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Experimental and Numerical Studies on Behaviour of FRP Strengthened Deep Beams with Openings

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ABSTRACT

Reinforced concrete deep beams are widely used as transfer girders in offshore structures and foundations, walls of bunkers and load bearing walls in buildings. The presence of web openings in such beams is frequently required to provide accessibility such as doors and windows or to accommodate essential services such as ventilating and air conditioning ducts. Enlargement of such openings due to architectural/mechanical requirements and/or a change in the building's function would reduce the element's shear capacity, thus rendering a severe safety hazard. Limited studies have been reported in the literature on the behavior and strength of RC deep beams with openings. When such enlargement is unavoidable adequate measures should be taken to strengthen the beam and counteract the strength reduction. The present experimental investigation deals with the study of deep beams containing openings and the validation of results with FEM model using ANSYS. A total of 5 deep beams with openings are casted without shear reinforcements and are tested under three-point loading. Test specimen has a cross section of 150x460 mm and a total length of 1200 mm. Two circular openings, one in each shear span, are placed symmetrically about the mid-point of the beam. The structural response of RC deep beams with openings was primarily dependent on the degree of the interruption of the natural load path. Externally bonded GFRP shear strengthening around the openings was found very effective in upgrading the shear strength of RC deep beams. The strength gain caused by the GFRP sheets was in the range of 68–125%. Finite element modeling of RC deep beams containing openings strengthened with GFRP sheets is studied using ANSYS and the results are compared with experimental findings.

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***KEYWORDS:** GFRP, FEM, RC DEEP BEAMS, WEB OPENINGS, SHEAR REINFORCEMENTS*

INTRODUCTION

Beams with large depths in relation to spans are called deep beams. As per the Indian Standard, IS 456:2000, Clause 29, a simply-supported beam is classified as deep when the ratio of its effective span L to overall depth D is less than 2. Continuous beams are considered as deep when the ratio L/D is less than 2.5. The effective span is defined as the centre-to-centre distance between the supports or 1.15 times the clear span whichever is less. They are structural elements loaded as simple beams in which a significant amount of the load is carried to the supports by a compression force combining the load and the reaction. As a result, the strain distribution is no longer considered linear, and the shear deformations become significant when compared to pure flexure. Because of their proportions deep beams are likely to have strength controlled by shear rather than flexure. On the other hand, their shear strength is expected to be significantly greater than predicted by the usual equations, because of a special capacity to redistribute internal forces before failure and to develop mechanisms of force transfer quite different from beams of common proportions (Winter and Nelson, 1987).

Deep beams are widely used as transfer girders in offshore structures and foundations, walls of bunkers, load bearing walls in buildings, plate elements in folded plates, pile caps, raft beam wall of rectangular tank, hopper, floor diaphragm and shear walls. With the strong growth of construction work in many developing countries, deep beam design and its behaviour prediction is a subject of considerable relevance. Traditional 2 design assumptions, especially regarding plane section remaining plane after bending for shallow beams, do not apply to deep beams. Even the definition of transition from shallow to deep beam is imprecise in most codes of practice. The ACI 318-99 and CIRIA Guide 2 use span/depth ratio to define RC deep beams while the Canadian code CSA 1994 and CEB-FIP model code employs the concept of shear span/depth ratio. The ACI code defines beams with clear span to effective depth ratios less than 5 as deep beams, whereas CEB-FIP 1993 code treats simply supported and continuous beams having span/depth ratios less than 2 and 2.5 respectively, as deep beams. However it should be noted that the design of these structural elements are not adequately covered by existing codes of practices.

METHODOLOGY

INTRODUCTION

This chapter deals with the design criteria of deep beams. The following are the criterion to design adeep beam as per Indian Standard code (IS 456:2000)

Definition

As per clause 29.1; A beam shall be deemed to be a deep beam when the ratio of effectivespan to overall depth, (l/D)is less than:

- 2.0 for a simply supported beam; and
- 2.5 for a continuous beam.

Lever Arm

As per clause 29.2 the lever arm z for a deep beam shall be determined as below For simply supported beam

$$\begin{cases} z = 0.2(l + 2D) & when\ 1 \le l/D \le 2 \\ z = 0.6l & when\ l/D < 1 \end{cases}$$

For continuous beam

$$\begin{cases} z = 0.2(l + 1.5D) & when\ 1 \le l/D \le 2.5 \\ z = 0.5l & when\ l/D < 1 \end{cases}$$

Where l is the effective span taken as centre to centre distance between supports or 1.15 times theclear span, whichever is smaller, and D is the overall depth.

REINFORCEMENT

As per clause 29.3.1, positive reinforcement is, the tensile reinforcement required to resist positive bending moment in any span of a deep beam shall:

- extend without curtailment between supports;
- Be embedded beyond the face of each support, so that at the face of the support it shall have a development length not less than 0.8 L_d where L_d is the development length for the design stress in the reinforcement; and
- Be placed within a zone of depth equal to$0.25D - 0.05l$adjacent to the tension face of the beam where D is the overall depth and l is the effective span.

As per clause 29.3.2, negative reinforcement is

A. Termination of reinforcement- For tensile reinforcement required to resist negative bending moment over a support of a deep beam:

- It shall be permissible to terminate not more than half of the reinforcement at a distance of 0.5 D from the face of the support where D is as defined in clause 29.2 of IS 456:2000; and
- The remainder shall extend over the full span.

B. Distribution- When the ratio of clear span to overall depth is in the range 1.0 to 2.5, tensile reinforcement over a support of a deep beam shall be placed in two zones comprising:

- A zone of depth 0.2 D, adjacent to the tension face, which shall contain a proportion of the steel given by

$$0.5\left(\frac{l}{D} - 0.5\right)$$

Where,
l is the clear span
D is the overall depth

- A zone measuring 0.3 D on either side of the mid-depth of the beam, which shall contain the remainder of the tension steel, evenly distributed. For span to depth ratios less than unity, the steel shall be evenly distributed over a depth of 0.8 D measured from the tension face.

MINIMUM THICKNESS

The minimum thickness of deep beams should be based on two considerations. First, it should be thick enough to prevent buckling with respect to its span and also its height.

The empirical requirement to prevent bulking can be expressed as follows: D/b<25 and L/b<50

Where „b" is thickness of the beam. Second, the thickness should be such that the concrete itself should be able to carry a good amount of the shear force that acts in the beam without the assistance of any steel.

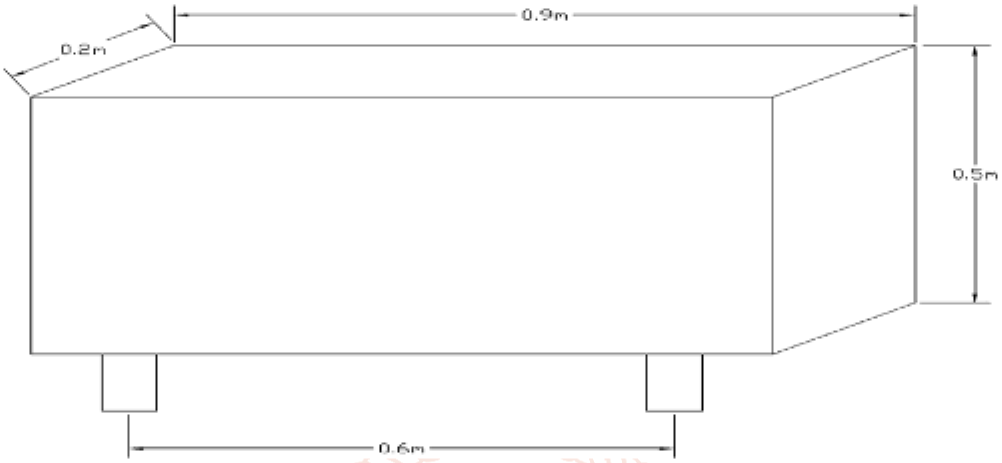
STEPS OF DESIGNING DEEP BEAMS

The important steps in the design of R.C. deep beams are the following:

- Determine whether the given beam is deep according to the definition.
- Check its thickness with respect to buckling as well as its capacity to carry the majorpart of the shear force by the concrete itself.
- Design for flexure.

- Design for the minimum web steel and its distribution in the beam.
- Design for the shear, if the web steel already provided is inadequate, design additionalsteel for shear requirements
- Check safety of supports and loading points for local failure.

DESIGN EXAMPLE
Overall Depth (D) = 0.5m
Width (b) = 0.2m



Overall Length (L) = 0.9m
Effective Span (l) = 0.6m
Clear cover = 25mm
Diameter of steel rods = 16mm
Effective Depth (d) = D-25-(16÷2)
= 500-25-8
= 467mm

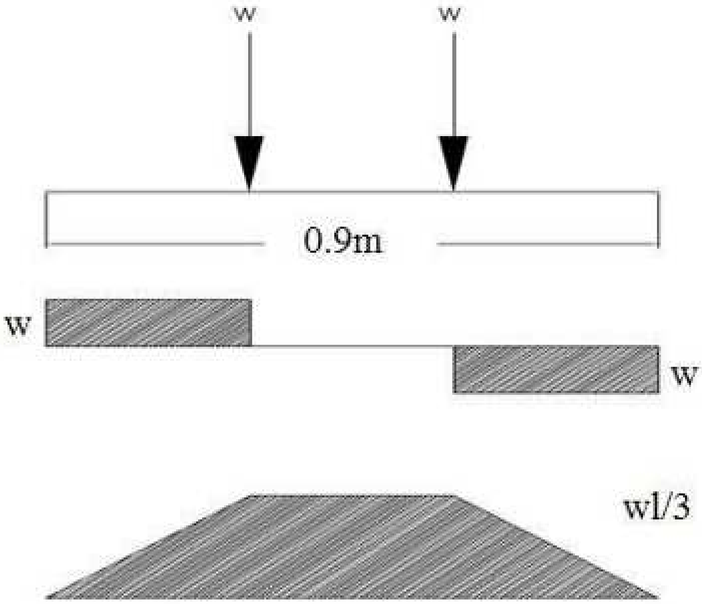


FIG. SFD AND BMD OF THE SHOWN BEAM

Providing concrete grade M_{20} and Fe $415f_{ck}= 20$ N/mm^2

Considering a balance section

Moment of resistance (M_u) = 0.138 $f_{ck}bd^2$
= $0.138\times20\times200\times467^2$
= 120.38 KN m

Equating bending moment = Moment ofresistance Wl/3 = 120.38

W=601.9 KN

1. Calculation of lever arm For
simply supported beam
$z = 0.2(l+2D)$
$= 0.2(0.6+2(0.5))$
$= 0.32m$

Moment of resistance with respect to compression in concrete
$0.87\ f_yA_{st}\ z = M_u$ $0.87\times415\times A_{st}\times320 = 120.3$
8×10^6 $A_{st}=1041.92\ mm^2$

2. Calculation of zone of depth
Zone of depth $= 0.25D-0.05l$
$= (0.25\times0.5-0.05\times0.6)$
$= (0.125-0.03)$
$= 0.095m$

Provide 6 bars of 16mm diameter @ 0.095m from soffit

3. Calculation of minimum horizontal reinforcement
Minimum horizontal reinforcement = 0.002×gross concrete area
$= 0.002\times200\times1000$
$= 400mm^2$
- $200mm^2$ on both the sides Provide 3 bars of 6mm diameter on both the faces @ 120mm c/c

4. Calculation of minimum vertical reinforcement
Minimum vertical reinforcement = 0.0012×gross concrete area
$= 0.0012\times200\times1000$
$= 240mm^2$

- $120mm^2$ on both the sides Provide 5 number of stirrups of 6mm diameter @ 180mm c/c

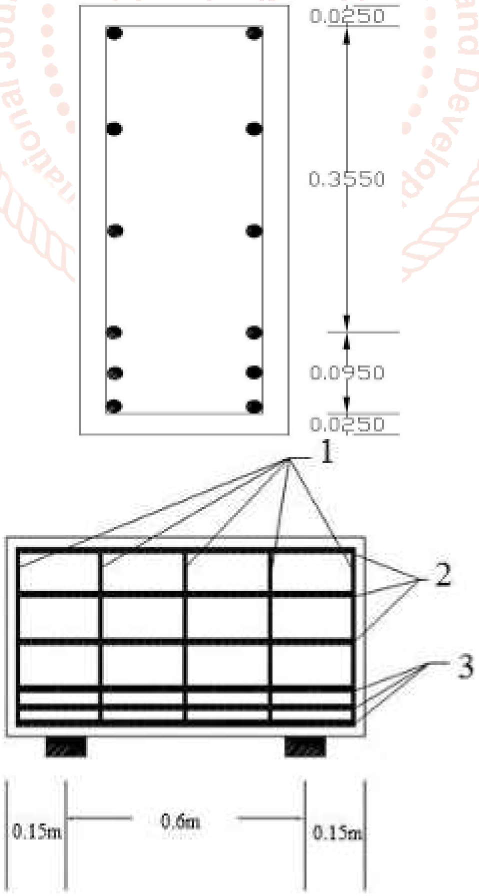


FIG. REINFORCEMENT DETAILING

- 5 no. of stirrups of 6mm diameter @ 180mm c/c.
- 6 no. of 6mm diameter bars @ 120mm c/c.
- 6 no. of 16mm diameter bars spaced equally @ 0.095m from soffit.

CASTING OF BEAMS

Beam Dimensions

As per clause 29 of IS 456:2000 the beam dimensions were finalised as follows:
Length (L) = 1.2 m
Width (b) = 0.15 m Depth (D) = 0.46 m
Effective span (l) = 0.9 m

It has been tested after 28 days with three point loading.

Casting of specimen

For conducting experiment, the proportion of 1: 2: 4 is taken for cement, fine aggregate and course aggregate. The mixing is done by using concrete mixture. The beam is cured for 28 days. Three cubes are casted and are tested after 28 days to determine the compressive strength of concrete for 28 days.

Materials for casting

Cement

Portland Slag Cement (PSC) (Konark Cement) is used for the experiment. It is tested for its physical properties in accordance with Indian Standard specifications. It is having a specific gravity of 2.96.

Fine aggregate

The fine aggregate passing through 4.75 mm sieve and having a specific gravity of 2.67 are used. The grading zone of fine aggregate is zone III as per Indian Standard specifications.

Coarse aggregate

The coarse aggregates of two grades are used one retained on 10 mm size sieve and anothergrade contained aggregates retained on 20 mm sieve. It is having a specific gravity of 2.72.

Water

Ordinary tap water is used for concrete mixing in all the mix.

Concrete properties

Concrete grade = M15
Characteristics strength = 15N/mm^2
Degree of quality control = Good
Degree of exposure = Mild

REINFORCEMENT DETAILING

High-Yield Strength Deformed bars of 12 mm and 8 mm diameter are used for the longitudinal reinforcement and 6 mm diameter bars are used as stirrups. The tension reinforcement consists of 2 no‟s 12 mm diameter HYSD bars. Two bars of 8 mm of HYSD bars are also provided as hang up bars .The detailing of reinforcement of the beam is shown in figure.

GLASS FIBRES

Fibreglass (or glass fibre) (also called glass-reinforced plastic, GRP, glass-fibre reinforced plastic, or GFRP), is a fibre reinforced polymer made of a plastic matrix reinforced by fine fibres of glass. Fibreglass is a lightweight, extremely strong, and robust material. The glass fibres are divided into three classes: E-glass, S-glass and C-glass. The E-glass is designated for electrical use and the S-glass for high strength. The C-glass is for high corrosion resistance, and it is uncommon for civil engineering application. Of the three fibres, the E-glass is the most common reinforcement material used in civil structures.

Although strength properties of glass fibres are somewhat lower than carbon fibre and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favourable when comparedto metals, and it can be easily formed using moulding processes. The plastic matrix may be epoxy, a thermosetting plastic (most often polyester or vinyl ester) or thermoplastic. Common uses of fibreglass include boats, automobiles, baths, hot tubs, water tanks, roofing, pipes, cladding, casts and external door skins.

Typical Properties	E-Glass	S-Glass
Density (g/cm^3)	2.60	2.50
Young's Modulus (GPa)	72	87
Tensile Strength (GPa)	1.72	2.53
Tensile Elongation (%)	2.4	2.9

MIXING, COMPACTION AND CURING OF CONCRETE

Mixing of concrete is done thoroughly with the help of machine mixer so that a uniform quality of concrete is obtained. Compaction is done with the help of needle vibrator in all the specimens and care is taken to avoid displacement of the reinforcement cage inside the form work. Then the surface of the concrete is levelled and smoothened by metal trowel and wooden float. Curing is done to prevent the loss of water which is essential for the process ofhydration and hence for hardening. It also prevents the exposure of concrete to a hot atmosphere and to drying winds which may lead to quick drying out of moisture in the concrete and there by subject it to contraction stresses at a stage when the concrete would notbe strong enough to resists them. Here curing is done by spraying water on the jute bags spread over the surface for a period of 14 days.

STRENGTHENING OF BEAMS

At the time of bonding of fibre, the concrete surface is made rough using a coarse sand paper texture and then cleaned with an air blower to remove all dirt and debris. After that the epoxyresin is mixed in accordance with manufacturer's instructions. The mixing is carried out in a plastic container (100 parts by weight of Araldite LY 556 to 10 parts by weight of Hardener HY 951). After their uniform mixing, the fabrics are cut according to the size then the epoxy resin is applied to the concrete surface. Then the GFRP sheet is placed on top of epoxy resin coating and the resin is squeezed through the roving of the fabric with the roller .Air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface are eliminated.

EXPERIMENTAL SETUP

The Deep beams with holes are tested in the loading frame of the "Structural Engineering" Laboratory of Larsen & Toubro Lab Gopi Krishna Sagar, Guna. The testing procedure for the all the specimen is same. First the beams are cured for a period of 28 days then its surfaceis cleaned with the help of sand paper to make the cracks clearly visible after testing. One point loading arrangement is used for testing of beams.

The load is transmitted through a load cell and spherical seating directly at the midpoint ofthe beam. The specimens placed over the two steel rollers bearing leaving 150 mm fromthe ends of the beam. One dial gauge is used for recording the deflection of the beam and is placed at the center of the beam.

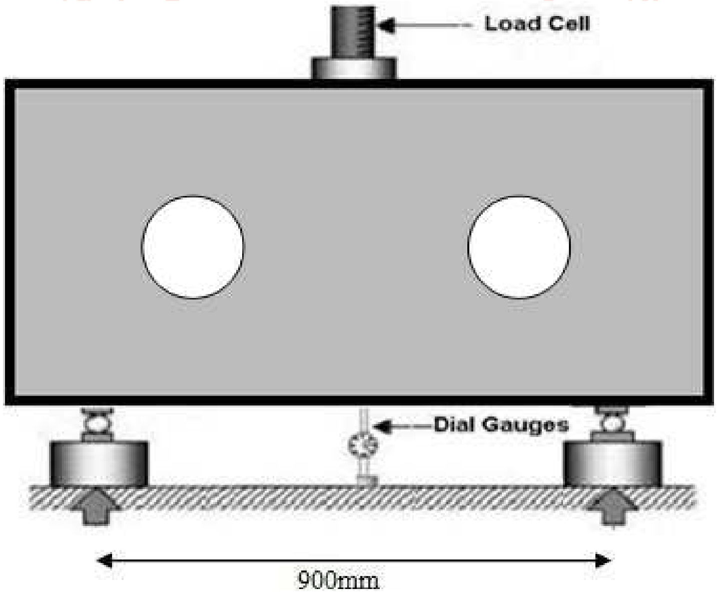


FIG. EXPERIMENTAL SETUP

FABRICATION OF GFRP PLATE

There are two basic processes for molding hand lay-up and spray-up. The hand lay-up process is the oldest and simplest fabrication method. The process is most common in FRP marine construction. In hand lay-up process, liquid resin is placed along with FRP against finished surface. Chemical reaction of the resin hardens the material to a strong light weight product. The resin serves as the matrix for glass fibre as concrete acts for the steel reinforcing rods.

The following constituent materials were used for fabricating plates:
1. Glass Fibre
2. Epoxy as resin
3. Hardener as diamine (catalyst)
4. Polyvinyl alcohol as a releasing agent

A plastic sheet was kept on the plywood platform and a thin film of polyvinyl alcohol was applied as a releasing agent by the use of spray gun. Laminating starts with the application ofa gel coat (epoxy and hardener) deposited in the mould by brush, whose main purpose was toprovide a smooth external surface and to protect fibers from direct exposure from the environment. Steel roller was applied to remove the air bubbles. Layers of reinforcementwere applied and gel coat was applied by brush. Process of hand lay-up is the continuation ofthe above process before gel coat is hardened. Again a plastic sheet was applied by applying polyvinyl alcohol inside the sheet as releasing agent. Then a heavy flat metal rigid platform was kept top of the plate for compressing purpose. The plates were left for minimum 48 hours before transported and cut to exact shape for testing. Plates were casted using two different glass fibres of 2 layers, 4 layers which are closely spaced and the specimen of 2 layers, 4 layers which are largely spaced and are tested.

FIG. SPECIMENS FOR TESTING

No. of layers	Length (cm)	Width (cm)	Thickness (cm)
2(closely spaced)	15	2.3	0.1
4(closely spaced)	15	2.3	0.25
2(largely spaced)	15	2.3	0.3

TABLE. SIZE OF THE SPECIMENS FOR TENSILE TEST

DETERMINATION OF ULTIMATE STRESS

The ultimate stress, ultimate load and young's modulus was determined experimentally by performing unidirectional tensile test on the specimens cut in longitudinal and transverse direction. The dimensions of the specimens are shown in Table 4.2. The specimens were cut from the plates by diamond cutter or by hex saw. After cutting by hex saw, it was polished inthe polishing machine. For measuring the young's modulus, the specimen is loaded in INSTRON 1195 universal tensile test machine to failure with a recommended rate of extension. Specimens were gripped in the upper jaw first and then gripped in the movable lower jaw. Gripping of the specimen should be proper to prevent slippage. Here, it is taken as50 mm from each side. Initially, the stain is kept zero. The load as well as extension was recorded digitally with the help of the load cell and an extensometer respectively. From thesedata, stress versus stain graph was plotted, the initial slope of which gives the Young‟s modulus. The ultimate stress and the ultimate load were obtained at the failure of the specimen.

No. of layers of the specimen	Ultimate stress (MPa)	Ultimate Load (N)	Young‟s modulus(MPa)
Layers(closelyspaced)	172.79	6200	6829.9
Layers(closelyspaced)	209.09	9200	7788.5
Layers(largelyspaced)	268.6	30890	6158
Layers(largelyspaced)	271.48	31221	6224.02

TABLE. RESULT OF THE SPECIMENS

TESTING OF BEAMS

All the five are tested one by one. Four with FRP and one without FRP which is taken as the control Beam .All of them are tested in the above arrangement. The gradual increase in load and the deformation in the strain gauge reading are taken throughout the test. The dial gauge reading shows the deformation. The load at which the first visible crack is developed is recorded as cracking load. Then the load is applied till the ultimate failure of the beam.

FIG. SPECIMEN SHOWING THE CRACK PATTERN (BACK)

Load (KN)	Deflection (mm)at L/2	Remarks
10	0.15	
20	0.23	
30	0.32	
40	0.44	
50	0.54	
60	0.69	
70	0.89	
80	1.12	
90	1.39	1st crack appeared
100	1.69	
110	1.94	
120	2.49	Ultimate load

TABLE. DEFLECTION VALUES OF CONTROL BEAM

FIG. BEAM 2 AFTER TESTING

FIG. FLEXURE CRACK AT THE MIDPOINT OF THE BEAM

FIG. DEBONDING OF GFRP AT 232 KN

Load (KN)	Deflection (mm) at L/2	Remarks
10	0.19	
20	0.28	
30	0.39	
40	0.49	
50	0.59	
60	0.65	
70	0.75	
80	0.86	
90	0.90	
100	1.02	
110	1.13	
120	1.24	
130	1.39	
140	1.57	
150	1.67	
160	1.80	
170	1.94	
180	2.14	
190	2.31	1st crack appeared
200	2.75	
210	3.00	
220	3.10	
232		Ultimate load

TABLE. DEFLECTION VALUES OF BEAM-2

FIG. U-WRAP GFRP WRAPPED AT BEAM 3

FIG. DEBONDING OF GFRP

Load (KN)	Deflection (mm) at L/2	Remarks
10	0.19	
20	0.29	
30	0.39	
40	0.49	
50	0.58	
60	0.64	
70	0.72	
80	0.80	
90	0.88	
100	0.94	
110	1.08	
120	1.19	
130	1.34	
140	1.51	
150	1.62	
160	1.69	
170	1.80	
180	1.93	
190	2.28	
200	2.33	1st crack appeared
210	2.42	
220	2.54	
230	2.74	
240	2.92	Crack started insidethe fibre
270		Ultimate load

TABLE. DEFLECTION VALUES OF BEAM-3

FINITE ELEMENT ANALYSIS

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. ANSYS is a general purpose finite element modelling package for numerically solving a wide variety of problems which includestatic/dynamic structural analysis (both linear and nonlinear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. The Deep beams with tensile reinforcement and without shear reinforcement have been analyzed using a finite element (FE) model in ANSYS. Here, a linear analysis is considered throughout the study by assuming that there is a perfect bonding between reinforcement and the steel.

FINITE ELEMENT MODELLING

SOLID65 is used for the 3-D modelling of solids with or without reinforcing bars (rebar).The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modelling reinforcement behaviour. Other cases for which the element is also applicable would be reinforced composites (such as fibreglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined.

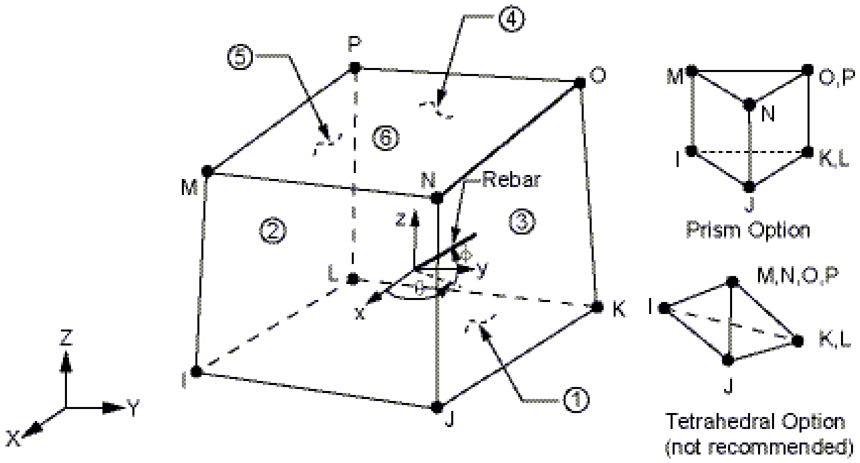


FIG. SOLID65 ELEMENT

STEEL REINFORCEMENT.

To model concrete reinforcing, discrete modelling is used by assuming that bonding between steel and concrete is 100 percent. BEAM188 is used as reinforcing bars, it is a quadratic beam element in 3-D. BEAM188 has six degrees of freedom at each node. These include translations in the x, y, and z directions and rotations about the x, y, and z directions. This element is well-suited for linear, large rotation, and/or large strain nonlinear applications.

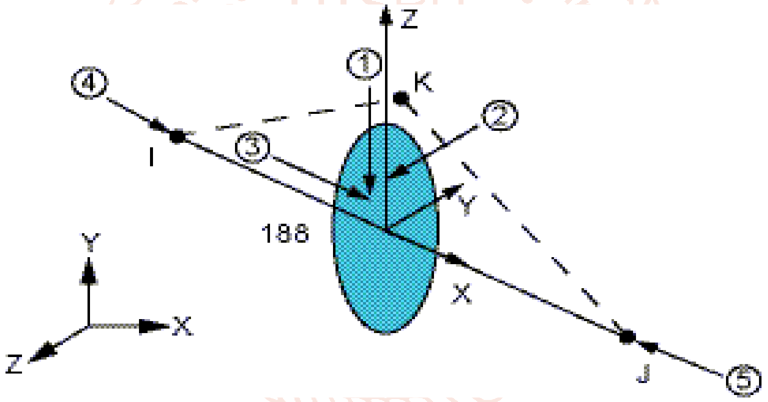


FIG. BEAM188 ELEMENT

STEEL PLATES

To model supports and under the load steel plate is used, which SOLID 45 is used, it is used for the 3-D modelling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

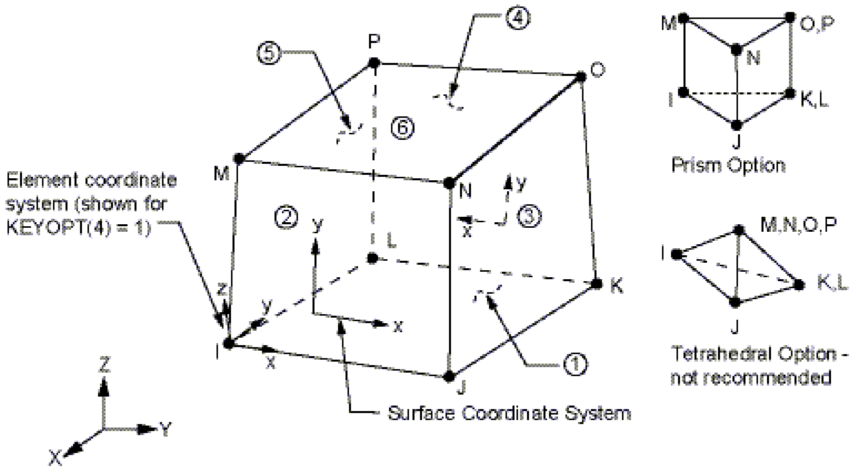


FIG. SOLID45 ELEMENT

LAMINATES

To model laminated composites SHELL 91 is used. It may be used for layered applications ofa structural shell model or for modelling thick sandwich structures. Up to 100 different layers are permitted for applications with the sandwich option turned off. When building a model using an element with *fewer* than three layers, SHELL 91 is more efficient than SHELL 99.

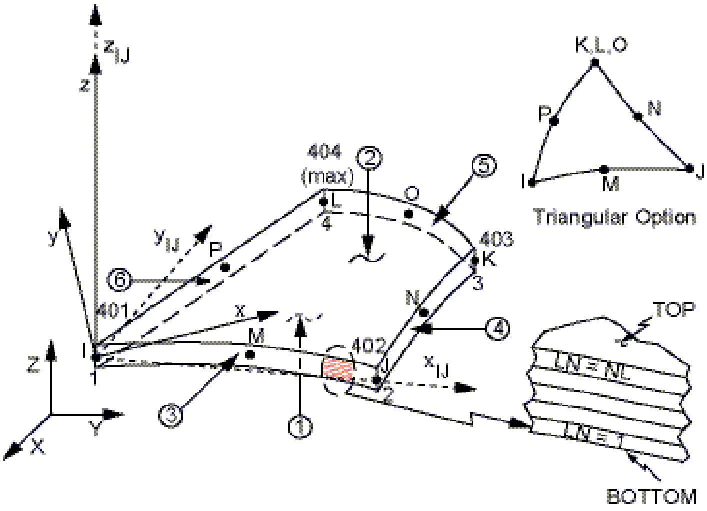


FIG. SHELL91 ELEMENT

MATERIAL PROPERTIES.

Linear analysis is considered for modelling of deep beam with openings, summarizes thematerial linear properties and elements used in the modelling.

Materials	Density (kg/m3)	Elastic Modulus (MPa)	Poison's ratio	Fc28 (MPa)	Fy (MPa)	Element Used
Concrete	2400	19364	0.17	15	-	SOLID65
Reinforcing Steel	7850	210000	0.27	-	415	BEAM188
Steel Plate	7850	210000	0.27	-	415	SOLID45

TABLE. MATERIAL PROPERTIES AND ELEMENTS USED IN THE MODELLING.

GEOMETRY AND LOADING CONDITIONS.

Simply supported beam is considered having and overall length of 1200 mm with effective length of 900 mm. Size of the beam is 150 x 460 mm. Figure 5.5 shows the control beam with boundary conditions used in the analysis. Single point loading is applied at the midpoint of the beam. To get the accuracy of results mesh size considered as 25 mm as edge length.

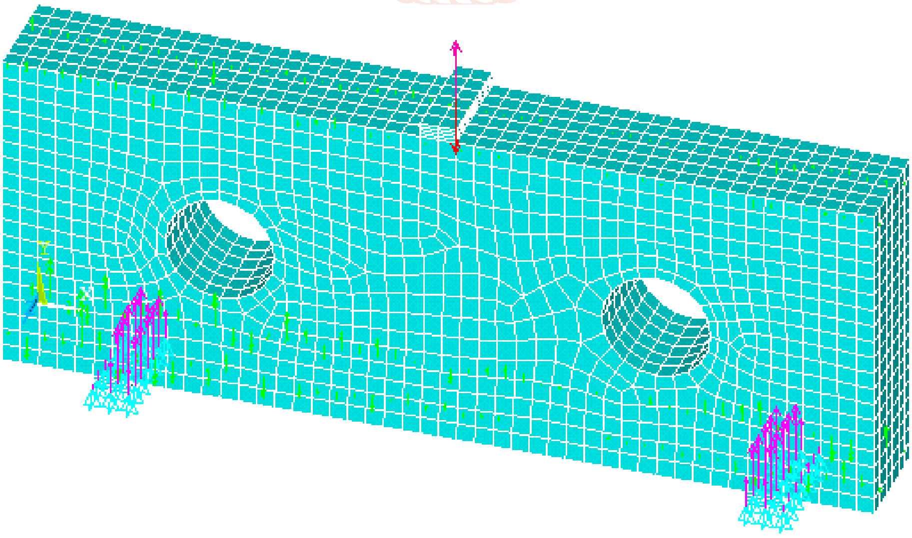


FIG. DEEP BEAM MODEL IN ANSYS

High-Yield Strength Deformed bars of 12 mm and 8 mm diameter are used for the longitudinal reinforcement and 6 mm diameter bars are used as stirrups. The tension reinforcement consists of 2 no"s 12 mm diameter HYSD bars. Two bars of 8 mm of HYSD bars are also provided as hang up bars .The detailing of reinforcement of the beam is shown in figure 5.6 and figure 5.7 shows the deep beam model with FRP.

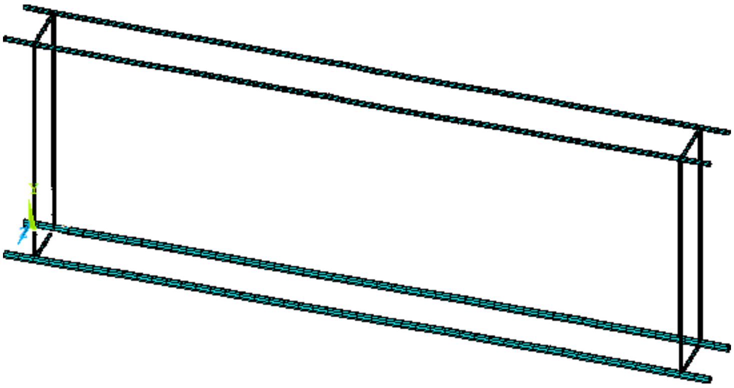


FIG. REINFORCEMENT MODEL IN ANSYS.

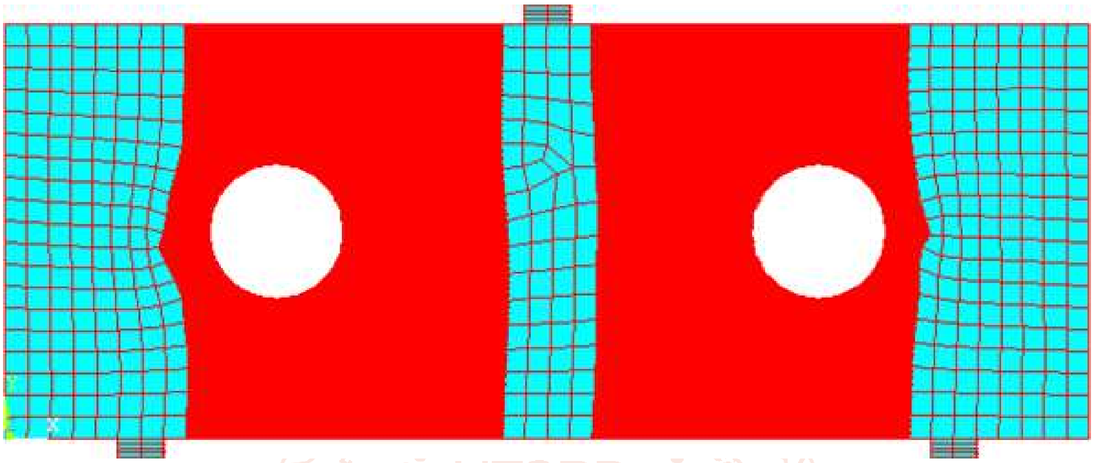


FIG. DEEP BEAM MODEL WITH FRP IN ANSYS.

RESULTS AND DISCUSSIONS

INTRODUCTION

In this chapter the experimental results of all the beams with different types of layering of GFRP are interpreted. Their behavior throughout the test is described using recorded data on deflection behavior and the ultimate load carrying capacity. The crack patterns and the mode of failure of each beam are also described in this chapter. All the beams are tested for their ultimate strengths.Beams-1 is taken as the control beam. It is observed that the control beam had less load carrying capacity when compared to that of the externally strengthened beams using GFRP sheets.

All the beams except the control beam are strengthened at clear shear span with GFRP sheets in different patterns. Beam-2 is strengthened using double layer u-wrap of GFRP(closely spaced) and similarly beam -3 is strengthened using four layer u-wrap of GFRP(closely spaced) sheets. Beam-4 is strengthened using double layer full wrap of GFRP(largely spaced)and beam-5 is strengthened using four layer full wrap of GFRP(largely spaced) sheets.

FAILURE MODES

The following failure modes are investigated for a GFRP strengthened section:

- Debonding of the FRP from the concrete substrate (FRP debonding).
- Rupture of FRP sheets.
- Shear failure.
- Flexure failure.

A number of failure modes have been observed in the experimental study of RC deep beams with openings strengthened in shear by GFRPs. These include shear failure, shear failure due to GFRP rupture and crushing of concrete at the top and failure in flexure. Rupture of the FRP laminate is assumed to occur if the strain in the FRP reaches its design rupture strain before the concrete reaches its maximum usable strain. GFRP debonding can occur if theforce in the FRP cannot be sustained by the substrate. In order to prevent debonding of the GFRP laminate, a limitation should be placed on the strain level developed in the laminate.

The GFRP strengthened beam and the control beams are tested to find out their ultimate load carrying capacity. It is found that all the beams failed in shear and some in flexure. Thebeams which failed in shear showed frame type failure which occurs by the formation of two independent diagonal cracks one in each member bridging the two solid beam segments leadsto failure.Beam-2 and beam-3 failed due to debonding of GFRP sheet followed by shear cracks and a flexure crack at the midpoint of the beam. Beam-4 failed due to rupture of GFRP sheets followed by shear cracks and a flexure crack at the midpoint of the beam.Beam-5 failed due to rupture and debonding of GFRP sheets followed by shear cracks and a flexure crack at the midpoint of the beam.

LOAD DEFLECTION ANALYSIS

Here the deflection of each beam at different positions is analyzed. Linear analysis of beamsis done in ANSYS and mid-span deflections of each beam are compared with ANSYS model.Also the load deflection behavior is compared between different wrapping schemes havingthe same reinforcement. It is noted that the behavior of the shear deficient beams when bonded with GFRP sheets are better than the control beams. The use of GFRP sheet hadeffect in delaying the growth of crack formation.

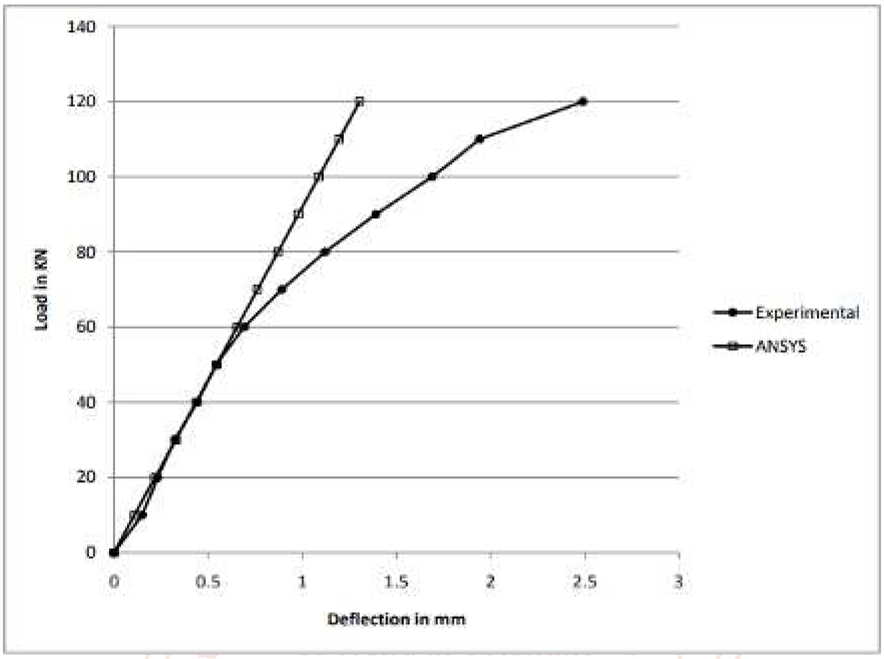


FIG. LOAD VS DEFLECTION CURVE

Beam 1 is taken as the control beam which is weak in shear. In Beam1 no strengthening is done. Three point loading is applied on the beam and at the each increment of the load, deflection values at L/2 are taken with the help of dial gauge. Using this load and deflection data, load vs. deflection curve is plotted. At the load of 90 KN first crack appeared. Laterwith the increase in loading values the crack propagated further. The Beam1 failed completely in shear showing frame type failure. Since liner FEM model is being adopted, the deflections obtained using ANSYS are in good agreement for lower range of load values when compared with experimental results.

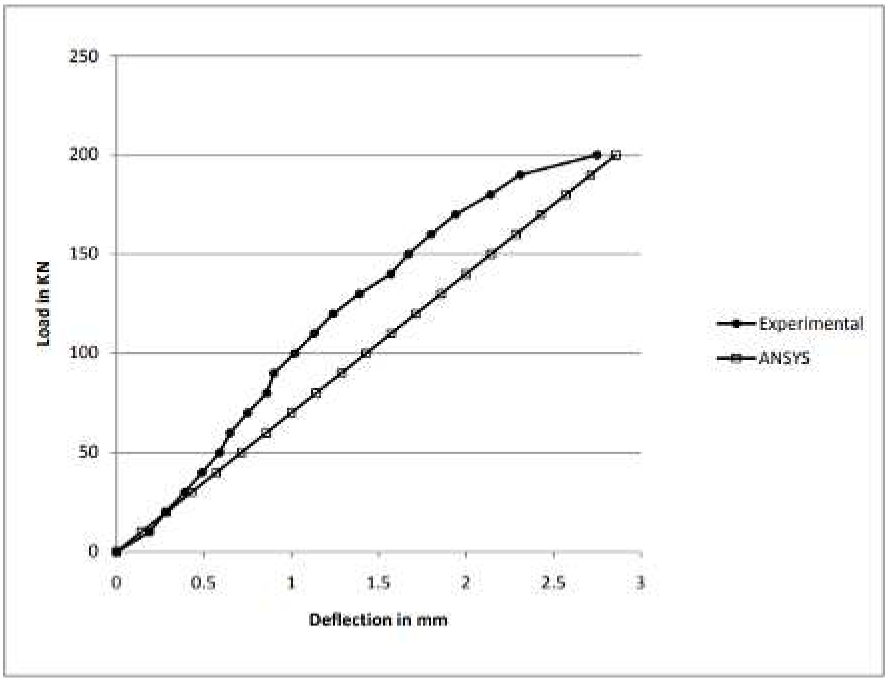


FIG. LOAD VS. DEFLECTION CURVE FOR BEAM-2.

Beam-2 is strengthened using double layer u-wrap of GFRP(closely spaced).Three point loading is applied on the beam and at the each increment of the load, deflection values at L/2 are taken with the help of dial gauge. Using this load and deflection data, load vs. deflection curve is plotted. At the load of 190 KN initial hairline cracks appeared. Later with the increase in loading values the crack propagated further. Beam-2 failed due to debonding of GFRP sheet followed by shear cracks and a flexure crack at the midpoint of the beam. Since liner FEM model is being adopted, the deflections obtained using ANSYS are in goodagreement for lower range of load values when compared with experimental results.

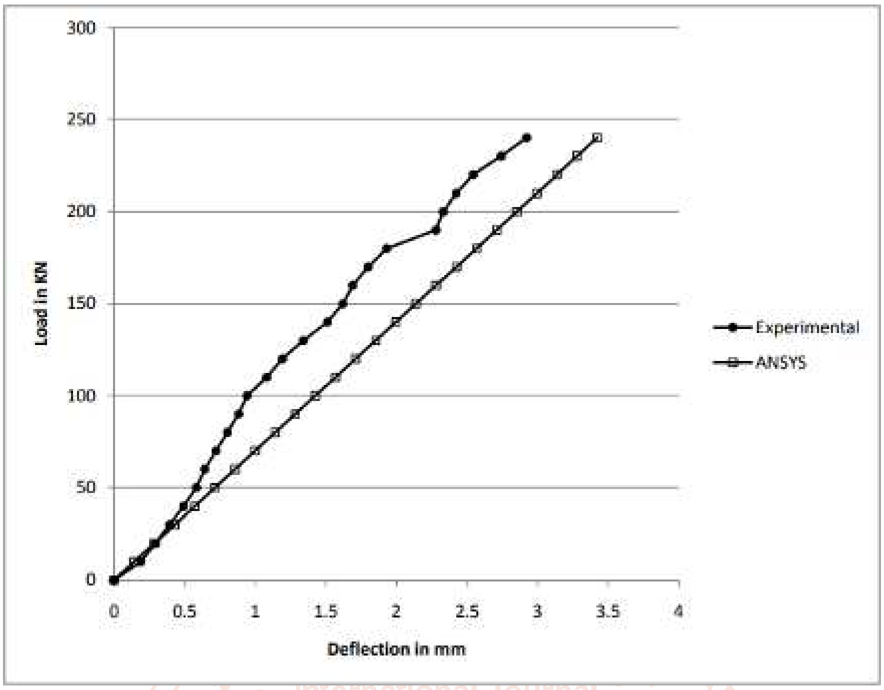


FIG. LOAD VS. DEFLECTION CURVE FOR BEAM-3.

Beam-3 is strengthened using four layer u-wrap of GFRP(closely spaced).Three point loadingis applied on the beam and at the each increment of the load, deflection values at L/2 are taken with the help of dial gauge. Using this load and deflection data, load vs. deflection curve is plotted. At the load of 200 KN initial hairline cracks appeared.

Later with the increase in loading values the crack propagated further. Beam-3 also failed dueto debonding of GFRP sheet followed by shear cracks and a flexure crack at the midpoint of the beam. Since liner FEM model is being adopted, the deflections obtained using ANSYSare in good agreement for lower range of load values when compared with experimental results.

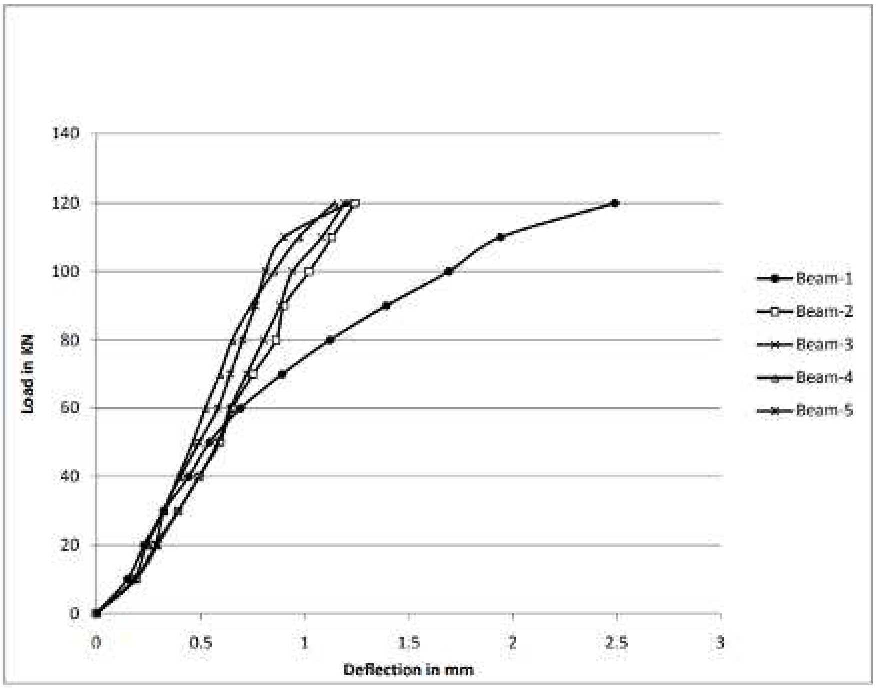


FIG. LOAD VS. DEFLECTION CURVE FOR ALLTHE BEAMS

Here all the beams are compared with respect to their deflection and load data. And it can be interpreted that all the beams which are strengthened, shows less deflection when compared to the control beam. Among all the strengthened beams, beam-4 which is strengthened using double layer full wrap GFRP (largely spaced) sheets shows the minimum deflection.

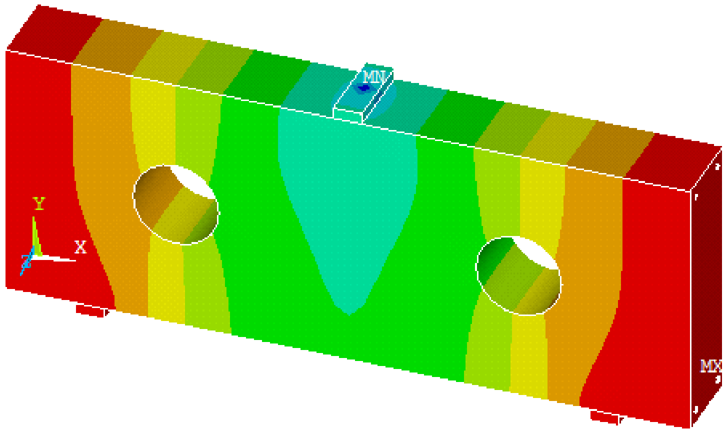


FIG. GENERALIZED DEFLECTION PLOT OFDEEP BEAM MODEL IN ANSYS

ULTIMATE LOAD CARRYING CAPACITY

The load carrying capacity of the control beam and the strengthened beams are plottedbelow. It is observed that beam 3 is having the maximum load carrying capacity.

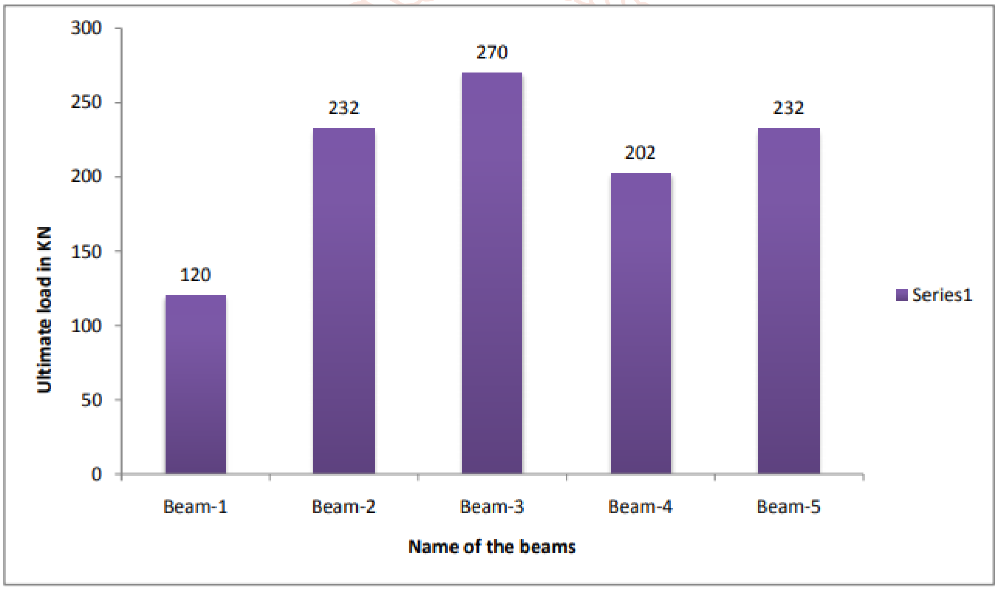


FIG. ULTIMATE LOAD CARRYING CAPACITY

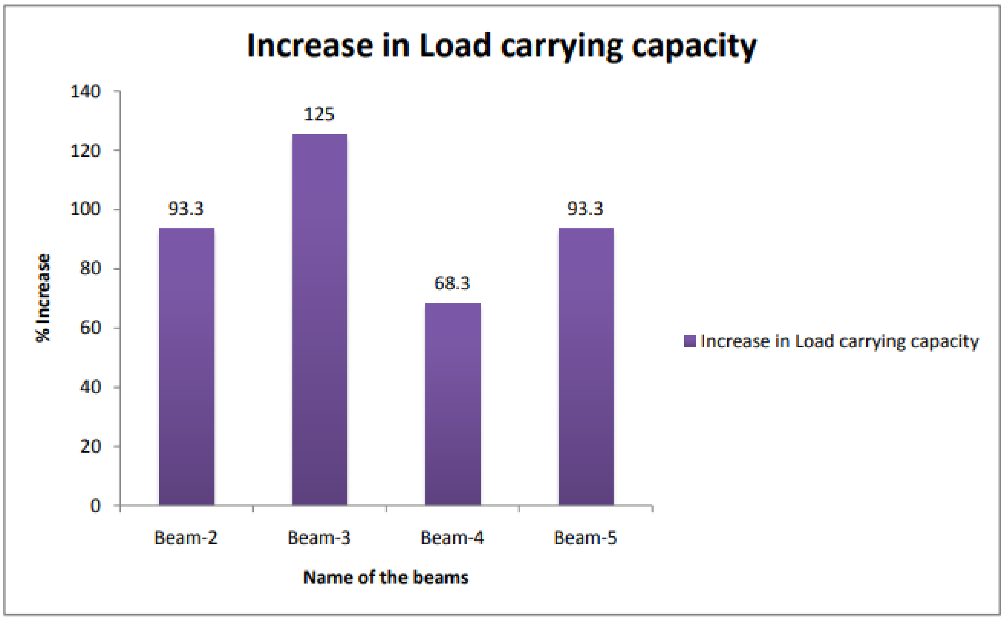


FIG. ULTIMATE LOAD CARRYING CAPACITY

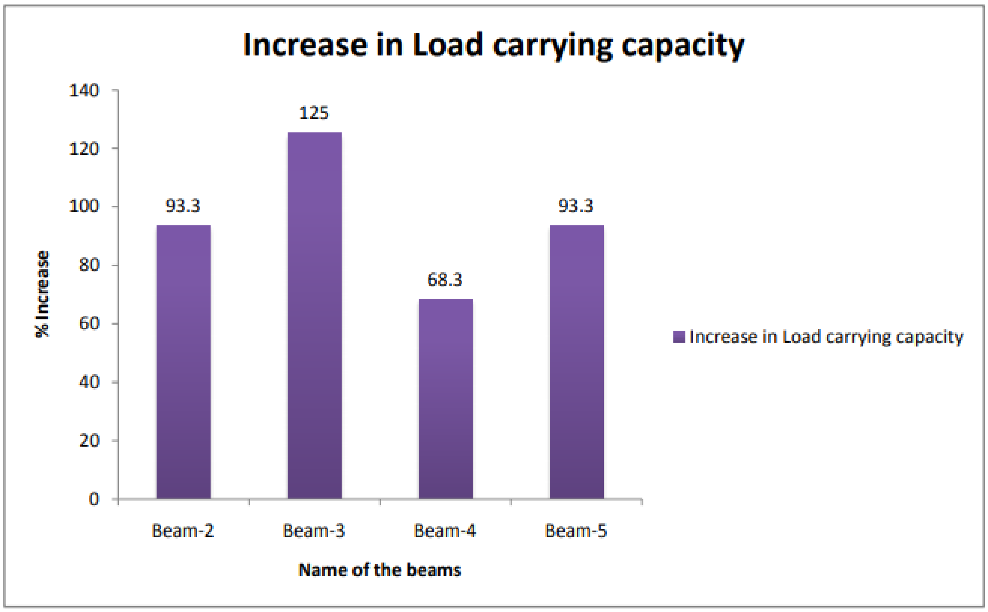


FIG. PERCENTAGE INCREASE IN ULTIMATE CARRYING CAPACITY W.R.T. CONTROL BEAM.

From the above figure we can observe the amount of increase in the strength for eachstrengthened beam with respect to the Control Beam.

CONCLUSIONS AND FUTURE SCOPE

CONCLUSIONS

The present experimental study is done on the shear behavior of reinforced concrete deep beams containing openings strengthened by GFRP sheets. Five reinforced concrete (RC) deepbeams containing openings weak in shear having same reinforcement detailing are casted and tested under three point loading. From the calculated strength values, the following conclusions are drawn:

1. The ultimate load carrying capacity of all the strengthen beams is higher when compared to the control Beam.
2. Initial shear cracks appear at higher loads in case of strengthened beams.
3. The load carrying capacity of the strengthened beam 3 which was strengthened using four layer u-wrap GFRP (closely spaced) was found to be higher when compared to beam 2 which was strengthened using double layer u-wrap GFRP(closely spaced).
4. The load carrying capacity of the strengthened beam 5 which was strengthened using four layer full-wrap GFRP (largely spaced) was found to be higher when compared to beam 4 which was strengthened using double layer full-wrap GFRP(largely spaced).
5. GFRP which is closely spaced showed better load carrying capacity when compared toGFRP which is largely spaced.
6. In lower range of load values the deflection obtained using ANSYS models are in good agreement with the experimental results. For higher load values there is a deviation with the experimental results because linear FEM has been adopted inANSYS modeling.

SCOPE OF THE FUTURE WORK

Strengthening of deep beams containing openings with different type of FRP (like carbon fibre reinforced polymer).Studying the shear behavior of deep beams with openings by varying the opening locations. Deboning of FRP can be prevented by anchoring the beams using steel plates.

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