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Studying Shear Behavior of Self Compacting Concrete T- Beams Strengthened With Carbon Fiber Reinforced Polymer Sheets

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Abstract

The investigational program consists of testing ten simply supported T- beams molded by using Self Compacting Concrete (SCC) with two point loads.All beams have the same dimensions (1500 * 300 * 100) mm and flexural reinforcement. In this study three parameters were considered: shear span to effective depth ratio (a/d), the shape of CFRP sheets and distribution of CFRP sheets.The specimens were divided into two groups (A and B), Group A with (a/d) equal to 2.5 and group B with (a/d) equal to 3. Each group involves five beams strengthened by CFRP strips. In addition to eight Self Compacting Concrete (SCC) beams strengthened by Carbon Fiber Reinforced Polymer (CFRP), there were two reference beams. These reference beams had no strengthening by CFRP strips. All ten beams were made of SCC with f'c equal to 40 MPa.The experimental results indicated that the Strengthened with (U) shape on the web only get good resistance to the shear force with shear span (a/d = 2.5) more than Shear span (a/d = 3) when we applied two-point load on the spaceman

.**Keywords:** Self-Compact Concrete (S C C), Carbon Fiber Reinforced Polymer (C F R P), Shear Failure crack, Shear Force, T-Beam,

1. Introduction

It is well known that concrete is a very important building material because of most advantage specifications such as the high compressive strength and little tensile strength and a brittleness manner.

A concrete beam without any kind of reinforcement will crack and fail when subjected to a reasonable load, the failure happens suddenly in most cases.The most common and famous ways to reinforce the concrete structure is to using steel bars that are located in the structure before casting the concrete.Since a concrete structure typically has a very long life, it is not unusual for the demands and loads on the structure to change with time. The structure may have to transmit larger loads at a later date, or fulfill new standards.In dangerous cases a structure will have to be repaired due to an accident. Another reason can be found that errors have been made during the design or construction stage resulting need for strengthening the structure before usage. If any of these situations arise, we need to determine whether it is more economical to strengthen the present structure or to replace it.In case of a new structure, strengthening an existing is often more difficult, since the situations are already set. (1) Strengthening or repairing weakening infrastructure, such as bridges and buildings, has become a main challenge to construction activity all over the world. (2)

There are many different ways to repair or advance a concrete structure. There is often an opportunity to use a cast on technique to change the physical appearance of the structure and in that way given it to some different properties of strength and stiffness.However, this also means that the structure needs more space which is not always possible. (1)

There is an increasing need for repairing, strengthening, or retrofitting of concrete structures all over the world, and there can be many reasons for strengthening due to the frequently high cost of new construction, increased loads, alteration of structural system, and so on. The need exists for strengthening in flexure as well as in shear and torsion.On the other hand, reinforced concrete is a composite containing steel reinforcement, sand and gravel fillers, and a Portland cement matrix.FRP is selected as strengthening material because of its remaining tensile strength and stiffness compared to other composite materials. (3)

Also, externally bonded CFRP can be used to repair and strengthen damaged pre-stressed concrete girder bridges. (4) .FRP composites contain high strength fibers embedded in a polymer resin. The fibers are the main load carrying element and have a wide choice of strengths and stiffness with a linear stress-strain relationship up to failure.Fiber types typically used in the fabrication of FRP composites for construction are carbon, glass, and aramid. All these fibers are available commercially as continuous filaments. (5)The polymer matrix is used to bind the fibers composed and to transfer the forces between the fibers and to defend the fibers from external mechanical and environmental damage. The shear forces created between the fibers are limited to the properties of the matrix. Matrix is also a limited factor when applying forces perpendicular to the fibers. It is important that the matrix must have the capability to sustain higher strains than the fibers. (6) .FRP composites have become more general and accepted by designers, contractors, and proprietors due to mixtures of their unique characteristics. In addition, these materials are non-corrosive, non-magnetic, and generally resistant to chemicals. (5)

A contrast among Carbon FRP (CFRP), Aramid FRP (AFRP), and Glass FRP (GFRP) strips (based on fiber area only), and reinforcing steel in terms of stress-strain relationship is shown in Figure. (1-1a), and another comparison between fibers and FRP and matrix in Figure. (1-1b). (7).

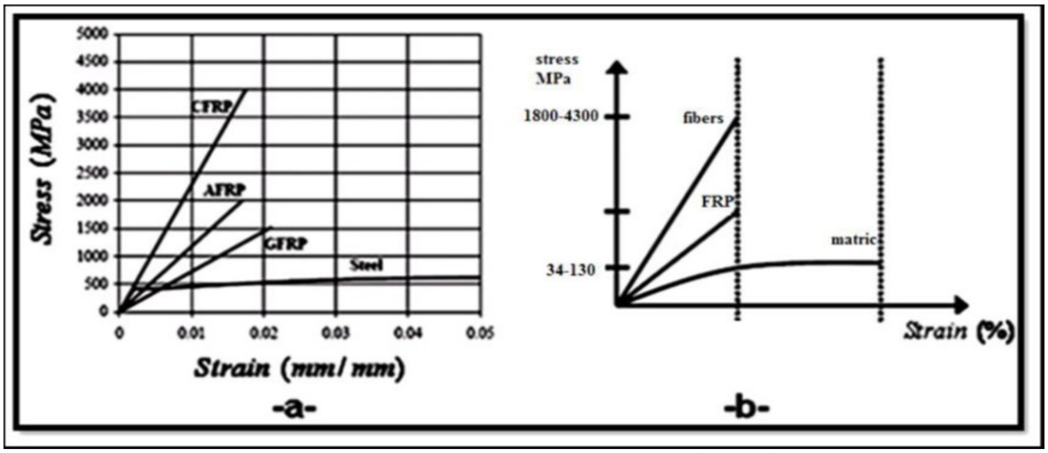

Figure 1. A comparison in stress-strain relationship of (7)
a - CFRP, AFRP and GFRP Sheets and Reinforcing Steel
b- Fibers, FRP and matrix

Fiber Materials:
Some materials exist for fibers glass and reinforced carbon. The properties of strengtheningmaterial at civil engineering near of 95% refer to forcarbon fibers (1) .Figure 1.2 concludes a typical response uni-axial fiber waste materials and steel. HM and HS contractions are high modulus and high strength separately. And also we have to knee that the fiber materialtakes a linear elastic conduct until failure which is brittle.

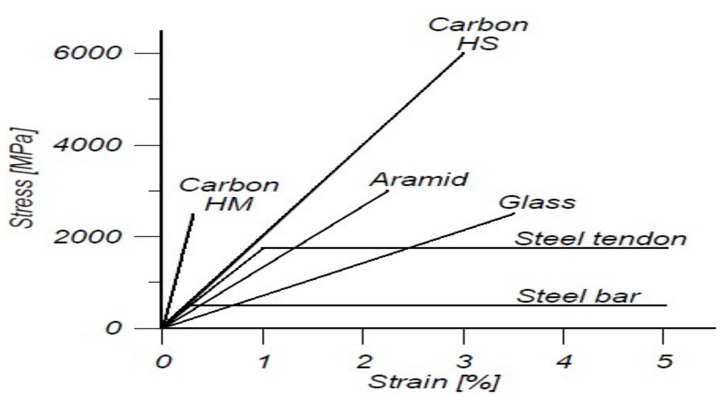

Figure 2. Stress-strain curves of Fibers FRP and matrix (8)

Mechanical properties of the FRP:

- Constituent Materials
- Fiber Amount
- Fiber Orientation
- Non-Corrosive
- Fatigue Life

- Non-Magnetic Properties
- High Specific Strength and Stiffness
- Brittle Material Retort
- Ductility

FRP Strengthening in RC Members:

There are techniques for amplifying almost as long as structures have been existing. At earliest times there was very limited structural information, some structures have been strengthened by addition of additional members supports or higher dimensions' methods still used today. (9)

As building knowledge has advanced the strengthening techniques have become more urbane.

It is important to emphasize that it is often difficult to strengthen a structure than the creation of a new one.

Precautions are taken to existing materials often deteriorated condition while taxes and strengthen existing geometry.

2. Previous Research Works On Beams:

Investigation on the behavior of CFRP retrofitted reinforced concrete structures has in the last decade become a very important research field.

In terms of experimental application several studies were completed to study the behavior of retrofitted beams and investigated the various parameters influencing their behavior.

Adhikaryet al (2004) (10)

By using two CFRP shear plate changed packaging scheme this person tests conducted eight RC simply supported beam strengthened as; U-shape wrap and the two sides of the beam. Examined the effectiveness of cross layers to each other vertically and horizontally; The direction of arrangement of the fibers the most significant parameter is (90 °, 0 ° and 90 ° + 0) °) One and two number of layers.

Al-Amery (2006) (11)

Tested six RC beams; having various combinations of CFRP sheet and stirrups in addition to an un-strengthened beam, as control test. CFRP provided CFRP sheet for flexural strengthening and CFRP stirrups for shear strengthening or with a couple of CFRP sheets and stirrups, for overall strengthening. From the experiment, two beams were tested in four-point bending over a total span of (2300 mm) and a shear span of(700 mm), while the beams RR3-RR6 were tested in three points bending over a total span of (2400mm) and shear span of (1200 mm). The CFRP sheets consisted of three layers, while CFRP stirrups consisted of one layer and extra anchorage mechanism for the CFRP sheets.

Anil (2006) (12)

Improved the shear capacity of RC T-beams using unidirectional CFRP composites and compared between the experimental and analytical used ACI Committee report. He tested six beams of sizes; 120mm width 360mm depth 1750mm length and 75mm flange thickness. Two of these beams were control specimen and four beams were strengthened with different configurations of CFRP strips, all these beams were tested under cyclic loading. These beams had longitudinal reinforcement and no stirrups for beams except one of the control beam.

3. Materials:

3.1 Cement

Ordinary Portland cement (Mass) type (I) is used in this study, results indicate that available cement conforms to the Iraqi Specification (IQS) No.5/1984. (13)

3.2 Fine Aggregate

Natural Aggregate and fine aggregate (sand) was used in concrete mix from (Al-Akhaidher) region in Iraq in this study. The sieve analysis was performed at Material Laboratory in Technical Institute in Baghdad to guarantee its validity for mixing.

The fine aggregate has 4.75 mm maximum size with rounded-shape particles and smooth texture with fineness modulus of 2.84. The grading of the fine aggregate is shown in Table (1) of the Iraqi Specification No.45/1984 (14) and British Standards (B.S.) 882:1983 (15) , while figure (3) shows sieve analyses.

Table 1. Grading of fine aggregate

No.	Sieve size	Passing (%)		
		Fine aggregate	Iraqi specification No.1984 /45for Zone II [50]	ASTM C33-03 [51]
1	4.75 mm	90.56	90-100	95-100
2	2.36 mm	74.69	75-100	80-100
3	1.18 mm	60.44	55-90	50-85
4	600 mm	43.47	35-59	25-60
5	300 mm	13.72	8-30	5-30
6	150 mm	1.98	0-10	0-10
7	Pan	0	-	-

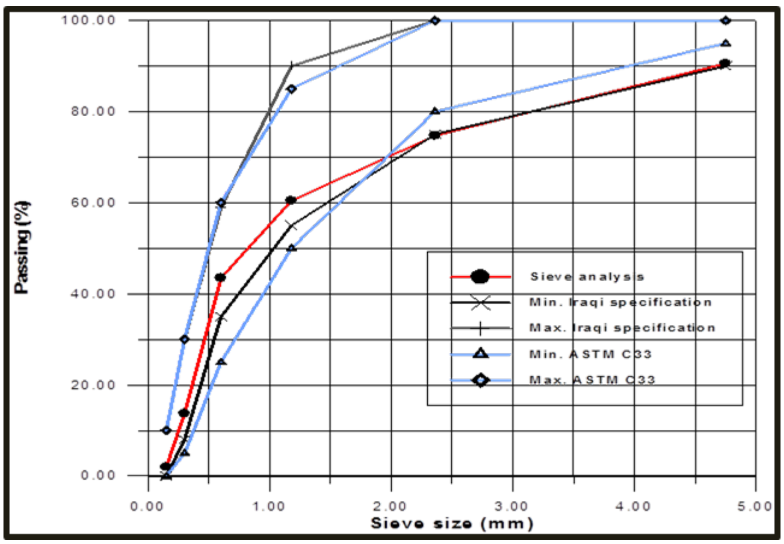

Figure 3. Sieve analysis of fine aggregate

3.3 Coarse Aggregate (Gravel)

Natural gravel of maximum size 18 mm brought from Al-Niba'ee region was used. Before using it, the sieve analysis was performed at Material Laboratory in Technical Institute in Baghdad to ensure its validity for mixing and choosing the primary proportions of mix materials.

Table (2) show the grading of this aggregate which conforms to the Iraqi Specification No.45/1984 (14) , and Figure (4) shows sieve analyses .

Table 2. Grading of coarse aggregate (gravel)

Sieve size (mm)	%Passing by weight	Limits of the Iraqi Specification(80) No.45/1984
12.5	99.6	100
9.5	85	85 -100
4.74	4.8	0 – 25
2.36	1	0 – 5
1.18	0	-

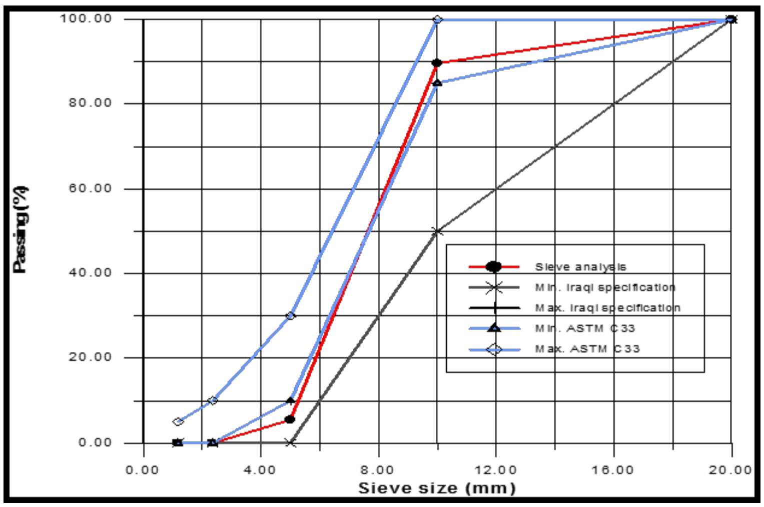

Figure 4. Sieve analysis of coarse aggregate

3.4 Limestone

The particle size of the powder is limestone less than 0.125 mm (Sieve No.200), Limestone powder has been used as filler for concrete production for many years. It has been found to increase workability and early strength, as well as to reduce the required compaction energy. The increased strength is found particularly when the powder is finer than the Portland cement particles which satisfies EFNARC 2005 (16) recommendations.

3.5 Super plasticizer

In this work, the used superplasticizer is known commercially as "GLENIUM54". It is compatible with all Portland cements that meet documented international standards.

Superplasticizer concrete shows a large increase in slump without segregation. However, this delivers enough periods after mixing for casting and finishing the concrete surface. Therefore, no retarders are required.

3.6 Woven carbon fiber

SikaWrap®-300C/60 Woven carbon fiber fabrics for structural strengthening was used for outside strengthening of the tested beams, Figure (5). This type is confidential as mid strength carbon fiber as reported by the manufacturer. It is unidirectional, the weft is 1% of total areal weight for keeping the fibers dependable together; the weft material as reported by the manufacturer is white thermoplastic heat-set fibers, and the width of the fabric roll is 30 cm and 50 cm.

Table (3-11) shows the practical description of Carbon fiber reinforced polymers (CFRP) from SikaWrap®-230 C. This system was made by (Sika Switzerland).

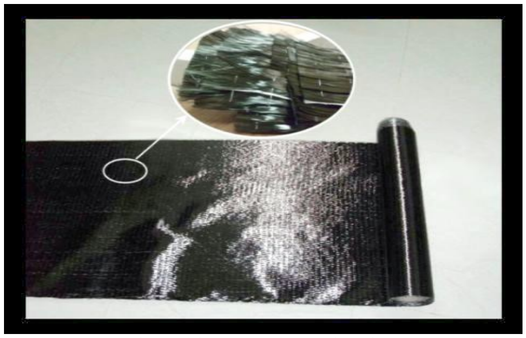

Figure 5. Carbon fiber reinforced polymers (CFRP)

Table 3. The technical properties of carbon fiber reinforced
Polymers (CFRP) from SikaWrap®-230 C*

Areal Weight	300 g/m2 ± 15 g/m2
Mechanical/ Physical Properties Laminate Properties	With Sikadur®-330 Laminate thickness 0.166 mm per layer: Ultimate load: 390,000 N/mm width per layer Tensile E-modulus: 23,000 N/mm2 (based on typical laminate thickness of 1.0 mm)

3.7 Adhesive, Materials

Sikadur®-330 this product is suggested by the same suppliers or factories of CFRP constructer to use for bonding CFRP sheets with the concrete.

3.8 Silica Fume

A grey colored identified silica fume was used as an admixture in SCC mix to improve its properties. The fineness of the used silica fume was 20000 m^2/kg

3.9 Steel Reinforcing Bars

Deformed steel bars were used in this work. Tensile tests of steel reinforcement were carried out according to ASTM A615M-05a (17) and ASTM A496-02 (18).

Deformed steel bars were used in this work.

3.10 Water

Water used in mixing concrete should be clean and free from injurious amounts of soils, acid, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement, normal mineral water use for mixing the materials and also using for curing.

4. Concrete Mix Design

For the criteria of filling capability and separation it has to blend design of SCC must, conform. SCC blends are designed to have a characteristic in 28-day more than 40 MPa compressive strength should prepare in this study. The mixture was carried out the properties of design used in the present study according to EFNARC details (16).

The mixture design has a limited amount of material used in this study. Table (4) shows the mix design of SCC mix.

Table 4. Mixing properties

Material	Density (Kg/m3)	Weight (Kg/m3)	Volume (m3)
Cement	3150	450	0.143
Water	1000	180	0.18
Fine aggregate	2610	785	0.300
Coarse aggregate	2580	850	0.329
Limestone powder	2400	85	0.035
SP (Superplasticizer)	8.5	8.5	0.007
Condensed Silica Fume	6000	50	0.008
w/p	40 %		
w/c	30 %		

Table 5. Specifications of steel reinforcing bars

Steel type	Yield Stress (fy) (MPa)	Ultimate Strength (fu) (MPa)	Elongation
6 mm steel bar	486	590	0.00243
20 mm steel bar	457	667	0.00229

5. Research Objective

The aim of the present study is to investigate the external strengthened by using Carbon Fiber Reinforced polymer sheets on T section self-compact concrete beams with different shape from these sheets to get the stronger for shear behavior.

6. Experimental Investigation

Involves ten simply supported T-beams are used to investigational program of the testing formed by use of SCC with two points load, and all beams externally strengthened by carbon fiber reinforced polymer sheets on section with different shape in order to investigate the best. The CFRP sheets are fixing on the two set of shear span first group has a/d = 2.5 , and the other group has a/d = 3.All beams have the same dimension and flexural reinforcement and They have an overall length of 1500 mm a width of flange 300 mm and 100 mm width of web and the total height is 200 mm only 60 mm for the flange.

All beams are longitudinally reinforced with two bars of Ø20 mm diameter at bottom and tow bars of Ø6 mm at top. These beams were designed to avoid the flexural failure so that the failure is governed by shear.

On the upper surface are provided with two bars with 6 mm diameter and distorted stripes with a Ø6 mm for vertical shear reinforcement and provided at a distance of 240 mm centers.

The minimum reinforcement percentage amount according to the ACI318-11 of reinforcement the steel ratio is 0.109% which represents (19).

In this study three parameters were considered: Shear length to active depth effective (a/d) the shape of CFRP sheets was represented as (2 sides parallel, U-shape for web only vertical and 45 diagonal and U-shape web with flange vertical) and also CFRP distribution.

For every type of CFRP shape, two beams tested with (a/d) percentage equivalent to (2.5 and 3) correspondingly, each beam designation consists of two notations: the first notation is a Letter (A and B) which, embodies the kind of group while the second representation is a number(0 ,1 ,2 ,3 ,4) which characterizes sequence of the beam in the group as detailed above .

Each group involves four beams and there are two beams without strengthened for reference, All, beams casted by SCC with designed f'c equal to 40 MPa.

The shear span (a) the distance between support block to the center of loading block while the depth (d) is the distance between the centers of tensile reinforcement to the top of beam, it is 160 mm in all tested beams, therefore 530 mm the distance between the two points load to obtain (a / d) = 2.5, and need 380 mm to obtain (a / d) = 3.

The strengthening layouts by CFRP were practical:

Table 6. Ultimate Loads and Failure Modes of the Beam for group (A) Specimens

Specimen	**Description Of Specimen**	**Ultimate Load (kN)**	**Increase in Ultimate Load over A0 %**	**Failure Mode**
A0	a/d=2.5 No strengthening	140	---------	Diagonal shear failure
A1	a/d = 2.5 parallel strengthening two side of the web	160	14 %	Diagonal shear failure
A2	a/d = 2.5 U shape strengthening	230	64 %	Diagonal shear failure
A3	a/d = 2.5 U shape diagonal strengthening	190	35.7 %	Deboning of CFRP from flange
A4	a/d = 2.5 U shape strengthening web and flange	170	21.5 %	Deboning of CFRP from flange

Table (7): Ultimate Loads and Failure Modes of the Beam for group (B) Specimens

Specimen	**Description Of Specimen**	**Ultimate Load (kN)**	**Increase in Ultimate Load over B0 %**	**Failure Mode**
B0	a/d=3 No strengthening	120	-------	Diagonal shear failure
B1	a/d = 3 parallel strengthening two side of the web	130	8.5 %	Diagonal shear failure
B2	a/d = 3 U shape diagonal strengthening	190	58 %	Diagonal shear failure
B3	a/d = 3 U shape diagonal strengthening	160	33 %	Deboning of CFRP
B4	a/d = 3 U shape strengthening web and flenge	150	25 %	Deboning of CFRP

Table 8. Tests results of SCC beams for group A

Beams	A0	A1	A2	A3	A4
Shape ofCFRP	without	Double sheet Parallel sheets	Double sheet (U) shape (web only)	Double sheet (U) shape (web with flange)	Double sheet (U) shape (web with flange) diagonal
First Crack load (Pcr)	50	50	60	50	60
The deflection atfirstcrack					
Second Crack load	60	65	70	60	70
Ultimate load	140	160	230	190	170
The Deflection at failure	8	7.5	10	9	11
Mode of shear failure	Diagonal splitting	Diagonal splitting	Diagonal splitting	De-bonding	De-bonding
CFRP length (mm) per one sheet	0	280	380	580	500
Total shear area(m2)	0.119	0.119	0.119	0.119	0.119

Table 9. Tests results of SCC beams for group B

Beams	B0	B1	B2	B3	B4
Shape ofCFRP	Without	Double sheet Parallel sheets	Double sheet (U) shape (web only)	Double sheet (U) shape (web with flange)	Double sheet (U) shape (web with flange) diagonal
First Crack load (Pcr)	50	50	70	50	60
The deflection atfirstcrack					
Second Crack load	60	70	80	70	70
Ultimate load	120	130	190	160	150
The Deflection at failure	7	8	11	8	9
Mode of shear failure	Diagonal splitting	Diagonal splitting	Diagonal splitting	De-bonding	De-bonding
CFRP length (mm) per one sheet	0	280	380	580	500
Total shear area(m2)	0.119	0.119	0.119	0.119	0.119

7. Conclusions:

The following conclusions can be drawn from the test results of this study:

- ✓ All tested SCC beams was fail by shear, the shear failure took place by diagonal mode for greatest tested beams.
- ✓ It was invented that for all tested beams, the shear span to depth percentage of the active (a / d) from 2.5 to 3 increase cracking load.
- ✓ Strengthening the flange by CFRP strips shows not improvement on the behavior and shear capability of SCC beams,

- ✓ The U–shape was the best strengthening shape for improving cracking and ultimate loads that because the secondary strains came from the top face of beam.
- ✓ Almost for all SCC beams there was a small difference in the values of the diagonal cracking strength even for beams without strengthening (A0 and B0).
- ✓ An assessment of the load-deflection conduct demonstrations that the conduct of the SCC beams in group A (a/d=2.5) was normally similar to the beams in group B (a/d=3) so they had the same load-deflection conduct.
- ✓

Beam Section and Strengthening Details:

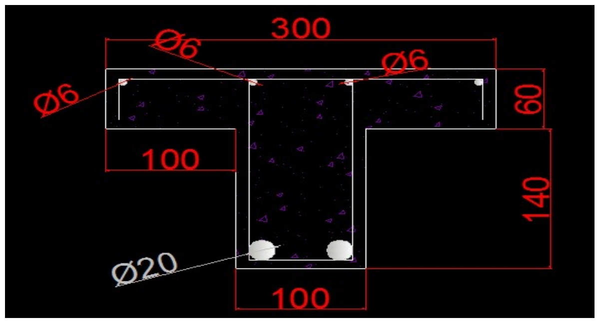

Figure 6. Beam Section (A0 or B0)

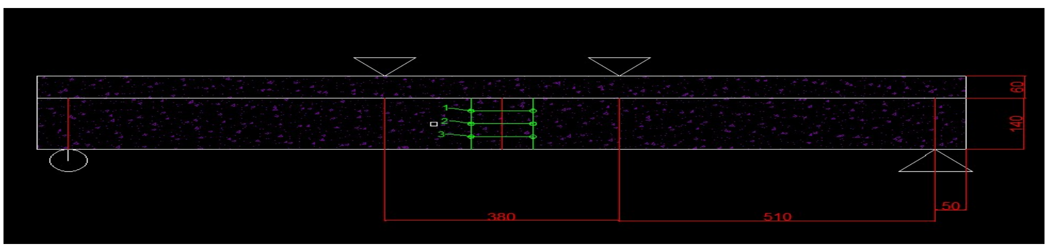

Figure 7. Beams details in group (A) a/d = 2.5

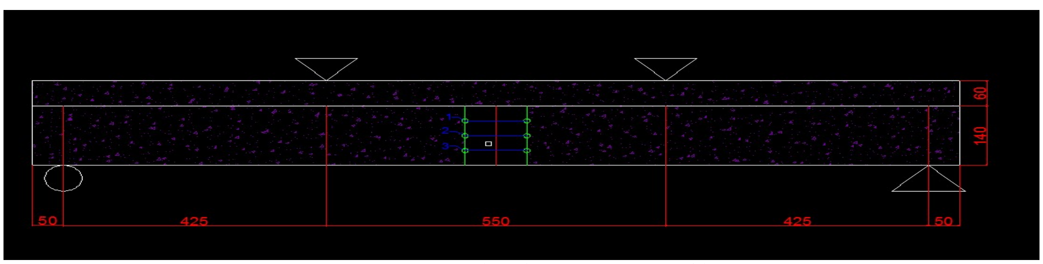

Figure 8. Beams details in group (B) a/d = 3

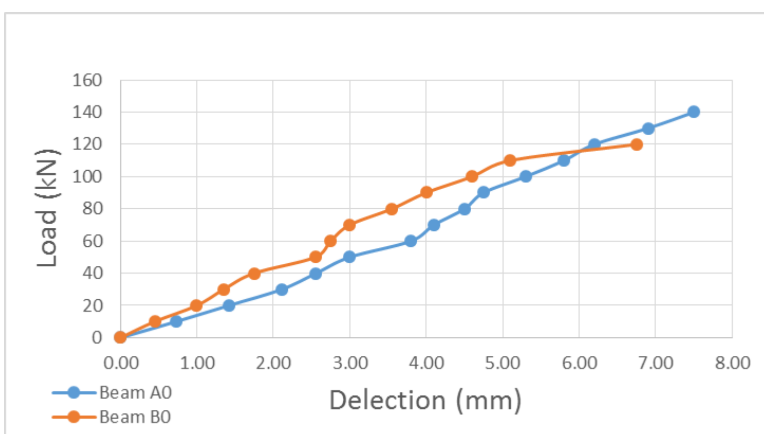

Figure 9. Load - Deflection chart for beams A0 and B0

1. Parallel Strengthened CFRP

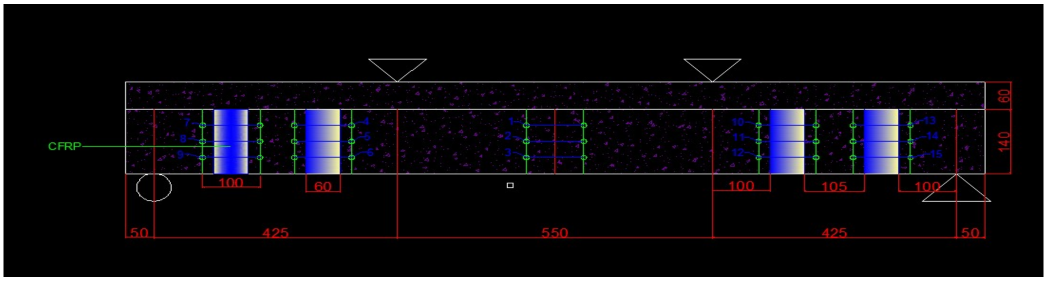

Figure 10. strength of beam (A1) a/d = 2.5

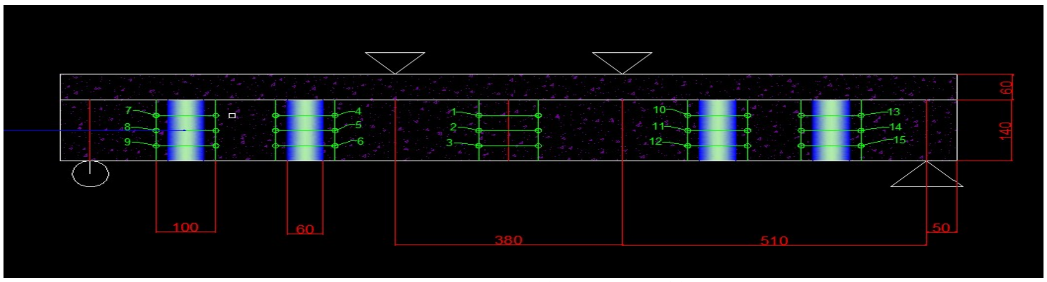

Figure 11. strength of beam (B1)a/d = 3

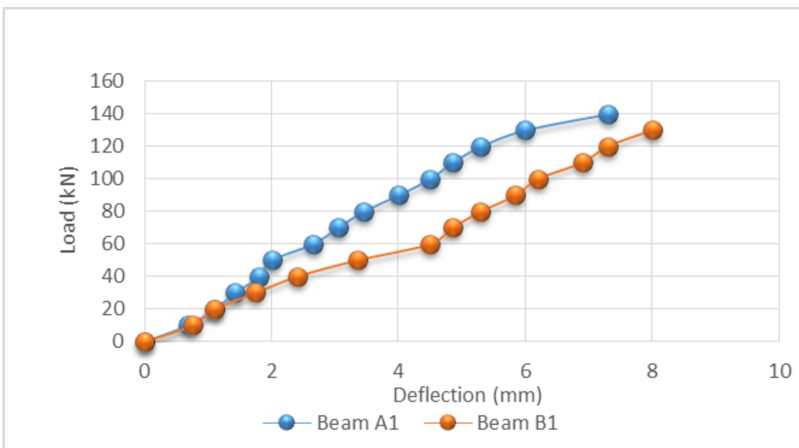

Figure 12. Load – Deflection chart for beams A1 and B1

2. (U) Shape Strengthened CFRP Web Only :

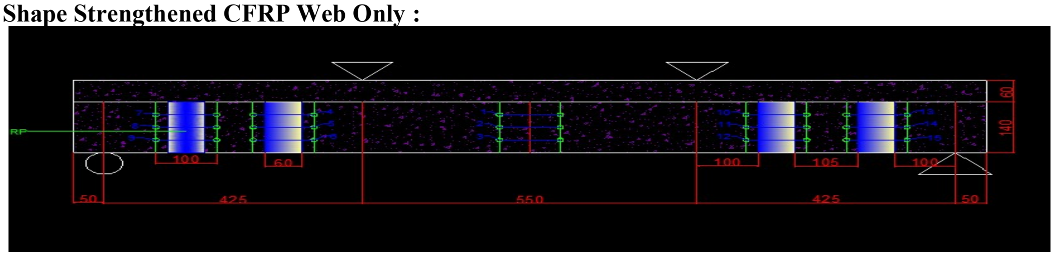

Figure 13). strength of beam (A2) a/d = 2.5

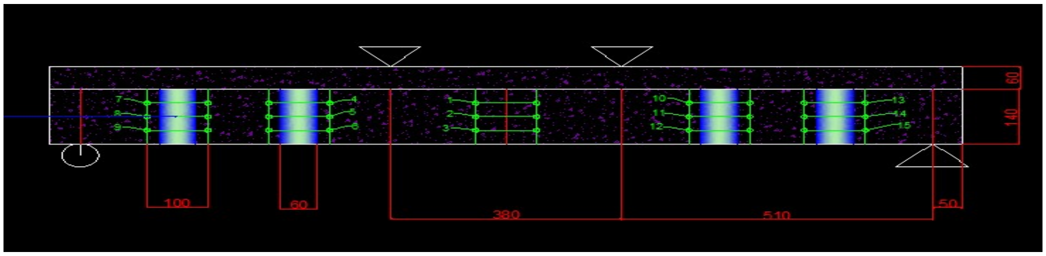

Figure 14. strength of beam (B2)a/d = 3

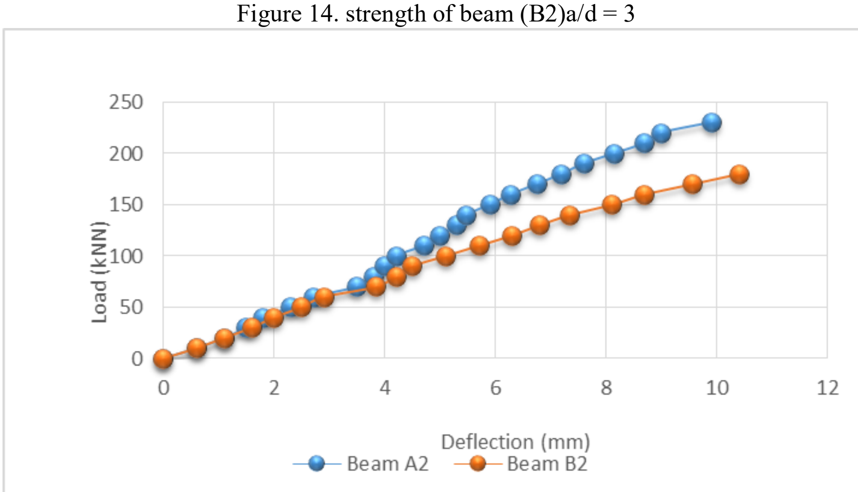

Figure 15. Load - Deflection chart for beams A2 and B2

3. (U) Shape Strengthened CFRP for web with Flange

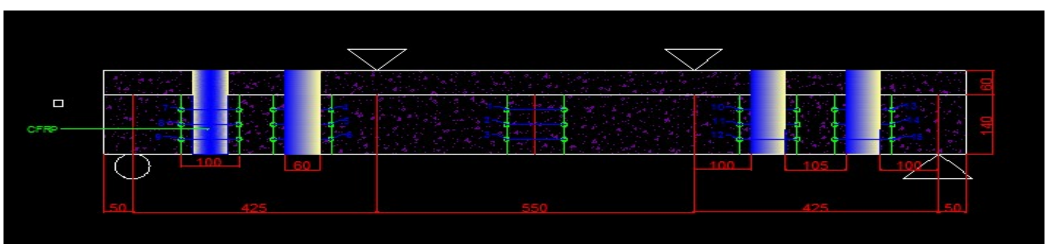

Figure 16. strength of beam (A3) a/d = 2.5

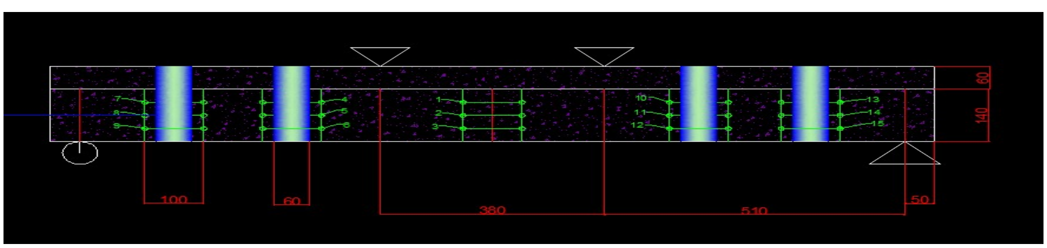

Figure 17. strength of beam (B3)a/d = 3

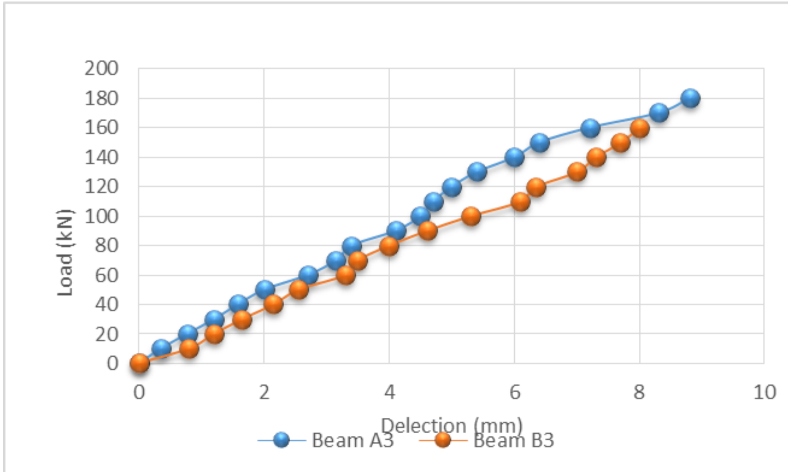

Figure 18. Load - Deflection chart for beams A3 and B3

4. *(*U) Shape Strengthened CFRP Web Only but Diagonal 45 degree

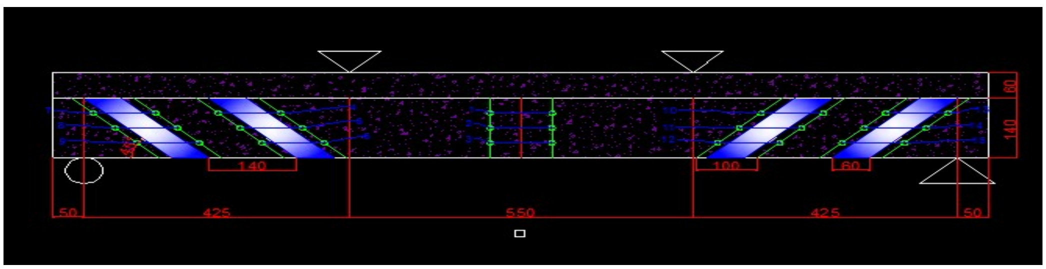

Figure 19. strength of beam (A4) a/d = 2.5

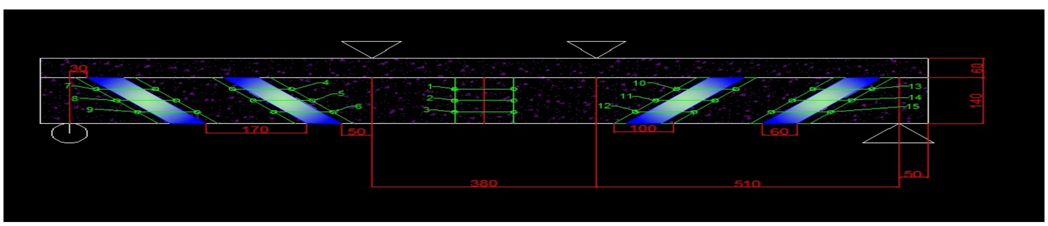

Figure 20. strength of beam (B4)a/d = 3

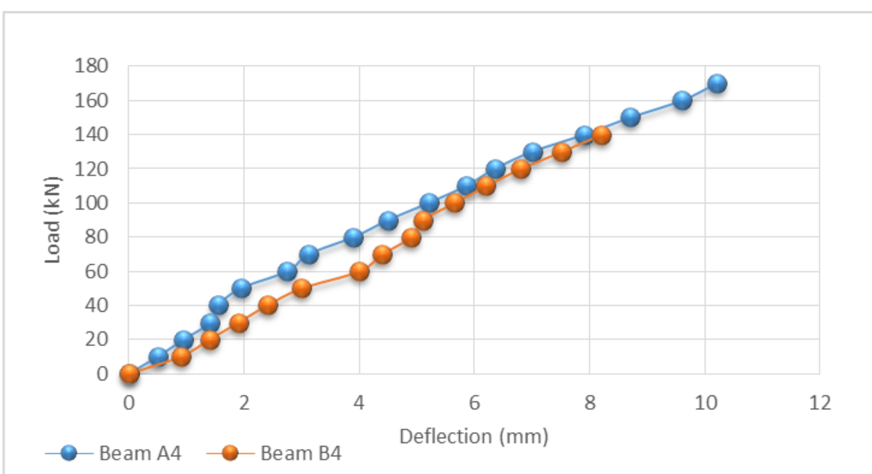

Figure 21 .Load - Deflection chart for beams A4 and B4


Figure 22. beam A0 before loading


Figure 23. beam B4 after failure


Figure 24. beam A3 after failure


Figure 25. Beam B2 after loading

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