

Assessment of friction capacity of pre-cracked concrete strengthened with external GFRP strips

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ABSTRACT: In reinforced concrete design, there are situations where transfer of shear across a specific plane needs to be considered. Examples of such situation include corbels, bearing shoes, ledger beam bearing, and a host of connection between precast concrete elements. In this study, the shear transfer behavior of reinforced concrete is investigated experimentally by conducting test on precracked push-off specimens. The major parameters considered are the amount of reinforcement and externally bonded fibre reinforced polymer fabrics through the shear plane. This paper illustrates the result of shear transfer capacity and modes of failure of the precracked reinforced concrete push-off specimens bonded externally with FRP. An experimental investigation was conducted to study the effectiveness of FRP as an external reinforcement.

Based on experiments performed it can be concluded that the external FRP reinforcement had controlled the shear slip along the shear plane and crack width. In the unstrengthened push-off specimens, the pre-existing crack along the shear plane will reduce the ultimate shear transfer capacity and increase of shear slip at all load levels. However in strengthened specimens, the external FRP reinforcement will control the increase of slip and increase the ultimate shear stress transfer capacity along the shear plane.

Key words: Shear friction, Push off, FRP, Pre-cracked

1 INTRODUCTION

External strengthening with Fibre Reinforced Polymer (FRP) fabrics is an effective technique for improving the structural performance and life span of the existing reinforced concrete structures. The FRP composite material has been attracted by many researchers because of its advantageous characteristics such as high strength to weight ratio, good corrosion resistance. This external FRP bonding technique has been widely used to strengthen reinforced concrete structures such as columns, beams, walls, chimneys, tunnels and silos (Khalifa et al. (1998)).

The shear transfer capacity of push-off specimens has been extensively studied (Birkland and Birkland (1966); Hofbeck et al. (1969); Mattock et al. (1976); Walraven and Reinhardt (1981); and Reinhardt and Walraven (1982)).

Extensive research has been executed out to study the shear transfer capacity of reinforced concrete push-off specimens. However, enhancement of shear transfer performance had very little attention among the researchers.

The GFRP sheets are used herein perpendicular to the shear plane to strengthen precracked push off specimens. These sheets are utilized at a known failure plane to resist shear stresses based on shear friction mechanism. Precracked push-off specimens were tested with these aims: (1) investigate the influence of reinforcement ratio; (2) determine the influence of crack in shear plane; (3) determine the modes of failure such as debonding or peeling of GFRP sheets and rupture or fracture of GFRP sheet along the precracked shear plane ; and (4) determine the contribution of GFRP composite connections in shear friction.

2 MATERIALS PROPERTIES

The average concrete compressive strength f'_c was 37 MPa. Mild steel reinforcement at the shear failure plane was used with an $f_y=360$ MPa. GFRP composite with an epoxy–resin matrix was used; the glass fibre and epoxy–resin properties are described in Table 1.

Table 1. GFRP properties

Material	Tensile strength(Mpa)	Tensile modulus(GPa)	Tensile strain(mm/m)
Glass fibre (unidirectional)	4760	77	22
Epoxy-resin	72	3.2	48
adhesive-epoxy primer	37	2.8	13

3 DESCRIPTION OF SPECIMENS

Push-off specimens were designed to fail in shear at a known plane, cracked plane, as shown in Fig. 1.

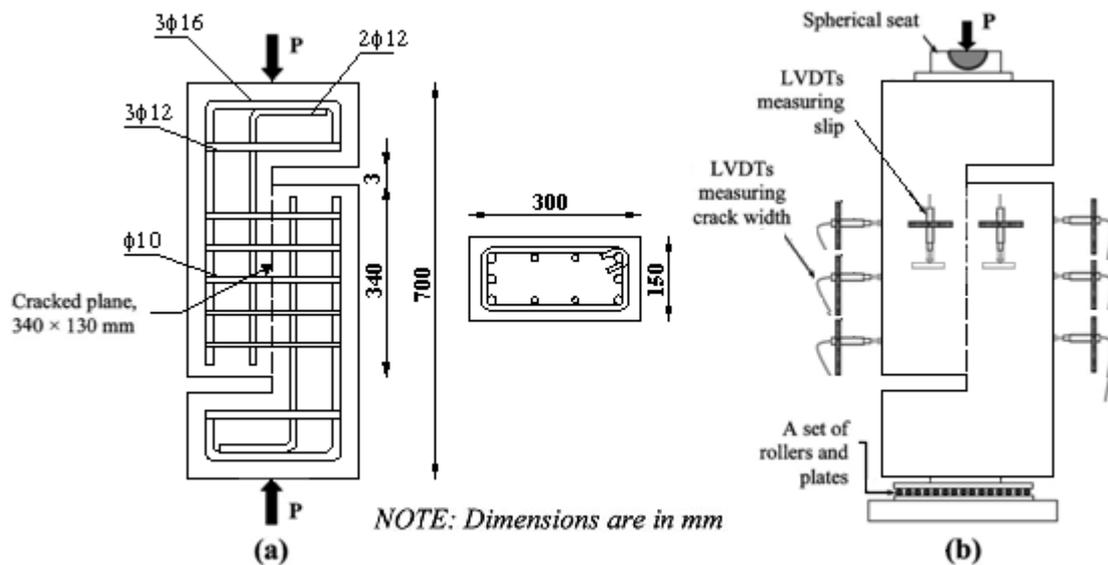


Figure 1. Test specimens and setup: (a) dimensions and reinforcement details; (b) schematic of test setup.

The push-off specimens were grouped into two series. Group R and RG had three specimens each. In group R there was three specimens R1, R2 and R3 with internal steel reinforcement ratio $\rho=1.54\%$, $\rho=1.23\%$ and $\rho=0.92\%$, respectively. The internal reinforcement in series RG was same as series R. However, these specimens were precracked and strengthened externally with GFRP strips represented as RG1, RG2 and RG3 with GFRP reinforcement ratio $\rho=0.35\%$, $\rho=0.35\%$ and $\rho=0.35\%$, respectively (see table 2). Figure 2 shows the typical push-off specimens in group R and RG. It should be considered that some tests on push-off specimens strengthened with external CFRP strips are being performed in structural laboratory of university of Tehran.

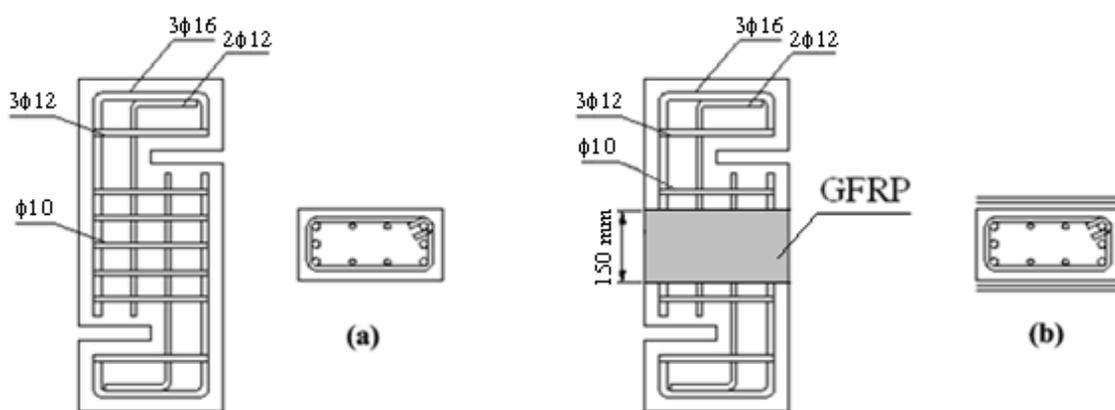


Figure 2. typical push-off specimens; (a) group R (b) group RG.

The slip of one side of the specimens relative to the other was measured by two LVDTs were mounted vertically and six more LVDTs were mounted horizontally to measure crack width every three seconds during the tests (see Fig. 1(b)). The electrical strain gauges were also

attached on the internal steel stirrups and on the GFRP sheets to measure the strain in the steel bars and GFRP.

The shear stress was deduced from Eq. (1).

$$\tau = \frac{P}{34 \times 13} \quad (1)$$

Where P = axial compressive load; 34×13 = area of shear section .

Two push-off specimens were tested for each of the experiments to investigate repeatability.

Table 2 describes push-off specimens.

Table 2. Summary of push-off specimens

Push-off specimens	Internal reinforcement (%)	GFRP reinforcement (%)	Wrapping scheme configuration	Number of layers n	GFRP strip width w_f (mm)
R1	1.54	-----	-----	-----	-----
R2	1.23	-----	-----	-----	-----
R3	0.92	-----	-----	-----	-----
RG1	1.54	0.35	Two-sided	2	150
RG2	1.23	0.35	Two-sided	2	150
RG3	0.92	0.35	Two-sided	2	150

4 TEST SET-UP AND PROCEDURE OF PUSH-OFF SPECIMENS

All of specimens were initially cracked along the shear plane before testing. The experiments were conducted under an axial displacement controlled compressive load P where applied in the rate of 0.1 mm/sec , as shown in Fig. 1. To apply an axially concentric load, Steel caps were placed on the top and bottom side of the specimens to center the load as shown in Figure 1. To prevent local compressive failure, gypsum was used inside the steel caps. The load was increased until failure occurred. Figure 1(b) and 3 shows the experimental setup of specimens.

5 DISCUSSION OF RESULT

5.1 Ultimate Failure Load and Failure Pattern

Specimens R1 and RG1 had similar amount of internal shear reinforcement ratio of $\rho=1.54\%$, and their area of shear plane was $340 \text{ mm} \times 130 \text{ mm}$. The ultimate failure load of the unstrengthened push-off specimen R1 was 232 kN and its corresponding shear stress was 5.25 MPa . Spalling of concrete was observed at bottom of the shear plane before it reached the failure load. The shear failure had occurred along the V-grooves of shear plane. However, in the case of specimen RG1 was failed due to debonding of GFRP sheets along the shear plane at a maximum load of 245.1 kN . At ultimate, the achieved shear stress of the strengthened specimen was 5.55 MPa . The shear stress increment was 5.65% higher than the unstrengthened specimen R1, The reason was due the contributions external GFRP reinforcement. It was also observed that a yielding of reinforcement in the steel stirrups at peak load before the failure of external GFRP reinforcement.

In specimens R2 and RG2, the amount of internal shear reinforcement ratio was $\rho=1.23\%$. The unstrengthened specimen R2 had attained a maximum load of 192.6 kN with a corresponding shear stress of 4.36 MPa . The strengthened specimen RG2 was failed with a GFRP debonding

mode of failure along the shear plane at an ultimate load of 205.7 kN; related to a shear stress of 4.65 MPa. The shear stress enhancement was increased 6.8% with respect to the specimen R2. The internal shear reinforcement of specimens R3 and RG3 were $\rho=0.92\%$. The specimen R3 failed at a peak load of 153.1 kN with a shear stress of 3.46 MPa. All the unstrengthened specimens R1, R2 and R3 failed along the shear plane or the V-grooves on the front and rear sides. The externally strengthened specimen RG3 was failed at the ultimate load of 164.9 kN with a corresponding shear stress of 3.73 MPa. There was an enhancement of 7.69% with respect to the unstrengthened push-off specimen R3. At ultimate failure, the specimen RG3 had yielding of internal steel stirrups similar to specimen RG2 and failed in debonding of GFRP sheets. Figure 4 shows the debonding failure pattern of the strengthened push-off specimen RG3. From the investigation, it was found that the increased amount of internal shear reinforcement in the strengthened push-off specimens reduced the contribution of shear enhancement by the external GFRP reinforcement. The ultimate failure load was found to be increased with increase in amount of internal shear reinforcement. Table 3 illustrates the summary of experimental investigation of the unstrengthened and strengthened push-off specimens.

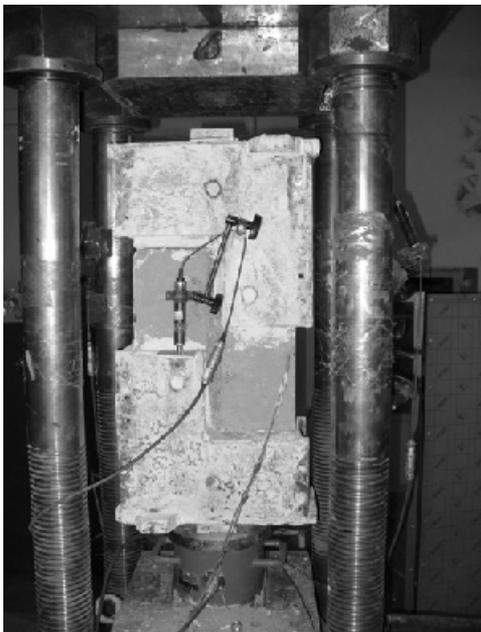


Figure 3. Experimental setup of specimens.



Figure 4. Debonding failure pattern of the strengthened Push-off specimen RG3.

Table 3. Summary of push-off test result

Push-off specimens	Concrete strength f'_c (Mpa)	Shear stress (Mpa)	Failure load P_u (kN)	Increment(%)
R1	37	5.25	232.0	-----
R2	37	4.36	192.6	-----
R3	37	3.46	153.1	-----
RG1	37	5.55	245.1	5.65
RG2	37	4.65	205.7	6.80
RG3	37	3.73	164.9	7.69

5.2 Shear Stress-Shear slip and Crack width Relationship

Figure 5(a) describes the shear stress related to shear slip of the strengthened and unstrengthened push-off specimens. The test results indicate that the strengthened push-off specimens have measured significantly lesser shear slip at each increment of load than the unstrengthened push-off specimens. But there was a sudden increase in shear slip at the peak load in the strengthened push-off specimens as a result of the fact that the FRP composites have brittle manner. The failure of the strengthened push-off specimens occurred with a loud noise. The stiffness of the strengthened push-off specimens was greater than the unstrengthened one. The direct shear test of the unstrengthened push-off specimens shows that shear stress increases with increase of internal shear reinforcement ratio. However in externally bonded push-off specimens, the contribution of GFRP sheet decreases with an increase in the amount of internal shear reinforcement ratio.

The shear stress in contrast to crack width of the strengthened and unstrengthened push-off specimens is shown in Figure 5(b). One can see from the Figure 5(b), the crack width of the strengthened push-off specimens was relatively less in comparison to the unstrengthened push-off specimens. It was observed that the reinforced concrete specimens with large initial crack width were lower in stiffness than specimens with smaller initial crack width. Increased shear stress increases the shear slip and crack width in the unstrengthened push-off specimens but in strengthened push-off specimens the increase of displacement (slip and crack width) level was relatively very less in comparison to the unstrengthened push-off specimens for the same load. It shows that the external bonded GFRP sheets control the slip along the shear plane and it also prevents the widening of crack. It was also remarkable that the strengthened push-off specimens showed greater value of shear slip and crack width at failure load than unstrengthened push-off specimens. Test results indicate that an increase in reinforcement parameter stiffens the initial straight portion of the curve, raises the linear response to a higher load level, and increases the ultimate strength and deformation.

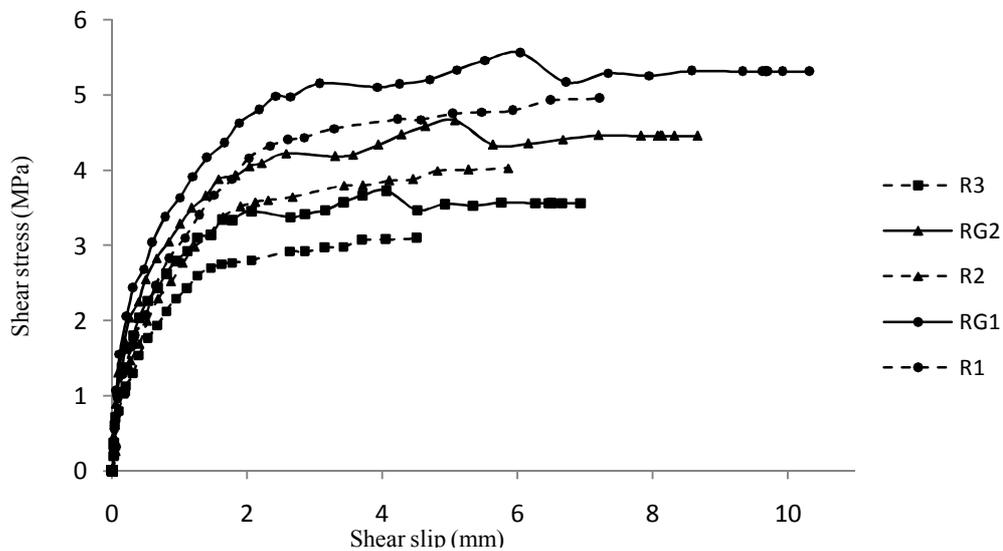


Figure 5(a). describes the shear stress in contrast to shear slip for series R and RG

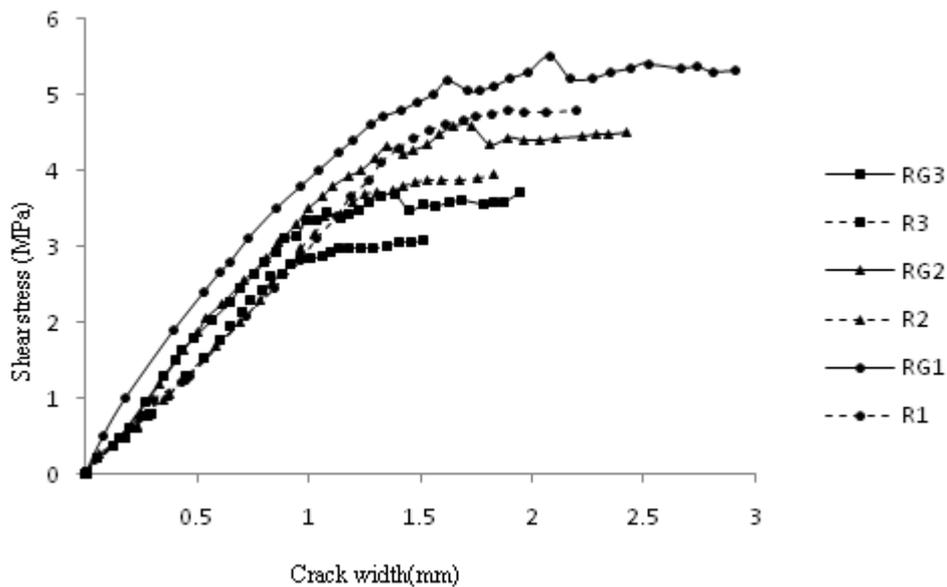


Figure 5(b). describes the shear stress in contrast to crack width for series R and RG

6 CONCLUSIONS

Test results of push-off pre-cracked specimens investigating the shear capacity, with variable reinforcement parameter, are reported. The contribution of the GFRP reduces with increased amount of internal shear reinforcement ratio. The external GFRP reinforcement had controlled the shear slip along the shear plane and crack width. In the unstrengthened push-off specimens, the pre-existing crack along the shear plane will reduce the ultimate shear transfer capacity and

increase of shear slip at all load levels (Hofbeck et al., 1969). However in strengthened specimens, the external GFRP reinforcement will control the increase of slip and increase the ultimate shear stress transfer capacity along the shear plane. The shear slip and crack width of the strengthened specimens was less compared to the unstrengthened specimens for the same load, however, the strengthened specimens had achieved greater shear and displacement (slip and crack width) over the unstrengthened push-off specimens at the ultimate failure load. There was a sudden increase of shear slip and crack width at the peak load. After debonding of GFRP sudden drop of shear stress occurs. The stiffness of the strengthened specimens was greater than the unstrengthened push-off specimens. The shear stress increase of the strengthened push-off specimens varies in the range of 5% to 8% with respect to the unstrengthened push-off specimens.

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