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Shear behavior of reinforced concrete wide beams strengthened with CFRP sheet without stirrups

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Abstract

Reinforced concrete wide beams (WBS) have been used in construction buildings because its provide many advantages; reducing the reinforcement congestion, reducing the quantity of the required formwork, providing simplicity for replication, and decreasing the storey height. The current study presents the results of four full-scale wide RC beams in order to study their shear behavior and investigate the effectiveness of carbon fiber reinforced polymer (CFRP) when using as shear reinforcement to improve the shear capacity of wide RC beams, one these beams was fabricated by (ANSYS) program this beam was unstrengthened with CFRP and without stirrups (control beam), the other two beams was strengthened with vertical and inclined CFRP sheet without stirrups and the last beam reinforced with shear stirrups (WBS). All beams casted with normal concrete strength (30 MPa), simply supported and under two point loads. The performances of these beams were measured in terms of; ultimate load, crack patterns, concrete and steel strains, deflection, and mode of failure. The results showed an increasing in ultimate load of strengthened beams with inclined, vertical CFRP and beam with shear reinforcement by (19.9%), (7.14%) and (39.8%) respectively as compared with the control beam, and this results means possibility of replacing the internal shear reinforcement with externally bonded CFRP.

Keywords: RC wide beams, strengthened beams, carbon fiber, shear failure.

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1. Introduction

Reinforced concrete wide beam (RCWB) is a horizontal member which is used in RC joist and ribbed slabs, its depth equals or slightly higher of slab depth as shown in Figure 1 [1] and Figure 2 [2].

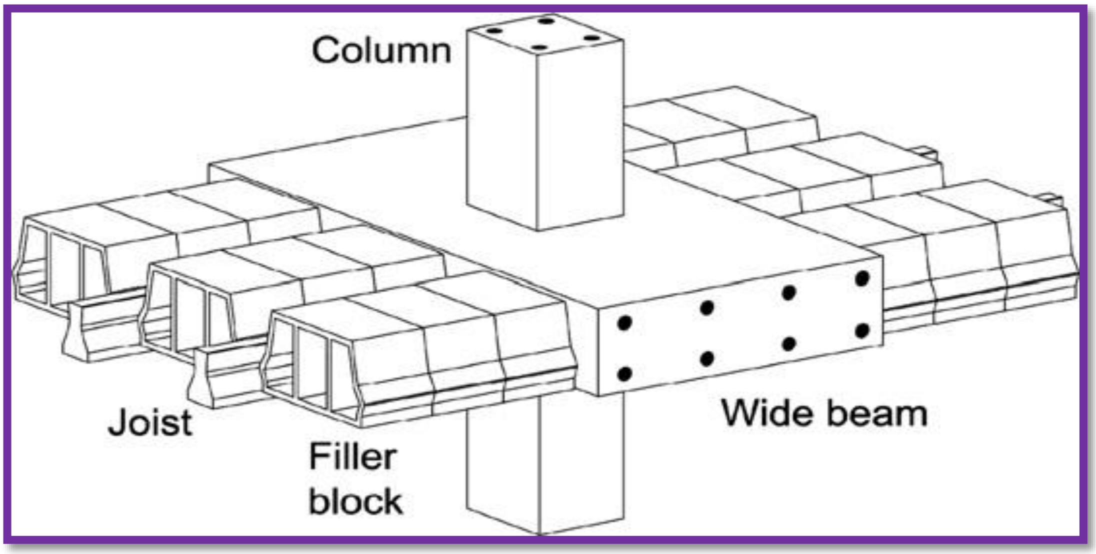

Figure 1: Typical RC joist slab-wide beam systems [1]

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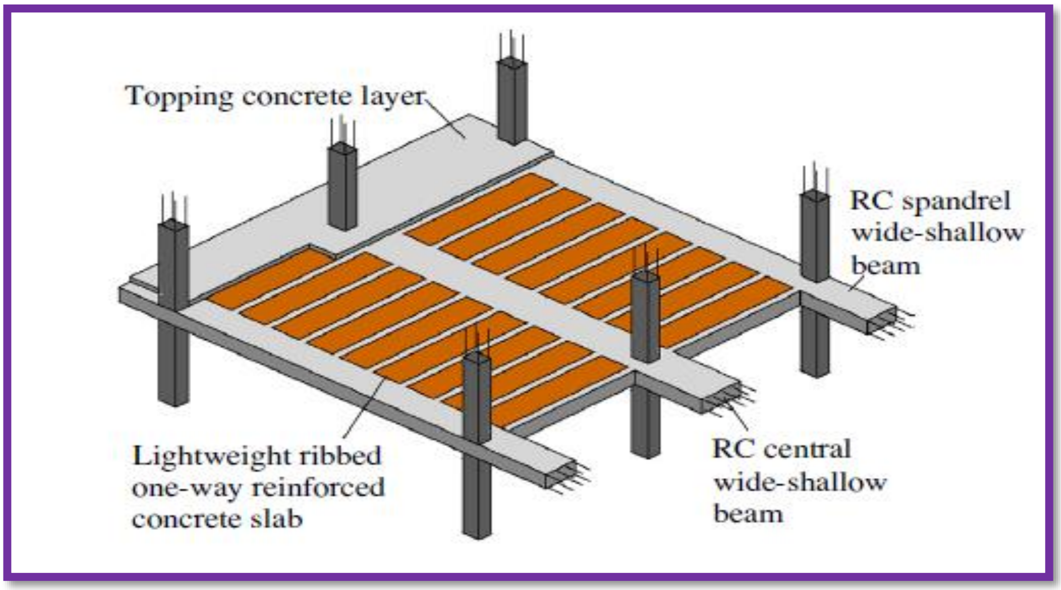

Figure 2: Typical floor made by WBS and ight weight ribbed one-way RC slab [2]

Wide beams began using more in recent years in construction buildings because its provide longer clear spans with a reasonable cost, minimize the overall slab depth to attain more floor clear height, easy to construct, preferred by architects and designers as it is less obstructing and give more flexible space [3]. It is used in several places such as warehouses, parking garages, rise buildings, and commercial buildings.

Wide reinforced beam having width to depth ratio not less than (2) [4]. In the (1980s), fiber reinforced polymers (FRPs) initiated being used in the applications of civil engineering. The difficult to use and install of steel plate due to its heavy weight, exhibition to corrosion, require ongoing maintenance and have a de-bonding failure. The adhesive between the steel strip and concrete can present problems in the behavior of the flexural member. All this disadvantages of steel plate make the externally bonded (FRPs) an alternative materials for strengthening, its use for strengthening RC beams, columns warehouse, commercial buildings, rise buildings, parking garages and chimney. The advantages of (FRPs) are: Increasing loading capacity, low density, cost-effective installation process, high mechanical properties, changes of building utilization, improved serviceability, seismic performance, structural upgrading to conform with current standards and substitute missing rebars. Also strengthening of RC beams is required for many reasons such as restoration of the capacity caused by degradation or errors in design of a member and design for heavier loads. Wide RC beams such as any structural member exhibition to failure for the reasons mentioned previously also this structural members have small nominal shear capacity due to its small effective depth if compared with the normal beams so one of the treatment methods is using CFRP to compensate this defect.

1.1 Mechanical Properties Of FRP

Three types of FRP, namely Carbon Fiber Reinforced Polymer (CFRP), Aramid Fiber Reinforced Polymer (AFRP), and Glass Fiber Reinforced Polymer (GFRP) have been used for retrofitting or strengthening structures in both engineering laboratory research activities and practice. Table 1 for FRP materials with unidirectional fibers demonstrates the wide variety of stiffness and strength that FRP materials may possess [5]. It must be noted; that the ranges in the table are indicative values and a specific product may have a properties outside the ranges of these values, especially when the fiber content in these composite materials is different from these ranges that considered in the Table.

Table 1 Typical Mechanical Properties of CFRP, AFRP, and GFRP Composites [5].

Unidirectional advanced composite materials	Fiber content (%by weight)	Density (kg/m^3)	Longitudinal tensile modulus (GPa)	Tensile strength (MPa)
Glass fiber/polyester GFRP laminates	50-80	1600-2000	20-55	400-1800
Carbon/epoxy CFRP laminate	65-75	1600-1900	120-250	1200-2250
Aramid/epoxy AFRP laminate	60-70	1050-1250	40-125	1000-1800

2.Literature Review

S. E. Mohammadyan-Yasouj et al.(2013) [4], They conducted an experimental program to investigate the shear behavior of RC wide beam with interior column, they tested six wide beams divided as follow: without shear reinforcement, with shear reinforcement, mid depth horizontal bars, independent bent-up bars, vertical stirrups, the combination of bent-up bars and vertical stirrups, and one more specimen without shear reinforcement but including about two-thirds of flexural reinforcement that were distributed in column band. The performances were measured in terms of crack patterns, deflection, ultimate load, concrete and steel strains and modes of failure. The results showed that the ductility and shear capacity of wide beams increased by bent-up bars system. Although the shear capacity increased to some extent by horizontal bars system .The results also showed that the RC beam with banded reinforcement reached larger failure load.

Ehab M. Lotfy et al.(2014) [6], They investigate the influence of shear spacing in the web on the shear strength of ten simply supported wide RC beams. All beams with the same dimensions (h =200 mm), (b =300 mm) and (L =1500 mm). The main parameters measured in this investigation: shear span (a) to depth ratio (d), spacing between stirrups (s) to depth ratio (d), spacing between stirrups, shear reinforcement ratio and number of vertical branches. The beams were divided into (2) groups each consists of (5) beams, one reinforcement will decreases, also they concluded that even when the shear reinforcement widely spaced of approximately 2d, has been shown that the brittleness of these beams without shear reinforcement (control beam), and the other four beams with different details of shear reinforcement. All wide RC beams exposed to two concentrated loads, with (a/d) = (3) and (4) for the first group, and the (a/d) = (2) and (5) for the second group. Test results demonstration that the shear reinforcement has a more effect on the mode of failure, ductility, and shear strength of the wide RC beams.

M. Said and T.M. Elrakib (2013) [7], carried out an experimental program on the shear behavior of nine RC wide beams with concrete compressive strength (29 MPa). One of the tested wide beams had no shear reinforcement (control beam) . The key parameters covered by their investigation were the effect of the amount, yield stress, existence, and spacing of the shear reinforcement on the ductility and shear capacity of the tested beams. The study demonstrations that the influence of shear reinforcement on the shear capacity is important and proportional to the spacing and amount of the shear reinforcement. They concluded that the shear capacity was increased from (32% - 132%) of the tested RC wide beams compared with the no shear reinforcement beam(control beam), they concluded also that the amount of shear reinforcement increases the ductility of the RC wide beams, also the ductility was increased as the spacing between shear reinforcement decreased.

Ahmed B. Shuraim (2012) [8], investigated the influence of shear reinforcement configurations in RC wide beams on the nominal shear strength. This was the assessment by testing 16 simply supported continuous wide beams supported on interior columns. Three of these beams without stirrups, seven beams with various configurations of stirrups to verify the trend, and six other beams with either two or four leg configuration. He concluded that wide beams with two leg stirrups configuration are susceptible to becoming shear deficient, RC wide beams with four-leg configurations showed more improvement in the increasing of nominal shear strength even when small area was used.

Adam S. Lubell et al. (2009) [9], investigated the influence of spacing of the shear reinforcement on the capacity of one way shear of RC wide beam, the study was conducted by tested of 13 of RC wide beam with normal strength concrete and with shear reinforcement close to minimum requirements as defined in ACI 318-02 [10]. They concluded that by increasing the spacing of shear reinforcement across the width of beam the effectiveness of the shear will decrease compared with the similar beam without web reinforcement.

3. Research Significance

Many researchers expressed the importance of shear capacity of wide beams and suggested guidelines to use stirrups in these beams. Considering code limitations, stirrup legs through the cross section in wide beams should be increased. CFRP as an innovative shear reinforcement contribute to the shear capacity of wide beams, which can also be developed into reinforced concrete slabs.

4.Materials and Methods

4.1 General

Contains the details of experimental work (specimen's details), properties and type of used materials, mixes details, fresh & hardened tests.

4.2 Experimental Program:

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The study presents results of experimental tests on three reinforced concrete wide beams that were part of a study on the influence of CFRP on concrete wide-beam capacity. Details of specimens and test setup are shown in Figure 3. All of the specimens was designed to nominal dimensions of (1800mm) length, (400mm)width, and (200mm) height.

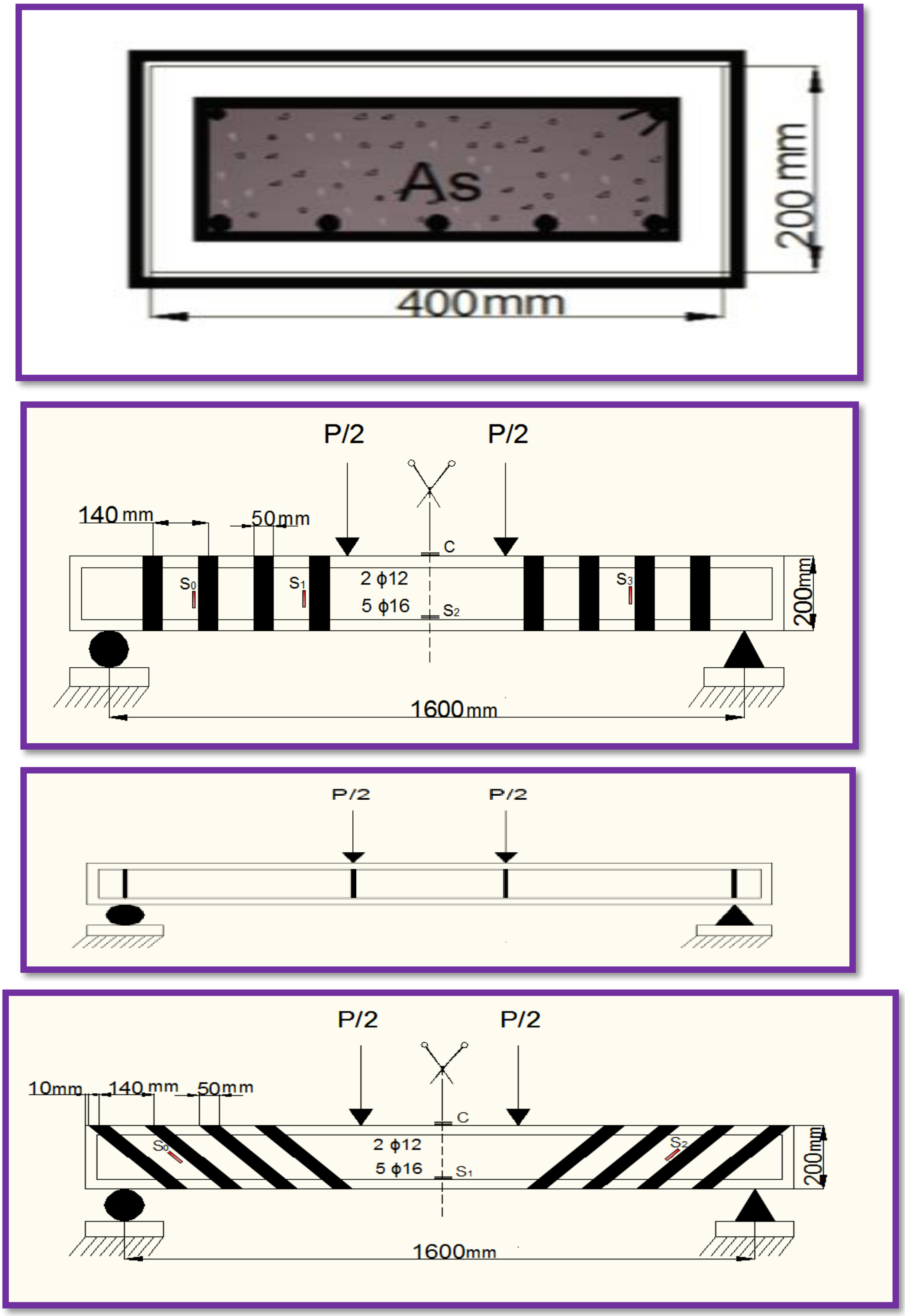

Figure 3: Typical dimensions and details of tested beam

4.3Materials

4.3.1 Cement

Ordinary Portland cement (OPC)(Type-I) (TASLUJA) is used in the current study.

4.3.2 Fine Aggregate

Natural sand (AL-Ukhaidher) with a maximum size of (4.75mm) is used through this work. The test of sieve analysis according to the Iraqi specifications 4/1984 [11]. The test results are shown in Table 2 and Figure 4.

Table 2 Grading of Fine Aggregate

Sieve size	Passing %	Iraqi specification No. 45/1984 for Zone(2)
4.75 mm	93	90-100
2.7mm	83.4	75-100
1.18mm	69	55-90
600μm	47.31	35-59
300 μm	15.405	8-30
150 μm	0.707	0-10
Pan	zero	zero

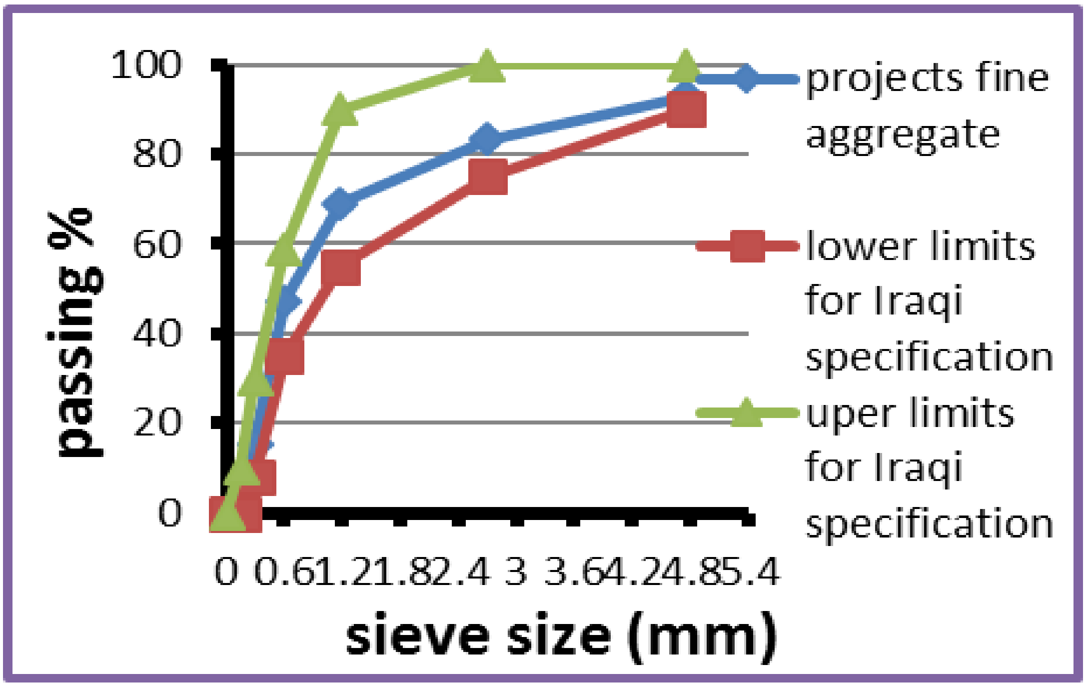

Figure 4: Grading of the fine aggregate

4.3.3 Coarse Aggregate

Crushed aggregate with maximum size (19 mm) from AL-Suddor region (Iraq). The gravel was washed, air dried and the sieve analysis is achieved before using it. The test of sieve analysis according to the Iraqi specifications 4/1984 [11]. The test results are shown in Table (3) and Figure 5.

Table 3 Grading of Coarse Aggregate.

Sieve size (mm)	Passing %	Iraqi specification No. 45/1984 for Zone(2)
37.5	100	100
20	95.559	95-100
10	31	30-60
5	0.771	0-10
Pan	zero	zero

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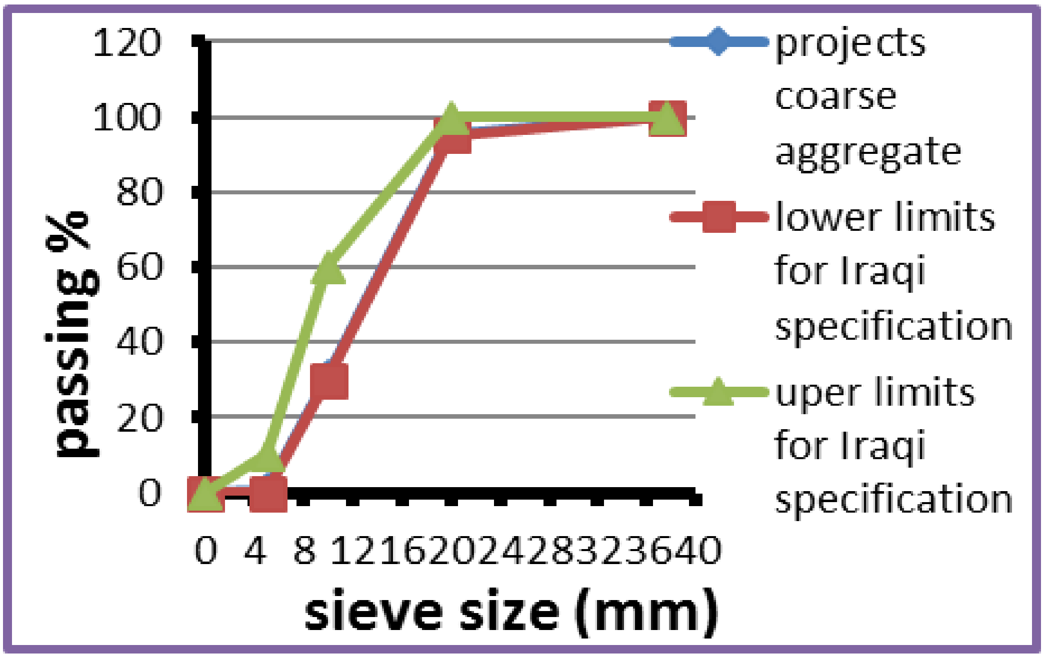

Figure 5: Grading of the coarse aggregate

4.3.4 Water

The process of mixing of concrete and curing was through potable water of Diyala

4.3.5 Steel Reinforcing Bars

Reinforcing steel bars properties was tested according to ASTM A615 [12]. The results are shown in Table 4.

Table 4 Reinforcing steel bars properties according to ASTM A615 [10].

Elongation at ultimate stress (%)	Ultimate stress (MPa)	Yield stress (MPa)	Bar area (mm^2)	Bar diameter (mm)
8	790	514	201	16 deformed
7	708	446	113	12 deformed
8	684	420	78.5	10 deformed

4.3.6 Carbon Fiber

Consist of two parts: Carbon Fiber sheet (SikaWrap**)**, and Impregnating Resin (Sikadur). The SikaWrap (230C) is an externally applied system with resin matrix (Sikadur 330) for strengthening of tested beams. The properties of carbon fiber and epoxy are shown below in Table 5 and 6 respectively.

Table 5 Properties of CFRP SikaWrap 230C (*).

Fiber type	Mid strength carbon fibers
Fiber orientation	0° (unidirectional).
Areal weight	230 ± 10 g/m^2
Fabric design thickness	0.131 mm (based on fiber content)
Fiber density	1.76 g/cm^3
Tensile strength of fibers	4300 MPa
Tensile E – modulus of fibers	238 GPa
Elongation at break	1.8 %
Fabric length/roll	$\geq$ 45.7 m
Fabric width	500 mm

(*) Provided by the manufacturer.

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Table 6 Properties of Impregnating Resin (Sikadur330) (*).

Appearance	**Comp. A: white** **Comp. B: grey**
Density	1.30 ± 0.1 kg/l (mixed)(at + 35°C)
Mixing ratio	A : B = 4 : 1 by weight
Open time	30 min (at + 35°C)
Viscosity	Pasty, not flowable
Application temperature	+ 10°C to + 35°C (ambient and substrate)
Tensile strength	30 MPa (cured 7 days at +23°C)
FlexuralE-modulus	3800 MPa (cured 7 days at +23°C)
Tensile E-modulus	4500 MPa (cured 7 days at +23°C)
Elongationat break	0.9% (7 days at +23°C)

(*) Provided by the manufacturer.

4.3.61Concrete Surface Preparations

The concrete surface was properly prepared to avoid the bond failure between the adhesive-concrete interface. The surface must be free from any material which cause bond failure such as dust. The surface was roughened and cleaned by acetone as shown in the Figure 6. The surface preparation was conforming to ACI Committee 440 [13]. The two part of adhesive was mixed according to the manufacturer recommendation that the two part (gray and white) mixed together with the ratio of (1:4) for a minimum (3 minutes) with a mixing rod that attached to the slow speed electrical drill (maximum 600 rpm) up to the material becomes smooth in consistency and a uniform grey color. Then poured the whole mixed adhesive into another clean container and mixing for a second time at low speed for (1 more minute) to maintain a minimal air entrapment. Then applied the adhesive to the tension face of RC beam by using spoon putty between the lines that laid out for carbon fiber reinforced polymer location. Care was taken in order to guarantee that the uniform coat of the adhesive was laid out. After that carbon fiber reinforced polymer was applied to the RC beam. The fabric was pushed into the adhesive in order to ensure a uniform application.

A- grinding of surface

B- cleaning of surface

C- application of acetone

Figure 6 :Concrete surface preparation

4.4Concrete Mixing And Placing

4.4.1 Concrete Mixing

A horizontal rotary mixer was used for mixing of concrete the with capacity of ($0.1m^3$), this mixer is available in the laboratory of material construction at College of Engineering(Diyala University). The concrete mix proportions is listed in Table 7.

Table 7 Mixing Materials for Concrete.

Water(Kg/ m^3)	**Gravel (Kg/ m^3)**	**Sand (Kg/ m^3)**	**Cement (Kg/ m^3)**
176	960	680	375
w/c =0.47	2.56	1.813	1

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The following tests were made:

1- Compressive strength (cubic and cylinders). According to BS EN 12390-3 [14] and ASTM C39 [15] respectively. The test of specimens are shown in Figure 7.

Figure 7 : Concrete Compressive Strength (Cubes and Cylinders)

2- Splitting tensile strength(cylinders). According to ASTM C496-96 [16]. The test of specimen is shown in Figure 8.

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Figure 8 : Splitting Tensile Strength Test

3- Modulus of rapture (prism). According to ASTM-C78 [17]. The test of specimen is shown in Figure 9.

Figure 9 : Modulus of Rupture Test

** All beam specimens were tested in a universal testing machine as shown in Figure 10.

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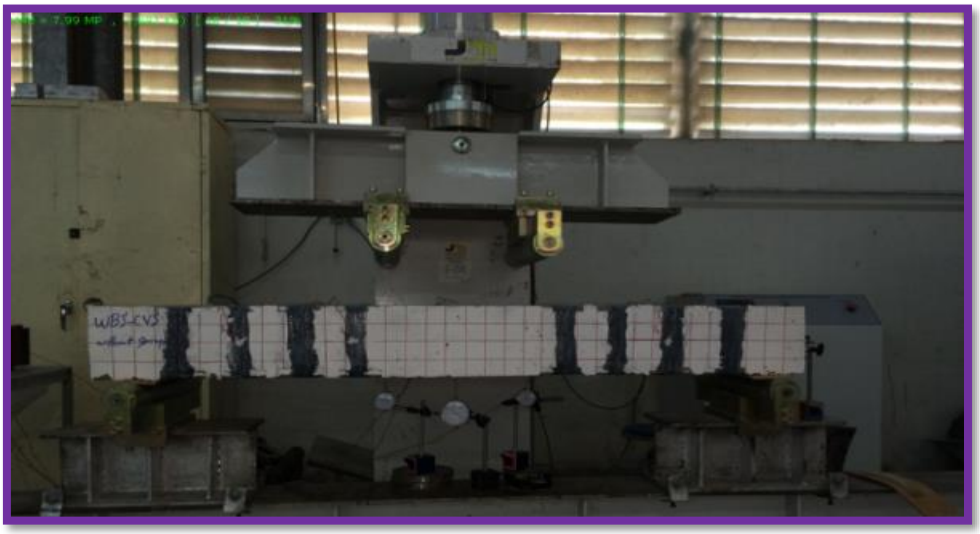
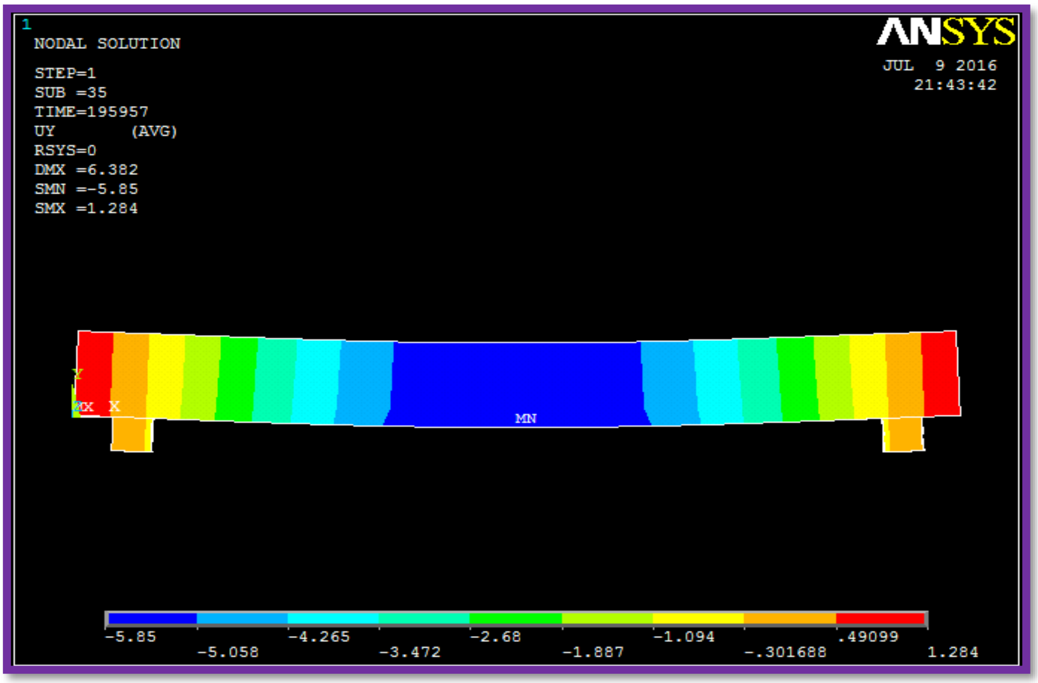


Figure 10 : load testing machine

5. Results and Discussions

5.1 Numerical analysis control beam (WBS-WOC)

This beam was modeled by (ANSYS 12) as control beam (without externally bonded CFRP). The ultimate load of this beam is equal to (196 kN) with maximum deflection equal to (6.38 mm), the type of failure of this beam is shear compression failure as shown in the Figure 11.



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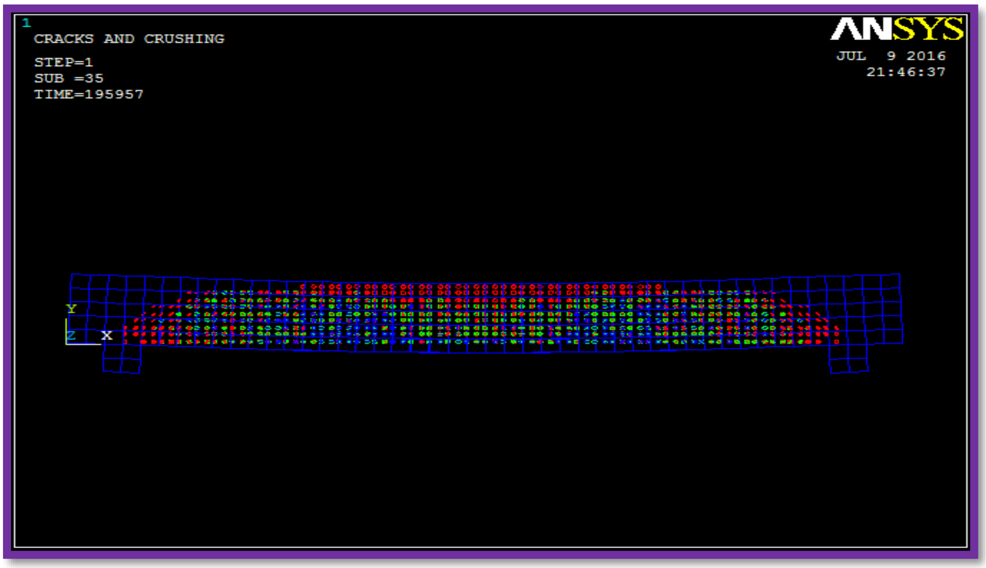
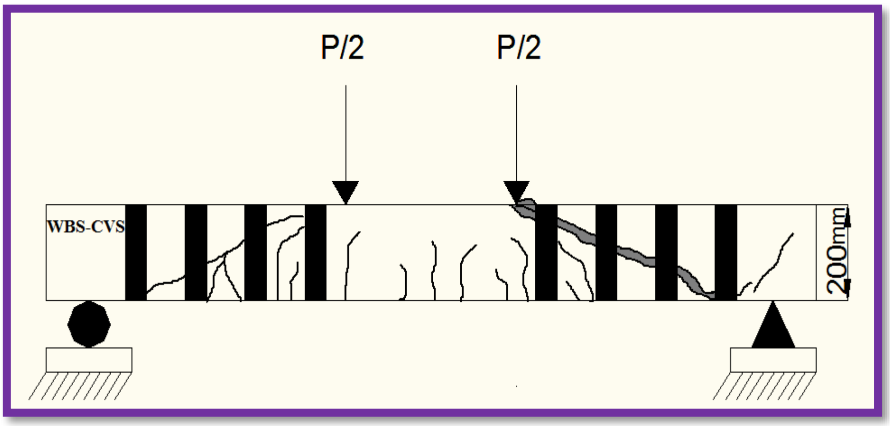


Figure 11: Failure of (WBS-WOC) beam

5.2 Strengthened Beam With CFRP (WBS-CVS)

This strengthened beam was tested by load increments of (20 kN). The CFRP was placed as vertical U-jacket, (i.e. CFRP in the flexural and shear zone and used as shear reinforcement) and without shear reinforcement just at supports and under the two point loads to avoid the concentration of stress at these points. This beam appeared to have a linear behavior up to the moment of cracking was reached, this behavior was continued but the stiffness of this beam was reduced with the load increment. When the reinforcement in the tension zone began to yield, flexural and shear cracks initiated in the beam, then the cracking sound was heard, which might be an indication of debonding failure of CFRP. The larger cracks reached approximately (80%) of the beam depth before the CFRP debonded directly under a large crack. The beam was continued to deflect with slight.
increase in the moment resistance up to the CFRP debonded as presented in the Figure 12. After this point the strains increased in the concrete and steel reinforcement, then the failure was travelled to the shear failure as shown in the Figure 13. The concrete strain was reduced as a result of the efficiency of the CFRP in the flexural and shear zone, the ultimate load of this beam equal to (210 kN). The strains of flexural reinforcement, concrete and CFRP are (0.0026 , -0.0038 and 0.0038 με) respectively, the ultimate load was increased by (7.14%) as compared with the control beam, the number of flexural and shear cracks were (4) and (7) respectively, minimum and maximum crack spacing of this beam (40 mm and 160 mm) respectively. This results means the possibility of using externally bonded CFRP sheet instead of using shear-reinforcement.



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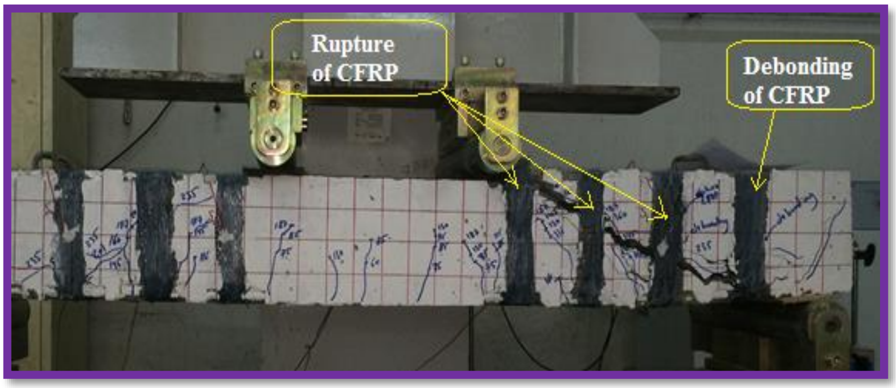

Figure 12: Rupturing and debonding of CFRP for (WBS-CVS)

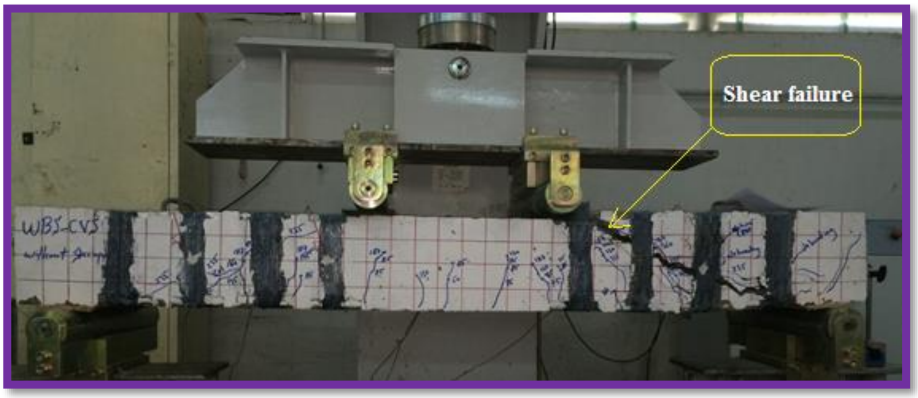

Figure 13: Failure of concrete for (WBS-CVS)

5.3 Strengthened Beam With CFRP (WBS-CIS)

This strengthened beam was tested by load increments of (20 kN). The CFRP was placed as inclined U-jacket, (i.e. CFRP in flexural and shear zone and used as shear reinforcement) and without the shear reinforcement just at the supports and under the two point loads to avoid the concentration of the stress at these points. This beam appeared to have a linear behavior up to the moment of cracking was reached, this behavior was continued but the stiffness of this beam was reduced with the load increment. When the reinforcement in the tension zone began to yield, flexural and shear cracks initiated in the beam, then the cracking sound was heard, which might be an indication of debonding failure of CFRP. The larger cracks reached approximately (80%) of the beam depth before the CFRP debonded directly under a large crack. The beam was continued to deflect with slight increase in the moment resistance up to the CFRP debonded as presented in the Figure 14. After this point the strains increased in the concrete and steel reinforcement, then the failure was travelled to the shear failure as shown in the Figure 15. The strain of concrete was reduced due to the effectiveness of the CFRP in the flexural and shear zone, the ultimate load of this beam equal to (235 kN)). The strains of flexural reinforcement, concrete and CFRP are (0.0027 , -0.0019 and 0.0043 με) respectively, the ultimate load was increased by (19.9%) as compared with the control beam, the number of flexural and shear cracks were (6) and (11) respectively which was decreased by four cracks as compared with the control beam, minimum and maximum crack spacing of this beam (30 mm and 175 mm) respectively.

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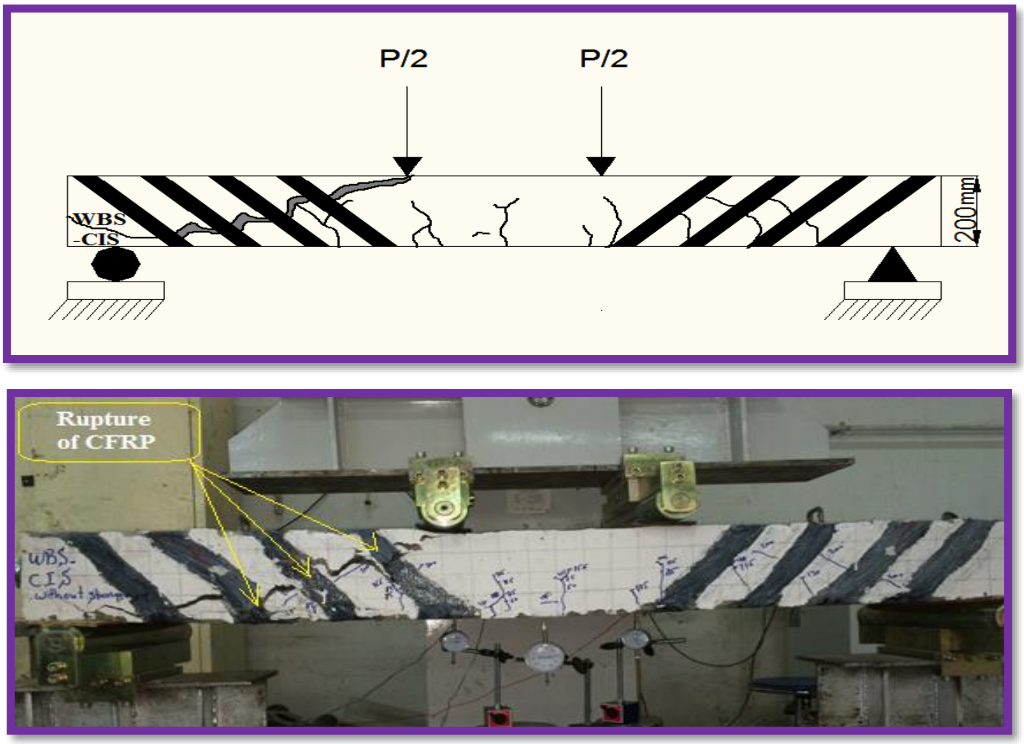

Figure 14: Rupture of CFRP for (WBS-CIS)

Figure 15: Failure of concrete for (WBS-CIS)

5.4 Beam With Shear Reinforcement (WBS)

This beam failure with experimental ultimate load (274 kN), the failure of this beam was shear compression failure as shown in the Figure 16. The strains of flexural reinforcement, shear reinforcement and concrete are (0.012, 0.0005 and -0.0029 με) respectively, with deflection equal to (-20.7 mm). The number of flexural cracks was (4), number of shear cracks (11) and minimum and maximum crack spacing of this beam was (20 mm and 125mm) respectively.

Figure 16: Failure of concrete for (WBS)

5.5 Load-Deflection Response for all beams

All the specimens were tested and load-mid-span, under loads and axial deflection responses of the specimens are presented in Figure 17 and Table 8 and 9. The ultimate load of the control beam (WBS-WOC) was (196 kN) with maximum deflection at mid-span (-6.38 mm), the ultimate load and deflection for the strengthened beam (WBS-CIS) was (235 kN) and (-11.54mm) respectively, the control beam with the internal shear reinforcement so the ultimate load for the control beam larger than the strengthened beams. The ultimate load and deflection for the strengthened beam (WBS-CVS) was (210 kN) and (-15.7mm) respectively, the beam (WBS-CIS) with load more than the load of (WBS-CVS) beam, and with less deflection.

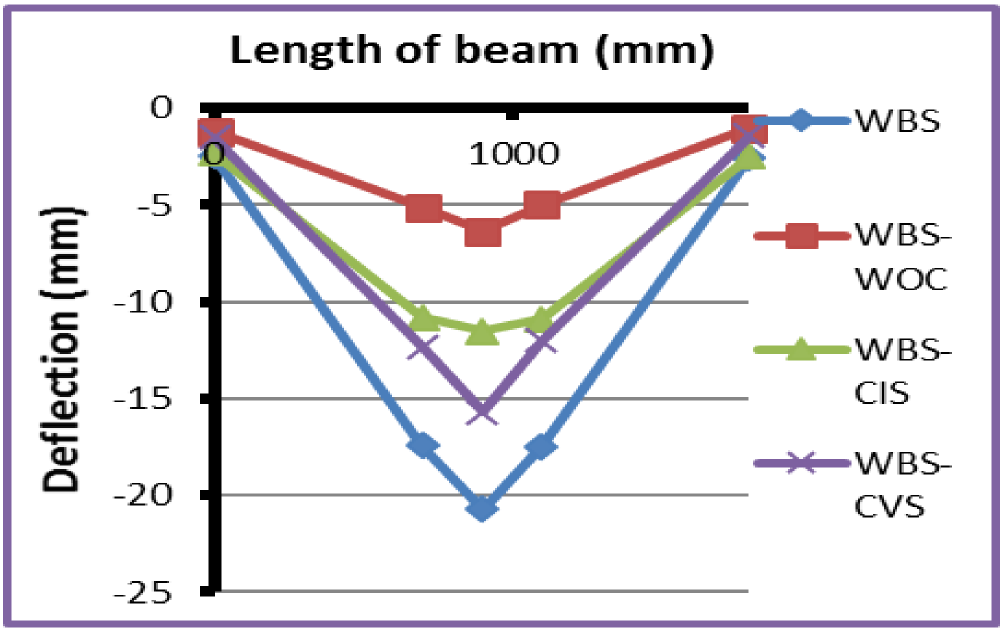

Figure 17 : Load-mid-span and axial deflection

Table 8 Experimental and theoretical load.

Type of beams	Theoretical load According to ACI 318M-14 (kN)	Exp. load (kN)	$P_{exp.}/P_{the.}$
WBS – CIS	205.7	235	1.14
WBS – CVS	205.7	210	1.02
WBS	196	274	1.39

Table 9 Experimental and theoretical deflection

Type of beams	Deflection at service load Δ_s (mm)					
	Measured Δ_s (mm) at		Predicted Δ_s (mm) at		% difference of Measured Δ_s at	% difference of Predicted Δ_s at
	mid-span	under load	mid-span	under load	mid-span	under load
WBS – CIS	-7.3	-7.23	-7.14	-7.10	-2.19	-1.80
WBS – CVS	-10.9	-9.85	-7.14	-7.10	-34.50	-27.92
WBS	-8	-6.91	-6.67	-6.61	-16.63	-4.34

5.6 Crack development of beams

The control beam have a large number of cracks, which started between two point load the developed to flexural-shear cracks and only shear cracks. The strengthened beam (WBS-CVS) and (WBS-CIS) have a small number of cracks and

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crack-width. The load crack-width for all beams is shown in the Figure 18 and Table 10.

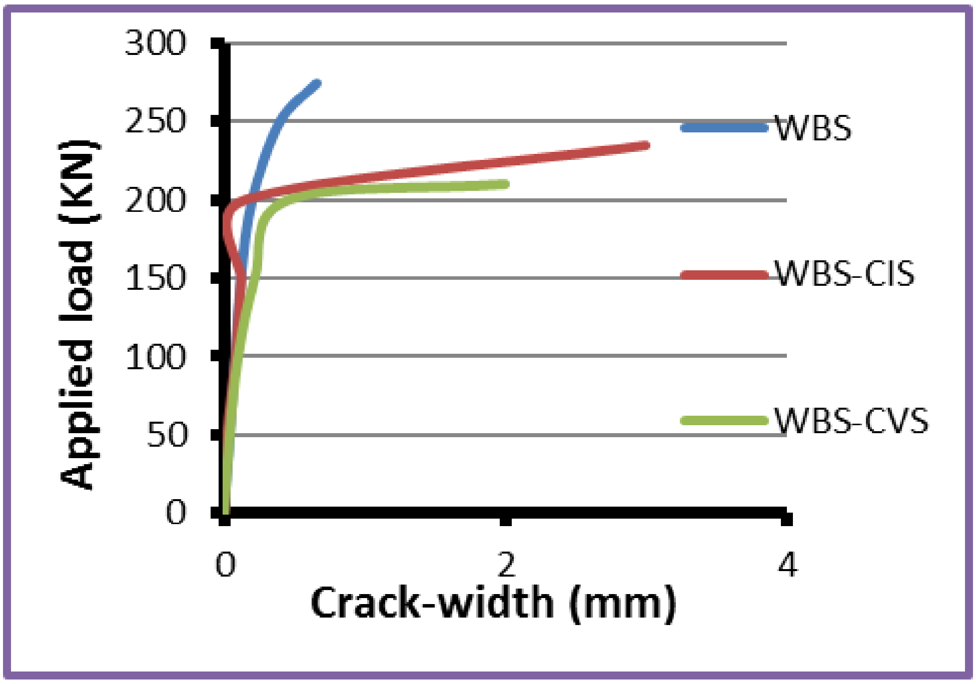


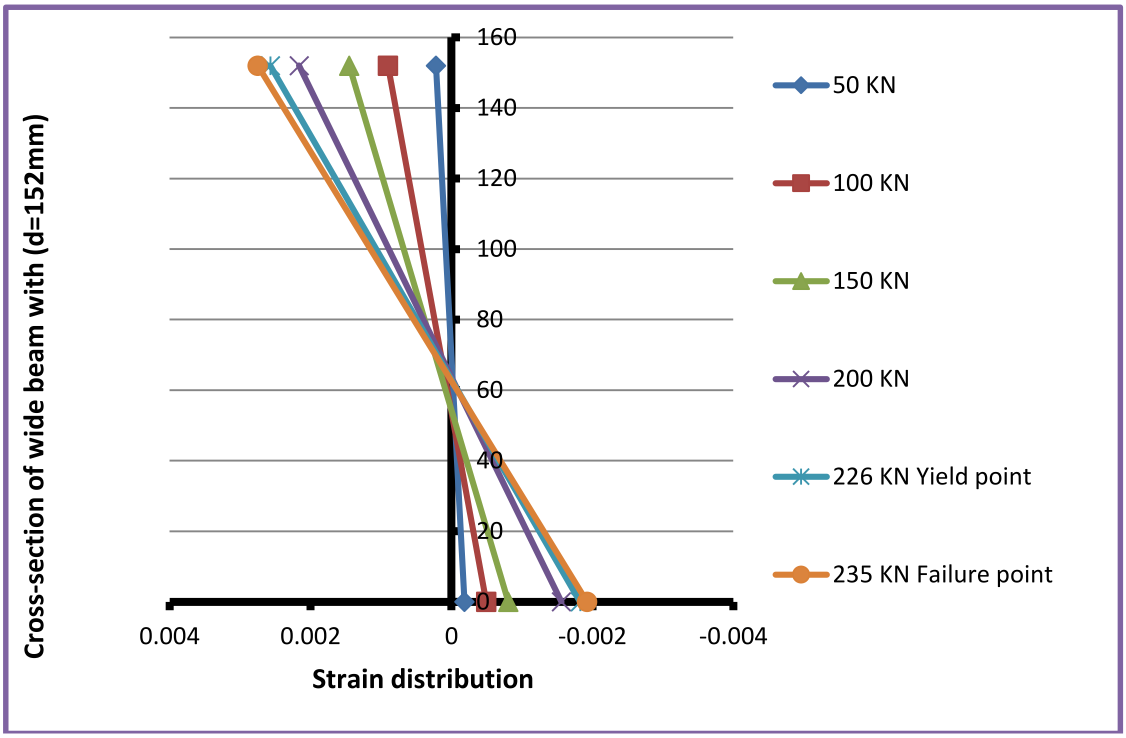
Figure 18 : Load-crack width curve

Table 10 Experimental and theoretical crack width.

Type of beams	Crack width (mm)	
	Experimental (At service load)	According to ACI 318M-14(At service load)
WBS – CIS	0.12	0.33
WBS – CVS	0.22	0.33
WBS	0.14	0.334

5.7 Strain profile for steel and concrete of Wide RC Beams

The strain in steel reinforcement and concrete for beam (WBS-WOC) was very large as compared with the strengthened beam due to effectiveness of CFRP and differences of the ultimate load of the control and strengthened beams. The strain profile of all tested beams are shown in the Figures 19, 20 and 21.



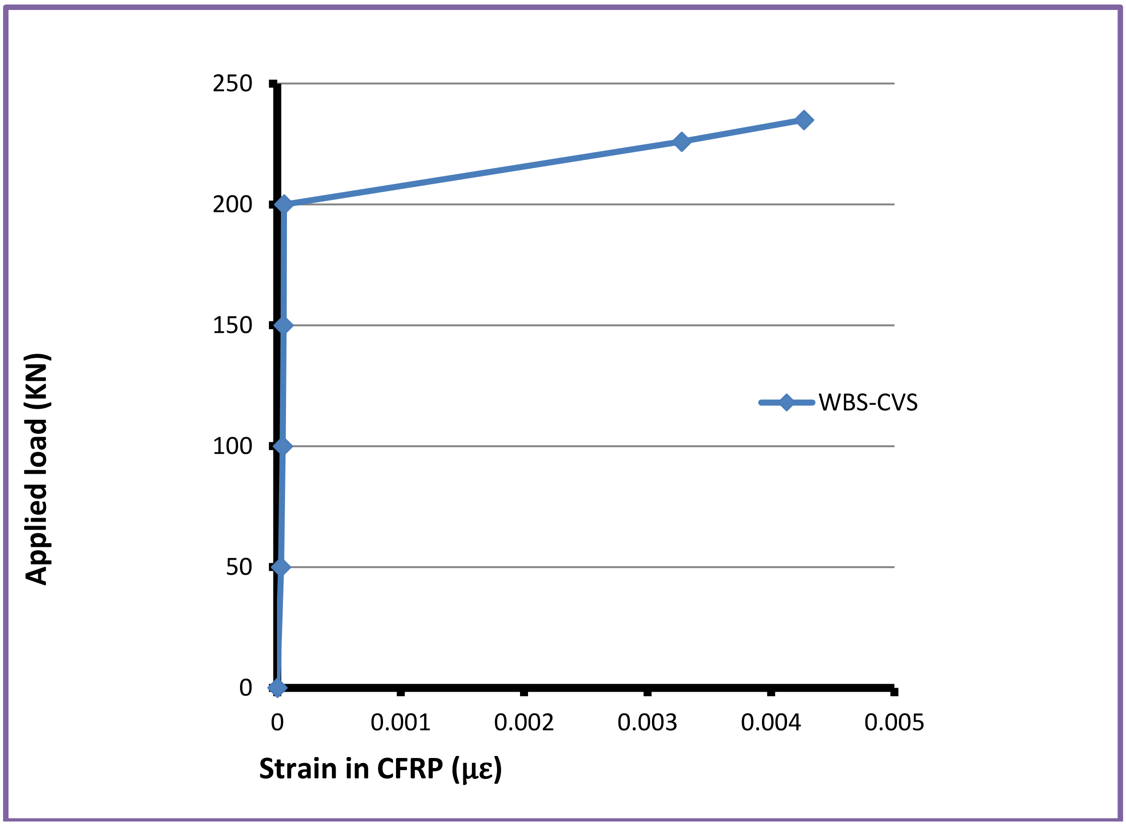
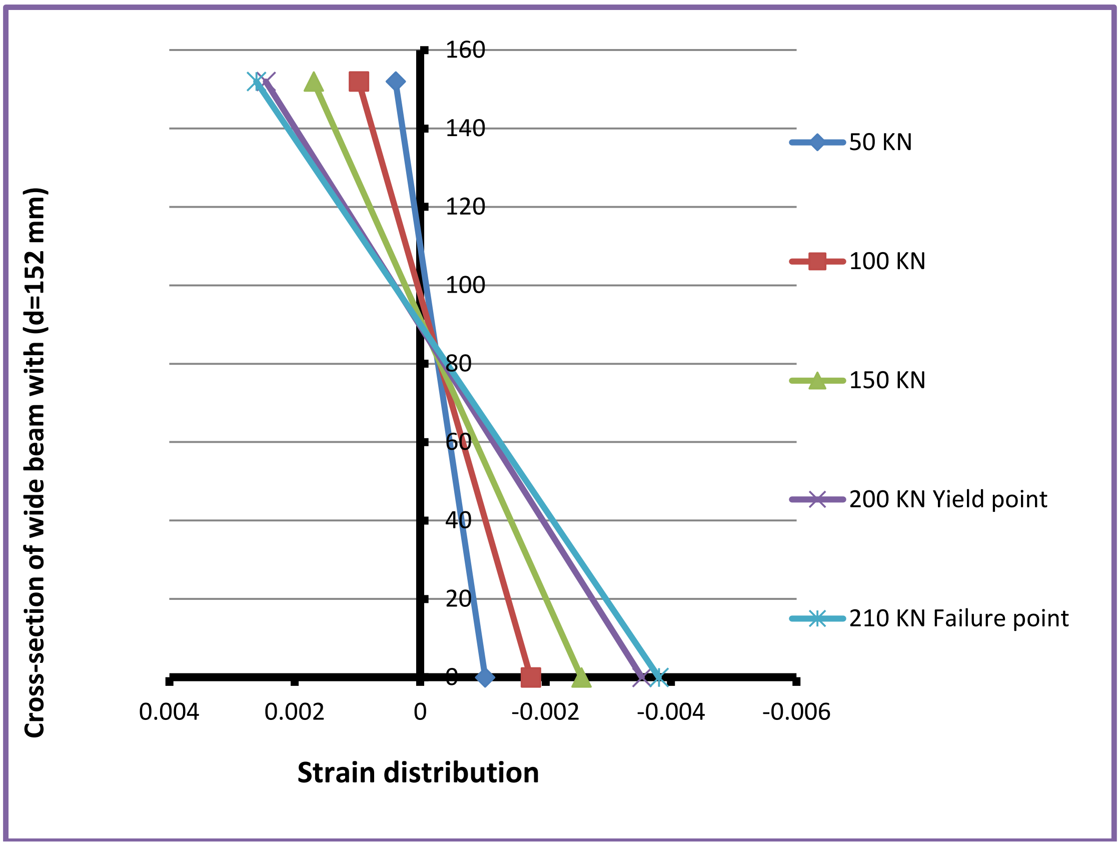


Figure 19: Strain profile and load CFRP strain of (WBS-CIS) beam



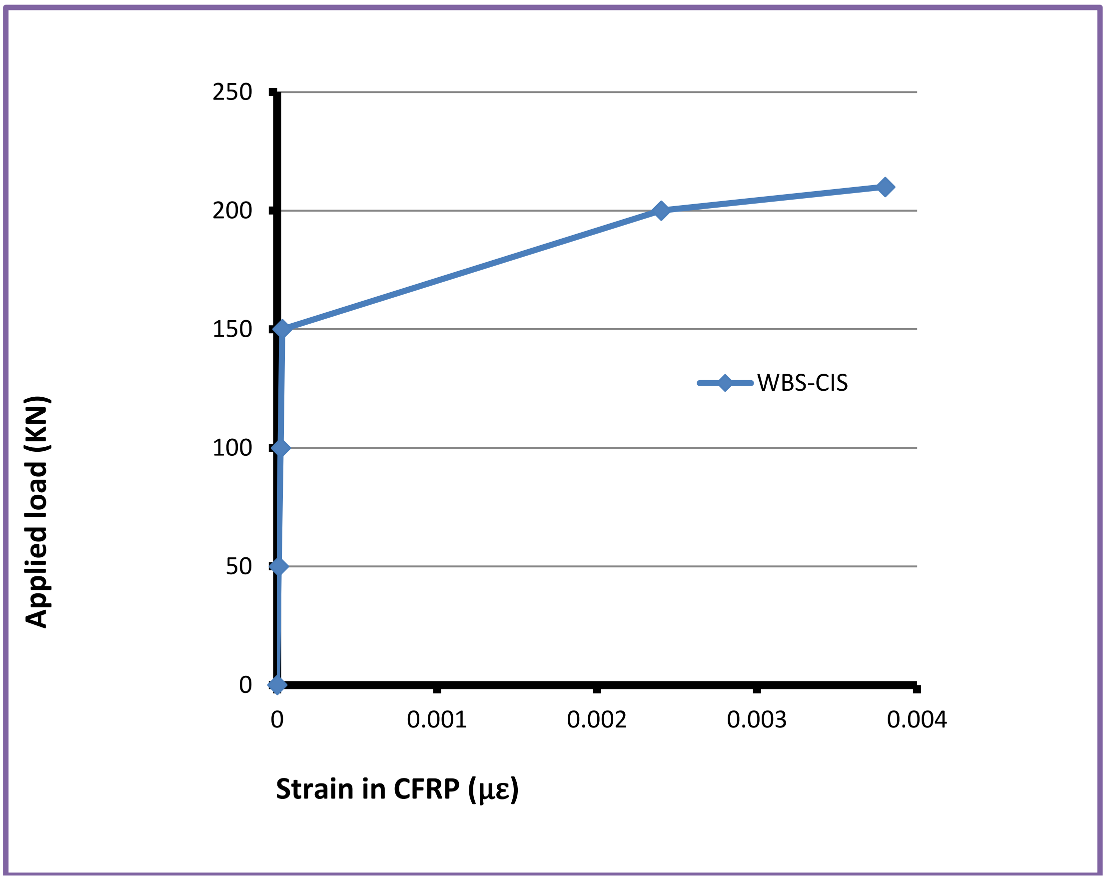


Figure 20: Strain profile and load CFRP strain of (WBS-CVS) beam

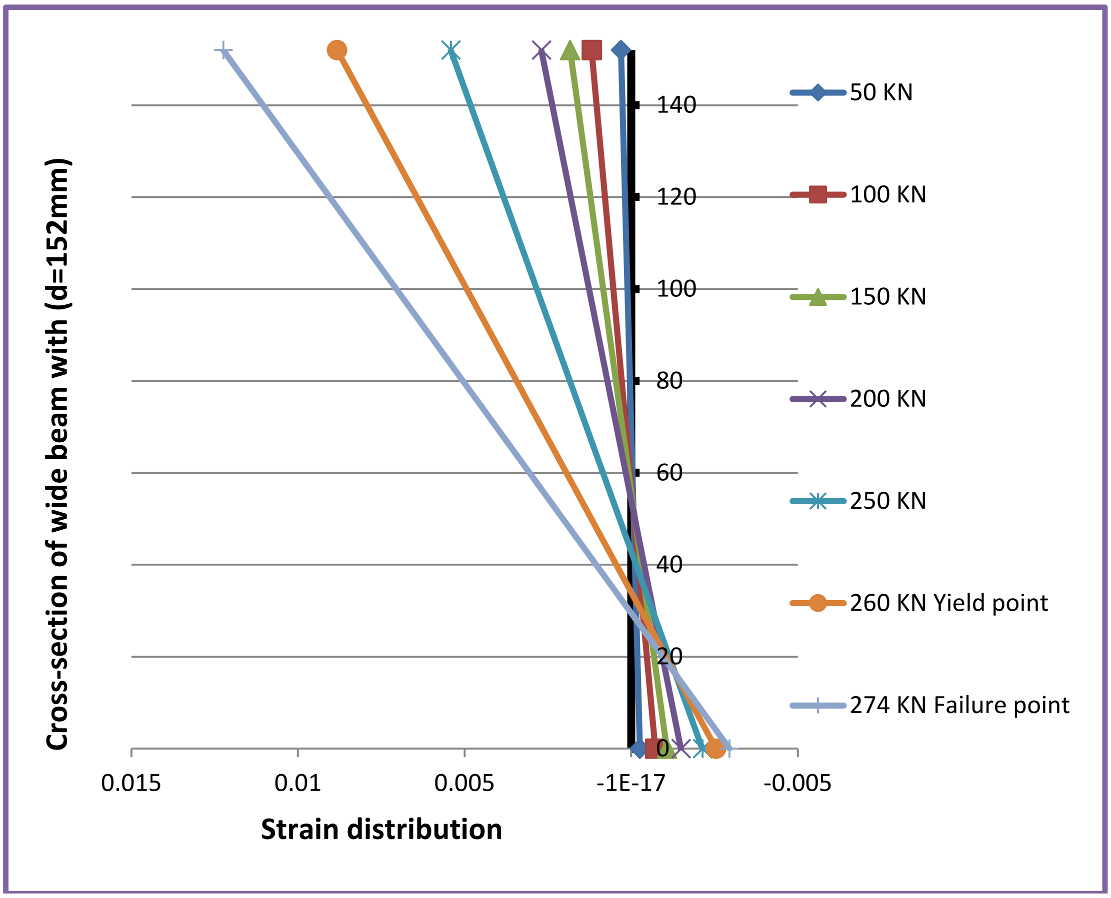


Figure 21: Strain profile and load CFRP strain of (WBS) beam

6.Conclusions

The following conclusions were obtained from the present study :

1. CFRP sheets can provide increase in strength and stiffness of beams when bonded to the web and tension face.
2- The results showed an increasing in ultimate load for beam (WBS) by (39.8%) as compared with the control beam.
3- The strengthening of beam with inclined externally bonded CFRP without stirrups having an increase in ultimate load as compared to the vertical externally bonded CFRP, because the inclined externally bonded CFRP provide a good confinement of concrete and prevent the propagation of the cracks at the first cracking stage.
4- The results showed an increasing in ultimate load for inclined and vertical CFRP by (19.9%) and (7.14%) respectively as compared with the control beam.
5- The deflection was decreased in the beam with inclined CFRP (WBS-CIS) by (36%) as compared with the beam with vertical CFRP (WBS-CVS).
6- The strain of concrete of the beam (WBS-CIS) was equal to (-0.0019), while the strain of concrete of the beam (WBS-CVS) was equal to (-0.0038) this is due to the effectiveness of inclined CFRP in the confinement of the concrete as compared with the vertical CFRP.

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