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Evaluation of Shear Strength of Concrete Beams Reinforced with GFRP Shear Plates

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***Abstract*— In this paper, a new type of GFRP shear reinforcement is proposed for reinforced concrete beams. The new GFRP shear reinforcement is manufactured into a plate shape with several openings to ensure high adhesion property with the concrete. The test was performed on six concrete beam specimens with shear span-to-depth ratio of 2.4 to experimentally investigate the performance of the proposed shear reinforcement. Test parameters include the shape of GFRP shear reinforcement and the amount of the GFRP reinforcement. We examined the effects of these parameters on the shear strength of the GFRP plate shear reinforced concrete beam. A shear strength equation for concrete beams with the proposed GFRP shear reinforcement is proposed based on modifying the existing shear strength equation for concrete beams with steel stirrups in ACI 318-11. Comparing the test results with the estimations based on the proposed equation, the results generally shows good agreement. Results from this paper show that the proposed system is a promising candidate for shear reinforcement in GFRP reinforced concrete beams.**

***Keywords*—Glass Fiber Reinforced Polymer, Reinforced Concrete Beam, Shear Reinforcement, Shear Strength.**

I. Introduction

The shear behavior of typical reinforced concrete beams is difficult to predict due to the characteristics of a sudden brittle failure. To prevent shear failure, steel bars in the form of stirrups are provided as shear reinforcement. However, rebar stirrups are causing corrosion of rebar and delaying construction period due to hand-applied processing. Nowadays, the study for a new shear reinforcement to replace rebar is being accelerated. FRP(fiber reinforced polymer) emerge as the alternative material because it offers many advantages such as light weight, durability, and corrosion resistance.

In this paper, GFRP(glass fiber reinforced polymer) plates with openings are used as shear reinforcement. This is the new shape of the shear reinforcement and installation process is relatively simple. Perforated GFRP plates with connecting devices as placing them in tension reinforcement were designed to be settled. GFRP plates are embedded in concrete and ensure composite action between the FRP and concrete. In addition, Perforated GFRP plates minimize bond failure by increasing the adhesive strength between the FRP and concrete also it can be improved shear performance of the structural members because of high strength of GFRP.

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To evaluate the shear performance of the new FRP shear reinforcement in concrete beams, shape of GFRP plates and reinforcement amount were chosen for test parameters. Cracking patterns and strain distributions of the test specimens were analyzed. The shear strength equation in ACI318-11(ACI Committee 318 2011) was evaluated by comparing calculated values with the experimental results to estimate the shear strength of the FRP reinforced concrete beams.

II. Experimental Program

A. *Experimental material*

The specimen material properties are shown in Table 1. In accordance with KS F standards, the average compressive strength of concrete measured at 28 days was 44.6 MPa. Deformed steel bars with a diameter of 25 mm were used as longitudinal reinforcement, and their tensile strength and modulus of elasticity are 500 MPa. Perforated GFRP plates are embedded in concrete as shear reinforcement and their tensile strength was 480 MPa. Specimens are shown in Figure 1.

TABLE I. PROPERTIES OF MATERIALS

	Area (mm^2)	**Strength (MPa)**	**Modulus of elasticity (GPa)**
Concrete	-	45	-
Tensile reinforcement (D25)	506.7	500	200
GFRP plate	-	480	50

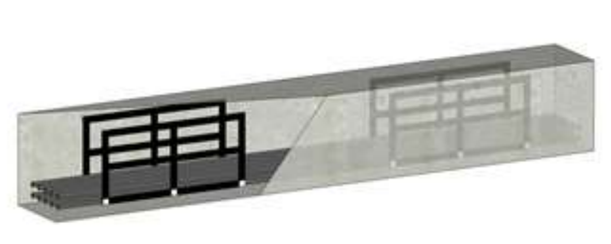

Figure 1. Schematic view of concrete beam reinforced with GFRP plates proposed in this study

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Figure 2. Shape of GFRP Plate.

TABLE II. DETAILS OF THE GFRP PLATES

specimen	Type	Ffu (MPa)	Width (mm)	Thickness (mm)	Center-to center spacing of vertical strips
A-1	A	480	20	4	340
A-2	A	480	30	4	340
A-3	A	480	50	4	340
A-4	A	480	70	4	340
B-3	B	480	37.5	4	230
C-3	C	480	37.5	4	230

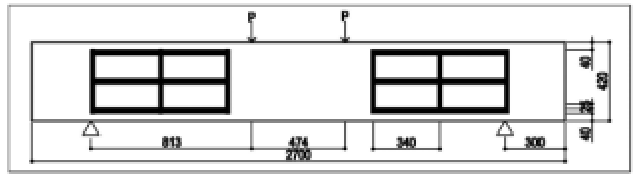
B. ***Specimen Details***

The test was performed on six concrete beam specimens to experimentally investigate the performance of the proposed shear reinforcement. Details of the FRP reinforcement used in each specimen are listed in Table 2. Figure 3 illustrates how FRP plates were placed in the specimens depending on their shapes. As listed in Table 2, all beam specimens were simply supported and their cross section was 350 mm × 420 mm and effective depth was 342 mm. The anchorage length was 300 mm from the point of support, Total span length of specimen was 2700 mm and clear span length was 2100 mm. Thickness of concrete cover was designed 40 mm and the shear span-to-depth ratio is 2.4 for all six specimens. In addition, this paper includes the details of GFRP plates in each specimen.

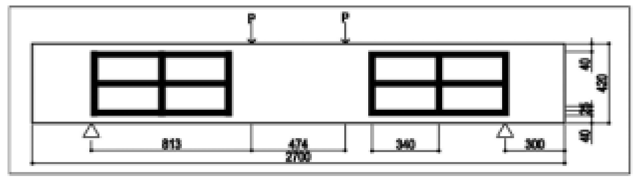
Test parameters include the opening size and area of GFRP plate, shape of them, the amount of the GFRP reinforcement, and the center-to-center spacing of vertical strips of GFRP plates to evaluate the shear performance of the GFRP plates in reinforced concrete beams

C. ***Experimental Method***

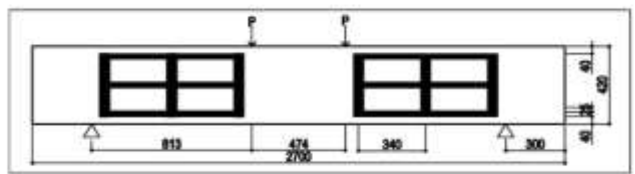
All six specimens was designed pin supported beams to satisfy the simple support condition. Load was applied to each specimen at a rate of 5 kN/min using a hydraulic UTM(universal testing machine) with maximum capacity of 5000 kN. as shown in Figure 6. The force generated by the hydraulic UTM was transmitted to the center of a steel spreader beam, which was installed to apply a two-point loading to the beam specimen. A linear variable differential transducer (LVDT) was installed at the bottom center of the specimen to measure vertical displacement. Steel strain was measured by attaching strain gauges near the supports and the bottom center of a main rebar to determine whether tensile reinforcement yielded or not. In addition, In order to investigate impacts of GFRP plates on shear strength, the shear strain of GFRP plate was measured by attaching 2 strain gauges in the horizontal component and the vertical component, respectively. Cracks were recorded every 100 mm and Loads and displacements also were recorded sequentially to the failure of specimens. Appearance of setting of specimen and strain gauge attaching positions are shown in Figure 4.



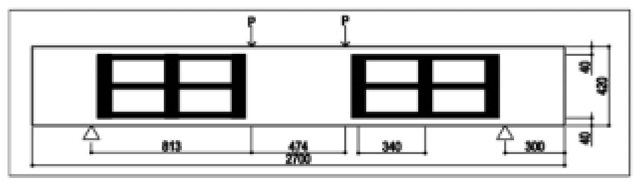
(a) A-1



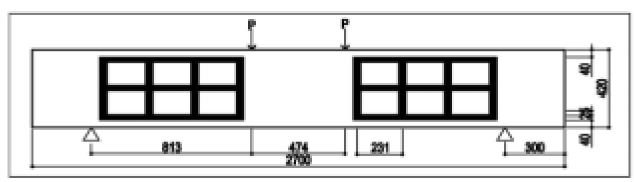
(b) A-2



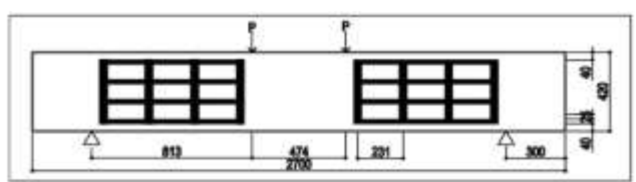
(c) A-3



(d) A-4



(g) B-3



(h) C-3

Figure 3. Arrangement of GFRP Plates in the Specimen.

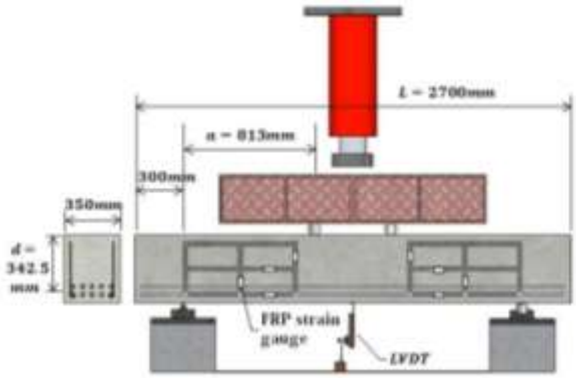


Figure 4. Specimens setting and strain gauge

TABLE III. TEST RESULRTS

SPECIMEN	P_{max} (kN)	V_{max} (kN)	Failuer Mode
A-1	570.75	285.38	Shear
A-2	589.28	294.64	Shear
A-3	774.38	387.19	Shear
A-4	897.31	448.66	Shear
B-3	870.19	435.10	Shear
C-3	755.48	377.74	Shear

III. Test Results

In this chapter, the shear performance of the new FRP shear reinforcement in concrete beams were evaluated through experimental results. An equation to estimate the shear strength of the FRP reinforced concrete beams was proposed based on ACI 318-11. Test results are listed in Table 3..

A. *Failure Mode*

As shown in Figure 5, All specimens were occurred the inclined cracks and the strong compressive force which generated from loading points and the compression strut. Examining the crack patterns according to the loading patterns, flexural cracks occurred at the tension surface in the middle of the span at approximately as 150 kN. After that, flexural shear crack occurred at a distance of as long as effective length from the supports at approximately 200 kN. The more the applied loads increased, the more cracks occurred. As the inclined cracks propagated toward the loading points, crushing of specimen occurred in the upper end region of the inclined crack at the final stage of failure.

In case of the reinforced concrete beams with GFRP plates, after GFRP plates is reached the ultimate strength, fracture of specimens and rupture of GFRP plates occurred at the same time.

Figure 5. Shear compression failure

B. *Amount of Shear Reinforcement*

In this chapter, the amount of reinforcement impacting on shear performance of specimens were evaluated. Figure 6 shows the relation between the test results and the theoretical predictions on shear strength provided for four specimens A-1, A-2, A-3, A-4. As expected, the results in Table 3 show that the shear strength increases as the total sectional area of FRP shear reinforcement in the critical shear span increases. These results that specimens displayed the experimental shear strengths close to the predictions by the proposed shear strength equation.

C. *Shape of GFRP Plate*

In order to compare the shear strengths of the specimens reinforced with the FRP plates with different shapes, three types of specimens(A-type, B-type, C-type)were tested. Load-deflection curve of three cases are shown in Figure 7. Three types of specimens showed the similar behavior before shear failure.

Under test results, B-3 is more effective integrated behavior than A-3 and B-3 shows the biggest shear strength. If attaching area between GFRP plates and concrete increase while meeting the condition of area ratio and the size of opening, the shear performance of reinforced concrete beams improves.

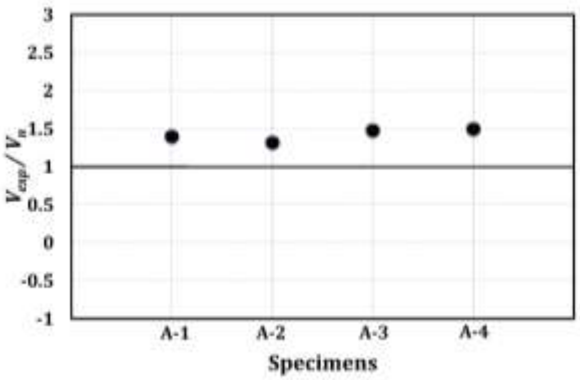


Figure 6. Ratio of the test result to the theoretical predictions on shear strength(V_{exp}/V_n)

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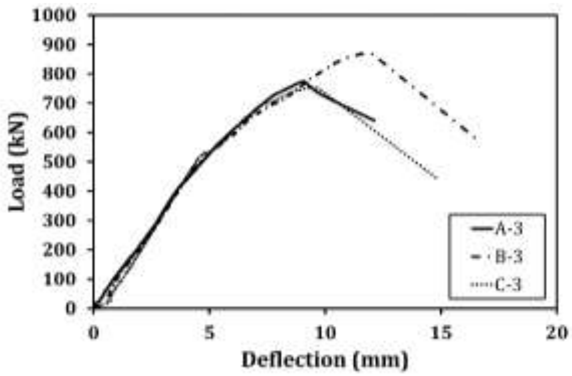

Figure 7. Load-deflection curve for the specimens with three different type of GFRP shear reinforcement

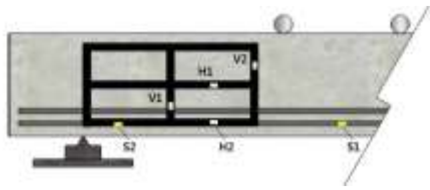

Figure 8. Location of strain gauge

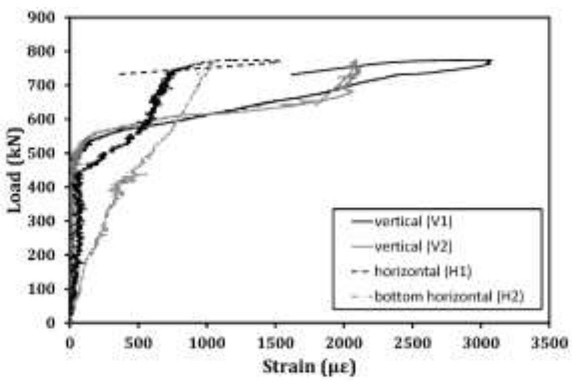

Figure 9. Load-strain curves for GFRP plate

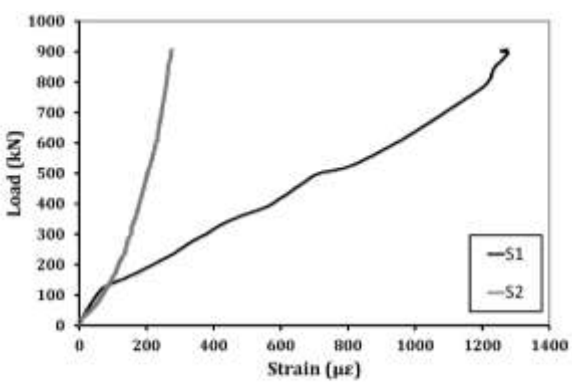

Figure 10. Load-strain curves for tensile reinforcement

D. Strain Distribution

The crack patterns and behavior of shear is analyzed with load-strain curve of specimens. As shown in figure 8, four strain gauges were installed at the center of horizontal and vertical components of the GFRP plate within the critical shear span. Three of them (V1, V2, H1) were installed around the area of shear crack occurrence, and one strain gauge (H2) at the bottom horizontal component of the plate near the main bars. In addition, the strain gauge installed at the center of main bars and near support, respectively.

Figure 9 showed that load-strain curve according to the horizontal and vertical components of GFRP plates. The strain of GFRP plates was in a linear elastic state until occurred initial cracks, followed by inclined cracks as load increased. After when occurred inclined cracks, the strain was greatly increased. When compared to the strain according to the horizontal and vertical components, the strains measured at vertical components(V1, V2) was large while the strains at H1 was small relatively.

Unlike the strains at other bonding locations, the strain at H2 near the main bars exhibited steady increase as load increased because they behaved similarly to the main reinforcement.

Figure 10 showed that load-strain curve of the center of main bars and near supports. Whether tensile reinforcement in the shear section can resist shear force or not. As shown in Figure 10, the strains measured at the center of main bars (S1) was about 1400 while the strains near supporting points (S2) was 300 which was small relatively. Therefore, the tensile reinforcement around the supports was found not to contribute significantly to the shear performance.

E. Shear Strength Equation

In this study, To estimate the shear strength of specimens was based on ACI 318-11. the shear strength is the sum of the strength carried by concrete and shear reinforcement. This experiment designed to induce shear failure. As shown in (1), the shear strength is the sum of the strength carried by concrete and shear reinforcement. (3) expresses the contribution of the FRP shear reinforcement, which was derived by replacing the sectional areas of steel stirrups with those of vertical components of the FRP plate in the existing ACI equation. As mentioned in the previous section, the horizontal components of an FRP plate did not have a significant contribution to the shear strength. The primary function of the top and bottom chords appears to be to anchor the vertical FRP strips. Only the vertical components were considered in the calculation of the sectional area of the FRP reinforcement. (4) and (5) were used to calculate the cross-sectional area of the vertical components and the number of the vertical components of the FRP plate within the critical shear span, respectively.

Table 4 show the results of the comparison of peak shear strength values, V_{exp} obtained from the experiment with the shear strength, V_n estimated by the above equations using (2) and using (3). The comparison indicates that the shear strength ratio (V_{exp}/V_n) was 1.30 on average with standard deviation of 0.29. specimens showed experimental values very close to the strength estimated by the proposed shear strength equation.

$$V_n = V_c + V_f. \quad (1)$$

$$V_c = (0.16\sqrt{f'_c} + 17\rho_w d/a)b_w d. \quad (2)$$

$$V_f = nA_f f_{fu} sin\alpha. \quad (3)$$

$$A_f = 2t_f w_f. \quad (4)$$

$$n = d/s(1+cot\alpha). \quad (5)$$

TABLE IV. SHEAR STRENGTH

Specimen	V_c (kN)	V_f (kN)	V_n (kN)	V_{exp} (kN)	V_{exp}/V_n
A-1	164.55	38.68	203.24	285.38	1.40
A-2	164.55	58.02	222.58	294.64	1.32
A-3	164.55	96.71	261.26	387.19	1.48
-4	164.55	135.39	299.94	448.66	1.50
B-3	164.55	107.22	271.77	435.10	1.60
C-3	164.55	107.22	271.77	377.74	1.39

IV. Conclusions

A FRP shear reinforcement was proposed for the design of reinforced concrete beams. The cracking patterns, failure modes and strain distributions of the test specimens were analyzed. An equation to estimate the shear strength of the beam strengthened with the FRP shear reinforcement was proposed by modifying the existing equation in ACI 318-11. Accuracy of the proposed shear strength equation was evaluated by comparing its estimates with the experimental results. The proposed system shows promise as a method for providing FRP shear reinforcement in concrete beams. The following specific conclusions were drawn from this study:

1) The investigation of the effect of the amount of FRP shear reinforcement on shear strength shows that an increased amount of shear reinforcement results in increased shear strength as expected.

2) The strain distribution measured during the test showed that the strains at vertical components of the FRP reinforcement were increased dramatically with increasing load, while the strains at horizontal components remained relatively small. This indicates that the horizontal components do not take much force, thus their contributions to shear force resisting capacity are not so significant. The top and bottom horizontal chords provided sufficient anchorage to develop the capacity of the vertical strips.

3) The comparison between the test values and the predictions by the proposed shear strength equation showed that it was able to accurately estimate the shear strength of concrete beams reinforced with the newly proposed FRP shear reinforcement. The averages and the standard deviations of the ratios between the test value and theoretical estimation V_{exp}/V_n were 1.30 and 0.29 using the simplified equation.

Acknowledgment

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References

[1] Higgins C., Williams G.T., Mitchell, M.M., Dawson M.R., and Howell D, "Shear strength of reinforced concrete girders with carbon fiber-reinforced polymer: Experimental results," ACI Structural Journal, vol. 109, 2012, pp.805-814.

[2] Yeh F.Y., and Chang K.C., "Size and shape effects on strength and ultimate strain in FRP confined rectangular concrete columns," Journal of Mechanics, vol. 28, 2012, pp.677-690.

[3] Mofidi Amir, and Chaallal Omar, "Shear strengthening of RC beams with externally bonded FRP composited: Effect of strip-width-to-strip-spacing ratio," Journal of composites for construction, vol. 15, 2011, pp. 732-742.

[4] Taha M.M.Reda, Masia M.J., Choi K.K., Shrive P.L., and Shrive N.G., "Creep effects in plain and fiber-reinforced polymer-strengthened reinforced concrete beams," ACI Structural Journal, vol. 107, 2010, pp. 627-635.

[5] Mazzotti C., Savoia M., and Ferracuti B., "An experimental study on delamination of FRP plates bonded to concrete," Construction and Building, vol. 22, 2008, pp. 1409-1421.

[6] ACI Committee 318, "Building code Requirements for Structural Concrete (ACI 318-11) and Commentary, American Concrete Institute, Farmington Hills, 2011.

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the proposed system is a promising candidate for shear reinforcement in GFRP reinforced concrete beams.