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Simulation analysis of large-diameter post-installed anchors in concrete

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HIGHLIGHTS

- A proposed finite element model could reproduce the experimental results.
- Numerical simulation verifies the failure mode of large-diameter anchor.
- Progressive failure of anchor can be parsed in four stages based on load–displacement curve.

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ABSTRACT

Large-diameter anchors are one of the important connection components in the reinforcement of industrial facilities. In the present study, a finite element (FE) model of large-diameter post-installed anchor system is appropriately established to investigate its pull-out performance and failure modes observed in the prototype experiments. The applicability of the proposed model is discussed through comparison of its results with experimental results (e.g., in terms of the ultimate load, corresponding displacement, and failure modes), and the parametric sensitivity based on the numerical results is studied. The results showed that the pull-out behavior could be well simulated using the proposed model. The progressive failure evolution process of the large-diameter anchor can be revealed by computational load–displacement curves. Thus, the proposed model of a large-diameter post-installed anchor can enable reliable design of anchor systems for industrial reinforcements.

1. Introduction

With the ageing of industrial and civil buildings, there is a requirement of continuous maintenance and reconstruction of existing structures, which leads to significant direct and indirect costs and a substantial waste of natural resources and energy. Therefore, structural retrofitting is becoming increasingly widespread worldwide. As a result, there is an impetus for increasing the knowledge base related to this field and for establishing design codes and standards that can help overcome the deficiencies observed in the case of most existing constructions.

Anchor systems form connections between different structural members and concrete, and they are commonly classified into two categories: cast-in-place anchors and post-installed anchors [1]. The performances of cast-in-place anchors and post-installed adhesive anchors have been studied extensively in the past, and suitable procedures have been established for designing them.

In the past few decades, numerous studies have investigated the behaviors of adhesive anchors. For example, Shah [2] conducted an experiment to investigate the pull-out performance of anchor bars anchored at different embedment depths in concrete. Further, some researchers investigated the pull-out behaviors of anchors in natural stone [3,4] and masonry [5]. Epackachi [6]studied the tensile and shear behaviors of single and group anchors in the ready-mix Grade C35/45, whereas some other researchers examined the tensile [7] and shear [8] behaviors of post-installed chemical anchors embedded in low-strength concrete. Furthermore, Obata [9] studied the effects of the free edge on the pull-out strength of a post-installed anchor by both experimental and analytical methods. The other factors influencing the effects of pull-out strengthen were also studied by both experimental and numerical analyses from several researchers [10–12].

In addition, several theoretical models have been proposed for the failure mechanisms of such anchors. For example, Doerr [13] proposed an elastic bond-stress model and McVay [14] proposed a uniform bond-stress model. Based on the latter model, Nilson [15] proposed a uniform bond-stress model that takes into account

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the actual resistance of the adhesive. Cook [16] also proposed classical theoretical models. Furthermore, following the introduction of numerical modeling, many researchers studied the behaviors of anchor systems through numerical simulations. For example, Dickin [17] simulated anchor wall behavior in loose and dense sand by using the variable elastic soil model and Lade's elasto-plastic soil model. Sakla [18] and Alqedra [18] used artificial neural networks designed in MATLAB to predict the tensile and shear capacities, respectively, of single adhesive anchors. Kim [1], Bajer [20], and Contrafatto [3] evaluated the performance of post-installed anchors by using some commercial simulation software.

However, most of these previous studies were based on small-diameter anchors, and those are seemingly unable to satisfy the requirements of industrial buildings, because numerous of relevant examples of the poor performance have been shown by the field observations of failures and past experimental tests on actual industrial prototypes [21,22]. Therefore, in the present study, on the basis of results of previous investigations, we employed experimental tests and finite element (FE) method simulations to study the performance of large-diameter post-installed anchors, with the aim of determining their ultimate loads and failure modes.

2. Overview of large-scale test

The experimental tests aimed to investigate the pull-out performances of large-diameter post-installed anchors in concrete. The tests employed an independently developed loading apparatus, a concrete foundation, steel bars, and an anchoring agent. To study the effects of different conditions on the post-installed anchor system, the following parameters were considered: four nominal bar diameters (36 mm, 48 mm, 90 mm, and 150 mm) and two embedment depths (8 and 12 times the bar diameter).

2.1. Test apparatus

Owing to a lack of readymade apparatuses for large-scale testing, an independently developed loading apparatus was adopted for applying a static pull-out force to the bars embedded in the concrete foundation. The test apparatus, shown in Fig. 1, consisted of four sets of individual hydraulic jacks (QF320T, maximum pressure of 320 tons), an ultrahigh-pressure oil pump (ZB4-500), a certain number (six sets) of displacement meters (JCQ), and a static stress test and data acquisition system (DH3815N). Prior to each test, all the components were calibrated accurately to ensure measurement precision.

2.2. Test materials

C25 concrete (the standard compressive strength of concrete is 25 MPa) was used in this study, and the pouring and curing of the concrete foundation were performed at a large-scale on-site experiments field to model real reinforcement environments. Either steel bars or glass-fiber-reinforced plastic (GFRP) bars are typically used in anchor systems. GFRP bars are also being introduced in concrete structures under special conditions [18–20,23]. Nevertheless, steel bars, which are conventional building materials, are used more widely in various engineering fields, especially in the metallurgical industry. In this study, epoxy resin was used as the anchoring agent. This resin has high mechanical strength and it exhibits good adhesion to the anchor system. It has been designed specifically for fastening anchors in solid base materials such as concrete, grout, stone, and solid masonry, and it is suitable for use under exceptional conditions, such as with underwater fastenings and oversized holes.

All the material parameters obtained from laboratory tests and from the material user guides are listed in Table 1. These parameters were also used for the numerical analysis.Table 2Table 3

2.3. Test method

The installation of the anchorages was characterized by the following phases:

Drilling of the sample: the drilling of each sample was performed by JX-1geological drill. To comply with construction requirement, the diameter of holes varies in diameter with that of anchor bar. For Φ36 and Φ48, the hole diameter was d + 20 mm. For Φ90, was d + 40 mm, and for Φ150, was d + 60 mm. At the same time, the drilling depth was deeper than the effective anchorage depth by 20 mm.

Hole cleaning: this step plays a very important role to determine whether can we get the real data, because the presence of dust inside the hole and on its wall surface prevents the optimal adhesion between the anchor agent and the concrete foundation; hole cleaning was carried out using clean water, specific brushes and compressed air, and the details of the cleaning method in experiment is that, we drilled the hole to the design elevation and confirmed the hole (aperture, hole depth, hole position, and

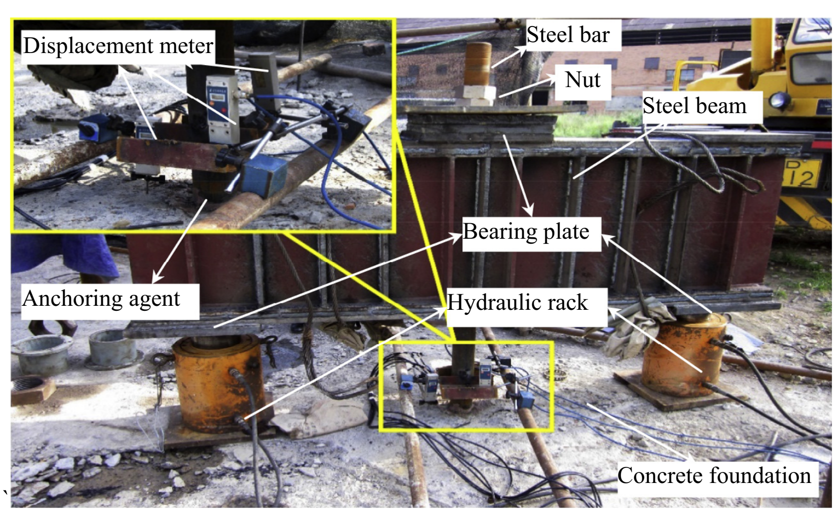

Fig. 1. Test apparatus.