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Shear capacity of cast-in headed anchors in steel fiber-reinforced concrete

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ABSTRACT

This paper investigates the concrete breakout shear capacity of a single cast-in headed anchor embedded in steel fiber-reinforced concrete (SFRC). Experiments were carried out for anchors with a diameter of 30 mm, embedment depth of 240 mm, and edge distance of 150 mm. Fiber volume fractions of 0.33, 0.67, and 1.00% were examined. In addition to shear tests, four-point bending tests were carried out to evaluate the relationship between the material properties of SFRC and the shear capacity of anchors. The experimental results show that the current design formulas are valid for anchors in conventional plain concrete but not appropriate for the shear capacity of anchors in SFRC. Using the equivalent flexural strength ratio, a revised design equation is proposed to incorporate the effect of the steel fiber content on the concrete breakout shear capacity and provide reasonably similar safety for anchors in both un-reinforced and SFRC.

1. Introduction

Cast-in (CI) anchors have come to play an important role in supporting and connecting structural elements and plant equipment. However, failure of the anchors results in losses of the function of structure and equipment that are directly related to the safety of the structure and people. Failure modes of anchors embedded in concrete can be divided into ductile failure, where failure is in the anchor shaft, and brittle failure, where failure is due to fracture of the concrete. Concrete failure produces a sudden fracture of the anchor system due to the brittleness of the concrete. Therefore, a reasonable decision about the fracture strength of the concrete is required for the concrete anchor system.

The design capacity for an anchor has been based on the concrete capacity design (CCD) method since the 2000 s. The current design standards for calculating the concrete breakout shear capacity have been derived from experimental data on small-size anchors embedded in concrete [1–6]. The American and European standards [7–9] account for the embedment depth and edge distance of anchor and the compressive strength of concrete to determine the concrete breakout shear resistance of the anchor. The recent revision of ACI 318-11[8] has accepted the experiments of Lee et al. [3], conducted for large-size anchors, to provide another equation in terms of only the concrete strength and anchor diameter. The theoretical background of the design standards on the concrete breakout strength of anchor will be discussed in more detail in the following Section 2.

Previous experimental studies have been carried out on anchors in the un-reinforced plain and steel bar-reinforced concrete. Therefore, the design equations provided in the current design standards determine the shear capaity of an anchor based on the resistance of either plain concrete, reinforced steel bar, or anchor shaft. Only a few studies have been recently performed to evaluate the behavior and capacity of anchors in fiber-reinforced concrete, which exhibits superior tensile performance to conventional concrete [10,11]. Nilforoush et al. [10] assessed the breakout capacity of a CI anchor bolt in steel fiber-reinforced concrete (SFRC) members subjected to monotonic tensile loads and showed a considerable increase in the anchorage capacity and ductility with the addition of steel fibers to the concrete mixture. Choi et al. [11] attempted to modify the current design equations using a regression analysis of test data for the concrete breakout failure of anchors in high-performance fiber-reinforced concrete under tension.

Cement-based material is essential for construction but is very vulnerable under tensile forces [12]. Therefore, studies have been carried out to enhance the tensile strength and ductility of the cement materials using short-length fibers. In particular, SFRC has mainly been developed since the 1960 s [13]. Many studies showed that the addition of steel fibers to the concrete improves the pullout behavior [14–17], flexural tensile strength [18–20], shear resistance at the crack interface [21–24], and ductility performance [25–27] of concrete members. The SFRC has been widely and reliably used in practial applications, such as tunnel shotcrete, precast tunnel segments, industrial pavement, and slabs [28–31]. These fiber-reinforced concrete structures are designed

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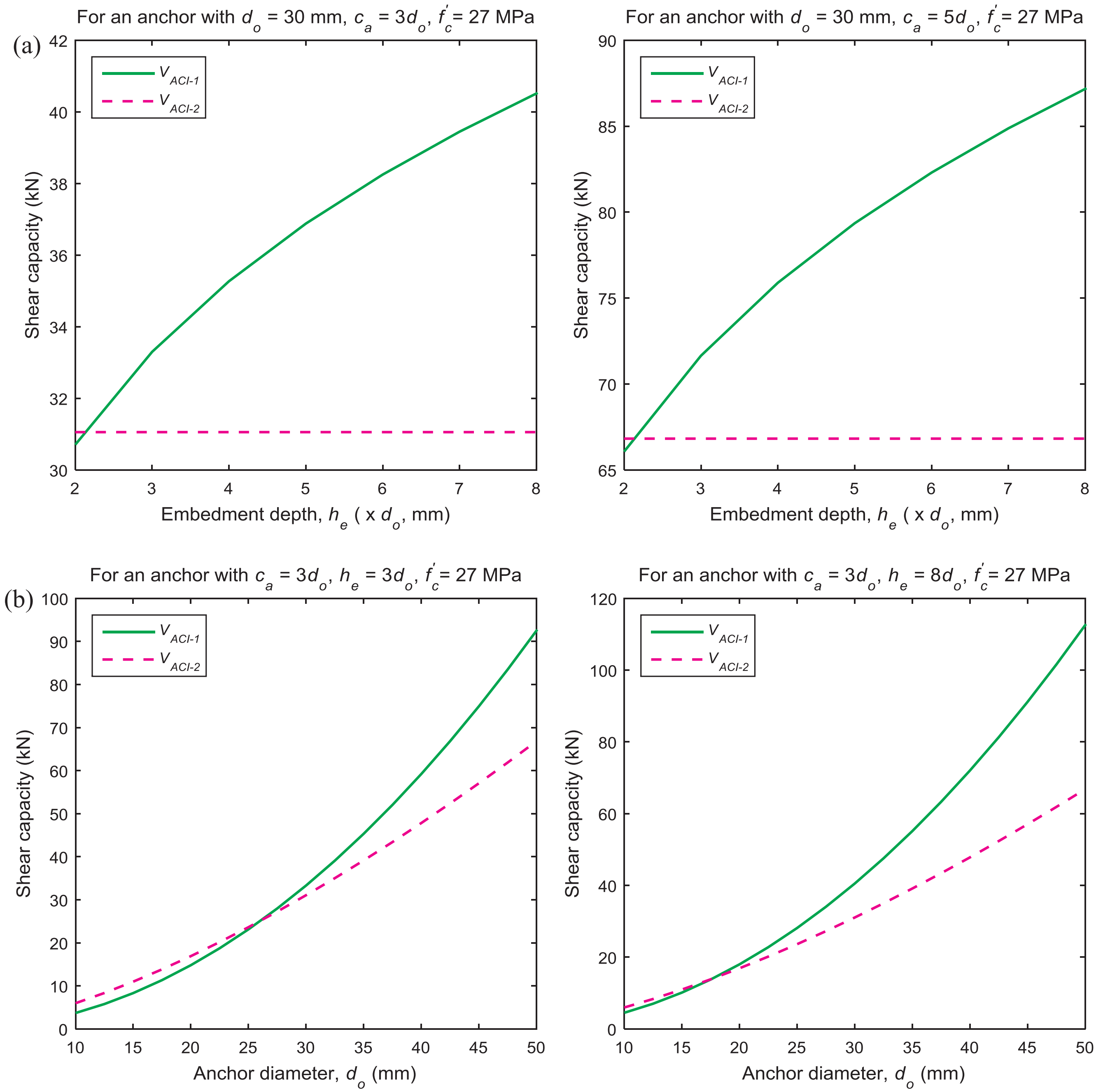

Fig. 1. Comparisons of the concrete breakout shear capacity of an anchor with the change in the (a) embedment depth and (b) anchor diameter.

using an equivalent flexural strength ratio to account for the improvement of the tensile capacity of concrete.

However, the structural behavior of the anchor system in SFRC has not been fully investigated, and only a few studies have been attempted under tensile loading. In this study, experimental investigations were carried out to examine the concrete breakout shear capacity of an anchor in SFRC. With increases in fiber volume fractions from zero to 1.00%, a monotonic shear load was applied to examine the shear behavior and breakout capacity of an anchor with a diameter of 30 mm, embedment depth of 240 mm, and edge distance of 150 mm. In addition to the shear anchor tests, material tests were also performed to evaluate the relationship between the material properties of SFRC and the shear capacity of the anchor.

To account for the effect of steel fibers in the concrete breakout shear capacity of an anchor, an equation term is proposed based on the experimental results and the equivalent flexural strength ratio. The tensile capacity of SFRC can be defined using the equivalent flexural strength ratio multiplied by the cracking strength of plain concrete. The technical report TR 34 [32] and ACI 360R-10 [33] has accepted the eqivalent flexural strength ratio to design industrial floor slabs. Furthermore, design of pile-supported fiber-reinforced concrete slabs and pavements can be performed using the equivalent flexural strengh ratio [34,35]. The proposed equation using the equivalent flexural strength ratio shows very good agreement with the experimental values with a reasonably safe margin similar to the safety of anchors in the un-reinforced plain concrete calculated from the current design equations.

2. Design guidelines for concrete breakout resistance

The concrete breakout capacity for anchors in concrete was