Strengtheningof Reinforced ConcreteSolid Slabswith CFRP Products

Muslim Abdul- AmeerKhudhair Al-kannoon and HaiderWafy Ali

Abstract-Carbon Fiber Reinforced Polymer (CFRB) has been effectively utilized in structural engineering; particularly in strengthening structural members.The current study addressesthe utilization of CFRP in one way strips concrete slabs subjected to a two line static loading system. Two different CFRP techniqueshave been used: externally strengthening and near surface mounted (NSM) techniques. Four samples of one way reinforced concrete strips slabs strengthened byseveral CFRP systems have been tested. Analysis results indicated that the laminate plate CFRP system is more efficient than other techniques.The maximum load carrying capacity of a 1500mm reinforced concrete slab with 0.314 steel ratio has been increased largely by 671%. This technique of strengthening has resulted in a decrease in the RCS maximum deflection by about 21%. In addition, the stiffness of RCS has increased and failure due to deflection occurred at 1.75% of the span length.

Key Words: strengthening slab, CFRP products, EBR, RC slab.

---

1 INTRODUCTION

Concrete slabs in structural engineering are generally structural members with significantly small depth to length and width ratios. Slabs are frequently used as the structural elements of floor and ceiling systems in reinforced concrete buildings. For increasing flexural strength of reinforced and prestressed concrete, there are two techniques using Carbon Fiber Reinforced Polymer (CFRP) products; namely, Near Surface Mounted (NSM) technique and Externally Bonded Reinforcing (EBR) technique. In brief, the first technique can be achieved by applying the following steps: (1) a groove should be firstly made in the concrete cover along the preselected direction;(2) 50% of the groove should be filled by the epoxy paste;(3) thereafter, the fiber reinforced polymer rod is laid and pressed gently; (4) finally, additional paste is applied and surface is leveled.In contrast, EBR technique is described as follows: (1) the surface should be cleaned and washed from lousy materials and then left to dry before installation;(2) after that, the surface is filled with putty, i.e. the high viscosity resin used for bonding the laminatewith the slab surface; (3)epoxy is applied to the laminate before putting in place; (4)pressure is applied to laminate with a roller or by hand so that the epoxy is uniformly distributed.

Empirical-based evidence has been found in the literature regarding increase in flexural and shear capacity of members strengthened by NSM technique.(1-3). Adopting fiber reinforced polymer using this technique has been found as an effective mechanism over the near future for making ordinary and prestressed weak concrete member much stronger. Applying bending test and using variety of longitudinal steel ratios and retrofits amounts, Yost JR. et al.,(2007)(4)also confirmed that strengthening using NSMR can boost the strength capacity efficiently. However, they noticed a decrease in the displacement and energy ductility.Limam O. et al., (2003)(5) performed an experimental study on RC two-way slabsstrengthened with CFRP strips which are bonded on the tension face of the slab and compared them with the analytical results. In their study, debonding of external FRP strip from slab was happened. Good agreement has been reached between experimental and analytic computations. That is,the ultimate load carrying capacity was almost similar; 120 kNand 123 kN have been achieved by experiments and theoretical analysis for the strengthened slab respectively.

The use of CFRP strips have been an effective solution in strengthening of slabs.That is because the load carrying capacity of control slab was much less than the strengthened slab and also the deflection of control slab was much higher than the strengthened slab.On the bases of easiness and quickness of installing of fiber reinforced polymers, it has been found that FRP rods require less

- *Muslim Abdul- AmeerKhudhair Al-kannoon, Department of Civil Engineering, Faculty of Engineering, Kufa University, Iraq.*
- *E-Mail: muslim.altameemi@uokufa.edu.iq*

installing time and offer more practicality in comparison with FRP laminates especially where members to be strengthened are adjacent (6). Utilizing rods has also the merit of preserving the original appearance of finishing where regions to be strengthened are located at negative flexural moment areas. That is because laminates usually requires protection against mechanical and environmental conditions and hence may disrupt the final appearance of finishing materials.

Considering (1.0 cm width x 0.14 cm thick) fiber laminate strip against (0.4-0.5 cm width x 1.2-1.5 cm thick) slit, Barros et al.(1) utilized two columns to examine the gain in strength; one with reinforcement ratio of 0.79% (4φ10 mm) while the second with 1.13% (4φ12). They reported that using CFRP with cross section area about 0.2% of the total column cross section area can increase load carrying capacity for the first and second columns by 92% and 34% respectively.This mechanism can be considered as asuccessful solution to the typical challenge of externally bonded reinforcing knowing as early debonding. In addition, maximum rupture strain near reinforcing polymers was measured. Having reported that, this can be another advantage of using near surface mounted method in strengthening flexural capacity of concrete columns.

This paper involvesan assessment about three separate economically-accessible carbon FRP (CFRP) frameworks to those fortifying of strengthened solid (RC) slabs. The three different CFRP frameworks incorporate overlay plates, fiber overlay sheets and last but not least CFRP bars. Fundamental manual requisition about remotely cement bonding, and close surface mounted (NSM) strategies were utilized within this test system. Two line loading system of static nature has been adopted to test the strengthened simply supported RC slabs.

2 EXPERIMENTAL PROGRAM

2.1 One way RCSDetails

Using ready mix concrete, five (1.5 x 0.3 x 0.06) m one-way strips reinforced concrete slabs have been constructed.Curing has been performed in the laboratory.Two deformed steel bars (Ø 6mm) spaced at 200mm c/c have been used as flexural reinforcement for each slab with 20mm standard protection cover (See Fig. 1a).Fig. 1(b) exhibits the typical support and loading conditions for each slab; slabsare simply supported at each end and loaded with two line loading concentrated at 0.4m apart from each support.

2.2 Concrete Mix Properties

Concrete was produced and casted at the structural engineering laboratory of the Engineering College (University of Kufa). Fine aggregate was backed in nylon bags and stored at dry place inside the laboratory. On the purpose of reaching aggregate with saturated-surface-dry condition, dust and impurities have been washed out and clean aggregate have then been dried by airand placed in closed plastic drums.

Three trial mixes have been carried out until adopting a mix which produced suitable levels of workability, flow and compressive strength. The adopted mix was used for all test slab samples.Each one cubic meter of fresh concrete consists of the following:

- Cement: 375 kg

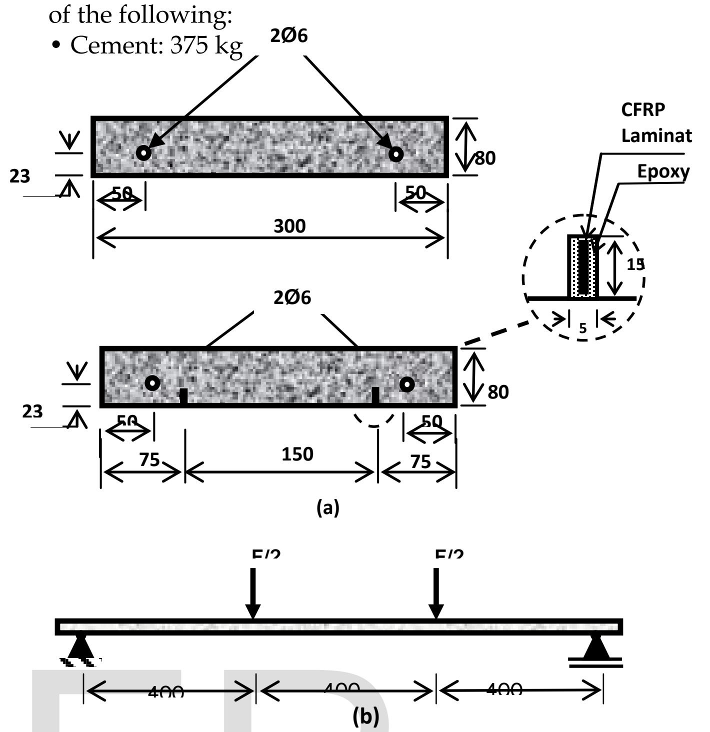
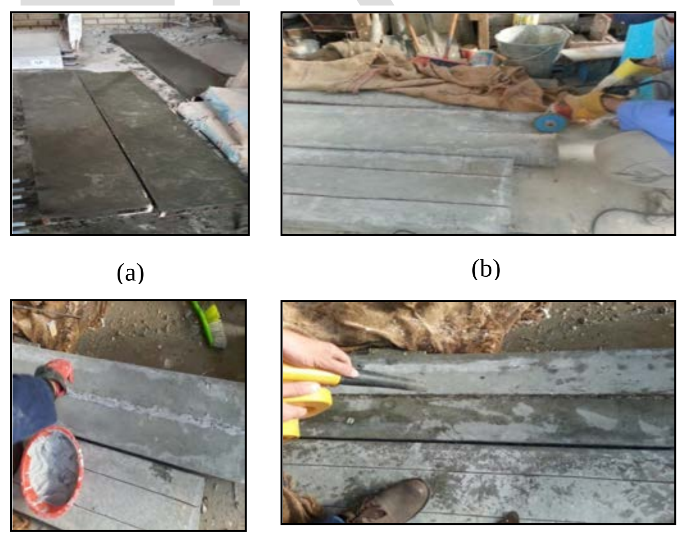


Fig. 1 . (a) RCS dimension and position of the steel bars and CFRP laminates, (b) load configuration.(all dimensions in mm).



(a) (b)

(d) (c)

Fig. 2. Steps of strengthening: (a) cast of samples, (b) opening the slits, (c) cleaning the slits, and (d) applying the epoxy adhesive and introducing the CFRP laminate into a slit.

- Sand: 693.75 kg
- Gravel: 975 kg

ISSN 2229-5518

• Water: 180 liter

By means of percentage by weight the adopted mix was approximately (1 : 1.85 : 2.6) (C:S:G), (w/c = 48 %).For this concrete mix, a 28 day cube compressive strength of (28-32 MPa) has been reached.

2.3 Steps NSM technique

Generally, the following steps are adopted for applying the NSM technique:

slits are firstly opened in the concrete cover by a saw-cut machine(5 mm width x 15 mm depth),see Fig. (2-b);

slits are cleared from dust using air blower,see Fig. (2-c);

CFRP laminate is cleaned adequately using proper cleaner such as acetone;following instructions and directions for use, epoxy is prepared;

apply epoxy adhesive properly along the slits and on the lateral faces of the CFR polymer;

with gentle pressure, place the CFRP laminate along the slit. It is highly advised to ensure proper and even distribution of epoxy adhesive between CFRP and slit; otherwise, unwanted voids might develop (see Fig. 2-d).

2.4CFRP Products

Three types of CFRP products were used in the present study; (1) CFRP sheets manufactured by (Sika) company named (SikaWrap-230 C); (2) CFRP bars manufactured by (Aslan) company, named (Aslan 201); and (3) CFRP laminate of Sika Corporation namedSikaCarboDur S512(7).Fig. 3 shows the (1.2 mm thick. x 50 mm width) SikaCarboDur laminate used in the study.ASTM Specification D3039(8) has been adopted to perform tensile tests for the three normal modulus CFRP samples of laminates.Table 1 shows the tensile strength of the (381mm length x 25 mm width x 229 mm length) laminates specimens after conducting tensile tests.

CFRP sheet (SikaWrap-230 C) is described as "a unidirectional woven carbon fabric". Table 2 includes several key characteristics of this polymer. It is useful to highlight that CFRP sheet are suitable for the dry application uses. Furthermore, Table 3 shows the particular epoxy (called Sikadur 330) recommended to be used with SikaWrap-230 C. This impregnation resin mainly consists of two components: resin and hardener. Comparatively, different impregnation resin (Sikadur-30)has been utilized with CFR polymer bars. It is also consists of two components, resin and hardener (see Fig. 4). Based on the technical specification of Sika product(7), Table 3 lists the key properties of the Sikadur-30 epoxy.

CFRP bars have been used as embedded reinforcement inside the concrete for one of five tested samples. Fig. 5 shows the CFRP bars (Aslan 201) that have been tested by the processed company according to (ASTM D7205).Theresults related to the mechanical and physical properties are shown in Table4.

TABLE 1
TENSILE STRENGTH OF CFRP LAMINATES

No. of specimen	σu (MPa)	Average(MPa)
1	2378.37	2358.61
2	2333.33	
3	2364.15	

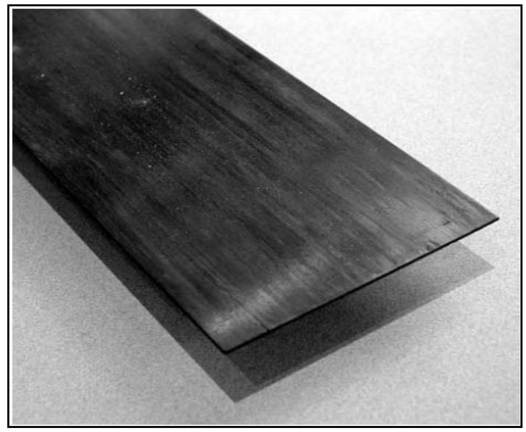


Fig. 3. Photo for SikaCarboDur S512.

TABLE 2
PROPERTIES OF CFRP SHEETS.[7]

Product Data	
Fiber Type	Mid strength carbon fibers.
Fabric Construction	Fiber orientation: 0o (uniderctional). Wrap: black carbon fibers (99% of total areal weight). Weft: white thermoplastic heat-set fibers (1% of total areal weight).
Packaging	Roll of width (300 mm).
Technical Data	
Areal Weight	230 g/m2
Fabric Design Thickness	0.131 mm
Fiber Density	1.76 g/cm3
Mechanical / Physical Properties	
Dry Fiber Properties	Tensile strength: 4300 MPa Tensile E-Modulus: 238 GPa Elongation at break: 1.8 %
Laminate Properties	Laminate thickness: 1 mm/layer (impregnated with Sikadur-330). Ultimate load: 350 kN/m width per layer (at typical laminate thickness of 1 mm). Tensile E-modulus: 28 GPa (based on typical laminate thickness of 1 mm)
System Information	

System Structure	The system configuration must be fully complied with and may be not be changed. Concrete primer: Sikadur-330 Impregnating / laminating resin: Sikadur-330 Structural strengthening fabric – SikaWrap-230 C.

TABLE 3
THE EPOXY RESIN(SIKADUR-30) PROPERTIES [7]

Type	Sikadur-30
Appearance	Com A: White Com B: Black
Density (kg/l) mixed	1.65
Mixing ratio by weight	A:B 3:1
Pot live (minute)	120min 40min
Tensile strength (MPa)	33
Flexural modulus (MPa)	12800

and

Fig. 5 . CFRP Bars (Aslan 201) used in this work.

3 STRENGTHENING TECHNIQUEOF SLAB SPECIMENS

It is useful to recall that dimensions, support conditions, ordinary reinforcements and CFRP laminate details for the tested slabs can be seen in Fig. 1. Two of the total five slabs have been chosen not to be strengthened by CFRP to form the control set (SL00 and SL01); one slab has been strengthened by CFRP barsusing near surface mounting method (SL02). The CFRP plate has been used to strengthen the forth slab specimen (SL03) using the pre-described externally strengthening technique. The fifth slab sample (SL04) has been strengthened with CFRP laminate externally bond. Concrete slab (SL04) was also strengthened with CFRP laminate but by using NSM technique. All the strengthened reinforced slabs have the same cross sectional area of CFRP. Table 4 shows all slab specimens tested in the current study along with their strengthening technique.

TABLE 4
PROPERTIES OF CFRP BARS.

Slab Specimen	Type of CFRP	Strengthening Technique
SL00	Without strengthening	--
SL01		
SL02	Bar Ø6 mm	NSM (Near Surface Mounted)
SL03	Plate(1.2 mm thickness and 20.1 mm width)	Externally bond
SL04	Laminate	Externally bond
SL05	Laminate	NSM (Near Surface Mounted)

Test	Result	Specifications (ASTM D7205)
Nominal diameter (mm)	6	--
Cross sectional area (mm2)	28.27	--
Bar length (m)	3	--
Tensile strength (MPa)	2704	≥2068
Modulus of elasticity (GPa)	163	≥124
Ultimate strain	0.017	0.017

TABLE 5
SLAB SPECIMENS STRENGTHENING TECHNIQUES.

4 TESTRESULTS

To evaluate the efficiency of strengthening and to determine the sufficient type of CFRP, failure mode and load at failure of the concrete slabs have been utilized as measures of effectiveness.The test results indicated that slabs strengthened with CFRP are with maximum load five times higher than equivalent load of non-strengthened slabs. Details of test details and results including CFRP method, maximum load, rise in load carrying capacity, reduction in deflection ratio and mode of failure for the five slabs can be seen in Table 6.

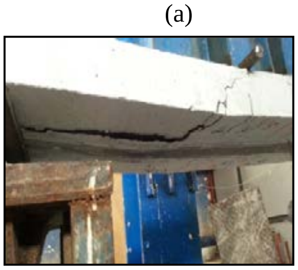
Depending on the modes of failure for the five slabs specimens shown in Table 6, it can be obviously noted that combined shear/flexure failure has been occurred for the slabs strengthened with CFRB bars and CFRP sheets alike. This type of failure could be belonged to the accompanied high increase in the load carrying capacity (See Fig. 6-b and Fig. 6-e). Fig. 7 exhibits load-deflection curves for the slabs sample. Slab SL01(reference slab), the non-strengthening specimen, failed at a load of3.5 kN and with maximum mid-span deflection of 75.44 mm.Slab SL02, strengthened with one Ø6 mm CFRP rod using NSM technique, was failed under failure load of 16 kN; that is, a 357% rise in capacity in comparison with SL01 slab. Similarly, SL02 is with 48% decrease in mid-span deflection with respect to maximum mid-span deflection of SL01. The mode failure was combined shear/flexural failure.The results also indicate that failure load of Slab SL03, strengthened with externally bond CFRP plate,was 27 kN; that is, 671% higher than SL01 carrying capacity. On the other hand, the mid-span deflection was found to be about 21% less than its corresponding value in slab SL01. The failure mode was found to be combined shear and debonding of the CFRP plate. Protection covers of epoxy and part of the slab main reinforcement concrete cover were shattered upon failure in an interesting way.

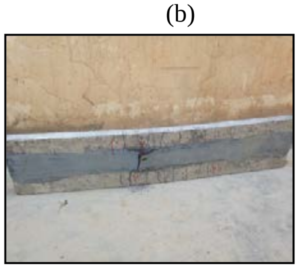
TABLE 6
SUMMARY OF THE SLAB TEST RESULTS.

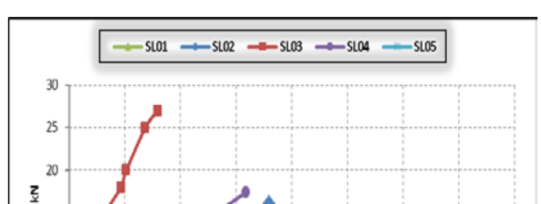
spacemen	CFRP technique	Max. load (kN)	increasing load (Pst.-Punst./Punst.)*100%	decreasing deflection (def./def.control)*100%	failure mode
SL01	control	3.5	-	-	flexural
SL02	NSM bar	16	357.14	48	shear/flexural combined
SL03	Externally plate	27	671.43	21	shear/ debonding of CFRP plate
SL04	Externally sheet	17.4	397.14	42	shear/ debonding of CFRP sheet
SL05	NSM sheet	10	185.71	43	shear/flexural combined


(a)


(b)


(c)


(d)



ISSN 2229-5518

Fig.7. Load-mid-span deflection curves for all tested. specimens.

4 Conclusion

The purpose of the study was to examine and appraise the effectiveness of different mechanisms for strengthening RC one-way slabs using CFR polymers. The laboratory results imply thatthe externally bonded CFRP plate was the most effective slab strengthening method against flexure failure among others. Speaking in numbers, in comparison with non-strengthened slabs, there is 670% increase in the load carrying capacity; both slabs are of 1.5 m long and with 0.314% steel ratio. Furthermore, CFRP plate-based strengthening has also yielded a 21% reduction in the mid-span deflection relative to the case of non-strengthened slab. Finally, this type of strengthening has also yielded an evident improvement in the stiffness.

References

[1] Barros, J.A.O., Sena-Cruz, J.M., Dias, S.J.E., Ferreira, D.R.S.M., Fortes, A.S., "Near surfacemounted CFRP-based technique for the strengthening of concrete structures", Workshop onR+D+I in Technology of Concrete Structures - a tribute to Dr. RavindraGettu, Barcelona,October 5, 2004, pp. 205-217.

[2] Barros, J.A.O., Fortes, A.S. 2004. "Flexural strengthening of concrete beams with CFRPlaminates bonded into slits", Journal Cement and Concrete Composites, in press.

[3] Barros, J.A.O., Dias, S.J.E., "Shear strengthening of reinforced concrete beams with laminatestrips of CFRP", International Conference Composites in Constructions - CCC2003, Cosenza,Italy, 16-19 September 2003, pp. 289-294.

[4] Yost JR, Gross SP, Dinehart DW, MildenbergJJ."Flexural behavior of concrete beamsstrengthened with near surface-mounted CFRP strips". ACI Structural Journal 2007;104(4):430–7.

[5] Limam, O., Foret, G. and Ehrlacher. A. "RC two-way slabs strengthened with CFRP strips: experimental study and a limit analysis approach" . Composite structures 60.4 (2003): 467-471.

[6] Alkhrdaji, T.; Nanni, A.; Chen, G.; and Barker, M. (1999), "Upgrading the TransportationInfrastructure: Solid RC Decks Strengthened with FRP," Concrete International,American Concrete Institute, Vol. 21, No. 10, October, pp. 37-41.

[7] Sika , "SikaCarboDur S512 Carbon fiber laminate for structural strengthening", Technical Data Sheet, Edition (5) , (Web Site:www.sika.co.id). 2011.

[8] ASTM D3039, "Tensile Properties of Polymer Matrix Composite Materials", Annual Book of ASTM Standard, Published January 2006.