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Experimental analysis of deep beam strengthened by Glass Fiber Reinforced Polymer Plate

Sayali Anil Kedge[1], M.V.Nagendra[2]

[1]PG Student, Civil department, Padmabhooshan Vasantraodada Patil Institute of Technology, Sangli, Maharashtra, India
[2]Associate Professor, Civil department, Padmabhooshan Vasantraodada Patil Institute of Technology, Sangli, Maharashtra, India

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Abstract - *The rapid development in construction industry increasing demand for new innovative material as a part of construction industry. Reinforced concrete deep beams had many useful applications particularly in tall buildings, foundations & offshore structures. Deep beams are often used as structural member in civil engineering works. Generally they are used as load transferring elements such as transfer girders, folded plates & foundation walls. IS 456-2000 page no. 51 clause no. 29.1 said about the deep beam that, the beams with span to depth ratio less than 2.5 for continuous beam as less than 2.0 for simply supported beam is considered as deep beam. Currently a great deal of research is being conducted concerning the use fiber reinforced plastic wraps, sheets in repair and strengthening of RC members. FRP application is very effective way to repair and strengthen structure which is become weak structurally over their life span. Experimental investigation on the flexural and shear behavior of RC deep beams strengthened using continuous glass fiber reinforced polymer plate (GFRP) sheets are carried out. Externally bonded RC deep beam with epoxy-bonded GFRP sheets were tested to failure. Two point static loading system used for the experiment. Two sets of beams were fabricated and tested up to failure. In SET I three beams strengthened in flexure were casted, out of which one is controlled beam and other two beams were strengthened using continuous glass fiber reinforced polymer (GFRP) sheets in flexure. In SET II three beams strengthened in shear were casted, out of which one is the controlled beam and other two beams were strengthened by using continuous glass fiber reinforced polymer (GFRP) sheets in shear.*

Experimental data on load, failure modes of each beam were obtained.

Key Words: Deep beam, glass fibre Reinforced polymer plate, epoxy resin

1. INTRODUCTION

1.1 Deep beam

Deep beams are often used as structural members in Civil Engineering works. Because of the geometric proportions of deep beams, their strength is usually controlled by shear rather than flexure, if normal amounts of reinforcements are provided. Reinforced concrete (RC) deep beams are generally used as load-transferring elements, such as transfer girders folded plates, and foundation walls. In buildings, a deep beam or transfer girder is used when a lower column on the exterior façade is removed for architectural purposes. In construction, deep beams are widely used in water tanks, underground bunkers, silos, nuclear reactors, etc., where walls act as vertical beams spanning between column supports. Sometimes pile caps are also designed as deep beams. Indian Standard Code IS:456-2000 (page no.51 , clause no.29.1) the beams with span to depth ratios less than 2.5 for continuous span and less than 2.0 for simply supported span are considered as deep beams.

1.2 Glass Fiber Reinforced Polymer

FRP can be applied to strengthen the beams, columns, and slabs of buildings and bridges. It is possible to increase the strength of structural members even after they have been

severely damaged due to loading conditions. In the case of damaged reinforced concrete members, this would first require the repair of the member by removing loose debris and filling in cavities and cracks with mortar or epoxy resin. Once the member is repaired, strengthening can be achieved through the wet hand lay-up process of impregnating the fiber sheets with epoxy resin then applying them to the cleaned and prepared surfaces of the member.

Glass fibers, also known commercially as 'fiberglass', are most extensively use reinforcements for polymer matrix composites due to their combination of low cost, high strength and relatively low density. Unlike carbon or Kevlar fibers glass fibers are isotropic thus avoiding loss of properties when loaded in the transverse direction. Fiberglass is produced by pulling molten glass through orifices at a temperature where the glass has just the right amount of viscosity.

1.2 Epoxy Resin

Epoxy resins are relatively low molecular weight pre-polymers capable of being processed under a variety of conditions. Epoxy resins are characterized by the presence of a three-member ring containing two carbons and an oxygen (epoxy group or epoxide or oxirane ring).

2. LITERATURE REVIEW

Vengatachalapathy.V, Ilangovan R. (2010): Paper on "A study on steel Fibre reinforced concrete deep beams with and without openings". This experimental study deals with the behavior and ultimate strength of steel fiber reinforced concrete (SFRC)deep beams with and without openings in web subjected to two point loading, nine concrete deep beams of dimensions 750mm×350mm×75mm thickness were tested to destruction by applying gradually increased load. Simply supported conditions were maintained for all the concrete deep beams. The percentage of steel fiber was varied from 0 to 1.0.The influence of fiber content in the concrete deep beams has been studied by measuring the deflection of the deep beams and by observing the crack patterns. The investigation also includes the study of steel fiber reinforced concrete deep beams with web reinforcement with and without openings. The ultimate loads obtained by applying the modified Kong and Sharp's formula of deep beams are compared with the experimental values. The above study indicates that the location of openings and the amount of web reinforcement, either in the form of discrete fibers or as continuous reinforcement are the principal parameters that affect the behavior and strength of deep beams. The conclusions can be drawn from the experimental results are obtained. Web openings may be provided in the compression zone of the beams and fiber content of 0.75%by volume may be added to improve the strength of the structure. The openings in the tension zone weaken the beam. Fiber content of 0.75%by volume of the beam improves the ultimate load and the first crack load of the beam. Additional of steel fibers increase the tensile strength of concrete matrix and also increase in the flexural rigidity of the beam.

D.N. Shinde, Pudale Yojana M, Nair Veena V (2014), Existing concrete structures may, for a variety of reasons, be found to perform unsatisfactorily. This could manifest itself by poor performance under service loading, in the form of excessive deflections and cracking, or there could be inadequate ultimate strength. Additionally, revisions in structural design and loading codes may render many structures previously thought to be satisfactory, noncompliant with current provisions. In the present economic climate, rehabilitation of damaged concrete structures to meet the more stringent limits on serviceability and ultimate strength of the current codes, and strengthening of existing concrete structures to carry higher permissible loads, seem to be a more attractive alternative to demolishing and rebuilding. This paper investigates the Flexural behavior of R.C.C. beam wrapped with GFRP Glass Fiber Reinforced Polymer) sheet. A total 8 beams, with (150×150) mm rectangular cross section and of span 700 mm were casted and tested. Three main variables namely, strength, ductility and damage level of R.C.C. under reinforced beam and R.C.C. beam weak in flexure were investigated. In first set of four R.C.C. under reinforced beams two were strengthened with GFRP sheet in single layer from tension face which is parallel to beam axis subjected to static loading tested until failure; the remaining two beams were used as a control specimen. In second set of four beams weak in flexure two were strengthened with GFRP sheet tested until failure; the remaining two were used as a control specimen. Comparison has been made between results of two sets.[Ref.3]

Swami P.S, Patil S.S, Kore P.N (2015): Carried out study on "Behavior of concrete deep beams with high strength reinforcement" They state that the high performance reinforcement continues to gain wider acceptance in industry practice, due to improved mechanical properties of new materials. For decades, methods of design and analysis of concrete members reinforced with normal strength steel have been developed. Recently, reinforcing steel (550 & 550) with strength higher than conventional steel has become commercially available. The introduction of high strength reinforcing steel can be useful to reduce the quantity of reinforcement required, thereby lessening reinforcement congestion and improving constructability. This paper presents construction and testing of several high strength reinforced concrete deep beams which includes three beams, designed for three different country codes, for each shear span to depth ratio as described and the test data is presented. The beam consists of simple span subjected to two point loading, each span being 0.7 m in length. The shear span to depth ratios ranged from 0.62 to 0.77. From the data revealed by the analysis, design and experimental work following conclusions are summarized Failure of deep beams was mainly due to diagonal cracking and it was along the lines joining the loading points and supports. The cracks pattern and failure mechanisms for deep beams reinforced with high strength reinforcement were similar to those deep beams with normal strength reinforcing steel. The strength of beams with 250 mm shear span is less than that of 200 mm shear span which means the strength of deep beam is inversely proportional to the shear span for the constant depth of the beam. It is assumed that the arching action of the main tension steel & the web steel together with concrete will carry the shear. All deep beams had low deflection at failure as there was no flexural failure. As reported by F. K. Kong the shear strength of deep beams is 2 to 3 times greater than that given by usual equations. But in this case due to use of high strength reinforcement the shear strength of deep beam is found 6 times greater than design loads.

3. OBJECTIVES

- To study the flexural behavior of reinforced concrete deep beams.
- To study the effect of GFRP strengthening on ultimate load carrying capacity and failure pattern of reinforced deep concrete beams.
- To study the shear behavior of reinforced concrete deep beams.
- To study the effect of GFRP strengthening on the shear behavior of reinforced concrete deep beams.

4. METHODOLOGY

The purpose of this research is to investigate the flexural and shear behavior of reinforced concrete beams strengthened with varying configuration and layers of GFRP sheets. More particularly, the effect of the number of GFRP layers and its orientation on the strength and ductility of beams are investigated. Two sets of beams were fabricated and tested up to failure. In SET I three beams strengthened in flexure were casted, out of which one is controlled beam and other two beams were strengthened using continuous glass fiber reinforced polymer (GFRP) sheets in flexure. In SET II three beams strengthened in shear were casted, out of which one is the controlled beam and other two beams were strengthened by using continuous glass fiber reinforced polymer (GFRP) sheets in shear.

MATERIALS AND EXPERIMENTAL PROCEDURE

To attain objectives, materials were collected from various sources. Material accumulation is the fundamental and vital role in any research work. However, the material that is utilized as a part of a work should not make any harm to the environment. To find out the goal of this examination, the experimental work was completed on eighteen deep beams. The source of the materials utilized for experimental work of the RC deep beam and testing strategies are given in the upcoming article.

4.1 Concrete

The concrete used for casting was prepared in the testing laboratory using a hand mix method of concrete. The concrete was (M25 Grade) with mix proportion adopted was (1:2.01:3.48) with water /cement ratio of 0.50. The material proportions per cubic meter of concrete:

1) 1332.47 kg/m^3 of coarse aggregate (maximum size 20mm)

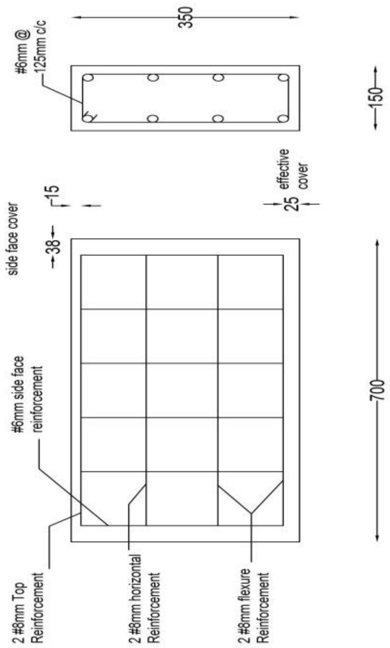
2) 770 kg/m3 of natural river sand (sp.gr =2.66)

3) 383 kg/m^3 of ordinary port land cement (43 grades)

4) 191.5 liters of water

4.2 Details of beam specimen

While reviewing literature of deep beam come to knew that the beam size is 700X150X350 mm. Accorded to the IS (10086-1982) & IS (516-1959) minimum size of specimen for beam mould is 700X150X150mm. There is no specified mould size was found in Indian standard codes, hence select the deep beam size as 700X150X350 mm which satisfies provision of IS (10086-1982) & IS (516-1959).At the same it satisfies IS 456-2000 clause no. 29.1 regarding deep beam.



4.2 Preparation of beam specimens

After all the collection of material next step was go through the specimen making from the collected material. The details of Specimen making is enlisted below.

4.2.1 Casting of Deep Beams Specimens

Six wooden moulds of the same dimensions were fabricated for casting the deep beam specimens to be tested in this study. The moulds were properly cleaned and greased for easy de-moulding after casting. The concrete required for casting was prepared using a concrete hand mix. Before pouring concrete, the reinforcement cages were placed inside the mould with suitable sized cover. The concrete was properly compacted. All the beams were cast to the same dimensions of 350 mm depth, 150 mm width and 700 mm overall length.

Placing of the cage in the mould

Beam cast

4.4 Fabrication Of Plate:

Following materials were used for fabrication of plate:

1. Polyvinyl alcohol as a releasing agent
2. Hardener as catalyst
3. Epoxy as resin
4. E-glass woven sheet as reinforcement

The GFRP sheets were bonded to the specimens after 28 days of casting. Before applying the epoxy, the concrete surface was smoothened and cleaned to insure a good bond between the epoxy glue and the concrete surface. The epoxy was hand-mixed and hand-applied at an approximate thickness of about 1 mm. The bond thickness was not specifically controlled, but the excess epoxy was squeezed out along the edges of the sheet, assuming complete epoxy coverage.

Resin has been applied on primer coat after 24 hours, before fixing the fibers at recommended areas on prepared bottom surface of deep beams. Then allowed for 30 minutes to achieve hardness to attract the newly cut GFRP materials for proper bonding.

Application Of Epoxy Resin

Fixing Of GFRP Plate

4.5 Experimental Set-up for Deep Beams Testing

The testing of deep beams in this work was carried out using a 1000 KN Universal Testing Machine (UTM) that was available at the institution for conducting the experiments. All the deep beam specimens were designed to be of the maximum possible dimensions that the UTM can support during testing. Due to capacity constraints and also due to constraints in increasing the overall depth of the specimen, the loading and support points of the beam were decided on the basis of the maximum available support span. The two point load was applied.

Applying a load on deep beam

Failure and cracks on deep beam strengthened in shear

Data acquisition on UTM for deep beam

5. RESULTS

All the deep beams were tested at UTM machine with capacity of 1000KN and following data were obtained.

Sr. No.	Type of beam	Beam Designation	Ultimate Load	Nature of Failure
1	Beam strengthened in Flexure	F1	105	Shear failure
		F2	135	Flexure + shear failure
		F3	158	Flexure + Shear failure + GFRP rupture
2	Beam strengthened in Shear	S1	102	Shear failure
		S2	144	Shear + flexure failure + GFRP rupture
		S3	182	Shear + Flexural failure + Crushing of concrete

5.1 General Result

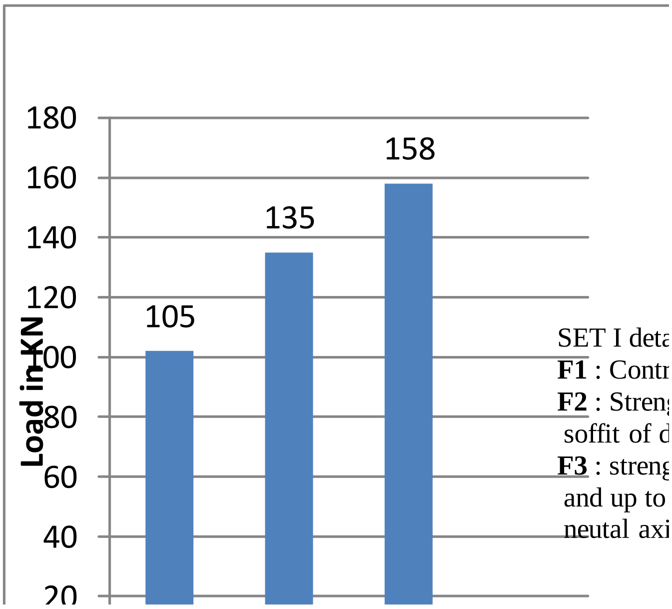
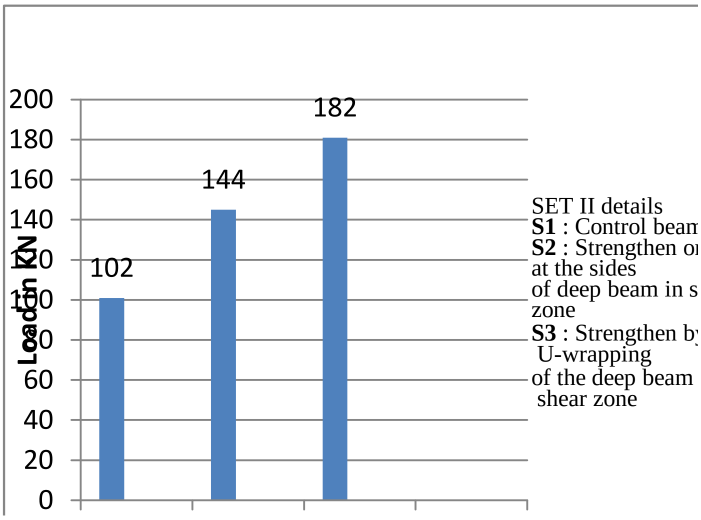
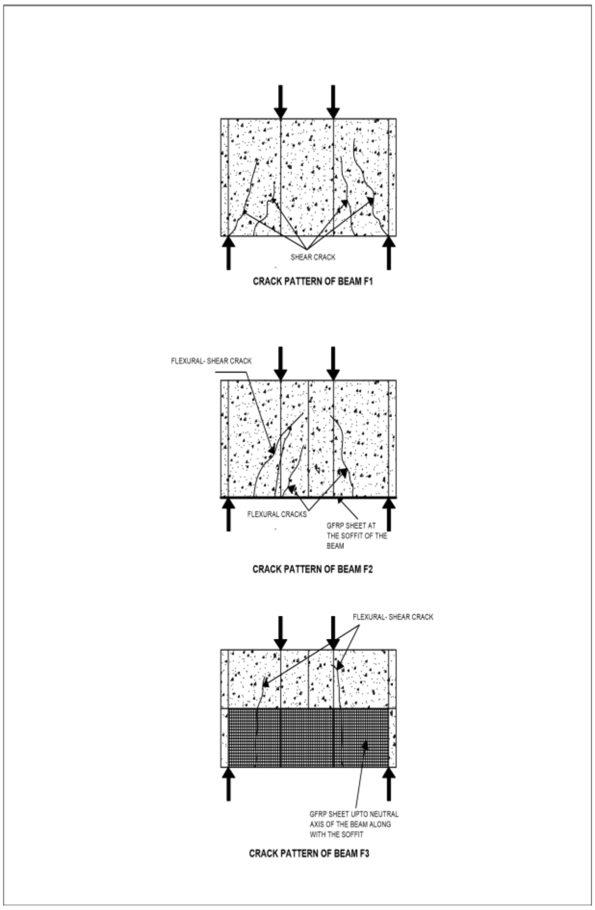


Figure 5.1.1 Ultimate Load Carrying Capacity Of SET I Deep Beam

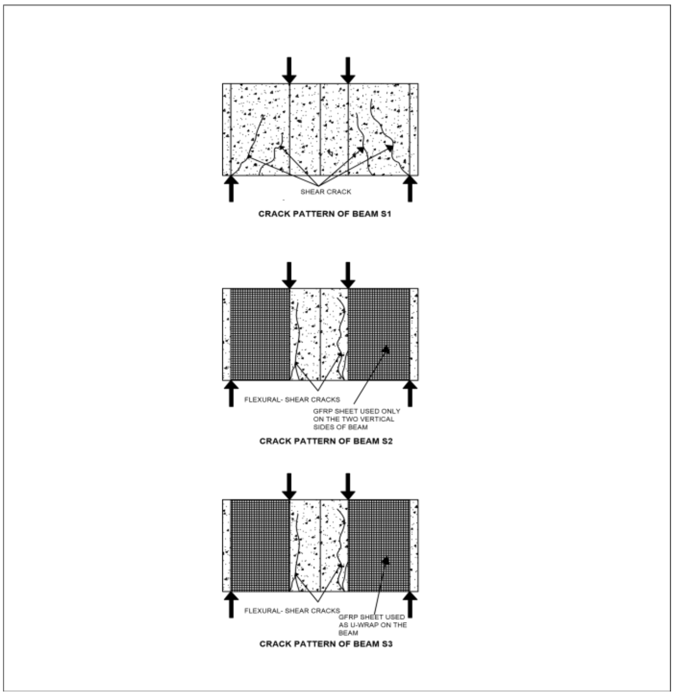


5.1.2 Ultimate load Carrying Capacity of SET II Deep Beam

5.2Crack Pattern:



5.2.1Crack pattern For SET I Deep Beam



5.2.2Crack Pattern for SET II Deep Beam

6. CONCLUSIONS

In this experimental investigation the flexural and shear behavior of reinforced concrete deep beams strengthened by GFRP sheets are studied. Two sets of reinforced concrete (RC) beams, in SET I three beams strengthened in flexure and in SET II three beams strengthened in shear were tested. From the test results the following conclusions are drawn:

A) For SET I Beams (F1, F2 and F3)

The beam failure mode was as expected.

At higher load, an initial diagonal crack appears by strengthening the deep beam at soffit. The ultimate load carrying capacity of strengthened deep beam F2 is more than the controlled deep beam F1.

Further load increased by strengthening the beam at the soffits as well as on the two sides of the deep beam up to the neutral axis from the soffit. The ultimate load carrying capacity of strengthen deep beam F3 is more than the controlled beam F1 and more than the strengthened deep beam F2.

After strengthening the beam in flexure, then flexure-shear failure of the beam takes place which is more dangerous than the flexural failure of the deep beam as it does not give much warning before failure. Therefore it is recommended to check the shear strength of the deep beam and carry out shear strengthening along with flexural strengthening if required.

Strengthening up to neutral axis of the deep beam increases the ultimate load carrying capacity, but the cracks developed were not visible up to a higher load. So that it gives less warning compared to the deep beams strengthen only at the soffit, due to invisibility of the initial crack.

The deep beam strengthened up to neutral axis increases ultimate load carrying capacity not significantly but the cost involvement is almost three times compared to deep beam strengthen by GFRP sheet at the soffit only.

B) For SET II Beams (S1, S2 and S3)

1. The deep beam failure mode as expected.
2. The control deep beam S1 failed in shear.
3. At higher load, the initial cracks in strengthen beam S2 and S3 appears as compared to the un-strengthened beam S1.
4. The initial cracks appears at the flexural zone of the deep after strengthening the deep beam in shear and then cracks widen and propagate towards the neutral axis with the increase in load. The final failure indicates

that the GFRP sheets increase the shear strength of the deep beam.

5. The ultimate load carrying capacity of the strengthened deep beam S2 is more than the controlled deep beam S1.

6. When the deep beam strengthen by U-wrapping in shear zone, the ultimate load carrying capacity is increased as compared to the control beam S1 and compared the deep beam S2 strengthen by bonding the GFRP sheets on the vertical sides alone in the shear zone of the deep beam.

7. When the deep beam strengthened in shear, then only flexural failure occurs which gives sufficient warning compared to the brittle shear failure.

8. The shear strength of deep beam using GFRP sheets can results in increased shear strength and stiffness with no visible cracks.

7. FUTURE SCOPE OF PRESENT STUDY

Future scope for this study is summarized below so that researcher may get attention for the future study.

1. Flexural behavior of RC deep beam externally strengthened with GFRP in different strengthening pattern can be studied.

2. This study can be extended by increasing length and width of cross-section

3. Application of FRP wrapping under condition of damage of RC deep under acid, chemicals etc. are to be studied.

4. In this study the shear behavior of deep beams externally strengthened with GFRP in different strengthening scheme is studied out.

5. The same can be studied out by the use of CFRP also.

6. In this study, all deep beams are strengthened with single layer of GFRP sheet instead of that the same can be strengthened with double layers.

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