

Analysis of the effect of various support distances to the bond-strength of plain anchor bolt in concrete

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Abstract. The structural components of reinforced concrete that withstand the tensile stress will be bonding stress affected by the friction between the reinforcing bar and the concrete. Anchoring depth, reinforcement diameter, and concrete quality are commonly assumed to influence bond strength; besides, the support distance of reinforcement may be one of the influencing factors. The samples in this study were cylindrical specimens with a diameter of 15 cm and 20 cm for the concrete compression strength and the bond-strength test, respectively, and double-L size 30 x 20 x 7.5 cm for the concrete shear test. Variables in this study include variations in the support distance represented by variations in the diameter of the supporting plate hole, namely 10 mm, 35 mm, 60 mm, 85 mm, and 110 mm. Plain reinforcement with a diameter of 10 mm was anchored at 150 mm depth in the centre of the concrete cylinder. The experimental results obtained 26.49 MPa and 10.86 MPa for concrete compression and shear strength, respectively. Based on various diameters of the supporting plate hole, the hole diameter of 10 mm to 60 mm had a stable increase in bond strength and a significant decrease when a larger hole diameter was used.

1 Introduction

In reinforced concrete structures, steel reinforcement is placed into concrete to provide tensile resistance to bending loads or to assist concrete in carrying compressive loads [1]. To ensure good cooperation between concrete and steel reinforcement as a composite material, the bond strength must be seen at the interface of these materials. One subject related to the quality control of reinforced concrete structures is the bond between steel reinforcement and concrete [2]. If the steel reinforcement and concrete bond are good, there will be a slight crack when the reinforcement is pulled out of the concrete [3].

The anchoring strength in concrete specified in the standards usually assumes that the bond is uniform. However, this assumption is not entirely correct because anchoring depth affects the bond stress [4]. The strength of the deformed reinforcement ties consists of 3 parts. First is the adhesion between concrete and steel reinforcement, the second is the friction between steel reinforcement and concrete around it. The last is mechanical bonding that affects the roughness of the steel reinforcement. Mechanical bonding is called a mechanical interlock which affects the strength of the primary bond [5]. The failure mode is generated from stress, shear strength and its combinations. A typical bond failure results in reinforcing reinforcement due to the release of concrete around the surface of the reinforcement combined with an adhesive failure along with the steel reinforcement [1,6]. The mode of a

connection failure in axial tensile loading follows the order of slip reinforcement, cracked concrete, steel plate bending and reinforcement breaking [7]. Normal force and shear stress were negatively and exponentially distributed in the fixed region of the anchor bolt [8]. Factors that influence the value of bond strength are anchoring depth, reinforcement diameter, and concrete quality. One aspect is thought to affect the bond strength of the anchoring in concrete, the support distance of anchors. The function of the supporting plate with a hole in bond strength testing is as a concrete barrier so that it does not lift and break during the test.

As for some studies on bond strength using plain reinforcement in normal concrete, research of bond strength using plain reinforcement with a diameter of 10 in normal concrete shows the bond strength decreases along with the increasing variation in the diameter of the supporting hole [9]. Research on bond stress on plain steel with diameters of 8, 10, 12, 16, and 19 in normal concrete shows that the strength of plain reinforcement of 8 mm, 10 mm, 12 mm diameter has increased but decreases in larger diameter [10].

1.1 Compressive Strength of Concrete

The compressive strength of concrete loads is the magnitude of the load per unit area, which causes the concrete specimens to be destroyed when loaded with a certain compressive force, which is produced by a compression testing machine [11]. The maximum compressive stress (f_c) can be formulated as Eq. 1.

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$$f'c = \frac{P}{A} \quad (1)$$

1.2 Shear Strength Of Concrete

If the force acting on the concrete exceeds the maximum shear strength that the concrete can withstand, then a concrete crack will arise. The friction force produces shear stress between particles of one particle to another. The following formula (Eq. 2) can calculate shear strength.

$$f_{shear} = \frac{P}{bh} \quad (2)$$

1.3 Basic Concept Of Anchoring Bond

Pull-out experiments can provide a good comparison between the bond efficiency of various types of reinforcement surfaces and their length of anchor (embedment length). The ratio of the length of the distribution of plain steel reinforcement to the length of distribution of reinforcing steel bars at the same stress is a factor of two so that the average bond stress for plain steel reinforcement is obtained as Eq. 3.

$$\mu = \frac{d_b f_y}{8l_d} \quad (3)$$

The development length of the steel reinforcement can be determined by Eq. 4 [12]:

$$l_d = \frac{d_b f_y}{2.1 \sqrt{f'c}} \quad (4)$$

2 Research Methods

2.1 Testing of Concrete Compressive Strength

Compressive strength testing was conducted after the concrete was 28 days old. This study aims to obtain the compressive strength value of concrete using a Compression Testing Machine.

2.2 Testing of Concrete Shear Strength

The shear strength test was carried out after 28 days of concrete with a double L-shaped specimen with size 300 x 200 x 75 mm. The double L-shaped specimen is placed in the Compression Testing Machine. Load reading is carried out at maximum load until the sample failures.

2.3 Testing of Concrete Bond Strength

Bond strength testing is done by placing a concrete cylinder on a loading frame equipped with a hydraulic jack and load cells, then the reinforcing bar embedded in the cylinder is pulled until pulled (Pull-Out Test, Fig. 1). The variations in the diameter of the supporting holes used are 10 mm, 35 mm, 60 mm, 85 mm and 110 mm (Fig. 2). The length of the embedded reinforcement is 150 mm with a steel reinforcement diameter of 10 mm on plain

reinforcing steel. This test is carried out on specimens 28 days old by pulling reinforcing steel embedded in a concrete cylinder.

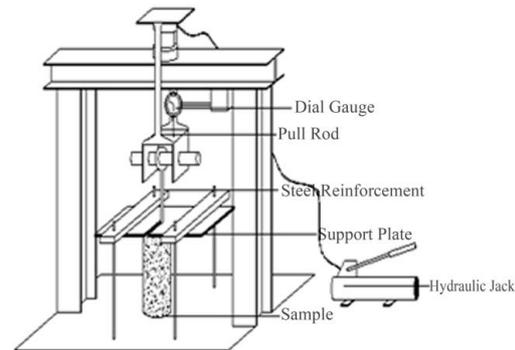


Fig. 1. Sketch of concrete bond strength test.

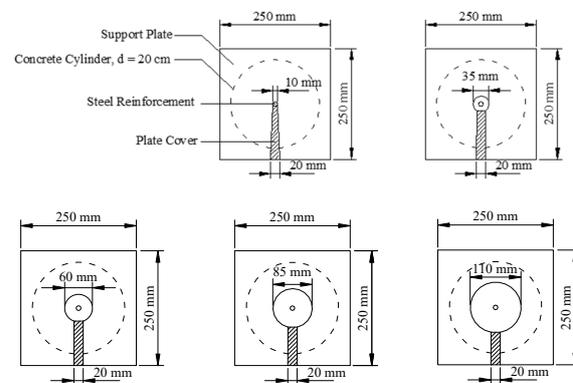


Fig. 2. Sketch of the diameter of support plate hole's variation

3 Result and Discussion

3.1 Compressive Strength of Concrete

The data obtained in this compressive strength test is the maximum load that causes the specimen to collapse. The test results obtained the value of normal concrete compressive strength of 26.492 MPa. This value indicates the compressive strength produced in all types of concrete is greater than the compressive strength required, equal to 20 MPa.

3.2 Shear Strength of Concrete

Data obtained in the shear strength test is a maximum load that causes the test object to collapse. From the test results, obtained shear strength of 10.864 MPa for normal concrete. The value of shear strength is needed so that experimental failures do not occur due to the fracture of the concrete bond before the reinforcement embedded in the test object is pulled out.

3.3 Bond Strength of Anchor Bolt

In this study, two data are obtained, namely the maximum load and the deformation value. Maximum load is the load when the steel bar is pulled from the concrete. At the same

time, the deformation is the length of the shift of steel uprooted from concrete.

Test the bond strength between plain steel reinforcement with concrete in normal concrete using as many as 15 cylindrical test specimens with three pieces per variation of the supporting hole diameter. A diagram of bond strength test results with variations in the diameter of the supporting plate in a normal concrete plain reinforcement can be seen in Fig. 3.

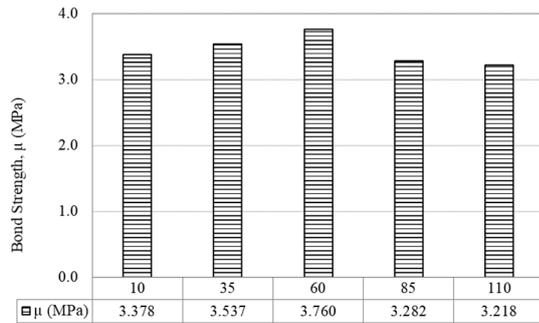


Fig. 3. Bond strength test results

Fig. 3. shows the maximum value of bond strength produced occurs at the diameter of the supporting hole size of 60 mm at 3,760 MPa, and the value of bond strength made at the minimum occurs at the diameter of the supporting hole size of 110 mm at 3,218 MPa. The diameter of a support hole of 10 mm to 60 mm shows a steady increase in bonding strength but a drastic decrease in the diameter of a support hole of 85 mm. This is due to the diameter of 85 mm and 110 mm in the presence of a short pedestal, which is only 45 mm apart so that the distribution is inadequate and the stress is not optimal. Whereas in the diameter of a supporting plate with a size of 60 mm, the bond between the reinforcement and the concrete will transfer the stress to the concrete around the reinforcement and the tension is still held by the support plate so that it reaches the maximum strength value. The graph which shows the relationship between load-deformation in normal concrete can be seen in Fig. 4.

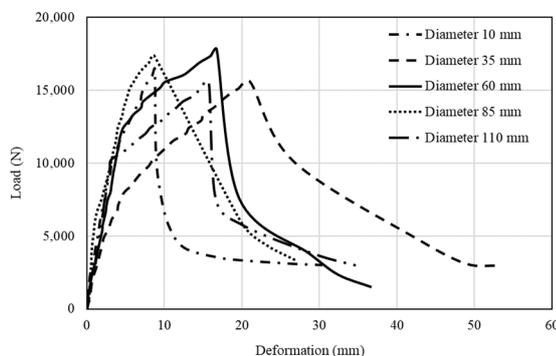


Fig. 4. The relation of load-deformation

The test results show that the maximum load value is generated by the supporting hole size of 60 mm. While the deformation obtained at 110 mm diameter of the supporting hole has a vast difference. It happens because the stress has reached a maximum at 110 mm support hole

diameter and is followed by a large strain value. It shows that the level of ductility is high.

3.4 Shear Strength Relationship with The Supporting Hole Diameter

The shear strength test results are then compared with the concrete bond strength test results by making a relationship between the development length based on the shear strength and the concrete bond (Fig. 5).

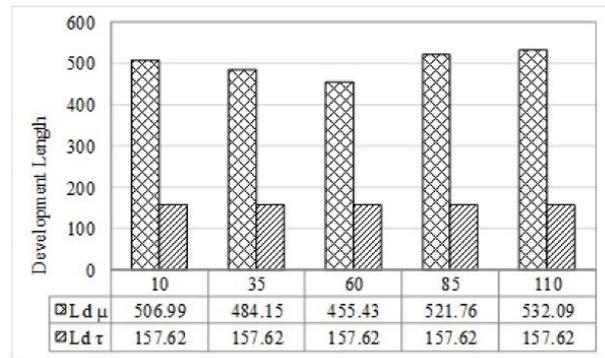


Fig. 5. Development length of bond and shear

The relationship between the development length of anchors with the shear strength for normal concrete is obtained. The development length of the bond strength is greater than the length of the shear strength. It shows that the failure of the test specimen occurred in the bond between reinforcing steel and concrete.

3.5 Analysis of the Bonding Coefficient

The diameter of plain reinforcement in normal concrete is then used to find the coefficient value of the development length of the experimental results (Fig. 6).

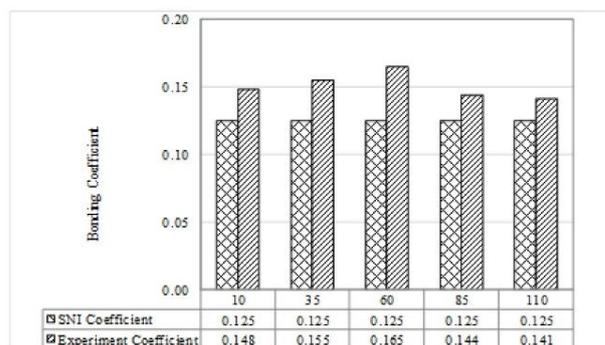


Fig. 6. The relation of diameter of support plate hole and bonding coefficient

The results shown in Fig. 6 are the bonding coefficient values that occur perfectly because the bonding coefficient values obtained from the experimental results in all variations of the diameter of the support hole are greater than the ACI coefficient value [12]. So the calculations based on experiments can be applied to the bond strength of normal concrete.

3.6 Analysis of the Development Length Coefficient

The results of testing the development length of plain reinforcement at the constant depth of anchoring are then analyzed the value of the coefficient of development length of the experimental results. This result was then compared with the value of the development length coefficient at ACI (Fig. 7) [12].

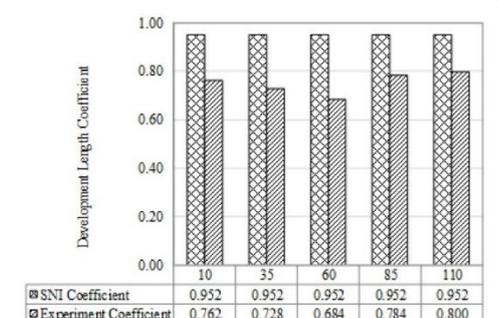


Fig. 7. The relation of diameter of hole and development length coefficient

Based on Fig. 7, it can be seen that the value of the development length coefficient obtained from experiments has a smaller value compared to the development length coefficient resulting from ACI [12].

3.7 Relationship Between Safety Factor and Supporting Plate Hole Diameter

The graph of the relationship between the safety factor and the diameter of the supporting plate hole in the normal concrete with plain reinforcement can be seen in Fig. 8.

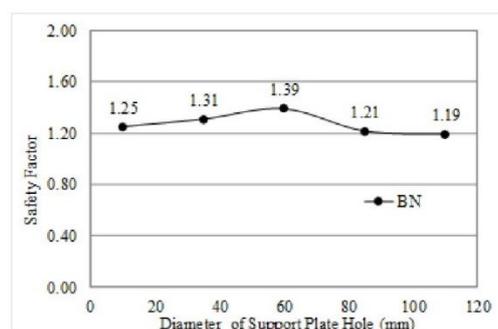


Fig. 8. The relationship between safety factor value and plate hole diameter

From Fig. 8, it can be seen that all variations in the diameter of the supporting plate hole in normal concrete with plain reinforcement have a safety factor value of more than 1. It shows that the application of anchoring depth based on ACI [12] produces a safe structure for normal concrete.

3.8 Failure Types

After the pull-out test is carried out, the next step is to observe the failure in all test specimens. The observations

show that the pattern occurs in all objects, namely bonding failure, where steel is pulled out of concrete without cracking on the surface of the concrete. The bond between the steel and concrete and the restraint ability of the concrete can withstand reinforcement when the maximum load is exceeded.

4 Conclusion

Based on the results of the research, the following conclusions can be drawn:

(1) In normal concrete with plain reinforcement is obtained, the maximum bond strength at the diameter of the supporting plate is 60 mm by 3,760 MPa, and the minimum bond is obtained at 110 mm at 3,218 MPa.

(2) The relationship between bond strength and shear strength obtained correlation value based on the diameter of the supporting plate hole to the bond strength and shear strength and reinforcement. The development length of bonding distribution is greater than the development length of the shear strength distribution. It shows that the failure occurred in the bond between reinforcement and concrete.

(3) Variations in the failure of the sample obtained in normal concrete are bonding failure where the loss of bonding to the steel reinforcement.

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