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Experiment of Pullout Expansion Anchor in Installation Cast in Place and Post Installed with Concrete Breakout Failure

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Abstract: The use of anchors in construction is gaining popularity to connect steel and concrete constructions, and to transmit tensile loads acting onto the concrete. This research aims to find out the difference in the strength of anchor based on two methods of installations that are cast in place compared to post installed with the influence of effective depth, diameter of anchor and quality of concrete, and failure of concrete breakout. Expansion anchor used in this study is "Sanko" M12x100 and ready-mix concrete PT Bonindo Ungaran, fc 25 MPa with 6 pieces of test specimens of 300x300x150 mm. Each specimen has 4 anchors with a distance between the anchors of 100 cm, the distance between the anchors to the edge of the concrete 100 mm, and the depth of installation (hef) of 60 mm. The result of the study is the predicted value of the anchor pullout capacity with the failure of concrete breakout due to the theoretical pullout, namely 42,223 N, anchor pullout test results with cast in place method of 40,574 N and post installed method by 37,494 N. Tensile strength tests (material) of anchor (fy) 338 MPa, for flat concrete compressive strength strength of (f'c) 25,698 MPa. The results of the cast in place pullout test are larger and better than post installed (40574 N>37494 N). Failure that occurred in cast in place method is a failure of concrete breakout and post installed method has occurred slip. Failures that occur are relevant to the theory.

Keywords: expansion anchor, concrete breakout, pullout, cast in place, post installed

INTRODUCTION

Anchor is a steel element planted either using cast in place method or post installed method into the hardened concrete and used to channel the loads (pullout and shear) which works into the concrete [2]. The use of anchor in construction is getting more popular to help channeling the concrete structures. The anchor installation has improved from cast in place method into post installed method by drilling. It can make the installation and unistallation easier to perform. Anchor installation using cast in place is generally used for new construction planning, while for post installed method is generally used for old construction either repairing or retrofitting.

There are various types of anchors: ring and hexagon bolt anchor, stud anchor, hooked anchor, notched anchor, undercut anchor, adhesive anchor, and expansion anchor [1]. Expansion anchor is post installed anchor whose installation on hardened concrete by hitting it until it is planted into the concrete and utilize the shear slip force between anchor and concrete [6]. It is a factory product that has relatively expensive price and limited size [5].

FIGURE 1. Expansion Anchor (Hammer Drive Anchor)

A pull-out test was conducted to find out the tensile capacity. There are possibilities on failures or damages that can happen, one of them is concrete breakout [5].

Concrete breakout happens due to over pull-out capacity into the concrete, so that it is damaged or broken and raise upwards [10]. The failure of the concrete breakout occurred in the installation of cast in place assuming the concrete cone with an angle of 35°. The concrete breakout failure mode estimates the anchor group that occurs by considering the factor of the amount of the concrete's distance or space, the distance of the edge of the anchor to the concrete, the depth of the installation [5].

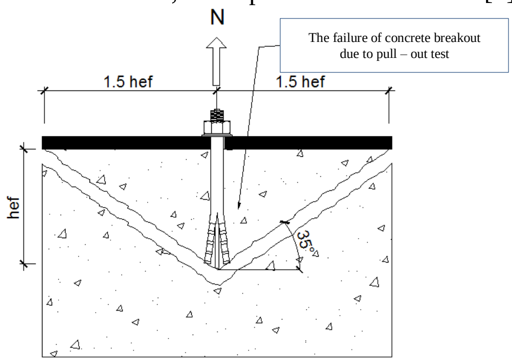

FIGURE 2. Concrete Breakout Failure Due to the Pull-out Test

In general, attachment collapse, the bond stress between concrete and reinforcement (steel) is influenced by [8]: a) adhesion, i.e. bonding due to the process of cement hardening reaction on the surface of the bone; b) friction, is a sliding prisoner against slips and interlocking when the bone is experiencing tensile tension; c) interlocking the reaction of the screw/rib protrusion to the concrete matrix around the reinforcement; d) gripping effect of gripping, due to shrinkage of concrete drying around the reinforcement; e) the effect of concrete quality which includes strong tensile and strong stress, due to the insistence by radial stress, concrete undergoes roving tensile stress; f) the effect of the mechanism of removal of the end of the reinforcement, the cutting of the reinforcement , and the crossing of the reinforcement; g) diameter, shape, and distance of the reinforcement.

"Pullout simulation of post installed chemically bonded anchors in UHPFRC" results that the h60 test (embedded anchor depth 60 mm) with pullout failure, h100 test (100 mm embedded anchor depth) with anchor fracture damage. For anchor depths of 40 mm (test h40), the failure mode is a combined pullout and concrete cone failure. The anchor used is a chemically bonded anchor type in UHPFRC (Ultra High-Performance Fiber Reinforced Concrete) concrete with a quality of 150 MPa fc concrete to 165 MPa. [4]

"Experimental Investigations on Concrete Cone Failure of Rectangular And Nonrectangular Anchor Groups" showed that (1) the results on the effect of eccentric loading and the effect of concrete anchor edge distances obtained from this experimental program confirm that both the effect of failure to break the concrete causes reduction of loading. (2) In the test for the similar loading efficiency value, the load is 26% higher when loading is far from the edge. The test results show that the correct loading position must be considered when predicting the cone resistance of the anchor group. (3) Investigation of the anchors group with varying thickness base plates showed a significant effect of base plate stiffness on the conical capacity of the concrete and on the non-linear load placement behavior of the anchor group. [3]

) "Experimental Evaluation of Tensile Behavior of Single Cast-In-Place Anchor Bolts In Plain And Steel Fiber-Reinforced Normal- And High-Strength Concrete" results in (1) the breakout capacity of concrete due to the tensile headed anchor increases. As the concrete thickness increases, the anchor capacity increases by 17% by increasing the member thickness from 1.5 to 3.0 times the anchor depth. (2) The tensile capacity of anchor bolts increases by increasing the strength of the concrete, the anchoring behavior in High-strength Plain Concrete (HPC) is more brittle than Normal-strength Plain Concrete (NPC). (3) The addition of steel fibers to the concrete mixture causes a significant increase in the capacity of the breakout headed anchor in both normal and high strength concrete. (4) The anchor tensile test which is tested for all failures to break the concrete cone, except for the anchor tensile test on the thinnest NPC concrete with concrete splitting failure. The failure mode of splitting of thin concrete can result in failure of breaking the concrete cone when the thickness of the concrete increases. (5) At the same anchor displacement, fewer cracks in the concrete were formed in the anchor bolts at Normal-Reinforced Fiber (NFRC) and High-strength Fiber Reinforced Concrete (HFRC) than in NPC and HPC concrete. [13] Fewer concrete cracks were formed in anchor bolts under Normal-Reinforced Fiber (NFRC) and High-strength Fiber Reinforced Concrete (HFRC) than in NPC and HPC concrete. [13] Fewer concrete cracks were formed in anchor bolts under Normal-Reinforced Fiber (NFRC) and High-strength Fiber Reinforced Concrete (HFRC) than in NPC and HPC concrete. [7]

"Strength of Bonded Anchors in Concrete in Direct Tension". Analyze the type of anchor bolt collapse in concrete by varying the concrete strength variables, anchor length and anchor diameter. For failure mode, loading is stopped when the concrete breaks. The broken concrete forms an angle of 45 ° at a depth of 50 mm, while at a depth of 100 mm and 150 mm the angle of breaking of the concrete varies around 30-40 degrees. [9]

According to ACI 2011 in planning, group anchor bolts are installed in a minimum distance of 6d (six times the diameter of the anchor bolt) from one anchor to another anchor (s1) or from the anchor to the edge of the concrete (ca1), is carried out so as not to occur splitting structure failure [2]. The effective depth of the anchor bolt in general should not exceed from 2/3 the thickness of the structure components.

The research was the pullout test of expansion anchors to concrete using the method of installation by cast in place and post installed, the failure mode of the concrete breakout. Specimens have dimensions of 300 mm x 300 mm x 15 mm with 25 MPa fc concrete quality. The anchor used for the expansion type is the hammer drive anchor with the brand "Sanko" M12 x 100 with a diameter of 12 mm and an effective depth (hef) of 60 mm. The aims of this present research were to figure out:

a. the predicted value of the anchor tensile capacity with the failure of the concrete breakout due to theoretical tensile.
b. the magnitude of the anchor pull out test results of the installation method by cast in place and post installed.
c. the comparison of the results of the anchor pull test with the cast in place installation method and the post installed.
d. the difference in the value of the theoretical anchor tensile capacity of the test results of the cast in place and post installed installation methods.
e. the failures that occur in the anchor pull test to the concrete by cast in place and post installed.

METHODOLOGY

Research methodology consisted of steps of conducting a research systematically and the data collection technique in the research. The research used laboratory experimental method, a test conducted in a laboratory adjusted to the theory and obtain the research results.

The research activity included the tensile test of anchor bolts using cast in place and post installed methods with diameter of 12 mm, effective depth (hef) of 60 mm, concrete quality of 25 MPa. This research aims to find out the different capacity of anchor pull-out installed in cast in place and post installed methods and the focus of failure on the concrete breakout.

The research was conducted from February to June 2020. Tensile testing (material) of anchor at the Laboratory of Mechanical Engineering Materials, Universitas Negeri Semarang, manufacture of ready mix concrete at PT Bonindo Ungaran, Semarang Regency, research settings for anchor tensile testing to concrete at the Laboratory of Materials and Engineering Structures at Civil Engineering Program, Universitas Negeri Semarang.

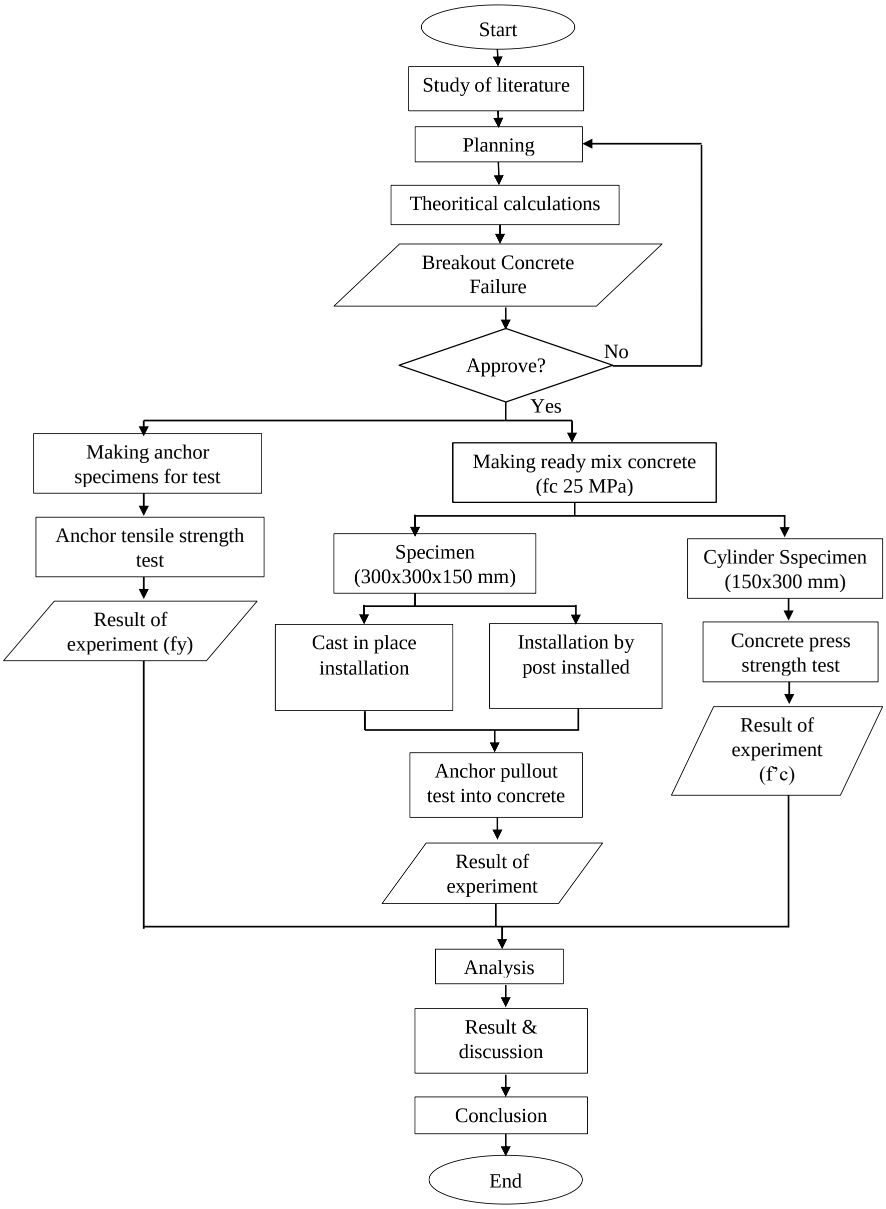

FIGURE 3. Research Flowchart

RESULT AND DISCUSSION

Before conducting the research of anchor tensile test into concrete with cast in place installation method and post installed method with concrete breakout failure, the testing stages were performed including: testing tensile (material) expansion type of anchor with brand "Sanko" M12 x 150 in Mechanical Engineering Laboratory of Universitas Negeri Semarang, and testing compressive strength of cylinder concrete 150 x 300 mm, ready mix fc 25 MPa in Batching Plan P.T. Bonindo Ungaran, Semarang Regency.

Here are the test results that produce data starting from the result of anchor (material) tensile test, the result of concrete compressive strength test, as well as the result of anchor tensile test into the concrete.

1. Anchor (Material) Tensile Strength Test

The test of anchor (material) tensile was carried out to determine the tensile strength of anchor expansion diameter 12 mm brand "sanko" M12x150. The testing was carried out using UTM (Universal Testing Machine) in the Mechanical Engineering Material Laboratory of Universitas Negeri Semarang. Testing the anchor (material) tensile strength was based on SNI 07-0408-1989 on how to test metal tensile and SNI 07-2529-1991 on testing method of concrete steel tensile strength, with the following test results on Table 1.

TABLE 1. Anchor (Material) Tensile Test Results

Specimen	D (mm)	L (mm)	ΔL (mm)	fy (MPa)	fu (MPa)	ε (%)
1	8	400	4.2	310	358	1.05%
2	8	400	5.2	385	425	1.30%
3	8	400	4.5	345	375	1.13%
4	8	400	4.5	310	375	1.13%
Average			4.6	337.5	383.25	1.15%

Based on the results of anchor (material) tensile strength test in Table 1, it shows an average yield strength (fy) of 337.5 MPa and an average ultimate strength (fu) of 383.25 MPa.

2. Concrete Compressive Strength Test

Concrete compressive strength test is conducted to determine the compressive strength of ready-mix concrete fc 25 MPa with specimen of cylinder concrete 150 x 300 mm at Batching Plant P.T. Bonindo Ungaran, Semarang. The test of concrete's compressive strength refers to SNI 1947-2011 on how to test the compressive strength of concrete with cylinder specimen. Testing by being loaded until it damaged the concrete cylinder as a specimen. Concrete compressive test results can be seen in the following table:

TABLE 2. Concrete Compressive Strength Test Results

Specimen	Age (day)	D (mm)	H (mm)	Compressive Force (ton)	Cylinder Strength 28 Days (kg/cm2)	Cylinder Strength 28 Days (MPa)
1	40	150	300	66.8	363.735	29.616
2	40	150	300	52.5	285.990	23.286
3	40	150	300	54.6	297.096	24.190
Average				58.0	315.607	25.698

Based on the compressive strength result on Table 2, it shows that the average concrete compressive strength is 25,698 MPa and has fulfilled the concrete compressive strength plan of 25 MPa.

3. Anchor Pullout Strength into Concrete

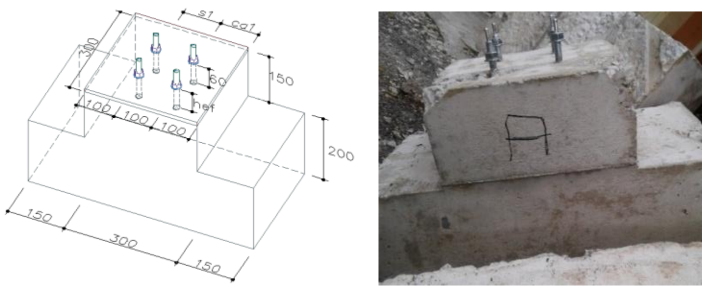

FIGURE 4. Specimens

The test of anchor pullout test into concrete was conducted at the Civil Engineering Structure and Material Laboratory of Universitas Negeri Semarang to find out the capacity of anchor tensile into concrete with concrete breakout failure in the testing. Anchor pullout strength was installed with cast in place or installation before concrete casting and post installed or installation was performed after the concrete hardens.

The dimension of the test specimen is 300 x 300 x 150 mm in the form of T beam, the specimen consists of 3 pieces for cast in place installation method and 3 specimens as post installed. Each specimen is mounted 4 pieces of expansion type of anchor brand "sanko" hammer drive anchor M12x100 diameter 12 mm, effective depth (hef) 60 mm.

The failure reviewed in the testing of anchor tensile into concrete is the failure of the concrete breakout in accordance with ACI 2011 concerning the anchoring to concrete that is included in the book of Steel Structure by Wiryanto Dewobroto and SNI 2847-2019 on structural concrete requirements for buildings and explanations. The calculation of the breakout strength of concrete was based on the recommended model, the CCD model, with a concrete breakout angle of about 35 °, as in Figure 2. The nominal strength of concrete breakout in Ncb tensile for group anchors, must not exceed the equation following [6]:

$$\text{Ncbg} = \frac{ANc}{ANco} Nb \quad (1)$$

where

ANc = Area of concrete damage projection on anchor group to calculate the tensile strength (mm2)

ANco = Maximum failure projection area for breakout strength due to the pull-out (mm2)

Nb = Strong base anchor breakout against tensile (N)

$$\text{Nb} = kc\,.\,\lambda a\,.\sqrt{fc}\,.\,hef^{1.5} \quad (2)$$

where

kc = 7 (expansion anchor including post installed anchor)

λa = modification factor for normal concrete material λ = 1

fc = quality of concrete (MPa)

hef = effective depth of anchor bolts (mm)

The ANc value was calculated by the basic approach of the square image resulting from projecting the failure surface onto the outer side of the anchor bolt of 1.5 hef of the anchor bolt ace, or is from the adjacent rows of anchor in the anchor group. ANc value can be calculated by equation:

$$\text{ANc} = (Ca1 + s1 + 1.5\ hef)(Ca2 + s2 + 1.5\ hef) \quad (3)$$

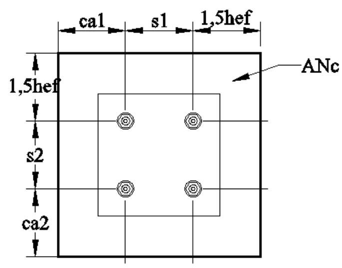

FIGURE 5. ANc Calculation

$$\text{ANco} = 9\ hef^2 \quad (4)$$

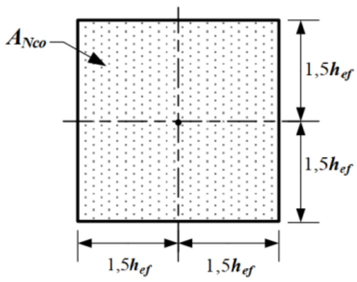

FIGURE 6. ANco Calculation

The ANc should not exceed n.ANco, where n is the number of anchors tightened in the group. Below the results of the theoretical calculation:

Nb $= kc \times \lambda a \times \sqrt{fc} \times hef^{1.5}$= 16267 kN

Ncbg $= \frac{ANc}{ANco} \times Nb$ = 42223 N

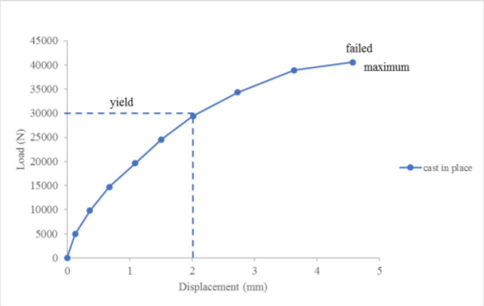

FIGURE 7. Graphic of Cast In Place Method Test Results

The result of the anchor tensile test into the concrete with cast in place installation method obtained maximum result of 40533.95 N with a displacement of 4.57 mm. The test result of the cast-in place installation method is smaller than the theoretical calculation results (40533.95 < 42223). There is a difference of 4% between theoretical calculation and test result.

Linearly, the tensile strength of the anchor to the concrete in the melting condition is 3000 N with a displacement of 2 mm. Therefore, the calculation is theoretically not yet usable and it is necessary to use a safety figure of 1.5.

The test results showed the failure on the concrete breakout. Failures occurred when the load was maximum and there is no additional load, the test specimen was the unreinforced concrete so that failure at maximum load and the concrete is brittle. Predict theoretically with the failure of the concrete breakout, the concrete cone with angle of 35° as in Figure 2. In the test of anchor tensile into the concrete, there is a breakout failure of concrete, because of the attachment between the concrete and the anchor such as adhesion, friction, and interlock, see Figure 8. There are no other failures, such as pull-out failures, side face blowout failures, and pull-out damage.

FIGURE 8. Post-test Failure of Cast in Place Method

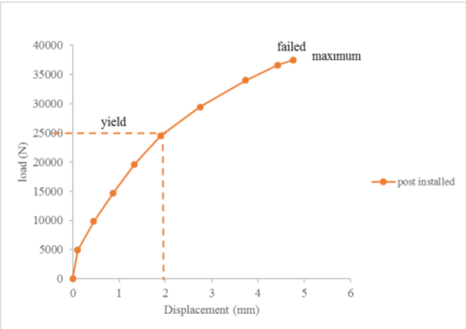

FIGURE 9. Graph Post Installed Method Test Result

Test result with post installed installation method obtained with a maximum load of 37493.9 N with a displacement of 4.77 mm. The test result of the post installed installation method is smaller than theoretical calculation (38147.67 < 42223). There is a difference of 11.20%.

In the elastic conditions on the graph, the load is 2500 N with a displacement of 2 mm. Thus, the security number is 1.25 and taken 1.5 for the security number so that the calculation can theoretically be used.

Failure occurred during the anchor tensile test on post installed installation method, failure confirmed the bond – slip theory. Failure at maximum load and no additional load occurred. Theoretically, the failure due to the tensile was that slips were marked with the pulled anchor, while the results of the anchor tensile test of post installed installation method, failure that occurred was slip, see Figure 10. No damage to the anchor. In the anchor tensile test of post installed installation method, the slip occurred because the installation of anchor in post installed relied only on the role of interlock, the treatment of concrete on the anchor installation with drilling caused crack on the concrete and the force of friction between the anchor and the concrete was reduced so that there was a slip.

FIGURE 10. Failure after Post Installed Method Test

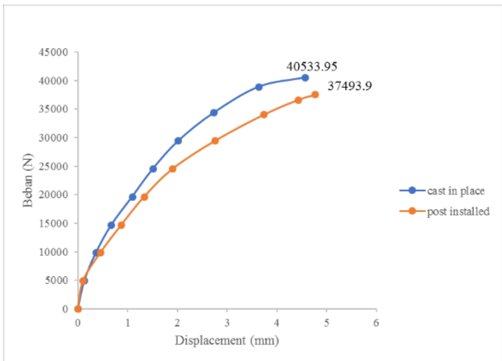

FIGURE 11. Result of Anchor Pullout Test into Concrete

The test results showed the cast in place anchor mounting method could receive a larger load (40533.95 N) and a smaller displacement (4.60 mm), while in post installed method testing the opposite was to receive a smaller load than cast in place (37493.9 N > 40533.95 N) with a displacement greater than cast in place (4.77 mm > 4.60 mm). Therefore, the installation of cast in place fencing is better than post installed.

In terms of the strength, the anchor installation of cast in place is bigger and the displacement is smaller than the installation of anchor on post installed. This means that the role of attachment that occurs (adhesion and interlock) in the anchor installation on cast in place is bigger and stronger. Therefore, it affected the attachment between the anchor and the concrete, which is a larger load that can be carried. The anchor in post installed installation is smaller load accepted because it relied only on the role of interlock at the end of the anchor that works and there is already a treatment on the concrete that is drilling that causes the force of friction between the anchor and the concrete is reduced, therefore slip or displacement that happens is bigger.

Failure which occurred at the test result in both cast in place and post installed had a difference of 7.5%. Failure occurred when the load reached its maximum. For the results of the anchor tensile test with cast in place installation, there is concrete breakout, due to the installation of anchor before casting there has been adhesion (concrete hardening process), friction (shear resistance to derailment), and interlock (inflated anchor working at the lower end). This role is what resulted in the concrete breakout occurred in the anchor tensile test into the concrete. While in the results of the anchor tensile test with post installed installation, the slip occurred because it relied only on the role of interlock at the end of the anchor that expands. The anchor installation by drilling reduces force of friction between the anchor and the concrete making it easy for slips or anchor pulled during testing. The treatment of concrete with drilling during the installation of anchor caused cracking in the concrete before testing and on the test result, failure did not occur on the concrete that was concrete breakout.

CONCLUSION

From the results of research on anchor tensile with expansion type with concrete breakout failure in cast in place and post installed installation method, which can be concluded that:

1. Predicted value of anchor tensile capacity with concrete breakout failure due to tensile theoretical of 42.223 N.
2. Result of anchor tensile test of cast in place installation method is 40,574 N and post installed installation method is 37,494 N. Average of tensile strength (material) is (fy) 338 MPa, for concrete compressive strength is (f'c) 25,698 MPa.
3. The result of the anchor tensile test of the cast in place method is bigger than the post installed (40574 N > 37494 N), so that the anchor installation with cast in place is better than the post installed.
4. There is theoretical difference in the value of anchor tensile capacity to the test result of cast in place and post installed installation method, where the theoretical calculation value is greater than the result of anchor tensile test with cast in place (42223 N > 40574 N) with a difference of 4%, in anchor tensile test with post installed is theoretically greater than the test result (42223 N > 37494 N) with a difference of 11.20%. There needs to be a safety number of 1.5 for the anchor tensile test into concrete in the research.
5. Failure that occurs in the anchor tensile test into concrete with cast in place is concrete breakout failure, while post installed, the slip has occurred. Failures that occur confirmed the relevant theory.

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