material is its ability to undergo large deformation and return to its original shape through stress removal (super elasticity) or heating (SMA effect). [1] In particular, SMA has distinct thermo mechanical properties, including super- elasticity, SMA effect, and hysteretic damping. These properties can be effectively utilized in the beam under reversed cyclic loading. Recent research works have shown that SMA can be used together with new orexisting reinforced concrete structures to provide them with new functionalities or to increase their safety and resilience.

2. FINITE ELEMENT ANALYSIS

For the numerical analysis of the reinforced concrete T-beam bridge was constructed as the model of Chamakkavu Bridge the details as shown in table 1. The bridge is located at Venmony village on the border of Alappuzha and Pathanamthitta districts across the Achankovil river were developed using non linear finite element analysis program, ANSYS 18.1

Table -1: Details of Chamakkavu Bridge

Bridge type	Prestressed T-beam bridge
Total span	60 m
Number of longitudinal girders	4
Number of cross girders	4
Grade of concrete	M30 for the whole structrues
Spacing of girder	2625 mm
Grade of steel	HYSD Fe 415
Carriage way	7.5 m
Effective span of the bridge	20 m

For the analysis, the dead load and vehicle load are considered by IRC: 6- 2000 details as shown in table 2. The figure 1 shows the geometrical diagram of T-beam bridge. The four numbers of longitudinal and cross girders are modelled by an effective span of 20 m.

Table -2: Details of dead load and vehicle load

Dead weight of slab	6.00	kN/m
Dead weight of wearing coats	1.76	kN/m
Weight of the vehicle IRC class AA	350	kN
Loading Area	850 × 3600	mm
Spacing	2050	mm

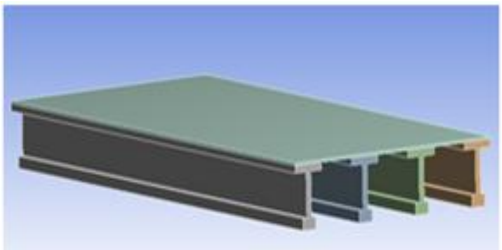

Fig -1: Geometrical model of T-beam bridge

2.1 Analysis of Single T-Beam with 2 Mm Crack on Mid-Span (STB 1)

From the analysis, the maximum equivalent stress obtained as 154.141 MPa. The total deformation is obtained as 2.206 mm, and the maximum principal stress is obtained 145.721 MPa as show in figure2,3.

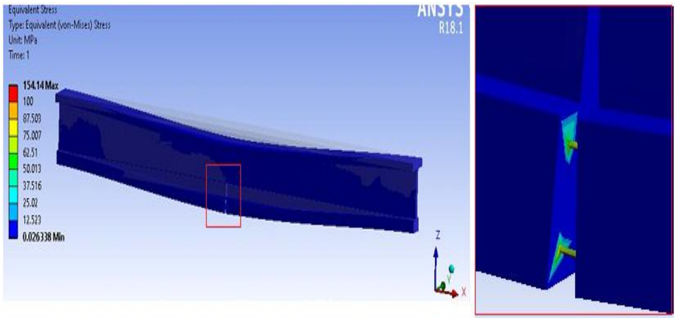

Fig -2: Maximum equivalent stress of a single T-beam girder

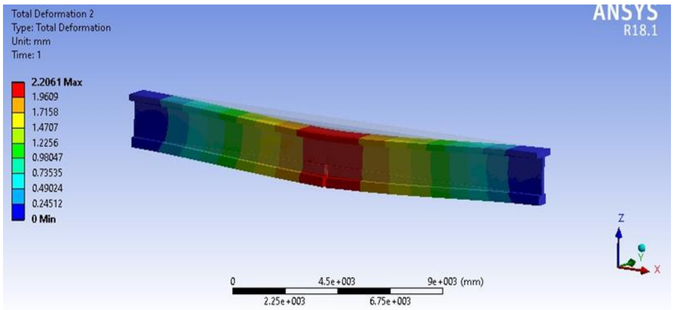

Fig -3: Total deformation of a single T-beam girder

2.2 Analysis of Single T-Beam with Ni-Ti SMA as Reinforcement (STN 2)

2.2.1 Material Properties of Ni-Ti SMA

Ni-Ti based shape memory alloy is the most useful of all kinds of SMA. The Ni-Ti alloy exhibits common shape memory behavior and is restored to its original shape after it is heated more than its phase transformation temperature. When heated to this temperature, the alloy transforms from its low-temperature monoclinic Martensitic structure to the high-temperature cubic Austenitic structure as shown in figure 4. The material properties of Ni-Ti SMA as shown in table 3

Table -3: Details of dead load and vehicle load

Properties	**Low temperature Ni-Ti**
Density (g/cc)	6.45
Yield Strength (MPa)	195
Elongation at Break %	15.5
Modulus of Elasticity (GPa)	28.0

From the analysis, the maximum equivalent stress obtained as 4.426 MPa. The total deformation is obtained as 1.449 mm, and the maximum principal stress is abtained 3.860 MPa as show in figure 4, 5.

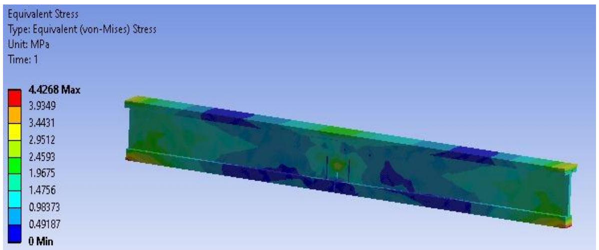

Fig -4: Maximum equivalent stress of a single T-beam girder

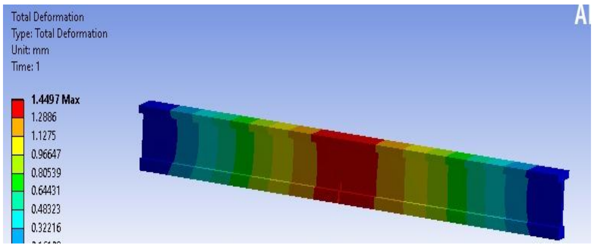

Fig -5: Total deformation of a single T-beam girder

2.3 Analysis of Single T-Beam with Ni-Ti SMA U-Shaped Clips (STN 3)

The model was designed with Ni-Ti SMA U-shaped clips externally connected in single T-beam girder. U-clips are connected externally with 2 inch SA 193 bolts. A193 B7 material is a standard material specification for chromium-molybdenum alloy steel fasteners for use in high tensile, high temperature and special purpose applications as shown in figure 6.

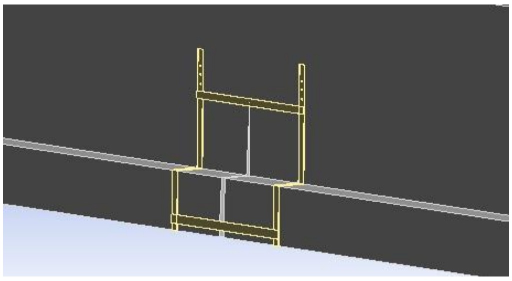

Fig -6: Geometrical diagram with Ni-Ti SMA

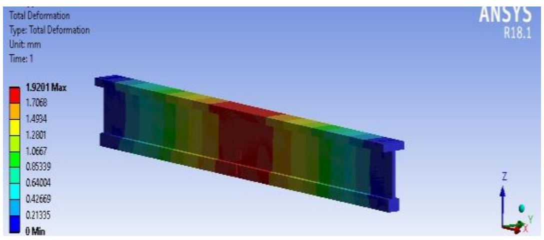

Fig -7: Total deformation of single T-beam girder with Ni-Ti U-shaped clips

From the analysis, the maximum equivalent stress obtained as 144.811MPa. The total deformation is obtained 1.920 mm, the axial stress is obtained 284.8 MPa. The maximum principal stress obtained as 136.811MPa. The FOS is obtained by dividing the yield stress with the obtained stress and it is 1.346. As shown in figure 7,8,9.

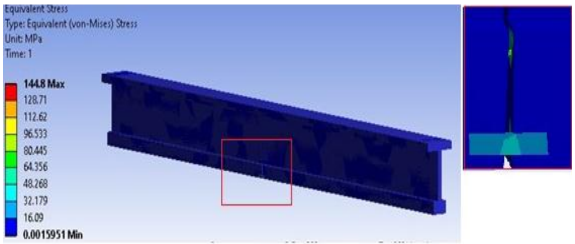

Fig -8: Maximum equivalent stress of single T-beam girder with Ni-Ti U-shaped clips

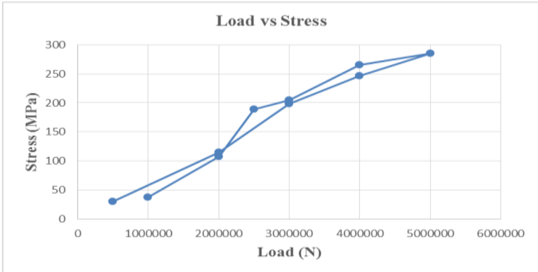

Fig -9: Load vs Stress graph of Ni-Ti U-shaped clips

2.4 Analysis of Single T-Beam with Cu-Ni SMA U-Shaped Clips (STC 4)

The model was designed with Cu-Ni SMA U-shaped clips externally connected in single T-beam girder. The material properties of Cu- Ni SMA U-shaped clips as shown in table 4

Table -4: Material properties of Cu-Ni SMA

Properties	Cu-Ni10Fe1
Density (g/cc)	8.9
Melting Range ºC	1105-1140
Electrical conductivity (S/m)	5.5
Modulus of Elasticity (GPa)	123

From the analysis, maximum equivalent stress obtained as 138.691MPa. The total deformation is obtained 1.905 mm, the axial stress is obtained 293.6 MPa. The maximum principal stress obtained as 131.911MPa.The FOS is obtained by dividing the yield stress with the obtained stress and it is 1.045.

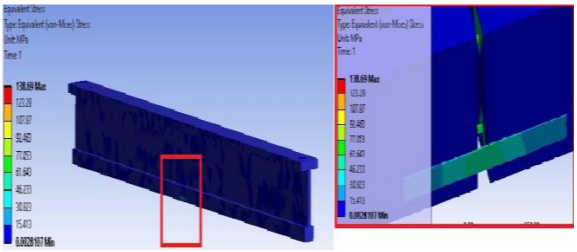

Fig -10: Maximum equivalent stress of single T-beam girder with Cu- Ni U-shaped clips

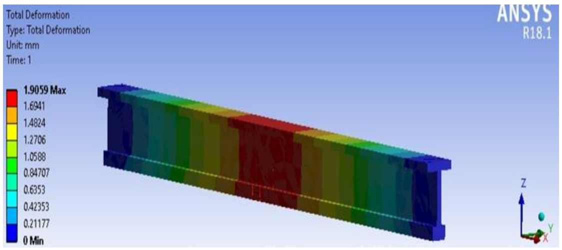

Fig -11: Total deformation of single T-beam girder with Cu- Ni U-shaped clips

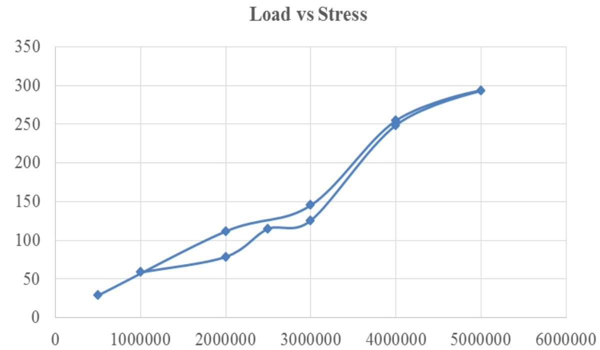

Fig -12: Load vs Stress graph of Cu- Ni U-shaped clips

3. RESULT AND DISCUSSION

Table 5, list out the parameters such as deformation and stress of reinforced concrete T-beam with SMA subjected to static and dynamic loading conditions. Table 6 listed out percentage decreases in deformation. Here it is evident that reinforced concrete T-beam with Ni-Ti as reinforcement is suitable for reduce the crack width, but it is being uneconomic because the high cost of Ni-Ti SMA. Also the different types of SMA U-shaped clip parameters such as deformation list out Table 7 shows less deformation. Cu-Ni U-shaped clips are less deformation than Ni-Ti U- shaped SMA.

Table -5: Results based on Equivalent stress criteria

Specifications	Stress value (MPa)	Deformation (mm)
STB 1	154.141	2.206
STN 2	4.4268	1.449
STB 3	144.811	1.920
STC 4	138.691	1.905

Table -6: Comparison deformation with SMA as reinforcement

Specifications	Deformation (mm)	% Decrease in deformation
STB 1	2.206	-
STN 2	1.449	34.315

Table -7: Comparison of deformation with SMA U-shaped clips

Specifications	Deformation (mm)	% Decrease in stress
STB 1	2.206	-
STN 3	1.920	12.96
STC 4	1.905	13.64

4. CONCLUSIONS

A numerical investigation was conducted to optimize the reinforced concrete T-beam bridge girder using Ni-Ti SMA as reinforcement and SMA U-clips (Ni-Ti, & Cu-Ni). Based on analysis, the following conclusions are made:

- Design and analysis of reinforced concrete T beam bridge using finite element program such as ANSYS is possible.
- Ni-Ti SMA used as reinforcement in T-beam bridge girder is more efficient than existing normal T-beam bridge girder under static and dynamic loading conditions.
- Single T-beam girder with Ni-Ti as reinforcement shows 34.31% less deformation as compared to normal T-beam girder under static and dynamic loading conditions.
- Single T-beam girder with externally connected Ni-Ti U-shaped clips shows 12.94 % less deformation

as compared to a normal T-beam girder under static and dynamic loading conditions.

- Single T-beam girder with externally connected Cu-Ni U-shaped clips shows 13.644 % less deformation as compared to a normal T-beam girder under static and dynamic loading conditions.
- Cu-Ni SMA U-clips shows better performance than Fe-Mn-Si and Ni-Ti SMA U-clips.
- While considering longer length of T-beam bridge Ni-Ti reinforcement becomes uneconomical because Ni-Ti SMA shows higher cost.
- While considering a sudden crack on the existing reinforced concrete T-beam it can repair with U clips without affecting the transportation. This method is economically safe.

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