Breakout Capacity of Headed Anchors with Delayed Installation

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Synopsis: The objective of this research was to evaluate the impact on concrete breakout capacity of anchors in tension due to delay in the installation using the puddle-in technique. The puddle-in technique is the process of installing an insert (anchor) into fresh concrete once the surface has been finished. The installation was delayed by up to 160 minutes. Another installation method, pre-installation, is the attachment of the insert to the formwork or reinforcement before the concrete has been poured.

The results discussed were obtained from research conducted at Curtin University of Technology, Perth as an undergraduate research project. Twenty four anchors were tested in tension. The principal test variables were anchor installation delay (and hence, loss of slump of the concrete) and concrete compressive strength at the time of anchor tension testing. The anchor type and edge distances were kept constant. The anchors all failed due to concrete cone breakout failure mode.

Several statistical analyses were conducted on the data; it was found that the imposed anchor installation delay did not affect anchor concrete breakout capacity, even when installation was delayed significantly resulting in zero slump concrete. However this conclusion is valid only when the anchors were tested with concrete compressive strengths around 15 MPa. The anchors tested at lower concrete compressive strength did exhibit a decrease in capacity when anchor installation was delayed.

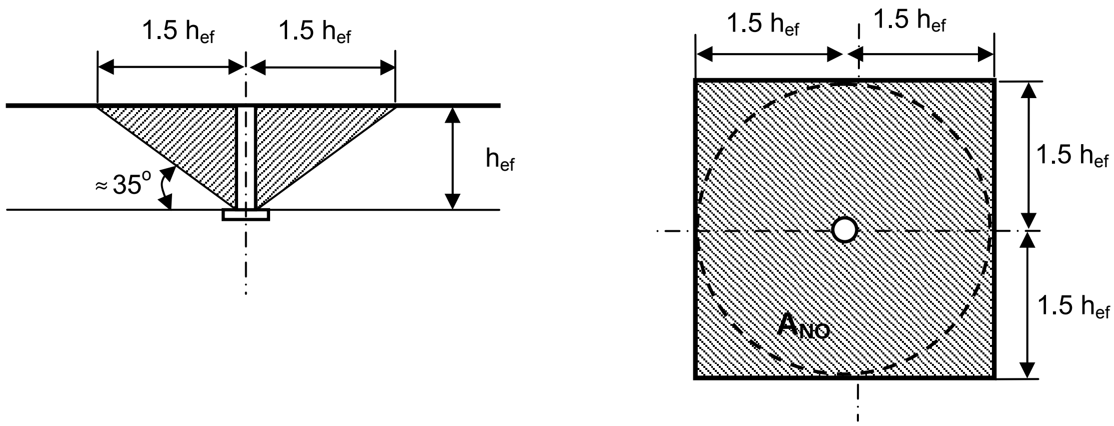
Keywords: anchors; tension failure; installation delay; concrete breakout; slump reduction; precast concrete.

1. Background

Previous research conducted at Curtin University has shown that the installation technique of anchors; puddle-in or pre-installed, does not adversely impact upon the concrete breakout capacity of the inserts (1,2). The research and associated industry survey highlighted a lack of information on the impact of installation technique on concrete breakout capacity of inserts.

The Concrete Capacity Design (CCD) approach has been calibrated using an extensive data bank of tests (3,4,5,6). The capacity of an insert under tension loading is calculated assuming a concrete breakout cone. The CCD is noted in the Australian Standard for Tilt-Up Concrete Construction to be a reliable model for predicting the concrete breakout strength of an insert and is presented in the National Precast Concrete Handbook as a design guide (7,8). The anchorage of the insert and therefore its capacity is affected by many variables. These include proximity to edges and holes, concrete strength at lifting, embedment depth and the presence of cracks. Other failure modes are possible including concrete splitting, edge breakout, steel rupture or bond failure/pull out (8).

The CCD approach is based upon an idealized concrete failure cone that has an angle of inclination of 35 degrees between the failing surface and the surface of the concrete member. This angle corresponds to the observation that the horizontal extent of the concrete breakout surface is approximately three times the embedment depth. The projected failure of the concrete cone breakout is simplified to a rectangular plan of area $(3h_{ef})^2$. The idealized concrete breakout cone is shown in Figures 1(a) and 1(b) (7).



(a) Section through failure cone (b) Plan of failure cone

Figure 1. Idealized concrete breakout cone.

The Precast Concrete Handbook provides SI unit equations to determine the concrete cone failure load (7). The failure load is a characteristic value (5% fractile), that is, the failure load has a 95% percent probability of the actual strength exceeding the nominal strength. The nominal concrete breakout failure load, N_b, of a single anchor unaffected by edge influences or overlapping cones of failure of neighboring anchors is given by (7):

$$N_b = 10\, h_{ef}^{\;1.5} \sqrt{f'_c} \quad \text{(newton)} \qquad (1)$$

Where h_{ef} = effective embedment depth (mm)

f'_c = characteristic compressive strength, $f_c' \leq 65$ MPa (MPa)

The basic formula is modified by factors to take into account the shape of failure surface of multiple anchors, the eccentricity on a group of anchors, edge distance, spacing and absence/presence of cracking. Anchors located in regions of cracking (0.3-0.4 mm crack width) show a reduction in the concrete capacity of about 25 to 35 percent compared to un-cracked concrete (9).
The calculated concrete breakout failure load is therefore:

$$N_{bcalc} = 10 h_{ef}^{\;1.5} \sqrt{f_c'}\, \psi_1 \psi_2 \psi_3 \frac{A_N}{A_{NO}} \quad \text{(newton)} \qquad (2)$$

A_{No}=projected area of a single anchor $= 9h_{ef}^2$;

A_N=actual projected area at the concrete surface; and

ψ_1 =1.0 for a single anchor (as is the case for the Curtin research),

ψ_2 =1 if $c_1 \leq 1.5h_{ef}$, (as is the case for the Curtin research)

ψ_2 =0.7 + 0.3 ($c_1/1.5h_{ef}$) if $c_1 \geq 1.5h_{ef}$ where c_1 = distance to the nearest edge;

ψ_3 =1.25, (as is the case for the Curtin research), if analysis shows that $\sigma_{ct} < f'_{cf}$ in region of anchor at service load, otherwise 1.0.

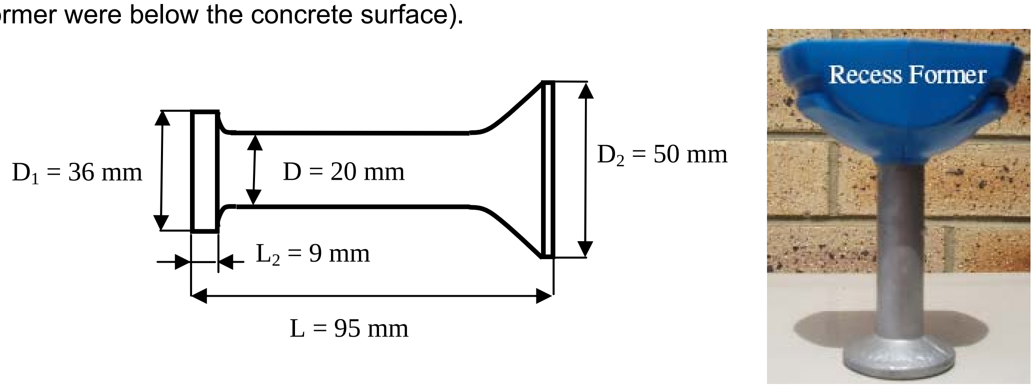
2. Test Programme

2.1 Overview

The test program was divided into two stages; trial and principal testing. First, the trial test on four anchors with delayed installation times attempted to determine the range of delay times and slumps that would differentiate anchor concrete breakout loads. Once the slump range was determined and the test setup was satisfactory, the principal testing was undertaken resulting in three further concrete pours (pour 2, 3 and 4) and a total of 24 anchor tests. Of these 24 anchors, 3 were pre-installed and 5 were puddle-in with no delay and 16 were installed with delays of between 30 minutes and 160 minutes. Slump values at the time of insert installation ranged from 56 mm to zero.

2.2 Anchors

The anchors used in this investigation are a proprietary lifting product. The anchors tested were a headed anchor with a length of 95 mm as shown in Figure 2(a). The anchors were fitted with a plastic recess former, as shown in Figure 2(b), giving an effective embedment depth, h_{ef}, of greater than 95 mm (if the recess former was flush with the concrete surface h_{ef} would be approximately 103 mm, even greater if the recess former were below the concrete surface).



(a) Schematic of headed anchor used in research (b) Recess former and anchor

Figure 2. Headed anchor used in research.

2.3 Concrete Panels

Testing of the anchors was undertaken using panels with two anchors embedded in each concrete panel. The panels were fabricated in the Curtin University Civil Engineering Laboratories. The width of the panel and spacing of the anchors was chosen to avoid the influence of edge distances and/or anchor proximity on the failure cone. The panels were 2250x1200x250 with the anchors spaced 875mm apart (Figure 3). For concrete pours 1 and 2, two such panels were cast and for concrete pours 3 and 4 four panels were cast in one 9 m long casting bed using timber separators for the panels. Lifting inserts (1.3t anchors) were cast into the panels to enable removal of the panel after testing. Their locations were generally in diagonally opposed corners to prevent interference with the concrete break out cone of the test anchors.

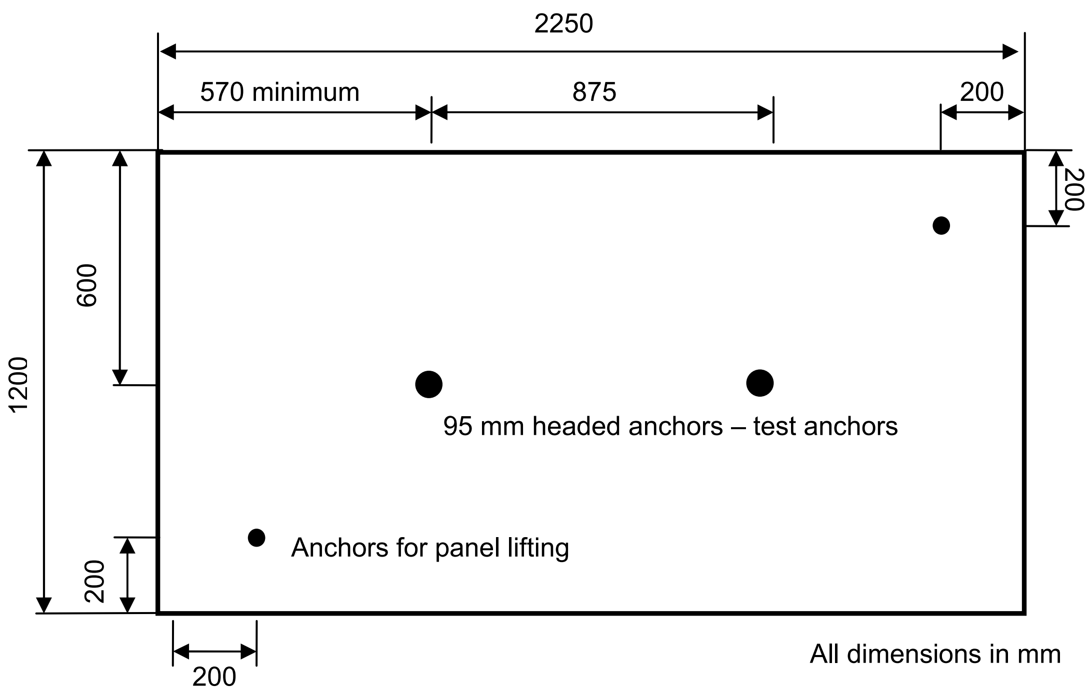


Figure 3. Panel dimensions and anchor locations

2.4 Concrete

The concrete used in the fabrication of the panels was specified to achieve 15MPa at time of testing approximately 24 hours after pouring. To achieve the desired compressive strength, ready mixed concrete with a 28 day nominal strength of 40MPa was supplied. Concrete slump on arrival ranged from approximately 65 mm to 100 mm. By the time the concrete had been poured and finished, the slump had reduced to between 56 mm to 35mm.

2.5 Anchor Installation Method and Delay

The anchor installation techniques used in this research were pre-installed installation and puddle-in installation. Pre-installed anchors were secured in position by attaching them to a timber slat suspended across the formwork as shown in Figure 4(a). The method of installing a puddle-in anchor is a gentle up and down motion of the anchor into the concrete after the concrete has been vibrated and screeded. Puddle-in installation occurs immediately after the concrete surface has been screeded. In this research, the time at which the anchor was installed after finishing the concrete was extended. As the slump decreased to zero with increased delay, anchor installation became more difficult. The anchors were tapped in with a rubber mallet until the recess formers were flush with the finished concrete surface. For the highly delayed anchor installation the anchors required considerably more effort to install and the anchors were hammered into the concrete with high frequency blows of the rubber mallet.

(a) Preinstalled anchor before casting (b) Puddle-in technique

Figure 4. Anchor installation – methods

2.6 Tension Test Set-up

The principle of the testing procedure is to self react the jack off the specimen to reduce the need for a hold-down system. A 250x150RHS spreader beam is positioned on a 1030mm diameter concrete liner (spreader cylinder), 44mm thick and 900mm deep for the 20 tonne jack to be centered on top as shown in Figure 5(a). A custom made loading frame built specifically for this test is placed on the jack ram and connected to the anchor via a lifting clutch (Figure 5(b)).

(a) Elevation showing spreader beam and jack (b) View into liner showing lifting clutch

Figure 5. Tension test set-up.

3. Test Results

3.1 Concrete Breakout Cone

The expected failure load for anchors in tensile load conditions at ultimate loading is a breakout prism, i.e. a concrete cone failure. All the failure modes were brittle concrete failure, with no prior cracking of the concrete surrounding the anchor. The failure angle of the concrete breakout cone was determined to be an average of 25 degrees. It was found that a considerable shift of angle occurs; the angle of failure is relatively steep with an average of 27 degrees at the base of the cone before it becomes shallow with an average of 15 degrees. The concrete cone failure surface was a truncated circle with one face of the concrete cone at the surface being straight (Figure 5(b)). This failure pattern was consistent with failures observed in previous research (1,2).

3.2 Concrete Composition

Ten specimens were selected to examine the concrete composition in the vicinity of the anchor and across the entire concrete breakout cone cross section. In order to inspect the concrete composition, the concrete breakout cones were machine sawn directly next to the anchor, with 1-2mm clearance to protect the saw blade. The specimens selected were samples of pre-installed, no-delay, delayed and long delay (no slump) anchor installation. There were no significant differences in the concrete composition. They were equally random in terms of aggregate distribution and paste and/or void variation.

3.3 Surface Disturbance

During anchor installation, radial ripples in the concrete surrounding the anchor were observed. This disturbance was observed for all puddle-in anchors, with no delay or with delay. It was observed that the later the anchor was installed; the disturbance radius and ripple depth increased. In some cases the disturbance of concrete around the head of the anchor was visually significant as shown in Figure 6(a) and the ridges of the concrete surface were of the order 0.5mm high as shown in Figure 6(b) for the anchor of pour 2 (test 8) which was installed after 150 minutes delay.

(a) Plan view (b) Elevation

Figure 6: Surface disturbance around anchor void former

3.4 Concrete Breakout Loads (N_{btest}) and Concrete Properties

The failure loads of the anchor, the anchor installation method and concrete properties as recorded are shown in Table 1. Three concrete batches had compressive strengths at time of testing of 15 MPa and the fourth was only 9 MPa. All concrete was ordered as the same mix from the same batching plant and all specimens were tested 24 hours after casting. The 28 day compressive strength of all concrete was over 40 MPa. It would appear the early age strength gain of concrete in pour 4 was compromised.

The data was grouped and statistical analyses performed for a number of different groupings of data. By considering the anchor installation delay in terms of both time delay and a percentage loss of slump, three groups of anchor installation type were defined. These were: a no delay group consisting of pre-installed or immediate puddle-in anchors where the time of delay was zero. The slump at the time of immediate installation was taken as the datum slump. The second group was moderate delay in installation where the average time of delayed installation was approximately one hour (56 minutes) after concrete finishing and the loss of slump, compared with the datum with no delay, was around one half (56%). The third group was long delay in installation where the delay was over two hours on average (125 minutes) and the loss of slump, compared with the datum with no delay was on average 96%, essentially a zero slump concrete. The data is shown in Table 2. Tables 2 is sub-divided into pours 1 to 3 and pour 4 to compare the averages and standard deviations of grouped data with variation in the concrete compressive strength at time of testing.

The concrete breakout load of the anchors of the two delayed groups and the non delayed group for pours 1 to 3 were analyzed using the ANOVA statistical method; analysis of coefficient of variation between groups. The average concrete breakout load and standard deviation for each is shown in Table 2 and was 90 ±4 MPa for the non delayed group, 90 ±5 MPa for the moderate delay group and 89 ±5 MPa for the long delay group. The ANOVA analysis for this indicated that there was over 90% probability that the delay resulted in no change in the concrete breakout capacity (statistically stated as: the probability of this result assuming the null hypothesis, there is not a real effect due to delay, is 0.92).

Table 1: Recorded data for concrete and test breakout loads

Pour	Test	Anchor Installation Method/Time		Concrete Properties					Test Concrete Break-out Load
		Pre-installed?	Time delay (mins)	28 day $f_{cm.28}$ (MPa)	Test day $f_{cm.test}$ (MPa)	Slump @ arrival (mm)	Slump @ installation (mm)	Slump Loss (%)	N_{btest} (kN)
1	1	No	0	44±2	15±1	90	56	-	97.0
1	2	No	30		15±1		35	38	89.0
1	3	No	50		15±1		29	48	93.0
1	4	No	92		15±1		10	82	91.0
2	5	No	0	No data	14±1	65	35	-	91.0
2	6	No	0		14±1		35	-	90.0
2	7	No	120		14±1		0	100	89.0
2	8	No	150		14±1		0	100	80.0
3	9	Yes	Not applic.	46±1	15±1		90	-	89.0
3	10	No	90		15±1		13	63	95.0
3	11	No	0		15±1		35	-	83.0
3	12	No	160		15±1		0	100	91.0
3	13	Yes	Not applic.		15±1	90	35	-	87.0
3	14	No	90		15±1		13	63	83.0
3	15	No	160		15±1		0	100	93.0
3	16	No	0		15±1		35	-	92.0
4	17	No	45	42±2	9±1	100	33	59	82.5
4	18	No	65		9±1		16	80	58.6
4	19	No	125		9±1		0	100	61.8
4	20	No	125		9±1		0	100	50.3
4	21	No	45		9±1		33	59	75.3
4	22	No	125		9±1		0	100	53.7
4	23	Yes	Not applic.		9±1		80	-	85.6
4	24	No	45		9±1		33	59	75.4

Table 2: Grouping of test data for ANOVA analysis

Pour	Test	No Delay		Moderate Delay				Long Delay			
		$N_{btest}\ (kN)$	$\frac{N_{btest}}{N_{btestdatum}}$	$N_{btest}\ (kN)$	Slump Loss (%)	Delay (min)	$\frac{N_{btest}}{N_{btestdatum}}$	$N_{btest}\ (kN)$	Slump Loss (%)	Delay (min)	$\frac{N_{btest}}{N_{btestdatum}}$
1	1	97.0	1.0								
1	2			89.0	38	30	0.92				
1	3			93.0	48	50	0.96				
1	4							91.0	82	92	0.94
2	5	91.0	1.00								
2	6	90.0	1.00								
2	7							89.0	100	120	0.98
2	8							80.0	100	150	0.88
3	9	89.0	1.01								
3	10			95.0	63	90	1.08				
3	11	83.0	0.95								
3	12							91	100	160	1.04
3	13	87.0	0.99								
3	14			83.0	63	90	0.95				
3	15							93.0	100	160	1.06
3	16	92.0	1.05								
1-3	**Average**	**90.0±4**	**1.00±0.03**	**90.0±5**	**53±10**	**65±30**	**0.98±0.07**	**89.0±5**	**96±8**	**136±30**	**0.98±0.07**
4	17			82.5	59	45	0.96				
4	18							58.6	80	65	0.68
4	19							61.8	100	125	0.72
4	20							50.3	100	125	0.59
4	21			75.3	59	45	0.88				
4	22							53.7	100	125	0.63
4	23	85.6	1.0								
4	24			75.6	59	45	0.88				
4	**Average**	**85.6**	**1.0±0.0**	**78±4**	**59±0**	**45±0**	**0.90±0.05**	**56±5**	**95±10**	**110±30**	**0.66±0.06**
All	**Average**		**1.00±0.03**		**56±9**	**56±23**	**0.95±0.07**		**96±8**	**125±30**	**0.84±0.18**

The concrete breakout loads for pour 4 were 85.6 kN for the one non delayed anchor, 78±4 kN for the moderate delay group and 56 ±5 kN for the long delay group. To assess if the delay had affected concrete breakout load additional data was required. Test data from previous research at Curtin University for the same anchor type without delayed installation which was tested at concrete compressive strength of 8 MPa was used (1). This enabled an indicative ANOVA analysis to be performed. The ANOVA analysis indicated the probability of this result, assuming the null hypothesis, is 0.028. That is, there is a high likelihood that the anchor installation delay resulted in a difference in the mean concrete breakout capacity of the anchors for pour 4 which was tested at low concrete strength.

For the concrete breakout loads to be analyzed as one data set, actual test concrete breakout load could not be used. A normalized relationship was used; the concrete breakout loads were expressed as a ratio of the breakout load after delayed installation (N_{btest}) to the datum concrete breakout load for non delayed anchor(s) of the same concrete pour ($N_{btestdatum}$). The datum was taken as the average of the concrete breakout load for all pre-installed or immediately puddle-in anchors for that pour. For pour 1 the $N_{btestdatum}$ was 97kN (only one test with no delay), for pour 2 the $N_{btestdatum}$ was 90.5 kN, for pour 3 the $N_{btestdatum}$ was 87.8 kN and for pour 4 the $N_{btestdatum}$ was 85.6kN (only one test with no delay). The data is presented in Table 2 where the ratio of failure load for the two groups of delayed installed anchors to the datum failure load is shown.

It was found the ratio of the capacity of the anchor with delayed installation to immediate installation was to 0.95±0.07 for the moderate delayed anchors and was 0.84±0.18 for the long delay anchors. Analysis of variance (ANOVA) between the groups indicated there was an effect on concrete breakout capacity due to anchor installation delay when data from all pours was used. The probability of this result assuming the null hypothesis, which is, there is not an effect, is 0.044.

Assessing the data for pour one to three only, it was found that the ratio of the capacity of the anchor with delayed installation to immediate installation was to 0.98±0.07 for the moderate delayed anchors and 0.98±0.07 for the long delay anchors. For the normalized data for the pours one to three, the probability of this result, assuming the null hypothesis, which is, there is not an effect, is 0.764. That is, the effect of delay for the anchors with concrete compressive strength around 15 MPa was statistically unlikely.

3.5 Capacity Predictive Formula CCD

Table 3 summarizes the experimental failure loads compared to the concrete breakout capacity predicted using the CCD method (N_{bcalc}) as described in Equation 2. The only variable considered is compressive strength, the installation method or time of delay was disregarded. The average concrete breakout loads for each pour is shown in Table 3. The data indicates that the CCD method is a conservative predictor of concrete breakout capacity with the ratio of test to failure load approximately two fold. Previous research found the average ratio of test to calculated failure load for the same anchor with different installation techniques (albeit all anchors installed immediately after finishing or pre-installed) was 1.9±0.2. Combining data from the two research populations, a total of 39 tests, and the overall ratio is 2.0±0.2.

This calculated capacity data is determined using h_{ef} = 95 mm. This value is used as the worse case scenario of the anchor head being at the concrete surface, an embedment depth which is guaranteed at least equal to the actual effective embedment depth. The actual effective embedment depth is more likely to be in excess of 103 mm, in which case the ratio of N_{btest} to N_{bcalc} would be 85% of the values reported below, that is, a ratio of 1.8±0.2.

Table 3: Calculated (predicted) and test concrete break-out capacity

Pour	Concrete Compressive Strength- at time of test $f_{cm.test}$ (MPa)	Average Test Concrete Breakout Load $N_{btest}\,(kN)$	CCD Method $N_{bcalc}\,(kN)$	$\frac{N_{btest}}{N_{bcalc}}$
1	15±1	93±3	45±1.5	2.0±0.1
2	14±1	88±5	44±1.5	2.0±0.1
3	15±1	89±5	45±1.5	2.0±0.1
4	9±1	68±13	34±2.0	2.0±0.4

Analysis of variance (ANOVA) was conducted on the ratio of test to calculated capacity between the groups; no delay, moderate delay and long delay. This indicated there was an effect on concrete breakout capacity due to puddle-in anchor delay when data from all pours was used. The probability of this result, assuming the null hypothesis, is 0.98, that is, there is a difference in the ratio of test to calculated concrete breakout load due to the delay. However, when the data for the pours 1 to 3 only is assessed the probability of this result, assuming the null hypothesis, is 0.023. It was concluded that the delayed anchor installation did not compromise the ability of the CCD formula to predict the anchor concrete breakout load for anchors tested with concrete compressive strength of 15 MPa.

The complete data for the current research and previously published research is shown graphically in Figure 7. Note that pre-installed anchors and non delayed puddle in anchors are plotted separately, however, they form one group defined in this paper as no delay anchors. There is a greater scatter in the data for lower strength concretes. This is reflected in AS 3850 which states that testing should be done at greater than 15 MPa.

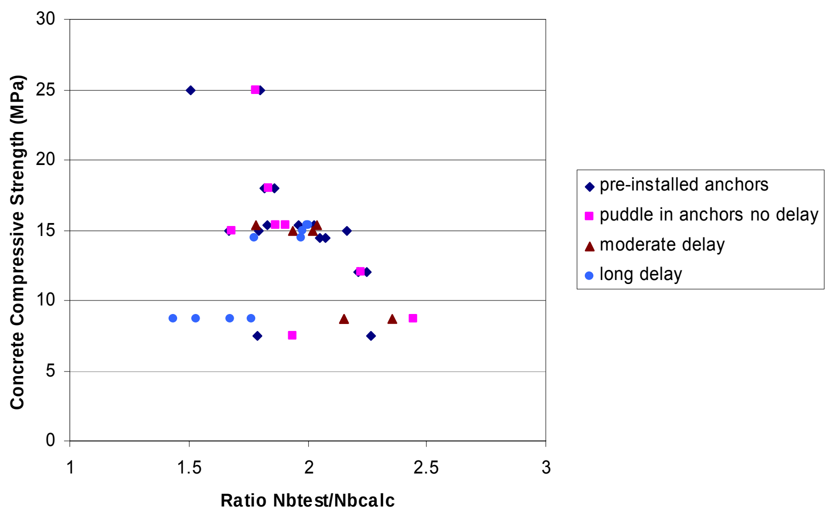


Figure 7. Ratio of Test Concrete breakout load to Calculated Concrete Breakout Load

4. Conclusions

From the data it was found that delaying the installation of the anchor in concrete has no effect on the concrete breakout capacity when the concrete breakout tests were conducted at a compressive strength of at least 15 MPa. The delay in anchor installation may be significant for anchors tested at lower concrete compressive strengths and further testing may be warranted to test this hypothesis given the extremely small sample numbers.

It can be concluded that the concrete composition through the cross section and the concrete surface disturbance surrounding the anchor had no effect on the anchor concrete breakout capacity and the characteristics of the concrete breakout cone. It was found that the average angle of failure is twenty five degrees. Also, it was found that there is a major difference in slope between the base and the top of the breakout cone. This is consistent with previous research with shallow embedment depth anchors. The large cone engagement surface means that disturbance of the concrete around the anchor does not impact on the concrete breakout load. This may not be the case if the disturbance around the anchor is such that premature pullout of the anchor can occur.

It was concluded that the CCD predictive model is conservative. The ratio of test failure load to CCD predicted failure load was an average ratio of 2.0 ± 0.2. Analysis of the ratios of test concrete breakout load to calculated concrete breakout load as a function of time of delay and concrete compressive strength confirmed the conclusion that delay in anchor installation may be significant for anchors tested at lower concrete compressive strengths.

5. Recommendations

Delaying the installation of puddle-in anchors is not recommended due to the disturbance of the concrete surface and concrete around the anchor. However, if anchor installation is delayed, the capacity of the anchor due to concrete breakout may not necessarily be compromised. A combination of delayed anchor installation and low concrete compressive at time of engaging the anchor may render the anchor concrete breakout capacity compromised, and is therefore not recommended.

This investigation was limited to 24 test samples. It is recommended that this investigation be extended with a larger statistical population.

6. Acknowledgement

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