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FLEXURAL STRENGTHENING OF REINFORCED CONCRETE WIDE BEAMS WITH DIFFERENT WIDTH OF CFRP

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ABSTRACT: - Reinforced concrete wide beams (WBS) have been used in structural buildings to reduce floor heights, reinforcement congestion and facilitate the run of services under the floor. This paper presents the test results of four full-scale simply supported wide RC beams of (30 MPa) concrete strength under four-point bending up to failure in which their flexural behavior was studied. One of these was un-strengthened with carbon fiber reinforced polymer sheets (CFRPs), the three other beams were strengthened by using externally (CFRPs) bonded with epoxy with deferent width in flexural zone: beam strengthened with (30%) of cross-section width of beam, beam with (60%b) and beam strengthened with (100%b), The performances of the tested beams were measured as deflection, crack patterns, ultimate load, steel and concrete strains, and modes of failure. All beams with the same dimensions, reinforcement ratio and designed as under reinforced concrete (flexural failure). The test results showed that the strengthened beam with (60%b) provided the best flexural capacity as compared with the other strengthened beams. This beam increasing flexural capacity up to (29%) as compared with the control beam.

***Key words**: wide beam, beams strengthened, carbon fiber, flexural-shear crack.*

1- INTRODUCTION:

In design of structural building, modern architectural constrictions are pushing the designer to provide more floor clear height and longer clear span at a reasonable cost, which can be attained through the use of wide RC beams or flat plate slabs. 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 [1–7]. 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, Improved 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 any structural member exhibition to failure for the reasons mentioned also this structural members have small nominal flexural and shear capacity due to small effective depth if compared with the normal beams so one of the treatment methods are using CFRP to Compensate for the lack.

1-1 MECHANICAL PROPERTIES OF FRP:

Three types of FRP, namely CFRP, AFRP, and 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. 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.

1-2 DUCTILITY:

Ductility is a desirable property for structural members because it allows the redistribution of stresses and provides caution of impending failure. The design of FRP composite as external reinforcement in flexural zone is fairly rational forward. It is depended on Bernoulli's hypothesis of (strain compatibility) that plane section remain plane; which needs perfect bonding between concrete and FRP, and the capability of the concrete substrate to transfer shear stresses to the FRP laminate. After yielding of the steel reinforcement, the RC beam can still carry the increasing in loads, even at a lower rate of deflections than prior to yielding of steel, and the FRP composite maintains elastic behavior up to failure occurs suddenly. Failure is precipitated as brittle failure such as FRP rupturing, de-bonding, or concrete crushing.

2- LITERATURE REVIEW:

Bing and Qian (2011): this study shows that the use of FRP in repairing of damaged RC beam_ column joints can reinstate the performance of these damaged joints with relative ease. This repairing process by FRP suggesting that it is a cost_ effective alternative way to complete destruction and replacement.

Rajeh A. Al-Zaid et al. (2014) : Studied the behavior of damaged wide RC beams and strengthened by CFRP. Eight wide RC beams were tested under two point load one of these beams was unstrengthened and all other specimens strengthened with two deferent widths of CFRP(240mm)and (480mm). Prior to strengthening the specimens were exposed to preloading (30%-95%) of their flexural capacity. They determined that the undamaged strengthened specimens showed ultimate capacity (8%) more than pre-damaged strengthened beams

Ahmed K. El-Sayed et al. (2014): Studied the behavior of strengthened wide RC beams by CFRP plates. Their experimental program involved of five full-scale wide RC shallow beams: three of these specimens were tested under sustained load (to a period 600 days) and other two specimens tested under static loading. They concluded that the strengthened beams with CFRP plates showed clear improvements in each of (short term deflection and crack width) as compared with the unstrengthened specimen. However the strengthened specimens did not demonstrate much progress in long term (deflection and crack width).

3-MATERIALS&METHOD:

3-1 GENERAL:

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

3-2 EXPERIMENTALPROGRAM:

The experimental program involves of testing four wide RC beams. All beams tested as simply supported and have the same flexural reinforcement and dimensions. All beams are designed as under reinforced (flexural failure), the dimensions are: overall length of 2000 mm, a height of 250 mm a width of 550 mm and as shown in Figure (1).

3-3MATERIALS:

3-3-1CEMENT:

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

3-3-2.FINE AGGREGATE:

Natural sand (AL-Ukhaidher) with a maximum size (4.75mm) is used through this work. The test of sieve analysis according to the Iraqi specifications 4/1984 (9). The test results are shown in table (2) and fig. (2) respectively.

3-3-3COARSE AGGREGATE:

Crushed aggregate with maximum size (19 mm) from AL-Niba'ee 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 (9). The test results are shown in table (3) and fig. (3) respectively.

3-3-4 Water:

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

3-3-5 Steel Reinforcing Bars:

Reinforcing steel bars properties was tested according to ASTM A615 (10) as in table (4).

3-3-6 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.

3-3-6-1 Concrete surface preparation:

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 (4). The surface preparation was conforming to ACI Committee 440 (11).

3-4:Concrete Mixing andPlacing:

3-4-1Concrete Mixer:

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

The following tests were made:.

1- Compressive strength (cubic and cylinders). According to ASTM C39 [12]. The test of specimens are shown in fig. (5).

2- Splitting tensile strength(cylinders). According to ASTM C496-96 [13]. The test of specimen is shown in fig. (6).

3- modulus of rapture (prism). According to ASTM-C78 [14]. The test of specimen is shown in fig. (7).

** All beams were tested in a (universal testing machine) as shown in fig.(8).

4- RESULTS AND DISCUSSIONS:

4-1 General:

In the current study, four wide RC beams are tested. All these beams with the same dimensions and steel area, but with different strengthening width in flexural zone (WBF = control beam), (WBF_1= strengthened beam with CFRP 30%b), (WBF_2= strengthened beam with CFRP 60%b), and (WBF_3= strengthened beam with CFRP 100%b). In order to study their ultimate load, crack width, deflection and strain of concrete and steel reinforcement.

4-2 Load-Deflection curve of Wide RC Beams:
The deflection was recorded for every load-increment for all beams, beam (WBF) have a small load as compared with other strengthened beams. The deflection was recorded at mid-span, under two point load, later and axial by (DIAL GAUGES). The behavior of beam (WBF) was different from the other beams, it was failed at load (330 kN) with mid-span deflection (-32.3 mm) and ductility ratio (1.125). The strengthened beams have approximately the same behavior, but each beam different from other in ultimate load this is due to effect of CFRP width. The ultimate load of beam (WBF_1 = 412kN) with mid-span deflection (-33.2 mm) and ductility ratio (1.08), ultimate load of beam (WBF_2 = 425kN) with mid-span deflection (-32.4 mm) and ductility ratio (1.14), and the ultimate load of beam (WBF_3 = 433kN) with mid-span deflection (-30.6mm) and ductility ratio (1.13), the load-deflection for all beams is shown in fig.(9).

4-3 Load-crack width curve of Wide RC Beams:
The beam (WBF) have a large flexural crack width and number as compared with the strengthened beams, the strengthened beams have a small flexural crack width due to confinement of CFRP in flexural zone. The load- crack width for all beams is shown in fig.(10).

4-4 Strain profile for concrete and steel of Wide RC Beams:
The strain in each of concrete and steel was recorded by strain gauges, the strain in concrete and flexural reinforcement reduced in all strengthened beams due to effectiveness of CFRP width as compared with the control beam. The strain profile across beam depth for all beams are shown in the figures (11), (12),(13) and fig.(14).

4-5 Type of failure for tested beams:
All beams designed to have flexural failure. The type of failure of beam (WBF) was flexural failure, beam (WBF_1) have a flexural with de-bonding of CFRP, and the other strengthened beams (WBF_2) and (WBF_3) have a shear failure with rupture of CFRP, this change in failure from flexural to shear due to effective of CFRP (i.e. an increase in the flexural capacity in order to compensate for the value of the effective depth by CFRP). The mode of failure for all beams are shown in the figures (15), (16),(17) and fig.(18).

5- CONCLUSIONS:
The following conclusions were obtained from the present study:
1) The strength and stiffness of strengthened beams was increased by using CFRP to the tension face.
2) The mode of failure and magnitude of the increase are related to the width of the CFRP.
3) The strengthened beams by CFRP sheet was more ductile and give warning signs such as debonding or rupturing of CFRP before failure.
4) The ultimate load for strengthened beam (WBF_3) was increased by (31%).
5) The results of the current study show that CFRP sheet may use to increase the stiffness and strength against the load without causing catastrophic brittle failure associated with this strengthening system.

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Table (1): Typical mechanical properties of CFRP, AFRP, and GFRP Composites [8]

Unidirectional advanced composite materials	Fiber content (%by weight)	Density (kg/$\mathbf{m}^3$)	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

Table (2): Grading of fine aggregate

Total weight of fine aggregate = 3.122 Kg					
Sieve size	The remaining weight	The remaining weight %	Accumulated %	Passing %	Iraqi specification No. 45/1984 for Zone(2)
4.75 mm	0.218	6.996	6.996	93	90-100
2.7mm	0.3	9.628	16.624	83.4	75-100
1.18mm	0.448	14.377	31	69	55-90
600μm	0.676	21.694	52.695	47.31	35-59
300 μm	0.994	31.899	84.595	15.405	8-30
150 μm	0.458	14.698	99.293	0.707	0-10
Pan	0.022	0.706	100	zero	zero
	3.116				

Table (3): Grading of coarse aggregate

Total weight of coarse aggregate = 1.0259 Kg					
Sieve size (mm)	The remaining weight	The remaining weight %	Accumulated %	Passing %	Iraqi specification No. 45/1984 for Zone(2)
37.5	Zero	Zero	Zero	100	100
20	0.0455	4.441	4.441	95.559	95-100
10	0.66147	64.559	69	31	30-60
5	0.30973	30.23	99.23	0.771	0-10
Pan	0.0079	0.771	100	zero	zero
	1.0246				

Table (4): Reinforcing steel bars properties according to ASTM A615 [9]

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

Table (5): 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	≥ 45.7 m
Fabric width	500 mm

(*) Provided by the manufacturer.

Table (6):Sikadur330 (Impregnating Resin) (*)

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.

Table (7): Materials required

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

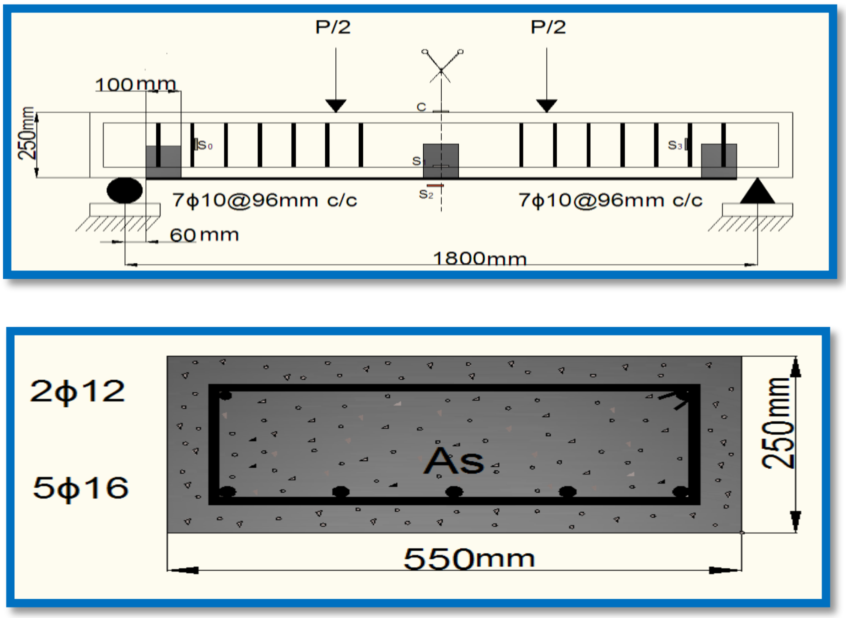


Figure (1): Typical dimensions and details of tested beams

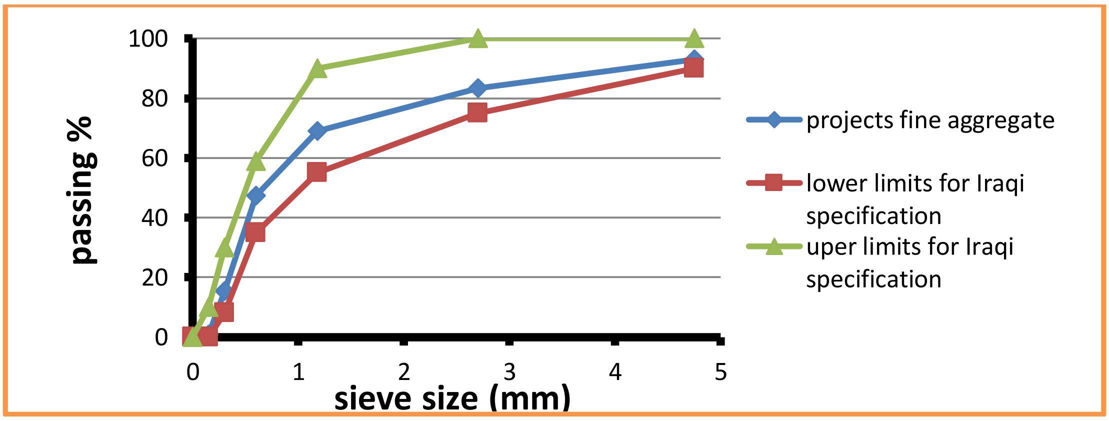


Fig. (2) : Grading of fine aggregate

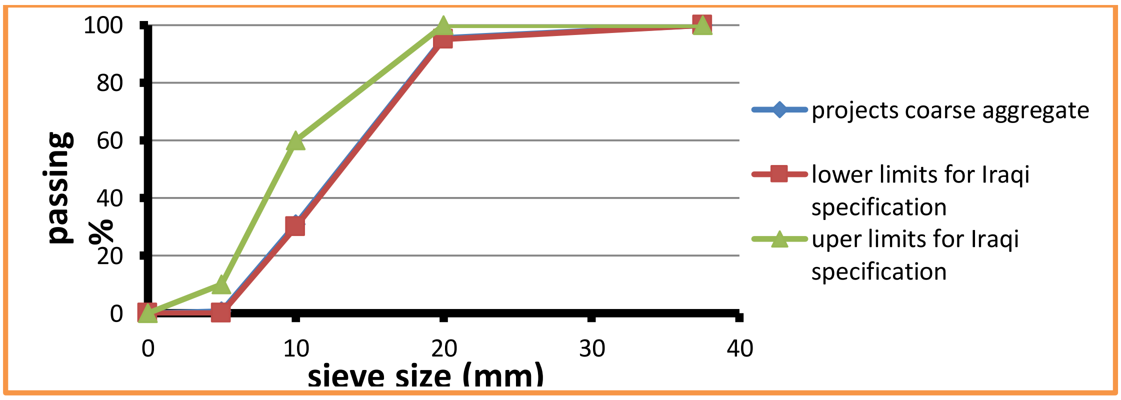


Fig.(3) :Grading of Coarse Aggregate

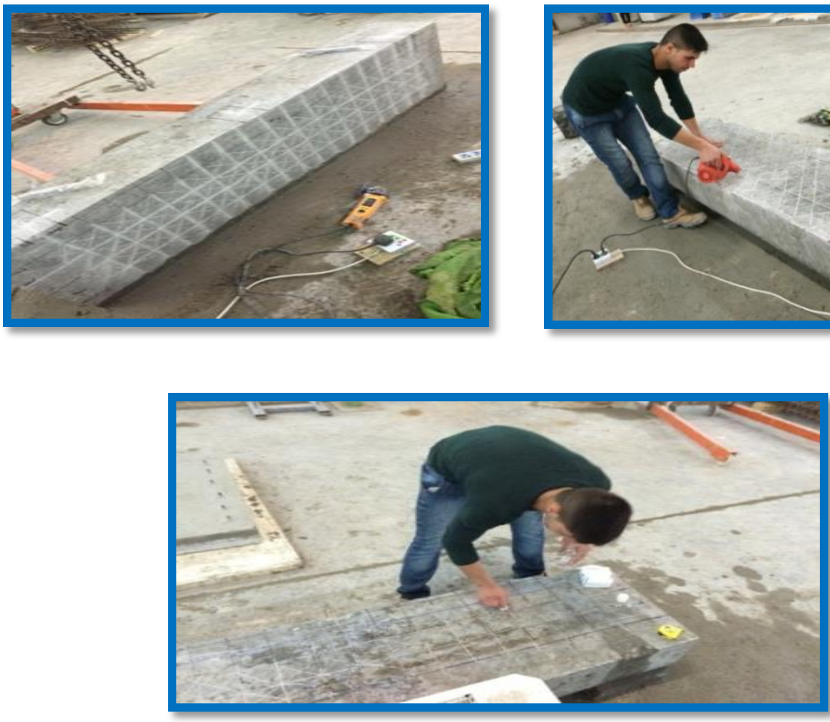


Fig. (4): Concrete surface preparation

Fig. (5): Concrete Compressive Strength (Cubic and Cylinders)

Fig. (6): Splitting Tensile Strength Test

Fig. (7): Modulus of Rupture Test

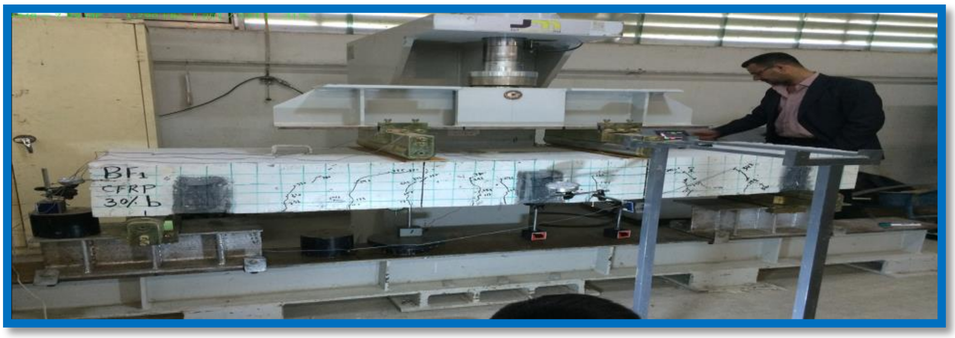


Figure (8): Load testing machine

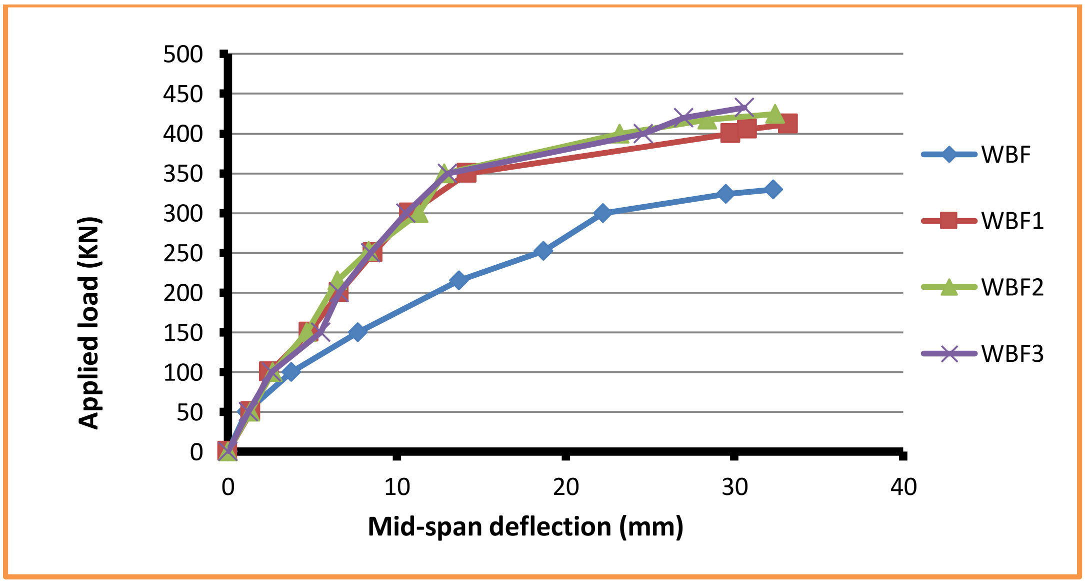


Figure (9): Load_ deflection curve for all tested beams.

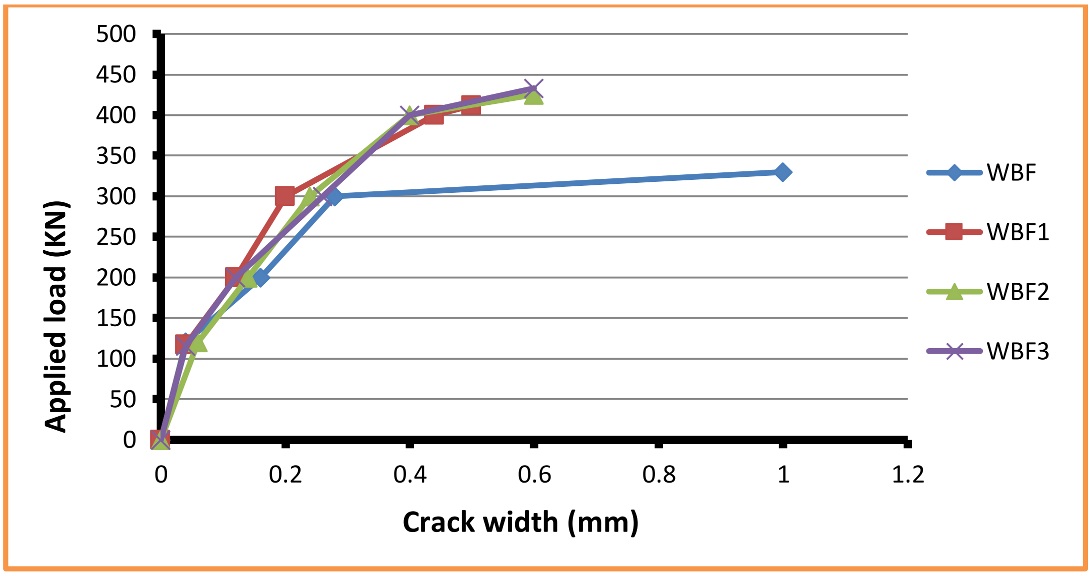


Figure (10): Load_ crack width curve for all tested beams.

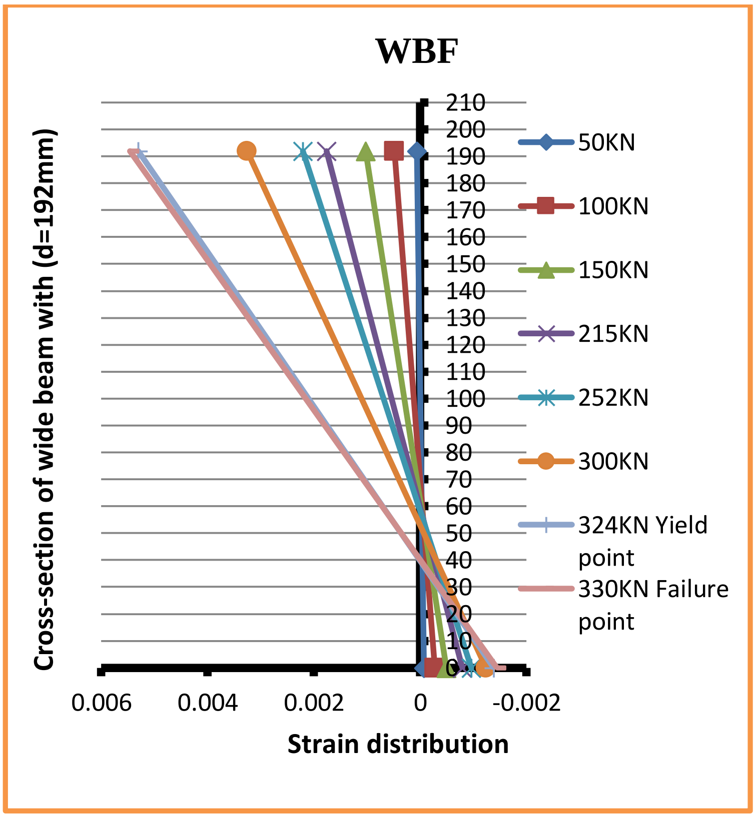


Figure (11): Strain profile for beam (WBF).

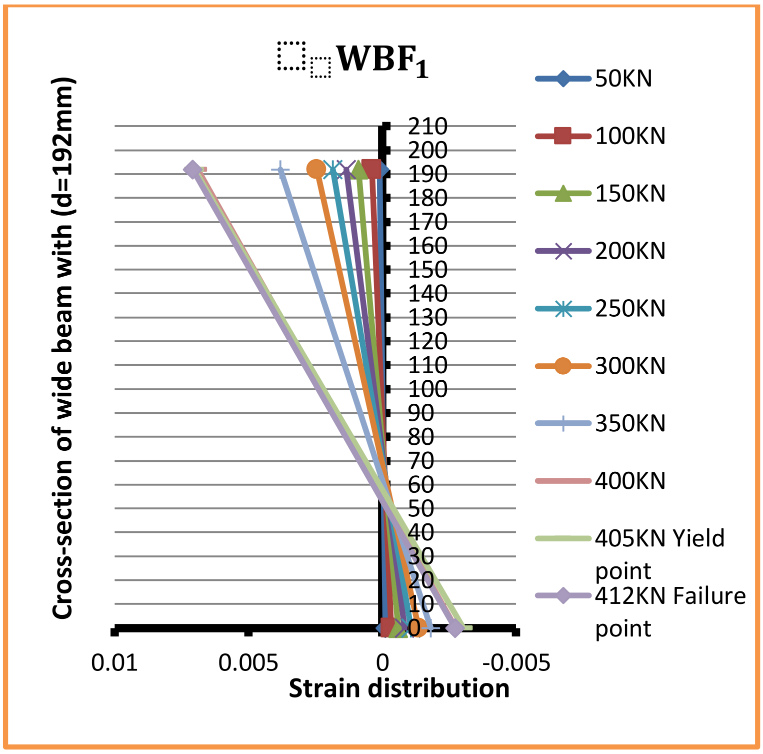


Figure (12): Strain profile for beam (WBF1).

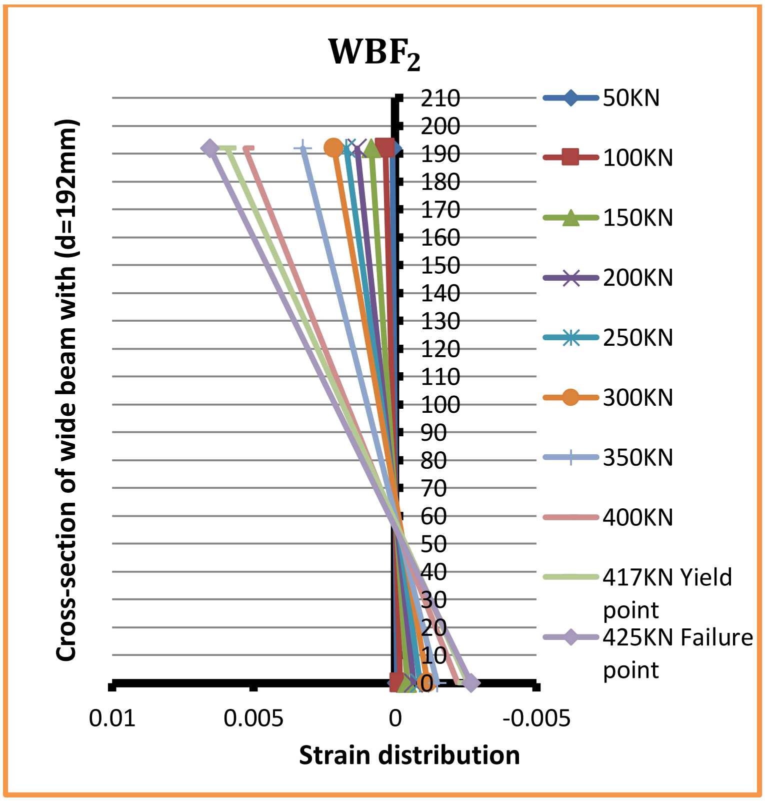


Figure (13): Strain profile for beam (WBF_2).

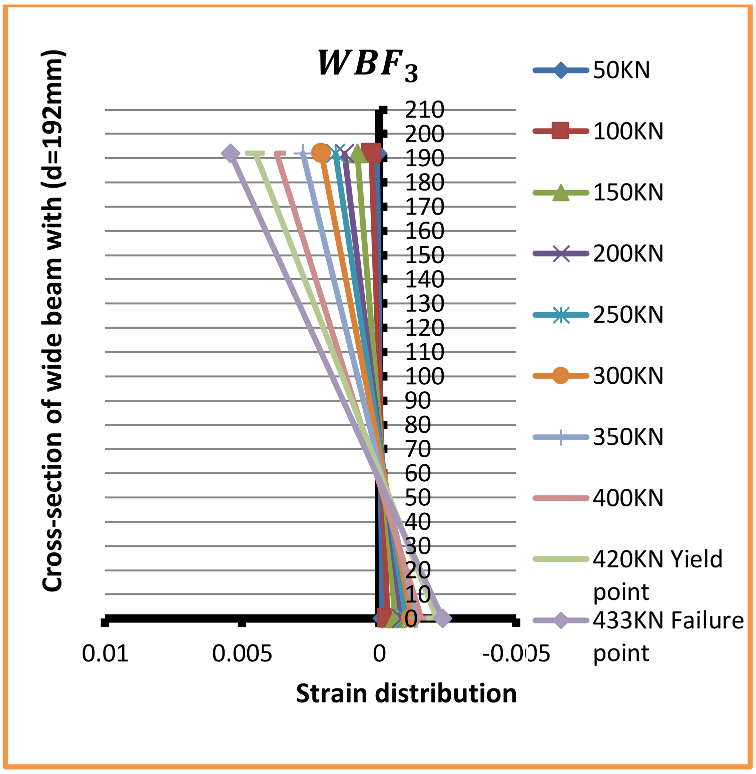


Figure (14): Strain profile for beam (WBF_3)

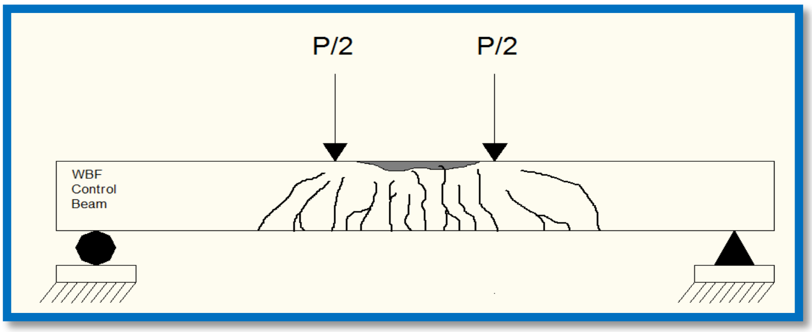


Figure (15): Failure of beam (WBF).

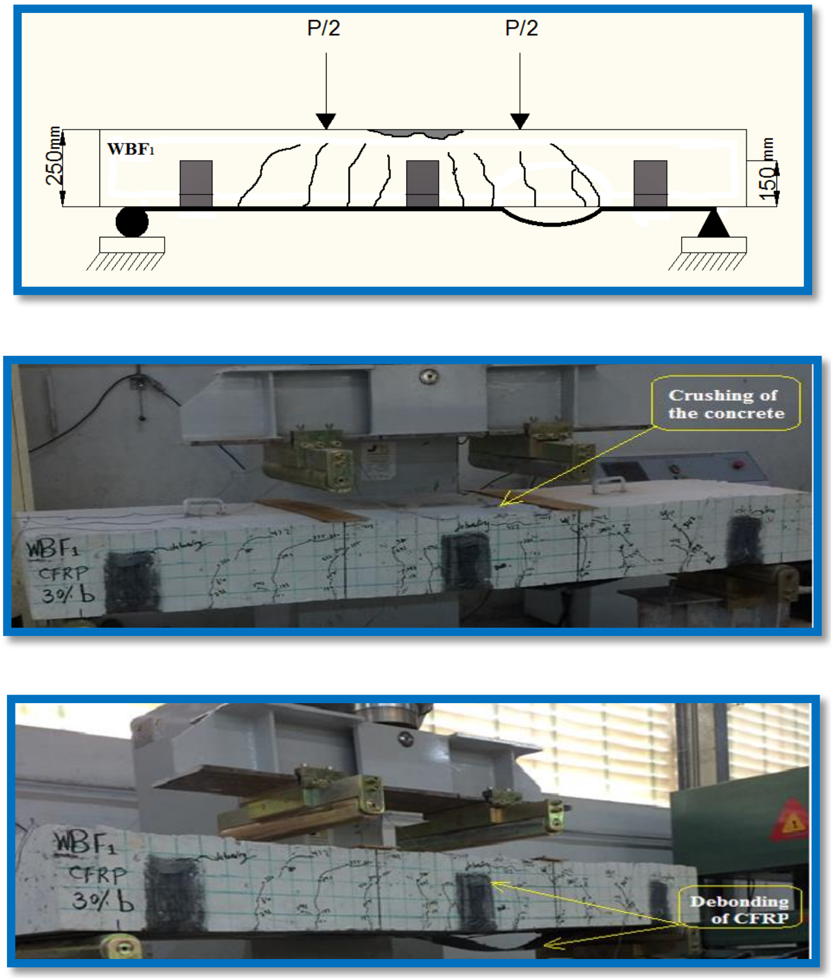


Figure (16): Failure of beam (WBF$_1$).

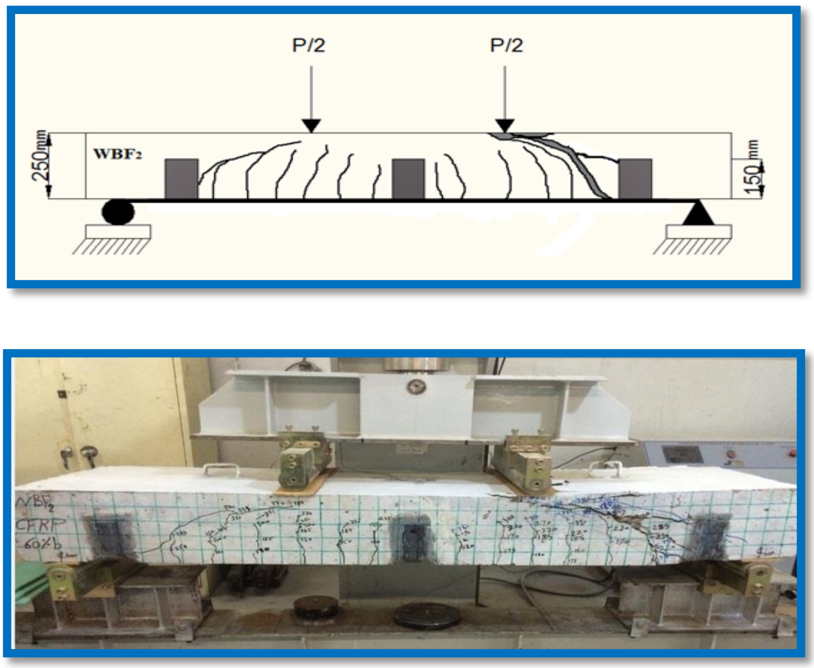
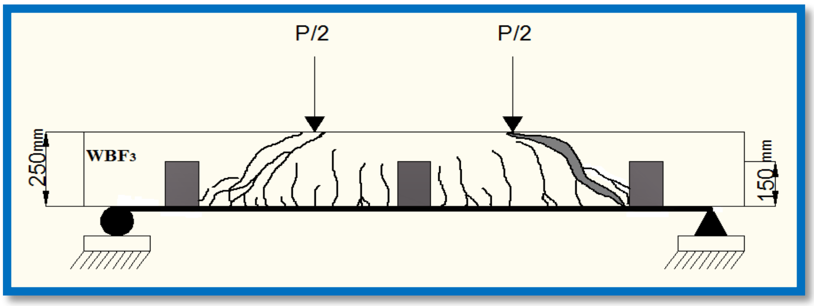
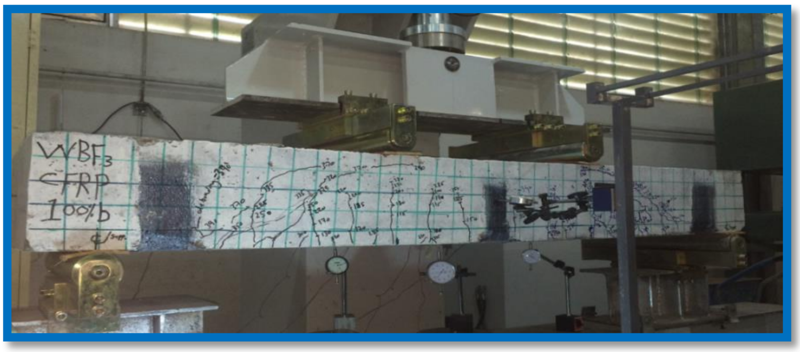


Figure (17): Failure of beam (WBF2).





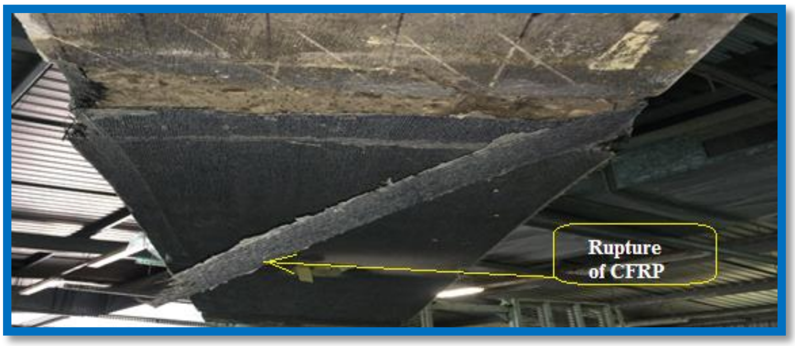


Figure (18): Failure of beam (WBF3).

تقوية الانحناء للعتبات المسلحة العريضة بأختلاف عرض الياف الكاربون البوليميرية

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الخلاصة

تم استخدام العتبات العريضة في المباني الهيكلية لتقليل ارتفاع الطابق, تزحم حديد التسليح, وتسهيل ادارة الخدمات تحت الطابق. يقدم هذا البحث نتائج الاختبار لاربعة عتبات عريضة النطاق وذات اسناد بسيط وذات مقاومة انضغاط (30ميجا باسكال) تحت اربع نقاط انحناء حتى الفشل التي تمت فيها دراسة سلوك الانحناء. احدى هذه العتبات كانت غير مقواة بالياف الكاربون البوليميرية, العتبات الثلاث الاخرى كانت مقواة بالياف الكاربون البوليميرية خارجية الربط بالايبوكسي باختلاف العرض في منطقة الانحناء : عتبة مقواة ب (30%) من عرض المقطع العرضي للعتبة, عتبة مقواة ب (60%) من عرض المقطع العرضي و عتبة مقواة ب (100%) من عرض المقطع العرضي, الاداء للعتبات المفحوصة تم قياسه عن طريق الهطول, انماط التشقق, الحمل الاعظم, انفعالات الحديد والخرسانة , وشكل الفشل. كل العتبات بنفس الابعاد, نسبة حديد التسليح, ومصممة للفشل تحت الخرسانة المسلحة (فشل الانحناء). بينت النتائج ان العتبة المقواة ب (60%) من عرض المقطع العرضي اعطت افضل سعة انحناء اذا ما قورنت بالعتبات الاخرى. هذه العتبة تزيد من سعة الانحناء بمقدار (29%) اذا ما قورنت مع عتبة السيطرة.