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EXPERIMENTAL STUDIES ON THE BEHAVIOUR OF RC BEAM USING CFRP FABRICS IN SHEAR ZONE

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ABSTRACT

This project provides a review of existing literature on the strengthening of reinforced concrete beams using external glued-on Fiber reinforce plastics (FRP), particularly carbon fiber reinforced plastics fabrics. Firstly the properties of CFRP are listed and a summary of the technical data of commercial CFRP is presented. The results of an extensive survey of the large number of research project and field application of the glued-on CFRP sheets for strengthening pf concrete structures are summarized. Flexural and shear behavior are described as well as the different modes of failure reported in the literature. Issues related to durability, which is of concern to the current study, are addressed. The experimental program includes testing of concrete beams wrapped with CFRP fabrics. The steel reinforcement and CFRP fabrics plays a major role in the achievement of crack control. Proper and evenly grading size of aggregates enhances the strength of concrete. For M30 grade of concrete the strength will be studied by conducting compression tests on cubes and tests on beams using static loading foe all the specimens. Design mix for M30 grade of cement and theoretical calculations which was carried out is also presented.

Keywords— CFRP,FRP.

I. INTRODUCTION

Carbon Fiber composites and reinforced polymer offer unique advantages in many applications where conventional materials cannot provide satisfactory service life. The high strength-to-weight ratio and the excellent resistance to electrochemical corrosion of composites make them attractive materials for structural applications. In addition, composites are versatile and can be formed to any desired shape and surface texture. They are generally constructed of high performance fibers such as carbon, or, glass which are placed in a resin matrix. By selecting among the many available fibers, geometries and polymers, the mechanical and durability properties can be tailored for a particular application. This synthetic quality makes CFRP a good choice for civil engineering applications as well.

Carbon fibers have a high elastic modulus and high strength in both tension and compression, and are utilized in this study. Composed almost entirely of carbon atoms, the fibers are generally available as bundles of 500-150,000 filaments of approximately five microns in diameter called “yarn.” These are then assembled directly into CFRP products or into intermediate forms such as continuous fiber sheets or fabrics. Continuous fiber sheets are made of parallel yarns attached to a flexible backing tape for handling. Fabrics are made of yams stitched into a geometric

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form. The yarns may run unidirectional like the continuous fiber sheets, or be woven at different angles into a fabric. Since there is no adhesion between individual fibers, a polymer or resin matrix is used to transmit forces between the fibers. Polymers, which include the epoxy used in this study, have the advantages of low cost, ease of workability, and some have good resistance to environmental effects. The hand, or contact layup is the oldest method of assembling a CFRP. The epoxy is applied to one or both sides of the fabric and worked between the fibers using an ordinary paint roller and hand pressure. The surface may then be finished with a flexible blade to remove excess epoxy before curing occurs.

II. LITERATURE STUDY

2.1 GENERAL

Literature pertaining to study on the shear strengthening of RC beam using carbon fiber reinforced plastic.

2.2 LITERATURE ON SHEAR STRENGTHENING OF RC BEAMS

Swamy *et al*[7] (1987) investigated on the effect of glued steel plates on the first cracking load, cracking behavior, deformation, serviceability, and ultimate strength of reinforced concrete beams. Total twenty-four rectangular (155 x 255 mm X 2500 mm) beams were tested. Three steel plate thicknesses, 1.5 mm, 3 mm, and 6 mm were used, all of constant width of 125 mm. The results indicated that the addition of glued steel plates to a reinforced concrete beam can substantially increase the shear stiffness, flexural stiffness, reduce cracking and structural deformations at all load levels, and contribute to the ultimate shear and flexural capacity. The net effect of the reduced structural deformations was that the serviceability loads were substantially increased by the stiffening action of the glued plates

Hamid *et al*[7] (1991) investigated the RC Beams strengthened with GFRP (Glass fiber reinforced plastic) plates. Five rectangular beams with cross section 205mm x 455mm and one T-beam with cross section flange 610mm x 75mm, web 205mm x 380mm were tested to failure under four point bending, all beams were simply supported on a clear span of 4.57 m (15 ft) and two concentrated loads symmetrically placed about the mid-span. The results indicate that the shear strength of RC beams can be significantly increased by gluing 6mm GFRP plates. All beams were strengthened with GFRP plates that were 152 mm wide (6 in.) by 6 mm thick (0.25 in.) and 4.26 m long (14 ft) and bonded to their tension flanges. The epoxy bonded plates improved the cracking behavior of the beams by delaying the formation of visible cracks and reducing crack widths at higher load levels.

Norris *et al*[15] (1997) investigated the shear and flexural strengthening of RC beam with carbon fiber sheets. He studied in strengthening of RC beam and casted nineteen concrete beams (1220mm) with cross section 127mmx203mm. He proved that CFRP (carbon fiber reinforced plastic) sheets can provide increase in strength and stiffness to existing concrete beams when bonded to the web and tension face. The CFRP sheets are epoxy bonded to the tension face and web of concrete beams to enhance their flexural and shear strengths. When the CFRP sheets were placed perpendicular to cracks in the beam, a large increase in stiffness and strength was observed and there was no difference in behavior between the pre-cracked beams and the un-cracked ones at the ultimate level.

Chaallal *et al*[12] (1998) studied on shear strengthening of RC beams by externally bonded side CFRP sheets and mainly concentrated on shear strengthening of RC beam. Here three series of 1,300-mm-Iong RC beams (eight in total) having cross-sectional dimensions of 150 mm X 250 mm were considered and were then subjected to a four-point flexural bending test.

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Diagonal side CFRP (Carbon fiber reinforcement plastic) strips outperformed vertical side strips for shear strengthening in terms of crack propagation, stiffness and shear strength.

Mukhopadhyaya *et al*[13] (1998) studied on structural response of beams strengthened with GFRP plates and focused on strengthening of RC beam. Here six simply supported beams of 150 X 250 X 3,000 mm in size were tested under two point loading. The test results show that the GFRP (Glass fiber reinforcement plastic) plate with low stiffness and high strain at failure can be used for shear and flexural strengthening without compromising ductility, and if designed properly, it can even increase ductility.

Spadea *et al*[6] (1998) investigated on structural behavior of composite RC beams with externally bonded CFRP (Carbon fibre reinforced plastic). Here Four beams 140 X 300 mm are taken ,three with bonded CFRP plates on the tension face, one of which were provided with carefully designed external anchorages at the ends of the plates. Were it was tested under four-point bending. The tests were carried out under displacement control. Failure of the strengthened beam occurred in a brittle manner, with explosive debonding of the CFRP sheet. With such a mode of failure, the CFRP plated beam without any external anchorage was unable to make use of the full potential of the CFRP plate, which was clearly underused.

Alex Li *et al*[1] (2001) investigated the shear strengthening of RC beam with externally bonded CFRP sheets. Here Five types of beams of arbitrary dimensions with different strengthening carbon-fiber–reinforced plastic sheets were used and two point loading test was conducted. The results of tests performed in the study indicate that stiffness increases while increasing the CFRP sheet area at the flanks and measuring by the strain gauges showed that strengthening the entire lateral faces of the beam is not necessary. For the strengthened beam, the ultimate strength can have a significant increase in comparison with the normal beam.

Spadea *et al*[4] (2001) studied on strength and ductility of RC beams repaired with bonded CFRP laminates. Here two point loading test was conducted upon 11 beams of cross section 300x140. The load-deflection and moment-curvature responses of the original beam were drastically and adversely affected by bonding of the CFRP (Carbon Fiber Reinforced Polymers) laminate and the results emphasize that the significant increase in strength obtained by strengthening with bonded CFRP laminates.

Charlo Pellegrino *et al*[3] (2002) investigates on fiber reinforced polymer shear strengthening of reinforced concrete beams. Total 11 beams have been tested. Except for the control tests, all tests were done on beams with sided-bonded CFRP sheets. The comparison between the experimental CFRP and the theoretical the shear capacity increment is due to Carbon Fiber Reinforced Polymer. The result indicates that the effectiveness of the shear strengthening is strongly increased.

Tavakkolizadeh *et al*[8] (2003) investigated the strengthening of steel-concrete composite girders using carbon fiber reinforced polymers Sheets. Here total of three large-scale composite girders made of W355X13.6 ,A36 steel beam and 75-mm thick by 910-mm wide concrete slab were prepared and tested with 1,3,5 layers of CFRP sheets. The result indicates that the load-carrying capacity of a steel-concrete composite girder was improved significantly by this CFRP method and Ultimate load-carrying capacities of the girders significantly increased by 44, 51, and 76% for one-, three-, and five-layer.

2.3 LITERATURE SUMMARY

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From the review of literature, it has been found out that much work has not been done shear strengthening of RC beams with CFRP sheets. So this study on shear strengthening is adopted.

III. EXPERIMENTAL STUDY

3.1 GENERAL

In the experiment program of this research, tests will be conducted on reinforced concrete beams with external bonding of CFRP sheets in the shear zone. The beam will be tested under two-point loading to investigate their structural behaviour. The objective of this experimental investigation is to determine:

1) Structural behaviour of RC beam;
2) Shear strength of RC beam;
3) Shear failure of RC beam and
4) Shear strengthening of RC beam using CFRP (carbon fibre reinforced polymer) sheets

Experimental investigations always show the real behaviour of the structure, an element or a joint. These are conducted on models to study the behaviour in detail. Experimental investigations are usually cumbersome, laborious, and time-consuming and most of the time requires skilled labour. This chapter includes the experimental specifications regarding the carbon fibre reinforced polymer (CFRP) sheets to be used and the member properties and their dimensions.

3.1.1 SPECIMEN AND EXPERIMENTATION DETAILS

A 5 rectangular RC beam is going caste and tested under the two point load. Out of 5 beams one is control beam and remaining 4 are test specimen. This experimental study is to be established the shear strengthening of RC beam is bonding with Carbon fibre reinforced polymer (CFRP) sheet.

Beam Dimension Details

Size: 2000 x150 x 250 mm

Effective cover: 20 mm

Grade of concrete: M30

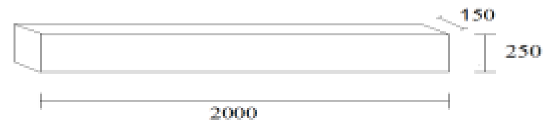

Fig 3.1 Dimensions of beam (All dimensions in mm)

Type of material

Sheet: Carbon fibre reinforced polymer

Glue for bonding: Nitowrap 30 (Base), Nitowrap 410 Harder, Nitowrap 410 Base

3.2 PROCEDURE FOR BONDING CFRP:

- Grind the specimen area where CFRP is going to apply.
- Clean the surface and close the tiny holes with putty.
- Mix the primer base in correct ratio.
- Apply the Nitowrap 30 primer base and leave it for 20 hours.
- Mix the harder and base in 1:2 ratio.
- Apply the Nitowrap 410 (Harder + Base) and immediately paste the CFRP and keep for drying.
- Again apply the Nitowrap 410 (Harder + Base) above the CFRP.

WRAPPING OF CFRP SHEET:

3.2.1 Surface preparation

Concrete surfaces to be treated shall be free from oil residues, demoulding agents, curing compounds, grout holes and protrusions. Incase of

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distressed structures, the concrete surface to be wrapped, shall be structurally repaired prior to treatment. Corrosion induced damages shall be repaired with Renderoc range of mortars and Galvashield XP shall be installed wherever necessary. Structural damages shall be repaired by using epoxy grouting/appropriate mortar from the Renderoc range.All depressions, imperfections etc., shall be repaired by using Nitocote VF/ Nitomortar FC, epoxy putty.

Fig 3.2 surface preparation

3.2.2 Mixing

Before mixing, the contents of each can should be thoroughly stirred to disperse any settlement, which may have taken place during storage. The base and hardener are emptied into a suitable container and the material is thoroughly mixed for at least 3 minutes. Mechanical mixing using a heavy-duty slow speed (300 - 500 rpm), drill, fitted with a mixing paddle is recommended.

Fig 3.3 Base primer Mixing

3.2.3 Primer

The mixed material of Nitowrap 30 epoxy primer is applied over the prepared and cleaned surface. The application shall be carried out using a brush and allowed for drying for about 24 hours before application of saturant.

Fig 3.4 Applying primer on beam specimen

3.2.4 Saturant

The mixed material of Nitowrap 410 saturant is applied over the tack free primer. The wet film thickness shall be maintained @ 250 microns.

Fig 3.5 Saturant

3.3 RESEARCH SIGNIFICANCE

The present study seeks to establish a simple experimental procedure which can be used to strengthening the shear capacity of rectangular beams with external bonding of CFRP sheets. Result of this

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experimental program could be very useful in establishing design guidelines and future code for structures reinforced.

3.4 TESTS ON CEMENT

A PPC 53 Grade sample was tested to obtain the following characteristics:

- Specific gravity
- Standard consistency
- Initial setting time
- Final setting time

3.4.1 Calculation

Table 3.1 Specific Gravity of Cement

S. No	Description	Weight in Kg
1	Weight of empty bottle (w_1)	0.45
2	Empty bottle + water (w_2)	1.12
3	Empty bottle + Kerosene (w_3)	0.98
4	Empty bottle + Kerosene + cement (w_4)	1.02
5	Weight of cement	0.05
Specific Gravity = 3.12		

3.4.2 Test Result

Standard consistency of cement = 28 %

Initial setting time = 32 minutes

Final setting time = 320 minutes

Specific gravity = 3.12

3.5 TESTS ON FINE AGGREGATE

In the present investigation, the river sand which was available near Chennai, sand was used as fine aggregate and the following tests were carried out on sand

- Specific Gravity
- Sieve Analysis
- Bulk density

3.5.1 Calculations

Table 3.2 Specific Gravity of Fine Aggregate

S. No	Description	Weight in Kg
1	Weight of empty bottle (w_1)	0.46
2	Empty bottle + fine aggregate (w_2)	0.89
3	Empty bottle + fine aggregate + water (w_3)	1.51
4	Empty bottle + water (w_4)	1.26
Specific gravity = 2.60		

3.6 TEST ON COARSE AGGREGATE

In the present investigation, locally available crushed blue granite stone aggregate of size 10 mm and down, was used and the various tests, carried out on the aggregates, are given below.

- Specific Gravity
- Bulk Density
- Sieve Analysis And Fineness Modulus

3.5.1 Calculation

Table 3.3 Specific Gravity of Coarse Aggregate

S. No	Description	Weight in Kg
1	Weight of empty cylinder (w_1)	0.55

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2	Empty cylinder + coarse aggregate (w_2)	1.65
3	Empty cylinder + coarse aggregate + water (w_3)	2.05
4	Empty cylinder + water (w_4)	1.36
Specific gravity = 2.90		

3.7 TEST SETUP

Tests will be carried out on 5 reinforced beam specimens and all are strengthened for shear capacity using external bonding using CFRP sheets. The beam with 150 X 250 mm cross section and 2000 mm clear span will be simply supported and subjected to two concentrated static loads. Steel stirrups of 8mm diameter were at 160 mm spacing along the beam length for all beams.

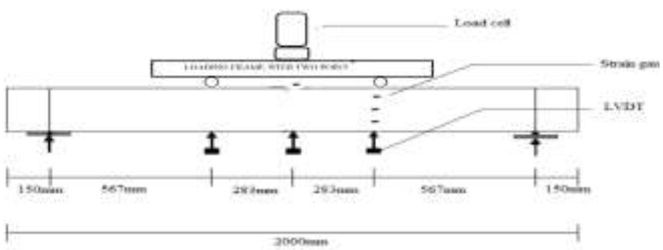

Fig 3.1 Load setup

3.8 DETAILS OF SPECIMEN TESTING

Total five specimens are tested. One is control beam without wrapping CFRP and remaining four are with wrapping CFRP. The five specimen's names are CB (control beam), FSW (full side wrap), SUWS (Side U Wrap at Shear), VWS (Vertical Wrap Stirrups), and IWS (Inclined Wrap Stirrups).

Table 3.4 Details of specimen and reinforcement

Details of beam	Types of beam	Testing of beam (days)	Reinforcement in beam: Longitudinal – Nos. and size at top	Longitudinal – Nos. and size at bottom	Stirrups – Diameter (mm)	Stirrups – Spacing (mm)
Control Beam	CB	28	2#10	2#12	8	160
Full side wrap	FSW		2#10	2#12	8	160
Side U Wrap At Shear	SUWS		2#10	2#12	8	160
Vertical Wrap Stirrups	VWS		2#10	2#12	8	160
Inclined Wrap Stirrups	IWS		2#10	2#12	8	160

Fig 3.6 Load setup of Control beam

Fig 3.7 Load setup of Full Side Wrap

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Fig 3.8 Load setup of Side U Wrap at Shear

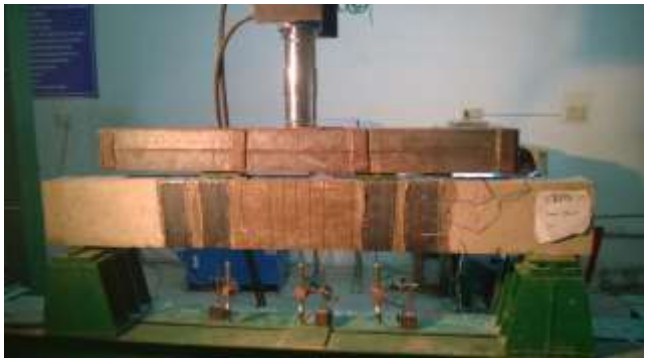

Fig 3.9 Load setup of Vertical wrap stirrups

Fig 3.10 Load setup of Inclined Wrap Stirrups

IV. THEORETICAL INVESTIGATION

4.1 GENERAL

This chapter deals with the computation of the theoretical calculation such as Mix design. The concrete mix has been designed for M30 grade as per IS 10262 – 2009. The specified concrete grade involves the economical selection of relative proportions of cement, fine aggregate, coarse aggregate and water. Although compliance with respect to characteristics strength is the main criteria for acceptance, it is implicit that concrete must also have desired workability in the fresh state and impermeability and durability in hardened state.

4.2 MIX DESIGNED FOR M30 GRADE CONCRETE

Mix designed on recommended guide lines is really a process of making an initial guess at optimum combination of ingredients and final mix proportion is obtained only on the basis of further trail mixes. As mentioned earlier under the project a comparative study was carried. To arrive at a concrete mix for this study mix design M30 concrete was carried as per IS code 10262 – 2009.

Step: 1 Design stipulations

- Characteristic compressive strength required in field at 28 day = 30 N/mm^2
- Maximum size of aggregate= 20 mm
- Degree of quality control = Good
- Type of exposure= Severe

Step: 2 Test Data for Materials

Cement used – ordinary Portland cement (53 grate)

- Specific gravity of cement= 3.12
- Specific gravity of fine aggregate= 2.60
- Specific gravity of coarse aggregate= 2.90

Water absorption

- Coarse aggregate = 0.75 %
- Fine aggregate = 1.0 %

Step: 3 Target Mean Strength of Concrete

$f_{ck} = f_{ck} + t \times s$ (4.1)

Where,

f_{ck} = Target average compressive strength at 28 days

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f_{ck} = Characteristic compressive strength at 28 days

s = Standard deviation

t = A static depending upon the accepted proportion of low result

The values t and s are taken from the table 1 and table 2 of IS 10262- 2009

$$f_{ck} = f_{ck} + t \times s$$

$$= 30 + (1.65 \times 5)$$

$$= 38.25$$

Step: 4 Selection of Water - Cement Ratio

From Table 5 of IS 456, free water cement ratio required for the target mean strength of 38.25 N/mm is 0.50. This is the maximum water – cement ratio prescribed for severe exposure in Appendix A of IS 456-2000 adopt water cement ratio of 0.50.

Step: 5 Select of Water and Sand Content

From Table 2 IS 10262 – 2009 for 20 mm maximum size of aggregate sand conforming to grading zone III water content per cubic meter of concrete = 186 kg and sand content as percentage of total aggregate by absolute volume = 35 percentage.

Maximum water content for (25 to 50 mm slump range) = 186 liters

Estimate water content for 150 mm slump range = 186 + (12/100)*186=208.32 lit

Step: 6 Determination of cement content

- Water – Cement ratio = 0.50
- Water = 208.32 lit/ m^3
- Cement = 208.32/0.50 = 416 kg/m^3

From table 5 of IS 456,

Minimum content for 'severe' exposure condition = 320 kg/m^3

416 kg/m^3 > 320 kg /m^3

Hence OK.

Step: 7 Determination of volume of coarse and fine aggregate content

From the IS 10262:2009 Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (zone III) for water – cement ratio of 0.50 = 0.6

In the present case water – cement ratio is 0.50. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water – cement ratio is lower by 0.10, the proportion of volume of coarse aggregate is increased by 0.02. Therefore, correct proportion of volume of coarse aggregate for the water –cement ratio of 0.50 = 0.6.

- Volume of coarse aggregate = 0.6 m^3
- Volume of fine aggregate = 1-0.6 m^3
  = 0.4 m^3

Step: 8 Mix Calculations

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete = 1 m^3
b) Volume of cement = (mass of cement/specific gravity of (Cement x 1000)
   = (416/3.12) x (1/1000)
   = 0.133 m^3

c) Volume of water = (mass of water/ specific gravity of water x1000)

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= (208.32/1) x (1/1000)
= 0.208 m^3

d) Volume of all in Aggregate = [a - (b + c)]
= [1 – (0.133 + 0.208)]
= 0.658 m^3

e) Mass of coarse Aggregate x specific gravity = d x volume coarse aggregate of Coarse aggregate x 1000
= 0.658 x 0.6 x 2.90 x 1000
= 1146.10 kg

f) Mass of fine Aggregate = d x volume of fine aggregate x specific gravity of Fine aggregate x 1000
= 0.658 x 0.4 x 2.90 x 1000
= 685.02 kg/m^3

Step: 9 Mix Proportion

- Cement = 416 kg/m^3
- Water = 208.32 kg/m^3
- Fine aggregate = 685.02 kg/m^3
- Coarse aggregate = 1146.10 kg/m^3
- Water cement ratio = 0.50

Table 4.1 Mix Design

Water	Cement	Fine aggregate	Coarse aggregate
208.32	416	685.02	1146.10
0.50	1	1.6	2.8

Ratio: 0.50 : 1 : 1.6: 2.8

V. DESIGN OF THE TEST SPECIMENS

5.1 DESIGN OF M30 BEAM

Overall depth = 250mm

Effective depth = 230mm (clear cover 20mm)

Breadth = 150mm

Span = 2000 mm

F_{ck} = 30N/mm^2

F_y = 415N/mm^2

$X_{u\,max}/d$ = 0.48

From annexure of IS 456-2000

$M_{u\,lim}$ = $0.36 \times X_{u\,max}/d\ (1-0.42X_{u\,max}/d)\ bd^2 \times f_{ck})$ (5.1)

= 0.36 x 0.48(1-0.42 x 0.48) x 150 x 230 x 230 x 30

= 3.28KNm

M_{max} = WL/3

M_{max} = $M_{u\,lim}$

WL/3 = 3.28 KN m

W = 4.92KN

From annexure of IS 456-2000

X_u/d = $0.87 \times F_Y A_{st}/0.36 f_{ck} bd$ (5.2)

0.48 = 0.87 x 415 x A_{st}/0.36 x 30 x 150 x 230

A_{ST} = 462.92 mm^2

Provide 12mm dia bars @ the bottom and 10mm dia @the top

5.2 SHEAR REINFORCEMENT DESIGN

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Nominal shear stress (from IS456-2000, clause 40.1)

T_V $= V/bd$ (5.3)

$= 14.605 \times 1.5/150 \times 230$

$= 0.63$

$100A_{st}/bd$ $= 100 \times 191.64/150 \times 230$ (5.4)

$= 0.456$

From the table of IS 456-2000

T_c =.271 N/mm^2

Since $T_V < T_C$

V_{us} $= V_U - T_C\, b\, d$ (5.5)

$= 21907 - 0.27 \times 100 \times 230$

$= 15697$

Choose 10mm links $A_{sv} = 157\text{mm}^2$

V_{us} $= 0.87 f_y A_{sv} d/S_V$ (5.6)

S_v $= 0.87 \times 415 \times 157 \times 230/15697$

$= 830.57$

$S_{v\ max}$ $= 0.75 \times 230$

$= 172\text{mm}$

Provide 8mm dia link @160 mmc/c

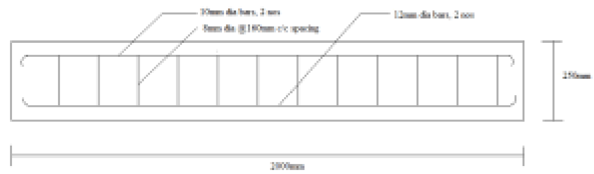

Fig. 5.1 Reinforcement details

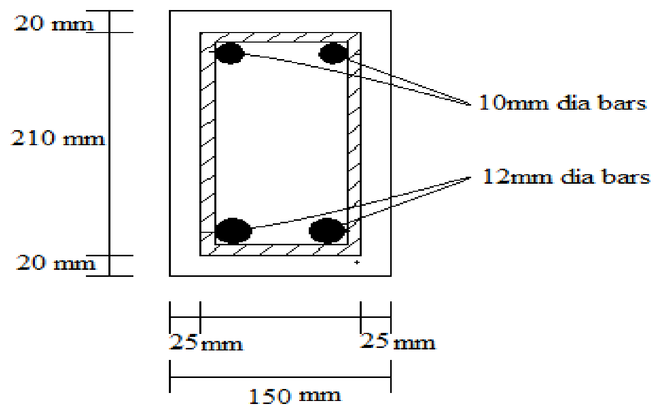

Fig. 5.2 Cross section of Beam

VI. RESULT

6.1 GENERAL

In the phase of the project work theoretical and experimental investigation were carried out and the following result were obtained.

WORK CARRIED OUT

- The specific gravity of the cement tested is 3.12.
- The initial and final setting time of the cement is 32 minutes and 320 minutes respectively.
- The Specific gravity of the fine aggregate tested is 2.60.
- The specific gravity of the coarse aggregate tested is 2.74.

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- The mix design for M30 concrete is arrived as 1: 1.6: 2.8 and the water content ratio is 0.50.
- The beam section details found after calculation are 2000 * 150 * 250 mm.
- 15 cubes are casted and tested.
- 4 beam specimens with CFRP bonding are casted and tested.
- 1 normal beam without CFRP bonding is casted and tested.

6.2 CUBE TESTING

The cube specimens of size 150mmx150mmx150mm are tested by compression testing machine after 7 days, 14 days and 28 days of curing. Samples were weighted before being put in the compression Testing Machine (CTM). The load was then applied until failure and the crushing load was noted. The compressive strength of each sample was determined as follows;

Compressive strength = Crushing Load (N) /Effective Area (mm^2)

Fig. 6.1cube before testing

Fig. 6.2 cube after testing

Table6.1 Cube testing values

Cube test	Max load kN (28days)	Average Strength N/mm^2
1	660	698.2
2	692.7	
3	648.5	
4	746.3	
5	742.7	

6.3 CRACKING PATTERN AND GRAPH'S: The below figure shows the cracking pattern after the loading. As applying the load the beam deflect and appears cracks, observe the initial crack and final crack.

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CONTROL BEAM: This is a cracking pattern of a control beam, the initial crack at 33.5 KN and final crack at 123.9 KN. The ultimate load is 123.9 KN.

Fig 6.1 Cracking pattern of Control beam

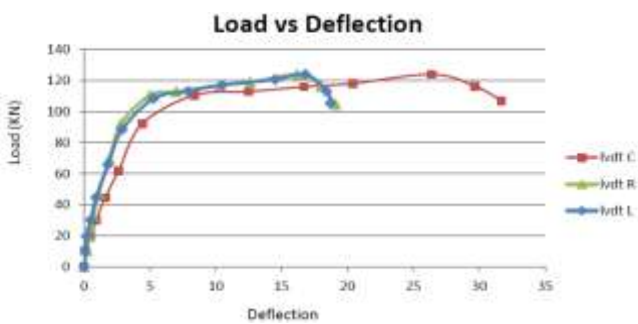

Fig 6.1.1 Load vs Deflection Graph of control beam

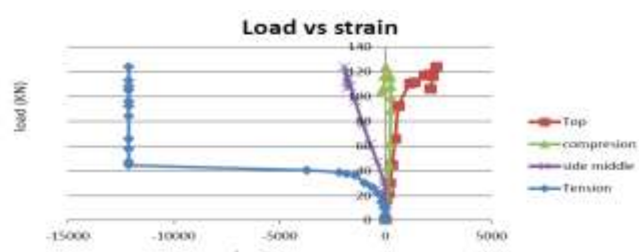

Fig 6.1.2 Load vs Strain Graph of control beam

FSW SPECIMEN: This is the cracking pattern of FSW specimen. The initial crack occurs at 51.1 KN and final crack at 157.5 KN. The ultimate load is 158.8 KN. Total CFRP covered area is 1400 mm (Length), 170 mm (Height).

Fig 6.2 Cracking pattern of FSW specimen

Fig 6.3 Debonding of FSW specimen

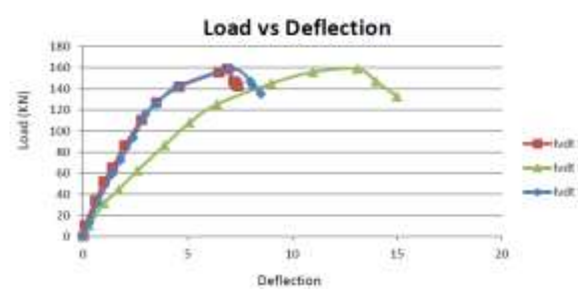

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Fig 6.2.1 Load vs Deflection graph of FSW specimen

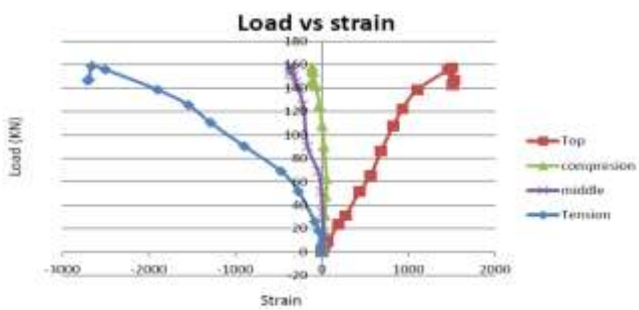

Fig 6.2.2 Load vs Strain graph of FSW specimen

SUWS SPECIMEN: This is the cracking pattern of SUWS specimen, an Initial crack at 41.9 KN and final crack at 122.6 KN. The ultimate load is 122.6 KN. CFRP is wrapped at shear area as U section, width 250 mm.

Fig 6.3 C racking pattern of SUWS specimen

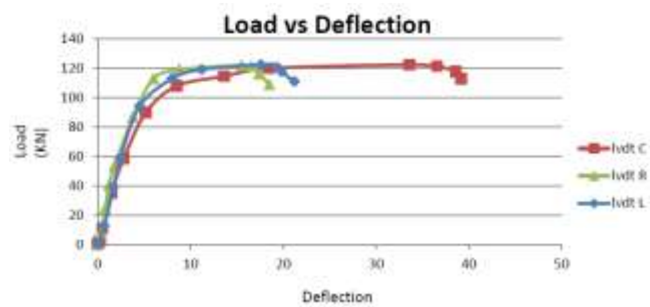

Fig 6.3.1 Load vs Deflection graph of SUWS specimen

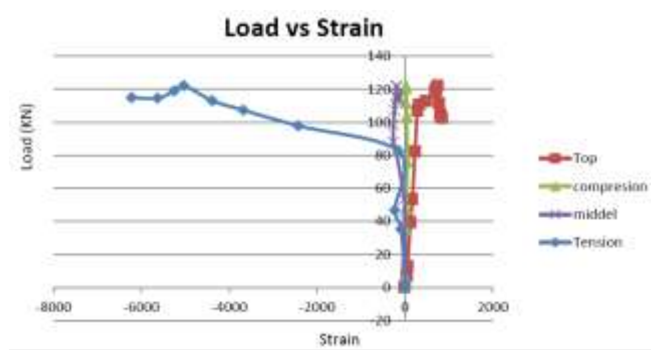

Fig 6.3.2 Load vs strain graph of SUWS specimen

IWS SPECIMEN: This is the cracking pattern of IWS specimen, an Initial crack occur at 22.6 KN and final crack at 123.8 KN. The ultimate load is 123.8 KN. Inclined CFRP stirrups are wrapped at angle 60^{o} with the width of 60 mm.

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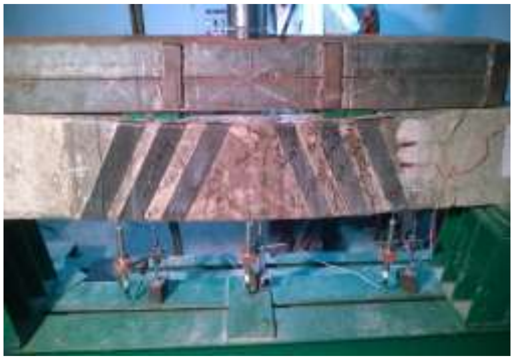

Fig 6.4 Cracking pattern of IWS specimen

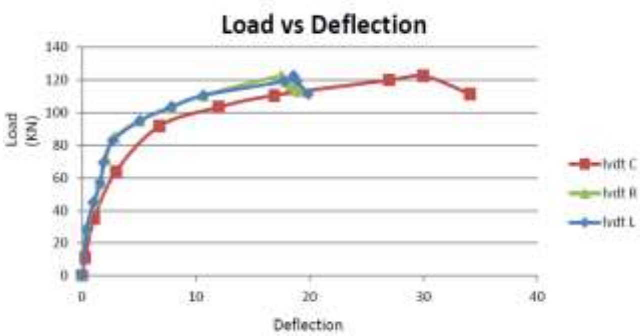

Fig 6.4.1 Load vs deflection graph of IWS specimen

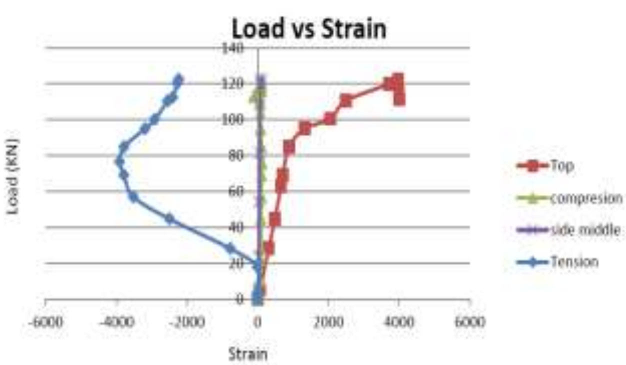

Fig 6.4.2 Load vs Strain graph of IWS specimen

VWS SPECIMEN: This is the cracking pattern of VWS specimen, an Initial crack occur at 54 KN and final crack at 129 KN. The ultimate load is 129 KN. Vertical CFRP stirrups are wrapped at angle 90^o with the width of 100 mm at shear.

Fig 6.5 Cracking pattern of VWS specimen

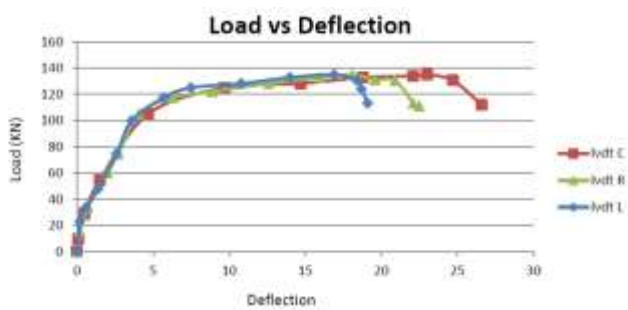

Fig 6.5.1 Load vs deflection graph of VWS specimen

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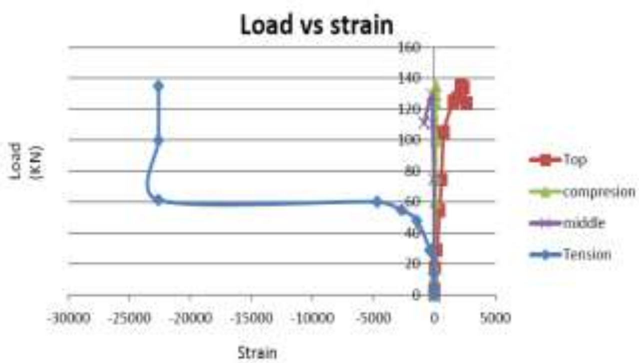


Fig 6.5.2 Load vs Strain graph of VWS specimen

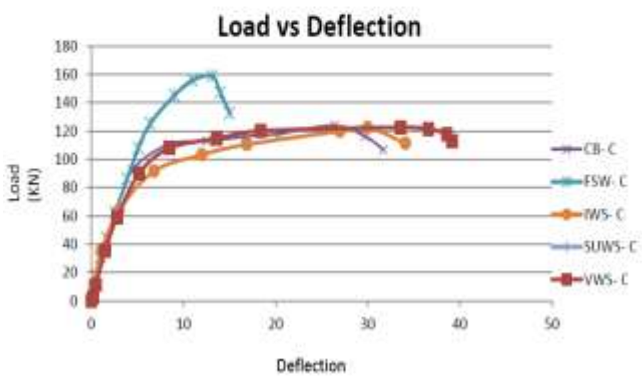
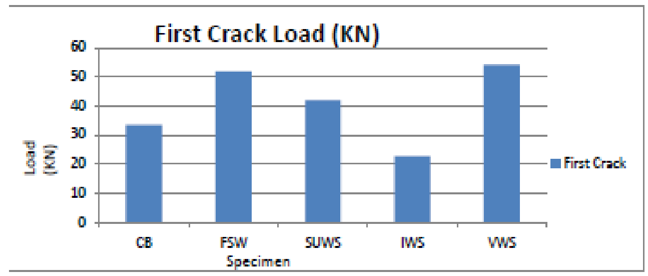
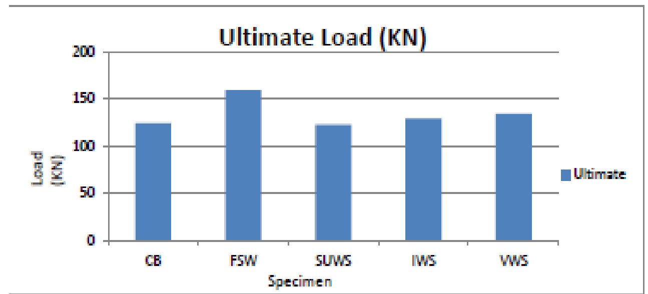


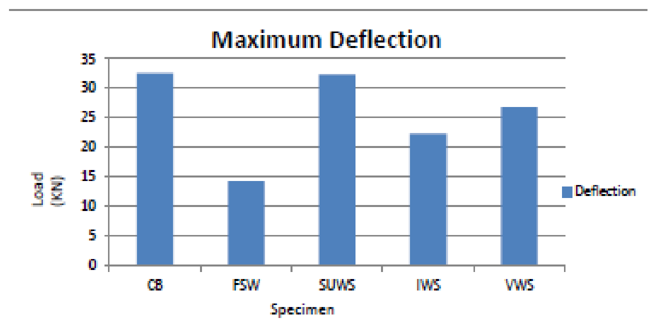
Fig 6.6 Load vs deflection graph of all specimens

Table 6.2 Comparison of Ultimate Load and Maximum Deflection

	SPECIMEN	FIRST CRACK LOAD (KN)	ULTIMATE LOAD (KN)	MAXIMUM DEFLECTION (mm)
1	C B	33.5	123.9	32.6
2	FSW	51.8	158.8	14.3
3	SUWS	41.9	122.6	32.4
4	IWS	22.6	129	22.4
5	VWS	54	133.8	26.8







VII. CONCLUSION

Results of test performed in the present study demonstrated the feasibility of using externally applied epoxy-bonded CFRP wrap is to increase the load-carrying capacity in shear of RC beams. In particular, the following conclusions can be drawn:

1. The use of CFRP can be advantageous, because it is easier to maintain a relatively uniform epoxy thickness throughout the bonding length.
2. Restoring or upgrading beam shear strength using CFRP wrap can result in increased shear strength and stiffness by substantially reducing shear cracking.

3. The results of tests performed in this study indicate that stiffness increases while increasing the CFRP sheet area at the flanks.

4. Maximum shear strength was obtained for the beam FSW compare to other beams.
5. From the all beam specimen FSW specimen deflection is less and load bearing capacity is more.
6. Compare to the control beam FSW specimen increase by 48%, IWS increase by 5% and VWS increased by 9%
7. The magnitude of the increase and the mode of failure are related to the direction of the reinforcing fibers.
8. This was true whether shear cracks in the beam were repaired. When CFRP is wrap to the cracks in the beam.
9. The mode of failure associated with this application of CFRP was more ductile and preceded by warning signs such as snapping sounds or peeling of the CFRP.
10. The results of this study show that CFRP is used to increase the strength and stiffness of beams without causing catastrophic brittle failures associated with this strengthening technique.
11. This experimental study result indicates that we can increase the beam strength with CFRP (Carbon Fiber Reinforced Polymer).

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