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An Experimental Investigation on Effect of GFRP Sheets on Deep Beams

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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.

Keywords:- Beam, GFRP, Laps and joints, FRP

1.0. INTRODUCTION

1.1. DEEP BEAM

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 Continuous beams are consid[1]ered as deep when the ratio L/D is less than 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.

Fig. 1.1 Deep Beam without openings

1.2. DEEP BEAM WITH OPENINGS

Large openings through structural members are frequently required for mechanical and electrical conduits or even for means of passageways, such as openings for doors and hallways in buildings. Openings in deep beams may be desired for such things as windows and doors, or for passage of utility lines and ventilation ducts

1.3. FIBRE REINFORCED POLYMER (FRP)

High strength non-metallic fibres, such as carbon, glass and aramid fibres, encapsulated in a polymer matrix in the form of wires, bars, strands or grids have shown great potentials as reinforcement for concrete, particularly where durability is of main concern. It is commonly known as fibre reinforced polymer or, in short, FRP

1.3.1. ADVANTAGES OF FRP

FRP materials have higher ultimate strength and lower density as compared to steel. When these properties are taken together they lead to fibre composites having a strength/weight ratio higher than steel plate in some cases. The lower weight of FRP makes installation and handling significantly easier than steel. [3] These properties are particularly important when installation is done in cramped locations. Other works like works on soffits of bridges and building floor slabs are carried out from man-access platforms rather than from full scaffolding.The availability of long lengths and the flexibility of the material also simplify installation:

- Laps and joints are not required
- The material can take up irregularities in the shape of the concrete surface
- The material can follow a curved profile; steel plate would have to be pre-bent to the required radius.
- The material can be readily installed behind existing services
- Overlapping, required when strengthening in two directions, is not a problem because the material is thin.

1.4. IMPORTANCE OF STRENGTHENING

As infrastructures have aged, interest in the need for an effective means to rehabilitate concrete structures has increased. One of the most challenging tasks in this regard is to upgrade the overall capacity of the concrete structures in strength and ductility.[1] Recently, composite materials have been widely employed to retrofit concrete structures due to their advantages in non-corrosiveness, high resistance to chemicals, high strength-to-weight ratio, and improved response in fatigue and damping. Concrete columns retrofitted by external steel jackets improved both the shear and bending responses of the members. Recently, fibre reinforced polymer (FRP) materials have been promoted as one of the most promising and economical alternatives for rehabilitating concrete structures.

1.5. OBJECTIVE

The objective of this investigation is to study the shear behaviour of deep beams containing openings loaded up to failure and to study the effects and enhancement of strength in deep beams [2]containing openings when strengthened externally by FRP

2.0. DESIGN OF DEEP BEAM

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

1) 2.0 for a simply supported beam; and
2) 2.5 for a continuous beam.

2.1. 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:

a) extend without curtailment between supports;
b) 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 Ld where Ld is the development length for the design stress in the reinforcement; and
c) 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.
d) 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

2.2. MINIMUM THICKNESS

The minimum thickness of deep beams should be based on two considerations. First,[2] 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 $L/b<50$

2.3. Lever Arm

As per clause 29.2; The lever arm z for a deep beam shall be determined asbelow:
a) For simply supported beams:
Z=0.2(L+2D), when 1<L/d<2 Z=0.6L, when L/d<1
b) For continuous beams:
Z=0.2(L+1.5D), when 1<L/d<2.5
Z=0.5L, when L/d<1
Where *L* is the effective span taken as centre to centre distance between supports or 1.15 times the clear span, whichever is smaller, and *D* is the overall depth.

2.4. Reinforcement

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c) be placed within a zone of depth equal to0.25*D*–0.05*l*adjacent to the tension face of the beam where *D* is the overall depth and *l* is the effective span.

2.5. 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[2] force that acts in the beam without the assistance of any steel.

2.6. Steps of Designing Deep Beams

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

1) Determine whether the given beam is deep according to the definition.
2) Check its thickness with respect to buckling as well as its capacity to carry the major part of the shear force by the concrete itself.
3) Design for flexure.
4) Design for the minimum web steel and its distribution in the beam.
5) Design for the shear, if the web steel already provided is inadequate, design additional steel for shear requirements
6) Check safety of supports and loading points for local failure.
7) If the beams are not top loaded design the special features required for deep beam action under the special loading conditions.
8) Detail the reinforcements according to accepted practice.

3.0. EXPERIMENTAL STUDIES

3.1. 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.[3] 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.

3.2. Materials for casting

3.2.1.Cement

Portland Slag Cement (PSC) 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.

3.2.2.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.

3.2.3.Coarse aggregate.

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

3.2.4.Water.

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

3.3. Concrete Properties.

- Concrete grade = M15
- Characteristics strength = 15 N/mm2
- Degree of quality control = Good
- Degree of exposure = Mild

3.4. 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 figures.

Fig no: 3.4

Fig no: 3.4.1

3.5. Glass Fibres

Fibreglass (or glassfibre) (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 [3][1]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 compared to 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.

3.6. 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. [2]Curing is done to prevent the loss of water which is essential for the process of hydration 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 not be 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.

3.7. 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 epoxy resin 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.During hardening of the epoxy, a constant uniform pressure is applied on the composite fabric surface in order to extrude the excess epoxy resin and to ensure good contact between the epoxy, the concrete and the fabric. This operation is carried out at room temperature. Concrete beams strengthened with glass fibre fabric are cured for 24 hours at room temperature before testing.

4.0. EXPERIMENTAL SETUP

The Deep beams with holes are tested in the loading frame of the "Structural Engineering". The testing procedure for the all the specimen is same. First the beams are cured for a period of 28 days then its surface is 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.

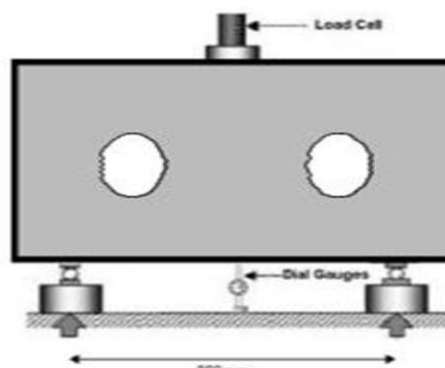

Fig.4.3 : Application of Load

4.1. Fabrication of Gfrp Plate

There are two basic processes for moulding: 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. [1]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

4.2. Testing Of Beams

Fig no: 4.1

Fig no: 4.1.1

4.2. FINITE ELEMENT ANALYSIS

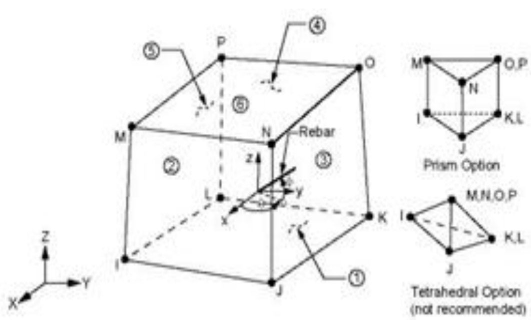

Fig no: 4.2 Finite Element Modelling Reinforced Concrete.

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,[2] 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.

5.0. RESULTS AND DISCUSSIONS

5.1. Load Deflection Analysis

Here the deflection of each beam at different positions is analyzed. Linear analysis of beams is done in ANSYS and mid-span deflections of each beam are compared with ANSYS model. Also the load deflection [2] behavior is compared between different wrapping schemes having the 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 had effect in delaying the growth of crack formation.

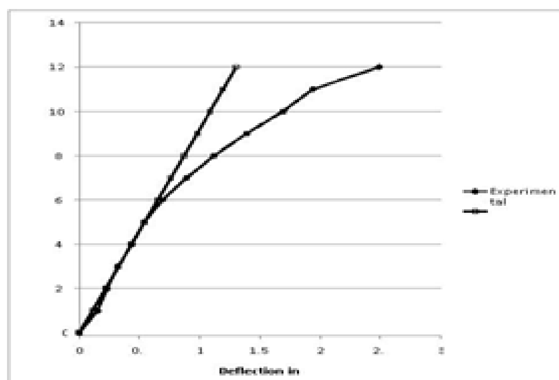

Fig no: 5.1 GFRP sheet had effect in delaying the growth of crack formation.

6.0. CONCLUSION

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 to GFRP 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 in ANSYS modelling.

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