Analytical Study on Effect of Bar Size on Pull-out force for Reinforcing Bar Embedded in Concrete Blocks

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Abstract:
The most commonly used test method for measuring the bond strength between reinforcing bars and concrete is the pull-out test of pulling a reinforcing bar out of a concrete block. During serviceability and durability design the bond of reinforcing bars is important in crack control. This paper presents numerical model for studying the size effect on pull-out force. This research considers three bar size diameter, which is 10, 12 and 16 mm bar diameter. The finite element ANSYS software was used for the numerical analysis. The specimens are analyzed until the specimens failure were occurred. The analytical results indicate that the pull-out force increase with increasing bar diameter. The pullout force for specimens S12 and S16 are increase (7% and 35%) compared with specimen S10 respectively.

Keywords: Concrete; bar size; pull-out; finite element; ANSYS.

1. Introduction
Effective bonding between the reinforced bars and concrete is essential in reinforced concrete for the full development of composite action. The bond between the bars and concrete plays a significant role in the structural behavior of reinforced concrete [1]. Insufficient bond may lead to excessive slippage of the steel bars, this leads to ineffective reinforcing bar anchorage and serious cracking of reinforced concrete [2]. Generally, the bonding of the concrete reinforcing bars is important in regions subject to normal stress, shear stress and bending like the beam column on buildings and the narrow
stitches on bridges [3–6]. Therefore, it is necessary to take into account the bonding strength of reinforcing bars during the ultimate strength.

In the serviceability and durability design process the bonding of bars is also important. Firstly, the width of the crack will be associated with the slip bonding of the reinforcement bar at each crack because the amount of the bond-slip is actually the same on both sides of the crack [7]. Secondly, by strengthening the bond between concrete and reinforcement bars, it is possible to delay and/or even modify the cracking process so that the cracking or at least the scope of cracking is avoided [8]. In order to study the effects of bond strength and bond slip, an analysis of bond characteristics of reinforcement bars and concrete is required.

Rose and Russell [9] studied the effects of strand surface conditions on bond performance through testing of tensioned and non-stressed strand with diameter 12.7 mm and reported that the pull-out tests on tensioned strands were difficult and the results of the tests of the bonds of the strands were inconsistent. In terms of its effect on bond strength, the authors show that bonding has been improved with the roughened strand surface (for example, weathered strands).

The pull-out test was carried out by Girgis and Tuan [10] with un-tensioned prestressing strands in diameter of 15.2 mm embedded in self-consolidating plain concrete. The pull-out force was applied by two different methods into small prism specimens. Their results indicated a higher bond strength than traditional supporting of the specimen on the same side of the tested strand when the concrete blocks were held on their back.

Al-Fatlawi [11] was analyzed the pull-out concrete cylinder with a single steel bar 11]. The ANSYS finite element program has been used to study the behavior of bond between the concrete and the steel reinforcement in the 3D finite element model. Experimental results from three pull-out specimens were analyzed to show the accuracy of the finite element numerical result. Good agreement was achieved between the result of the finite element and experimental results.

The experimental and finite element analysis of the pull-out test is presented by Al-Fouadi et al. [ 12] on 32 concrete specimens. Eight concrete specimens were tested in the experimental program, which were grouped into lightweight self-compacted and normal self-compaction concrete and mixtures between them. In the studied mixtures, the average bond strength in normal self-compaction concrete has been found to be higher than in small self-compression concrete. The study showed a difference of around 27.86% in the CM mix compared to the MCF100 mix. Twelve reinforced concrete specimens have been analyzed for the nonlinear finite element. The results of the experimental analyzes and finite elements are compared.
In this study, numerical model was developed to study the effect of size on pull-out force. Three bars size diameter are considered in this study, which are 10, 12, and 16 mm diameter. The numerical analysis was conducted by the finite element ANSYS software. The specimens are analyzed until it failure by the ultimate cracks.

2. Analytical work

In the analysis of the specimens, the finite element ANSYS [13] software was applied.

2.1. Finite elements modeling

SOLID65 has been used for the 3D modelling of concrete solids that are able to crack in tension and crash in compression. It is a three-dimensional reinforced solid concrete. Eight-node element, with three degrees of freedom in each node. The reinforcement was modeled with LINK8 (2-node discreet link elements). This elements can only transmit the axial force. In order to avoid stress concentration, steel plates at loading points have been added. The plates were modeled with SOLID45 (solid element), with an 8-node and a three-degree freedom in every node.

2.2. Material properties

In this study, Desayi and Krishnan's multilinear stress-strain relationship [14] is used for compression concretes. For steel bars, the strain-stress curve adopted by the European Standardized Committee [15] is used. Steel reinforcement bars can only transfer axial forces due to their slenderness.

2.3 Geometry
A 150 mm x 150 mm x 150 mm cube is considered for the modeling. In this study, it consider a perfect bonding between concrete and steel bar reinforcement. The length is modelled (Figure 1a), with the steel bar of 500 mm (including the embedded length). For finite element analysis the models should be meshed as an initial step (Figure 1b). The model needs to be divided into a series of small elements which combine together. The stresses and strains at this points are calculated after loading [13].

The displacement boundary condition on the top of the reinforcement steel bar (figure 1c) are applied as load. The geometric boundaries of the model are also applied by fixing the nodes in three directions in the top of the cube and fixing the nodes adjacent to the bar reinforcement and nodes of unbound part in two directions (x and y direction). Only positive Z direction (upward) for displacement is given on top of the steel bar reinforcement.

| a) Geometry | b) Finite element mesh | c) Boundary conditions |
|-------------|-----------------------|------------------------|

**Figure 1** Geometry, finite element mesh and boundary conditions of specimen

2.4. Material properties (model parameters)
Density, elasticity modules, tangent and yield stresses are specified for the steel reinforcing bar. Also, the Poisson’s ratio is defined for the steel bar. The distribution of stress in the concrete depends mainly on the properties of the concrete rather than on the reinforcement steel bar. This study considers the yield stress of steel reinforcement equal to 400 MPa for various concrete strengths.

The coefficient of shear transfer, $\beta_t$, is symbolic to the crack open faces. Domains of $\beta_t$ is from 0 to 1 with 0 values for a total shear loss (smooth crack) and 1 values for a total shear (rough crack) [13]. For comparison with practical results, shear transfer coefficient was used value 0.30 to obtain the theoretical load displacement relationship. Table 1 shows parameters of material properties considered in the finite element analysis for the reinforcement of bars.

### Table 1 Material properties (model parameters) for reinforcement bar

| Parameter                   | Reinforcement Bar |
|-----------------------------|-------------------|
| Diameter (mm)               | 10 or 12 or 16    |
| Modulus of elasticity (MPa) | 200000            |
| Poisson's ratio             | 0.3               |
| Yield strength (MPa)        | 400               |
| Young modulus (MPa)         | $2 \times 10^5$   |
| Tangent modulus (MPa)       | 21                |
| Density (gm/mm$^3$)         | 0.0078            |

### 3. Results and Discussions

In order to analyze the specimens, a nonlinear analysis of finite elements was performed. The analysis is done by using the ANSYS package for the finite element models [13]. The validity and accuracy of the implemented finite element method is done. The validity of the finite element model was defined by ensuring the pull-out load compared with the results of the experiment is reasonably predicted. An experimental-analytical comparison is based on ultimate load for all specimens.
The results of the finite element analysis were compared with the experimental results [12] and summarized in Table 2. As shown in Table 2, good agreement has been achieved between the experimental results and the results of the finite element analysis. The analysis implicitly reflected the importance of the evaluated test parameters for pull-out force capacity. The analysis reflected the importance of the pull-out force parameters evaluated.

Table 2 Finite element and experimental bond failure loads

| Specimens      | Pull-out force (kN) | Error % |
|----------------|---------------------|---------|
|                | Experimental [12]   | Finite Element Analysis | $E = \frac{F_{E} - F_{Test}}{F_{Test}}$ |
| MC100-Level 4  | 76.98               | 74.23   | -3.6 |
| MF100-Level 4  | 86.49               | 83.45   | -3.5 |
| MCF100-level 4 | 58.45               | 57.78   | -1.1 |

3.1 Effect of bar diameter on pull-out force.

From Table 3, it can be observed that the pull out force increase with increasing bar diameter. The pullout force for specimens S12 and S16 are increase (7% and 35%) compared with specimen S10 respectively. For the same level of containment, larger bars achieve higher total bond forces than smaller bars. The dimensions of a developed bar also play an important role in contribution the reinforcement of the transverse bond. With larger bars slipping, increased strains and higher stresses are mobilized in the transverse reinforcement, providing better confinement.

Table 3 Finite element Pull-out forces

| Specimens | Steel bar Diameter (mm) | Pull-out force (kN) |
|-----------|-------------------------|---------------------|
| S10       | 10                      | 55.15               |
| S12       | 12                      | 59.17               |
| S16       | 16                      | 74.65               |
3.2 Crack and crashing patterns

From Figures 2a and 2b, it be observed that the cracks are start appearing in the surrounding concrete area with the steel bar. While from the Figures 2c and 2d, the cracks (the red dots) start to spread from inside (the surrounding concrete area with the reinforcing steel bar) to the outside surface for all mixes in various directions.

Figure 2 represent the crashing and crack patterns evolution for the specimen S10.

3.3. Tension stress in reinforcement steel bar

For the specimens S16 and S12, Figures 3 and 4 show the tensioning stress in reinforcing steel bar at various depth (H= 0.0, 20, 40, 60, 80 and 100 mm). It is observed in all figures that when the value of H = 0.0 m (at the surface), the tensioning stress value are negligible. As H values increase, the tension stress values begin to increase (shifting from surface to depth). This increase is to a certain extent after which the curve of the H = 80 mm is identical to the curve of the H = 10 mm.
3.4 Stress in surrounding concrete

Figure 5 show the shearing stress for the specimen S10 in concrete in XY plane at different depth. The crack occurs when the pullout load apply on the specimen, so the cracks on the surrounding concrete were first observed and started to grow and spread. From Figure 5, can be observed that the maximum values of shearing stress occur at H=80 mm. When the distance H is increase that lead to increase the shear stress.
The normal stress in XX plane in surrounding concrete for the specimen with 12 mm bar diameter is shown in Figure 6.

**Figure 5:** Stress distribution in concrete ($\sigma_{yz}$) for the specimen S10 at maximum force

**Figure 6** Stress distribution in concrete ($\sigma_{xx}$) for the specimen S12 at maximum force

4. Conclusions

This paper presents finite element analysis of pullout force on concrete cube specimens. The main parameter was steel bar diameter. The dimensions of the specimens are 150*150*150 mm. Three steel bar diameters are considered in this study which are 10, 12 and 16 mm. The analysis of the finite elements was done with the software ANSYS. In comparison with the experimental results the results computed from finite element analysis have been very
there is a good agreement between the results of the analytical and experimental. The following conclusions can be drawn from the analysis of finite elements for concrete specimens:

1– From results, it can be observed that the pull out force increase with increasing bar diameter. The pullout force for specimens S12 and S16 are increase (7% and 35%) compared with specimen S10 respectively.

2– The cracks in the surrounding concrete were first observed.

3– It is observed that the maximum values of shearing stress occur at H= 80 mm.

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