Performance of Cast-in and Post-installed Anchors in Early Age Concrete

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Abstract

This study investigates the behaviour of cast-in headed anchors with void formers and screw anchors in early age concrete. Experimental results obtained showed that for cast-in headed anchors with void formers, pull-out failure through the void can take place prior to the development of concrete cone failure. A new prediction model is proposed in this paper to estimate the capacity of anchors undergoing this new failure mode. Further, results of screw anchors tested in early age concrete showed that early installation does not affect the 28 days performance of the anchors used in this study.

Introduction

Anchors are widely used in the concrete industry mainly as means of connection and lifting. Anchors can be categorized into two main groups, cast-in and post installed. Cast-in headed anchors are widely used as lifting means for prefabricated concrete elements. Lifting anchors are usually installed with void formers to enable easy attachment of the lifting clutches in addition to keeping the anchor flush with the surface to guard the anchor during storage and transport. Post installed anchors can be further classified into expansion, bonded, undercut, and screw anchors. In this paper, the tensile behaviour of cast-in headed anchors and screw anchors in early age concrete is discussed. The focus on the performance in early age concrete is due to the fact that in practice the anchors are loaded before full maturity of the concrete. However, prediction models found in international standards are based on anchors loaded in 28 days concrete.

Background

Headed anchors

Headed anchors loaded in tension fail by pulling out a concrete cone, given that the bearing stress at the bearing head does not exceed 10.5 \( f_c \) [1], and the thickness of the concrete substrata is enough to avoid splitting failure (2 \( h_{ef} \)). Capacity of anchors failing by pulling out a concrete
cone can be predicted by CC-method shown in Equation 1 [2]. This formula is derived for anchors installed in mature concrete (>28 days), without the presence of a void former.

\[ N_{u,c}^0 = 16.8 h_{ef}^{1.5} f_c^{0.5} \]  \hspace{1cm} \text{Equation 1}

Where, \( h_{ef} \) is the effective embedment depth

\( f_c \) is the average compressive strength

Ayad Al-Yousuf [3] investigated the performance of cast-in headed anchors in early age concrete. The experimental program covered the tensile behaviour in high and normal strength concrete at an age as low as 18 hours. The study concluded that the CC-method is capable of capturing the capacity of anchors tested in early age concrete. Anchors tested in the study by Ayad Al-Yousuf [3] were installed without void formers. Recent studies [4, 5] investigated the performance of cast-in headed anchors with void formers in early age concrete. It was found that pull-out failure through the void is taking place prior to the development of the concrete cone failure. Pull-out failure was found to be taking place at low bearing pressures at the anchorage zone (<10.5 \( f_c \)). Therefore, currently available prediction models are unable to capture such failure mode accurately.

**Screw Anchors**

Screw anchors with shallow embedment depth generally fail by pulling out a concrete cone, the cone generated starts at the tip of the first thread on the anchor. However, for deeper embedment depths, the concrete cone becomes shallow where only concrete near the surface break and the remaining length of the anchor is pulled out. The effective embedment depth for screw anchors is determined as shown in equation (2) [2].

\[ h_{ef} = h_{nom} - 0.5h_t - h_s \]  \hspace{1cm} \text{Equation 2}

Where, \( h_{nom} \) is the full length of the screw inside the concrete

\( h_t \) is the thread pitch

\( h_s \) is the distance from the screw tip and the first thread

Studies on screw anchors in mature concrete found that the capacity is in correlation with \( h_{ef}^{1.5} \), with the failure load being about 20% lower than that of typical expansion anchors. Therefore, it was established that the CC-method prediction model for expansion anchors can be used to
predict the capacity of screw anchors. However, the effective embedment depth is reduced by a factor of 0.85. Equation 3 is the modified CC-method formula for screw anchors.

\[ N_{u,c}^0 = 14.6 \, h_{ef,1}^{1.5} \, f_c^{0.5} \]

Equation 3

Where, \( h_{ef,1} \) is the reduced effective embedment depth (0.85\( h_{ef} \))

\( f_c \) is the cylinder compressive strength

Mohyeddin et al [6] investigated the performance of screw anchors in early age concrete. The embedment depth of the anchors tested was 115 mm and the compressive strength investigated ranged from 9.9 to 41.8 MPa. Nonlinear regression analysis on the results of this study produced a prediction model for screw anchors in early age concrete. Upon review of this new model it can be observed that it is really similar to the model in equation (3) with a difference of only 10%. Given the nature of screw anchors and their product dependability, the performance in mature concrete compared to early age is not significantly different.

**Aims and significance**

Equations (2) and (3) have been developed for anchors in mature concrete. In reality anchors may be installed and loaded before the concrete is 28 days old. For cast-in headed anchors that are used for lifting, it is a common practice to load the anchors when the concrete reaches a compressive strength of 15 MPa. However, prediction models used to design the anchors does not take into consideration loading before 28 days. Further, the CC-method assumes a square root correlation between the compressive strength and the tensile strength of the concrete. This may hold true for mature concrete, but for early age it requires further investigation. Screw anchors have become popular in recent years especially in the residential construction industry. Screw anchors are commonly used to fix bottom plates of typical timber framing to an early age cast in-situ concrete slab. However, loading of the screws usually takes place when the concrete has reached 28 days. Early installation effect on the 28 days performance of the anchor has not been investigated in literature, where the majority of the prediction models available assume that the screw anchors are installed and loaded in mature concrete.

**Experimental Program**

**Materials**

Concrete used in this study was ordered from a local supplier, the mix was ordered to be a general Portland cement mix with no supplementary cementitious materials with 28 days
characteristic compressive strength of 25 MPa. The concrete had a slump of 80 mm, and a maximum aggregate size of 14 mm. The concrete was poured directly into the formwork from the mixing truck with the application of vibration to ensure proper compaction. The concrete slabs were covered with a damp cloth and a plastic sheet to avoid loss of moisture.

Specimen geometry

The testing program covered two types of anchors, cast-in headed anchors with void formers and post-installed screw anchors. Figure 1 shows a schematic of the tested cast-in headed anchors, where the effective embedment depth investigated was 50 mm and the diameter of the anchor head was 25 mm. Figure 2 shows a schematic of the screw anchors tested, where the nominal embedment depth from the surface was 80 mm with a fixture thickness of 20 mm and the size of the anchor was M12. Both cast-in headed anchors and screw anchors were installed in concrete slabs with a thickness of 200 mm. This thickness is adopted to avoid splitting failure since for both types of anchors it is more than twice the embedment depth.

Test setup

The load was applied as a uniform displacement to the anchor while simultaneously monitoring the displacement using a custom loading plate. The support was applied through a ring of a relatively large diameter to avoid confining the area in the proximity of the anchor. The concrete cone capacity method estimates the projected cone base to have a radius of \((1.5 \times h_{ef})\) based on the \((\sim 35^\circ)\) cone angle. Taking this into consideration the support ring was chosen to have a radius of (200 mm) which is larger than the predicted cone radius. Figure 3 shows a schematic of this testing setup.

Figure 1. Geometry of cast in headed anchors tested.
Results and discussion

Headed anchors

Headed anchors were tested at 4 hydration ages (43, 91.5, 166, 334 hr) at which the concrete compressive strength was measured to be 7, 11.2, 14.2, and 17.8 MPa. For anchors tested at the first three hydration ages (below 17.8 MPa), the failure mode was pull-out failure. Anchors tested when the compressive strength was 17.8 MPa exhibited concrete cone failure for 5 out of 9 anchors while the other four failed in pull-out as shown in Figure 4. However, when
assessing these anchors using prediction models from literature, the predicted failure mode is a concrete cone failure for all 4 hydration ages.

![Concrete Cone Failure Diagram]

Figure 4. Pull-out failure through the void observed experimentally.

Experimental results obtained from this study, showed that for cast in anchors with an effective embedment depth of 50 mm installed in a 30 mm radius void former, pull-out failure is taking place when the bearing pressure at the anchorage zone is \( \sim 3.1 f_c \). Further, since the pull-out is taking place through the void, this indicate that the embedment depth for this failure mode is governed by the distance from the anchor foot to the bottom of the void former \( (h_{ef}-30 \text{ in Figure 1}) \). Experimental results obtained were used to generate a finite element model that was used to investigate embedment depths of up to 70 mm. Detailed description of the FE model used in this study can be found in [7].

The 70 mm embedment depth with a 30 mm radius void former produces a critical embedment depth for pull-out failure of 40 mm. Analysis results showed that when reaching the 40 mm mark, design code prediction models start to apply, i.e. pull-out failure take place when the bearing pressure at the anchorage zone reaches a value of \( \sim 10.5 f_c \). This is due to the fact that the study [8] that most design code formulas are derived from, did not investigate anchors with embedment depths less than 40 mm. Figure 5 shows a summary of results obtained from this study and how they align with the literature for large embedment depths. The solid line in the figure represent the line that separates concrete cone failure from pull out failure. The horizontal axis represent the effective embedment depth of the anchor, the vertical axis shows the bearing stress at the anchorage zone ratio to the concrete compressive strength. As shown in the figure the critical bearing stress triggering pull-out failure increases with increase in embedment depth. The solid line shows the summary of Furche’s [8] results, where the
The minimum effective embedment depth investigated was 40 mm from the surface as the anchors tested were not installed with void formers. However, for anchors tested in this study since pull-out failure is taking place through the void, the effective embedment depth will be reduced as shown in Figure 1, leading to an equivalent embedment depth on Figure 5 of 20 mm. Finite element analysis were used to fill the gap between the 20 mm tested and the 40 mm found in literature, leading to the dots shown on Figure 5.

Figure 5. Summary of critical bearing pressure at the anchorage zone as a function of embedment depth.

Results presented in Figure 5 were used to derive a prediction model for this new failure mode. The model generated is presented in Equation 4.

\[ N_{pull-out} = k A_{brng} f_c \]  

**Equation 4**

Where, \( N_{pull-out} \) is the pull-out failure load (N)

- \( k \) is a factor based on the embedment depth
- \( A_{brng} \) is the bearing area at the anchorage zone (mm\(^2\))
- \( f_c \) is the compressive strength (MPa)

Factor \( k \) for each embedment depth can be taken as the average \( \sigma_b / f_c \) given in Figure 5. Alternatively, it can be determined using equation 5.

\[ k = 0.42h_{red} - 5 \]  

**Equation 5**

Where, \( h_{red} \) is the distance from the anchor foot to the bottom of the void formation (mm)
**Screw Anchors**

To investigate the effect of early age installation on the 28 days capacity of screw anchors, 5 anchors were installed at the age of 2 days and tested at 28 days. For comparison, another 5 anchors were installed and tested instantly at 28 days. The first set of anchors were installed when the concrete had a compressive strength of 6.8 MPa. However, testing was conducted when the concrete was at 28 days and the compressive strength was measured to be 24 MPa. Anchors installed at early age had an average ultimate capacity of 31.1 kN with an average displacement at peak load of 1.59 mm. Anchors installed and tested at 28 days exhibited an identical behaviour where the average ultimate capacity was 31.8 kN with an average displacement at peak load of 1.58 mm. Furthermore, no significant differences were observed on the failure modes and load displacement shape.

**Conclusion**

This study investigated the behaviour of cast in headed anchors and screw anchors in early age concrete. For cast in headed anchors with void formers loaded at an early age, a new failure mode of pull-out through the void has been observed. Results obtained from testing and finite element analysis were used to propose a new prediction model that is able to estimate pull-out failure through the void for shallow embedment anchors. The newly developed model take into consideration that the critical embedment depth for pull-out through the void is equal to the distance from the anchor foot to the bottom of the void formation. The investigation on screw anchors was to study the effect of early age installation on the ultimate capacity of the anchor after 28 days. Results obtained revealed no significant effect on the overall performance of the anchor, where both sets of anchors tested had a very similar average ultimate capacity.

**References**


