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Behavior of post-installed large-diameter anchors in concrete foundations

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HIGHLIGHTS

- Prototype experiments of post-installed large-diameter anchors are studied.
- The classic failure modes of post-installed large-diameter anchor systems are given.
- Enrich the literature and empirical data on post-installed large-diameter anchors.

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ABSTRACT

The pull-out force for post-installed large-diameter anchors embedded in concrete foundations was investigated. The main aim is to determine the optimum bonding force and ultimate tensile force of the anchor bar. Anchor bars with various diameters were tested, and different embedment depths were used. The results obtained indicate that the pull-out force improved marginally with an increase in the bar diameter. The primary failure modes observed for the large-diameter anchors included steel bar pull-out, concrete annulus damage and combined cone damage. Increasing the bar diameter gradually changed the failure mode from steel bar pullout to a combination of cone damage and concrete annulus damage. Finally, grooved bars were found to be more suitable for use in post-installed anchor systems.

1. Introduction

After decades of growth and development, industrial and civil buildings all over the world are entering a phase of gradual deterioration and aging, the demand for improved safety of existing infrastructure has rapidly increased. This is particularly the case in China. The result increasing in the threat to safety as well as concerns about reliability has led to such building structures requiring continuous maintenance and repair. In seismic regions, such as south-western China, the structural deficiency of existing constructions is a particularly acute problem, because of lacunae in construction knowledge and the design code. In addition, as concrete structures become more complex, the systems used to connect steel to concrete and concrete to concrete add to the problem [1]. This had made it necessary to demolish aging buildings and to reconstruct them in a structurally satisfactory manner. However, the direct and indirect costs involved in the demolition and reconstruction of structurally deficient constructions are often prohibitive [2]. Therefore, structural retrofitting gets higher priority from engineers and is becoming increasingly the first choice of action. A number of remedial methods can be implemented in the case of existing buildings, in order to improve their mechanical characteristics. Among the various methods available, the use of anchor systems is one of the most effective ones.

Anchor systems are commonly used in plain or reinforced concrete, as well as for structurally strengthening and retrofitting existing constructions and for connecting new structural elements to existing ones. Using post-installed anchor systems is a very efficient connection technique for structural reconstruction and expansion, and there have been a large number of studies on the behavior of adhesive anchors. Cook et al. [3] studied the database including 888 European and American tests and developed a better and more user-friendly design model than those existing previously. Eligehausen et al. [4] proposed a new failure mode and verified its validity using a worldwide database containing 415 tests. Further, Eligehausen has [5] reviewed the development of adhesive

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anchors in the United States. Finally, abundant design principles for engineers referring in ACI318 [6].

In recent years, numerous studies have been performed to investigate the behavior of adhesive anchors and the effects of the embedment length, the type of anchoring agent used, the edge distance, and the spacing of anchors in concrete substrates. Pull-out tests were performed by Shahi et al. [7] on steel bars anchored at two different embedment lengths using materials from two different manufacturers. Makoto et al. [8] studies the effects of a free edge on the pull-out strength of anchor systems both experimentally and analytically. Researchers have also investigated the behavior of post-installed anchors in both natural stone [2,9] and masonry [10]. At the same time, a few studies have investigated the behavior of adhesive anchors under external loading. The tensile behavior of post-installed chemical anchors embedded in low-strength concrete has also been studied [11], and so has the shear behavior of epoxy anchors embedded in low-strength concrete [12]. Kwon et al. studied the behavior of post-installed shear connectors under static and fatigue loading [13]. Further, a comprehensive description of the effects of the loading rate on the load-bearing behavior of anchors with different failure modes has also been reported [14]. Several failure modes [14–18] have been proposed in the literature for determining the failure load of adhesive anchors in concrete. In most cases, these modes are related to specific products, and the diameter of the test bars used is usually less than 40 mm.

Unfortunately, anchor bars with diameters of less than 40 mm do not satisfy the requirements for industrial buildings, especially in the metallurgical industry, and very limited information is available on the behavior of post-installed large-diameter anchors in concrete foundations. In this study, pull-out tests were performed on large-diameter anchors (diameter (Φ) = 36 mm, 48 mm, 90 mm, or 150 mm) for different embedment depths (8d and 12d) using different anchoring agents (organic and inorganic agents) and steel bars with different types of surfaces (plain and grooved), in order to investigate the behavior of adhesive anchors embedded in concrete under tensile loads. The aim was to establish the relationship between the pull-out force and the characteristics of the post-installed large-diameter anchors, as well as establish design guidelines for retrofitting of old equipment in large steel plants.

2. Background of anchor systems

2.1. Types of anchors

Post-installed anchors are embedded in holes that are drilled into existing concrete foundations. Thus, any load applied to the supported structure is passed by the anchoring system to the primary system through the frictional forces that develop between the sides of the holes and the anchor wedges and sleeves or any other mechanical locking devices attached. The mechanism of load transfer depends on the type of anchor system installed.

Traditionally, on the basis of the load-transfer mechanism involved, post-installed anchors are classified into two categories:

(1) Mechanical anchors: these anchors transfer load through friction and mechanical interlocking.
(2) Adhesive anchors: these anchors rely on adhesion between the anchor and the adhesive or that between the adhesive and the concrete to transfer loads [2].

2.2. Adhesive anchor system

An adhesive anchor system consists of a steel bar or threaded rod that is inserted into a hole drilled in concrete, with a structural adhesive acting as the anchoring agent between the concrete and the steel. Structural adhesives for adhesive anchor systems include both organic and inorganic anchoring agents. Organic anchoring agents are available pre-packaged in glass capsules or as two-component systems requiring proportioning and mixing by the user [2], while inorganic anchor agents are grouted into the hole using grouting tools. A schematic describing the typical adhesive anchor systems is shown in Fig. 1.

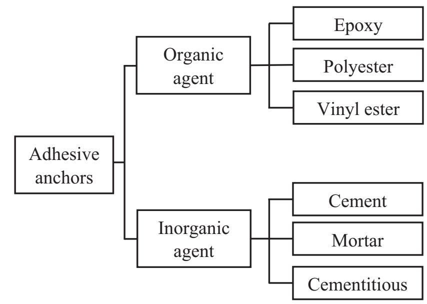

Fig. 1. Types of adhesive anchor systems and the adhesives used in them.

2.3. Modes of failure of adhesive anchors in concrete

Anchor systems may be subjected to tensile or shear loads or a combination of the two. In the past decades, the theoretical modes of failure of adhesive anchors have been examined; however, all of these studies have involved bars with small diameters (usually less than 36 mm). And the basic failure modes were verified by many studies. Table 1 shows the failure modes usually observed in anchor systems.

As mentioned above, most previous studies have focused on small-diameter anchor systems that use bars with a diameter of less than 40 mm. Thus, there is a lack of data on large-diameter anchor systems that use different anchoring agents and are anchored in concrete. This is an urgent issue with respect to reinforcement projects in industrial plants. Thus, in this study, we attempted to understand the behavior of post-installed large-diameter anchors, so that safe and reliable design guidelines can be developed for structural reinforcement.

3. Materials and methods

We performed pull-out tests to investigate the effects of large-diameter bars on the pull-out strength of anchor systems. During these tests, three parameters were taken into account. These parameters are listed in Table 2, while the results of the tests performed on the large-diameter anchor systems are listed in Table 5. (See Figs. 2 and 3).

3.1. Test apparatus

The tests consisted of applying a static pull-out force to bars embedded in a concrete foundation. Owing to the large scale of the experiment, ready-made apparatus was not available for the tests. Thus, a customized loading device was developed. The test apparatus, shown in Fig. 4, consisted of 4 sets of individual hydraulic jacks (QF320T, maximum pressure of 320 tons), an ultrahigh-pressure oil pump (ZB4-500), a displacement meter (JCQ), and a static stress test and data acquisition system (DH3815N).

3.2. Test materials

The test materials were selected carefully on the basis of purpose of the experiment. Plain concrete was used for the concrete foundation. Steel bars with two types of surfaces (plain and grooved) and four different diameters were used. Finally, flowing grout was used as the anchoring agent.