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Performance and design of post-installed large diameter anchors in concrete

Dongpo Wang [a], Dongsheng Wu [a,*], Chaojun Ouyang [b], Mingang Zhai [c]

[a] State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu 610059, China
[b] Key Laboratory of Mountain Hazards and Surface Process, Chinese Academy of Science, 610041 Chengdu, China
[c] CCCC High-Tech Science and Technology Industry Development Co, Ltd., China

HIGHLIGHTS

- Four combined-anchor types were studied in the prototype experiment.
- The modified design equation for large diameter anchor was proposed.
- Experiment results of the ultimate load were predicted by the modified design equation.
- Both performances of experiment and design concepts complement the deficiency status of large diameter anchor effectively.

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ABSTRACT

Knowledge deficiency in design concepts promotes the performance investigation of post-installed large diameter anchor systems. The investigation involves testing of 48 specimens, including four combined-anchor types (grout-plain, grout-grooved, epoxy-plain, and epoxy-grooved). Anchor bars with diameters 36 mm, 48 mm, 90 mm, 150 mm were chosen, and the selected embedment depths were 8, 10, 12 times the bar diameters. Results indicated that tensile capacity is related to the bar diameter, anchoring agent, bar surface type, and embedment depth. Based on the results and existing design models, a modified design equation is proposed. A comparison of test results with the results of modified equation shows that the modification provides a better estimation for the post-installed large diameter anchor systems. The modified equation can be applied to the design of anchoring reinforcement for engineering.

1. Introduction

The gradual deterioration and aging of concrete structures have led to increased threats to safety and reliability of building structures, creating the need for continuous maintenance or repair. The direct and indirect costs of demolition and reconstruction of structurally deficient constructions are often prohibitive. Therefore, structural retrofitting is becoming increasingly widespread and concrete structures are becoming more complex because of the addition of steel-to-concrete and concrete-to-concrete connecting element systems [1,2]. Among all the methods available for making these connections, the post-installed anchor system is one of the most effective.

An anchor system that provides a connection between different structural members can be classified as either "cast-in-place" or "post-installed". In previous research, the performance of cast-in-place anchors [3] and post-installed mechanical anchors [4] was studied. As a conclusion of these studies, some consistent procedures were established for designing cast-in-place anchors [3,5,6] and post-installed anchors [1,4], and the post-installed anchor is being more widely used in building structure reinforcement and reconstruction projects because of their economic and flexible installation.

In the past two decades, numerous experiments have been conducted to investigate the behavior of adhesive anchors. Shah [7] performed pull-out tests on steel bars anchored at two different embedment lengths using the material of two manufacturers. Obata [8] focused on the effect of a free edge on the pull-out strength, both experimentally and analytically. Eligehausen [4] spent several years investigating the behavior of adhesive-bonded anchors when located in groups. Contrafatto and Paganoni concentrated on the behavior of post-installed anchors in both natural stone [9,10] and masonry [11]. The tensile behavior of post-installed chemical anchors embedded in low-strength concrete

* Corresponding author.
E-mail address: dongsheng-wu@live.com (D. Wu).

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Notation

τ	bond stress (MPa)
$\bar{\tau}_{36}$	average bond stress when d = 36 mm (MPa)
$\bar{\tau}_{8d}$	average bond stress when h_{ef} = 8d (MPa)
$\bar{\tau}_{d}$	average bond stress referring diameter (MPa)
$\bar{\tau}_{h_{ef}}$	average bond stress referring embedment depth (MPa)
N_{μ}	ultimate predicted strength of anchor (kN)
d	diameter of anchor (mm)
d_0	diameter of hole (mm)
h_{ef}	embedment depth (mm)
f_c	compressive strength of concrete (MPa)
h_{cone}	depth of shallow concrete cone (mm)
λ	stiffness characteristic of the adhesive anchor system (mm^{-1})
n	numbers of test
$\psi_{p,g}$	reduction factor of bar surface type
η_1	modification factor of bar surface type
η_2	modification factor of anchoring agent type
η_d	modification factor of diameter of anchor
$\eta_{h_{ef}}$	modification factor of embedment depth

was studied by Yilmaz in [12], and the shear force of epoxy anchors embedded into low-strength concrete was studied by Çalışkan in [13]. In addition, Eligehausen [14] investigated the behavior of adhesive anchors under sustained loads. Epackachi conducted an experiment to investigate the tensile and shear behaviors of post-installed adhesive anchors considering single and group anchor and verified the existing design models [15].

Previous studies on anchor systems focused bar diameters less than 36 mm, which are too small to satisfy the requirements of industrial building engineered construction. This scarcity of information has created a demand for the study of the performance of post-installed large-diameter anchors.

2. Background: the existing design concepts

The post-installed anchor system is based on the transfer of the applied load from the steel anchored element, through the adhesive layer, to the concrete along the entire bonded surface [9]. Compressive strength of the concrete, hole cleaning, embedment depth, and bar diameter affect the resistance of anchor Cook and Eligehausen collected a worldwide database of more than 1000 tests and described those failure models detailed in [1,4]. The current design concepts for the calculation of the ultimate load for failure in traction of individual post-installed anchors are summarized in Table 1, which also shows the possible failure mechanisms.

The Concrete Cone Model is used when the embedment depth is very small, so that the ultimate load depends on the square root of the concrete compressive strength and the embedment length.

The Bond Model is used for connections that are dependent on the bond strength of the anchoring agent, the bar diameter, and the embedment depth. Three failure modes are considered:

(1) Adhesive/Concrete Sliding: The bond model, in which sliding failures occur between bond failures models at the adhesive/concrete interface.
(2) Steel/Adhesive Sliding: The bond model, in which slipping failures occur between bond failures models at the steel/adhesive interface.
(3) Bond Models Neglecting the Shallow Concrete Cone: Similar to bond models, except that the embedment length is reduced to account for the shallow concrete cone.

The Combined Cone/Bond Model utilizes the concrete cone model for shallow embedment and combined cone/bond models for deeper embedment.

The Steel Bar Failure Model is based on the steel bar yield strength.

In most prior studies, the pull-out performance and the design approaches for post-installed large diameter anchors, which are commonly used for retrofit projects have not been studied exhaustively yet. To fill this gap, the pull-out performance of post-installed large diameter of 36-, 48-, 90-, and 150 mm adhesive anchors are studied in this paper, considering the effects of embedment depth, anchoring agent type, and the bar surface type. Based on the test results and the existing design concepts, the equation of predicting ultimate load is modified to fit the design requirement of post-installed large diameter anchor system.

3. Overview of the experimental test

The experimental details of the properties of component materials, the method of specimen preparation, and the loading procedure of experimental tests has been presented in a prior paper of [21]. Based on the prior study, the embedment depth of 10d (10 times diameter) and the organic agent of epoxy resin are considered in this experimental investigation. A brief overview of the experimental procedure is presented in the following subsection.

3.1. Preparation of materials

The materials for this experimental test were carefully selected. Plain concrete hardened without developing cracks was used as the anchor foundation. Two categories of steel bar surfaces (plain bar, grooved bar) with four anchored bars nominal diameters (36 mm, 48 mm, 90 mm, 150 mm) and three embedment depths (8, 10, 12 times the bar diameter) were used for the connecting bars. Flowing grout and epoxy resin were used as the anchoring agents, and the concrete blocks were cast using ready-mix Grade C25.

The field test setup is shown in Fig. 1. All the tests on concrete took place at the indoor laboratory. The post-anchored bars used steel bars with two surface treatment types, as shown Fig. 1. The associated material specifications of the two steel bars shown in Fig. 1 are listed in Table 2, and a sketch of anchor testing floor plans shown in Fig. 2.

For comparing the performances of the inorganic and organic anchor agents in large-diameter anchor tests, the flowing grout for inorganic agent, and the Hilti RE-500 epoxy resin for organic agent were used. The mixture proportion of the flowing grout and the epoxy resin are listed in Table 3.

3.2. Preparation of apparatus and method

An independently-developed loading apparatus was used for applying a static pull-out force because of the lack of ready-made apparatus for large-scale testing. The test apparatus, shown in Fig. 3, consisted of four sets of individual hydraulic jacks (QF320T, max pressure of 320 tons), an ultrahigh-pressure oil pump (ZB4-500), six sets of displacement meters (JCQ), and a static