ISSN: ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

Rehabilitation of RC deep beams failing in shear using CFRP sheets and steel plates.

Waleed Nadhim Hassan 1

M. Sc. Student,

Dr.Yousif Jabbar Lafta 1

Lecturer.

Dr.Jamal Abdulsamad Khudhair 1

Professor

1 Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq

Abstract

In this study, structural repair is conducted on several damaged reinforced concrete deep beams failing in shear. nine reinforced concrete deep beams tested under loading up to failure or to 0.80 % of failure load , with rectangular cross section (180x300 mm) and with varied length (950,1150 and 1400) mm depend on a/d ratio 1,1.5 and 2 respectively ,the beams are cast to investigate the shear strength before and after repair. The specimens are tested as simply supported beams under two-point loads (200mm) apart at mid span. Deflections were measured at mid span of the beams at each loading stages

After loading to the required level, the beams are repaired and retested to investigate the effect of the CFRP sheets and steel plates in restoring the capacity for the damaged beams. Beams are repaired by replacement of the crushed concrete and filling the large cracks by cementitious grout then gluing external steel plate or CFRP sheets. After repairing, the beams were divided into two groups (A and B), group A is strengthened with CFRP sheets, while group B, with steel plates of (1.5 mm) thicknesses. The results show that, in case of repairing with steel plates, the ultimate load can be increased up to (179.5%) times those of the original beams. In case of repairing with CFRP sheets, the ultimate load can be increased up to (154.0%) times those of the original beams. Control beams that were loaded to failure then repaired with CFRP sheets showed lower strength than the original beams because those beams are very damaged than other beams that had been loaded to (80%) of ultimate load.

Keywords: Deep beams, Shear failure, Rehabilitation, CFRP sheets; Steel plate

1. Introduction

Reinforced Concrete Deep Beams represent one of the essential elements utilized in various kinds of construction parts, such as high-rise buildings, foundations, bridge girders, and shear walls [1][2]. These concrete members are distinguished by their low shear span to effective depth ratio (a/d), which is smaller than 2.0[3][4][5]. Deep beams are usually vulnerable to degradation during their service life due to weathering effects and Sulphur attacks, which causes by several factors such as construction errors and underestimating concrete cover and steel reinforcement. Rather than dismantling and reconstructing existing structures, restoration and strengthening with composites materials and steel plates has become a realistic and cost-effective option. In recent works, concrete repair and strengthening technics based on fiber-reinforced polymer composites have been introduced[6]. These technologies offer greater stability and maintain the concrete elements' original load-carrying capacity.

The properties of CFRP, a polymer matrix reinforced with carbon fibers, can be summarized by the outstanding modulus of elasticity (228 GPa)), high tensile strength (7 GPa), low density (1800 kg/m^3), and tremendous chemical inertness[7]. CFRP is expensive, but it has very high mechanical properties; however, one of the main disadvantages is brittleness. Therefore, the main use of CFRP is reinforcing and/or rehabilitation of a concretes. Several studies have been conducted on the properties of CFRP to improve its mechanical properties and to better understand its own behaviors. Rao, et al. (2004) [8], studied the shear behavior of reinforced concrete deep beams with and without shear reinforcement. FRP textiles have been used in several ways, including external bonding (EB) of the FRP fabrics. [9] [10]. The results showed that fracture behavior and crack propagations were improved due to using hybrid CFRP/VGCF laminates.

Deep beams are generally exposed to either a central point load or two symmetrical point loads, forming a tied arch in the beam following diagonal cracking[11]. According to de Paiva and Sies, the main mechanisms of failure of the tied arch are shear failure [12]. Shear failure occurs when the concrete rib collapses by crushing the crown or the tension tie ruptures [13]. Sharif et al. [14] examined ten reinforced concrete beams that had been preloaded up to (85%) of their ultimate flexural capacity, as well as ten elements repaired with (FRP) panels of varying thickness. Despite the brittleness of (FRP) plates, repaired beams gave sufficient ductility and increase flexural capabilities. F, Ojaimi [15] used four technics for strengthening beams that fail in shear Self-Compacted Fiber Reinforced Concrete Jacket without Stirrups (S.-J. + Steel Fiber), Self-Compacted Concrete Jacket with Stirrups

(S.-J. + Stirrups), Self-Compacted Concrete Jacket with Ferrocement Jacket (S.-J. + Ferrocement), and Self-Compacted Fiber Reinforced Concrete Jacket with External Steel Reinforcing Bars (S.-J. + Ferrocement + R) .

The objective of the current study is to investigate the effectiveness of rehabilitation using either CFRP sheets or steel plates after the deep beams were loaded to failure or 80 % of failure load.

Experimental program

This part introduces the specimens and their structures. Following that, the discussion of material properties and the test setup. The entire tests were carried out in the structure laboratory at the AI-Basrah University in the Department of Civil Engineering.

2.1 Test specimens and construction

A schematic of the test specimens and reinforcement layout is depicted in Fig. 1. The cross-section of all specimens was identical (180×300) mm; three different ratios of (a/d) have been employed (a/d=1,1.5, and 2). Table 1 presents a total of nine specimens that were tested under a two-point load with a 200 mm fixed distance between the load for all specimens. The specimens include three control beams (DB-1-CS-CFRP ,DB-1.5-CS-CFRP and DB-2-CS-CFRP) were loaded up to failure, six specimens with an initial per-load (80% of the ultimate load), namely (DB-1-RS-CFRP ,DB-1.5-RS-CFRP, DB-2-RS-CFRP) and (DB-1-RS-SP , DB-1.5-RS-SP, DB-2-RS-SP) retrofitted with either carbon fiber reinforced polymer or steel plates, after being grouted with cementitious grout to fill the cracks of the initially loaded component and replacement the damaged part of concrete. The identification code DB-1.5-CS-CFRP or DB-1.5-RS-CFRP was assigned for each specimen . For example, "DB-1.5-CS-CFRP" stands for control deep beam element with (a/d) equal to 1.5, specimens "DB-1.5-RS-CFRP", and " DB-1.5-RS-SP" stands for the elements initially loaded up to 80% of its ultimate capacity and rehabilitated with CFRP or steel plate, respectively.

The beams were designed to fail in shear, 3Ø16mm flexural reinforced were used with 2Ø8 stirrups were provided at the ends of all specimens.

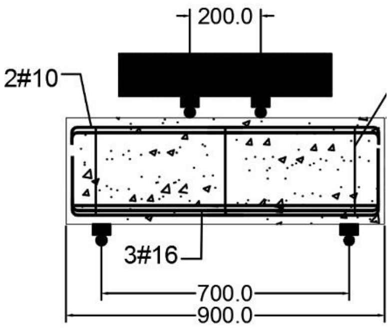

Fig. (1): Details of loading and specimens for (a/d) = 1

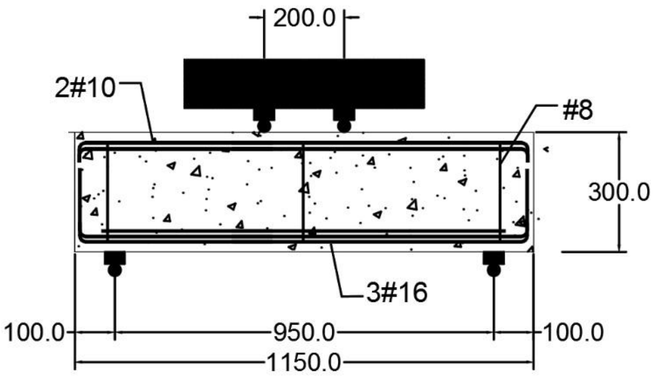

Fig. (2): Details of loading and specimens for (a/d) = 1.5

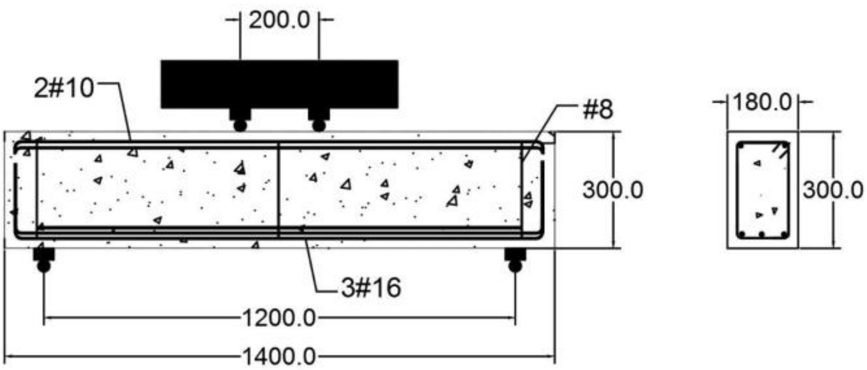

Fig. (3): Details of loading and specimens for (a/d) = 2

Table 1; Summary of specimens

Design Nation	(a/d) ratio	Reinforcing Bars			Beams Length (L)	Clear Span(L_n)
		Bottom	**Top**	**Stirrups**	**mm**	**mm**
DB-1-CS-CFRP *DB-1-RS1* *DB-1-RS2*	1	3 Ø16	2 Ø10	None	900	950
DB-1.5-CS-CFRP *DB-1.5-RS-CFRP* *DB-1.5-RS-SP*	1.5	3 Ø16	2 Ø10	None	1150	950
DB-2-CS-CFRP *DB-2-RS-CFRP* *DB-2-RS-SP*	2	3 Ø16	2 Ø10	None	1400	1200

2.2 Materials and properties

Table 2: Mix proportions of the concrete

Mix Proportion	Cement Content (Kg/m3)	Water cement ratio (by weight)	Slump (mm)	fcu 28-day (MPa)
1:1.2:2.4	450	0.45	140	35

2.2.1 Concrete: Table 2 presents the mix proportions of the concrete used for the specimens. Concrete cubes (150 mm × 150 mm × 150 mm) were fabricated and cured at the same conditions as the RC deep beam specimens to maintain the consistency between the material properties used in the tests and the deep beam specimens. Complying to Iraqi Specification No.5/ 1984 [16], Ordinary Portland cement (Type I) is used in this study. It is of falcon origin .Natural sand from (Basrah-Shlat) region in Iraq is used for concrete mixes test results indicate that the fine and coarse aggregate grading and the sulfate content are within the limits of Iraqi Specification No. 45/1984 [17].

2.2.2 Steel bars and steel plate: Deformed steel bars were used for longitudinal and traverse reinforcement and Steel plates with thicknesses of (1.5) mm which were used as external reinforcement to strengthen the damaged beams are showed in table 3

Table (3): Properties of steel bars.

Nominal Diameter (mm)	**Modulus of Elasticity (Es) (GPa)**	**Yield Stress (fy) (MPa)**	**Ultimate Stress (fu) (MPa)**
8 deformed	200	400	676
10 deformed	200	485	719
16 deformed	200	517	635
Steel plate (1.5mm)	200	265	330

2.2.3 CFRP Sheet: In this study, a unidirectional fiber corrosion resistant laminate termed Sika Wrap–300 C constructed from carbon fiber reinforced polymer manufactured by Sika Company, Switzerland as showed in fig(4), with a width of 600 mm and a thickness of 0.167 mm (based on fiber content) mm was utilized. Table (4) shows the properties of CFRP laminates which are taken from manufacturer's specification (Sika 2005) . [18]

Table (4): Properties of CFRP laminates [18]

Sika Fiber	Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Tensile Strength at break (MPa)	Strain at break (%)
Sika Wrap -300 C	> 3500	> 230000	> 4000	> 1.7

2.2.4 Epoxies: two types of epoxy are utilized, each with a specific function in repairing damaged beams. Sikadur® 330 is utilized as an impregnation resin for the dry application technique of SikaWrap® fabric reinforcement. For use in a wet application method, a primer resin is required. Sikadur® 31/41 is an excellent adhesive component for concrete surfaces with steel plates, and it is used in this application.Sikagrout® 200 used for sealing the surface cracks[19] [20].

2.3 Concrete Mix Proportion: Mix proportion is important for NC. Many trial-mixes are often required to generate the data necessary to identify optimum mix properties.A4.75mm sieve is used to sieve the fine aggregate, producing a fineness modulus (F.M.) of 2.72 t. The coarse aggregate is cleaned and dried to eliminate dust before sieving on a 14mm sieve size.Slump tests were conducted for mixes with 440, 460, 480, and 450 kg/m3 cement. Content of these mixes use sand to aggregate weight ratios.Adjust the w/c ratio to produce the required (140mm) slump for each cement content. Finally the mix that used by weight were (cement 455 kg/m3 ,sand 540 kg/m3, 1080 kg/m3 and water 203 kg/m3).

2.4 Mix Procedure: The interior surface of the mixer was cleaned and moistened before use. The mix ingredients were added in the following order: one third of the mixing water was added to gravel and sand in mixer and mixed for about one minute, then cement was added and mixed for thirty seconds. After one third of mix water was added and mixing continued for a minute. The remaining water was added gradually and shirred for two to three minutes so that a homogeneous mix was obtained.

2.5: Casting and Compaction: Before casting the specimens the workability of the concrete mix is checked using the slump test .The beam specimen was cast in two layers and each layer was compacted using a poker vibrater. for each casting day, nine concrete cubes and six cylinder were cast for the evolution of compressive strengths splitting tensile strength and modules of elasticity.

2.6 Curing : After casting, the specimens were enclosed in nylon to prevent water from evaporating. A water curing tank was used for 28 days to cure the control specimens units. After that, they were taken out of the containers and kept in the laboratory for a few days to dry off the moisture.

2.7 Hardened Concrete properties : The testing of the concrete cubes showed the concrete compressive strength has an average value of 35.4 MPa. And the testing of cylinders for splitting strength indicated that the tensile strength was 4.94 MPa. The modulus of elasticity found to be about 32802 MPa

3. Test Setup : The beam-specimens were tested over a simply supported span of 700, 950, 1200mm, as illustrated in Fig.(5). Two point loads were applied; the distance between two point loads was 200mm. The beam test was started by the application 100kN load to set and check the dial gages then unloading to zero. At zero loading, the initial reading of the dial gage. Then, the load was increased gradually in steps, while the strain, and deflection measurements were recorded simultaneously until failure occurs. A magnifying glass was used to detect the cracks at each load. Cracks were detected and drawn on the face of the tested beam.

Fig.5 Simply supported reinforced deep-beam under two axial load,

4. Repairing Steps of Damaged Beams: Control-beams were extensively damaged in the tests due to excessive loading, while other beams cracked with loading up to 80% of the failure-load or ultimate-load. Nine beams were divided into three groups based on their a/d ratio. Within each group, one beam was loaded to failure and then repaired with CFRP sheet, the second beam was loaded to 80% of failure load and then repaired with CFRP sheets, and the third beam was loaded to 80 % of failure load then repaired with steel plate, This is done to compare and clarify the activity of bonded plates in strengthening after damage of beams, as well as to observe the structural behavior of the restored beams. The exterior CFRP sheets bonded to repaired beams have the same depth (300mm) and width (180 mm) but varied in length (700,950 and 1200mm).

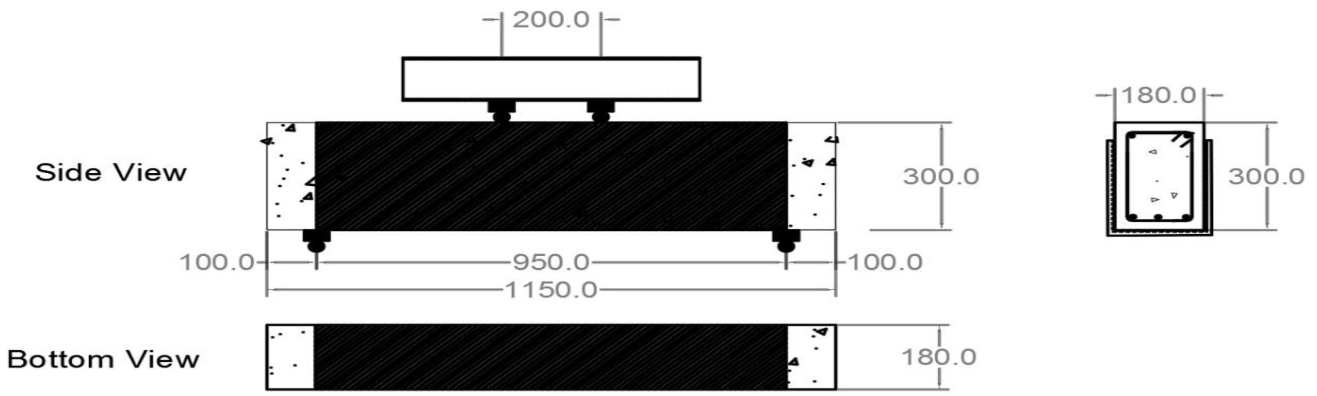

Figure (6): Details of external CFRP sheets for repaired beams in Shear.

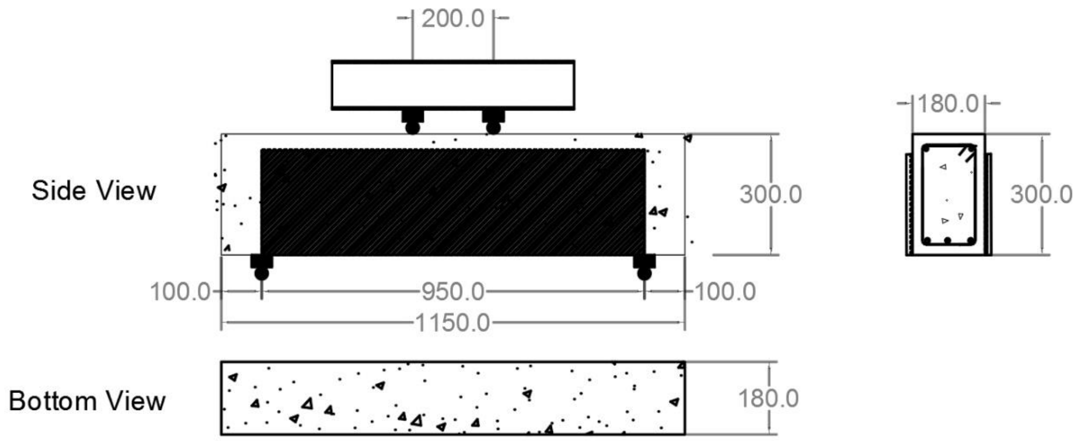

Figure (7): Details of external Steel Plates for repaired beams in Shear.

The exterior steel plate was bonded to repair beams have depth (250 mm) on two side only constant thickness. As illustrated in fig(6)and fig(7)

It is essential that the integrity of the beams has to be restored prior to the plates and sheets are glued to the beams. The following is an outline of the repair work according to structural strengthening with sika systems [23]:

- The first step in repairing restore the original shape of the specimen. A reverse load is applied to the beam until it straightens out again, or almost so.
- Crushed concrete in the failure zone is chipped out in both tension and compression zones. Then, it is replaced by cementitious grout with higher properties than old concrete, as shown in Fig (8).

Fig (8). Repaired beams with cementitious grout

- A surface cleaning machine was used to clear the concrete surface on all faces of the deep-beam sides, as illustrated in Fig .8. The specimen's two corners have been further chamfered with a radius of R=10mm to avoid a reduction in strength caused by sheet bending at the corners, after which they were cleaned and dried.as shown in Fig (9)

Figure (9): Cleaning surface of concrete and chamfered corners

- Beams that repair with CFRP sheets Firstly, the two-parts of epoxy (A and B) was mixed in 2:1 ratio by using electrical drilling machine attached to the mixing bullet, the resulting material was grey paste. The epoxy mix was applied to the surface of concrete at all area of the CFRP sheets. The epoxy mixer was also poured on surface of CFRP and then applied to the surface of concrete (bottom and two sides).
- Beams that repair with steel plate, the two-parts of epoxy (A and B) with mix ratio: A: B =1 : 4 by weight or volume mix all of component B with component A using low speed drill and paddle until a uniform consistency is obtained . The epoxy mixer was also poured on surface of steel plate and then applied to the surface of concrete two sides.

Result and Discussion

5.1 Details of Test and analysis: The experimental results for beams examined before and after repairing are reported. The beams were subjected to two-point loads with increment rate of 20 kN, Then beams were with, (a/d) of (1, 1.5, and 2).After loading to the required level , the cracks were repaired by cement grouting followed by externally bonded steel plate or CFRP sheets. The load-deflection relationships at mid-span and cracking behavior, deflection, and ultimate load for each beam before and after repair are shown and discussed.

The arch action become more effect at smaller shear span to effective depth ratio.

5.2 Behavior Of Beams Under Loads: The ultimate load of the specimen (DB-1-CS-) was (492 KN), which is higher than the ultimate load of the specimens (DB-1.5-CS and DB-2-CS), and the deflection of the specimen (DB-1-CS) is (4.95 mm), which is lower than the deflection (6.04 and 10.5 mm) of the specimens (DB-1.5-CS and DB-2) respectively. In this study, the best shear span ratio (a/d) is (1), which showed greater value of ultimate load owing to the struts' compression path verticality convergence, which implies the load is passed directly to the supports. The first crack appears in (170–235 kN) for a/d = 1 group, (160–196 kN) for a/d = 1.5 group, and (101–130 kN) for a/d = 2 group.

After repair, the beams were divided into two groups, three beams repaired with steel plates, and other beams repaired with CFRP sheets.

5.2.1 Behavior of Beams Repaired with CFRP Sheets: This group consists of six beams , three of them (DB-1-CS-CFRP, DB-1.5-CS-CFRP, and DB-2-CS-CFRP) were loaded to failure then repaired with CFRP sheets , the other (DB-1-RS-CFRP, DB-1.5-RS-CFRP, and DB-2-RS-CFRP) were loaded to 80 % of failure load then also repaired by CFRP sheets. These deep beams are damaged due to shear stresses. The ultimate strength of the tested beams Pu is (492, 285, 195 kN). The efficiency of repairing is defined as the ratio of the repaired beam strength to its original (as a percentage).In general, beams loaded up to 80% of failure load repaired with CFRP sheets exhibit ultimate loads greater than (or equal) those for the original beams as illustrated in table (5)

Table 5 Percentage Deep Beams sheer Strength before and after Rehabilitation.

Beam Designation	a/d	Beam strength before Rehabilitation Pu, (kN)	Beam strength after Rehabilitation Pur, (kN)	Pur / Pu %
DB-1-CS-CFRP	1	492	315	64.0
DB-1-RS-CFRP			473	96.1
DB-1.5-CS-CFRP	1.5	285	185	64.9
DB-1.5-RS-CFRP			301	105.6
DB-2-CS-CFRP	2	195	142.5	73.1
DB-2-RS-CFRP			301	154.4

The control deep beams (DB-1-CS-CFR, DB-1.5-CS-CFRP, and DB-2-CS-CFRP) did not show any increase in ultimate load since they fail before reaching their original capacity owing to complete beam damage. The beam (DB-2-RS-CFRP) achieves the best ultimate load result by with shear strength efficiency (154.4 percent). This beam collapse was due a new flexural shear crack in the opposite span, distant from the repaired cracks, creating substantial local interfacial stresses between the CFRP sheets layer and the concrete at the crack zone. This causes debonding or crushing of sheets beginning in this zone.

Beam (DB-1.5-RS-CFRP) has repaired efficiency (105.1%), and the beam failed due to the reopening of a previously repaired major shear crack that spreads across the width of the beams to the opposite face and a new failure mode develops in the flexural zone, resulting in the beam's final failure, with tearing off of the concrete cover and separation of CFRP sheets at this zone.

Beam (DB-1-RS-CFRP) fails by reopening healed cracks and debonding of sheet from one end that began under the crack zone. The use of epoxy glue is insufficient to achieve composite action between concrete and steel, and so cannot avoid debonding failure. This beam has a restored efficiency (96.1 percent).

5.2.2 Deflection of repaired beams with CFRP sheets : The load-deflection curves are illustrated in Figs.(15) to (20), which show

Figure (9): Failure mode for Rehabilitated Deep Beam with (a/d=**1**) failed in **shear** - **DB-1-CS-CFRP**

Figure (10): Failure mode for Rehabilitated Deep Beam with (a/d=**1**) failed in **shear** - **DB-1-RS-CFRP**

Figure (11): Failure mode for Rehabilitation Deep Beam with (a/d=**1.5** failed in **shear** - **DB-1.5-CS-CFRP**

Figure (12): Failure mode for Rehabilitated Deep Beam with (a/d=**1.5** failed in **shear** - **DB-1.5-CS-CFRP**

Figure (13): Failure mode for Rehabilitated Deep Beam with (a/d=2 failed in **shear** - **DB-2-CS-CFRP**

Figure (14): Failure mode for Rehabilitated Deep Beam with (a/d=2 failed in **shear** - **DB-2-RS-CFRP**

the comparison of load vs. mid-span deflection for control, original (loaded to 0.8 Pu) and repaired beams. It can be noticed that for beams loaded to failure then repaired with CFRP (DB-1-CS-CFRP, DB-1.5-CS-CFRP and DB-2-CS-CFRP), the deflections of the repaired beams (at 60% of ultimate load) are greater than their original beams by (361.3, 329.6 ,133.1 %) respectively.

The best deflection is achieved in beam (DB-2-RS-CFRP), the repaired beam showed, at service load (which is 70% of ultimate load), (69.4 %) lower deflection compared to control beam deflection, which means a significant increase in stiffness which was provided by CFRP.

The deflection of repaired beam (DB-1-RS-CFRP) is lower than that of the original beam with ratio 87.0 %, and beam (DB-1.5-RS-CFRP) recorded ratio (108.2%) therefore, its showed lower stiffness.

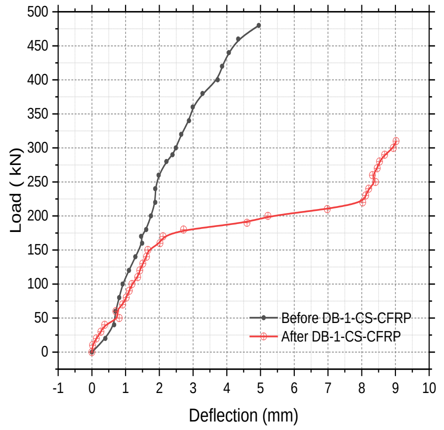

Fig.(15):Load-Deflection curve for beam(DB-1-CS-CFRP).

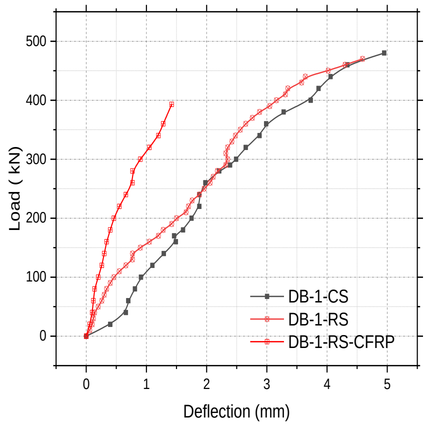

Fig.(16):Load-Deflection curve for beam(DB-1-RS-CFRP).

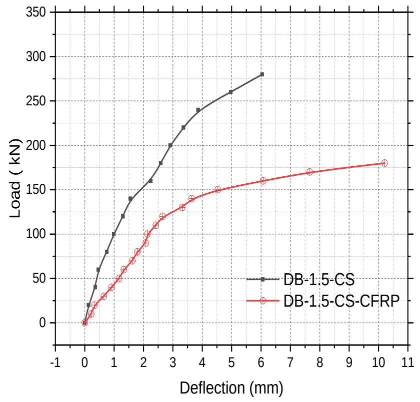

Fig.(17):Load-Deflection curve for beam(DB-1.5-CS-CFRP).

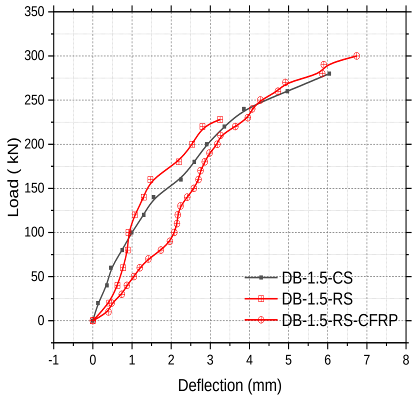

Fig.(18):Load-Deflection curve for beam(DB-1.5-RS-CFRP).

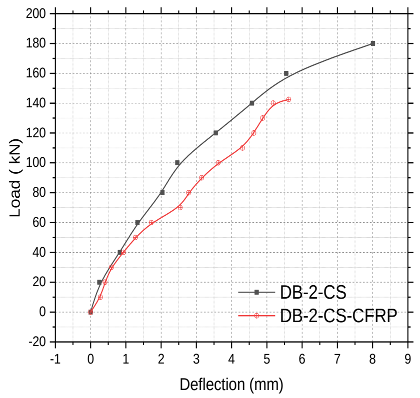

Fig.(19):Load-Deflection curve for beam(DB-2-RS-CFRP).

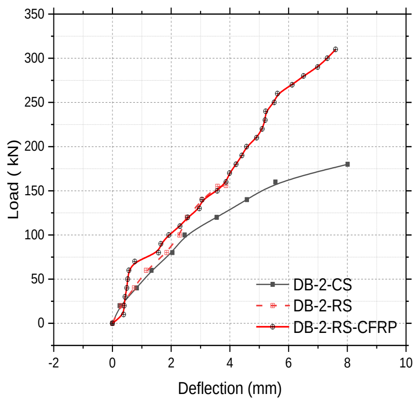

Fig.(20):Load-Deflection curve for beam(DB-2-RS-CFRP).

5.3.1 Behavior of Beams Repaired with Steel Plates

This group includes three beams identified as (DB-1-RS-SP, DB-1.5-RS-SP, DB-2-RS-SP). all of these deep beams are repaired by steel plates with constant thickness (1.5mm). that attached to the sides of beam for a height of 250 mm. The beams were loaded to 80 % of failure load . These deep beams are damaged due to shear stresses. The ultimate strength of the tested beams Pu is (492, 285, 195 kN) . In general, all beams repaired with steel plate exhibit ultimate loads larger than those of the original beams, with the exception of beams with a/d =1, for which the repair was inefficient when compared to other a/d ratios for steel plate or CFRP sheets repair.

Table (6) Percentage Deep Beams Strength before and after Rehabilitation.

Beam Designation	**a/d**	**Beam strength before Rehabilitation P_{us}, (kN)**	**Beam strength after Rehabilitation P_{ur}, (kN)**	**P_{ur} / P_{us} %**
DB-1-RS-SP	**1**	**492**	**474**	**96.3**
DB-1.5-RS-SP	**1.5**	**285**	**402**	**141.1**
DB-2-RS-SP	**2**	**195**	**350**	**179.5**

The beam (DB-2-RS-SP) achieves the best ultimate load result by recording repairing shear strength efficiency (179.5 percent). This beam collapses as a result of a new flexural shear crack that extends towards the point of applied loads, creating substantial local interfacial stresses between the steel plate layer and the concrete at the crack zone. This causes plate debonding to begin in this zone.

Beam (DB-1.5-RS-SP) has repaired efficiency 141.1 percent. Reopening of a previously repaired major shear crack caused the concrete cover to tear off and the steel plate zone to separate in this beam, which led directly to its failure.

Beam (DB-1-RS-SP) has a repaired efficiency of 96.3 percent, but fails in the same way as other beams that have been repaired due to shear damage, by reopening mended cracks and debonding steel plates from one end that started under the crack zone. The use of epoxy glue is sufficient to achieve composite action between concrete and steel, and so can avoid debonding failure. The stress concentration in the adhesive layer is considered to initiate the debonding of plates or concrete covers glued to reinforced concrete beams.

Figure (21): Failure mode for Rehabilitated Deep Beam with (a/d=**1**) fail in **shear** - **DB-1-RS-SP**

Figure (22): Failure mode for Rehbilitated Deep Beam with (a/d=**1**.5) fail in **shear** - **DB-1.5-RS-SP**

Figure (23): Failure mode for Rehabilitation Deep Beam with (a/d=2 fail in **shear** - **DB-2-RS-SP**

5.3.2 Deflection of repaired beams with Steel Plate:

Figure (24) shows the deflection of beam (DB-1-RS-SP) which is (217.4%) higher than that of the control beam at service load, which can be related to the difference in stiffness between the integrated (original) beam and the bonded (repaired) beam, as well as the presence of hair line cracks in the repaired beam.

Fig (25 and 26) illustrates that, for beams (DB-2-RS-SPand DB-1.5-RS-SP) , the deflections, at service load, of the repaired beams are smaller than those of the control beam's with ratios of (94.6,84.4 %) respectively.

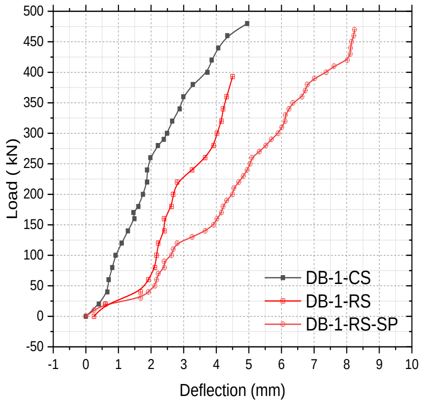

Fig.(24):Load-Deflection curve for beam(DB-1-RS-SP) compare with deflection of control beam.

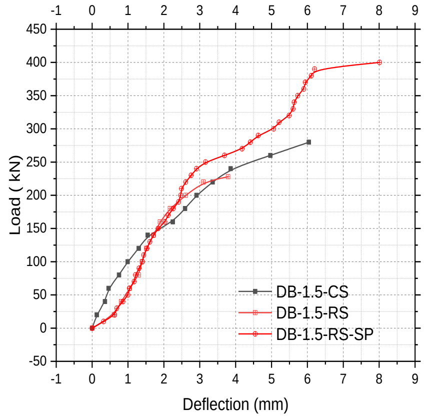

Fig.(25):Load-Deflection curve for beam(DB-1.5-RS-SP) with compare with deflection of control beam.

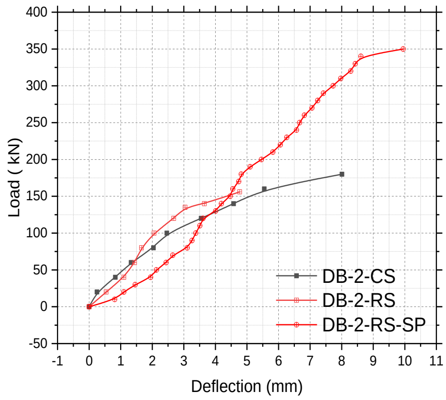

Fig.(26):Load-Deflection curve for beam(DB-2-RS-SP) compare with deflection of control beam.

6. Conclusions :

1. Beams repaired with CFRP exhibit increase in repair efficiency of ultimate loads (96.1, 105.6, and 154.4 %) compared to original beam strength before repairing which are lower than those belonging to beams repaired with steel plate (96.3, 141.1 and 179.5 %) increase in repair efficiency.
2. Control deep beams which were loaded to failure then repaired exhibited low repair efficiency compared to origin beams (64.0, 64.9 and 73.1 %),
3. When a/d increases the behavior of the beams approaches ordinary beams, and the repair efficiency increases, which indicates that the two repair methods used in this study are more effective on ordinary beams than deep beams.
4. Best reduction in deflection values is recorded in beams repaired with CFRP sheets where the deflection after repair have smaller value than the original beams. per contra the beams that repair with steel plate which recorded a value larger than the original.

References :

[1] S. Z. Al-sarraf, I. A. S. Al-shaarbaf, and A. S. Diab, “Effect of Steel Fiber on The Behavior of Deep Beams With and Without Web Opening,” vol. 29, no. 1, pp. 1–19, 2011.

[2] G. S. Suresh and S. Kulkarni, “Experimental study on behaviour of RC deep beams,” International Research Journal of Engineering and Technology (IRJET), vol. 03, no. 08. pp. 676–679, 2016.

[3] A. El-Kareim, A. Arafa, A. Hassanin, M. Atef, and A. Saber, “Behavior and strength of reinforced concrete flanged deep beams with web openings,” Structures, 2020.

[4] T. S. S. Al-Gasham, “Reinforced Concrete Moderate Deep Beams with Embedded PVC Pipes,” Wasit J. Eng. Sci., 2015.

[5] W. Y. Lu, H. T. Hsiao, C. L. Chen, S. M. Huang, and M. C. Lin, "Tests of reinforced concrete deep beams," Comput. Concr., 2015.

[6] Y. T. Obaidat, S. Heyden, O. Dahlblom, G. Abu-Farsakh, and Y. Abdel-Jawad, "Retrofitting of reinforced concrete beams using composite laminates," Construction and Building Materials. 2011.

[7] A. Y. Chen, S. Baehr, A. Turner, Z. Zhang, and G. X. Gu, "Carbon-fiber reinforced polymer composites: A comparison of manufacturing methods on mechanical properties," Int. J. Light. Mater. Manuf., 2021.

[8] Rao, G.A., K. Kunal, and R. Eligehausen. Shear strength of RC deep beams. in Proceedings of the 6th International Conference on Fracture Mechanics of Concrete and Concrete Structures. 2007.

[9] Boumaaza, M., et al., Behavior of pre-cracked deep beams with composite materials repairs. Structural Engineering and Mechanics, 2017. 63(5): p. 575-583.

[10] Godat, A., F. Hammad, and O. Chaallal, State-of-the-art review of anchored FRP shear-strengthened RC beams: A study of influencing factors. Composite Structures, 2020. 254: p. 112767.

[11] Bresler, B. and J.G. MacGregor, Review of concrete beams failing in shear. Journal of the Structural Division, 1967. 93(1): p. 343-372.

[12] Lafta, Y.J. and K. Ye, Specification of Deep Beams Affect the Shear Strength Capacity. Civil and Environmental Research, 2016. 8: p. 56-68.

[13] de Paiva, H.R. and C.P. Siess, Strength and behavior of deep beams in shear. Journal of the Structural Division, 1965. 91(5): p. 19-41.

[14] Sharif, A., et al., Strengthening of initially loaded reinforced concrete beams using FRP plates. Structural Journal, 1994. 91(2): p. 160-168.

[15] Ojaimi, M.F., Experimental Study on Shear Strengthening of Reinforced Concrete Beams Using Different Techniques of Concrete Jacketing. Basrah Journal for Engineering Science, 2021. 21(2).

[16] No, I.S., Portland cement Iraqi Central Organization for Standardization and Quality Control. 1984, Baghdad-Iraq.

[17] No, I.S., 45, Natural Sources for Gravel that is Used in Concrete and Construction. 1984, Baghdad.

[18] Sika Wrap–300 C;SDS No. 020206020010000011[Online]; Sika acquired PAREX Group: 1910, Switzerland, https://www.sika.com/;May 2017, Version 01.01.

[19] Sikadur -31/41 ;SDS No. 01 04 02 03 001 0 000001 [Online]; Sika acquired PAREX Group: 1910, Switzerland, https://www.sika.com/;May 2017, Version 01.01.

[20] Sikagrout® 200 ;SDS No. 020206010010000040 [Online]; Sika acquired PAREX Group: 1910, Switzerland, https://www.sika.com/;Sptember 2016, Version 01.01.

[21] ASTM Standards: C192/C192M-02, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory", 2001, ASTM International, 100 Bar Harbor Drive, West Conshohocken, PA 19428-2959, USA, 8pp.

[22] ASTM Standards: C39-86, "Compressive Strength of Cylindrical Concrete Specimens", 1989, Annual Book of ASTM, Standard American Society for Testing and Materials, Philadelphia, Pennsylvania, Section 4, Vol. 04.02, PP.20-24.

[23] Sika group, "structural strengthening with sika systems" 1910, Switzerland, https://www.sika.com/;pp.18 .