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Numerical Analysis on the Effect of Bar Diameter on Bond Stress-Slip Behavior in ABAQUS

Sana Shaukat[*1]

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

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

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Abstract **–** This paper presents a numerical analysis on the effect of changing the rebar diameter on bond stress-slip mechanism in reinforced concrete specimen. The aim is to develop a validated FEM model in ABAQUS and to observe the effect of different diameters (10mm,12mm, and 16mm) through it. There are many studies which show contradictory results in case of increasing the bar diameter as according to some researchers, increase in bar diameter increased the bond strength as it can bear higher forces meanwhile other suggested that higher the bar diameter, lesser will be the interlocking with the concrete surface. The results presented in this paper show that with an increase in the bar diameter the bond strength values decreased. Moreover, 10mm and 12mm rebars showed a pull-out failure meanwhile 16mm rebar showed a splitting behavior. The Contact Cohesive Behavior (CCB) technique, which replicates the bond stress-slip behavior in reinforced concrete, is used to study the concrete-rebar interface. Furthermore, the Concrete Damaged Plasticity Model (CDPM) is used to model the nonlinear behavior of concrete. The method used to model the ribbed rebar interface doesn't involve modeling the rebar's ribs, but another method is utilized which is to model a plain bar specimen which is connected to the concrete by elements with specific properties to simulate the bond interface efficiently. The FEA models adequately represent the pull-out test simulations which are later compared to results of experimental results of pull-out tests from another research to prove the validity of the numerical simulations.

Keywords – Bond-Slip Behavior, ABAQUS, FEM, Ribbed Reinforcing Bar, Bond Strength

I. INTRODUCTION

Bond-slip is a complex phenomenon affecting coordinated deformation and load-bearing capacity due to the interaction between rebar and concrete. The rebars significantly distort because of this process, damaging the nearby concrete [1]. While the main factor of bond strength in concrete is its compressive strength, the geometry, form, and orientation of the reinforcement bars are also significant factors [2]. It has been discovered that deformed steel bars are two to ten times stronger than plain or smooth bars. This is because the ribs on deformed bars create an interlocking mechanism that improves the bond interaction [3-5]. The rebar's diameter and size have a major effect on the concrete's bond strength. Numerous investigations have demonstrated that the bar's diameter can affect bond strength in both favorable and unfavorable ways. Multiple studies have established that the bond strength with the concrete surface decreases as the bar diameter increases [6-10]. However, some studies have produced contradictory results, indicating that an increase in bar diameter can enhance bond strength. This improvement is attributed to the larger bars' ability to withstand higher forces, which may compensate for any potential reduction in bond efficiency at the concrete interface [11, 12].

II. MATERIALS AND METHOD

In ABAQUS, a two-dimensional axisymmetric model is created for a concrete block with embedded ribbed rebar. The concrete cube has dimensions of 160mm x 160mm, and the diameters of the bars used are 10mm, 12mm, and 16mm. After creating the model, finite element simulations are performed to replicate the pull-out test results. Table 1 shows the material and plasticity parameters for concrete grade 40, covering both tension and compression behavior, in accordance with the concrete damage plasticity (CDP) model documentation[13]. For the bar diameter, we assumed a linear stress-strain relationship in the material model for reinforcing steel[14]. Table 2 displays the parameters that were used. Surface-to-surface contact interaction was used to establish contact cohesive behavior (CCB) in order to model the bond-slip. A type of finite elements with four nodes called the bilinear axisymmetric quadrilateral (CAX4) was used to discretize the rebar and the concrete block. Using the ABAQUS Standard solver, three finite element sizes—1.0 mm, 2.0 mm, and 4.0 mm—are utilized for computations

Table 1: Material properties for concrete with CDP model for grade C40

Concrete Material Parameters	**C40**	**Parameters for plasticity**	
Elasticity of Concrete		**Dilation Angle**	31
E(GPa)	30	Eccentricity	0.1
	0.2	fb0 / fc0	1.16
		K	0.67
		Parameter of viscosity	0
Compressive behavior		**Compression damage**	
Yield Stress (MPa)	**Inelastic Strain**	**Damage Parameter C**	**Inelastic Strain**
20.4	0.0	0.0	0.0
25.6	2.66667E-05	0.0	2.66667E-05
30.0	0.00008	0.0	0.00008
33.6	0.00016	0.0	0.00016
36.4	0.000266667	0.0	0.000266667
38.4	0.0004	0.0	0.0004
39.6	0.00056	0.0	0.00056
40.0	0.000746667	0.0	0.000746667
39.6	0.00096	0.01	0.00096
38.4	0.0012	0.04	0.0012
36.4	0.001466667	0.09	0.001466667
33.6	0.00176	0.16	0.00176
30.0	0.00208	0.25	0.00208
25.6	0.002426667	0.36	0.002426667
20.4	0.0028	0.49	0.0028
14.4	0.0032	0.64	0.0032
7.6	0.003626667	0.81	0.003626667
Tensile behavior		**Tensile damage**	
Yield Stress (MPa)	**Cracking Strain**	**Damage Parameter T**	**Cracking Strain**
4.0	0.0	0.0	0.0
0.04	0.001333333	0.99	0.001333333

Table 2: Parameters for steel in numerical simulations

Bar Diameter (db)	**Bond Length (lb)**	**Bar Cover (c)**	**Modulus of Elasticity of Steel (Es)**	**Poisson ratio (ν)**
Mm	**mm**	**mm**	**GPa**	
10	50	75	210	0.3
12	60	74	209	0.3
16	80	72	214	0.3

III. RESULTS

The outcomes of the numerical simulations for pull-out tests on concrete grade C40 with three distinct bar diameters are displayed in Figure 1.

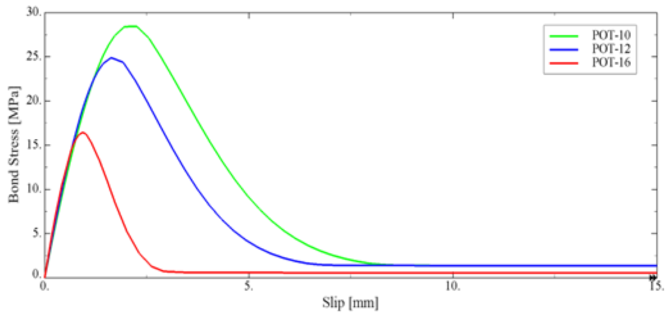

Figure 1: Comparison of Numerical Simulation Curves for 10mm, 12mm, and 16mm Rebars

Additionally, the experimental results from [11] for pull-out studies utilizing three distinct bar diameters (10mm, 12mm, and 16mm) for concrete grade C40 are shown below in Figure 2.

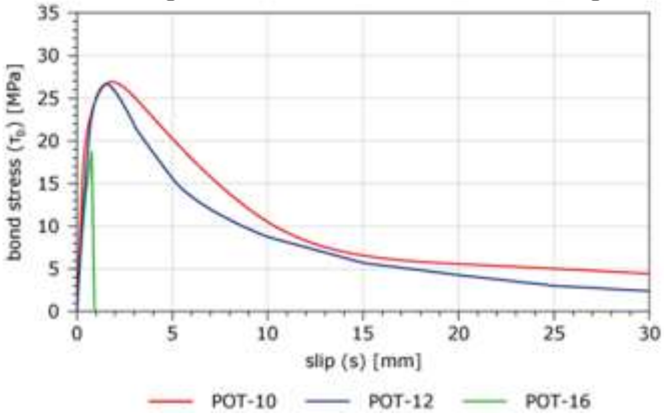

Figure 2: Comparison of Experimental Pull-Out Test Curves for 10mm, 12mm, and 16mm Rebars

A comparison of the experimental and numerical results is shown in Table 3 and Figure 3

Table 3: Comparison of Numerical and Experimental Max Bond Stress Values for Rebars

Diameter of Rebar	**Experimental Results**	**Numerical Results**
	Max Bond Stress (MPa)	
10	25.12	28.45
12	25.22	24.73
16	16.71	16.44

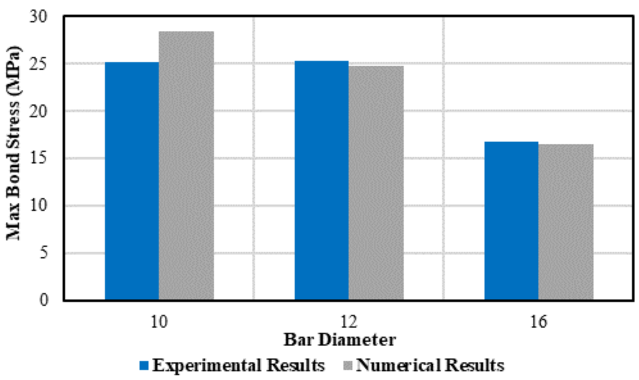

Figure 3: Numerical and Experimental Max Bond Stress Comparison for Rebars

IV. DISCUSSION

To validate the FEM model results created in ABAQUS for rebar diameters of 10mm, 12mm, and 16mm in concrete grade C40, experimental results (Figure 2) from M. Burdziński and M. Niedostatkiewicz were referenced. These experiments involved the same rebar diameters in C35/45 grade concrete for a 160x160mm concrete block. Comparing these with numerical simulations results (Figure 1) shows that the 16mm bar exhibits splitting failure, while the 10mm and 12mm bars show pull-out failure. The accuracy of the numerical model is confirmed by the close match between the experimental data and the numerical simulations, as shown in Table 3 and Figure 3.

V. CONCLUSION

In conclusion, the bond between the rebars and the surrounding concreate weakens as the diameter decreases which is indicated by the decrease in bond strength. Bars with diameters of 10 mm and 12 mm exhibit pull-out failures, signifying tension failure of the bars with no corresponding failure in the surrounding concrete, whereas the 16 mm bar demonstrates splitting failure due to the concrete cracking and splitting due to high localized stresses.

ACKNOWLEDGMENT

The experimental results for pull-out tests from the research by M. Burdziński and M. Niedostatkiewicz, titled “Experimental-Numerical Analysis of the Effect of Bar Diameter on Bond in Pull-Out Test,” was utilized for validating the numerical simulations carried out in ABAQUS in this study.

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