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3-D Non Linear Finite Element Modeling of Exterior R.C Beam-Column Joint Partially Reinforced With Shape Memory Alloys (SMAs) and Existing of Transverse Beam

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ABSTRACT: The beam-column joint (BCJ) in reinforced concrete construction is considered to be the crucial zone in the reinforced concrete frame, as it is the critical element subjected to a complex state of forces during severe ground shaking. Its behavior has a significant influence on the response of the structure, namely with reference to its ductility and energy dissipating capability. This research focuses on studying the effect of using superelastic shape memory alloy (SMA), and a transverse beam (secondary beam) on the ductility of exterior reinforced concrete beam-column joints. Some of parameters controlling the ductility of joints are studied. Finite element analysis using ABAQUS is used to investigate the ductility behavior of exterior reinforced concrete joints. SMA is considered one of the methods to improve the ductility of exterior reinforced concrete joints at the plastic hinge zone, in this paper, SMAs with super-elastic effect are referred to as Nitinol SMAs is used which composition are Nickel-Titanium alloys (55.9% Ni and 44.1% Ti). In addition to add transverse beam. In this reasearch, the beam-column joint has a concrete compressive strength of 21 MPa. The concrete damage plasticity model (CDP) is used for concrete , while the bilinear model is used for steel. On the other hand, the real behavior of SMA, as studied in the literature review, is used for the modeling of SMA. In order to validate the model, numerical analysis is compared with the experimental work. The result showed that both SMA and the tranverse beam enhance the ductility of the joint effectively.

Key Words: Ductility, Shape Memory Alloy, Transverse Beam, Beam Column Joint, Finite Elements, Damage Plasticity Model

1 INTRODUCTION

Ductility is a vital characteristic property of structures which respond inelastically during severe loads, especially in reinforced concrete beam column joints. Ductility is defined as the ability of a structural element to deform inelastically without excessive loss due to degradation in stiffness or strength occurring abruptly. The most common sources of inelastic structural deformations are rotations in the potential plastic hinge zone. The energy dissipation mechanism should be chosen so that the desirable displacement ductility is achieved with the smallest rotation demands in the plastic hinges zone. The development of plastic hinges in frame columns is usually associated with very high rotation demand and may result in total structural instability. The transverse beam surrounding the joint and the level of axial load in the column, in addition to the use of highly elastic material as a reinforcement such as shape memory alloy, and the use of composite material as a strengthening technique, will clearly affect the ductility of the joint. For example, Abu Tahnat et al. (2018) studied the effect of using CFRP on the ductility of the BCJ. In his study, the study showed that the using of CFRP wraps around beam converts brittle failure to ductile failure. Halahla et al. (2014) and Rahman et al. (2014) investigated the effect of using CFRP on the performance of a beam column joint. They found that the CFRP sheets were warped diagonally around the joint, and the study showed the mode of failure of joint shift from shear joint failure to a flexural failure in the beam. Youssef et al. (2008) conducted experimental testing on two large-scale specimens of exterior reinforced concrete beam-column joints in order to investigate the effect of using a shape memory alloy bar on the ductility of the joint. The first specimen is reinforced with regular steel rebars (specimen JBC-1), while another one is reinforced with SMA bars at the plastic hinge region of the beam, with the regular steel bars in the rest portion of the joint (specimen JBC-2). The specimens were subjected to a constant axial load at column (3.5 MPa), and then they were tested under cyclic loading at the tip of the beam. The study shows the extent of the ductility increase for specimen which was reinforced with a shape memory alloy.

Finite element analysis (F.E.) is an efficient and economical technique for evaluation and investigation of the behavior of structural elements. Many researchers have used F.E. software to evaluate the behavior of R.C beam column joints (Santarsiero (2018), Shaaban and Said (2018), Najafgholipour et al. (2017) Eslami and Ronagh (2015)). Also, some researches studied the effect of using SMA at joint region such as Zafar and Andrawes (2012), they found that the frames with SMA–FRP composite reinforcement at joint region exhibit higher performance levels including lower residual inter-story drifts, high energy dissipation and thus lower damage, which are important for structures in highly seismic zones. Oudah and El-Hacha (2017) studied the performance of R.C joints using SMA bars anchored using screwlock steel anchors, results showed that the increasing the anchor depth in the joint led to increasing the post-cracking stiffness. Also, Alam et al. (2007) investigated the seismic performance of joints reinforced with superelastic SMAs compared to regular steel, the results showed that the joint with SMA was able to recover most of its post-yield deformation requiring minimum amount of repair even after a strong earthquake. However, numerical evaluation of the effect of using shape memory alloy bars for the plastic hinge zone for reinforced a concrete beam column joint and the effect of a transverse beam is conductted in this paper. The commercial F.E. software ABAQUS is used to conduct finite element modeling. The numerical results are validated with the experimental results obtained from Youssef et al. (2008).

2 FINITE ELEMENT MODELING

2.1. Geometry of Beam Column Joint

Youssef et al (2008) conducted an experimental test on two large-scale specimens of exterior reinforced concrete beam-column joints. These specimens had the same dimensions and reinforcement details as shown in Figure 1. The first specimen is reinforced with regular steel rebars (specimen JBC-1), while the other is reinforced with SMA bars at the plastic hinge region of the beam, with regular steel bars in the remaining portion of the joint (specimen JBC-2). The specimens were subjected to a constant axial load at column (3.5 MPa), and then they were tested under cyclic loading at the tip of the beam.

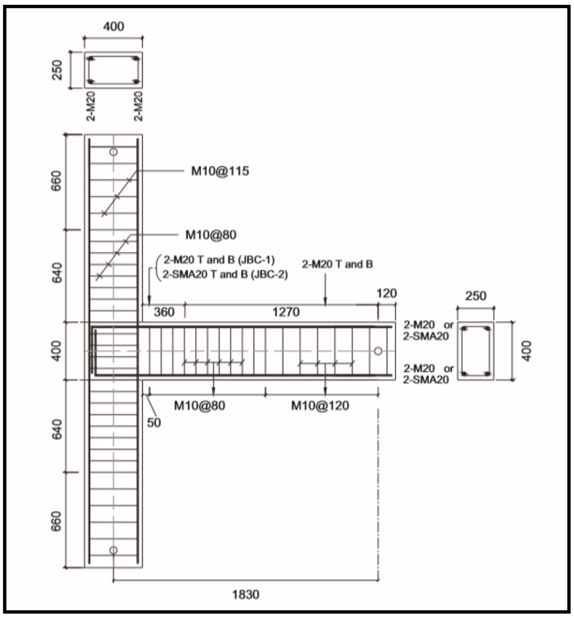


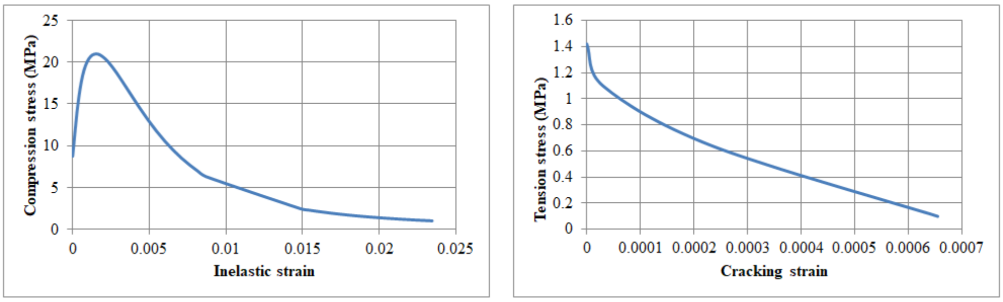
Figure 1. Dimensions and reinforcement details for the exterior reinforced concrete beam-column joints (Youssef et al. (2008))

2.2. *Materials*

The concrete damage-plasticity (CDP) model is utilized to simulate the complex compressive and tensile plastic behavior of concrete. This model consists of two main failure criteria: the tensile cracking and compressive crushing of the concrete. Moreover, the plasticity model adopts the yield function proposed by Lubliner et al. (1989) and modified by Lee and Fenves (1998), and follows a non-associated flow rule. The plastic model parameters associated with concrete are given in Table 1. The response of degraded concrete is presented by two independent uniaxial damage variables, dt and dc, which are assumed to be functions of the plastic strains. In this study, these parameters are calculated by using the equations which were developed by Jankowiak and Łodygowski (2005). The modulus of elastisity of concrete is 21538 MPa with poison ratio 0.2. Figure 2 shows the stress-strain curves and damage-strain curves of concrete which are used in the finite element model.

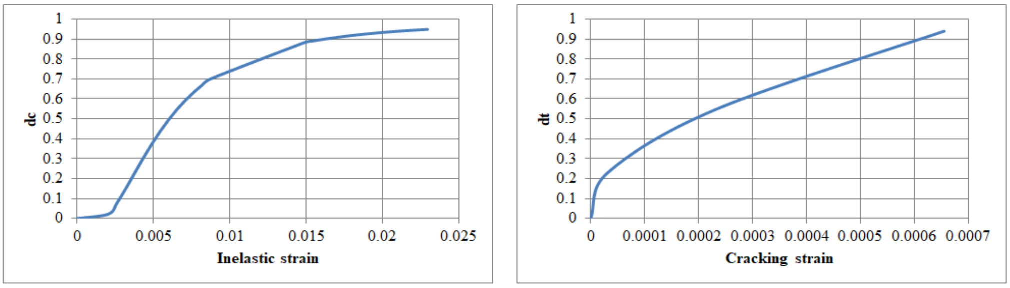
Table 1: Plastic model parameters of concrete

Parameter name	Value
Dilation angle (ψ)	36°
Eccentricity (e)	0.1
f_{b0}/f_{c0} (ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress	1.16
K (the ratio of the second stress invariant on the tensile meridian)	0.667
Viscosity Parameter	0



(a) Compressive stress vs. Inelastic strain

(b) Tensile stress vs. Cracking strain



(c) Compressive damage vs. Inelastic strain

(d) Tensile damage vs. Cracking strain strain

Figure 2. Definition of concrete damage-plasticity model parameters in ABAQUS used for parametric study

The most commonly used SMA is Nickel-Titanium alloys (55.9% Ni and 44.1% Ti). Its use is widespread due to its corrosion resistance, and stability in seismic applications while still displaying super-elasticity and shape memory effect. In this paper, SMAs with superelastic effect are referred to as Nitinol SMAs is used. For Steel reinforcements and SMA bars, these two materials are modeled using elastic model until yield strain while the isotropic plasticity model is used after yield strain up to failure. However, a general model is considerd for modeling steel reinforcement, also the actual behaviour of SMA, which was tested experimentally by Youssef et al. (2008) as shwon in Figure 3, is used to define SMA in ABAQUS. Figure 4 a and b show the stress inelastic strain for steel reinforcment and SMA, respectively.

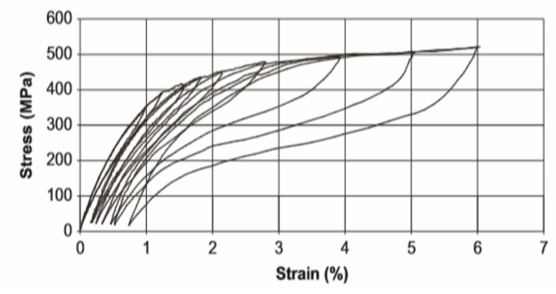
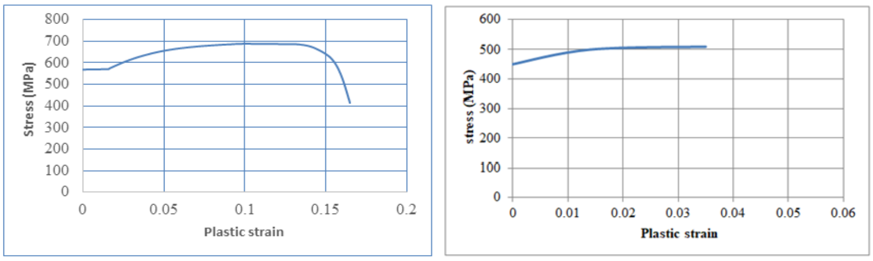


Figure 3. Experimental cyclic tensile strength of SMA rebars (Youssef et al. (2008))



(a) (b)

Figure 4. a) Stress-Plastic strain of Steel Reinforcement, b) Stress-Plastic strain of SMA.

2.3. *Load and boundary conditions*

The boundary conditions used in modeling are the same boundaries which were conducted experimentally by Youssef et al. (2008). The bottom end of the column is restrained in three directions (X, Y, Z) to behave as a pin support, while the top end is restrained in two directions (X, Z) to behave as a roller support.

Loads are simulated using static analysis method. The constant axial load (3.5 MPa) is initially applied at the top end of the column as reported by experimental tests. After that, monotonic displacement is applied at the tip of the beam to study the load-deflection curve when increasing the displacement. It should be noted that all boundaries, including loads, are not applied directly on the concrete. They are applied at the rigid plate to avoid any unwanted localized distortions which may occur at loading points.

2.4. *Element type and mesh*

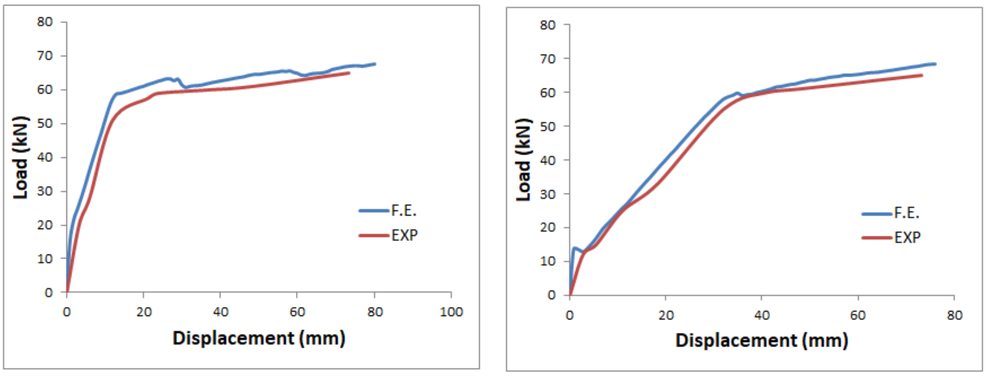
An eight-node linear brick element (C3D8R) is used to model the solid elements like concrete, whereas steel reinforcement and the SMA bars were modeled as a 2-node linear 3-D truss (T3D2). The accuracy of the results depends upon the finite element mesh, constitutive material model and the boundary conditions. Adequate attention has been paid to the development of hexa-dominated mesh and to assigning interaction between various surfaces. The components of a composite girder are meshed using a part-by-part basis instead of using global or sweep features. Thus a regular structured hex-dominated mesh is generated. Sensitivity study are conducted to eliminate the effect of mesh size on accuracy of results, Mesh size of 15mm is adapted for joint region while mesh size 30 mm is adapted for regions that are far away from the joint region.

3 FINITE ELEMENT RESULTS

The F.E. model is used to clarify the effect of the transeverse beam and the SMA bars on the ultimate capacity of BCJ and ductlity. In this section, the effect of the transeverse beam on the behavior of BCJ, along with the effect of using SMA bars in the joint zone of BCJ and the mode of failure, are investigated.

3.1 *Validation of results*

The F.E. results without a transverse beam are validated with the experimental results carried out by Youssef et al. (2008). The envelop of loops from cyclic load, which noticed form experimental work, are compared with monotonic load from F.E analysis. This method is used by Abu Tahnat et al. (2018) and showed a good result. Figure 5 a and b show the results of the verification. The model showed good agreement and capability to predict the behavior of BCJ including concrete and steel reinforcment.



(a) (b)

Figure 5. Comparison between experimental and numerical results for a) joint JBC-1, b) joint JBC-2

After conducting the verification for material and model. Exterior R.C joint with transverse beam is developed as shown in Figure 6.

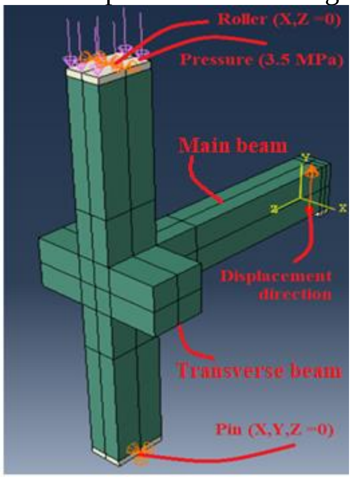
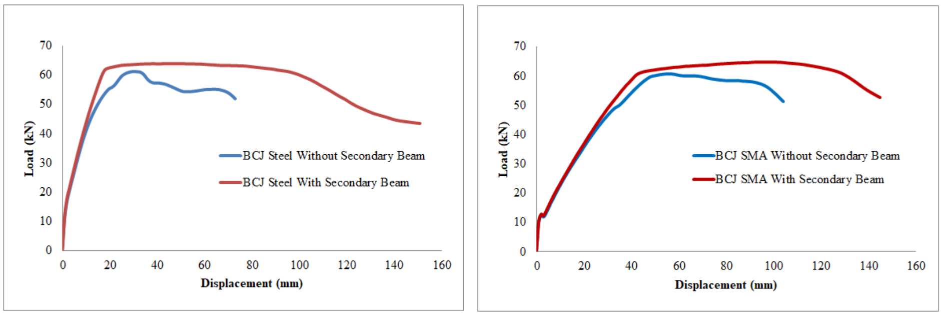


Figure 6. Geometry of exterior R.C joint with transverse beam, and boundary conditions

3.2 *Ultimate capacity of BCJ*

The F.E. results for BCJ, both with and without a transverse beam, and partially reinforced with SMA bars, are compared with the control sample, as shown in Figure 7 a and b. The use of a transverse beam for both joints improves the strength and stiffness of BCJ as compared to the control sample. The results show that, generally, when replacing steel rebars with SMA rebars at the plastic hinge region, the ductility (in terms of displacements) increases .On the other hand, the stiffness of the joints with steel rebars is larger than the joints with SMA rebars. This is attributed to the larger modulus of elasticity of steel compared with SMA rebars. However, there are no significant changes in the load capacity of joints when replacing steel bars with SMA bars. Figure 8 shows the tensile damage at the failure stage without a transverse beam, which indicates the crack propagation in the joint region. The damage distribution looks similar for steel and SMA reinforcement. BCJ with SMA bars shows higher displacement at failure stage. Figure 9 illustrates the tensile damage for the joints with a transverse beam. The results show that, at the failure stage, the transverse beam and the SMA reinforced joint always shows higher ductility and displacement compared with the steel reinforced joint.



(a)

(b)

Figure 7. a) Effect of transverse beam for BCJ with steel bars, b) Effect of transverse beam for BCJ with steel bars

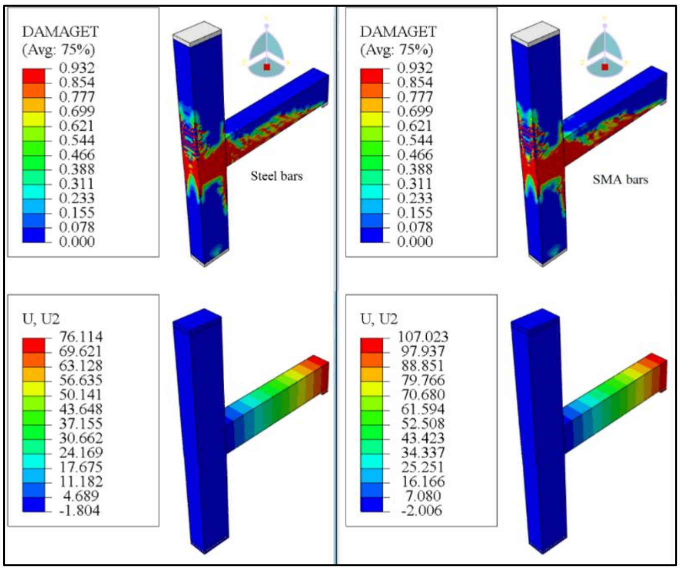


Figure 8. Tension damage for SMA and Steel before modelling transverse beams at failure stage

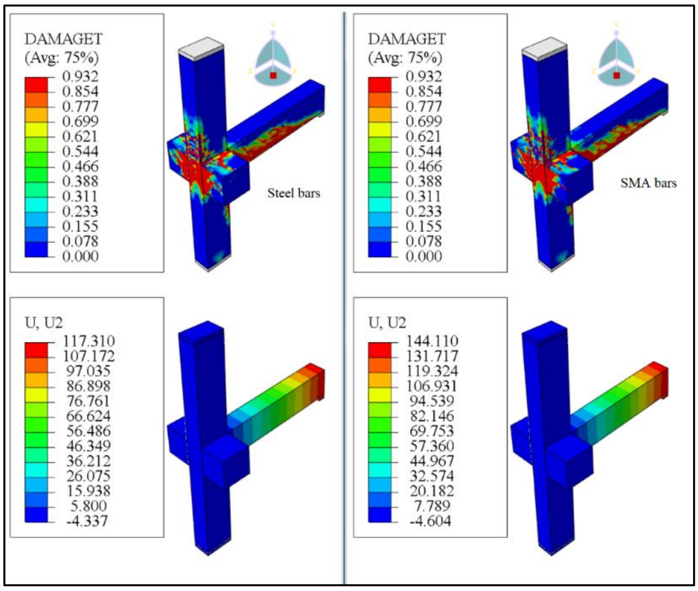


Figure 9. Tension damage for SMA and Steel after modelling transverse beams at failure stage

4 CONCLUSION

A three-dimensional finite element model of a reinforced concerete beam-column joint (BCJ) partially reinforced with shape memory alloys bars (SMA), including a transeverse beam, was developed. The F.E. model was used to calculate the effect of using SMA bars and a transeverse beam on the ultimate bearing capacity and the ductility of the joint. The result shows that the use of a transeverse beam for both joints improves the strength and stiffness of the BCJ as compared to the control sample. Also, the results show that, generally, when replacing steel rebars with SMA rebars at the plastic hinge region, the ductility (in terms of displacements) increases. On the other hand, the stiffness of the joints with steel rebars is larger than the joints with SMA rebars.

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