Pullout Test of Retrofit Anchors using Deformed Reinforcement and Adhesive

 

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ABSTRACT

An experimental study was carried out to determine pullout behavior of a new type of anchor bolt that used deformed reinforcement and a commercial adhesive. Concrete slabs and columns with about 20-MPa compressive strength were used for 136 pullout tests performed. Test variables included anchor diameter (10 mm ~ 32 mm), embedment depth (10Φ or 15Φ), edge effect, and presence of transverse reinforcement in existing concrete. In Type-S test, where the edge or reinforcing steel effect was not included, the anchor pullout strengths increased with increasing anchor diameters. Anchors with 15Φ embedment depth had higher pullout strengths than those with 10Φ embedment depth. The largest average pullout load of 208 kN was determined for anchors made with D25 reinforcement and with 15Φ embedment depth. In Type-E tests, where the anchors were installed close to the edge of existing concrete, there were reductions in pullout strengths when compared to those determined in Type-S tests. In Type-ER tests, influence of the reinforcement in existing concrete on the anchor pullout strengths was examined using reinforced concrete and plain concrete columns. Test results indicated that existing transverse reinforcement (column ties) did not help increase the pullout strength. The overall pullout test results revealed that the new anchor bolt can develop large pullout strengths while the anchors can be made of materials that are readily available in the market.

Keywords : bonded anchor, retrofit, pullout, deformed reinforcement, adhesive, rehabilitation, strengthening

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1. INTRODUCTION

The post-installed anchors (or retrofit anchors), such as expansion anchors and chemical anchors, are often used in strengthening, rehabilitation, or extension of existing reinforced concrete structures.[2,3] They transfer various loads from added structural members (steel or reinforced concrete) to existing reinforced concrete beams, columns, or walls. An example, a reinforced concrete structure under construction, is shown in Fig. 1. Due to a design change, the column from the floor above would apply a large concentrated load in the mid-span of a reinforced concrete beam (not shown in Fig. 1) and there was a need to strengthen the beam. Structural steel shapes were used to increase the moment capacity of the section and the steel plate and expansion anchors were used to transfer the moment and shear to the existing column as shown in Fig. 1.

Fig.1 Strengthened Reinforced Concrete Structure Using Structural Steel Shapes and Anchor Bolt

Examples that frequently call for the use of retrofit anchors also include construction using slurry wall. In highly populated commercial or business district in Korean cities, slurry walls are often constructed to build exterior walls below grade. Use of retrofit anchors usually becomes necessary as the reinforcing steel in the slurry wall is often improperly positioned or damaged. Although existing commercially available anchors have been successfully used in rehabilitation and strengthening projects, they have some inherent drawbacks:

(1) selection of anchor diameter and length is limited by the available anchor sizes;

(2) the pullout strength provided by the largest commercially available anchor may not be sufficient to satisfy the structural demand; and

(3) the anchors are relatively expensive.

The objective of this study was to devise a new type of structural anchor bolt and experimentally evaluate the performance in pullout: deformed reinforcement used with a commercial adhesive. It was conceived at the beginning of the study that, with a combination of a good commercial adhesive and readily available steel reinforcement, it would be possible to provide anchor bolts that can resist a large pullout force. New anchors, made of materials that are readily available in the market, are likely to be more economical than existing anchors while a structural engineer will be given more freedom as to the selection of the retrofit anchors. The experimental program in this study was carefully prepared to reflect the results of the study in the field, especially in the steel-to-concrete connection in strengthening, rehabilitation, or extension of existing reinforced concrete structures.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Plain concrete slabs and columns and reinforced concrete columns were used for the pullout test. It needs to be noted that the construction practices in Korea in the past decades included use of relatively low strength structural concrete. Concrete with about 20-MPa compressive strength was used in this study since it was likely that the test results would be applied for rehabilitation or extension of existing reinforced concrete structures in the future. The slabs and columns were cast in five different batches while the maximum size of coarse aggregate was 25 mm. Table 1 summarizes the concrete compressive strength.

All slabs were plain concrete slabs and only minimal amount of reinforcement necessary to stabilize slabs during movement was used. Grade SD40 and grade SD30 deformed reinforcement were used for the main bars and the column ties, respectively, in the reinforced concrete columns.

'Table 1 Summary of Concrete Strengths

Batch no.	Comp. strength		Remarks
	28 day (MPa)	56 day (MPa)	
1	21.1	26.2	slabs
2	17.8	25.2	slabs
3	23.4	-	slabs
4	--	25.2	4 reinf. conc. cols. + 4 plain conc. cols.
5	19.8	--	4 reinf. conc. cols. + 4 plain conc. cols.

2.2 Test Specimens

The test specimens (anchor bolts) were fabricated in the following fashion: (1) Grade SD40 bars were cut into proper lengths, (2) compression force was applied on one end of the bars to increase the cross-sectional area, (3) the upset end, thus created, was threaded, and (4) a pair of nuts served as head of the anchors.

Figure 2 shows new type of anchors devised in this study. A manufacturer who produces mechanical couplers for reinforcement fabricated and supplied the anchors. The adhesive used is of hybrid type and is available in the market.4

2.3 Test Series and Variables

Three different types of pullout tests were performed in this study: Type-S, Type-E, and Type-ER. Standard pullout tests, or Type-S tests, were performed to determine the pullout mechanism and pullout strength of the anchors. Eight plain concrete slabs, 1.8 m long, 1.8 m wide, and 0.4 m deep, were used for the Type-S tests. Test variables were the anchor diameter (eight different deformed reinforcement: D10, D13, D16, D19, D22, D25, D29, and D32) and the embedment depth (ten times the bar diameter, or 10Φ, or 15Φ). The anchors were installed in the slab interior region away from edges: the minimum edge distance was 1.5 times the embedment depth.1 A total of 70 Type-S tests was completed.

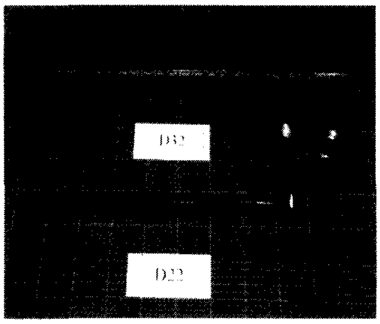


Fig.2 Anchor Bolts: D32 and D22 deformed reinforcement with upset end

It needs to be noted that, as shown in Fig. 1, the retrofit anchors often need to be installed close to edge in the field.

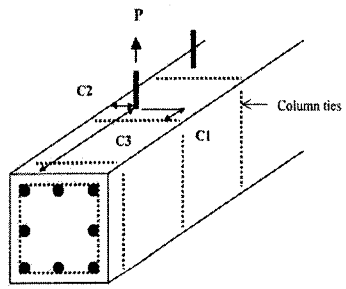
The objective of the edge pullout tests, or Type-E tests, was to determine the amount of reduction in the pullout strength, if any, as the anchors are installed close to edges: the edge distance was 2Φ. In Type-E tests, six different deformed reinforcement were used: D16, D19, D22, D25, D29, and D32. The embedment depth was either 10Φ or 15Φ. A total of 30 tests was completed. In Type-ER tests, the influence of reinforcement in existing concrete on the anchor pullout strength was examined using reinforced concrete and plain concrete columns. Sixteen columns (0.4 m x 0.4 m x 1.8 m), eight reinforced concrete and eight plain concrete columns, respectively, were prepared for test. The pullout tests were performed close to the column longitudinal edge. The pullout strengths of anchors determined in reinforced concrete columns and in plain concrete columns were compared. The purpose was to examine if the presence of transverse reinforcement, i.e. the column ties, influences the pullout strength. Figure 3 shows schematics of the Type-ER tests. The distance between the anchor and the column tie, C1, was 3Φ while the edge distance, C2, was 80 mm as shown in Fig. 3. In Type-ER tests, six different deformed reinforcement were used: D16, D19, D22, D25, D29, and D32. The embedment depth was always 10Φ. A total of 36 tests was completed. Table 2 summarizes all pullout test variables.

2.4 Installation of Test Specimens, Test Setup, and Test Procedure

Installation of an anchor bolt consisted of drilling, drill-hole cleaning, injection of adhesive in the drill hole, and anchor installation. The diameter of the drill hole was 3 mm to 8 mm larger than the nominal reinforcement diameter depending on the size of the reinforcement. Following the drilling and the drill-hole cleaning, adhesive was injected in the drill hole and an anchor was installed in place. The pullout test setup is shown in Fig. 4.

Note 1: 10×bar diameter,
2: Number of tests performed.

The reaction frame consisted of two steel supports, a beam resting on the supports, and a base for the hydraulic cylinder as shown in Fig. 4. The loading assembly, which consisted of a steel box and a high-strength steel rod, was used to connect vertically the anchor and the 300-kN-capacity hydraulic cylinder.



Column reinforcing detail;
Main bars: 8 - D19
Column ties: D10 at 250mm
Cover = 25mm
C1 = 3×bar diameter
C2 = 80mm
C3 > 300mm

Fig.3 Schematics of Type-ER Test

Table 2 Pullout Test Variables

Test type	Embedment depth	D10	D13	D16	D19	D22	D25	D29	D32	Total	Remarks
S	10ϕ[1]	5[2]	5	5	5	5	5	5	5	40	slabs
	15ϕ	5	5	5	5	5	5	--	--	30	slabs
E	10ϕ	--	--	3	3	3	3	3	3	18	slabs
	15ϕ	--	--	3	3	3	3	--	--	12	slabs
ER	10ϕ	--	--	3	3	3	3	3	3	18	reinf. conc. columns
	10ϕ	--	--	3	3	3	3	3	3	18	plain conc. columns
Total		10	10	22	22	22	22	14	14	136	

A round hole at bottom of the steel box allowed the threaded end of the anchor to protrude inside so that nuts could be applied in the box. The high-strength steel rod then connected the steel box and the hydraulic cylinder. The anchors were subjected to pullout as the pullout force was slowly applied using the hydraulic cylinder operated by a hand pump. The anchor displacement was measured on top of the anchor using a LVDT.

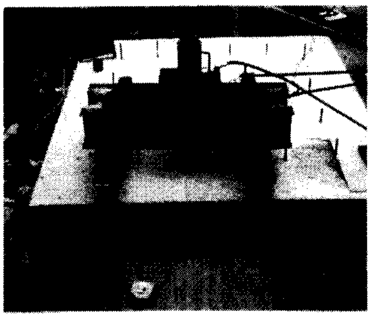


Fig.4 Setup: Hydraulic cylinder, reaction frame, loading assembly

The applied force was measured using a pressure transducer. Signals from the LVDT and the pressure transducer were recorded using an electronic data acquisition system while the sampling rate was one data set per second. When the displacement exceeded the anchor diameter, it was assumed that the anchor failed in pullout and the test was stopped in the Type-S tests. In the Type-E and the Type-ER tests, the test was discontinued after the displacement exceeded 15 mm. It needs to be noted that, in this study, pullout tests were performed after allowing twelve hours or longer cure time for the adhesive although not longer than one hour was normally required in the field.4 This unusually long cure time was employed in an attempt to avoid any possible variation in the adhesive strength that may influence the test results.

3. TEST RESULTS

3.1 Pullout Load vs. Displacement Behavior

The standard pullout tests (Type-S) were performed to determine the basic pullout mechanism and the pullout strength of the anchors. As the anchors were subjected to pullout in Type-S tests, three different failure types were observed: (1) concrete cone failure followed by gradual bond failure between adhesive and concrete, (2) bond failure, and (3) steel fracture in tension. The great majority of anchors failed in the first mode. The steel fracture was observed in some anchors made with D10 reinforcement and was never observed in any other anchors having diameters larger than 10 mm.

Figure 5 shows a load-displacement plot of an anchor typical with the 10 embedment depth. The displacement began to increase slowly as the pullout load increased. As the pullout force approached the peak load, the concrete surrounding the bar failed in a shallow conical shape. The thickness of the concrete cone was typically about 40 % of 10Φ embedment depth while the cone diameter varied typically between 3/4 and three times of the embedment depth. The pullout resistance of the anchor began to decrease immediately after the concrete cone developed. The pullout load decreased as the slip between the adhesive and the concrete increased as shown in Fig. 5. Figure 6 shows a different load-displacement behavior that was typical of an anchor with the 15Φ embedment depth. The displacement increased slowly as the pullout load increased. As the pullout force approached the peak load, small amount of concrete surrounding the anchor again failed. The pullout load kept increasing, however, which indicated that the anchor still effectively resisted the load. As the displacement further increased, the pullout load remained about the same as shown in Fig. 6. The load-displacement plot showed a relatively flat load plateau. Figure 7 shows a slab after test. The sizes of concrete cones developed varied from one test to another as shown in Fig.7 It needs to be noted that the sizes of the cone in anchors with the 15Φ embedment depth were typically much smaller than those with 10Φ embedment dept

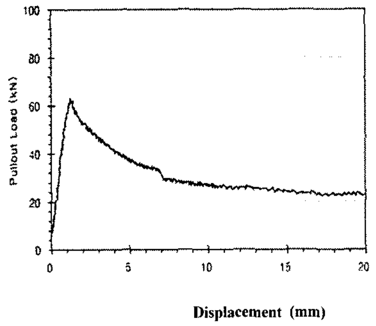


Fig.5 Typical Type-S Test Result: Load vs. displacement, D16, embedment depth = 10Φ

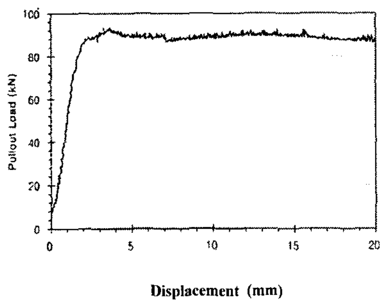


Fig.6 Typical Type-S Test Result: Load vs. displ., D16, embedment depth = 15Φ

Anchors were installed close to edges in edge pullout tests or Type-E tests. In the Type-E pullout tests, two distinctively different failure types were observed: (1) concrete failure followed by the gradual bond failure and (2) concrete failure accompanied by a sudden bar pullout. Although the majority of the anchors tested failed in the first mode, some anchors were pulled out suddenly and completely. Figures 8 and 9 show load-displacement plots determined in the two different modes. As the sudden bar pullout shown in Fig. 8 occurred without any warning, it was clearly not a desirable failure mode for structural applications. This was observed in about 10% of all anchors tested close to edges.

Fig.7 A Slab after Test

Most anchors showed load-displacement plots similar to one shown in Fig. 9. As the pullout force increased and approached the peak load, tensile cracks developed on the side face of the concrete slab. The first crack that developed typically resembled cross section of a shallow concrete cone as shown in Fig. 10. Cracks also appeared on the top surface and progressed in directions approximately parallel to the edge before pulling out a chunk of concrete. The pullout resistance of the anchor began to decrease shortly after the first crack appeared and secondary cracks typically developed further down on the slab side face closer to the tip of the anchor as shown in Fig. 10. It is noted that, in a number of tests, a splitting crack developed on the side face of the slab along the anchor location, which indicated that the edge distance of 2Φ employed in this study provided insufficient cover. In Type-ER tests, the pullout failure mode was always a concrete cone failure followed by the gradual bond failure in the reinforced concrete columns and the load-displacement plots were similar to that shown in Fig. 5. In the plain concrete columns, the failure mode was mostly the concrete failure followed by the gradual bond failure. For anchors made with D29 and D32 reinforcement and embedded in plain concrete columns, the failure mode was a sudden bar pullout at peak because the expansion anchors, was observed in the anchors made with D25 reinforcement and with the 15Φ embedment depth as shown in Table 3.

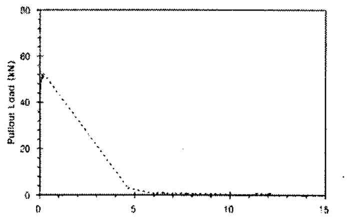


Fig.8 Sudden Bar Pullout: Load vs. displacement

plain concrete reached the flexural strength before the peak load was applied. Type-ER pullout test results of these anchors (D29 and D32) on plain concrete columns were therefore not reliable and not reported.

The average pullout strengths increased with the increasing anchor diameters in general as shown in Fig. 11. It is observed that the average pullout strengths of anchors with the 15Φ embedment depth are 23 % to 28 % higher than those of the anchors with the 10Φ embedment depth. The only exception is the test results of D10. The average pullout strengths remained about the same as the embedment depths increased probably because the development length is already reached with the 10Φ embedment depth. The highest average pullout load of 208 kN, which is significantly higher than the pullout resistance provided by large commercial

Table 3 Summary of Test Results

Test type	Replicate no.	D10 (10Ø/15Ø)	D13 (10Ø/15Ø)	D16 (10Ø/15Ø)	D19 (10Ø/15Ø)	D22 (10Ø/15Ø)	D25 (10Ø/15Ø)	D29 (10Ø/15Ø)	D32 (10Ø/15Ø)
S	1	43 / 49	59 / 81	71 / 87	118 / 142	156 / 163	125 / 251	138 / --	165 / --
	2	47 / 46	70 / 74	66 / 96	125 / 146	141 / 217	140 / 148	134 / --	194 / --
	3	47 / 38	57 / 82	63 / 94	104 / 142	111 / 133	186 / 170	139 / --	149 / --
	4	46 / 48	59 / 85	81 / 99	140 / 156	138 / 220	208 / 241	181 / --	151 / --
	5	47 / 48	67 / 84	82 / 91	105 / 137	153 / 147	173 / 232	164 / --	159 / --
	average	**46 / 45**	**62 / 81**	**72 / 93**	**118 / 145**	**140 / 176**	**166 / 208**	**151 / --**	**164 / --**
E	1	--	--	59 / 78	69 / 93	61 / 92	60 / 133	95 / --	84 / --
	2	--	--	52 / 64	80 / 88	58 / 107	68 / 119	154 / --	101 / --
	3	--	--	51 / 78	60 / 102	53 / 140	98 / 102	136 / --	113 / --
	average	--	--	**54 / 74**	**70 / 94**	**57 / 113**	**75 / 118**	**128 / --**	**99 / --**
	E/S(%)	--	--	74 / 80	59 / 65	41 / 64	45 / 57	85 / --	60 / --
ER (reinf. conc.)	1	--	--	70 / --	70 / --	88 / --	88 / --	150 / --	166 / --
	2	--	--	48 / --	56 / --	88 / --	91 / --	142 / --	172 / --
	3	--	--	89 / --	89 / --	80 / --	82 / --	152 / --	178 / --
	average	--	--	**69 / --**	**72 / --**	**85 / --**	**87 / --**	**148 / --**	**172 / --**
ER (plain conc.)	1	--	--	61 / --	81 / --	103 / --	97 / --	n/a	n/a
	2	--	--	57 / --	87 / --	91 / --	107 / --	n/a	n/a
	3	--	--	57 / --	96 / --	81 / --	101 / --	n/a	n/a
	average	--	--	**58 / --**	**88 / --**	**92 / --**	**102 / --**	**n/a**	**n/a**

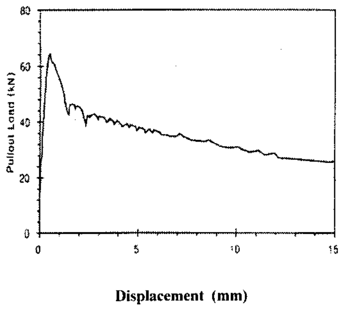


Fig.9 Typical Type-E Test Result: Load vs. displacement, D16, embedment depth = 15Φ

Fig.10 Type-E Pullout Test Result: Crack development observed during test

3.2 Pullout Strength

The Type-S tests were performed with 10Φ and 15Φ embedment depths for anchors made with D10, D13, D16, D19, D22, and D25 reinforcement, and with 10Φ embedment depth for anchors made with D29 and D32 reinforcement. Five replicate tests were completed. Test results are included in Table 3 and Fig. 11.

The Type-E pullout tests were performed with 10Φ and 15Φ embedment depth with D16, D19, D22, and D25 reinforcement, and with 10 Φ depth for anchors made with D29 and D32 reinforcement.

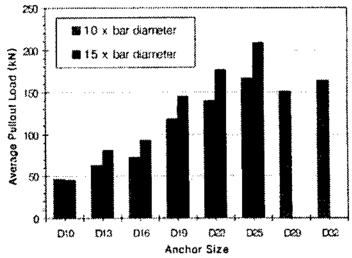


Fig.11 Type-S Pullout Test Results : Embedment depth = 10Φ or 15Φ

Three replicate tests were performed. The test results are shown in Table 3 and Fig. 12. The average pullout strength determined in the Type-E tests was lower than that in the Type-S tests for the anchors of the same diameter, probably because of the loss of confinement by surrounding concrete. The pullout strengths determined in the Type-S and the Type-E tests were compared. The average pullout strengths determined in the Type-E tests were lower than those in the Type-S tests. The ratio of the average pullout strengths between the two different test types ranged between 41 % and 85 % as shown in Table 3 for the anchors with the 10Φ embedment depth. The ratio ranged between 57 % and 80 % for anchors with the 15Φ embedment depth.

Using reinforced concrete and plain concrete columns, the influence of existing transverse reinforcement (column ties) in concrete on the anchor pullout strength was examined in Type-ER tests. It is observed from test results in Table 3 and Fig. 13 that the pullout strengths of the anchors embedded in reinforced concrete columns are in general not higher than those of the anchors in plain concrete columns. Test results therefore indicated that column ties did not help increase the pullout strength of anchors. It is noted in Table 3 that the average pullout strengths determined in Type-ER tests (edge distance = 80 mm) are lower than those in standard tests (Type-S) for anchors of the same diameter. It is also noted that the average pullout strengths in Type-ER tests are typically higher than those determined in Type-E tests (edge distance = 2Φ) probably because of different edge distances.

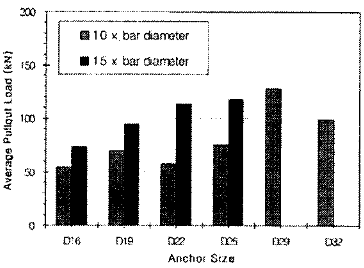


Fig.12 Type-E Pullout Test Results:
Embedment depth = 10Φ or 15Φ

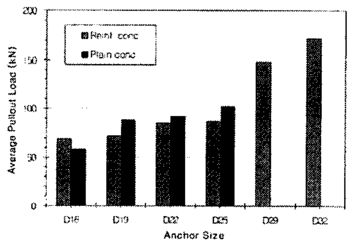


Fig.13 Type-ER Pullout Test Results:
Embedment depth = 10Φ

4. CONCLUSIONS

The objective of this study was to evaluate the pullout performance of a new type of retrofit anchors that used deformed reinforcement and a commercial adhesive. Results of 136 pullout tests indicated that the anchors can develop large pullout resistance while the anchors can be made of materials that are readily available in the market. The load-displacement behavior and the pullout strength were experimentally determined with the conclusions summarized as follows.

Standard Pullout Tests (Type-S):

(1) The anchor pullout strengths increased with increasing embedment depths and anchor sizes.

(2) Some anchors made with D10 reinforcement fractured in tension both with embedment depths of 10Φ and 15Φ. For anchors with diameters larger than 10 mm, the failure mode was the shallow concrete cone failure followed by the gradual bond failure between the concrete and the adhesive.

(3) The largest average pullout load of 208 kN, which is significantly higher than the pullout resistance provided by a large expansion anchor, was determined for the anchor made of D25 reinforcement and with 15Φ embedment depth.

Edge Pullout Tests (Type-E):

(1) The average pullout strength determined in the Type-E tests was lower than that in the Type-S tests for the anchors of the same diameter because of the loss of confinement by surrounding concrete.

(2) The ratio of the average pullout strengths between the two different test types (Type-E/Type-S) ranged between 41 % and 85 % for the anchors with the 10Φ embedment depth. The ratio ranged between 57 % and 80 % for anchors with the 15Φ embedment depth.

(3) In some tests, concrete cone failure occurred with the sudden bar pullout. This type of failure was observed in about 10% of all anchors tested.

(4) The splitting crack, which developed in some edge tests, indicated that the edge distance of 2Φ employed in this study provided insufficient cover.

(5) Development of splitting cracks and the sudden bar pullout failure observed in some tests indicated that the edge distance larger than 2Φ needs to be employed for actual structural applications in the field.

Edge Pullout Tests with Reinforcement (Type-ER):

(1) The pullout strengths of anchors embedded in reinforced concrete columns were not higher than those of anchors embedded in plain concrete columns. Test results indicated that transverse reinforcement (column ties) did not help increase the pullout strength.

(2) The pullout mode was the concrete cone failure followed by gradual bond failure for all anchors installed in reinforced concrete columns.

(3) The average pullout strengths in Type-ER tests are typically higher than those determined in Type-E tests probably because of longer edge distance.

ACKNOWLEDGEMENT

The authors gratefully acknowledge support for the study primarily by Korean Small and Medium Business Administration and Kyonggi-Do. Supplementary financial support by Hilti Corporate Research and Hilti Korea Co., Ltd. is acknowledged. Adhesive and installation equipment used in the study were also supplied by Hilti.

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