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Experimental investigation of post-installed adhesive anchors in concrete under tension and shear loads

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ABSTRACT: One of the most widely used techniques in the rehabilitation of concrete structures is the application of post-installed adhesive anchors in concrete. The main purpose of this study is to evaluate the efficiency and safety of this technique under domestic Iranian workshop conditions. This study focuses on the effects of parameters such as adhesives used in Iran, embedment depth, edge distance, and the use of either single or group of anchors in both reinforced and plain concrete members. The design procedure is in accordance with ACI 318-19 guidelines. For this study, eight tension and eight shear tests are carried out and the type of failure and the factors affecting their behavior are examined. The results show that by increasing embedment depth and distance from the edge of the concrete member, both tensile and shear capacities increase. In group installation, by reducing the rebar spacing, the nominal bond strength between adhesive and concrete decreases due to the initiation of cracks in adjacent rebars. Finally, the comparison of experimental results with ACI 318-19 equations shows that the code predicts the tensile and shear failure capacities with safety factors of at least 1.5 and 2, respectively.

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1- Introduction

Over the past few decades, especially after several devastating earthquakes, the improvement of existing structures has become a major concern for engineers around the world. In this regard, numerous studies and various methods for repair, retrofitting and improvement have been conducted and reported in the literature. One of the well-known techniques in this field is the use of post-installed anchors in concrete members. This method is mostly used to add a new seismic system to the existing structure, strengthen and expand the foundations, and connect steel components to the concrete structure.

In 1998, Lehr and Eligehausen [1] performed experiments on a group of 4 anchors. They observed that by decreasing the distance of the anchors, the resulting stresses merge into each other, and this causes less strength for the group in comparison to four single anchors. In 2001, Çolak [2] concluded that the maximum capacity of the post-installed anchors linearly increases by increasing depth, but this increase becomes nonlinear when the depth exceeds 75 mm. In 2006, Eligehausen et al. [3] developed a behavioral model for post-installed anchors using numerical modeling and experimental studies. Experimental results showed that for group installation when the distance between the rebars is small, the concrete between the rebars had little effect on strength and only the surrounding concrete affected the strength. The study showed that by increasing the distance between a group of four anchors from 50 mm to 150 mm, the tensile capacity increased about 3.5 times that of a single anchor. In 2015, Ipakachi et al. [4] tested single and group of post-installed rebars under tensile and shear loads. They evaluated the models and the parameters that affect the behavior of both single and group of rebars under shear and tension loads.

2- Experimental Program

In the current study, the behavior of post-installed anchors under tensile and shear loads in reinforced and unreinforced concrete members is studied. In all samples, the rebars are installed into prepared holes and Hilti injectable adhesive is used. The concerned parameters include installation depth, rebar spacing in group installation, edge distance, and group performance. The instructions of the adhesive manufacturer and the rules of the relevant regulations [5-8] are observed in the installation and testing of the samples. Details of specimens are provided in Tables 1 and 2.

TRebar size and hole diameter are 14 and 20 mm, respectively. All tensile and shear tests have been conducted under unconfined boundary conditions in accordance with the relevant codes.

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Table 1. Specifications of tension specimen

Element type	Concrete sample dimensions (mm^3)	Test name	Test type	Depth (mm)	Spacing (mm)
Unreinforced concrete	2700×400×400	TTS-1	single	150	---
		TTM-1	group	150	400
Reinforced concrete	2700×400×400	TTS-2	single	150	---
		TTS-3	single	150	---
		TTS-4	single	200	---
		TTM-2	group	150	400
		TTM-3	group	150	200
		TTM-4	group	200	200

Table 2. Specification of shear specimen

Element type	Concrete sample dimensions (mm^3)	Test name	Test type	Edge distance (mm)	Spacing (mm)
Unreinforced concrete	2800×400×300	STS-1	single	100	---
		STS-2	single	150	---
		STS-3	single	200	---
		STM-1	group	150	300
Reinforced concrete	2800×400×300	STS-4	single	100	---
		STS-5	single	150	---
		STS-6	single	200	---
		STM-2	group	150	300

3- Results and Discussions

3- 1- Tensile Test

The failure mode in unreinforced concrete sample (TTS-1) is concrete cone failure, and the mode in reinforced samples is bond failure with a circular crack of a diameter of 7 cm. In group tension tests, with a spacing of 40 cm in unreinforced concrete sample, the concrete sample is divided into two pieces under flexural action and transverse cracks. In fact, flexural failure starts before exhausting bond capacity of the rebars. In a similar test on a reinforced concrete sample, bond failure governs the strength such that circular and radial cracks are formed around group of anchors. Figure 1 represents an example of failure in single and group of anchors in tension tests.

3- 2- Shear Test

In the test of unreinforced STS-1 sample, concrete cone failure mode occurs. The cone is formed at an angle of about 45 degrees, but cracks are observed up to 1.5 times its distance from the edge. By increasing the edge distance to 15 cm, the same results are repeated. When the edge distance reaches 20 cm, the rebar is deformed and the cone failure mode is not observed. In the reinforced STS-4 sample, a concrete cone failure mode is observed again. The main cone is formed with an angle of more than 45 degrees and its cracks are observed up to 2 times the edge distance. In the STS-5 specimen, cracks related to concrete cone failure with an angle of 45 degrees are created. In STS-6 specimen, the rebar failed under shear action, and cone failure is not observed. In STM-1 specimen, both rebars are simultaneously subjected to shear load to investigate the effect of group installation. In this test, the experiment continued until concrete cone failure was formed. In STM-2 specimen, in front of both rebars, concrete crushing happened. The crack between two rebars and the crack between the rebar and the edge of the sample expanded until a conical failure mode is fully formed. Figure 2 represents an example of failure in single and group of anchors in shear tests.

a. Single test **b. Group test**

Fig. 1. Example of tension test results

a. Single test **b. Group test**

Fig. 2. Example of shear test results

4- Comparison of the Measured and Predicted Results

The results of experiments are compared with that recommended by ACI 318-19 [9]. The nominal capacities of the tests are compared with values predicted by ACI 318-19. It is observed that minimum safety factors of 1.5 and 2, for tension and shear, respectively, exist for the tested samples.

5- Conclusions

In this study, the behavior of post-installed anchors under tensile and shear loads for domestic conditions are examined and failure modes and tensile and shear capacities are evaluated. A summary of the results are as follows.

By increasing the embedment depth, a significant decrease in the number of cracks around the tensile rebar is observed.

Bond strength of the adhesive is independent of reinforcing the concrete.

Linear relationship between installation depth and tensile capacity does not exist.

By reducing spacing between rebars in group of anchors, resistance capacity of the group is reduced.

The effect of group installation is more effective in reinforced samples relative to unreinforced samples under shear load.

In group tests, the depth of cracks created during the test is much greater than single tests.

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