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Tensile behavior of post-installed chemical anchors embedded to low strength concrete

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HIGHLIGHTS

- Analyzed parameters are bar diameter, embedment depth and free edge distance in low strength concrete under axial loading.
- Embedment depth and free edge distance must be at least 15 times bar diameter for ductile behavior.
- ACI 318 recommendation uses very conservative approach for shallow anchors and larger bar sizes in low strength concrete.
- Putting an upper limit for bar diameter is proposed. Smaller ones are more suitable to ACI 318 for low strength concrete.

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ABSTRACT

In the scope of this paper, tensile capacities of post-installed chemical anchors embedded to 5.9 and 10.9 MPa concrete blocks are investigated. Pull-out tests are applied to 80 ductile steel bars (S420a). For the anchor diameters, 12, 16 and 20 mm are chosen. On the other hand, 10, 15 and 20 times the bar diameter are selected as free-edge distance and embedment depth for monotonic tensile loading tests. The results indicate that installation of anchors into low-strength concrete with sufficient embedment depth and free-edge distance is not unsafe as previously expected. To obtain ductile failure in low strength concrete, free-edge distance and embedment depth of minimum 15 times the anchor diameter should be required. Furthermore, a comparison of test results with ACI 318 capacities is done and it is observed that ACI 318 has quite an over-conservative approach for the tensile capacity of post-installed anchors when low-strength concrete is considered.

1. Introduction

Anchors used to provide connection between different structural members and concrete can be presented in two categories such as cast-in-place and post-installed. Post-installed anchorages can be generalized in various kinds as mechanic, grouted and chemical. In previous researches, behavior of cast-in-place anchorages [1] and post-installed mechanical anchorages [2] are studied quite in detail. As a conclusion of these studies, for designing cast-in-place anchorages [3] and mechanical anchorages [4] some consistent procedures were established.

One of the best solutions to meet fastening forces between concrete and steel is chemical adhesives [5]. Usage of chemical adhesives applied to the reinforced concrete structures goes back to 1960s for the bonding of steel plate reinforcements [6]. Especially, studies on chemical anchors, which are frequently used in strengthening implements, are comparatively new and due to diversity in application materials, a code which points out design restrictions has not brought up yet [7]. At this point, this is the reason why the presented paper recommends some restrictions for the design of post-installed chemical anchors [8].

Due to the developments in the last few decades, in adhesives such as high-strength polyester, vinylester and epoxy, chemical anchors have been used widely after 1990s [9–11]. Cleanness of hole, drilling method, humidity level of concrete, environment temperature and many parameters besides adhesive material type can affect bond strength of anchors [2].

In some studies, the adhesive thickness and additives [12], embedment depth [9], anchorage bar diameter [13,14], steel strength [15], free edge distance [16] and distance between anchorages [17] are the parameters analyzed. Some other studies investigated the effect of concrete strength and aggregate variety [14,18]. In addition, the behavior of both single and group anchors

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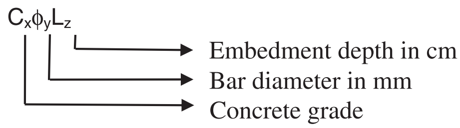

Fig. 1. Labeling of specimen.

Table 1
Strength of materials.

Material		Average compressive strength (MPa)	Yield strength (MPa)	Tensile strength (MPa)
Concrete	C5	5.9	N/A	N/A
	C10	10.9	N/A	N/A
Bar diameter (mm)	12	N/A	492	583
	16	N/A	522	626
	20	N/A	457	559
Epoxy		69.5	N/A	16.9

N/A: not applicable.

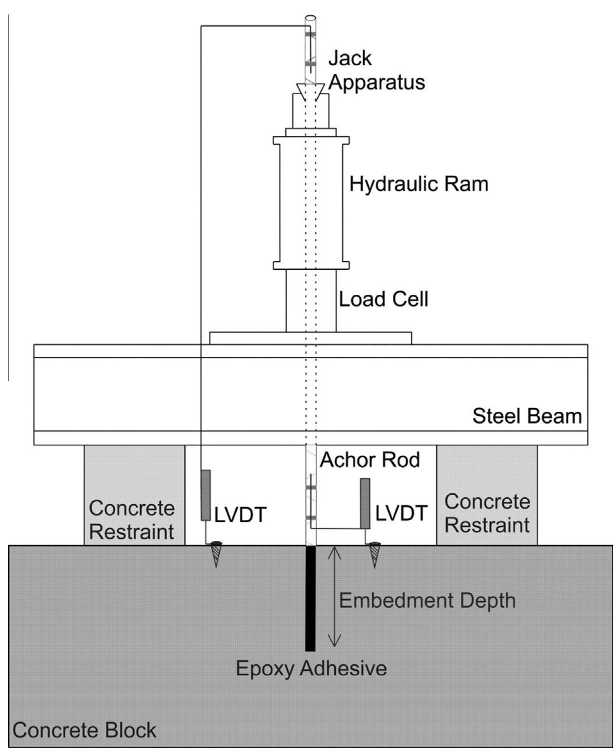

Fig. 2. Test set-up.

has been studied as well [2]. Some researches focused also in the increase in tensile strength related to the increase in loading pace rate under dynamic loads [19,20]. Besides, there are some studies about partially bounded anchorages which can be categorized in the group of chemical anchor behavior studies [1,21]. In a very recent study, shear behavior of epoxy bonded anchors were investigated and researchers suggested capacity reduction factors for such cases [22]. It is revealed that the existing formulations does not reflect the behavior of anchors to low strength concrete. In addition, there are studies to estimate ultimate strength of anchor determined by the means of artificial intelligence [23,24].

Literature shows that the anchors design criteria were established by extensive experimental background, implemented in the practice code provisions. However, most of the above mentioned researches were carried out for normal strength concrete. On the other hand, most of the buildings, which are in need of strengthening, have low strength concrete [25]. Therefore, anchoring reinforcement to low strength concrete with chemical adhesives is a concern to study. In this study, tensile behavior of epoxy resin anchors embedded to low strength concrete and factors affecting the bond strength capacity were investigated.

2. Materials and method

2.1. Test specimen

Most of the strengthening implementations are carried out for the weak and low strength concrete structures. Therefore the anchorage specimens were prepared with 420 MPa yield strength steel rods embedded to two different types of low compressive strength concrete: C5 (5 MPa) and C10 (10 MPa). Specimen groups were characterized by different diameter (12 mm, 16 mm and 20 mm), free edge distance and embedment depth (10∅, 15∅ and 20∅) of the bar. Concrete blocks were drilled with a diameter 4 mm larger than steel rod diameters. Then, holes were cleaned by oil-free compressed air. Concrete dust was vacuumed out of laboratory in order to provide dust free perfect connection. The holes were filled with epoxy and steel bar were fixed to the location slowly by rotating down to obtain air free bond. The extra epoxy was daubed to the surface of the steel bar by means of a spatula. The specimens were coded to identify their bar diameter, embedment depth and concrete compressive strength as shown in Fig. 1.

Average values of concrete compressive strength, tensile strength of bars, compressive and tensile strength of epoxy are given in Table 1.

2.2. Test set-up

A steel beam with double U cross-section was used as a support of a hydraulic jerk to pullout the steel bars from concrete block. In order to better view its failure mode, and allow the concrete to fail freely, the beam was placed on two concrete supports as shown in Fig. 2. A hydraulic ram is used to pull the anchor rods. A jack above the cylinder is fixed to give tension force to the anchor. Test principle consists in the hydraulic ram's cell's elevation with oil pressure and anchor rod's connection to the cylinder cell with jack apparatus. The test was arranged to pull the anchorages from the concrete in a straight way by means of linked tendons.

Axial load is applied to the test specimens with slow increments up to yield or pry out limit, then the tests were controlled by displacement until its ultimate capacity. LVDTs (linear variable differential transformer), load cells and data logger (CODA system) were used in the test setup to obtain instant and accurate load and load versus displacement values.

3. Test results

Tensile stress-time graphs of C5 and C10 tests are shown in the Figs. 3 and 4. In those graphs, an increase of the bearing capacity of anchors related to the bar diameter cannot be observed as previously expected for each embedment depth of anchor. In other words, there is not a significant difference particularly in the anchors with 10∅ embedment depth. However, in the case of 15∅ and 20∅ embedment depth all the anchors reached the yield strength capacity except C5-∅12-L18. The main reason for such a result for C5-∅12-L18 specimen can be due to insufficient magnitude of free edge distance (18 cm). In addition, it is seen that the failure mechanism of especially 10∅ anchorages is controlled by the concrete. The same situation is observed in C5 anchors; that is, the ultimate capacity is controlled by concrete failures such as crack, debonding, splitting and cone. On the other hand, C10 and/or 15∅ specimen failure is characterized by steel failure.

Free edge distance ratio ($c/\varnothing$) is defined as the ratio of free edge distance to bar diameter. Changes in anchor strength relating to free edge distance ratio on C5 and C10 concrete blocks are presented in Fig. 5. Yield strength and ultimate strength of steel bars are shown as a horizontal line in the graphs as well. According to these results, only one of the anchors having $c/\varnothing = 10$ reached ultimate strength of steel bar. All the anchors with 12 mm diameter in