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NUMERICAL MODELING OF APPLIED NEAR-SURFACE MOUNTED ON REINFORCEMENT SLAB WITH ABAQUS CAE

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Abstract: Reinforced concrete (RC) is the most applied material in modern construction. Research on strengthening RC concrete members has also been widely carried out. Over time, concrete elements might deteriorate due to several factors, such as load, creep, or any other environmental aspects, leading to stiffness or strength reduction. Following the rapid development of studies on RC, the development of strengthening of concrete structure Reinforced Polymer (FRP) is also the case to overcome concrete deterioration. To improve the strength capacity of the concrete beams, Ega (2020) investigated the effect of epoxy adhesive length on the bonding strength of rebar using several laboratory tests. The result of the study yielded that the optimum length for the epoxy was 150 mm with a strength increase of up to 165.3%. The laboratory tests were modeled numerically using Abaqus CAE to simulate the behavior of the RC beam. Investigating the ideal mesh size and crack model behavior was the first stage of modeling. An RC beam previously experimentally tested by Ega (2020) was used for validation. Therefore, this research compares the numerical results from the Abaqus simulation with experimental data results. The specimen tested for this research was a concrete beam of 1200 mm x 450 mm x 120 mm subjected to 3-point loading. This study aims to develop a suitable numerical model for one of the tested beams and facilitate the design of NSM that follows the character of the previous research.

Keywords: Abaqus, near-surface mounted, reinforced concrete, numerical modeling, mesh convergence

INTRODUCTION

Reinforced concrete (RC) is one of the most applied materials in modern construction. According to Cusatis et al. (2015), concrete structures can also undergo deterioration caused by several factors caused by several chemical and physical phenomena. Research on strengthening RC concrete members has also been widely carried out. One of the well-known strengthening concrete structure methods is Fiber Reinforced Polymer (FRP).

Another popular method among many strengthening methods is Near-surface Mounted (NSM) method. It provides external steel reinforcement to the concrete surface and offers a reasonable price. This research observes the finite element side of the experiment. Ega (2020) investigated the effect of the epoxy adhesives lengths on the bond strength of rebar using several laboratory tests. The result of the optimum length for the epoxy was 150 mm. This study conducted a numerical analysis to obtain an appropriate finite element model for those retrofitting methods.

Concrete as a material has very complex characteristics, so non-linear modeling is required. In Abaqus non-linear material of concrete can be modeled with the concrete damaged plasticity model. The concrete model considers the isotropic crack and crack conditions resulting from the compressive and tensile forces. Mesh size is determined by its convergence. Model validation will be compared with the results of Ega's research (2020).

LITERATURE REVIEW

Rebar adhesion strength

Adhesion strength is the ability provided by the reinforcing steel and the concrete covering it to withstand the forces that cause the bond between steel and concrete to break (Winter & Nilson, 1993). Figure 1 shows the rebar adhesive interaction with concrete in general.

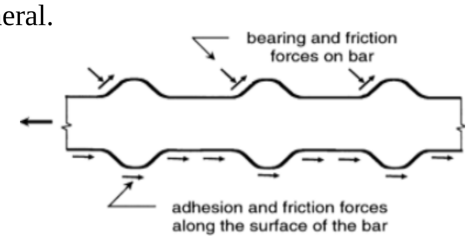

Figure 1. Adhesion on rebar (ACI committee, 2016)

Near-surface mounted

In the research report of Soliman et al. (2011), the definition of the Near-surface Mounted (NSM) method obtained from previous research is described, namely a structural reinforcement method by attaching external reinforcement to a concrete blanket, so that the risks of damage to the reinforcement can be overcome. Figure 2 shows some of NSM's practical applications.

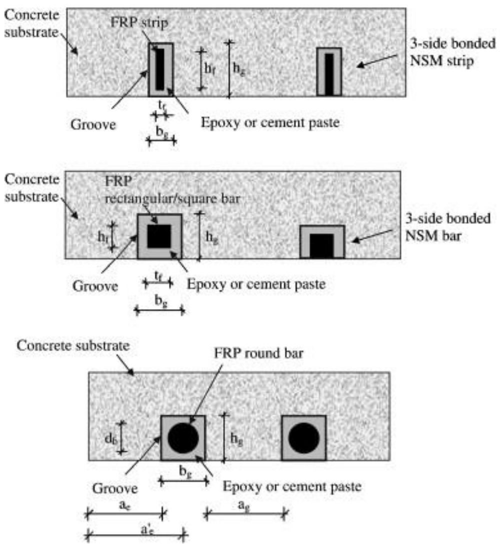

Figure 2. Near-surface mounted application option (L. De Lorenzis, 2007)

Lorenzis et al. (2000) described the history of using this method, namely when Asplund 1949 reinforced concrete bridges in Sweden. An increase in the capacity of the negative moment is required for this bridge, considering that there was a massive decrease during construction. Reinforcement is done by making a groove with a certain depth on the bridge's surface, and then embedding reinforcing steel into the groove with cement mortar adhesive (Lorenzis et al., 2007).

Bond strength

Bond strength is the shear stress that occurs on the surface of steel and concrete reinforcement, where there is a transfer of force/load between the reinforcement and the surrounding concrete, which can increase the stress on the steel (Park & Paulay, 1974). In screw reinforcement, there is a significant increase in bonding capacity due to the interlocking of the screw and concrete.

There are 3 stress components that contribute to the bond strength between the two parts of the reinforcing thread (Figure 3), as follows:

1. Shear stress v_a, due to adhesion along with the reinforcement.
2. Bearing stress f_b, on the face of the thread.
3. Shear stress v_c, which acts on the concrete surface between 2 adjacent threads.

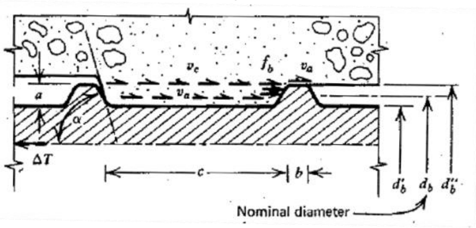

Figure 3. Bond strength on rebar (Park & Paulay, 1974)

Bond transfer mechanism on Rebar

Wight and MacGregor (2012) describe the bond transfer mechanism in reinforcement and concrete. When the threaded reinforcement is loaded for the first time, adhesion and friction occur. However, this attachment transfer mechanism is lost immediately, leaving the attachment transferred by the bearing force to the threaded portion of the reinforcement (Figure 4a.). The same bearing stress but in the opposite direction occurs in the concrete around the reinforcement (Figure 4b). The forces on the concrete have longitudinal and radial components, as shown in Figures 4c and 4d.

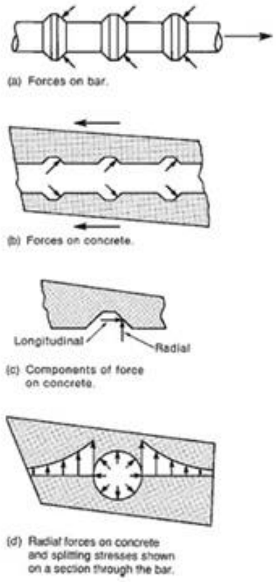

Figure 4. Bond transfer mechanism (Wight & Mac Gregor, 2012)

As these cracks expand, the attachment transfer decreases rapidly unless reinforcement is provided to resist the opening from the crack splitting. The load when the splitting failure occurs is a function of the minimum distance from the reinforcement to the concrete surface or the adjacent reinforcement, the tensile strength of the concrete, and the average adhesion strength. If the concrete cover and the space between the reinforcement are more significant than the diameter of the reinforcement, then there will be a pull-out failure.

Distribution length

The distribution length l_d, is the minimum length of the reinforcement at which the stress on the reinforcement can increase from zero to reach its yield strength, f_y (Wight and MacGregor, 2012). If the distance from the point where the reinforcing stress is equal to the end of the reinforcement is less than the length of the reinforcement, then the reinforcement will come off the concrete.

RESEARCH METHOD

This research was conducted at the Computing Laboratory of the Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada.

Material

The material used has the properties shown in Table 1 as follows.

Table 1. Material properties

Material	$f_{c'}$ *(MPa)*	f_y *(MPa)*	f_u *(MPa)*	ρ *(kN/m3)*
Concrete	21.95	-	-	2400
D10 rebar	-	485.806	685.685	7850
D13 rebar	-	487.412	648.724	7850
Epoxy	-	-	-	3600

The factors of concrete damage plasticity are shown in table 2 as follows.

Table 2. Concrete damage plasticity

Material	Dilation Angle	Eccentricity	f_{b0}/f_{c0}	K	Viscosity Parameter
Concrete	30	0.1	1.16	0.67	0.0001

Experimental beam and finite element model

The experimental beam that was used as comparative data is from Ega's (2020) experiment. One reinforced concrete beam with a span of 1400 mm was subjected to flexural loading. There was one concentrated load placed right in the middle of the beam. The beam was 1400 mm long and the dimensions of the beam section were 450 × 120 mm. The longitudinal reinforcement is shown in figure 6a and 6b. The beam has no shear reinforcement, this reinforced concrete beam was fabricated and tested at the Structural Laboratorium of Universitas Gadjah Mada. This paper considers the behavior of the reinforced concrete beam and the similar behaviour of the finite element model with its ideal mesh size. The finite element model was shown in Figure 7.

Modeling scenario

Finite element simulation was carried out using Abaqus CAE 6.14. One of the important steps in the numerical modeling process is to determine the ideal meshing system. The mesh size is obtained from the mesh convergence test. A mesh convergence test is done by making a linear beam model. The linear model is given a specific compressive load. The results of the deflection of the compressive load are compared with the manual calculation of the deflection of the beam. The difference in deflection is influenced by the variation of the mesh size. The best mesh size is obtained from the deflection value closest to the analytical results. The mesh size will be used for plastic modeling. The results of the meshed model are shown in Figure 8.

Concrete material is modeled with elastic and plastic parameters. The elastic parameter consists of young's modulus and material density. The concrete Damage Plasticity parameter is applied as a plastic model on the Abaqus property module. Ideally, the rebar bond is modeled in 3D with the bond-slip parameter. In this study, the rebar bond is simplified as a perfect bond.

Concrete and Epoxy are modeled as homogenous solids with mesh configured as 3D 8-noded hexahedral (brick) elements with reduced integration (C3D8R), while rebar is modeled as a truss element. In this research, C3D8R gives nearly similar results to the non-reduced integration one and increases the computational efficiency. The plastic model with NSM reinforcement is shown in Figure 9.

A deflection load is applied to the beam. The value of the deflection load given is by the experimental test of Ega (2020). The model is loaded until it collapses. After the beam collapses, the results of the collapsed beam are compared with the experimental failure. The observed outputs are reaction force, crack pattern, stress, and displacement.

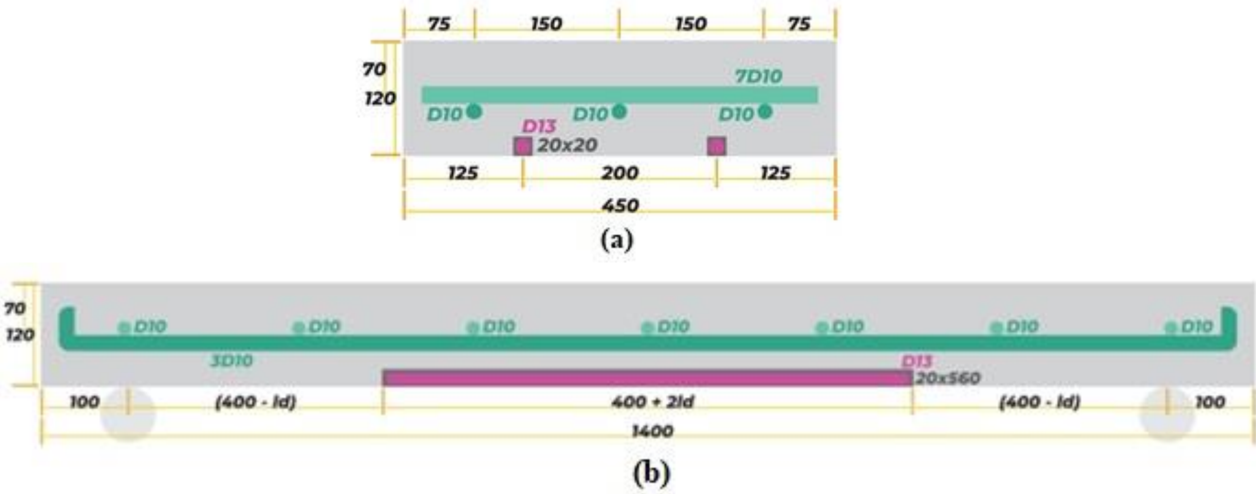

Figure 5. Experimental plate schematic (dimension in mm)

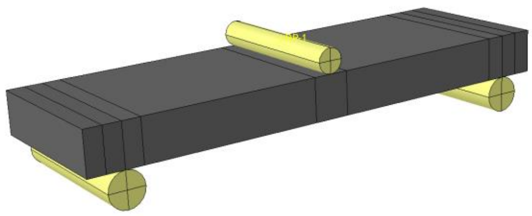

Figure 6. Finite element modeling in Abaqus

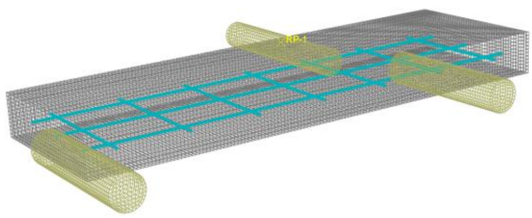

Figure 7. Finite element modeling in Abaqus with mesh view

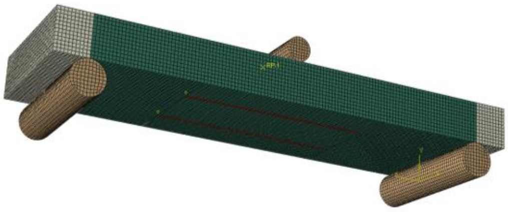

Figure 8. Finite element model

RESULT AND DISCUSSION

Mesh convergence result

In this study, numerical simulations were carried out to validate the experimental results from previous studies. The numerical model in the form of a finite element model was set with a certain mesh size. The modeling results were influenced by the mesh size. The right mesh size was needed so that the modeling results were close to the results of the modeling. There were also other things to consider when selecting a mesh. The number of elements present and the element partition also affects the mesh selection process. The excessive number of elements (very fine mesh size) gives the best results, but the more elements used, the greater the computational load generated. The following are the results of the mesh convergence test shown in Figure 10 and Table 3.

Table 3. Mesh convergence test result

Mesh size (mm)	Element count (n)	Deflection (mm)	Error (%)
25	10754	0.2575	2.387
15	22289	0.2546	1.287
10	76275	0.2525	0.399
Analytical	-	***0.2515***	-

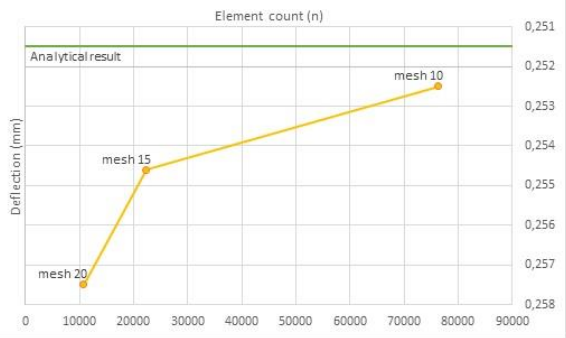

Figure 9. Mesh Convergence Graph/correlation between mesh size and deflection value

Numerical model result

In a model with no reinforcement, there is a difference between numerical and experimental curves. The curve shows that numerical modeling results are more upright than experimental ones. This shows that the numerical results have more brittle properties. The comparison graph of the model results is shown in Figure 11.

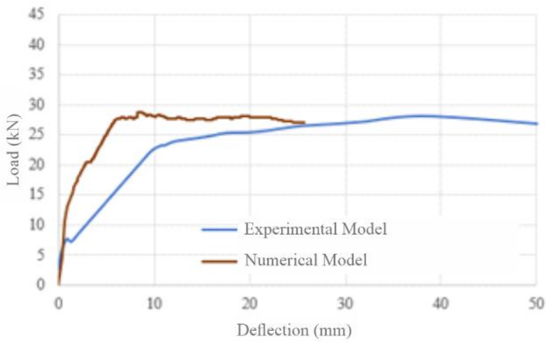

Figure 10. Model results comparison graph

After being reviewed visually, an indication of slippage was found in the experimental experiment. It is indicated by the experimental crack characteristics. Pure flexural cracks in slabs are usually flexural cracks that are below the loaded site. A visual comparison of research results is shown in Figure

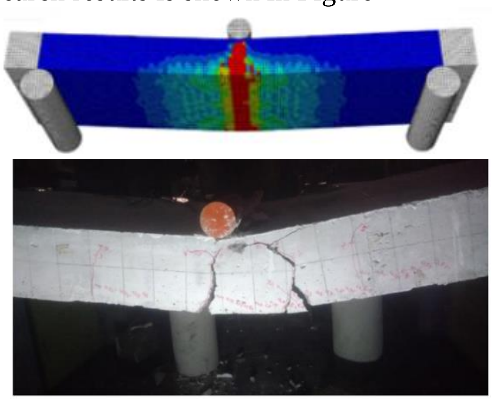

Figure 11. Visual comparison of research results

In the reinforced beam model, the graph results are quite close. Both curves have similar maximum load and stiffness values. The results of the comparison graph between the numerical and experimental models are shown in Figure 13.

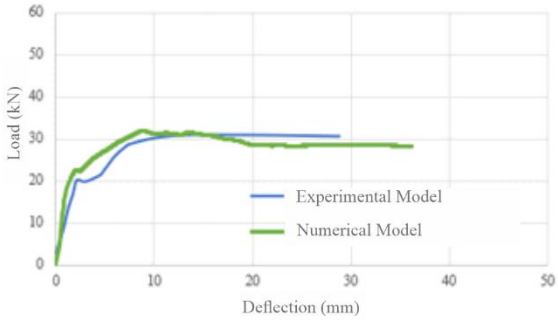

Figure 12. Comparison graph between the numerical and experimental models

Visually there is a difference in the crack pattern on the model. However, both models have the same shear damage. A visual comparison of research results is shown in Figure 14.

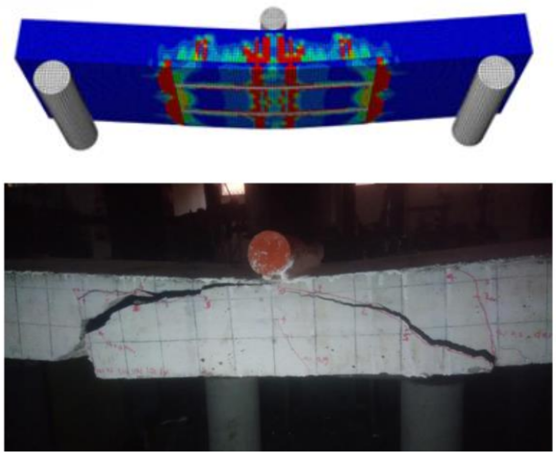

Figure 13. Visual comparison of research results

CONCLUSION

This research presents a finite element modeling that can be used to show non-linear behavior that occurs in reinforced concrete elements. This is supported by the uniformity between experimental results and numerical modeling results.

The mesh size used also matches the analytical results as evidenced by the mesh convergence test, which is use of a mesh size of 10.

Following these results with previous research. The numerical model that has been made can be further developed as a basic model for further research with various variations.

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