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Research Article

Numerical Modeling of Reinforced Concrete (RC) Specimen to Simulate Bond-Slip Behavior Using ABAQUS

Sana Shaukat*[1], Muhammad Fiaz Tahir [1]

[1] *Department of Civil Engineering /University of Engineering & Technology Taxila, Pakistan*

(sanashaukat99@gmail.com) Email of the corresponding author

https://orcid.org/0009-0005-7669-7451.

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***Abstract* –** This study presents a numerical modelling approach to investigate the bond-slip behavior of reinforced concrete (RC) specimens using the finite element analysis software ABAQUS. The paper outlines the modelling procedure and methodology employed to facilitate the analysis of the bond-slip interaction between concrete and steel reinforcement. In this study, a 10 mm steel rebar is embedded in a concrete block to simulate realistic reinforced concrete (RC) specimen behavior. Material properties for concrete grade 30, including both tension and compression behaviors as well as plasticity parameters, are carefully incorporated into the model to ensure a realistic simulation of material performance under load. The modelling approach utilizes an axisymmetric representation to reduce computational complexity while maintaining the accuracy necessary for reliable results. To accurately simulate bond-slip behavior, the Contact Cohesive Behavior (CCB) method is used. This method enables a detailed representation of the interaction between concrete and reinforcement, capturing the bond-slip mechanism that governs the transfer of stresses between the two materials. By simulating bond failure and the corresponding slip at the steel-concrete interface, this study provides insights into the effect of bond strength on overall structural behavior. The finite element model accurately replicates real-life pull-out test conditions, providing valuable data for predicting bond-slip behavior and improving the design of reinforced concrete structures.

Keywords –Contact Cohesive Behavior, ABAQUS, Bond-Slip Behavior, Reinforced Concrete, FEA.

I. INTRODUCTION

As a reinforced concrete structure is subjected to increasing loads, the stress at the interface between concrete and steel grow, eventually leading to a reduction in the interface's ability to transfer stress beyond certain load thresholds [1-3]. This deterioration gradually extends to the surrounding material [4]. As this process progresses, the stress transfer capacity of the interface significantly diminishes, resulting in notable displacements between the steel and concrete. Significant research efforts have been dedicated to understanding the key mechanisms involved in stress transfer between steel and concrete [5-8].

Numerous researchers have attempted to numerically simulate the key mechanisms of stress transfer between steel and concrete across various scales. However, while many of these models can effectively capture the phenomenon, they are often unsuitable for analyzing entire structures due to the significant computational demands they impose [9].

ABAQUS is a powerful finite element analysis (FEA) software widely used for simulating the bond-stress slip behavior in reinforced concrete, thanks to its advanced material modeling and customization capabilities [10]. Contact Cohesive Behavior is a modeling approach used to represent the interaction between two surfaces, accounting for the gradual degradation of bond strength under shear and normal stresses. It accurately captures the bond-slip relationship, making it ideal for simulating reinforced concrete behavior [10].

This research specifically focuses on the Contact Cohesive Behavior approach within the interaction module of ABAQUS to effectively simulate bond-stress slip behavior, while also detailing the other steps involved in modeling a reinforced concrete specimen.

II. MATERIALS AND METHOD

In ABAQUS, the step-by-step procedure for modeling a reinforced concrete (RC) specimen, as illustrated in Figure 1, is explained in detail below. This procedure outlines the necessary steps and considerations to accurately simulate the behavior of the RC specimen, including the definition of material properties, boundary conditions, and loading scenarios, which are essential for obtaining reliable results in bond strength analysis.

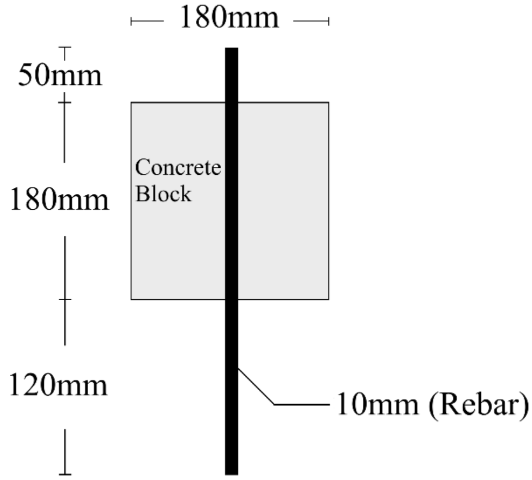

Figure 1: Specimen to be modelled in ABAQUS software

A. Part-Module

In the 'Part' module, we defined the geometry as shown in Figure 1, with the concrete block dimensions set to 180 mm x 180 mm and the rebar having a diameter of 10 mm. We selected the modelling space as 'axisymmetric' and set the type to 'deformable' for both the concrete and rebar.

B. Property-Module

Material properties are defined for the two parts created in the "Part" module. First, the material behaviour for concrete is specified under the "elastic" category, followed by the definition of plasticity within the "concrete damaged plasticity" model. This includes the "compressive behaviour" with "compression damage," where inelastic strain and yield stress values are used. Similarly, the "tension behaviour" with "tension damage" is defined using inelastic strain and yield stress values. Material properties for steel are also defined for the rebar, covering elastic properties, density, and plasticity. Table 1 [11] shows the parameters for steel while Table 2 [12] presents the material and plasticity parameters for concrete grade 30.

Table 1: Parameters for steel to be used in material manager

Bar Diameter (db)	**Modulus of Elasticity of Steel (Es)**	**Poisson ratio (ν)**
mm	**GPa**	
10	210	0.3

Table 2: Material properties for concrete grade C30

Concrete Material Parameters	C30	Parameters for plasticity	
Elasticity of Concrete		**Dilation Angle**	31
E(GPa)	26.6	Eccentricity	0.1
	0.2	fb0 / fc0	1.16
		K	0.6667
		Parameter of viscosity	0
Compressive behavior		**Compression damage**	
Yield Stress (MPa)	**Inelastic Strain**	**Damage Parameter C**	**Inelastic Strain**
15.30	0	0.0	0
19.20	4.82490E-05	0.0	4.8249E-05
22.50	00.000119844	0.0	0.000119844
25.20	00.000214786	0.0	0.000214786
27.30	00.000333074	0.0	0.000333074
28.80	00.000474708	0.0	0.000474708
29.70	0.000639689	0.0	0.0006396889
300	0.000828016	0.0	0.000828016
29.70	0.001039689	0.010	0.001039689
28.80	0.001274708	0.040	0.001274708
27.30	0.0015330171	0.090	0.001533074
25.20	0.001814786	0.160	0.0018147860
22.20	0.002119844	0.250	0.002119844
19.20	0.002448249	0.360	0.0024482490
15.30	0.0027	0.490	0.00280
10.80	0.003175095	0.640	0.003175097
5.70	0.00357354	0.810	0.003573541
Tensile behavior		**Tensile damage**	
Yield Stress (MPa)	**Cracking Strain**	**Damage Parameter T**	**Cracking Strain**
3	0.0	0	0.0
0.03	0.000943396	0.99	0.001167315

C. Assembly-Module

In the Assembly module, the parts created are positioned and assembled according to the configuration shown in Figure 1.

D. Step-Module

In the Step Manager, a static, general step is created. Meanwhile, in the Field Output Requests Manager, the following are generated:

- Bond failure with the variable CSDMG output variables
- Concrete damage with DAMAGEC, DAMAGET, and SDEG output variables
- Contact analysis with CDISP, CFORCE, CSTATUS, and DBS output variables
- Global_R with S and U output variables

In the History Output Requests Manager, the following are generated:

- Shear stresses with CSTRESS variables
- Slip measurement with U2 variables

E. Interaction-Module

A surface-to-surface contact interaction was employed to define the contact cohesive behaviour (CCB) for modelling the bond-slip, with rebar assigned as the master surface and concrete assigned as the slave surface with a smoothing degree of up to 0.2 for the master surface.

F. Load-Module

Boundary conditions are applied as follows:

- Axis of symmetry with type Symmetry/Antisymmetric/Encastre
- Fixed end of the rebar with type Displacement/Rotation, selecting U1 and U2
- Pull-upward force with type Displacement/Rotation, selecting U1 and U2, and a U2 value of 30

G. Mesh-Module

The ABAQUS Standard solver uses finite element sizes of 2.0 mm for the computations.

H. Job-Module

A job is created and submitted for analysis.

III. RESULTS

The analysis results obtained after the modelling procedure for the reinforced concrete specimen are shown in Figure 2 and Figure 3.

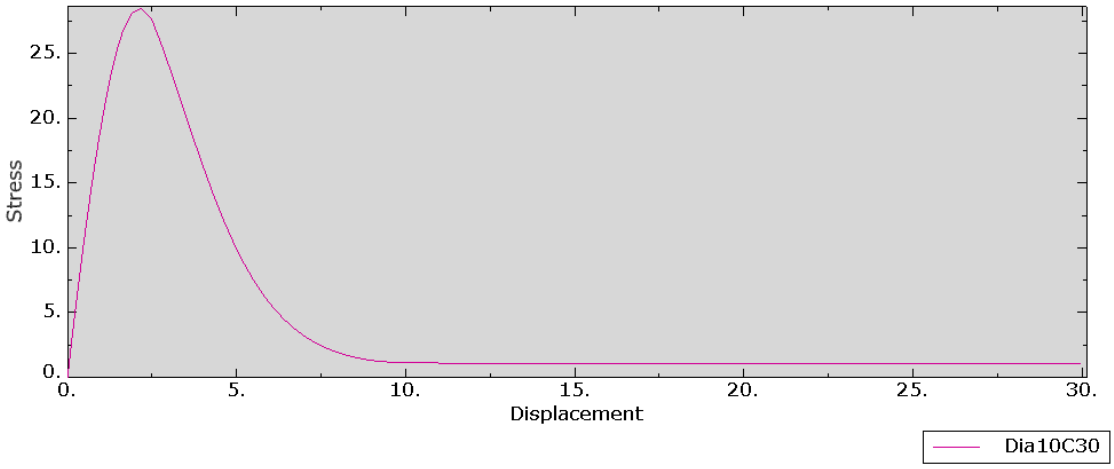

Figure 3: For C30 concrete, the bond stress-slip curve for 10 mm rebar

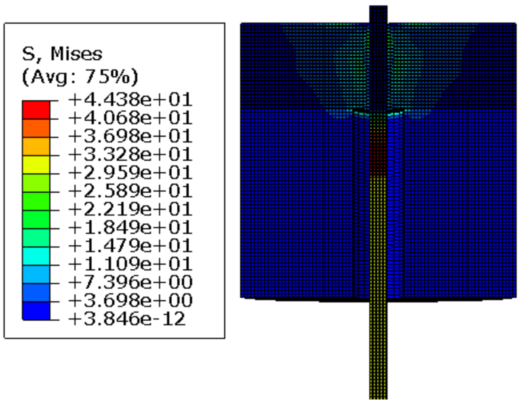

Figure 2: Deformed shape contours generated in ABAQUS after FEM simulations

IV. DISCUSSION

The results presented in the figures were obtained by following the modelling procedures outlined for concrete grade C30 and 10mm diameter rebar. Bond stress-slip is a critical parameter in reinforced concrete (RC) specimens, as it governs the interaction between the concrete and reinforcement, ensuring structural integrity and efficient load transfer. Accurately characterizing this behaviour is essential for predicting the performance of RC structures under various loading conditions. Numerical analysis plays a key role in studying bond stress-slip, as it provides detailed insights into the complex interactions at the concrete-reinforcement interface—interactions that are difficult to capture through experimental methods alone. The Contact Cohesive Behaviour (CCB) method effectively models this bond interaction at the concrete–reinforcement interface.

V. CONCLUSION

In this study, numerical analysis was conducted using ABAQUS, a finite element analysis software, to simulate bond behaviour. The study presents a step-by-step procedure that can be applied to components beyond the specimen used in this research, enabling the generation of bond stress-slip curves and deformation contours using the same software.

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