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Tensile load capacity of screw anchors in early age concrete

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HIGHLIGHTS

- The tensile performance of screw anchors installed and loaded early age concrete is examined.
- The relationship between the tensile and compressive strength of concrete at early age is studied.
- Failure modes of screw anchors installed in early age concrete are examined.
- The only equation available from the literature to estimate the tensile strength of screw anchors is further analysed.

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ABSTRACT

Screw anchors are gaining popularity in construction due to simplicity of their installation, ability to load them straight after the installation and ease of their removal. Existing models to predict the strength of screw anchors under tensile loading are based on the assumption that anchors are installed in mature concrete. This assumption is normally violated to escalate construction time. There is limited knowledge available in literature on behaviour of screw anchors in early age concrete. This research focuses on evaluating the behaviour of screw anchors installed and loaded in early age concrete. The relationship between the tensile and compressive strength of concrete as well as the ultimate strength of anchors and observed modes of failure are presented for a particular screw anchor based on 70 tensile tests. The experimental results have also been compared with the predicted values from the literature and specifications provided by the anchor manufacturer.

1. Background

Using chemical and mechanical anchors is one of the popular methods of connecting structural components and building services to concrete. Amongst several types of anchors, screw anchors have gained their popularity mainly due to their quick and easy installation and their removal when not required. Even though some of the design standards include screw anchors, e.g. ACI 318 [1] and TS 101 [2], there is little research available on how to estimate the strength of screw anchors (Olsen et al. [3]). The first and most substantial research on screw anchors was carried out by Kuenzlen and Eligehausen [4] followed by some more recent studies, e.g. Olsen et al. [3] and Stuart et al. [5]. Kuenzlen and Eligehausen [4] conducted 500 tests to examine the tensile strength of screw anchors of 8–18 mm diameter and embedment depth of 30–110 mm in concrete of cylinder compressive strength of 25.5 MPa (using a factor of 0.85 to convert the cube strength to cylinder). They found no meaningful correlation between the diameter of anchor and the tensile strength, and the type of thread was found to have only some minor influence on the tensile strength. Furthermore, they observed two failure modes depending on the embedment depth of anchors, viz. pure concrete cone for shorter depths, and a combined concrete cone and pull-out for deeper embedment depths (Fig. 1); in other words, the cause of failure was either partly or merely dominated by formation of a concrete cone. Based on the above observation Kuenzlen and Eligehausen [4] proposed Eq. (1) to calculate the effective depth of anchors, $\mathbf{h_{ef}}$:

$$\mathbf{h_{ef}} = \mathbf{h_{nom}} - 0.5 * \mathbf{h} - \mathbf{h_s} \tag{1}$$

where $\mathbf{h_{nom}}$ is the distance from the concrete surface to the tip of the anchor, $\mathbf{h}$ is the distance between threads, and $\mathbf{h_s}$ is the distance between the tip of an anchor and its first thread.

Kuenzlen and Eligehausen [4] also noted that the tensile strength of anchors varies proportional to $\mathbf{h_{ef}^{1.5}}$. Therefore, by using the effective depth calculated using Eq. (1), Kuenzlen and Eligehausen [4] adopted Concrete Capacity Method, which was developed by Fuchs et al. [6], and proposed Eq. (2) to estimate the

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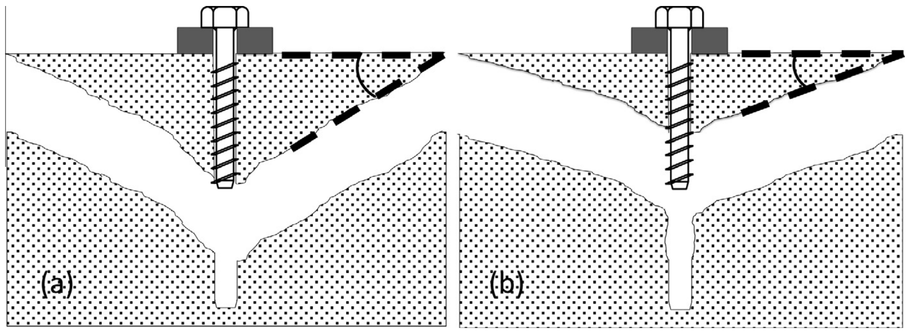

Fig. 1. Failure modes observed by Kuenzlen and Eligehausen [4] showing the angle between the concrete surface and the sides of the cone (a) concrete cone failure and (b) combined pull-out and cone failure.

tensile strength of screw anchors. It should be noted that Concrete Capacity Method was originally developed to describe the tensile strength of anchor studs, expansion and undercut anchors based on concrete cone failure mode Eligehausen et al. [7]. Eq. (2) is valid for screws with a threaded length greater than 0.8$\mathbf{h_{ef}}$, and effective depth between 10$\mathbf{d_0}$ (where $\mathbf{d_0}$ is the screw diameter) and 150 mm.

$$\mathbf{N_U^0} = 10.5 * \mathbf{h_{ef}^{1.5}} * \sqrt{(\boldsymbol{f}_{c,200})} \tag{2}$$

where $\mathbf{N_U^0}$ is the tensile strength of the screw anchor (N), $\mathbf{h_{ef}}$ is the effective depth given by Eq. (1) (mm), and $\boldsymbol{f}_{\mathbf{c,200}}$ is the compressive strength of concrete (N/mm^2) measured using 200 mm cube samples.

Olsen et al. [3] expanded the data generated by Kuenzlen and Eligehausen [4] by considering another 353 tests covering a wider range of diameter, 6.35–19.05 mm, and embedment depth, 25.4–127 mm. They also recommended that despite differences in the observed failure modes the equation recommended by Kuenzlen and Eligehausen [4] remains the best to fit the experimental results.

Stuart et al. [5] conducted 40 experiments on four types of screw anchors from different manufacturers (hence having different thread patterns) designed to be used in 10 mm holes. Two classes of concrete, i.e. C20/25 with the actual compressive strength of 25–35 MPa, and C50/60 with the actual compressive strength ranging between 55 and 65 MPa were used (only the range of compressive strength is presented with no information on the tensile strength). The actual drilled holes in C20/25 concrete was 10.40 mm and in C50/60 concrete was 10.15, both within the accepted hole size variation by ETAG 001-Annex A [8]. The embedment depth for all screws was 70 mm. Whilst the failure mode of screws in C20/25 concrete is not noted, in the case of screws tested in C50/60 concrete, with an exception of one anchor which failed due to excessive torque applied during installation, all screws failed due to a combined concrete cone and pull-out failure mode, with an average cone depth ranging between 30% and 66% of the nominal embedment depth of 70 mm depending on the type of the screw, and approximate average of 40% across all types.

2. Aim and experimental schedule

Eq. (2) has been developed based on tests where anchors were installed and tested in mature concrete, an assumption which does not always reflect real situations where tight construction programs may require anchor installation/loading to be carried out well before the concrete is 28 days old. Furthermore, the theory behind this equation is based on Concrete Capacity Method and concrete cone failure mode, where the tensile strength of anchors relates to the tensile strength of concrete, and hence the other assumption made is that the tensile strength of concrete is proportioned to $\sqrt{\boldsymbol{f_c}}$.

This research focuses on the tensile behaviour of screw anchors installed in early age concrete, and hence aims at determining the ultimate strength and failure mode of screw anchors installed and loaded before the concrete gains its 28-day strength. It also investigates the suitability of using $\sqrt{\boldsymbol{f_c}}$ as a substitute for the tensile strength of concrete, given the relationship between the tensile and compressive strength of concrete is not constant at all ages and/or concrete strengths, e.g. Winters and Dolan [9].

Seventy screw anchors were installed in two types of concrete grade. Concrete was purchased from a local provider in the City of Perth in Western Australia. Normal class concrete, as specified in AS 1379 [10], with the maximum aggregate size of 20 mm and a slump of 80 mm made of general purpose cement (type GP), as per AS 3972 [11], was used. Two types of mix were used; one with the characteristic compressive strength, $\boldsymbol{f'_c}$, of 25 MPa at 28 days, here referred to as N25 concrete, and another with the characteristic compressive strength of 40 MPa at 28 days, here referred to as N40 concrete. Anchors were tested under tension loading in concrete with different ages (24 h, 36 h, 48 h, 72 h, 7 days, 14 days and 28 days). The compressive and tensile (splitting/Brazilian)

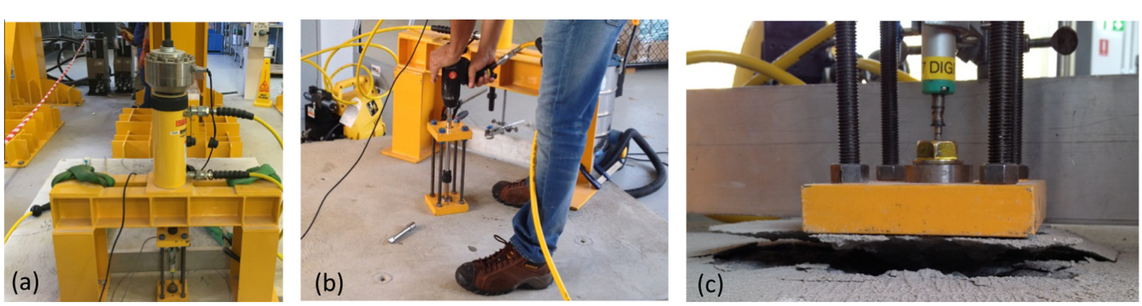

Fig. 2. (a) Reacting frame, load cell, cylinder jack, displacement transducer and fixture, (b) anchor installation and (c) displacement transducer.