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Performance of RC Slabs Strengthened with Mechanically Fastened Composites

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ABSTRACT: This paper presents an experimental study of using the mechanical anchors for strengthening one-way RC slabs in flexure. Seven one-way slabs are strengthening in flexure with mechanical anchors. The slabs are simply supported on two sides and measure 2000 x 400 x 120 mm. Different strengthening patterns are used with different spacing between anchors. The load–deflection responses of all slabs tests are plotted, in addition to selected strain results. The mechanical anchors are found to be a valid alternative to the bonded system resulting in a rapid, economic, and effective system. These tests have explored numerous different failure modes and factors affecting the behavior of mechanical anchors FRP-strengthened RC slabs. The behavior of the specimens including the failure modes is also discussed. It is concluded that anchors increase the strength and slip capacity, in comparison with unanchored control slabs.

1 INTRODUCTION

The application of Fiber Reinforced Polymer (FRP) as Externally Bonded Reinforcement (EBR) for strengthening of existing Reinforced concrete (RC) structures is a widely used technique and its effectiveness when compared to conventional methods is well documented Kalfat et al. (2011). The major deficiency of EBR is the premature debonding of the FRP from the concrete substrate prior to the development of the full strength of the FRP laminates. More effective use of the FRP laminates can be made either by enhancing the bond between the FRP and the concrete by using an anchor located at the end of the FRP laminates to transfer the load carried by the FRP laminates directly into structure. This study aims at examining the potential use of mechanical anchors system to upgrade RC slabs deficient in flexural strength. The experimental program including seven slabs, six are strengthened slabs in addition to the control one, is conducted to study the effect of mechanical anchors system on flexural behaviour. The structural performance of RC slabs strengthened with FRP anchors system is studied and compared to that of control slab and slabs strengthened FRP system without anchors. The effect of varying the number and location of anchors along the slab span on overall flexural behaviour is investigated.

2 TEST PROGRAM

2.1 Materials

The 28-day compressive strength of concrete is 30 MPa. The steel reinforcement is Grade 360 with nominal yield and ultimate strength of 360 and 520 PMa, respectively. The CFRP strip is Sika S1012. Sika CarboDur S1012 has an elasticity modulus of 155 GPa, a rupture tensile strength of 3100 MPa and an ultimate elongation of 1.9%.

2.2 Test specimen

Test specimen is 2000 mm long, 400 mm wide and 120 mm deep. Each slab is singly reinforced at tension side by three No. 12 deformed steel bars with a concrete clear cover 25 mm. For the strengthened slabs, one CFRP strip having a width 50 mm and a thickness of 1.2 mm is bonded to the tension face of the slab.

2.3 Test matrix

The test matrix is given in Table 1. A total of seven slabs are used in the study. One slab (S-01) is used as a control while the other six slabs are strengthened with CFRP strip. One slab (S-02) is without anchor. Slab (S-03) had two anchors, one anchor at each end, while slabs (S-04, S-05, and S-06) have four anchors, two anchors at each end with anchor spacing 100, 150, and 200 mm respectively. The remaining one slab (S-07) had six anchors, three at each end with anchor spacing 200 mm.

Table 1. Test matrix.

Specimen	Number of anchors	Anchor spacing (mm)
S-01	-	-
S-02	-	-
S-03	2	-
S-04	4	100
S-05	4	150
S-06	4	200
S-07	6	200

2.4 Test set-up and instrumentation

The test setup is shown in figure 1. All slabs are tested under four-point bending with an effective span of 1800 mm and a shear span of 600 mm. laod is applied monotonically at the mid-span of the slab using a hydraulic actuator having a capacity of 200 kN. A spreader beam is usaed to transfer the load to the slab through two loading points placed at the ends of the middle third of the slab span. One (LVDT) is placed under the mid-point of the slab to measure the deflection while a load cell is used to record the load. One strain gauge, is bonded to the surface of the CFRP strip, at the mid-span. Similarly one strain gauge is bonded to the steel reinforcement bar, at the mid-span.

Figure 1. Test set-up.

3 TEST RESULTS

3.1 Failure mode

The control slab (S-01) failed by yielding of steel reinforcement followed by crushing of concrete. Slab (S-02) is strengthened with CFRP strip without anchorage without warning by delamination of CFRP after yielding of steel reinforcement. Slab (S-03) is strengthened with CFRP strip with only one mechanical anchor is failed by bearing failure of CFRP from one side as shown in Figure 2. All of the remaining slabs are strengthened with CFRP strip with anchorage failed by crushing of concrete which is preceded by yielding of steel reinforcement, thus presence of anchorage prevent debonding of the CFRP strip and hence the slab developed its full flexural capacity.

Figure 2. Bearing failure of the FRP Strip.

3.2 Load-deflection relationship

The load versus mid-span deflection relationships for all slabs is shown in Table 2. The ultimate load of slab (S-02), which is strengthened with CFRP strip without anchorage, is about 22% higher than that of the control slab. Slab (S-03) failed by bearing of the CFRP strip. The mid-span deflection at ultimate load of slab (S-03) is 30% higher than that of the control slab. But the ultimate load of slab (S-03), which is strengthened with CFRP strip with anchorage, is about 23% higher than that of the control slab and 7% higher than that of the slab (S-02).

3.3 Effect of anchorage number and spacing

A slab with (2) anchors is increased (30%) in strength over the theoretical capacity of the control slab. The debonding load is increased (7%) compared to the slab without anchors. A slab with (4) anchors, spaced at 100 mm, had the largest debonding load and the highest is increased (52%) in strength over the theoretical capacity of the control slab. The debonding load increased 25% compared to the slab without anchors. A slab with 6 anchors is increased (63%) in strength over the theoretical capacity of the control slab. The debonding load is increased 34% compared to the slab without anchors. Although ductility is reduced in the slabs with FRP reinforcement, the debonding ductility ratio of the slabs with anchors is increased over the slabs without anchors. The anchors are effective in delaying debonding of the FRP strip by slowing the propagation of debonding cracking. The anchors are provided anchorage along the bonded length that led to a profound improvement of the bond behavior, particularly for the full anchorage FRP bonded strengthened slabs.

Table 2. Test results.

Specimen	Pu (kN)	Δu (mm)	Mode of failure
S-01	46	23	Concrete crushing
S-02	56	26	FRP delamination
S-03	60	30	bearing of FRP strip
S-04	70	32	Concrete crushing
S-05	72	32	Concrete crushing
S-06	73	34	Concrete crushing
S-07	75	35	Concrete crushing

Pu and Δu refer to ultimate loads and mid-span deflections, respectively.

4 CONCLUSIONS

Based on research results the following conclusions can be drawn.

1. The strengthening slab without anchorage increased the ultimate loads by about 22% relative to those of the control.
2. The mechanical anchors applied to FRP-strengthened RC slabs are found to increase the ultimate loads of the slabs by 35 up to 63 %, in comparison with control slab.
3. The mechanical anchors are effective in delaying debonding of the FRP strip by slowing the propagation of debonding cracking.
4. The mechanical anchors are provided anchorage along the bonded length that led to a profound improvement of the bond behavior, particularly for the full anchorage FRP bonded strengthened slabs.
5. The minimum number for the mechanical anchors is two to provide anchorage along the bonded length and to avoid the bearing failure of FRP strip.
6. The mechanical anchors spacing 100, 150 and 200 are found to have no major influence on the ultimate capacity of the FRP-strengthened RC slabs.

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