STUDY ON EFFECT OF GFRP SHEETS ON DEEP BEAMS

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Abstract:
Reinforced concrete deep beams serve various structural functions in offshore structures, foundations, bunkers, and buildings. These beams often require web openings for accessibility or to accommodate essential services like ventilation ducts. However, limited research exists on the behavior and strength of RC deep beams with openings. When enlarging openings is necessary, appropriate measures must be taken to strengthen the beam and mitigate strength reduction. This study involves casting and testing five deep beams with openings under three-point loading. The test specimens have a cross-section of 150x460 mm and a total length of 1200 mm, with two circular openings symmetrically placed in each shear span about the beam's midpoint. The structural response of RC deep beams with openings depends significantly on the degree of interruption of the natural load path. External bonding of GFRP sheets around the openings proved highly effective in enhancing the shear strength of RC deep beams, resulting in a strength gain ranging from 68% to 125%.
Keywords: GFRP Sheets, Deep beams, Load-carrying capacity, Shear reinforcements

Introduction:

Deep beams are structural elements with large depths relative to their spans, classified as such by Indian Standard IS 456:2000, Clause 29. According to this standard, simply-supported beams are deep when the ratio of effective span L to overall depth D is less than 2, while continuous beams are considered deep when L/D is less than 2.5. Effective span is defined as the center-to-center distance between supports or 1.15 times the clear span, whichever is less. Deep beams carry significant loads to supports through compression forces, resulting in nonlinear strain distribution and significant shear deformations compared to pure flexure. Due to their proportions, deep beams are often governed by shear rather than flexure. Despite this, there is limited research on deep beams with openings, which are often necessary for mechanical and electrical conduits, passageways, or utility lines and ventilation ducts.

By incorporating openings in deep beams to accommodate utilities, there is potential for reducing the overall building storey height. High-strength non-metallic fibers, such as carbon, glass, and aramid fibers, embedded in a polymer matrix in the form of wires, bars, strands, or grids, have shown significant promise as reinforcements for concrete, particularly where durability is paramount. Commonly referred to as fiber-reinforced polymer (FRP), this material offers exceptional lightweight properties, extraordinary strength, and high corrosion resistance, making it an appealing choice for structural rehabilitation. Furthermore, its availability in thin sheet form minimizes alterations to existing member dimensions. The objective of this study is to investigate the shear behavior of deep beams with openings loaded to failure and to assess the effects and strength enhancement of deep beams with openings when externally strengthened with FRP.

Literature Review:

K. Sachan conducted an experimental study on the behavior of fiber-reinforced concrete deep beams, testing a total of 14 concrete deep beams to failure to analyze the effects of fiber content, reinforcement percentage, and loading type. The study concluded that the addition of steel fibers significantly increased the ultimate strength of deep beams.

H. K. Lee investigated the behavior and performance of RC T-section deep beams externally strengthened in shear with CFRP sheets through a series of experimental tests. The study aimed to understand the behavior of reinforced concrete T-section deep beams strengthened with CFRP sheets in shear.

H. S. Kim studied the structural behaviors of deep RC beams under combined axial and bending forces through experimental studies. Specimens with different shear span-to-depth ratios were subjected to axial loads to investigate their effect on the structural behaviors of deep RC beams.

Mohd. Zamin analyzed the behavior, design, and analysis of high-strength reinforced concrete (HSC) deep beams regarding neutral axis variation. Six HSC deep beams were designed and casted with self-compacted concrete (SCC), focusing on the stress-strain distribution along the beam section at mid-span and the variation of the neutral axis within the depth.

T. M. Roberts explored the influence of fibers on the shear failure of deep beams using a test program with 'Duoform' brass-coated fibers. The results demonstrated that steel fibers can prevent shear failure in deep beams.

Experimental Procedure:

Design of Deep Beams: The design process for R.C. deep beams involves several crucial steps:

1. Determine if the given beam qualifies as "deep" according to the defined criteria. Assess its thickness to ensure resistance against buckling and its ability to bear the majority of the shear force through concrete alone.
2. Design the minimum required web steel and determine its distribution within the beam to accommodate flexural loads.
3. Assess the shear capacity of the beam. If the existing web steel is insufficient to meet shear requirements, design additional reinforcement for shear resistance.
4. Verify the safety of supports and loading points to prevent local failures.
5. Check for any potential service openings required in the beam and incorporate them into the design, ensuring they do not compromise the structural integrity.
6. Consider the impact of any external factors, such as environmental conditions or dynamic loads, on the design and reinforcement requirements.
7. Review the design calculations and drawings to ensure compliance with relevant codes and standards.
8. Prepare detailed construction drawings and specifications based on the finalized design.
9. Execute the construction of the deep beams according to the approved design and specifications.

10. Conduct quality control checks during construction to ensure adherence to the design specifications and standards.
11. After construction, conduct comprehensive testing of the deep beams to evaluate their structural performance under various loading conditions.
12. Analyze the test results to validate the design assumptions and identify any areas for improvement or refinement in future designs.

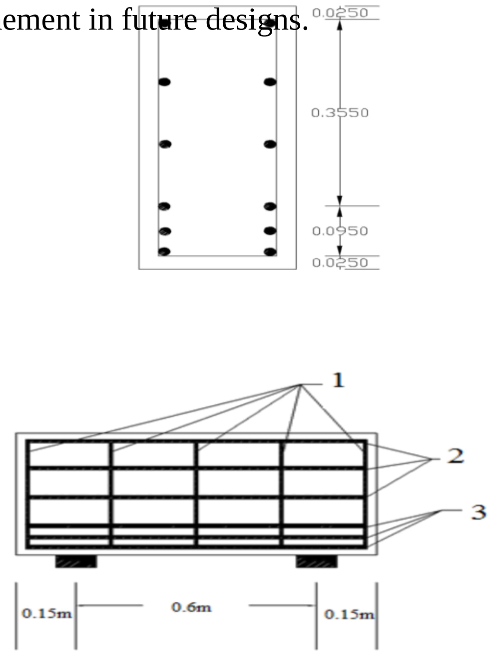

Fig. 3.2 Reinforcement Detailing

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 the soffit.

Materials for Casting:

- Cement: Portland Slag Cement (PSC) (Konark Cement) is utilized for the experiment, tested for its physical properties in accordance with Indian Standard specifications, with a specific gravity of 2.96.
- Fine Aggregate: Fine aggregate passing through a 4.75 mm sieve with a specific gravity of 2.67 is used, graded as zone III per Indian Standard specifications.
- Coarse Aggregate: Two grades of coarse aggregates are used, one retained on a 10mm size sieve and another grade retained on a 20mm sieve, with a specific gravity of 2.72.
- Water: Ordinary tap water is employed for concrete mixing in all the mixes.

Fabrication of GFRP Plate: The fabrication process involves two basic methods: hand lay-up and spray-up. The hand lay-up process, the oldest and simplest method, involves placing liquid resin along with FRP against a finished surface. A plastic sheet is placed on a plywood platform, and a thin film of polyvinyl alcohol is applied as a releasing agent using a spray gun. Laminating begins with the application of a gel coat (epoxy and hardener) deposited in the mold by brush, serving to provide a smooth external surface and protect fibers from direct exposure to the environment. A steel roller is then used to remove air bubbles. Layers of reinforcement are applied, followed by additional gel coat application with a brush. This process continues until the gel coat is hardened. Another plastic sheet, coated with polyvinyl alcohol, is applied inside as a releasing agent, and a heavy, flat metal rigid platform is placed atop the plate for compression purposes. The plates are left for a minimum of 48 hours before being transported and cut to exact shape for testing. Plates are cast using two different glass fiber configurations: 2 layers and 4 layers, closely spaced, and specimens of 2 layers and 4 layers, largely spaced. The dimensions and mechanical properties of GFRP sheets are presented in Tables 1 and 2.

Table 1: Size of the Specimens for Tensile Test

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 2: Results of the Specimens

No. of Layers	**Ultimate Stress (MPa)**	**Ultimate Load (N)**	**Young's Modulus (MPa)**
2 Layers (Closely Spaced)	172.79	6200	6829.9
4 Layers (Closely Spaced)	209.09	9200	7788.5
2 Layers (Largely Spaced)	268.6	30890	6158
4 Layers (Largely Spaced)	271.48	31221	6224.02

Testing of Beams: All five beams are tested one by one, with four using FRP and one without FRP, which serves as the control beam. The testing is conducted in the arrangement described above. The gradual increase in load and the deformation in the strain gauge readings are recorded throughout the test. Dial gauge readings are used to measure deformation. The load at which the first visible crack develops is recorded as the cracking load. Then, the load is applied until the beam fails ultimately. The deflections at the midpoint for the beams with and without GFRP are recorded with respect to the increase in load and are provided in Table 3. The deep beam after casting is depicted in Fig. 1. The ultimate load values and percentage increase in load-carrying capacity are illustrated in Fig. 2 and Fig. 3.

Fig. 1: Deep Beam Specimen for Testing

- Beam 1: Control Beam
- Beam 2: Double-layered U-wrap GFRP (closely spaced) bonded in the clear shear span
- Beam 3: Four-layered U-wrap GFRP (closely spaced) bonded in the clear shear span
- Beam 4: Double-layered Full-wrap GFRP (largely spaced) bonded in the clear shear span
- Beam 5: Four-layered Full-wrap GFRP (largely spaced) bonded in the clear shear span

Results:

Table 3: Deflection and Ultimate Load of Beams

Beam Designation	Yield Load (kN)	Ultimate Load (kN)	Deflection (mm)
Beam 1	90	120	2.49
Beam 2	190	232	3.10
Beam 3	200	270	2.92
Beam 4	150	200	2.85
Beam 5	150	232	2.58

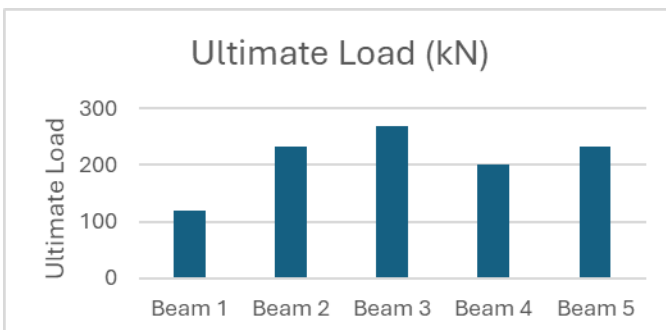

Fig 2 Ultimate Load

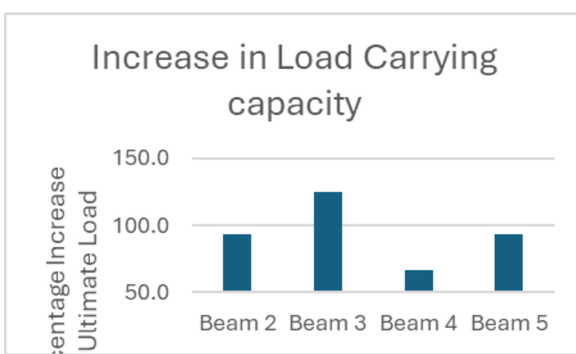

Fig 3: Percentage increase in ultimate carrying capacity w.r.t control beam

Conclusions:

Based on the calculated strength values, the following conclusions can be drawn from the experimental study:

1. The ultimate load carrying capacity of all the strengthened beams is higher compared to the control beam.
2. Initial shear cracks appear at higher loads in the case of strengthened beams.
3. The load carrying capacity of strengthened beam 3, which was reinforced using four layers of u-wrap GFRP (closely spaced), was found to be higher compared to beam 2, which was reinforced using double layers of u-wrap GFRP (closely spaced).
4. The load carrying capacity of strengthened beam 5, which was reinforced using four layers of full-wrap GFRP (largely spaced), was found to be higher compared to beam 4, which was reinforced using double layers of full-wrap GFRP (largely spaced).
5. GFRP reinforcement with closely spaced layers exhibited better load carrying capacity compared to GFRP reinforcement with largely spaced layers.

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