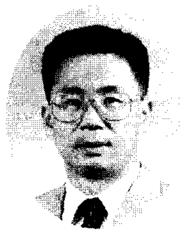
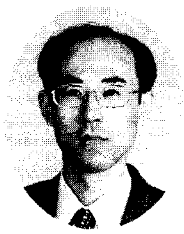
Direct Shear Test of Retrofit Anchors Using Deformed Reinforcement and Adhesive





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ABSTRACT

A new type of retrofit anchor bolt that uses deformed reinforcing bars and a commercial adhesive was developed and then an experimental study was carried out to determine the behavior of the anchors in direct shear. The steel-to-concrete interface was tested. Plain concrete slabs with about 20-MPa compressive strength were used for 23 direct shear tests performed. Test variables were anchor diameters (D16, D22, and D29) and edge effect. Three different shear tests were completed: simple shear, edge shear where anchors were pulled against the concrete core, and edge shear where anchors were pushed against the concrete cover. In the simple and the edge shear tests where the anchors were pulled against the core, the theoretical dowel strength determined by $f_y/\sqrt{3}$ was achieved but with relatively large displacements. The shear resistances increased with the increasing displacements. In the edge shear test where the anchors were pushed against the cover, the peak shear strengths significantly lower than the theoretical dowel strength were determined due to cracks developed in concrete when the edge distance was 80 mm. The peak strengths were about 50% of the dowel strength for D16 bar, and about 25% or less of the dowel strength for D22 and D29 bars. Test results revealed that the edge shear where the anchor was pushed against the cover controled.

Keywords : bonded anchor; retrofit; direct shear; deformed reinforcement; adhesive; rehabilitation; strengthening.

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1. Introduction

The retrofit anchors are often used to transfer forces between added structural steel and reinforced concrete members in the strengthening or extension of existing reinforced concrete structures. As an example, a strengthened reinforced concrete girder is shown in Fig. 1 where the retrofit anchors are required to connect the steel end plate and the reinforced concrete column. The steel-to-concrete connection needs to resist the bending moment and the shear force. The objective of this study- was to evaluate the shear transfer capacity of a new type of retrofit anchor bolt that used deformed reinforcing bars and commercial adhesive.

Fig. 1 Strengthened reinforced concrete girder

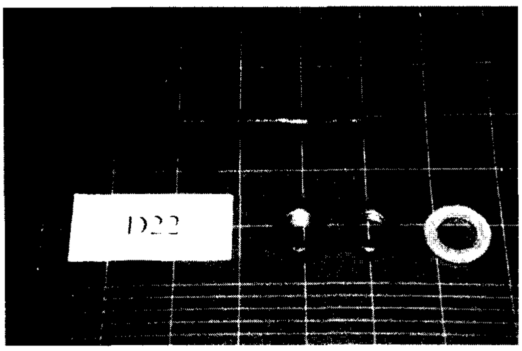


Fig. 2 Anchor bolt: D22 bar with threaded upset end and nuts

The pullout capacity of the anchors was published elsewhere.[1] Two advantages for these anchor bolts are: (1) Selection of the anchor diameters and lengths is relatively free because the reinforcing bars of various diameters are simply cut into required lengths and used as the bolts; (2) The new anchor bolts are more economical than existing retrofit anchors such as expansion anchors and other commercially available chemical anchors.

2. Experimental Program

2.1 Materials

Four plain concrete slabs, 1.8 m long, 1.8 m wide, and 0.4 m thick, were used for tests. The slabs were cast in two different batches with the maximum coarse aggregate size of 25 mm. Table 1 summarizes the compressive strength of the slabs. Relatively low strength structural concrete of less than 20-MPa strength was used for tests. Such a low strength concrete was typically used in the past decades in Korea, and the retrofit anchors were likely to be used for the strengthening or extension of the existing reinforced concrete structures.

Fig. 2 shows an anchor bolt developed in this study. It was fabricated in the following fashion:

(1) Grade SD40 reinforcing bar was cut into proper length;
(2) Large compression force was applied on one end of the bar to increase the cross-sectional area;
(3) The created upset end was threaded;
(4) A pair of nuts and a washer served as the head of anchor.

A manufacturer who produces mechanical

couplers for the deformed reinforcement fabricated and supplied the bolts. The adhesive was commercially developed by an adhesive manufacturer to install dowels (reinforcing bars) in concrete and is readily available in the market.[2]

Table 1 Compressive strength of slabs

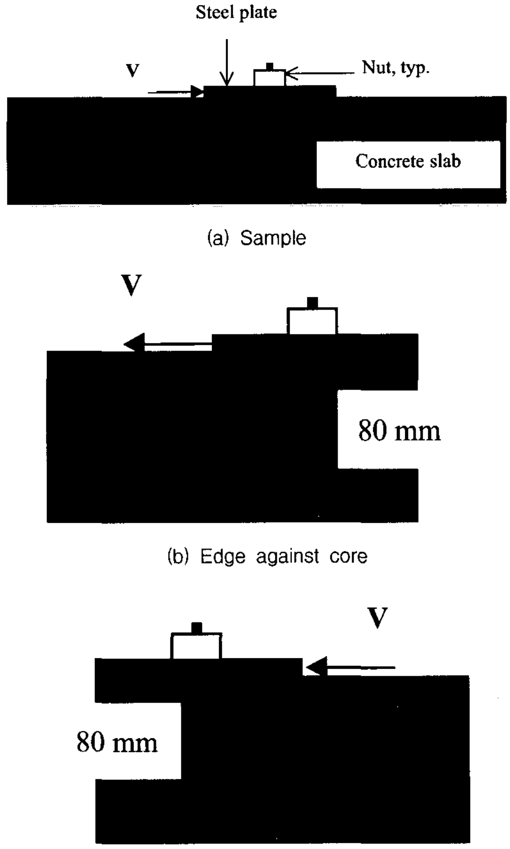
Batch No.	Slab No.	28-Day f_{ck} (MPa)
1	400-1, 2	17.4
2	400-3, 4	19.9

2.2 Test Types and Variables

Three different types of direct shear tests were performed for the anchors fabricated using D16, D22, and D29 reinforcing bars: Simple direct shear test, edge shear test where the anchors were pulled against the core of the slab, and edge shear test where the anchors were pushed against the slab edge. Fig. 3 shows the schematic drawings of the three different direct shear tests. In the simple shear test, the anchors were installed in the interior region of the slabs away from edges. In the edge shear tests, the anchors were installed close to the slab edges with an edge distance of 80 mm (distance between the slab edge and the center of the anchor cross section). The 80-mm distance was chosen because it was close to the minimum distance in the field: The anchors are typically installed inside the main bars while the concrete cover of at least 40 mm is required for beams and columns.[3] The anchor embedment depth was ten times the bar diameter in all tests. A total of 23 direct shear tests was completed as shown in Table 2 which summarizes the test variables and the number of tests performed.

Table 2 Test variables and number of tests

Test Type	Size			Total
	D16	D22	D29	
Simple shear	3	3	3	9
Edge against core	2	2	3	7
Edge against cover	2	2	3	7
Total	7	7	9	23



(a) Sample

(b) Edge against core

(c) Edge against cover

Fig. 3 Direct shear test types

2.3 Anchor Installation, Test Setup, and Test Procedure

A direct shear test setup shown in Figs. 4 and 5 was devised for tests.[4] Anchors were installed in the plain concrete slab. Installation of an anchor consisted of drilling, drill-hole cleaning, injection of the adhesive in the drill hole, and anchor installation. The diameter of the drill hole was 6 mm to 8 mm larger than the nominal bar diameter depending on the size of the reinforcing bars. Following the drilling and the drill-hole cleaning, the adhesive was injected in the drill hole and an anchor was installed in place. A 20-mm-thick mild steel plate was placed on the smooth trowel-finished top surface of the slab in such a way that the threaded upset end of the anchor protruded through a hole fabricated in the steel plate. The loading assembly, reaction block, high-strength steel rod, and hydraulic cylinder shown in Fig. 4 were used to apply the shear force.

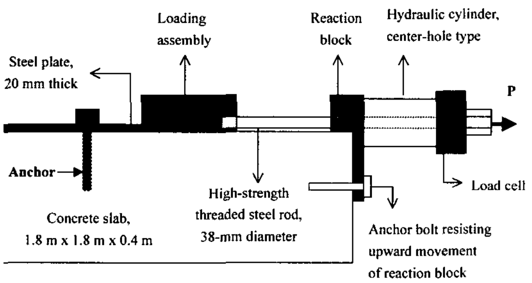


Fig. 4 Direct shear test schematics

The loading assembly consisted of a steel plate and a L-shaped steel block. A high-strength threaded steel rod of 38-mm diameter was used to connect the loading assembly and the 500-kN-capacity hydraulic cylinder. One end of the threaded rod was connected to the loading assembly while the other end was connected to the center-hole-type hydraulic cylinder, load cell, and a nut.

As the hydraulic cylinder extended, the rod pulled forward the steel plate which in turn applied the shear force to the anchor. The anchor displacements were recorded using LVDTs while the applied force was measured using a load cell as shown in Fig. 5. A computerized system was used for the electronic data acquisition. Sampling rate was one data set per second. When the horizontal displacement exceeded one bar diameter, it was assumed that the anchor failed in shear and the test was discontinued for the simple and the edge shear tests when the anchors were pulled against the slab core. Tests were discontinued at displacement smaller than one bar diameter for the edge shear test when the anchors were pushed against the slab edge, because the shear resistance decreased fast in this test type.

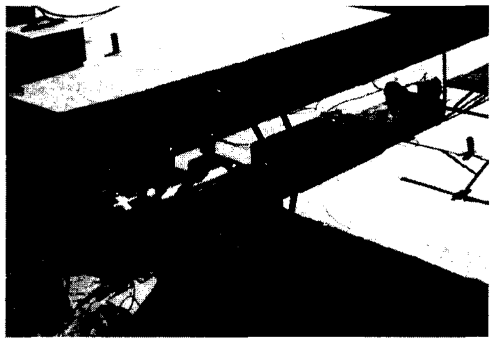


Fig. 5 Direct shear test setup

3. Test Results

3.1 Shear Forces Acting at Interface

The retrofit anchors in the field can be subjected to many different loading situations as shown in Fig. 6.[5] A structural steel member is connected to the concrete wall using the anchor bolts in Fig. 6(a). The mechanical behavior of the anchors is not affected by any edge conditions as shown. This type of an anchor application can occur in construction using slurry wall and strengthening and extension of concrete structures when the connection is required between the structural steel and the concrete wall. It is called the "simple" shear in this study when an anchor is subjected to the shear force while not bound to any edge conditions as shown in Fig. 6(a). Fig. 6(b) shows that the structural steel member may need to be connected to the concrete beam. Due to the limited beam height, the anchors are installed close to the top and the bottom faces of the beam as shown. The mechanical behavior of the anchors can be influenced by the existing edges. An anchor denoted as "A" in Fig. 6(b) is pulled against the concrete core when subjected to a downward shear force, herein called the "edge against core" in this study. On the other hand, an anchor denoted as "B" in Fig. 6(b) is pushed against the edge or cover when subjected to the same shear force. It is called the "edge against cover" in this study. It must be noted that a different loading situation also occurs in an anchor application as shown in Fig. 1. The edges exist in a direction parallel to the applied shear force at the connection between the structural steel plate and the concrete column in Fig. 1. This situation where the anchor shear behavior is influenced by edge existing in a direction parallel to the applied shear force, unfortunately, was not included in this study.

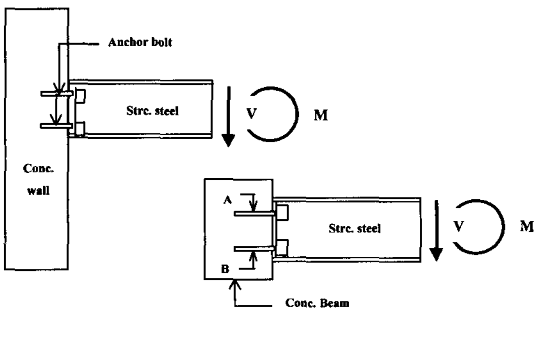


Fig. 6 Forces acting at steel-to-concrete interfaces

3.2 Relationship between Shear Load and Displacement

Fig. 7 shows shear load vs. horizontal displacement plots of the anchors fabricated using D16 bar. The horizontal displacements increase slowly as the shear loads increase. Both in the simple and the edge shear tests where the anchor is pulled against the slab core (edge against core), the responses are roughly linear until the shear loads reach the theoretical dowel strength. In Fig. 7, the theoretical dowel strength was determined using Eq. (1).

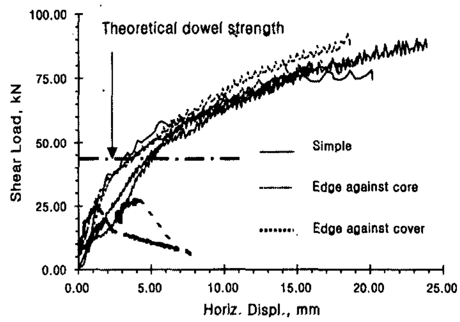


Fig. 7 Test results: D16, simple, edge against core, and edge against cover

Theoretical dowel strength =

$$f_y/\sqrt{3} * A \quad (1)$$

In Eq. (1), fy and A denote the yield strength of the reinforcing bar and the cross-sectional area of the anchor, respectively. The theoretical dowel strength is reached when the horizontal displacements are between 3 and 5 mm for the anchors fabricated using D16 bar. As the shear loads further increase, the stiffnesses (slope of the load-displacement curve) tend to decrease in Fig. 7. The shear resistances keep increasing with increasing displacements as shown. The overall shear load-displacement behavior can be roughly modeled using a bilinear relationship for anchors fabricated using reinforcing bars of small diameters such as D16.

In the edge shear test where the anchor is pushed against the slab cover (edge against cover), the load-displacement plots are significantly different from the other two types of the shear tests as shown in Fig. 7. The responses are roughly linear at the beginning, but the stiffnesses quickly decrease as the shear loads further increase and the peaks are reached at shear loads much smaller than the theoretical dowel strength in Fig. 7. The peak shear loads are reached when the displacements are between 1.5 and 4 mm for the anchors fabricated using D16 bar. At the peak, cracks developed in concrete surrounding the anchor in a shape of a half-pyramid as shown in Fig. 8. The shear resistance of the anchor began to decrease immediately after the crack development. It is important to note that, in Fig. 7, the peak shear loads approximately equal to 50% of the theoretical dowel strength are determined from the edge shear test where the anchors are pushed against the slab cover for the anchors fabricated using D16 bar.

Figs. 9 and 10 show shear load vs. horizontal displacement plots of the anchors fabricated using D22 and D29 reinforcing bars, respectively. In the simple and the edge shear tests where the anchors are pulled against the slab core, the responses are roughly linear at the beginning in Figs. 9 and 10. However, the stiffnesses quickly decrease with the increasing shear loads before the theoretical dowel strength is reached. As a result, the theoretical dowel strength is reached when the displacements are relatively large: The displacements are between 4.5 and 10 mm for D22, and 7and 12 mm for D29 bars, respectively. It needs to be noted that, in the edge shear test where the anchor is pulled against the core, a vertical splitting crack typically developed on the slab side face close to the top as shown in Fig. 11. The length of this splitting crack was typically two to three times the anchor nominal diameter.

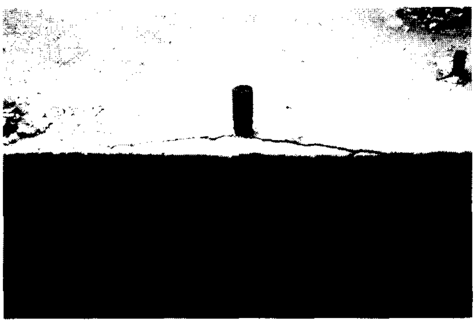


Fig. 8 Specimen after direct shear test : edge against cover

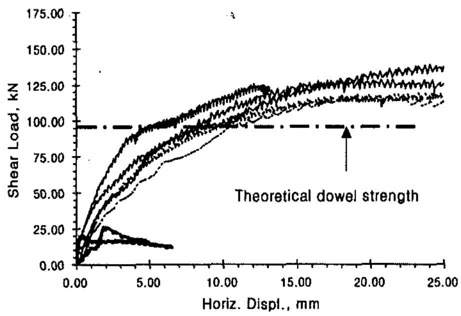


Fig. 9 Test results: D22, simple, edge against core, and edge against cover

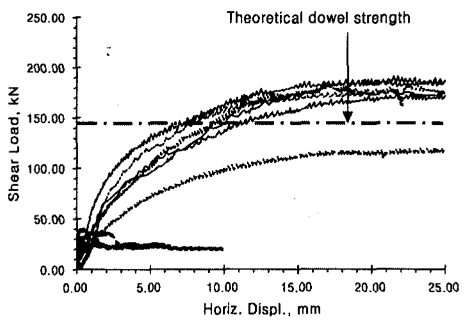


Fig. 10 Test results: D29, simple, edge against core, and edge against cover

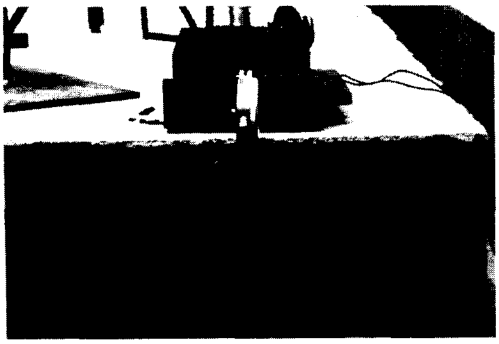


Fig. 11 Specimen after direct shear test : edge against core

In the edge shear test where D22 and D29 anchors are pushed against the slab cover, the load-displacement plots are again significantly different from the other two types of the shear tests in Figs. 9 and 10. The stiffnesses quickly decrease as the shear loads increase and the peak loads are reached at shear loads much smaller than the theoretical dowel strength in Figs. 9 and 10. This is due to the failure of concrete surrounding the anchor in a shape of a half-pyramid (See Fig. 8). The peak shear loads are reached when the displacements are very small: The displacements are less than 2 mm and 0.5 mm for D22 and D29 bars, respectively. The peak shear loads approximately equal only to 25% of the theoretical dowel strength are determined in the edge shear test where the anchor is pushed against the cover for anchors fabricated using D22 bar. The peak loads are about 20% of the theoretical dowel strength for anchors fabricated using D29 bar.

3.3 Discussion of Test Results

Test results shown in Fig. 7 indicate that the overall shear load-displacement behavior for anchors fabricated using reinforcing bars of small diameters such as D16 can be roughly modeled using a bilinear relationship. The theoretical dowel strength is reached when the horizontal displacements are relatively small. It can be interpreted that the bars remain in the vertical position with respect to the slab top surface at this stage and the primary load-resisting mechanism is the pure dowel action. The stiffnesses decrease as the shear loads larger than the theoretical dowel strength are applied. The stiffnesses decrease probably because the anchors do not remain vertical with respect to the slab top surface due to the relatively large displacements. The load-resisting mechanism changes and the anchor is subjected to the shear and the pullout forces at the same time.[6]

Test results shown in Figs. 9 and 10 indicate that the overall shear load-displacement behavior for anchors fabricated using reinforcing bars of relatively large diameters such as D22 and D29 can't be modeled using a bilinear relationship. The initial stiffnesses by the pure dowel action are not maintained until the theoretical dowel strength is reached probably due to the relatively low strength concrete used for tests. It is likely that the anchors do not remain vertical with respect to the slab top surface due to bearing failure of the relatively low-strength concrete. The shapes of the load-displacement curve, therefore, seem to be related both to the bar diameter and the concrete strength at the same time. For anchors with the smaller bar diameters such as D16, the bars yield in bending before the bearing failure of the concrete occurs. For the anchors with the larger bar diameters, the bars also yield in bending as the shear load approaches the theoretical dowel strength. At the same time, however, the bearing failure of the concrete seems to occur. The result is roughly a curvi-linear relationship as shown in Figs. 9 and 10.

4. Conclusions

Simple Shear

(1) The shear resistance of an anchor consistently increased with increasing displacement measured up to 25 mm.

(2) The theoretical dowel strength ($f_y/\sqrt{3}$ * A) was reached in all tests but with relatively large displacements.

(3) The theoretical dowel strength was reached when the horizontal displacements were between 3 and 5 mm for D16, 4.5 and 10 mm for D22, and 7 and 12 mm for D29 bars.

(4) Shear load-displacement plot can be roughly modeled using a bilinear relationship for anchors fabricated using D16 bar.

(5) Shear load-displacement behavior of the anchors fabricated using D22 and D29 bars can't be modeled using a bilinear relationship because of the early bearing failure of the low-strength concrete.

(6) The shapes of the shear load-displacement curve are related both to the bar diameters and the concrete strengths at the same time.

(7) For anchors with the smaller bar diameters, the bars yield in bending before the bearing failure of the concrete occurs. For the anchors with the larger bar diameters, the bars yield at the same time as the concrete bearing failure gradually occurs. The result is roughly a curvi-linear relationship.

Edge against Core

(1) The load-displacement plots of the anchors tested in edge-against-core condition (edge distance = 80 mm) were not significantly different from those obtained from the simple shear test of comparable anchors.

(2) The theoretical dowel strength ($f_y/\sqrt{3}$ * A) was reached in all tests except for one testing of D29.

(3) Splitting cracks developed on the slab side face as the shear loads increased in most tests.

Edge against Cover

(1) The shear resistance of the anchors tested in edge-against-cover condition (edge distance = 80 mm) was always significantly lower than that of the anchors tested in the simple or edge-against-core condition.

(2) The peaks were reached with very small displacements and the shear resistances immediately decreased with increasing displacements in all tests.

(3) The peak strengths were about 50% of the theoretical dowel strength for D16 and about 25% and 20% of the theoretical dowel strength for D22 and D29 bars, respectively.

(4) The peak shear loads were reached when the displacements were between 1.5 and 4 mm for D16 bars. The peak shear loads were reached when the displacements were less than 2 mm and 0.5 mm for D22 and D29 bars, respectively.

(5) Test results revealed that the edge shear where the anchors were pushed against the cover controled.

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