Al-Rafidain Journal of Engineering Sciences

Journal homepage https://rjes.iq/index.php/rjes

ISSN 3005-3153 (Online)

Structural Behavior of High Strength Reinforced Concrete Slabs Strengthened with CFRP

Hadi Naser Ghadhban AL-Maliki[1], Ali Hameed Aziz[2]

[1,2] Civil Engineering Department, Mustansiriyah University, Baghdad, Iraq

ARTICLE INFO

Article history:
Received 27 May 2025
Revised 27 May 2025
Accepted 23 June 2025
Available online 24 June 2025

Keywords:
High Strength Concrete,
RC Slab,
Strengthening,
CFRP Sheet,
Punching Shear

ABSTRACT

Structural behavior of ten RC slabs with dimensions of (900x900 mm), strengthened with CFRP and non-strengthened were evaluated experimentally, under concentrated load at the top fibers of their centers. All slabs were a simply supported of clear span (820x820 mm), which were made by normal and high strength self-compacting concrete; NSSCC, HSSCC. It was found that the tested slabs of HSSCC, e.g. from 30 to 60 MPa provide more resistance capacity of 18-23% than their counterparts made of NSSCC. Also, the latter increase is related to the decrease in the corresponding deflection under ultimate loads by (11-18%). In similar manner to the effect of HSSCC, the increase of reinforcement ratio results in the increase of resistance capacity by (21-27%). This leads to decrease in the corresponding deflection under the ultimate loads by (15-22%). In terms of the strengthened specimens with CFRP sheet, they also provide more resistance capacity by (25-33%) and a decrease in the corresponding deflection under ultimate loads by about (20-26%) as compared with non-strengthened specimens. Moreover, the obtained results indicated that the strengthened slabs along 50% of span length have a higher load capacity than those strengthened slabs along 25% of span length by (25%-33%). Further, the failure type of specimens was found to be in punching shear in all cases. However, the CFRP failures were found to be demolition, debonding, CFRP fracturing and peeling off.

1. Introduction

In response to the increasing need for repair or retrofit of RC structures in the world, a new structural strengthening technology has emerged. Ongoing development of cost-effective production techniques for carbon fibre reinforced polymers CFRP has progressed to the level that these once referred to as the space age materials are ready for construction industry. Reduced material cost, coupled with labor savings inherent with its low weight and high strength make FRP an attractive alternative to steel plates for post strengthening [1, 2].

The applications of carbon fibres in engineering field are multiple. In civil engineering, they are usually used in new buildings or in the repair and strengthening of existed buildings. Also, they can be used to strengthen the slabs, concrete columns, bridges, and various structural parts [3, 4]. The CFRP prove to have an excellent durability with time and a high resistance to environmental influences and surrounding conditions. In general, carbon fibres are used to strengthen and rehabilitate the damaged or worn out parts [5, 6].

The use of FRP to strengthen the concrete structures has been a crucial issue since the early 1990s. Research activities have been carried out to study the behaviour of CFRP reinforced concrete structures. Structural retrofit work has come to the forefront of industrial practice in response to the problems of old infrastructures. These problems have

Corresponding author E-mail address: alihaziz@uomustansiriyah.edu.iq
https://doi.org/10.61268/62q5jq91

coupled with revisions in the design structural codes to better accommodate natural phenomena and have indicated the required need for the development of successful structural retrofit technologies [7]. The important characteristics of repair-type work are such as the predominance of labours and their costs in comparison to the material costs, time and site constraints, long-term durability, difficulty in methodology selection and design, and the effective evaluation [8].

Basically, the procedure used for flexural strengthening of RC slabs is the same for the beams. This procedure usually includes the attaching of FRP sheets to the tension fibre of the floor slabs. Many studies have been investigated the behaviour of slabs strengthened with FRP strips [9-12]. However, other studies have also been explored the floor slabs strengthened with FRP sheets [9-13]. FRP sheets that covering a specific part of the slab can interrupt the evaluation of the quality of bond and any future investigations of the slab. In addition, these sheets can restrict the free movement of moisture out of the slab, which leads to the degradation of bond [10].

Zhang et al. [13] experimentally studied the behaviour of two-way RC slabs subjected to a central concentrated load having a steel plate bonded in the central region that was beneath the applied load. The slabs were found to fail by formation of yield lines around the perimeter of the bonded plate and along the diagonal lines of the unstrengthen part of the slab. This results in modifying the yield line pattern or the collapse mechanism of the strengthened floor slabs. In this method, the designer can choose the appropriate approach to strengthen any portion of the slab and hence forcing the yield lines away from this strengthened section [14]. The resistance capacity of strengthened slabs can be predicted by the yield line analysis. It can be assumed that the part of the RC slab without bonded FRP has a sufficient ductility to accommodate the yield lines formed [7].

Self-compacting concrete is a concrete that has the ability to flow and not isolate its components and it can be distributed in the space that occupies it and fills each part of the mold [15, 16]. It can be self-levelling without any external action, or it can be consolidated by tools. Among its characteristics and high tolerance for isolation, it can be described as site concrete and self-compacted. It consists of the same compounds that make up the ordinary concrete. These components are cement, sand, gravel, water, and additives. In any case, the addition of super-plasticizers is good for enhancing the workability of the mix [17].

In general, CFRP strengthening technic schemes can be used to enhance the ductility and the strength capacity of members. The current study involves the externally flexural strengthening with CFRP of the middle parts located at the tension fibre of high strength reinforced concrete slabs. The main objective is to experimentally investigate the behaviour of reinforced concrete slabs strengthened with CFRP. The considered parameters include the location and quantity of CFRP sheets, reinforcement ratio of the slab and the concrete compressive strength

2. Experimental Program

Ten square RC slabs of simply supported were cast and tested with dimensions of (900x 900x50mm) and different reinforcement ratio of (0.015) and (0.031) with (10mm) cover [2, 6]. Five of tested specimens were cast with NSSCC and the others were made with HSSCC, Table 1. Six tested specimens were strengthened with various ratios of CFRP [9, 13]; whereas the remaining specimens were left without strengthening and considered as controlling specimens. It may be noted that, CFRP length considered in a ratio to the sides length of the test slabs in this study were equal length. Also, the attached CFRP was one layer with a uniaxial sheet. Fig. 1 shows the details of the tested slab specimen.

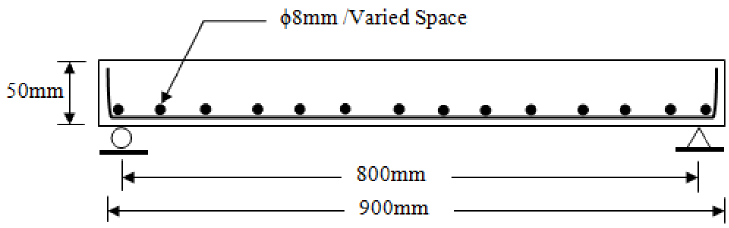


Fig.1. Details of the tested slab specimens

Table 1. Details of the tested RC slab specimens

Slab Coding	f'_c MPa	CFRP		ρ	Reinforcement
		Type	Length (mm)		
SN1	30	None	-----	0.015	Ø8 @100 Both Directions
SH2	60	None	-----		
SN3	30	Sheet	225x225		
SH4	60	Sheet	225x225		
SH5	60	Sheet	450x450		
SN6	30	None	-----	0.031	Ø8 @ 50 Both Directions
SH7	60	None	-----		
SN8	30	Sheet	225x225		
SH9	60	Sheet	225x225		
SH10	60	Sheet	450x450		

2.1 Materials

2.1.1 Concrete Mixes

To reach to the required concrete strengths, the current study involves several trail mixes for NSSCC and HSSCC. All adopted concrete mix proportions were evaluated based on previous studies [15-17]. Table 2 illustrates the used ratios of components for each concrete mix.

Table 2. Mix concrete ratios for 1 m^3

Material	Mix Type	
	NSC	HSSCC
Cement (kg)	422	450
Sand (kg)	590	865
Gravel (kg)	1180	780
SF(kg)	-	53
SP (Litter)	-	21
W/SP (%)	-	0.67
W/C (%)	0.45	0.33
Water (kg)	189	150

To evaluate the compressive strength of concrete (f_c') for each mix, three cylinders of standard size of (150x300 mm) were cast, then de-molded after (24) hours and kept in a specific tank filled with tap water for (28 days) of curing process at laboratory before the date of testing. The average compressive strengths of standard cylinders were (30MPa) and (60MPa) for NSSCC and HSSCC [19-21].

2.1.2 Steel Bars

Locally produce deformed steel bars of (8mm) diameter were used to reinforce all tested slab specimens. The steel bars were have yield tensile strength of (fy=460MPa), ultimate tensile strength of (fu=556MPa), and elongation of (Elongation=11.25%) and tested according to ASTM A615/615M-05a [18]. It may be noted that the reason of the low value of the elongation is because the armature diameter of (8mm) is not included in the tables of (ASTM A615M, which states in (Note 6) that the multiple bending distortion from mechanical straightening and fabricating machines can lead to excessive cold work, resulting in higher yield strengths, lower elongation values, and a loss of deformation height.

2.1.3 CFRP and Bonding Materials

Carbon fiber sheet (SikaWrapHex-230C) with (100cm) width, (t_f=0.13mm) thickness, (*ft*=3500MPa) tensile strength and (E_T=230GPa) Tensile E-modulus, was brought from a local supplier, was used for the external strengthening of tested slab specimens. A wet lay-up system was adopted to apply the CFRP sheets. An epoxy resin, (SikaDur-330), (one part hardener to four parts resin) was used to cure the CFRP. The epoxy resin have a tensile strength of (*ft* =30MPa) and Flexural E-modulus of (E_F=3800MPa).

The application of CFRP is started by cleaning the surface of specimens at the tension side. This process is a very crucial because it affects the bonding between CFRP and the model. The cleaning of model surface is performed by using the compressed air to ensure the removal of any dusts from the concrete slabs. After that, the considered side is scratched to make a rough surface to increase the bonding with the CFRP, which can be installed by a designed tool and specific glue. Hence, these steps are according to the ACI Committee-440R [22].

The next step is cutting the CFRP into square sheets with (250x250mm) and (500x500mm) dimensions. These dimensions were chosen as a ratio for the purposes of retrofitting the models in a similar method stated in [24]. Next, the amounts of CFRP were cleaned and prepared for placing on the indicated surface of RC slabs. After finishing the previous processes, the retrofitting process is begun with placing a layer of adhesive bonding between the surface of the model at the tension face and the carbon fibres by using a spatula. After the proper levelling of the adhesive bonding, the CFRP sheet is placed and pushed with a tight pressure by the fingers. The pressure is required to expel the air or gaps that can be generated between the surface of the model and the CFRP sheet and is also to ensure a coherent application [23-25].

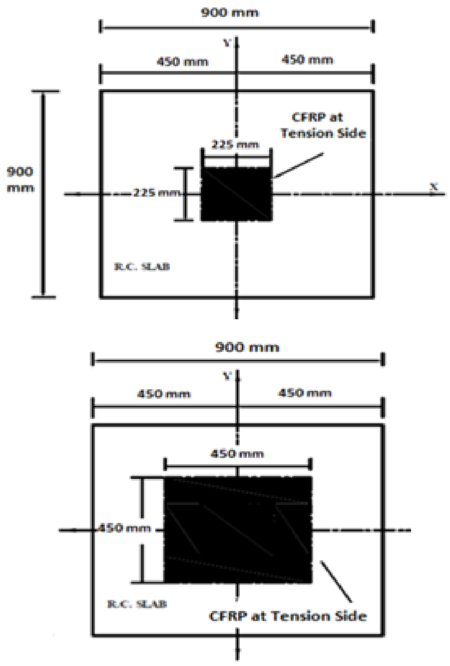


Fig.2. Strengthening with CFRP (0.25L2) and (0.5L2) at tension face

2.2. Test Procedure

Ten RC slab specimens were tested using a hydraulic-universal testing machine (MFI system) under monotonic loads up to the failure. The tested slabs were simply supported at all edges over a clear span of 820mm. The type of the applied loads was a concentrated load provide by cylindrical solid shaft of (50mm) diameter and (300 mm) length. Each specimen was ready and placed in correct position, and then a concentrated load was applied gradually, at the centre of the specimen with (2kN) increment and continued till to failure. The vertical displacements (deflection) were measured at the central and quarter of the span length using dial gauges of (0.01) accuracy, which were fixed on special holders beneath the specimens. Fig. 3 shows the typical arrangements and setup of the tested slab specimens.

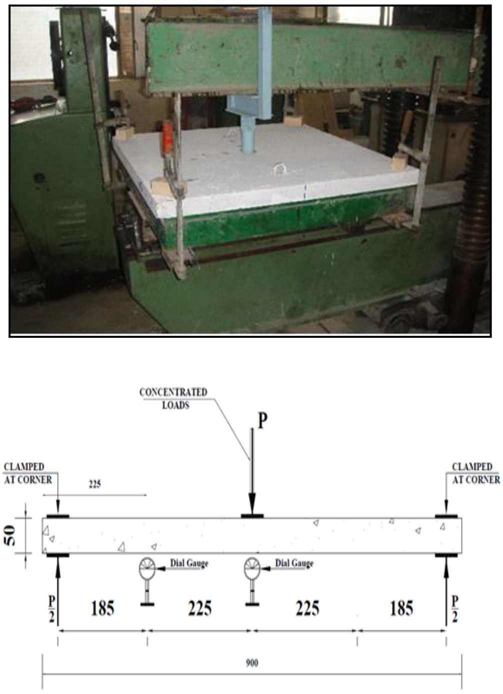


Fig.3. Typical schematic sketch of experimental arrangement and slab specimen setup

3. Results and Discussions

The results of the experimental work focus on measuring of the initial cracking load, the ultimate load, the maximum central deflection, and the increase in the maximum tolerance based on the considered parameters as provided in Table 3. The test results for each case were includes the central deflections and cracking are highlighted. The load versus deflection values were recorded for each slab specimen at the centre point and at a distance of (225 mm) from the centre of the slab. The failure mode for all specimens was punching shear. Moreover, this behaviour for specimens was by keeping other parameters constant as shown in Table 7.

3.1 First Cracking and the Ultimate Load

The first cracking load is the first indicator which referred to that the tensile stresses exceeds the tensile strength of concrete. The first crack was found to develop around the sides of the loading rod at a diameter of (50 mm) on the tension face of the non-strengthened slab centre. These cracks were formed at about (١8-23%) of the ultimate load as indicated in Table 3. In case of the strengthened slabs with CFRP sheets, the cracks were appeared in the tension face of the slab near one or more of the corners at about (18-٢٥%) of the ultimate load. The specimens have higher resistance loading capacity by about (21-27%). Also, these resistance capacities were increased by about (15-22%) in corresponding to the increase of the reinforcing ratio by double (i.e. 100%). RC slabs of high strength concrete, e.g. from 30 to 60 MPa provided resistance loading capacity of (18-23%), which was decreased the corresponding deflection under ultimate loads by (11-18%). A study of the effect of strengthening by CFRP sheets of two different dimensions as main variables of 500 x 500 mm and 250 x 250 mm was carried out. It can be demonstrated that the models strengthened with CFRP of different ratios of 25% and 50% L (L as span length) led to increase the load capacity of slab by (25%-33%). Comparisons between the ultimate load capacity of normal and high strengths self-compacting concrete slabs with and without strengthening CFRP at failure stages are shown in Figs. 4.

Table 3 Slab Specimens Test Results

Slab Coding	Load (kN)		Δ_{max} (mm)		P_{cr} / P_u (%)	Increase in Pu (%)
	Pcr	Pu	Center	L/4		
SN1	9	51	15.50	7.21	17.65	---
SH2	13	63	13.81	6.05	20.60	23.53
SN3	12	59	11.45	5.85	20.33	15.68
SH4	17	74	10.85	5.75	22.90	45.09
SH5	١٨	٧٨	10.11	4.55	23.00	52.95
SN6	١١	٥٧	13.25	7.25	19.30	---
SH7	14.5	٧٢	12.45	6.45	20.14	26.32
SN8	15	٦٤	10.22	5.52	23.44	12.30
SH9	١٩	٨٥	9.76	3.51	22.35	49.12
SH10	21	٩١	8.83	2.63	23.33	57.89

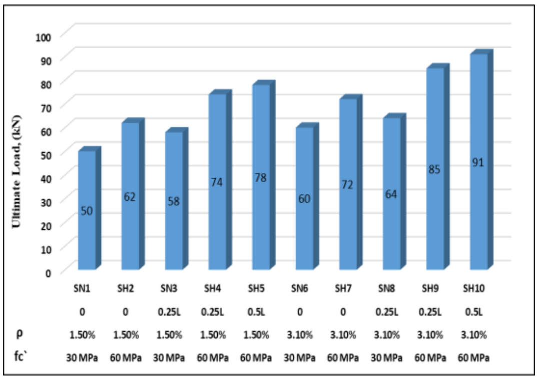
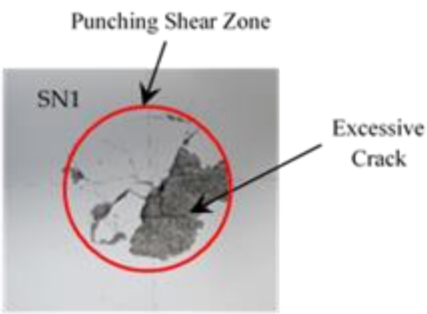


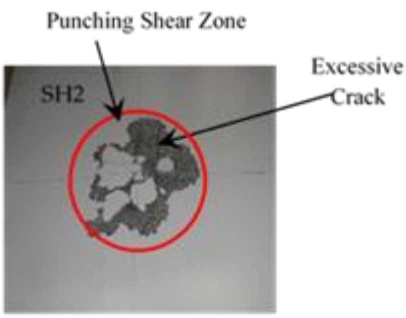
Fig.4. Ultimate Capacity Comparison for all Tested Slab Specimens

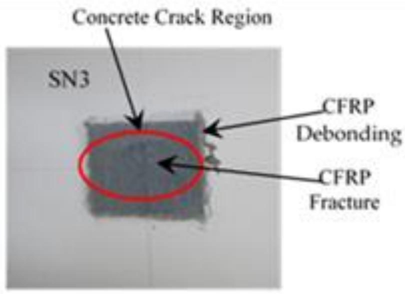
3.2 Crack Patterns and Modes of Failure

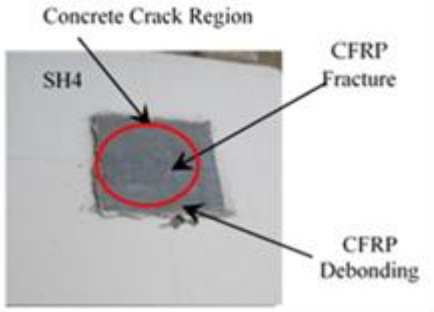
The crack patterns for all specimens with different parameters under concentrated applied load at the mid span is provided and shown in Fig. 5. The crack patterns clearly indicate that all tested slab specimens were failed in punching shear. Also, the shear failure circumference has a greater range for specimens that have lower compressive strength of concrete and a lower steel reinforcing ratio in comparison to other tested slab specimens. Likewise, the failure mode of the strengthening concrete slabs by CFRP sheets was in punching shear. Also, for the CFRP sheets, the types of failure were fractures of CFRP sheets, peeling off and debonding of CFRP sheets. The punching shear failure with fractures of CFRP sheets means that both the concrete and CFRP sheets works to its ultimate capacity before to reaching to the ultimate state. From the other words the punching shear failure with debonding of CFRP sheets means that the concrete reached its ultimate capacity and the bonding materials fails before the CFRP sheets reached to its ultimate response.

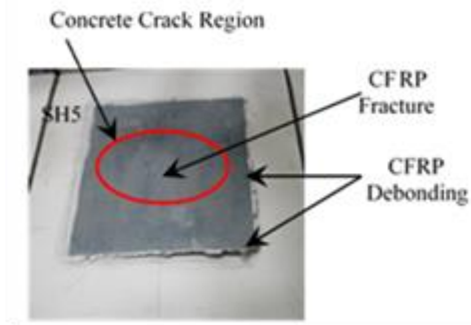
All mentioned previously failure modes were expected in such type of tests and each used material reached to its ultimate response in a certain manner.

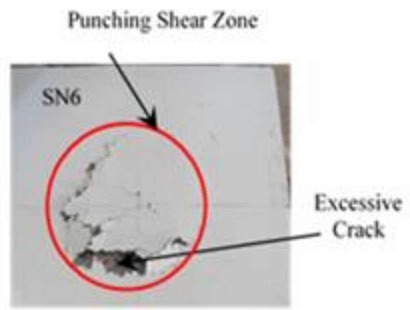


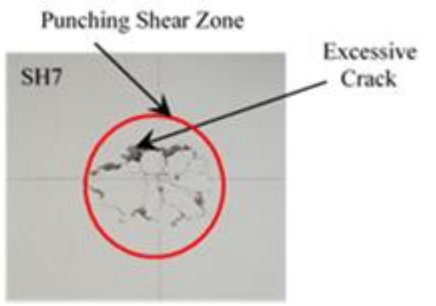












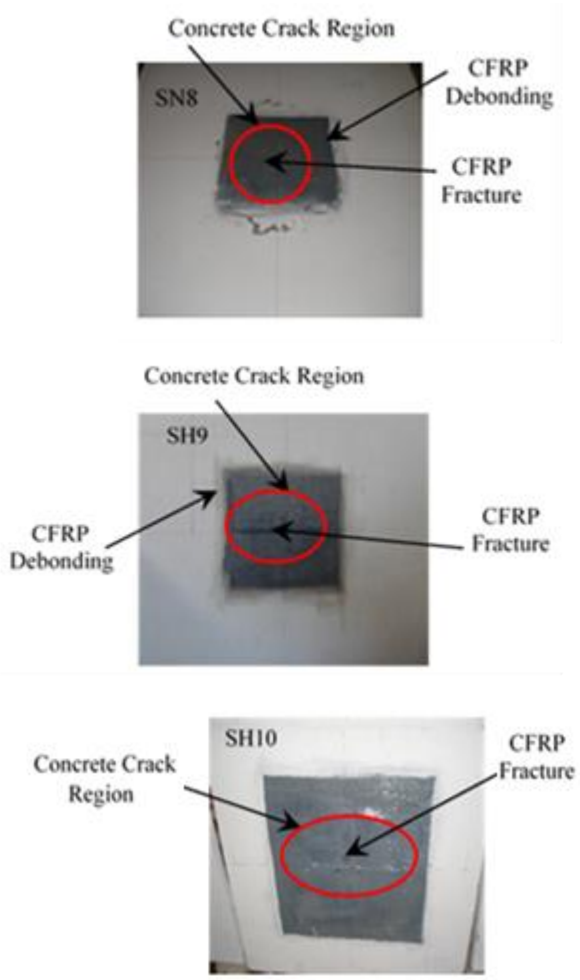


Fig.5. Crack Patterns and Failure Modes of tested slabs

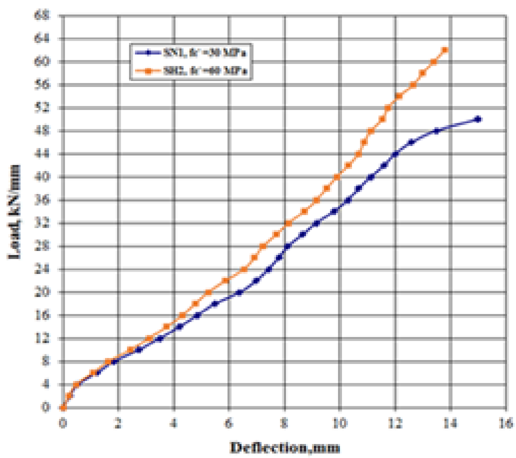
3.3 Load-Deflection Curves

The load-deflection relationships represent the instantaneous response of the tested slab specimens. The mid-span deflection curves of the tested slab specimens were measured each load steps of (2 kN) up to the failure, and provided in Figs. 6 to 15. The figures clearly show that at the first stage of applied loads, the relationships were approximately linear-elastic behaviour with low numbers of occurring cracks. While, the maximum bending exactly occurred at the mid-span of the extreme tension fibre of the tested slabs, when the first cracking loads were developed. The initial load-mid span deflection curves show the same trends with different quantity. These curves were gradually increased till the yielding of steel as stated in ref. [8, 11]. The strain hardening occurred after yielding of steel reinforcement of the slabs. When an increased load was applied, the deflection was increased as well with different quantity till the failure of slab. Also, it can be indicated that the CFRP provides more enhancement for load- deflection behaviours, which in other word the increase in the resistance loading capacity leads to decrease in the deflection when keeping other properties constant [22].

For the same compressive strength of concrete and steel reinforcement ratio, the tested slabs SN1 and SN3 have the mean and standard deviation values as indicated in Table 8. It is obvious that the CFRP ratio has affected the behaviour of slab specimen SN3. Similarly, other values of mean and standard deviation for the same models with different ratios of CFRP are also reported in Table 4. The effect of using the CFRP on the behaviour of models in terms of deflection and ultimate loads can be shown in Figs. 6 to 10.

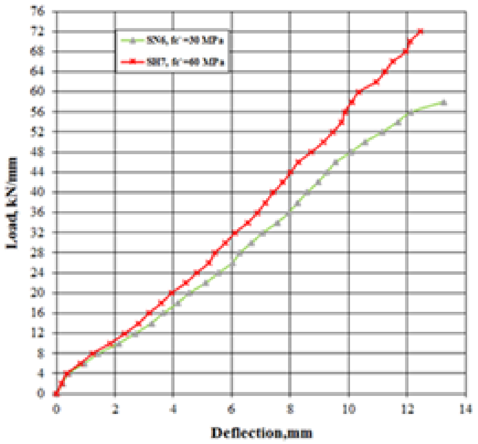
Table 4 Test results of all specimens for deflection standard deviation (STD)

Slab Coding	Average Defections	Standard Deviations
SN1, SN3	6.61	3.93
SN6, SN8	5.69	3.47
SH2, SH4, SH5	6.26	3.59
SH7, SH9, SH10	5.73	3.46



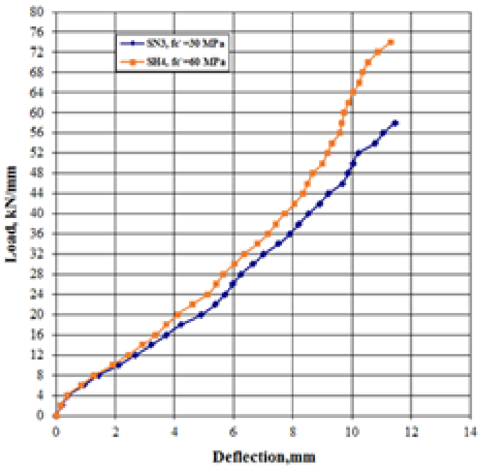
(A) $\rho = 0.015$

Fig.6. Effect of (f'_c) for Non-Strengthened Slab Specimens (SN1 and SN2)



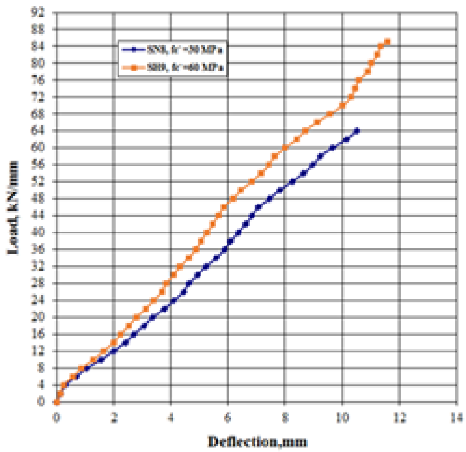
(B) ρ = 0.031

Fig.7. Effect of (f'_c) for Non-Strengthened Slab Specimens (SN6 and SN7)



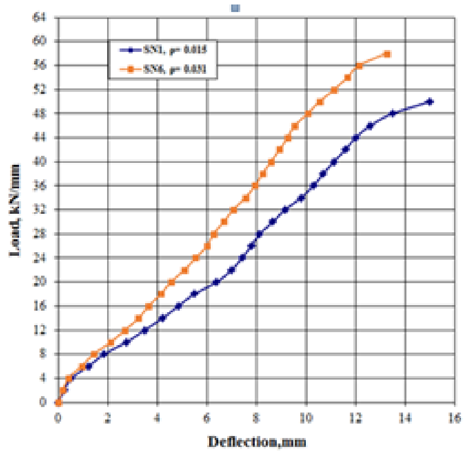
(A) *CFRP = 0.25L, ρ = 0.015*

Fig.8. Effect of (f'_c) for Strengthened Slab Specimens (SN3 and SN4)



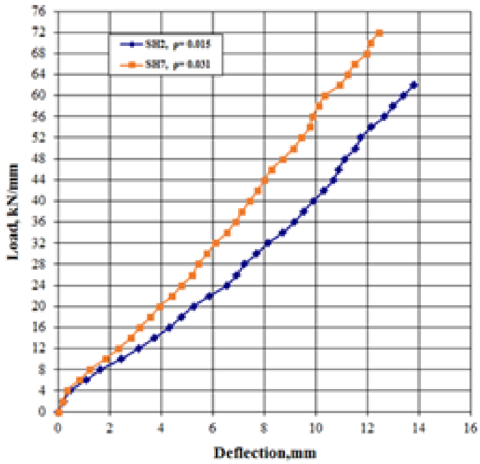
(B) CFRP = 0.25L, ρ = 0.031

Fig.9. Effect of (f'_c) for Strengthened Slab Specimens (SN8 and SN9)



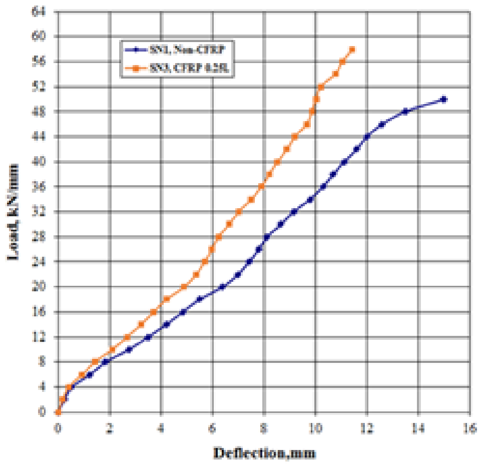
(A) *fc`=30MPa*

Fig.10. Effect of (ρ) for Non-Strengthened Slab Specimens (SN1and SN6



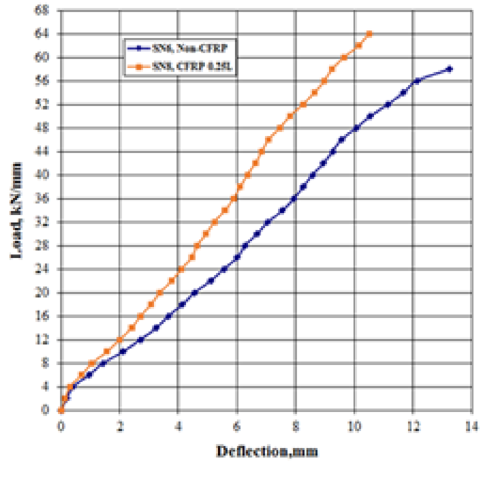
(B) fc`=60MPa

Fig.11. Effect of (ρ) for Non-Strengthened Slab Specimens (SN2 and SN7)



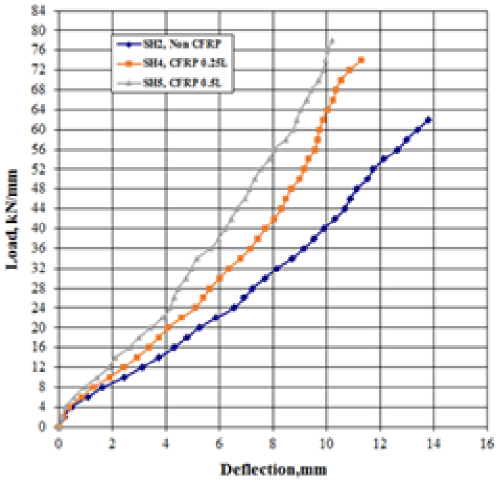
(A) *ρ = 0.015, fc`=30 MPa*

Fig.12. Effect of (CFRP) ratio for NSC Slab Specimens (SN1 and SN3)



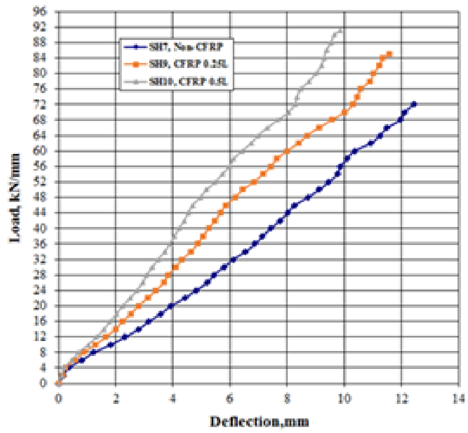
(B) ρ = 0.031, fc`=30MPa,

Fig.13. Effect of (CFRP) ratio for NSC Slab Specimens (SN6 and SN8)



(A) *ρ = 0.015, fc`=60 MPa*

Fig.14. Effect of (CFRP) ratio for HSC Slab Specimens (SN2, SN4 and SN5)



(B) ρ = 0.031, fc`=60 MPa

Fig.15. Effect of (CFRP) ratio for HSC Slab Specimens (SN7, SN9 and SN10)

5. Conclusions

The following conclusions are outlined:-

1-The RC slabs when used in high strength concrete, i.e. 30 to 60 MPa provided resistance to loading capacity of 18-23%, which resulted in decreasing the corresponding deflection under ultimate loads by 11-18%.

2-An increase in the reinforcing ratio by double, i.e. 100%, gave a higher resistance to loading capacity by about 21-27%, which led to decrease the corresponding deflection by about 15-22%.

3-The tested specimens which strengthened with CFRP sheet gained a higher strength capacity about 25-33%, which led to decrease the corresponding deflection under the ultimate loads by 20-26% as compared with the non-strengthened specimens.

4-It can be demonstrated that the models strengthened with CFRP of different ratios of 25% and 50% L (L as span length) led to increase the load capacity of slab by 25%-33%.

5-The used CFRP sheets works in its optimum state and failed in different ways, i.e. demolished, fractured, peeling off and debonding of CFRP sheets.

6-The pattern of demolition, occurred in the part of the tested slab strengthened with CFRP sheet, which was subjected to the demolition with an increase in the compressive strength of the concrete and the CFRP ratio.

7- The debonding failure is occurs due to the reduction in bond strength between concrete and CFRP which lead finally to local failure in the bond zone between the two materals.

8-The peeling off that occurs when the propagates of localized debonding and loss of composite action, i.e. the CFRP become not able to take loads.

9-This type of strengthening lies in the technical application of the supervising engineer or the executor when he needs to strengthen the structural parts including the flat concrete slabs.

Acknowledgement

The authors would like to thank Mustansiriyah University, (https://uomustansiriyah.edu.iq/), Baghdad, Iraq for their support in the present work.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] D.J. Oehlers, R. Seracino, Design of FRP and Steel Plated RC Structures, Elsevier, 2004. https://doi.org/10.1016/B978-0-08-044548-9.X5000-9.

[2] J.M. Longworth, Prestressed CFRP Sheets for Strengthening Two- way Concrete Slabs, M.Sc. Thesis, The Royal Military College of Canada, ON, Canada, 2004.

[3] O. Buyukozturk, O. Gunes, E. Karaca, Progress on understanding debonding problems in reinforced concrete and steel members strengthened using FRP composites, Constr. Build. Mater. (2004). https://doi.org/10.1016/S0950-0618(03)00094-1.

[4] International Federation for Structural Concrete (*fib*), Externally bonded FRP reinforcement for RC structures, 2001.

[5] J.G. Teng, X.Z. Lu, L.P. Ye, J.. Jiang, Recent Research on Intermediate Crack Induced Debonding in FRP Strengthened Beams, in: Proc. 4th Int. Conf. Adv. Compos. Mater. Bridg. Struct., Calgary, Alberta, 2004: pp. 1–12.

[6] A.S. Mosallam, K.M. Mosalam, Strengthening of two-way concrete slabs with FRP composite laminates, in: Constr. Build. Mater., 2003. https://doi.org/10.1016/S0950-0618(02)00092-2.

[7] A. Biddah, A. Hammami, A. Al-omari, Long Term Performance of Concrete Structures Strengthened Using FRP, in: Seventh Annu. U.A.E. Univ. Res. Conf. Mech. Eng. Dep. U.A.E. Univ., U.A.E, 2004: pp. 18–27.

[8] M. Adom-Asamoah, C.K. Kankam, Flexural behaviour of one-way concrete slabs reinforced with steel bars milled from scrap metals, Mater. Des. (2009). https://doi.org/10.1016/j.matdes.2008.07.048.

[9] M.A. Erki, P.J. Heffernan, Reinforced Concrete Slabs Externally Strengthened with Fiber Reinforced Plastics Materials, in: L. Taerwe (Ed.), Proc. 2nd Symp. Non- Met. FRP Reinf. Concr. Struct. (FRPRCS- 2), 1995: pp. 509–516.

[10] H. Marzouk, U.A. Ebead, K.W. Neale, Flexural Strengthening of Two-way Slabs Using FRPs, in: 6th Int. Symp. Fiber Reinf. Polym. Reinf. Concr. Struct., Singapore: pp. 427–436.

[11] V.M. Karbhari, F. Seible, W. Seim, A. Vasquez, Post-Strengthening of Concrete Slabs, in: Proc. Fourth Int. Symp. Fiber Reinf. Polym. Reinf. Reinf. Concr. Struct., Baltimore, Maryland, USA, 1999: pp. 1163–1173.

[12] M. Arockiasamy, A. Amer, M. Shahawy, Concrete Beams and Slabs Retrofitted with CFRP Laminates, in: Proc. Elev. Conf. Eng. Mech. ASCE, New York, USA, 1996: pp. 776–779.

[13] J.W. Zhang, J.G. Teng, Y.L. Wong, Z.T. Lu, Behavior of Two-Way RC Slabs Externally Bonded with Steel Plate, J. Struct. Eng. 127 (2001) 390–397. https://doi.org/10.1061/(ASCE)0733-9445(2001)127:4(390).

[14] D.Y. Yoo, N. Banthia, Y.S. Yoon, Predicting service deflection of UHPFRC beams reinforced with GFRP bars, Compos. Part B Eng. (2016). https://doi.org/10.1016/j.compositesb.2016.06.013

[15] A.M. Neville, Properties of Concrete, 4th Edition, Wiley: New York and Longmont, London, 2011.

[16] European federation of national trade associations representing producers and applicators of specialist building products (EFNARC), Specification and Guidelines for Self-Compacting Concrete, Rep. from EFNARC. Association House, 99 Wet Street, Farnham, Surrey, London, UK, 2002. https://doi.org/0 9539733 4 4.

[17] K. Wille, A.E. Naaman, G.J. Parra-Montesinos, Ultra-high performance Concrete with compressive strength exceeding 150 MPa (22 ksi): A simpler way, ACI Mater. J. (2011). https://doi.org/10.14359/51664215.

[18] American Society for Testing and Material (ASTM), A615/615M Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement, USA, 2012.

[19] American Concrete Institute (ACI), Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures Reported by ACI Committee 440, Michigan, USA, 2002.

[20] American Concrete Institute (ACI), ACI-318 Building Code Requirements for Structural Concrete and Commentary, USA, 2019. https://doi.org/10.14359/51716937.

[21] American Society for Testing and Material (ASTM), ASTM C78/C78M Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), Philadelphia, Pennsylvania, USA. (2002).

[22] American Concrete Institute (1ACI), ACI 440.1R-06, Guide for the design and construction of concrete reinforced with FRP bars, USA. (2006).

[23] O.A. Mohamed, M. Kewalramani, R. Khattab, Fiber reinforced polymer laminates for strengthening of RC slabs against punching shear: A review, Polymers (Basel). (2020). https://doi.org/10.3390/polym12030685.

[24] S.S. Aman, B.S. Mohammed, M.A. Wahab, A. Anwar, Performance of reinforced concrete slab with opening strengthened using CFRP, Fibers. (2020). https://doi.org/10.3390/fib8040025.

[25] H. Abbas, A.A. Abadel, T. Almusallam, Y. Al-Salloum, Effect of CFRP and TRM strengthening of RC slabs on punching shear strength, Lat. Am. J. Solids Struct. (2015). https://doi.org/10.1590/1679-78251277.