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Experimental Study of Pull-Out Failure on Sanko Hammer Drive Anchor Using Cast in Place and Post-Installed Methods on Ready-mix Concrete with Quality of 25 Mpa

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Abstract: Anchor serves to connect steel and concrete construction that can transfer steel pull-out load to concrete. Sanko hammer drive anchor usually has been available in the model of expansion that can be installed into concrete with cast in place and post installed methods. The experiment was aimed at comparing pull out failures of Sanko hammer drive expansion anchor using cast in place and post installed installation methods based on pull-out failure behavior. Experimental data were obtained from the pull-out strength test of Sanko hammer drive expansion anchor, compressive strength test and ready-mix concrete split tensile test, adhesion strength test and group anchor pull-out test which consists of four units of anchor with diameter of 10 mm planted 90 mm depth on T concrete beams with dimension of 300 mm x 300 mm x 150 mm as many as three beams for each of them using cast in place and post installed installation methods. The results of the experiment showed that concrete compressive tension value (f'_c) is 25.69 MPa, anchor tension value (f_u) is 383.25 MPa, anchor adhesion tension value (μ) with cast in place method is 2.25 MPa and post installed method is 1.56 MPa. Theoretically, the damage occurred in pull-out condition; while in the experiment, the test showed a difference in pull-out capacity using cast in place installation method of 38.38 kN with deformation of 13.81 mm, which is higher than theoretical value of 26,083 kN and using post installed method of 36.62 kN with deformation of 8.89 mm, which is higher than theoretical value of 18,084 kN and the experiment indicates that the anchor is perfectly pull-out.

Keywords: anchor, pull out, cast in place, post installed

INTRODUCTION

Anchor has an important role in connecting steel and concrete structure components. The development of anchor technology has reached the expansion anchor model where the anchor can be installed when the concrete has been hardened which is known as post-installed method, and the installation of anchor before concrete casting known as cast in place method. The mechanism of load transfer on anchors can occur in a variety of ways, and the main way is mechanical interlocks or bond slip that can cause concrete breakouts, pull-outs, and splitting [6].

The damage caused by pull-outs on anchors is similar to that of reinforced concrete, such as when deformation occurs in reinforced concrete due to flexural load, shear and its combination, so that the bond tension reaches the limit strength until it reaches the bond slip mechanism. According to Bali (2017), bond slip occurs when the composite bond between concrete and the surface of steel component has been lost so that it interferes with the distribution of voltage until finally happen a crack. Research conducted by Prasetyo (2019) shows that the increasing number of ribs or spiral area on the surface of the reinforcement affects the interlocking mechanism to reduce the bond slip effect. The research on spiral steel plate can reduce bond slip risk up to 70%. In general, the case of anchor pull-out can cause the failure of bond slip, where the anchor is pulled out of the concrete [3].

According to Philipp, (2012) pull-out failure is based on the anchor effective depth effect on concrete. Pull-out failure is also related to anchor capacity based on cast in place method and post installed installation methods. The definition cast in place method is generally that the anchor is installed before the concrete is poured, while the definition of the post installed method is that the anchor is carried out on concrete that has been hardened by perforating with a drill and then the anchor is installed.

The application of expansion anchors that accept pull-out axial loads need to be tested on post-installed and cast in place methods related to pull-out failures, to determine the possibility that anchors can be pulled out of concrete without damaging concrete material. Expansion anchor pull-out test was conducted to investigate the distribution of expansion anchor group strength on post-installed and cast in place concrete. Both methods used are reviewed based on the behavior of anchor failure due to pull-out, by pulling the expansion anchor group of hammer drive anchor type named "Sanko" amounted to 4 units with a diameter of 10 mm, planting in depth of 90 mm on ready mix concrete quality of 25 MPa on T beam of 300 mm x 300 mm x 150 mm and pulled using UTM machine, the testing is stopped when deformation continued to increase without any increase in loads.

METHODOLOGY

Pull out failure on Sanko hammer drive anchor using cast in place and post installed methods on ready mix concrete with quality of 25 MPa go through the stage of anchor tensile test, compressive strength test and pull-out test anchor group. The object of the experiment was Sanko hammer drive expansion anchor with a diameter of 10 mm (d_a) and an embedded length of 90 mm (h_{ef}). It also used T beam with size of 300 mm x 300 mm, 150 mm concrete ready mix with quality of 25 MPa installed four anchors with distance between anchors is 10 d_a or 100 mm. The dimensions of the test object have been theoretically tested to meet the failure requirements in pull-out behavior and meet the requirements of splitting on concrete with a minimum distance between anchors confirm article D.8 SNI 2847-2013. Cast in place method of three T beams mounted four anchors diameter 10 mm (d_a) with depth of 90 mm (h_{ef}) on wet concrete and after the concrete life of 28 days, the stick of Sanko hammer drive anchor is hit until flat. While in the post installed method, three of T beams were installed four anchors and each anchor point in the drill with diameter 10 mm (d_a) with depth of 90 mm (h_{ef}), the hole was cleaned, and then the anchor was planted and the anchor stick was hit until it has flat surface. Hitting Sanko hammer drive anchor can cause the tip of the anchor in the concrete bloom so that it can obtain the interlocking between the tip of the Sanko hammer drive anchor against the concrete.

Sanko Expansion Hammer Drive Anchor

Sanko hammer drive expansion anchor was used to bind / plant on the wall or concrete by knocking the stick until flat then tighten the bolts. After the knock process, the tip of the anchor can be firmly attached on the concrete/wall. The working system of post installed hammer drive anchor was that the tip of anchor works as interlocking on concrete; as well as the working system of cast in place hammer drive anchor, but it also worked as an adhesion along the anchor stick.

Anchor Adhesive Tension on Concrete

Nawy (1998) and Mac Gregor (1992) (in Prasetyo, 2019) said that in general, the adhesive tension between concrete and reinforcement is influenced by: a) Adhesion, that is a bonding due to the process of cement hardening reaction on the surface of the reinforcement; b) Friction, a shearing resistance to slippage and interconnecting when the reinforcement experience tensile tension; c) Interlocking, the reaction of spiral/rib reinforcement to the concrete matrix around the reinforcement; d) Gripping, an effect due to concrete drying around the reinforcement; e) The effect of concrete quality which includes tensile strength and compressive strength, due to insistence by radial tension, concrete undergoes roving tensile tension; f) Effect of tip reinforced anchor mechanism, reinforced bending and reinforced crossing; and g) Diameter, shape and distance of the reinforcement.

On cast in place system using expansion anchor, adhesion and friction factors are very clear due to the hydration reaction between cement and anchor cover, but the interlocking effect plays more role in the binding of anchor components into concrete. On post installed system, the interlocking factor plays a full role as the drill hole effect causes loss of adhesion and friction mechanisms.

Anchoring System

Anchors were used to connect structural and nonstructural elements into concrete. Anchors serve to transfer the tensile force and external shear force that work on the connection. The load transfer mechanism that occurs in anchors is usually identified such as mechanical interlock, friction and/or bond (attachment) as illustrated in the pictures below:

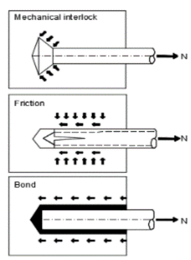


FIGURE 1. Load transfer mechanism on anchor (Eligehausen, et al. (2006)

Anchor Expansion

Anchor expansion basically consists of bolts with cone ends which are then developed to press into the wall of the drill hole on the concrete during installation. The anchor with expansion type transfers the load to the surrounding concrete by means of lateral expansion against the side of the hole in the drill. The principle of the load transfer mechanism that occurs in the expansion anchor is to take advantage of the friction of the anchor embedded against the concrete that surrounds it. The embedded anchor end withstands external tension forces through expansion force and friction force between the contact surface of the anchor tip embedded with the hole in the drilled concrete. The presence of compressive force produced by anchors during installation creates an interlocking mechanism on anchors as a function to withstand the external forces that occur [4]

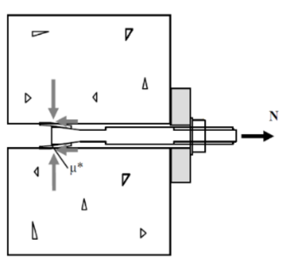


FIGURE 2. Distribution Mechanism of Forces on Expansion Anchor [7]

Anchor Pull-out Failure

Pull-out failure on post installed method may occur if the interlocking mechanism is not sufficient to withstand the external tensile forces resulting in slips, while the pull-out failure on cast in place method is assumed to use the bond slip approach and the interlocking role at the anchor tip. As in spiral reinforcement where the friction mechanism, adhesion, and interlock in rib reinforcement play an important role in the action of bonding between the steel components and concrete. The cone part on the tip of Sanko drive expansion anchor holds the role of mechanical interlock to withstand external forces channeled into concrete. Therefore, the capacity of pull-out anchor group theoretically as follows:

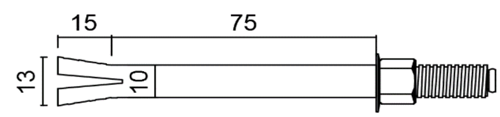


FIGURE 3. Sanko Anchor Hammer Drive

Specimen Data

Anchor:

n = 4 units

d_a = 10 mm

f_{ya} = 337,5 MPa

f_{ua} = 383,25 MPa

h_{ef} = 90 mm

Concrete:

f'_c = 25,698 MPa

μ_1 = 2,25 MPa

μ_2 = 1,56 MPa

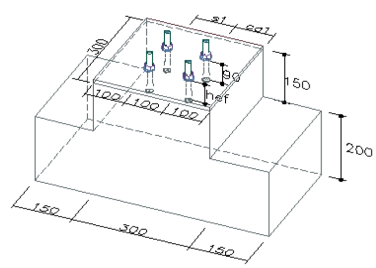


FIGURE 4. Test Object Specimen

Pull-out Failure

a. Cast in Place Method

h_1 = 75 mm

h_2 = 15 mm

d_{a1} = 10 mm

d_{a2} = 13 mm

$A_1 = \pi \cdot d_{a1} \cdot h_1$

$= 2356{,}194\ mm^2$

$A_2 = \pi \cdot \left(\frac{d_{a1}+d_{a2}}{2}\right) \cdot h_2$

$= 541{,}925\ mm^2$

$A_{1,2} = A_1 + A_2$

$= 2898{,}119\ mm^2$

$N_p = \frac{n \cdot A_{1,2} \cdot \mu_1}{1000}$

$= 26{,}083$ kN

b. Post Installed Method

h_2 = 15 mm

d_{a1} = 10 mm

d_{a2} = 13 mm

$A_{1,2}$ = 2898,119 mm^2

$$N_p = \frac{n \cdot A_{1,2} \cdot \mu_2}{1000}$$

= 18,084 kN

RESULT AND DISCUSSION

1. Cast in Place Method

Pull-out test data on anchor group using cast in place method is shown in the figure below:

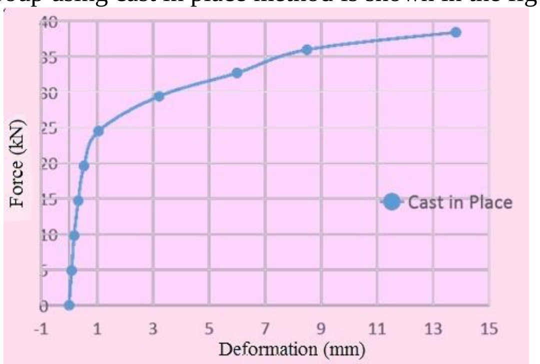


FIGURE 5. Relationship curve of Force-Deformation of Pull-out Test Using Cast in Place Method

As shown in the curve between force and deformation on pull-out testing using cast in place method, the ultimate force is achieved at 38.38 kN and deformation at 13.81 mm, the failure occurs when the ultimate force is exceeded.

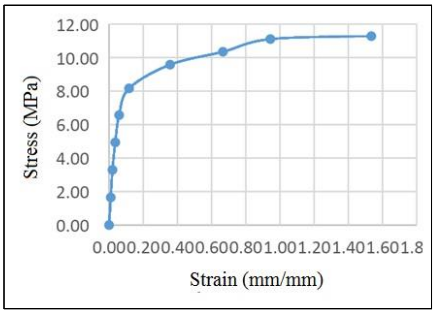


FIGURE 6. Curve of Stress-Strain on Anchor Test Using Cast in Place Method

In the figure 6 above, it provides curve slope information at the initial stage of receiving forces which indicates the modulus of anchor elasticity to concrete occurring at a tension of 7.90 N /mm^2 or at a force of 23.70 kN. While the results of the experiment show a smaller value than the analysis result (23.70 kN < 26.08 kN).

2. Post Installed Method

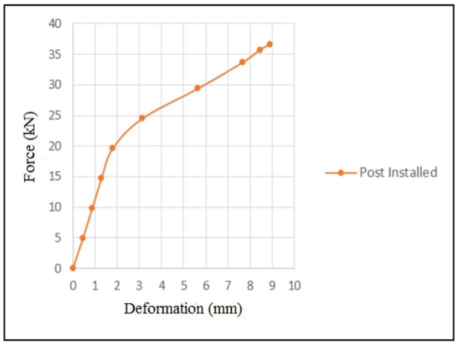


FIGURE 7. Relationship Curve between Force and Deformation on Pull-out Test Using Post Installed Method

It indicates the relationship curve between force and deformation that occurs in group anchors mounted based on the post installed method. On elastic curves, the force is 19.00 kN with a deformation of 1.6 mm. The ultimate force achieved is 36.62 kN with a maximum deformation of 8.89 mm and failed when the ultimate force is exceeded.

The slope of the curve at the initial stage of receiving force indicates the modulus of the anchor elasticity against the concrete occurring at a tension of 6.20 N/mm^2 or at a force of 18.61 kN. While, the results of the experiment show a greater value than the analysis result (18.61 kN >18.08 kN).

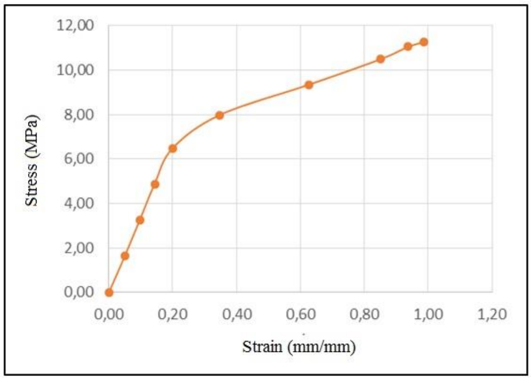


FIGURE 8. Curve of Stress-Strain on Anchor Test Using Post Installed Method

Comparison of Curve of Force Using Cast in Place Method and Post Installed Method

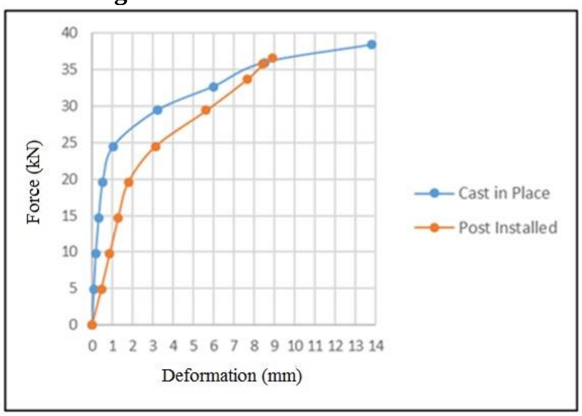


FIGURE 9. Curve of Force Comparison Using Cast in place method and Post Installed Method

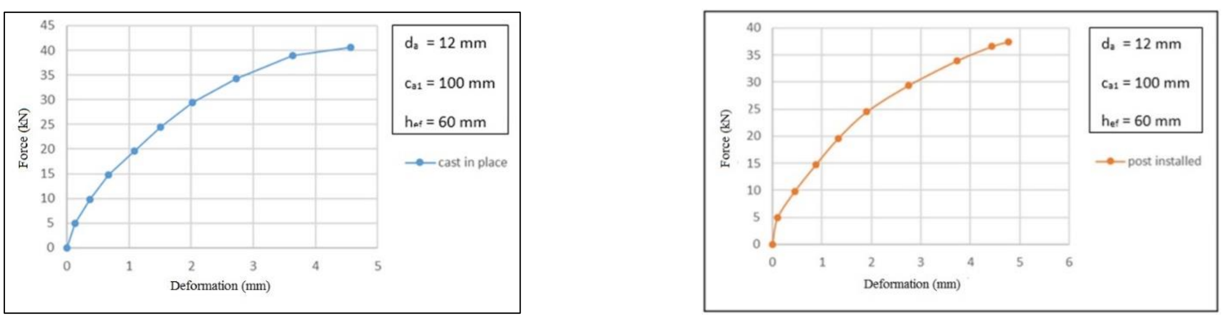
The curve above explains that the anchor installation method has a significant effect on the curve of force and deformation. The results of analysis using Cook's theory which show that the post installed method produced a smaller force than the cast in place method that is 18.08 kN<26.08 kN. Theoretically, the cast in place method takes into account the distribution of force along the area of the anchor cover, namely the influence of adhesion and interlocking mechanism at the tip of the anchor. In the post installed method, the distribution of force along the area of the anchor cover occurs unevenly, but the interlocking effect holds a large contribution in the force transfer mechanism. Therefore, the capacity of the resulting force is relatively smaller than the cast in place method.

Pull-out test results using cast in place method also showed a relatively larger force but a smaller deformation increase from the post installed method pull-out test results at the beginning of receiving tensile force (36.62 kN < 38.38 kN). However, when the maximum force was achieved, the post installed method resulted in a smaller deformation of 8.89 mm.

On elastic curves that occur in pull-out test using cast in place method, the resulting force is 23.70 kN with deformation of 0.7 mm, in post installed method the resulting force is 18.61 kN with deformation of 1.6 mm. If it uses larger force, the cast in place method gives a smaller deformation result than the post installed method. This means that the force distribution mechanism that occurs in the anchoring (adhesion and interlock) using cast in place method is stronger so that it affects the bond between anchor and concrete. The test result of post installed method is smaller because in theory, the distriution mechanism of force that occurs more rely on the interlock effect on the tip of the anchor and the treatment of concrete when drilling causes the mechanism of friction between the anchor against the concrete becomes reduced and uneven.

Comparison with Related Test Results

Based on research [5], the figures below are the curves of pull-out test results using cast in place and post installed methods:

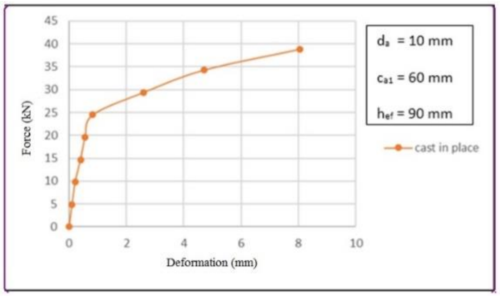


(a) **(b)**

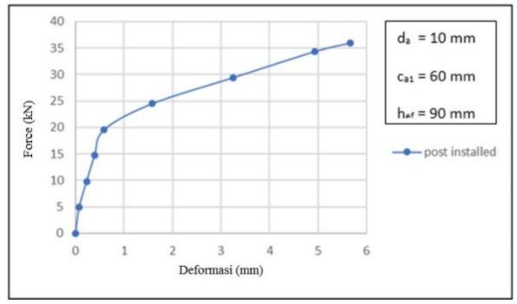
FIGURE 10 (a) Curve of Force-Deformation on Pull-out Test Using Cast in Place Method [5]
FIGURE 10 (b) Curve of Force-Deformation on Pull-out Test Using Post Installed Method [5]

The result of figure 10 (a) is:
s = 100 mm, c_{a1} = 100 mm, d_a = 12 mm,
h_{ef} = 60 mm
The result of figure 10 (b) is:
s = 100 mm, c_{a1} = 100 mm, d_a = 12 mm,
h_{ef} = 60 mm.

Another research [2], the figures below are the curves of pull-out test results using cast in place and post installed methods:



(a)

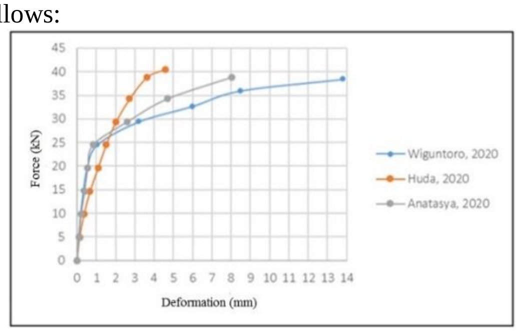


(b)

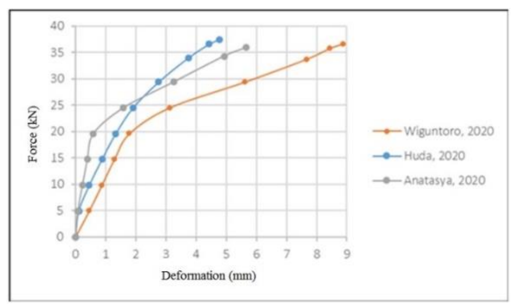
FIGURE 11 (a). Curve of Force-Deformation on Pull-out Test Using Cast in Place Method [2]
FIGURE 11 (b). Curve of Force-Deformation on Pull-out Test Using Post Installed Method [2]

The result of figure 11 (a) is:
s = 180 mm, c_{a1} = 60 mm, d_a = 10 mm,
h_{ef} = 90 mm.
The result figure 11 (b) is:
s = 180 mm, c_{a1} = 60 mm, d_a = 10 mm,
h_{ef} = 90 mm.

From some of the experiment results that have been shown, the results are compared and made curves as follows:



(a)



(b)

FIGURE 12 (a). Comparison of Pull-Out Test Results Using Cast in Place Method
FIGURE 12 (b). Comparison of Pull-Out Test Results Using Post Installed Method

The research [2] tested the behavior of pull-out failure in hammer drive type anchors with a diameter of 10 mm, with a distance to the edge of concrete c_{a1} = 60 mm or 6 times the diameter of anchors (still within the tolerance of ACI regulations 318-14) [1]. Based on the results shown in Figure 4.10 and Figure 4.11, it shows a relatively large average value of 45.14 kN and 45.44 kN. The difference is in the increase in the value of anchor deformation, where at a distance closer to the edge results in a smaller increase in the deformation value.

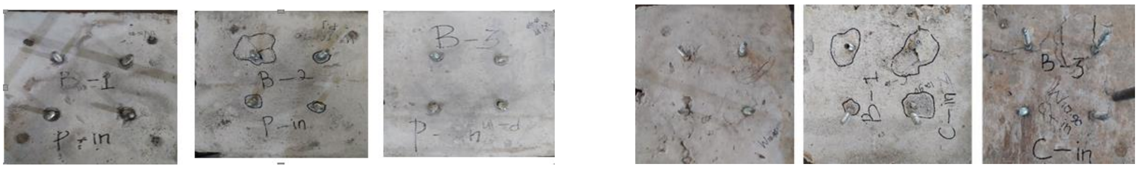
FIGURE 13. Form of Pull-out Failure on Anchor which is close to the edge [2]

Based on research [5]who tested the hammer drive anchor with a depth of anchoring along the h_{ef} = 60 mm, giving results where the depth of anchoring impacts the damage that occurs to concrete. The damage was controlled by breaking into concrete breakouts as in Figures below.

(a) **(b)**

FIGURE 14 (a). Concrete Breakout Damage on Cast in Place Method [5]
FIGURE 14 (b). Concrete Breakout Damage on Post Installed Method [5]

At a deeper depth in this study with h_{ef} = 90 mm, failure was controlled by the pull-out behavior shown in the following picture:



(a) **(b)**

FIGURE 15 (a). Pull-out Failure on Cast in Place Method
FIGURE 15 (b). Pull-out Failure on Post Installed Method

The maximum value of the anchor test result with a depth of h_{ef} = 60 mm (h_{ef}/d_a = 5), there is a difference of 3.34% greater than the anchor test with a depth of h_{ef} = 90 mm (h_{ef}/d_a = 9). Previous research has explained the relationship between depth installation (h_{ef}) and anchor diameter (d_a), where smaller h_{ef}/d_a ratio tend to fail on concrete damage with higher strength (N_u), while higher h_{ef}/d_a ratio tend to fail in pull-out conditions with lower strength (N_u). The depth of anchor installation h_{ef} = 90 mm and the diameter of 10 mm caused a different failure, namely the failure of the anchor pullout.

CONCLUSION

The results of tests showed results: concrete compressive tension (f'_c) of 25 MPa, anchor ultimate tension (f_u) of 383.25 MPa, adhesion tension (μ1) using cast in place anchoring method of 2.25 MPa, adhesion tension using post installed method of 1.56 MPa. Pull-out test results showed a force of 38.38 kN on cast in place method and 36.62 kN on post installed method. Based on the analysis of pull-out test results on specimens with anchor distance s = 100 mm, c_{a1} = 100 mm on concrete f'_c = 25 MPa using cast in place and post installed methods that has been described, it can be concluded as follows:

1. Based on the results of theoretical analysis of anchoring failure system, the type of failure was controlled on pull-out failure because it provided the smallest force value of the four types of failures which is 26,083 kN for cast in place method and 18,084 kN for post installed method. The results of the analysis showed similar results of experiments where the pattern of failure that occurs in the form of pull-out failure.
2. Pull-out test on both methods showed the results of 38.38 kN at deformation of 13.81 mm (using cast in place method) and 36.62 kN at deformation of 8.89 mm (using post installed method). However, Cook's theory provided less efficient results when applied to cast in place methods compared to post installed methods. In cast in place method, the force on elastic curve is lower than predicted result (23.70 kN < 26.08 kN), while in post installed method gives higher force to predicted result (18.61 kN > 18.08 kN).
3. Based on the test results, cast in place method is better than post installed method. This is evidenced by the greater value of ultimate force (38.38 kN > 36.62 kN) as well as the increase in deformation that makes a significant difference. The initial deformation increase in the cast in place method tends to be small because of the adhesion and interlock mechanism on the anchor against the concrete hole wall. In contrast to the post installed method, the increase in deformation at the beginning of tensile loading tends to be greater

because the surface effect of the drill hole causes an uneven force distribution mechanism and relies only on the interlock effect on the tip of the anchor.

4. The pattern of failure that occurs in concrete due to group anchoring shows that the distance between anchors does not affect the occurrence of pull-out damage as long as the distance used in the design is still in the calculation procedure in the sense that it is not greater than the critical distance (minimum distance = 6 d_a). The depth of anchor installation affects the type of damage that occurs in anchors or concrete. At the same distance between anchors, but the difference in the depth of anchor installation causes variations in the form of damage to the specimen. The strength value generated in shallow anchoring (h_{ef} = 60 mm) is greater than the value of deeper anchoring (h_{ef} = 90), but the deformation of anchors with shallow anchoring is much smaller than the deeper anchoring. The lower depth of anchor installation lead to the controlled damage towards the damage to the concrete breakout.
5. Experimentally, the distance of anchors affected the pull-out strength that occurs in the anchor against the concrete. The further distance between the anchor lead to the greater resulting force, as long as the distance is still smaller than the required critical distance. The results of the study confirm the theories that have been done in previous research.

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