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PULL-OUT RESISTANCE OF POST-INSTALLED ANCHORS WITH CRACKS REPAIRED BY EPOXY RESIN

Noritaka Morohashi[1]

[1] 1-2-1, Izumicho Narashino-shi Chiba 275-8575, JAPAN, morohashi.noritaka@nihon-u.ac.jp, Prof., Dept. of Architecture and Architectural Engineering, College of Industrial Technology, Nihon University, Dr.Eng.

ABSTRACT

In recent years, the effectiveness of repairing by injecting epoxy resin in cracks has been shown for buildings with a reinforced concrete structure that are cracked. In this study, we examined how the pull-out resistance improves when installing post-installed anchors after repairing cracks with epoxy resin on cracked concrete base material. Results indicate that, compared to the tests specimens without cracks, the test specimens which were cracked and were not repaired, tended to have a reduced pull-out resistance. On the other hand, for test specimens with cracks repaired by epoxy resin, compared to test specimens with small cracks, test specimens with large cracks were found to have an increased pull-out resistance, and in some cases, they were also found to have even an increased pull-out resistance compared to test specimens without cracks.

Keywords: Post-installed anchors, Crack repaired, Penetrating epoxy resin, Crack width

1. INTRODUCTION

In Japan, one of the world's most seismic nations, buildings get damaged by earthquakes. Cracks are one form of damage. The effectiveness of repairing by injecting epoxy resin in cracks has been shown for buildings with a reinforced concrete structure damaged by cracks. Moreover, when performing seismic retrofitting, post-installed anchors may be used in the future for buildings with repaired cracks. When doing so, the post-installed anchors installed in the presence of cracks are reported to have a decreased pull-out resistance, compared to sound concrete.

In this study, we aimed to confirm how the pull-out resistance improves when installing post-installed anchors after repairing cracks on cracked concrete base material.

2. EXPERIMENTAL

2.1 Test specimen overview and experimental procedure

The flow from making the test specimens to performing the pull-out test is shown in Figure 1, and the list of test specimens is shown in Table 1.

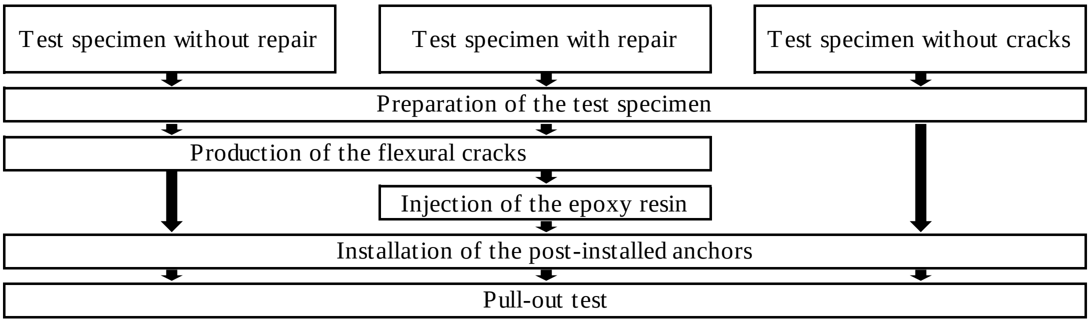


Figure 1. Flow from making the test specimens to performing the pull-out test

Table 1. List of test specimens

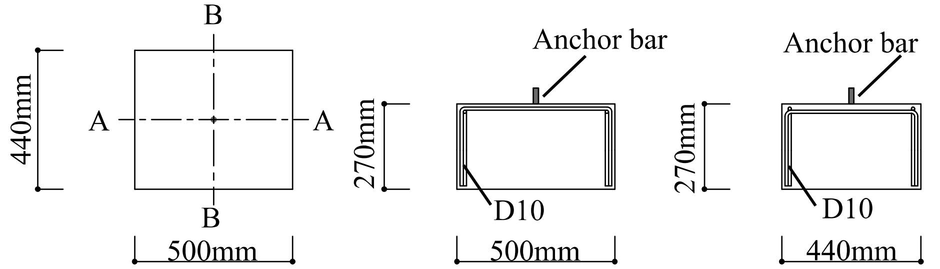
No.	Flexural crack	Repair by epoxy resin	Flexural crack on the anchor installed part	Effective embedding length (mm)
1	Yes	Yes	Small	80 (5da)
2	Yes	Yes	Large	80 (5da)
3	Yes	Yes	Small	112 (7da)
4	Yes	Yes	Large	112 (7da)
5	Yes	Yes	Small	144 (9da)
6	Yes	Yes	Large	144 (9da)
7	Yes	No	Small	80 (5da)
8	Yes	No	Large	80 (5da)
9	Yes	No	Small	112 (7da)
10	Yes	No	Large	112 (7da)
11	Yes	No	Small	144 (9da)
12	Yes	No	Large	144 (9da)
13	No	-	-	80 (5da)
14	No	-	-	112 (7da)
15	No	-	-	144 (9da)
16	Yes	Yes	Small	112 (7da)
17	Yes	Yes	Large	112 (7da)
18	Yes	No	Small	112 (7da)
19	Yes	No	Large	112 (7da)
20	No	-	-	112 (7da)

Concrete strength : No. 1 ～ 15 21N/mm^2
No.16 ～ 20 60N/mm^2

Anchor bar diameter : M16

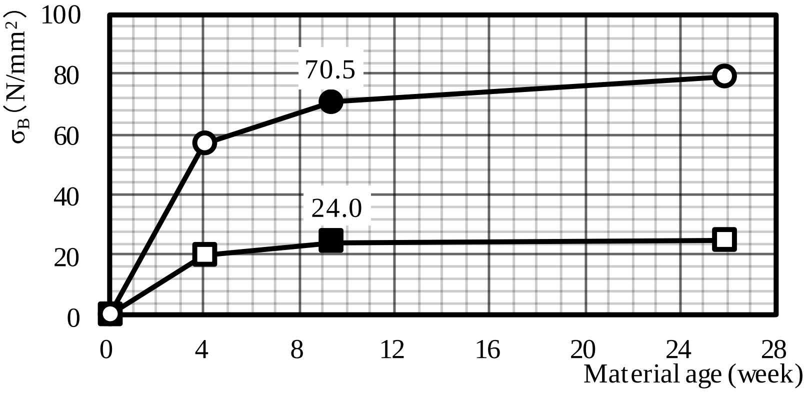
2.2 Shape of the Test Specimens

The shape of the test specimens is shown in Figure 2. The test specimens were rectangular parallelepipeds of 440 mm x 500 mm x 270 mm with U-shaped D10 arranged around the base material. Fifteen test specimens with the concrete strength set at 21 N/mm^2 and 5 test specimens with the concrete strength set at 60 N/mm^2 were prepared. The compressive strength and the splitting strength of the concrete during the test are shown in Figure 3 with black markers. The concrete strength was within the scope of application of the upper limit 36 N/mm^2 when installing post-installed anchors, and set at 21 N/mm^2 class as the concrete strength generally used in existing buildings and at the upper limit 60 N/mm^2 class of the design standard strength of RC standards.

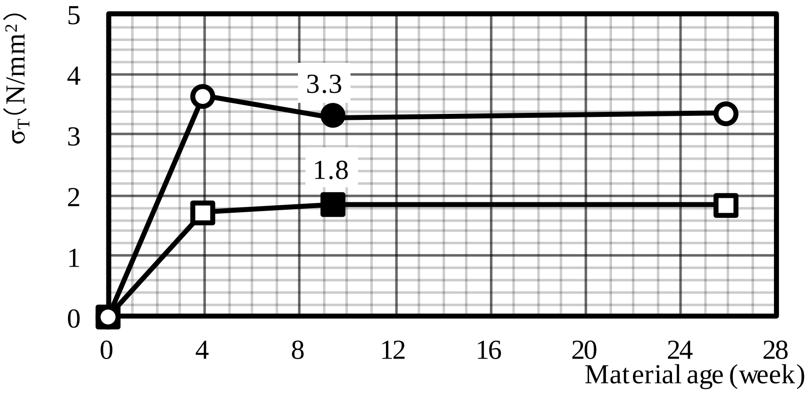


1)View from above 2)View of the AA section 3)View of the BB section

Figure 2. Shape of the test specimens



a) Compressive strength



b) Splitting strength

Figure 3. Concrete strength

The strength of the D10 (SD295A) with a reinforced base material is shown in Figure 4. A 100 mm x 100 mm grid was drawn on the test specimens and the cracks were observed.

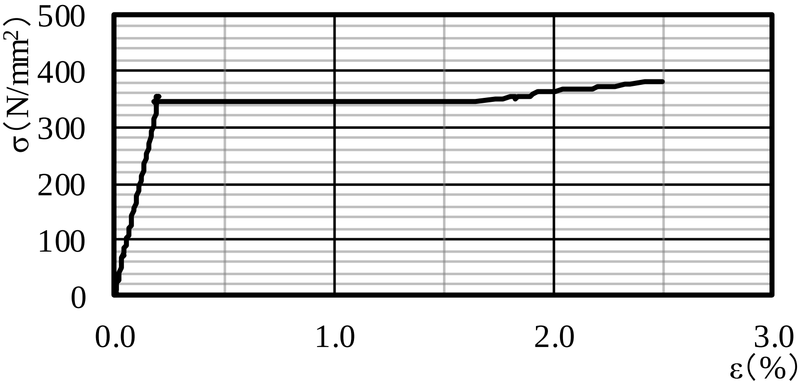


Figure 4. Strength of rebars with reinforced base material D10 (SD295A)
(The strain was measured by a strain gauge)

2.3 Method for Producing the Flexural Cracks

The flexural cracks were produced by a three-point bending test. The production method is shown in Figure 5. Two types of size of flexural cracks were set to compare the injection of epoxy resin. Since the acceptable crack width for the degradation of concrete is 0.3 mm in JASS5, a crack width of 0.4 mm (hereinafter referred to as small crack) or 0.8 mm (hereinafter referred to as large crack) when loading so as to be about 0.3 mm when unloaded, were used as criteria. Unloading was performed after visually confirming with a crack scale that the crack width was larger than the criteria. The width and depth of the flexural cracks are shown in Table 2. The crack width and the crack depth were measured on three points per test specimen with a microscope and an ultrasonic measuring device, respectively. Compared to during loading, the crack width was narrower after unloading. Moreover, the crack depth was around 50-186 mm for the small crack test specimens and around 62-204 mm for the large crack test specimens.

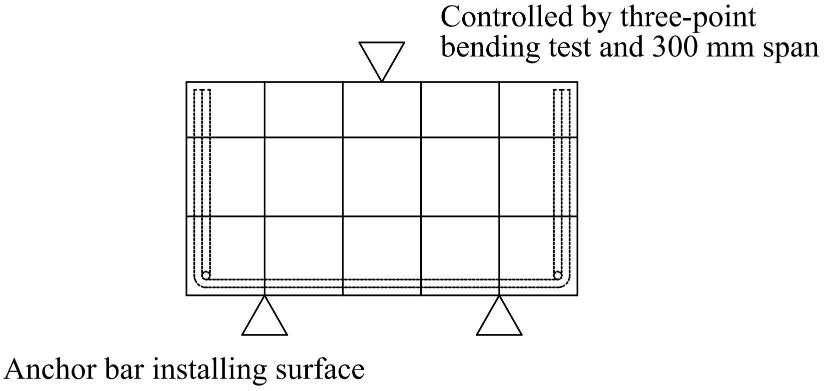


Figure 5. Method for producing the flexural cracks

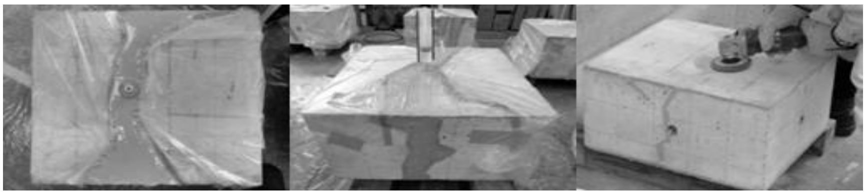
Table 2. Width and depth of the flexural cracks

No.	Measured position					
	End part 1		Middle		End part 2	
	Crack depth (mm)	Crack width (mm)	Crack depth (mm)	Crack width (mm)	Crack depth (mm)	Crack width (mm)
1	127	0.08	186	0.25	158	0.20
2	130	0.06	189	0.18	136	0.10
3	63	0.20	50	0.20	61	0.22
4	146	0.18	144	0.30	165	0.22
5	86	0.05	87	0.10	68	0.08
6	110	0.40	100	0.40	156	0.16
7	139	0.20	113	0.40	149	0.30
8	135	0.10	179	0.20	132	0.18
9	136	0.22	171	0.26	156	0.04
10	104	0.06	171	0.18	141	0.28
11	117	0.20	168	0.22	130	0.18
12	-	0.42	172	0.25	150	0.42
16	174	0.10	156	0.10	164	0.06
17	85	0.52	62	0.54	76	0.60
18	120	0.06	155	0.20	140	0.02
19	119	0.20	204	0.28	107	0.35

- : Unmeasurable

2.4 Method for Injecting the Epoxy Resin

The process for repairing the cracks is shown in Figure 6. It was cured by coating with bond along the cracks, to prevent the epoxy resin to leak (Figure 6(a)). Next, penetrating epoxy resin was injected using the automatic low-pressure resin injection method (Figure 6(b)). Finally, the surface was finished by polishing it with a grinder (Figure 6(c)). The properties of the penetrating epoxy resin used here are shown in Table 3, and the properties of the bond are shown in Table 4. Both the penetrating epoxy resin and the bond that were used were the type where a main agent and a curing agent are mixed.



(a) Coating by bond (b) Epoxy resin injection (c) Surface polishing

Figure 6. Process for repairing cracks on the base material

Table 3. Properties of the penetrating epoxy resin

Mixing ratio (main agent: curing agent)	10:3
Density	1.2
Compressive strength	123N/mm^2
Bending strength	59N/mm^2
Tensile shear strength	13N/mm^2
Adhesive strength	3.1N/mm^2

Table 4. Basic properties of the bond

	Main agent	Curing agent
Main components	Epoxy resin	Polythiol, tertiary amine
Appearance	White paste	Black paste
Mixing ratio (main agent: curing agent)	1:1	
Density	1.50±0.05	

2.5 Method for Installing the Anchors

The boring was made with a drill of 18.0 mm perforation diameter at the center of the test specimens. The effective embedding lengths were 5 da, 7 da and 9 da in order to study the differences in failure modes. In order to prevent failures in the anchor bars, the anchor bar material used here was SNB7. The strength of the anchor bars is shown in Figure 7. In the method for installing post-installed anchors, adhesive injectable cartridge types were used. The properties of the adhesive used are shown in Table 5. The adhesive was also the type where a main agent and a curing agent are mixed.

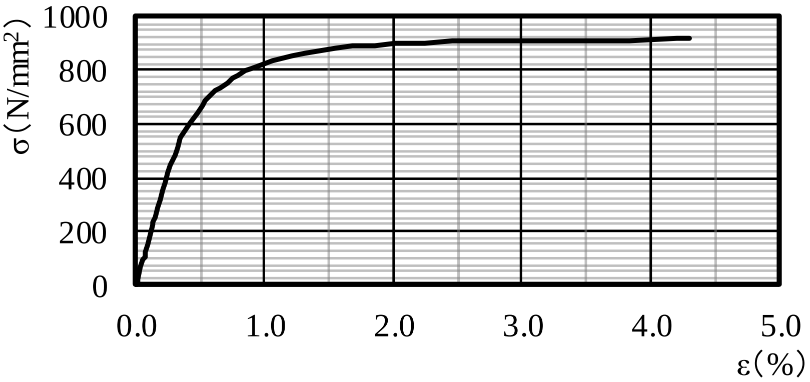


Figure 7. Anchor bar strength M16 (SNB7)
(The strain was measured by a strain gauge)

Table 5. Properties of the adhesive used in injectable cartridge types

Main agent	Non-styrene epoxy acrylate resin
Curing agent	BPO (Benzoyl peroxide)

2.6 Method for Pull-Out Testing on Anchor Bars

The pull-out test on anchor bars was performed by setting the test specimens as shown in Figure 8. The displacements were measured by using two wire-type displacement meters on the position of the anchor bars about 10 mm from the concrete surface, and the amount of displacement was the average value of the two meters.

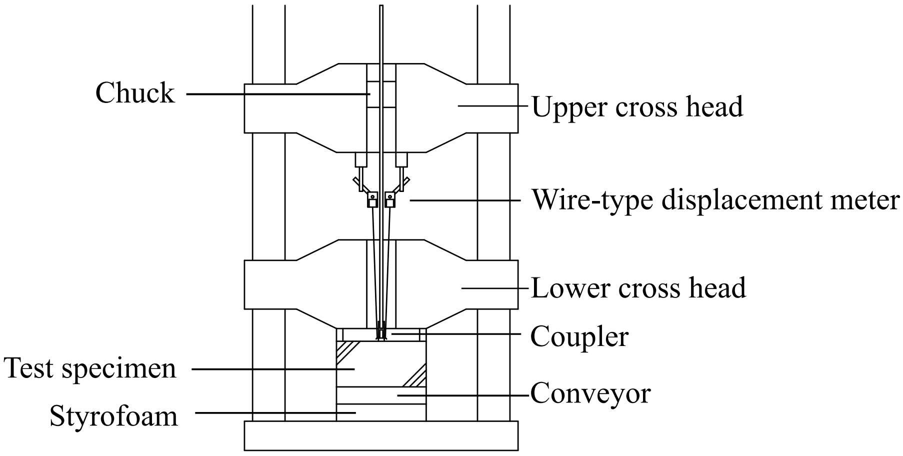


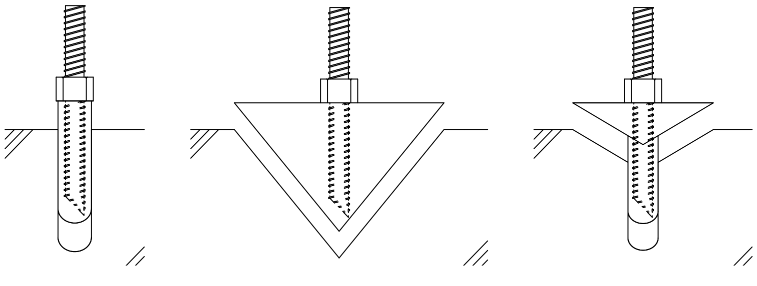
Figure 8. Pull-out testing method

3. TEST RESULTS

3.1 Maximum Load and Failure Modes

The loads and failure modes from the calculation results and the test results are shown in Table 6, and schematic diagrams of the failure modes are shown in Figure 9. The tensile strength calculation formula of the adhesive post-installed anchors is shown in Formula 1, which is shown in the seismic retrofitting design guideline for existing steel-reinforced concrete structure buildings and its commentary. Here, we review the test specimens without cracks (No. 13, 14, 15, and 20).

First, when the concrete strength is 21 N/mm^2, the calculated value of the cone-type failure is the smallest for the test specimen having an effective embedding length of 5 da. However, since the scope of the effective embedding length is 7 da or more in Formula 1, we assumed that the bond failure mode would precede. Nonetheless, the actual failure mode was a cone-type failure. For the test specimens having an effective embedding length of 7 da, we assumed from the calculated value that it would be a cone-type failure. The actual failure mode was a cone-type failure as predicted, and the maximum load was higher than the test specimens with an effective embedding



(a) Bond failure (b) Cone-type failure (c) Mixed failure

Figure 9. Schematic diagrams of the failure modes

Table 6. List of loads and failure modes

No.	Calculation results		Test results	
	Pull-out resistance (kN)	Predicted failure mode	Maximum load (kN)	Final failure mode
1	40.2	Bond failure	50.9	Cone-type failure
2	40.2	Bond failure	66.6	Cone-type failure
3	48.5	Cone-type failure	59.8	Cone-type failure
4	48.5	Cone-type failure	91.5	Cone-type failure
5	72.4	Cone-type failure	101.0	Cone-type failure
6	72.4	Cone-type failure	106.8	Cone-type failure
7	40.2	Bond failure	46.3	Cone-type failure
8	40.2	Bond failure	46.9	Cone-type failure
9	48.5	Cone-type failure	58.4	Cone-type failure
10	48.5	Cone-type failure	59.5	Cone-type failure
11	72.4	Cone-type failure	83.1	Cone-type failure
12	72.4	Cone-type failure	74.1	Cone-type failure
13	40.2	Bond failure	73.1	Cone-type failure
14	48.5	Cone-type failure	84.4	Cone-type failure
15	72.4	Cone-type failure	123.2	Cone-type failure
16	82.0	Cone-type failure	78.9	Cone-type failure
17	82.0	Cone-type failure	127.2	Cone-type failure
18	82.0	Cone-type failure	76.7	Mixed failure
19	82.0	Cone-type failure	86.3	Cone-type failure
20	82.0	Cone-type failure	103.7	Cone-type failure

length of 5 da. For the test specimens having an effective embedding length of 9 da, we assumed that the failure mode would be a cone-type failure. Moreover, we assumed that the pull-out resistance would be the greatest among the test specimens having a concrete strength of 21 N/mm^2, since the effective embedding length was the longest. The test results showed a cone-type failure as predicted, and the maximum load was the biggest among the test specimens having a concrete strength of 21 N/mm^2.

Next, when the concrete strength was 60 N/mm^2, since the concrete strength had increased, the maximum load also increased compared to when the concrete strength was 21 N/mm^2. This demonstrated that the longer the effective embedding length is, the maximum load increases, and that the higher the concrete strength is, the maximum load increases.

Formula 1. Tensile strength calculation formula for adhesive post-installed anchors

$T_a = \min(T_{a1},\ T_{a2},\ T_{a3})$ .... (1)

$T_{a1} = \sigma_y \cdot a_0$ .... (2)

$T_{a2} = 0.23\sqrt{\sigma_B} \cdot A_C$ .... (3)

$T_{a3} = \tau_a \cdot \pi \cdot d_a \cdot \ell_e$ .... (4)

However, $\tau_a = 10\sqrt{\sigma_B/21}$

Here,
T_a : tensile strength per anchor (N)
T_{a1}: tensile strength per anchor determined by the steel's yield (N)
T_{a2}: tensile strength per anchor
determined by the cone-type failure of the existing concrete skeleton (N)
T_{a3}: tensile strength per anchor
determined by the adherence strength of the adhesive anchor (N)

σ_y : standard yield point of the rebar (N/mm^2)

a_0 : effective sectional area in consideration of the screw machining of the joining bar, or nominal cross-section area of the anchor bar (mm^2)
σ_B : compressive strength of the concrete's existing section (N/mm^2)
A_C: effective horizontal projection area per anchor
to the cone-type failure of the existing skeleton concrete (mm^2)

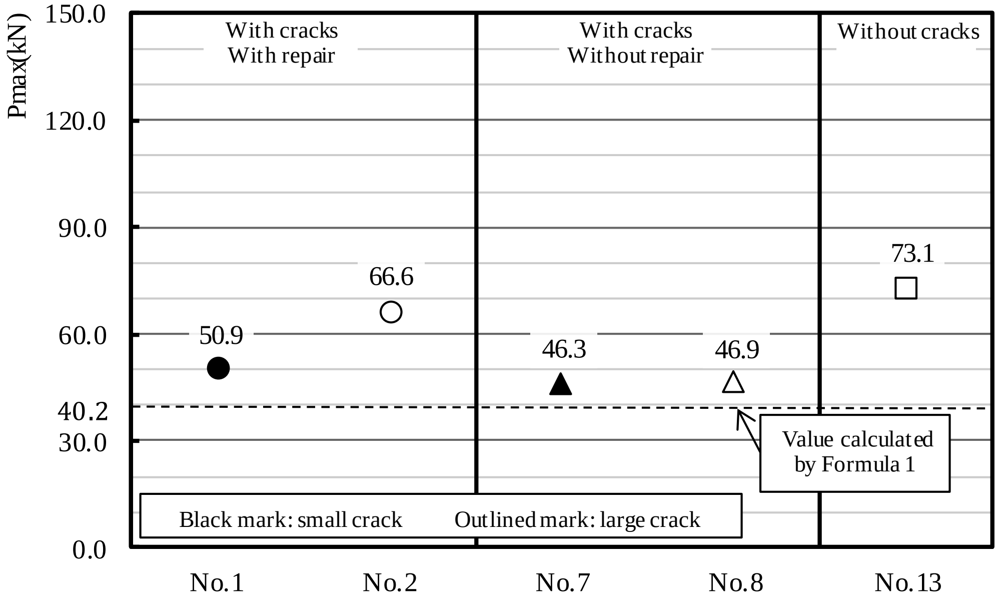
τ_a : adherence strength to the tensile force of the adhesive anchor (N/mm^2)

d_a: name of the anchor bar (mm)
ℓ_e : effective embedding length of the anchor (mm)

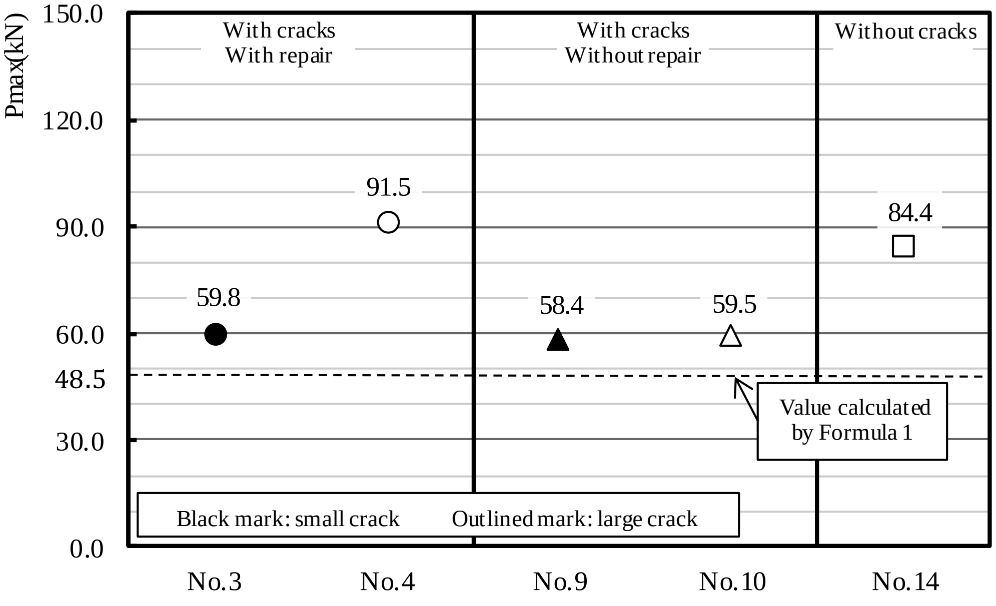
3.2 Impact of the Repair By Epoxy Resin on the Pull-Out Resistance

The comparison of pull-out resistance depending on whether the crack is repaired or not is shown in Figure 10 for each effective embedding length. For test specimens where anchor bars were installed without repairing the cracks (marked ▲ and △ in the drawing), the pull-out resistance tended to decrease at all effective embedding lengths regardless of the size of the crack, compared to test specimens without cracks (marked □ in the drawing). Relative to the test specimens without cracks, the pull-out resistance of test specimens with small cracks was about 63.3%-74.0%, and 60.1%-83.2% for test specimens with large cracks.

On the other hand, for the test specimens where the anchor bars were installed after repairing the cracks (marked ● and ○ in the drawing), some of the test specimens with large cracks (No.4 and No.17) had an increased pull-out resistance compared to the test specimens without cracks (marked □ in the drawing). Moreover, when considering the size of cracks for those with the cracks repaired, the test specimens with large cracks (marked ○ in the drawing) were found to have an increased pull-out resistance of about 105.7%-161.2% compared to test specimens with small cracks (marked ● in the drawing). This may be due to the fact that the penetrating epoxy resin didn't sufficiently reach the cracked part in the test specimens with small cracks and that the repair was insufficient. In test specimens with large cracks, the penetrating epoxy resin

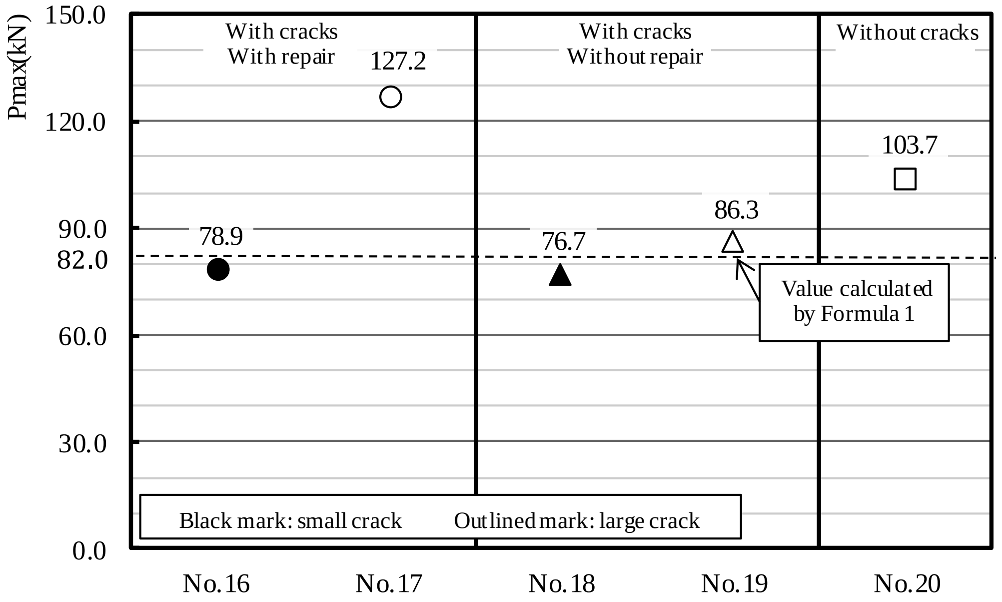


a) Effective embedding length 5 da (concrete strength 21 N/mm^2)

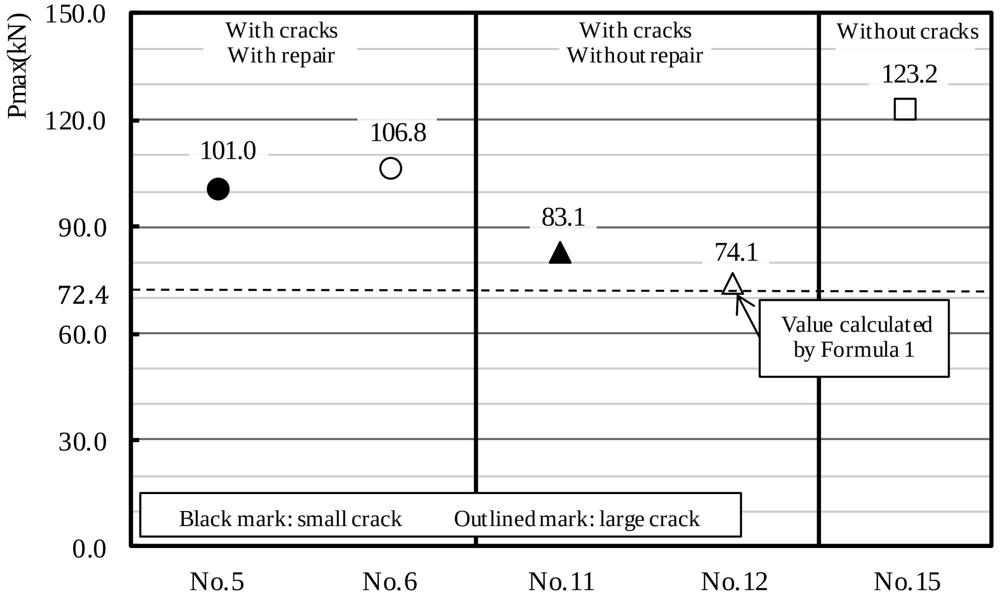


b) Effective embedding length 7 da (concrete strength 21 N/mm^2)

Figure 10. Pull-out resistance for each effective embedding length



c) Effective embedding length 7 da (concrete strength 60 N/mm^2)



d) Effective embedding length 9 da (concrete strength 21 N/mm^2)

Figure 10. Pull-out resistance for each effective embedding length

could sufficiently penetrate the cracks and became integrated in the cracked concrete, which may have led to have cases where the pull-out resistance exceeded that of test specimens without cracks.

As a result, the effectiveness of installing post-installed anchors after repairing the cracks was significant for the test specimens with large cracks, but for test specimens with small cracks, in some cases, the repair by epoxy resin was difficult, and the pull-out resistance was about the same as that of without repair.

4. SUMMARY

From the study of the pull-out resistance of post-installed anchors, repaired using penetrating epoxy resin in the base material cracks, the following findings were obtained within the range of this pull-out test.

1) With equal effective embedding length (7 da), the pull-out resistance increased when the concrete strength was 60 N/mm^2 compared to 21 N/mm^2.
2) Compared to test specimens without cracks, the test specimens with cracks but without repair of the cracks tended to have a decreased pull-out resistance.
3) In the test specimens with cracks repaired by epoxy resin, the test specimens with large cracks were found to have an increased pull-out resistance compared to test specimens with small cracks, and in some cases, were also found to have an increased pull-out resistance compared to test specimens without cracks.

This study has demonstrated that the pull-out resistance increases when installing post-installed anchors after repairing the cracks for the test specimens with large cracks, but we would like to further investigate the approximate crack width for which we can expect sufficient penetration of the penetrating epoxy resin.

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