

Literature Review on Cast-in-Place Anchors with Anchor Reinforcement under Tension

Jin-Young Park ^{a*}, Gyeonghee An ^a, Junhee Park ^a

^aStructural and Seismic Safety Research Division, Korea Atomic Energy Research Institute,
111 Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, Republic of Korea

*Corresponding author: jinpark@kaeri.re.kr

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1. Introduction

In nuclear power plants, seismic fragility assessments are conducted to estimate the conditional probability of failure of critical structures and equipment. Evaluation results indicate that the failure modes of many components are governed by the failure of their supporting anchors. While anchors can fail in both tensile and shear modes, common tensile failure modes include concrete breakout, bolt steel failure, pullout of headed anchors, bond failure, and splitting failure, with concrete breakout dominating the failure of many components. In practice, anchor reinforcements are installed around anchors to enhance the concrete breakout capacity. Therefore, it is essential to accurately evaluate the tensile strength of anchors with anchor reinforcement.

2. Literature Review

In this section, existing standards and experimental results regarding the tensile strength of anchors with anchor reinforcement are reviewed.

2.1 Design Standards

Figure 1 shows the typical anchorage details of anchor reinforcement as proposed in ACI 318-19 [1]. The standard states that if the development length of anchor reinforcement is adequately provided on both sides of the concrete breakout surface, the design strength of the reinforcement can be used in place of the concrete breakout strength. Due to limited experimental data, the standard does not specify restrictions on the diameter, location, or strength of the anchor reinforcement; however, the commentary recommends that the distance from the anchor to the anchor reinforcement should not exceed $0.5h_{ef}$ (h_{ef} : effective embedment depth of the anchor), and the maximum diameter should not exceed 16 mm. Similarly, the Korean concrete anchor design standard, KDS 14 20 54 [2], also recommends taking anchor reinforcement into account.

In the Eurocode [3], anchor reinforcement details are proposed under the term ‘supplementary reinforcement’. According to the standard, the yield strength of the reinforcement should not exceed 600 Mpa, and the bar diameter should be no larger than 16 mm. The distance

from the anchor to the reinforcement is limited to $0.75h_{ef}$, which allows a wider range than that recommended in ACI 318-19 [1] and KDS 14 20 54 [2]. Furthermore, the development length of the reinforcement in the direction of the concrete breakout surface is suggested to be at least four times the bar diameter (in case of anchorage with bends, hooks or loops), rather than following the standard development length for ordinary reinforcement. Due to the limited research on anchor reinforcement, different detailing provisions are proposed in the various standards.

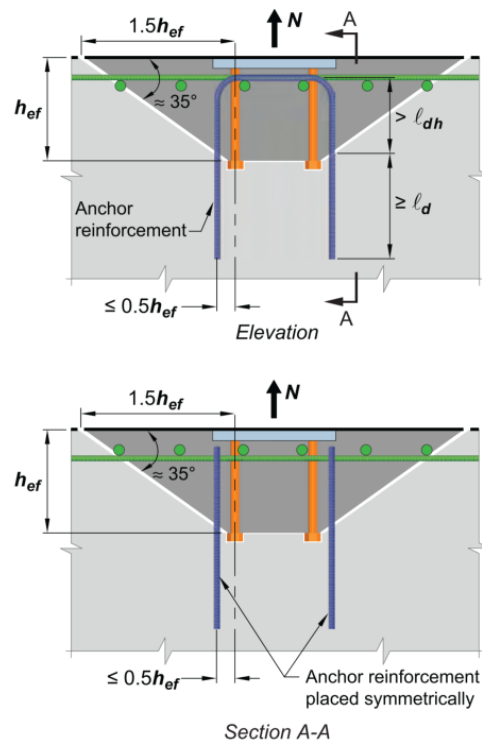


Fig. 1. Typical anchorage details of anchor reinforcement proposed in ACI 318-19 [1]

2.2 Previous Studies

Eligehausen et al. [4] provide a comprehensive overview of concrete anchors, which has served as the basis for many design standards. In their work, anchor reinforcement is referred to as ‘hanger reinforcement’, and is shown to enhance both the tensile strength and ductility of anchors.

Lee et al. [5] conducted tensile performance tests on large-diameter, deep-embedded cast-in-place (CIP) anchors used in nuclear power plants. The test specimens with anchor reinforcement consisted of anchors with a diameter of 69.9 mm, an embedment depth of 635 mm, and reinforcement bars with a diameter of 25.4 mm and a yield strength of 413.8 Mpa. The results showed that when the concrete cone failure load exceeded the yield strength of the anchor reinforcement, both mechanisms contributed to the tensile resistance, thereby increasing the overall tensile capacity. This increase in tensile strength corresponded to approximately 60% of the yield strength of the anchor reinforcement.

Henriques et al. [6] performed experiments on anchor reinforcement with diameters of 10 mm and 12 mm, while also considering the influence of surface reinforcement. The results showed that, in the absence of surface reinforcement, the addition of anchor reinforcement did not produce a significant increase in tensile capacity. In contrast, when surface reinforcement was provided, the tensile capacity increased by up to 61% compared with plain concrete, and ductility was also significantly improved.

Ferreira et al. [7] investigated the effects of varying the arrangement, spacing, and angle of anchor reinforcement relative to the concrete cone failure surface. Figure 2 compares the increase in anchor tensile capacity due to anchor reinforcement with results from other studies. In their experiments, the tensile capacity increased by up to 2.3 times, which was considerably higher than in other studies, and this was attributed to differences in reinforcement detailing. Moreover, the closer the anchor reinforcement was placed to the anchor, the greater the increase in tensile capacity. However, when the anchor reinforcement was arranged perpendicular to the cone failure surface, the strengthening effect was reduced compared with vertical placement.

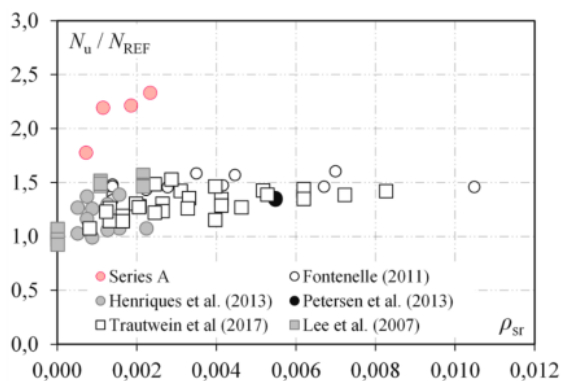


Fig. 2. Comparison of tensile capacity enhancement due to anchor reinforcement (Ferreira et al. [7])

Xu et al. [8] conducted experiments using tie bars and U-shaped bars as anchor reinforcements. The anchors had a diameter of 36 mm with embedment

depths of 150 mm and 200 mm, while the anchor reinforcement diameters were 12 mm and 16 mm. The results showed that with tie bar reinforcement, the tensile strength increased by 25-45%, whereas with U-shaped bar reinforcement, the increase was 45-75%. In addition, the crack patterns and ductility varied depending on the type of anchor reinforcement.

3. Conclusions

This study reviewed existing design standards and previous research on the tensile strength of anchors with anchor reinforcement. Various studies have investigated the effects of diameter, strength, arrangement, and type on anchor reinforcement. However, the reported increases in tensile capacity and ductility vary among experiments, and no reliable method has been established to accurately predict these effects. Future work will involve experimental studies on the detailed anchor reinforcement used in domestic nuclear power plants and the development of predictive methods for their tensile performance.

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