World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:11, No:7, 2017

Improvement of Load Carrying Capacity of an RCC T-Beam Bridge Longitudinal Girder by Replacing Steel Bars with SMA Bars

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***Abstract*—**An innovative three dimensional finite element model has beed developed and tested under two point loading system to examine the structural behavior of the longitudinal reinforced concrete Tee-beam bridge girder, reinforcing with steel and shape memory alloy bars respectively. 25% of steel bars are replaced with superelastic Shape Memory Alloy bars in this study. Finite element analysis is performed using ANSYS 11.0 program. Experimentally a model of steel reinforced girder has been casted and its load deflection responses are checked with ANSYS analysis. A comparison of load carrying capacity for the model between steel RC girder and the girder combined reinforcement with SMA and steel are also performed.

***Keywords*—**Shape memory alloy, bridge girder, ANSYS, load-deflection.

I. Introduction

BRIDGE is labeled as a lifeline structure of society. Cement concrete reinforced with steel bars is an extremely popular construction material but large numbers of concrete and masonry structures are deteriorated, or become unsafe due to changes in loading, configuration, changes in use, or environmental changing. Repair of these structures with is often difficult, expensive as the removal and transportation of large amounts of concrete causes concentrations of weight, dust, excessive noise, and requires long periods of time to gain its previous nature. The United States Federal Highway Administration reported that 31.4 % of United States' 582,000 bridges were structurally deficient or needed repair [1]. According to Hayes [2], bridges constructed in 1960's and 1970's were designed only for fourty to fifty years of service life and the cost of repair or retrofit for all deficient bridges are estimated to be around $50 billion, although only $5 billion is available in the budget for this purpose [2]. Not only in United States, some other countries like India, Japan and most of the countries in Europe are facing the same problem of repairing and renovation. Therefore, in the last two decades scientists and researchers are searching for new design concepts for a more dependable and cost effective bridges.

In recent years, advanced materials in the form of Superelastic (SE) Shape Memory Alloy (SMA) bar has been developed, which can undergo large inelastic deformations on loading and regain its original shape during removal of stressess, thus mitigating the problem of permanent deformation [3]. Structural applications of Superelastic Shape Memory Alloy bars as reinforcement in reinforced concrete sections may result significant changes in the behavior of concrete structures [4]. SMA bars can be used together with steel reinforcements to increase the load carrying capacity of the section [5] and greater economy can be achieved.

This paper presents a summary of the experimental and analytical study of longitudinal reinforcement concrete Tee-beam bridge girder model, and finite element study of the same bridge girder by replacing 25% of steel bars with SMA bars.

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II. Development of Model for Bridge Girder

Real type T-beam bridge longitudinal girder has been considered for analysis. Dimensions of the prototype and the model of the reinforced longitudinal girder is shown in Table I. Linear, slicing and cross-sectional scale factor are taken as 15, .079 and 1.185 respectively. A new girder was developed in this study in which 25% of steel reinforcement was replaced by SMA bars.

TABLE I
Dimensions of Prototype and Model

	Prototype	Model
Length(m)	15.00	1.0
Width(mm)	400	125
Depth(mm)	1400	250
Area of main steel (mm^2)	9695.08	201.06

TABLE II
Properties of Steel and Concrete

Yield stress of Steel	415
28- Day Compressive Strength of Concrete, fck (Mpa)	26.77

III. Experimental Study

Steel reinforced concrete (RC) girder was casted as per model dimension in Table I. HYSD steel flexural reinforcements were used of 4 Nos. -10 mm dia bars and shear reinforcements included 6 mm dia 2 legged stirrups. Cover for the rebar was set to 20 mm in all directions. The layout of the reinforcement configuration is as given in Fig. 1.

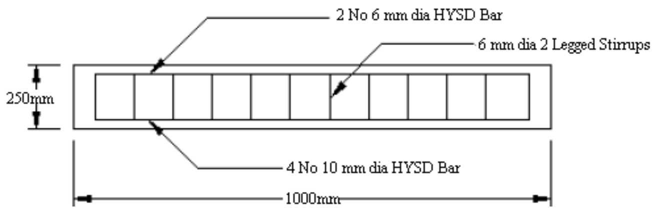

Fig. 1 Typical Detailing of the model girder

Fig. 2 Model steel reinforced bridge girder, after placing of concrete

A. Material and Mixes

Ordinary Portland cement was used throughout the study. The fine aggregate conforming to the medium zone [6] was washed with water to clean impurities present in the aggregate, and coarse aggregate was of 20 mm size crushed stone. Mix ratio used in the proportion of 1:1.24:3.7 alongwith water-cement ratio of 0.50. Casting of concrete mix was horizontally in the beam moulds and compacted by means of vibrator (Fig. 2). Curing period in complete immersion water was of for 28 days. Yield stress of steel reinforcement and 28-day's compressive strength of concrete are given in Table II.

IV. Finite Element Modeling Strategies

The FEA calibration study included modeling of a concrete beam with the dimensions and properties. 3D finite element model in ANSYS 11.0 [7] was performed with Graphical User Interface to create the model. Different types of elements are taken from ANSYS library. Table III summarizes the material and element types.

A. Modeling of Steel Reinforced Concrete Girder

A Solid65 element, of eight nodes with three degrees of freedom at each node was used for modeling of concrete which is capable of plastic deformation, cracking in three orthogonal directions and crushing. A Link8 element was used to model steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom [8]. In FE modeling, bridge girder was considered as volume. Length, width and depth were considered as 1000 mm X 120 mm X 250 mm as in Table I. Finite element model of beam is shown in Fig. 3.

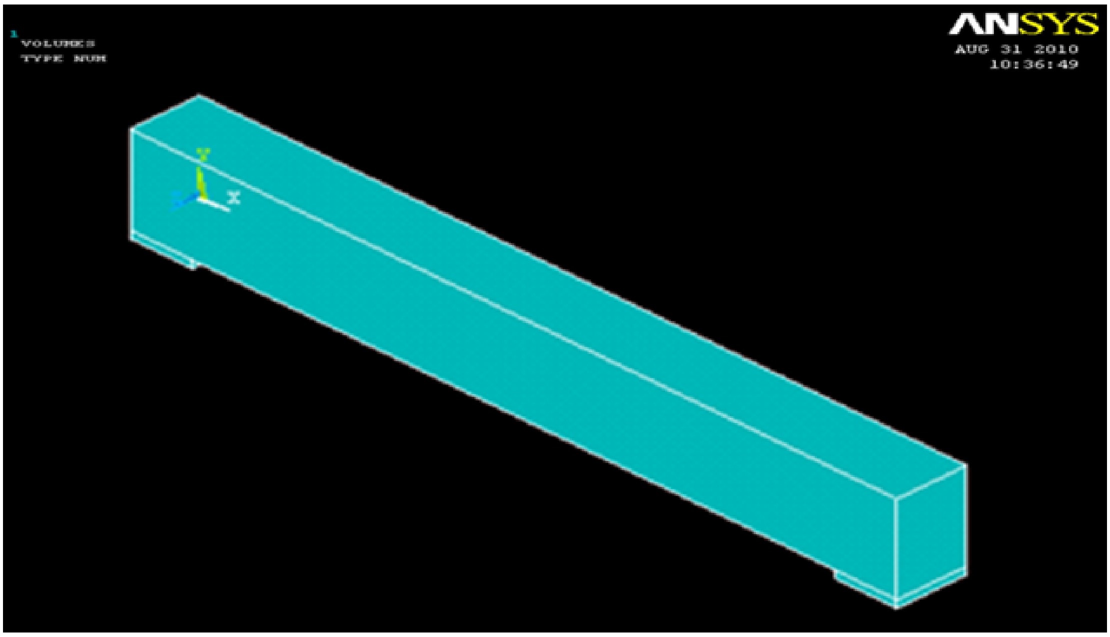

Fig. 3 Finite Element Model of girder

Link8 elements were used for flexural and shear reinforcement. Shear stirrups are modeled throughout the beam. Fig. 4 illustrates that rebars share the same nodes at the points of intersection with shear stirrups. For bonding, Combin 39 element was used. Supports were modeled as a roller support at one end and other end as a hinged support. Fig. 6 shows the loading and boundary condition of the beam. Two-point loading system is used for calculating mid-span deflection.

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B. Modeling of RC Girder Reinforcing with Steel and SMA Bars

In Fig. 5, 25% of steel bars were replaced by SMA bars and modeled with Link element keeping the total area of reinforcement same. Link1 element was used to model S.M.A bars. Material properties i.e. Modulus of Elasticity and Poisson's ratio of SMA bar was considered as 75GPa and 0.33 respectively as per Fanning [8]. All other steps are same described in Section IV A.

TABLE III
MATERIAL TYPES AND ELEMENT TYPES FOR F.E MODELING

Material Types	ANSYS Elements
Concrete	SOLID 65
Support	SOLID 45
Steel reinforcement (main r/f and stirrups)	LINK 8
Reinforcing SMA bars	LINK 1
Bond or No slip modeling	COMBIN 39

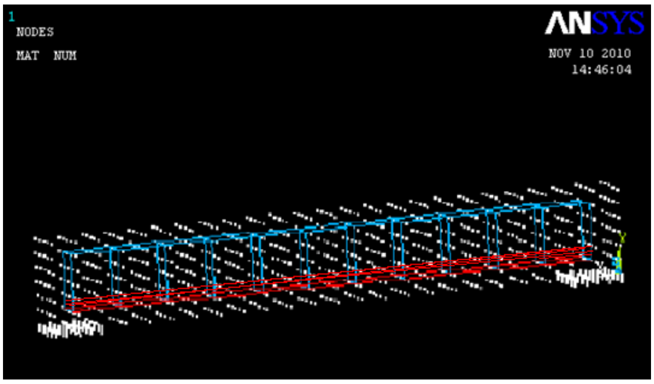

Fig. 4 Steel Reinforcement Configuration with Link 8 Element

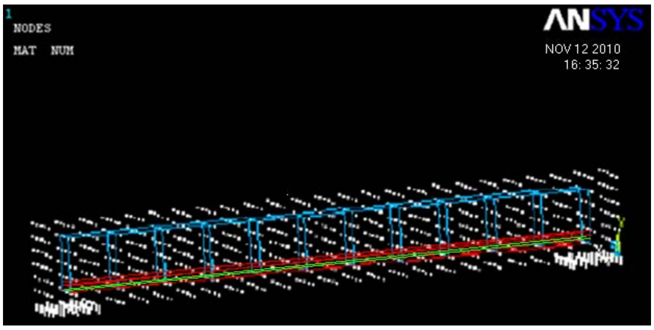

Fig. 5 Steel & SMA Reinforcement Configuration with Link 8 & Link 1 Element respectively

V. COMPARISON OF RESULTS AND DISCUSSION

The goal of the comparison of the FE model and the Experimental model is to ensure that the elements, material properties, real constants and convergence criteria are adequate to model the response of the member of different components that were analyzed for load deflection response.

A. Experimental Results of Steel RC Girder

The theoretical ultimate load for the beam was calculated as 54.20 kN. The experimental ultimate load determined was 68 kN. A plot of load versus deflection is shown in Fig. 8.

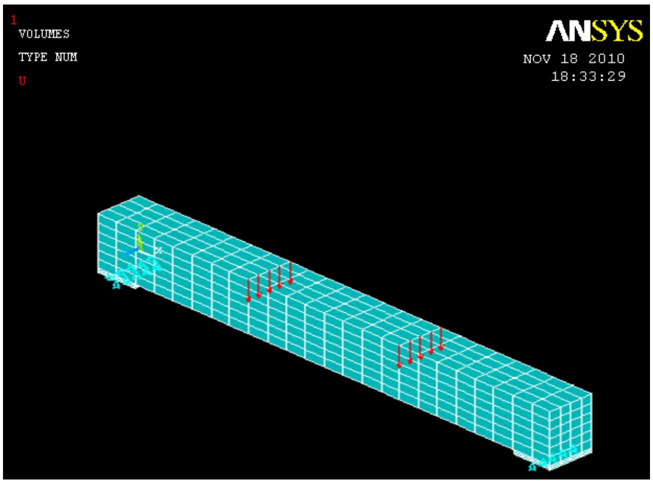

Fig. 6 Loading and Boundary condition

Experiment was done under two point loading system and the deflection at mid span at the ultimate load was found as 14.21 mm under. The test set up of the model girder in load frame is shown in Fig. 7.

B. FEA Results of Steel RC Girder

From FE prediction, the deflection at ultimate load was 14.02 mm. The full nonlinear load-deformation response can be seen in Fig. 8. This response was calibrated by setting the tolerances so that the load-deformation curve fits to the curve from experimental. Two-point loading system was used. The response calculated by using FEA is plotted with the experimental response. The entire load-deformation response of the model produced compares well with the response from experimental result.

Fig. 7 Arrangement for flexural testing in Load Frame

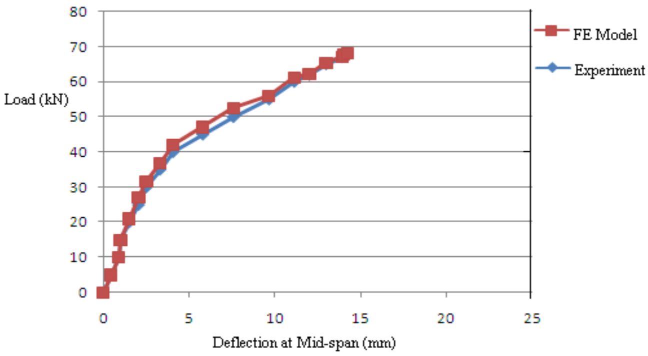

Fig. 8 Load-Deflection Curve from Experiment and ANSYS result (for Steel RC Girder only)

C. FEA Results of RC Girder Reinforced with Steel and SMA Bars

The comparison of load deflection curve for steel RC girder and the same bridge girder by replacing 25% of steel bars with SMA bars as main reinforcement are shown in Fig. 9. In this case it can be shown that the deflection is very less with compared to the girder reinforced only with steel. Here at load of 68 kN, deflection was 7.13 mm. The deflected shapes for both the girders in ANSYS are shown in Figs. 10 and 11. From Figs. 10 and 11, it is clear that deflection value at mid span is almost reduced half for the same loading condition in the case of girder replacing by 25% steel bars with SMA bars.

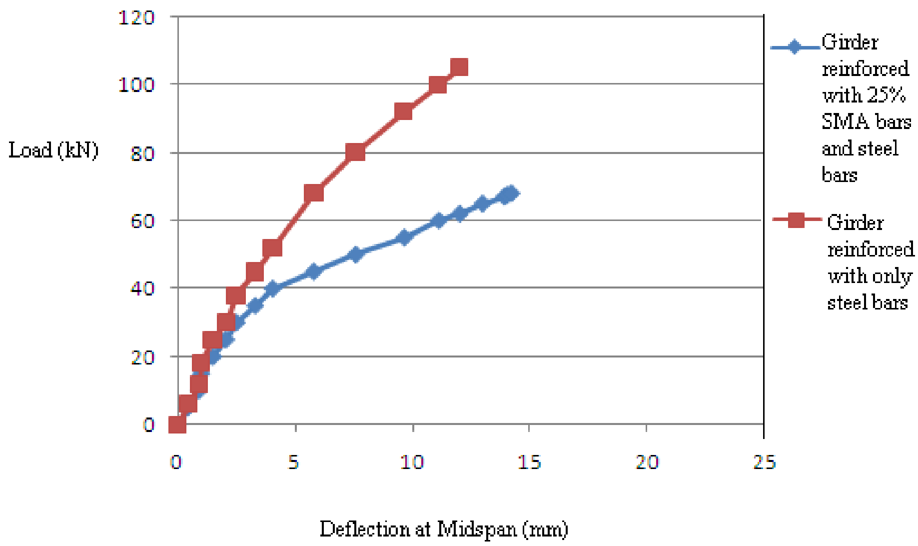

Fig. 9 Comparison of Load-Deflection Curve from ANSYS for steel RC girder and Girder replacing by 25% steel bars with SMA bars in main reinforcement

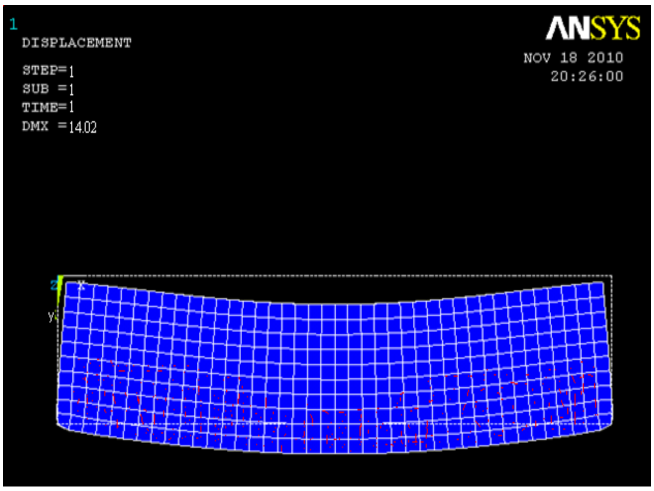

Fig. 10 Deflected shape of girder only with steel reinforcement (on loading of 68 kN)

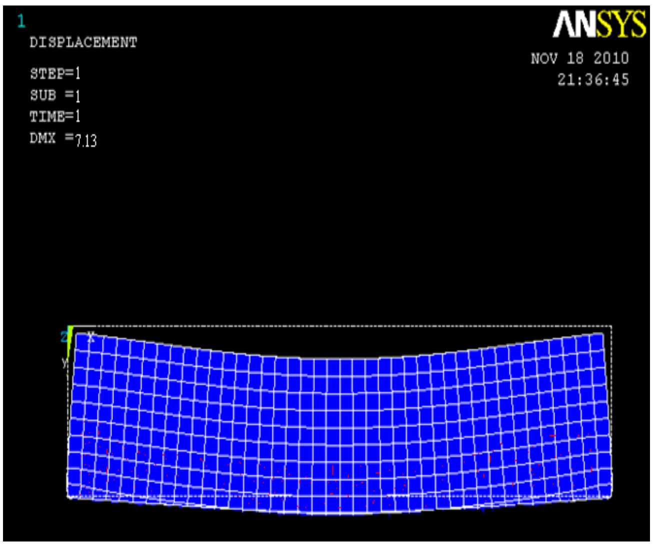

Fig. 11 Deflected shape of girder replacing of 25% steel bars with SMA bars (on Loading of 68kN)

VI. CONCLUSION

In this study, the failure mechanism of a RC girder is modeled quite well using FEA, and the prediction of failure load is almost similar to the failure load measured during experimental testing. The entire load-deformation response of the model matches very well with the response obtained from experimental result. It is observed that, partial use of shape memory alloy bars combining with steel reinforcement in RC bridge longitudinal girder increase its load carrying capacity very effectively and thus mitigates the problem of repairing due to deterioration of structure with time or any other changes in loading.

REFERENCES

[1] Anido, R.L., Troutman, and D.L., Busel, J.P., "Fabrication and Installation of Modular FRP Composite Bridge Deck," Proceedings of the 1998 International Composites Expo, Nashville, Tennessee, January 19-21, 1998, Session 4-A, pp. 1-6.

[2] Hayes, M.D., "Characterization and Modeling of a Fiber-Reinforced Polymeric Composite Structural Beam and Bridge Structure for Use in the Tom`s Creek Bridge Rehabilitation Project," M.S. Thesis in Engineering Mechanics, Virginia Polytechnic Institute and State University, Blacsburg, Virginia, 1998.

[3] M.S. Alam, M.A. Youssef, and M.Nehdi. "Analytical prediction of the behavior of superelastic SMA reinforced concrete elements", Engineering Structures 30(2008) pp. 3399-3411.

[4] Alam MS, Youssef MA, and Nehdi M. "Utilizing shape memory alloys to enhance the performance and safety of civil infrastructure: a review", Canadian Journal of Civil Engineering 2007, 34, pp. 1075- 1086.

[5] Saiidi MS, Zadeh MS, Ayoub C, and Itani A. "Pilot study of behavior of concrete beams reinforced with shape memory alloys", Journal of Materials in Civil Engineering, ASCE 2007, 19(6): pp. 454-461.

[6] Indian Standard Specification "IS: 456-2000 Plain and Reinforced Concrete – Code of Practice".

[7] ANSYS Manual Set, 2006, ANSYS Inc., Southpoint, 275 Technology Drive, Canonsburg, PA 15317, USA.

[8] Fanning, P., "Nonlinear Models of Reinforced and Post-tensioned Concrete Beams", Electronic Journal of Structural Engineering, Vol. 2, 2001, pp. 111-119.