SMAR 2017 – Fourth Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures

SMAR 2017

DEFLECTION OF SE-SMA REINFORCED CONCRETE BEAMS-COLUMN JOINTS

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ABSTRACT: A Finite element model is developed to study the structural behavior of reinforced concrete beam-column joints under a point load at a tip of the beam. The material used in this study is Superelastic Shape Memory Alloys (SE-SMAs) which contains nickel and titanium. Shape memory alloys (SMA) are a unique class of materials which have ability to undergo large deformation and also regain its undeformed shape by removal of stress or by heating. A two reinforced concrete beam-column joints were modeled, first beam-column joint (JBC-Steel) reinforced with only steel while the second beam-column joint (JBC-Steel-SMA) reinforced with steel in conjunction with SMA in the plastic hinge region of the beam. Finite element simulations are developed in order to reproduce the load-deflection behavior of reinforced concrete beams-column joints.

1 INTRODUCTION

Reinforced concrete structures are generally designed to support predefined sets of loads specified by design standards. But these structures are subjected to severe loading, it undergo permanent damage. For instance, under a severe earthquake, the reinforced concrete structure reinforced with steel would yield and permanent deformations are expected. Repairing damaged of reinforced concrete structures might not be feasible as, they may need to be demolished or replaced. Thus, there is a need for smart structures that can adjust to severe loading. Such structures can be made by using smart materials such as shape memory alloys (SMAs) (Alam et al. 2007; Alam et al. 2009).

SMAs are smart materials that can undergo large deformations and return to their undeformed shape upon unloading or by heating. Superelasticity, the shape memory effect, and the behaviour under cyclic loading are unique properties of SMAs which make them distinct from other metals and alloys (Janke et al. 2005). These unique properties can be utilized to achieve smart structures with properties that can adjust to the applied loading. The potential of using SMAs in civil engineering applications is increasing. These applications include using SMAs as prestressing tendons for concrete elements (Maji and Negret 1998; El-Tawil and Ortega-Rosales 2004), anchors for columns (Tamai et al. 2003), damping devices (Clark et al. 1995; Krumme et al. 1995), bridge restrainers (DesRoches and Delemont 2002), and primary reinforcement for concrete structures (Saiidi et al. 2007; Elbahy et al. 2009). Although many types of SMAs have been proposed, but superelastic nickel–titanium-based SMA (Ni–Ti SMA) was found to be the most appropriate for civil engineering applications.

The design of a structure should generally satisfy two basic criteria, namely strength and serviceability. The strength criterion allows the structure to safely support the design loads over its specified service life, and the serviceability requirements ensure satisfactory service life performance. The serviceability requirements include limits on allowable deflection, since excessive deflection is often perceived as failure. In addition, excessive deflection can lead to damage of nonstructural elements (Elbahy et al. 2010).

The aim of this paper is show the comparison in load-deflection behavior between Reinforced concrete beam-column joints reinforced with steel and reinforced concrete beam column joints partially reinforced with SMA. In this paper, the structural behavior of reinforced concrete (RC) beam-column joints under a point load at a tip of the beam has been numerically studied, using Finite Element Method. The material used in this study is Superelastic Shape Memory Alloys (SE-SMAs). In this study, two reinforced concrete beam-column joints were modeled in ANSYS, first beam-column joint (JBC-Steel) reinforced with only steel while the second beam-column joint (JBC-Steel-SMA) reinforced with steel in conjunction with SMA in the plastic hinge region of the beam. Finite element simulations are developed in order to reproduce the load-deflection behavior of reinforced concrete beams-column joints. The comparison results show that RC beams-column joint reinforced with steel in conjunction with SMA in the plastic hinge region of the beam show better improvement. Also, uniaxial JBC-Steel-SMA model able to reproduce the pseudo-elastic behavior.

2 DEVELOPMENT OF REINFORCED CONCRETE BEAM-COLUMN JOINTS MODEL

The elevation and cross sections of JBC-1 and JBC-2 are described in figure 1. The columns of the two joints have the same cross-section dimensions (250 mm x 400 mm) and reinforcement (four M20 longitudinal bars and M10 stirrups spaced at 80 mm in the joint region and 115 mm elsewhere). The beams of the two joints, JBC-1 and JBC-2, have similar cross-section dimensions (250 mm x400 mm) and amount of transverse reinforcement (M10 spaced at 80 mm in the plastic hinge region and 110 mm in the remaining length of the beam).

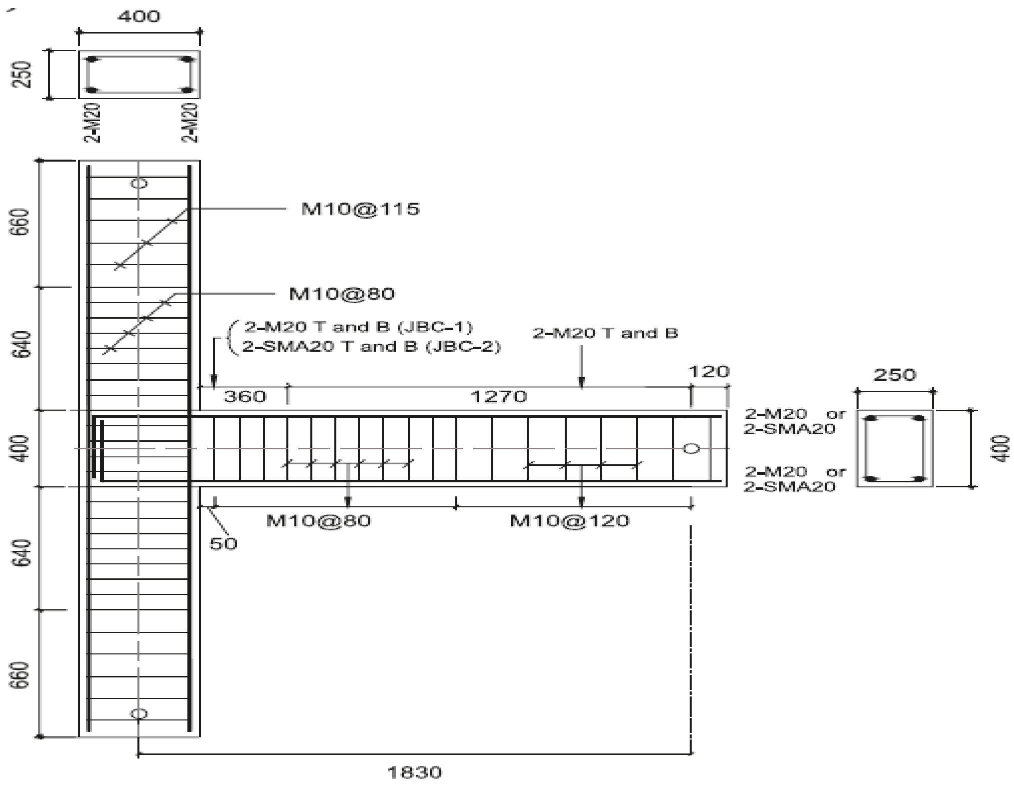

Figure 1: Reinforcement details of specimens JBC-1 and JBC-2 (all dimensions are in mm)

3 FINITE ELEMENT MODELING OF REINFORCED CONCRETE BEAM-COLUMN JOINTS MODEL

The FEA calibration study included modeling a concrete beam with the dimensions and properties. To create the 3D finite element model in ANSYS 15.0 there are multiple tasks that have to be completed for the model to run properly. Mechanical APDL was utilized to create the model, where APDL for ANSYS Parametric Design Language . Different types of elements are taken from ANSYS library. Table 1 and 2 summarizes the element type’s material types.

Table 1: Material properties used in the Finite Element Analysis.

MATERIAL	MECHANICAL PROPERTY	VALUE
Concrete	Compressive strength (MPa)	25
	Tensile strength (MPa)	2.5
	Strain at peak stress (%)	0.2
Steel	Modulus of elasticity (MPa)	200,000
	Yield strength (MPa)	415
	Strain hardening parameter (%)	0.5

Table 2: Material types and element types for finite element modeling

MATERIAL TYPES	ANSYS ELEMENTS
Concrete	Solid 65
Steel reinforcement	Solid 185
SMA reinforcement wires	Solid 185
Steel reinforcement for stirrups	Link 180

For steel-SMA reinforced concrete beam, SMA has been used in the plastic hinge region of the beam where the plastic hinge length has been calculated using different empirical equations as mentioned below

Empirical equations:

Empirical equations are used to estimate plastic length for a RC member. There are different types models are available. And these models are considered a proportional increase of Lp with an increase of member length, depth and longitudinal reinforcement dimensions. For instance, models proposed for estimating Lp by Sawyer 1964, Corley 1966, Mattock 1967, and Paulay and Priestley 1992 are presented in Eqs. (1) to (4), respectively.

1	Sawyer	$L_p = 0.075L + 0.25d$	(1)
2	Corley	$L_p = 0.5d + L/\sqrt{d}$	(2)
3	Mattock	$L_p = 0.05L + 0.5d_b$	(3)
4	Paulay and Priestley	$L_p = 0.08L + 0.022d_b f_y$	(4)

Where d represents the effective depth of the member in mm, db represents the bar diameter in mm, and fy is the yield strength of the rebar in MPa. The plastic hinge length has been calculated as per Paulay and Priestley [36] equation, and steel reinforcement has been used for the rest of the beam.

It is assumed that steel and SMA rebar are coupled together using mechanical anchorages/couplers (Oh BH and Kang Y 1987) . The fibre modelling approach (Sawyer 1964) has been employed to represent the distribution of material nonlinearity along the length and cross-sectional area of the member. The 3D reinforced concrete beam elements have been used for modelling the beam. Concrete has been represented using the mander et al. 1988 constitutive relationship and the cyclic response by martinez-rueda and elnashai 1997, and a bilinear kinematic strain hardening model is used for steel. SMA has been modeled according to the model of auricchio and sacco 1997.

4 MODELING OF STEEL REINFORCED CONCRETE BEAM-COLUMN JOINTS MODEL

The beam-column joint was modeled as volume. The model was 1920 mm long with a cross section of 250 × 400 mm and 3000 mm in height. As shown in figure 2.

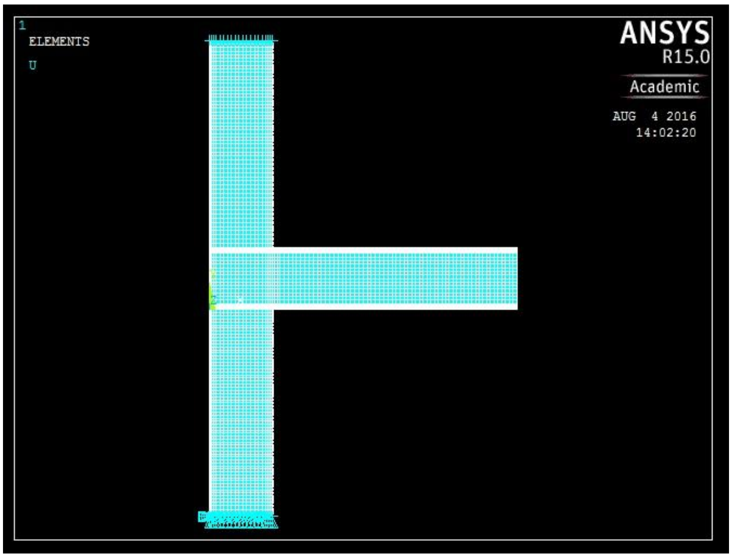

Figure 2: Volumes Created in ANSYS

A Solid65 element was used to model the concrete. This element has eight nodes with three degrees of freedom at each node. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. A Solid185 element was used to model steel reinforcement. This element has eight nodes with three degrees of freedom at each node. Solid185 elements were used to create the flexural reinforcement while Link180 elements were used for shear reinforcement. Shear stirrups are modeled throughout the beam. Fig. 3 illustrates that the rebar shares the same nodes at the points that it intersects the shear stirrups.

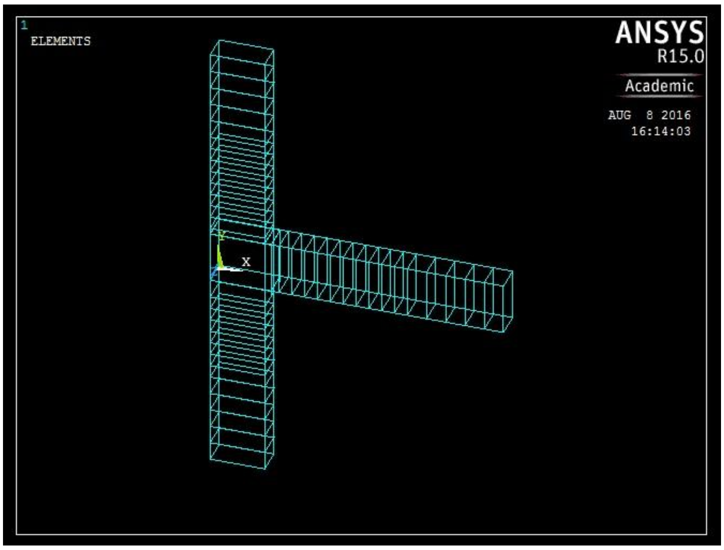

Figure 3: Reinforcement Configuration

To obtain good results from the Solid65 element, the use of a rectangular mesh is recommended. Solid185, embedded within the solid mesh. The inherent assumption is that there is full displacement compatibility between the reinforcement and the concrete and that no bond slippage occurs. Displacement boundary conditions are needed to constraint the model to get a unique solution. The bottom of the columns is hinged, roller support is used at the top of the columns, and a vertical downward point load "P" is applied at the beam tip as shown in Fig. 4.

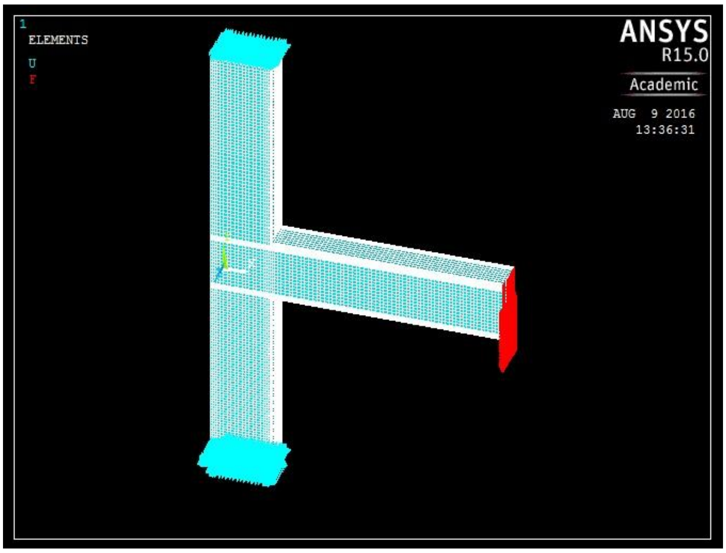

Figure 4: Loading and Boundary condition

5 MODELING OF BEAM-COLUMN JOINT REINFORCING WITH STEEL AND S.M.A BARS

Same approach was used to model this beam. But in case of JBC-2 a length of 360 mm of SMA bar was used at the critical portion of beam-column joints, while rest of the reinforcement was kept same as JBC-1. Solid185 element was used to model SMA bars. Material properties of S.M.A bar, i.e. modulus of elasticity and Poisson's ratio were taken as 60 GPa and 0.33 respectively. All other steps are same described for JBC-1. Material properties of S.M.A bar, is shown below in table 3.

Table 3: Material properties of Shape Memory Alloy bar

Material Model Number	Element Type	Material Properties	
1	Solid185	Linear Isotropic	
		EX	60,000 N/mm^2
		PRXY	0.3
		Shape memory alloy	
		SIG-SAS	520 N/mm^2
		SIG-FAS	600 N/mm^2
		SIG-SSA	300 N/mm^2
		SIG-FSA	200 N/mm^2
		Epsilon	0.07
		Alpha	0

6 RESULTS AND DISCUSSION

The goal of the comparison of the FE 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.

The comparison of load deflection curve for reinforced concrete beam-column joint reinforced with steel (JBC-1) and the same reinforced concrete beam-column joint reinforced with steel-SMA (JBC-2), where steel is partially replaced by SMA bar. The ultimate load taken by RC beam-column joints with traditional steel is 157 KN and shown deflection 60.9669 mm, while RC beam reinforced with Steel-SMA is 170 KN and deflection is 66.585mm. The load – deflection curve for both the beam-column joints in ANSYS are shown in Fig. 5. It is clear from the load deflection curve that the ultimate load carrying capacity of RC beam-column joint reinforced with steel-SMA is 8.280 % more than RC beam-column joint reinforced with traditional steel.

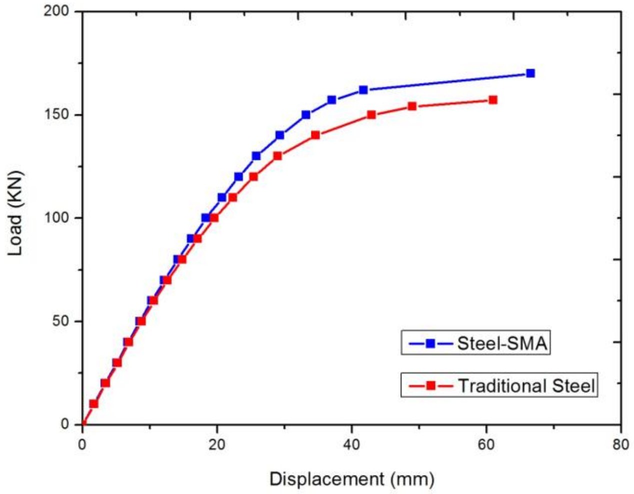

Figure 5: Load – Deflection curve of beam-column joints

Also, in the second case we can observe that the deflection is less compared to the steel reinforced beam-column joint (JBC-1). At load 157 KN, deflection of the beam-column joint by partially replacing steel with SMA bar are 37.0792 mm.

From, the in Fig. 5, it is clear that deflection value at mid span is almost reduced by 39.18% for the same loading condition in the case of beam-column joint by partially replacing steel bars with SMA bars.

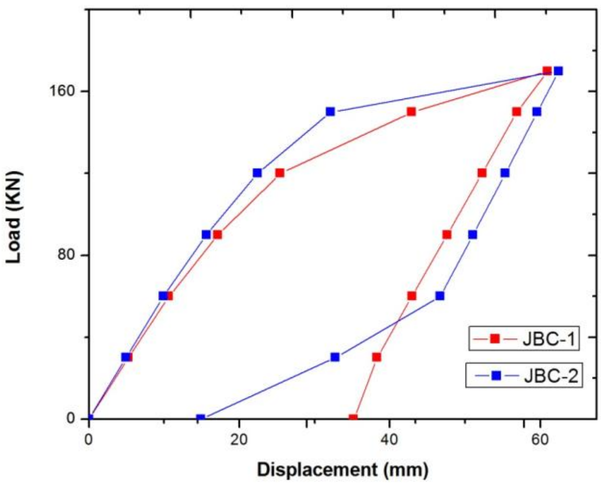

Figure 6: Numerical mid-span displacement versus load graph

Pseudo-elastic behavior is observed in Fig. 6 of JBC-2 while loading-unloading the structure. Thus the recovery is observed in reinforced concrete beam-column joints reinforced with steel in conjunction with SMA in the plastic hinge region of the beam compared to the reinforced beam-column joint (JBC-Steel) reinforced with only steel.

7 CONCLUSION

In this study, it is clear from the load-deflection curve that the ultimate load carrying capacity of RC beam-column joints reinforced with steel-SMA is 8.280% more than RC beam-column reinforced with traditional steel. A 39.18% of improvement is observed in deflection of beam-column joints reinforced with steel-SMA compared beam-column joints reinforced with steel. And also a pseudo-elastic behavior is observed in RC Beam-Column Joints reinforced with Steel-SMA. Thus, the partial reinforcement of SE- shape memory alloy bars with traditional steel in a reinforced concrete structure works effectively very well for civil structure.

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