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A Survey on Experimental Study on Shear Strengthening of RC T-Beams With Web Openings Using FRP Composites

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ABSTRACT: Shear collapse of reinforced concrete (RC) members is catastrophic and occurs suddenly with no advance warning of distress. In several occasions existing RC beams have been found to be deficient in shear and in need of strengthening. Conventional shear strengthening method such as external post tensioning, member enlargement along with internal transverse steel, and bonded steel plates are very costly, requiring extensive equipment, time, and significant labor. Conversely, the relatively new alternative strengthening technique using advanced composite materials, known as fiber reinforced polymer (FRP), offers significant advantages such as flexibility in design, ease of installation, reduced construction time, and improved durability. The overall objective of this study was to investigate the shear performance and failure modes of RC T-beams strengthened with externally bonded GFRP sheets. In order to achieve these objectives, an extensive experimental program consisting of testing eleven, full scale RC beams was carried out. The variables investigated in this study included steel stirrups, shear span-to-depth ratio, GFRP amount. The experimental results indicated that the contribution of externally bonded GFRP to the shear capacity is significant and depends on the variable investigated. The failures of strengthened beams are initiated with the debonding failure of FRP sheets followed by brittle shear failure. However, the shear capacity of these beams has increased as compared to the control beam which can be further improved if the debonding failure is prevented. An innovative method of anchorage technique by using GFRP plates has been used to prevent these premature failures, which as a result ensure full utilization of the strength of FRP. A theoretical study is also proposed by using ACI guidelines for computing the shear capacity of the strengthened beams.

KEYWORDS: Shear Strengthening, RC T-Beams, Web Openings, FRP Composites

I. INTRODUCTION

Shear strengthening of reinforced concrete beam is vital to obtain the ultimate flexural capacity with ductile behavior. Externally bonded CFRP laminate has been used as one of the most popular strengthening method for shear as compared to other available materials. However, premature failure of CFRP shear strips was found to be the major weakness of the system. It was due to insufficient bonded area of CFRP shear strip as compared to CFRP flexural laminate since the depth of reinforced concrete beam is smaller as compared to length. Thus, premature debonding of CFRP laminate is common in the case of shear strengthening.

1.1 Background and Motivation

Many natural disasters, earthquake being the most affecting of all, have produced a need to increase the present safety levels in buildings. The knowledge of understanding of the earthquakes is increasing day by day and therefore the

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seismic demands imposed on the structures need to be revised. The design methodologies are also changing with the growing research in the area of seismic engineering. So the existing structures may not qualify to the current requirements. As the complete replacement of such deficient structures leads to incurring a huge amount of public money and time, retrofitting has become the acceptable way of improving their load carrying capacity and extending their service lives. Retrofitting is specially used to relate to the seismic upgrade of facilities, such as in the case of the use of composite jackets for the confinement of columns. Retrofitting is making changes to an existing building to protect it from flooding or other hazards such as high winds and earthquakes. The maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public amount and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. To meet up the requirements of advance infrastructure new innovative materials/ technologies in civil engineering industry has started to make its way. Any technology or material has its limitations and to meet the new requirements new technologies have to be invented and used. With structures becoming old and the increasing bar for the constructed buildings the old buildings have started to show a serious need of additional retrofits to increase their durability and life. The retrofitting is one of the best options to make an existing inadequate building safe against future probable earthquake or other environmental forces. There are many other factors, considered in decision making for any retrofitting strategy. This proves to be a better option catering to the economic considerations and immediate shelter problems rather than replacement of buildings. Because replacement is very costly and structural behaviour also may change and it may cause inconvenience also.

1.2 Problem Statement

In traditional approach Shear collapse of reinforced concrete (RC) members is catastrophic and occurs suddenly with no advance warning of distress. In several occasions existing RC beams have been found to be deficient in shear and in need of strengthening. Conventional shear strengthening method such as external post tensioning, member enlargement along with internal transverse steel, and bonded steel plates are very costly, requiring extensive equipment, time, and significant labor. Conversely, the relatively new alternative strengthening technique using advanced composite materials, known as fiber reinforced polymer (FRP), offers significant advantages such as flexibility in design, ease of installation, reduced construction time, and improved durability.

1.3 Techniques

Generally four characteristics are defining a structure: load carrying capacity, durability, functionality and aesthetics. From these the first three are considered the most important, mainly for safety and comfort reasons. When one of these functions is not fulfilled, a construction may be in need of:

- Maintenance – keep the structure at a desired performance level, e.g. a steel bridge has to be periodically painted to avoid corrosion
- Repair – upgrade the structure to its original design level, e.g. a structure damaged from an earthquake has to be structurally repaired to be at the same performance level as before the earthquake
- Upgrading – to increase the performance of a structure to a higher level, e.g. if the traffic load on a bridge has increased, so the load bearing capacity has to be increased

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The actions mentioned above, are called rehabilitation methods.

There are mainly two types of techniques are available

1. Seismic resistance based design

- Concrete jacketing
- Steel jacketing
- FRP wrapping

2. Seismic response control design

- Elastic-plastic dampers
- Base isolators
- Tuned liquid dampers

And also many options for retrofitting a structure are possible

The ones which are used traditionally for a long time now such as addition of new Shear walls, addition of infill walls, addition of wing (side) walls, addition of buttresses, jacketing of reinforced concrete members, propping up , steel collars, casing, building up, bonding steel plates or steel jacketing. However, with increase in research and introduction of new materials and technology there are new ways of retrofitting the structure with many added advantages. Introduction of Fibre Reinforced Composites being one of them. It has proved to be a promising material and technology in repairs and retrofitting.

1.4 Fibre Reinforced Polymer (FRP)

Fibre Reinforced Polymer (FRP) composites comprise fibres of high tensile strength within a polymer matrix such as vinylester or epoxy. FRP composites have emerged from being exotic materials used only in niche applications following the Second World War, to common engineering materials used in a diverse range of applications such as aircraft, helicopters, space-craft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and civil infrastructure. The role of FRP for strengthening of existing or new reinforced concrete structures is growing at an extremely rapid pace owing mainly to the ease and speed of construction, and the possibility of application without disturbing the existing functionality of the structure. FRP composites have proved to be extremely useful for strengthening of RCC structures against both normal and seismic loads.

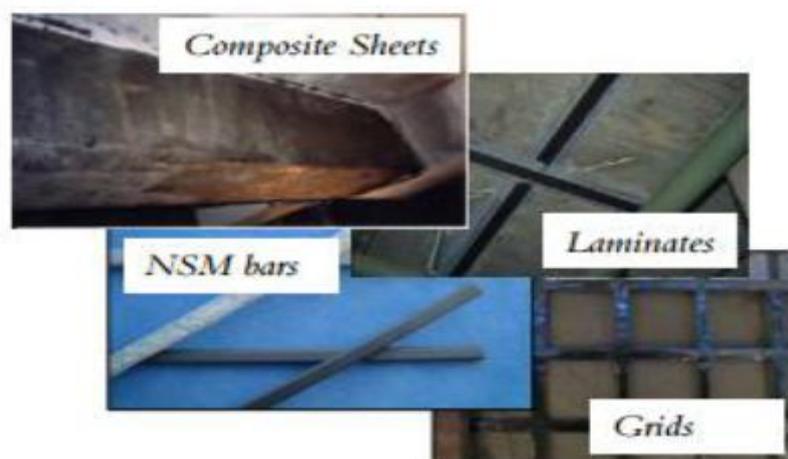


Figure 1-1. Various composite materials

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Advantages over other materials:

1. FRP is corrosion proof. When steel is in contact with water, oxygen, or other strong oxidants, or acids, it rusts.
2. Easy in transportation can be easily rolled.
3. High fatigue resistance.
4. Light weight. Hence, very high strength to weight ratio. The lower weight makes handling and installation significantly easier than steel. This is particularly important when installing material in cramped Locations.
5. Fiber composite materials are available in very long lengths while steel plate is generally limited to 6m. The availability of long length and the flexibility of the material also simplify installation and joints and laps are also not required.
6. Very less period of time is required.
7. Does not impact on detailing or form of historic structures. In general for FRP rapping no bolts are required, In fact use of bolts would seriously weaken the material unless additional cover plates are bonded on. Furthermore, because there is no need to drill into the structure to fix the bolts or other mechanical anchors there is no risk of damaging existing reinforcement
8. Low unit weight (150-900 g /m²).
9. Fiber composite strengthening materials have higher ultimate strength and lower density than steel.
10. Low energy consumption during fabrication of raw material and structure, and the potential for real time monitoring.

Disadvantages:

1. The main disadvantage of externally strengthening structures with composite materials is the risk of fire, vandalism or accidental damage, unless the strengthening is protected.
2. Below 5°c temperature we cannot use FRP.
3. The lack of experience of the techniques and suitably qualified staff to carry out the work.
4. Lack of accepted design standards.

1.5 Strengthening using FRP

Most of the elements of a structure can be strengthened with FRP composite materials. This means in fact that FRP composites can take up the majority of the forces developed in a structure as long as they are transmitted by the strengthened element to the composite as tensile stresses.

Strengthening with externally bonded FRP fabric has shown to be applicable to many kinds of structures. Currently, this method has been applied to strengthen such structures as column, beams, walls, slabs, etc.

The use of external FRP reinforcement may be classified as

- Flexural strengthening
- Improving the ductility of compression members
- Shear strengthening.

1.5.1 Flexural strengthening using FRP:

The laminates are generally made up of Carbon fibres blended in an epoxy matrix. These when applied with epoxy, act as external tension reinforcements to increase the flexural strength of the RCC members. Beams, Plates and columns may be strengthened in flexure through the use of FRP composites bonded to their tension zone using epoxy as a common adhesive for this purpose. The direction of fibers is parallel to that of high tensile stresses. Both prefabricated FRP strips, as well as sheets (wet-lay up) are applied.

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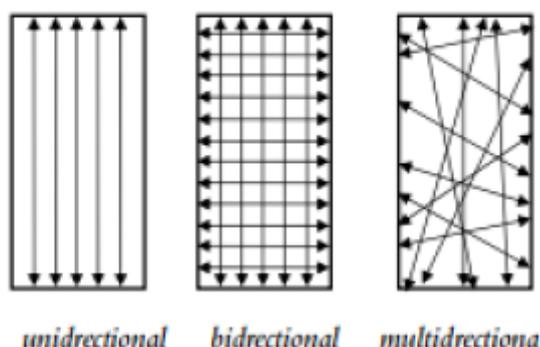


Figure 1-2. Fibre directions in composite materials

1.5.2 Shear strengthening:

When the RC beam is deficient in shear, or when its shear capacity is less than the flexural capacity after flexural strengthening, shear strengthening must be considered. It is critically important to examine the shear capacity of RC beams which are intended to be strengthened in flexure.

Various FRP bonding schemes have been used to increase the shear resistance of RC beams. These includes bonding FRP to the sides of the beam only, bonding FRP U jackets to both the sides and the tension face, and wrapping FRP around the whole cross section of the beam. The use of fibres in two directions can obviously be beneficial with respect to shear resistance even if strengthening for reversed loading is not required, except for unlikely case in which one of the fibre directions is exactly parallel to the shear cracks. In this sense, FRP plates with fibres in three or more directions may also be used.

FRPs are strong only in the directions of fibres, the fibres may be oriented in such directions as to control shear cracks. Because shear forces and bending moments in a beam may be reversed under conditions such as cyclic loading and earthquake attacks, fibres may thus be arranged at two different directions to satisfy the requirement of shear strengthening in both directions.

Two main modes of failure are recognized by the research society for FRP strengthened beams are:

1.5.3 Fibre failure in the FRP:

It occurs when the tensile stress in the fibres exceeds the tensile strength. It is characterized by a rapid progressive fibre failure in the composite, especially for sheets, but the failure is in most of the cases brittle. The orientation of the fibres with respect to the principal strain in concrete affects the ductility of the composite.

1.5.4 Anchorage failure :

Also known as bond failure is governed by the properties of the weakest materials in contact, i.e. concrete and adhesive. When the shear strength of one of these two exceeds the force then transfer cannot be ensured anymore and a “slip” is produced. The debonding can take place in concrete, between the concrete and adhesive, in the adhesive, between the adhesive and the fibres. The most common debonding failure observed is at the surface of the concrete, which is an explicable phenomenon since the concrete is the weakest element in this “interaction chain”. The anchorage failure is considered as more dangerous than tensile failure because it cannot be foreseen and can almost not be controlled at all. The failure mode of a strengthened beam depends also on the configuration of the strengthening used. From the configurations used the one to be avoided is the side bonded because it is the most exposed to

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debonding failure due to its limited anchorage length. The fully wrapped configuration is the safest since the failure is controlled by fibre rupture, but it is quite uncommon with this type of free bound configuration for a beam in a structure. Probably the most used configuration is the U wrapped system. Since the beams are connected to slabs, consequently T section behaviour, this configuration is safer than the side bonding but still has critical regions.

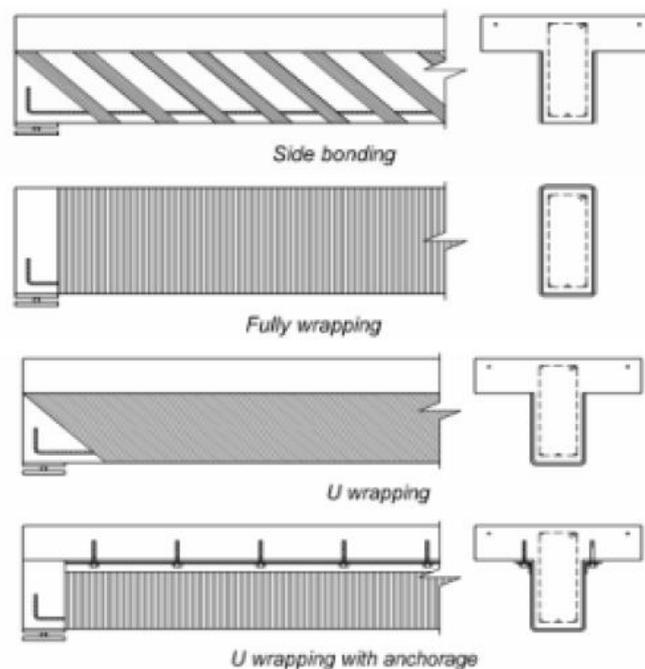


Figure 1-3. Shear strengthening configurations using FRP

Anchorage devices for FRP reinforcement used to strengthen members in flexure

Three general categories of anchorage type have been investigated to date to prevent debonding in RC members strengthened with FRP

- (a) U-jacket anchors
- (b) Mechanically fastened metallic anchors
- (c) FRP anchors

1.5.5 FRP U-jacket anchors:

FRP U-jacket anchors involve the application of uni-directional or bi-directional fibre to the ends of flexural FRP reinforcement to prevent or delay debonding initiating from the plate end. U jackets can also be placed along the length of the member to prevent or delay debonding initiating away from the plate end. The ultimate function of a U-jacket is to provide the confinement necessary to resist the tensile peeling stresses and longitudinal crack propagation at fibre termination points or intermediate cracks.

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1.5.6 Metallic Anchorage Systems: Metallic anchorages are one of the earliest forms of FRP end anchorage devices investigated by researchers (e.g. Sharif et al. 1994; Jensen et al. 1999). Investigations have been conducted on: adhesively bonded metallic plates with mechanical fasteners (refer Figure 4), adhesively bonded metallic U-jackets, and those with end clamping. Researchers have found the use of metallic anchorages to provide a superior increase in anchorage strength in addition to ductility enhancement.

1.5.7 FRP Anchors:

Anchors made from rolled fibre sheets or bundled loose fibres are a promising form of anchorage because they can be applied to wide FRP-strengthened structural elements such as slabs and walls. They are discrete and do not suffer from the same constraints as U-jackets. Such anchors are referred to as FRP spike anchors, fibre anchors, fibre bolts and FRP dowels, amongst other names, but are herein collectively referred to FRP anchors. The anchor can be hand-made (in the laboratory or on site) or manufactured from glass or carbon fibre sheets or loose fibres which have been rolled or bundled.

1.5.8 Anchorage devices used for FRP reinforcement

Although fully wrapping the beam cross-section with FRP has been demonstrated to provide the most effective strengthening solution for shear and torsion applications. It is seldom achieved in practice due to the presence of physical obstructions such as beam flanges. This form of failure is usually premature, sudden, non-ductile and has resulted in the development of many innovative anchorage details at the web-flange interface. These include

1. FRP enveloping the web of the beam in a U-shape, including termination at the underside of the beam flange with no anchorage.
2. Wrapping the web and flange of the beams through drilled holes through the beam flanges.
3. Mechanically fastened metallic anchors installed at the underside of the beam flange to anchor FRP U wrap legs.
4. Embedment of the FRP U-jacket legs into the beam flanges, through pre-cut grooves using adhesive bonding.
5. FRP anchors installed to restrain the legs of the FRP U-jackets.
6. Mechanical substrate strengthening over the anchorage zone of FRP shear reinforcement
7. FRP enveloping the web of the beam and anchored at the underside of the beam flanges with unidirectional or bi-directional fibres. U jacketing is now the most popular shear strengthening solution due to its high practicality, but it is limited by end peeling of the U-jacket legs.

1.6 Objective

The main objectives of the present work are:

1. To study the structural behaviour of reinforced concrete (RC) T-beams with a transverse hole under static loading condition.
2. To study the contribution of externally bonded Fiber Reinforced Polymer (FRP) sheets on the shear behaviour of RC T-beams.
3. To know the suitability of the FRP composites as repair materials for deteriorated RC Structures.
4. To examine the effect of different parameters such as steel stirrups, number of layers, different shear span to effective depth ratio etc. on enhancement of load carrying capacity and load deflection behaviour.
5. To investigate the effect of a new anchorage scheme on the shear capacity of the beam.

1. REVIEW OF LITERATURE

Saira P.N et al. investigate the improvements in the structural behavior of the RC beams retrofitted with various types of FRP such as glass fibers, coir fibers, banana fibers, jute fibers and cotton fibers. The ultimate load was found to be

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high for beams retrofitted with FRP composite than control beam. Modulus of rupture also is found high for RC beams retrofitted with fibers such as glass, banana, jute, cotton, coir corresponding to ultimate load. This showed that the use of both natural and artificial FRP was very effective in case of flexural strengthening of structures. The load-deflection behavior was better for beams strengthened with FRP compared to the control beams.

SAMER BARAKAT et al. to study and analyze the parameters that most influence the shear behavior of RC members strengthened with EBFPR. The analysis of this available data confirmed Predictions of the ACI design model for S-bonded, U-wrapped and W-wrapped EBFPR RC beams. that the shear problem involves a number of parameters, which are related and interacting such as the properties of FRP and the existence of the internal shear reinforcement among others. This paper attempts to identify and assess the most important factors that influence the shear failure of EBFPR strengthened RC beams by compiling and analyzing previously reported experimental data in the literature. These data are compiled in an updated database described herein.

MdAshrafAlam et al. The main objective of this research is to offer a design guideline for shear strengthening of reinforced concrete beam using CFRP laminate by eliminating deboning failure. The proposed method prevented the complete separation of CFRP laminate although a micro deboning was noticed before failure of the beam. Strengthened beam with proposed design did not show the premature failure. The strains of shear link and CFRP laminate were found to be compatible unless the laminated deboned. Thus, the proposed design guideline, based on the bond strength of concrete and strain compatibility, could be used for shear strengthening of RC beam using CFRP laminate.

RuiGuo et al. This paper investigates the shear strengthening effect of a number of reinforced concrete (RC) beams strengthened by a reinforcement layer which combines carbon fiber reinforced polymer (CFRP) grid and polymer cement mortar (PCM). A total of ten RC beams, including three types of specimens as Series A and seven kinds of specimens as Series B, were prepared and investigated. Compared to the specimen with a reinforcement layer only in the web, better performances of specimens reinforced in both the web and haunch regions are obtained in terms of the second stiffness and the ultimate shear capacity, reconfirming that the CFRP grid-PCM layer used for the full sectional reinforcement of RC beams with an I-shaped profile is indispensable. Local deboning failure usually occurs at the FRP grid-concrete interface prior to the rupture of the CFRP grid. In addition, using the effective strain of the FRP rod to predict the effective/actual strain for the CFRP grid can be considered to be secure, but is somewhat over-predictive.

Kamal G.Sharobim et al. This paper presents experimental investigation for eight beams in two sets each one component of control beam and three beams strengthened by the three different methods without changing its dimensions. The beams were tested under four point loads. Ultimate loads, load-deflection curves, cracking and crushing patterns for strengthening beam had been compared with those of the RC beams without strengthening in shear and flexure stresses. Strengthening by using SFRC did not achieve the aim of the search. The result showed that beams strengthened using CFRP had increased in load capacity about 24% and 27% in shear and flexure stresses receptivity, while the beams strengthened using SFRC were the lowest and did not achieve the aim of paper.

Sivagandan.M et al. This paper also explains about the effect of GFRP on the control of deflection, cracks propagation and failure pattern. Finally use of U wraps with one and two layer of GFRP gives the strength similar to that of the control beams without openings. is mainly concentrated on strengthening techniques of RC T-Beam with web opening in shear region using glass fiber reinforced polymer (GFRP) i.e., U-Wrap and face wrap. From the experimental results it is observed that, the load carrying capacity decrease in the strengthened beam with opening compare to control beams and was increased in case of Strengthened beams compared to unstrengthen beams. The presence of openings leads to decrease in stiffness and improves in deflection of beams compared to control beam. The main advantages in the strengthening process by GFRP wrapping are it has low self-weight, high strength to weight ratio, easy to transport, easy to install and requires less time. These are some of the limitations in this system is relatively less economical and pot life of resin will be less so the wastage will be more.

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Sainath B Tole et al. Studies are carried out to strengthen the RC T-Beams in shear by bonding FRP sheets externally, even then the performance of beams with FRP jackets under shear are not understood fully. Therefore this study provides a scope to explore the prospect to strengthen the T-Beams which is deficient in shear using FRP bonded externally. This project includes experiment on CFRP retrofitted RC T-Beams using four-point loading to fail in shear. Beams were casted with different configurations and compared with the control T-Beams. The results show that there is an improvement in shear capacity when retrofitted with CFRP wraps. cases of loading, geometrical configurations, flexure beams and girders, RC T-beams strengthened using fiber reinforced polymer (FRP) fabrics subjected to combined shear and torsion. The shear and torsion carrying capacities were increased up to 71% more than the control specimen, as well as increasing the stiffness of the beams after cracking as compared to that of the control beam. Strengthening increased the deformability of the beam and preserved its integrity up to failure.

P. Vijaya Kumar et al. This paper experimental investigation was done on RC beams to check the shear behavior by comparing control RC beams with strengthened RC beams. To observe the shear behavior considered RC Beams were made weak in shear and then Retrofitted. various research works are being carried out to know the shear behavior of various reinforced structural elements. The beam is weak in shear is due to some additional horizontal forces acting which is parallel to beam surface will generate some stress on the beam. The concrete was failed in tension zone for the retrofitted beam because of hardened FRP. It is easy to keep up a moderated uniform thickness of epoxy resin all through the bounding length. Restoring the sheer quantity of beam using GFRP was exceeded the normal strategy.

El-Samny M.K. et al. study describes the result of an experimental investigation on the response of creating opening in reinforced concrete beams after and before casting using steel wire mesh, steel angles, steel straps, steel stirrups system and reinforcement beams around the opening. The beams were instrumented and tested under two-point load. The experimental program consisted of testing thirteen simply supported reinforced rectangular beams. The main parameters of study are the different methods of strengthening. presented experimentally the effect of introducing opening in the shear zone on the flexural, shear capacity and behavior of reinforced concrete beam. Different conventional techniques of strengthening around the openings were used. The results were compared to a tested beam that that was pre-reinforced around the openings as well as a control beam without opening. studied the behaviour of reinforced concrete (RC) beams with large openings strengthened by externally bonded carbon fiber-reinforced polymer CFRP laminates. A total of six simply supported beams consisting of two solid beams and four beams with openings were cast and tested under four-point bending. Each beam had a large opening placed symmetrically at mid-span. Test parameters included the opening shape and size as well as the strengthening configuration for the CFRP laminates.

T. P. Meikandaan et al. Experimental investigations on the flexural and shear behavior of RC beams strengthened using continuous glass fiber reinforced polymer (GFRP) sheets. Infrastructure decay caused by premature deterioration of buildings and structures has led to the investigation of several processes for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget. Structural strengthening may be required due to many different situations.

Aadil Mansuri et al. This study designing of any structure is that it should serve for the period it has been designed to serve. But before the design period is over the structure needs maintenance due to reasons like change in loading conditions, functional change, damages due to earthquakes etc. The structure constructed during ancient time and which are still existing demand more repair. However, some of the new structures also show the sign of deterioration. Various mechanism are available in the market for strengthening of RC beams like Ferro Cement, Micro-Concrete, external plate bonding, concreting, sprayed concrete etc. The de-bonding of the strengthened part took place. Strengthening of beam carried with welded wire mesh and Micro-Concrete shows the least deflection even at first crack and at ultimate load.

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Haya H. Mhanna et al. This study is to compare the performance of a U-Wrapped T-beam with two completely wrapped rectangular beams. The first strengthened rectangular specimen (WBR1) has a depth equivalent to the T-beam's web height, while the second strengthened rectangular specimen (WBR2) has a depth equivalent to the T-beam's total depth. In addition, a control T-beam and two rectangular beams were cast and tested as benchmark specimens. The experimental test results showed that the beam strengthened by U-Wrapped CFRP sheets increased the control beam's shear strength by 114.82%, while the increase in shear capacity of the completely wrapped equivalent WBR1 and WBR2 beams over their control .investigated shear strengthening of RC beams using U-Wrapped and completely wrapped CFRP laminates. Three-point bending tests were performed on all beam specimens, and the mid-span load displacement response curves were plotted.

III. RESEARCH METHODOLOGY

The objective of the experimental program is to study the effect of externally bonded (EB) fiber reinforced polymer (FRP) sheets on the shear capacity of reinforced concrete T-beam with a transverse opening in shear span under static loading condition. Eleven number of reinforced concrete T-beams are cast and tested up to failure by applying symmetrical four-point static loading system. These beams were divided into 2 groups designated as A and B. The difference between two groups was in transverse steel reinforcement. Out of eleven number of beams, four beams were not strengthened by FRP and in that two beams were considered as a control beams and two beams were solid beams without transverse opening, whereas all other seven beams were strengthened with externally bonded GFRP sheets in shear zone of the beam.

The variables investigated in this research study included steel stirrups (i.e., beams with and without steel stirrups), shear span-to depth ratio (i.e., a/d ratio 2.66 versus 2), and end anchor (i.e., U-wrap with and without end anchor).

3.1 TEST SPECIMENS

All eleven reinforced concrete T-beams had a span of 1300 mm, 150mm wide web, 350mm wide flange, 125mm deep web, 50mm deep flange and effective depth of 125mm. The arrangement of reinforcement of beams under group-A consists of 2numbers of 20mm ϕ and 1number of 10mm ϕ HYSD bars as tension reinforcement, four bars of 8mm ϕ are also provided as hang up bars and without any shear reinforcement. The arrangement of reinforcement of beams under group-B consists of 2numbers of 20mm ϕ and 1number of 10mm ϕ HYSD bars as tension reinforcement, four bars of 8mm ϕ are also provided as hang up bars and 8mm ϕ bars are provided as shear reinforcement at 200 mm spacing.

3.2 MATERIAL PROPERTIES

3.2.1 Concrete

For conducting experiment, the proportions in the concrete mix are tabulated in Table 3.1 as per IS: 456-2000. The water cement ratio is fixed at 0.55. The mixing is done by using concrete mixture. The beams are cured for 28 days. For each beam six 150x150x150 mm concrete cube specimens and six 150x300 mm cylinder specimens were made at the time of casting and were kept for curing, to determine the compressive strength of concrete at the age of 7 days & 28 days are shown in table 3.2.

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Table 3.1 Nominal Mix Proportions of Concrete

| Description | Cement | Sand (Fine Aggregate) | Coarse Aggregate | Water |
|--|--------|-----------------------|------------------|-------|
| Mix Proportion (by weight) | 1 | 1.67 | 3.33 | 0.6 |
| Quantities of materials for one specimen beam (kg) | 44.4 | 74.11 | 147.85 | 22.5 |

The compression tests on control and strengthened specimen of cubes are performed at 7 days and 28 days. The test results of cubes are presented in Table 3.2.

Table 3.2 Test Result of Cubes after 28 days

| Specimen Name | | Size of Cube Specimen | Size of Cylinder Specimen | Average Cube Compressive Strength (MPa) | Average Cylinder Compressive Strength (MPa) |
|---------------|------------|-----------------------|---------------------------|---|---|
| Group-A | Solid beam | 150x150x150 | 150φ x300 | 35.23 | 25.15 |
| | CBA | 150x150x150 | 150φ x300 | 35.88 | 20.93 |
| | SBA2-1 | 150x150x150 | 150φ x300 | 36.5 | 21.86 |
| | SBA2-2 | 150x150x150 | 150φ x300 | 34.87 | 23.72 |
| | SBA2-3 | 150x150x150 | 150φ x300 | 36.47 | 20.46 |
| | SBA4-1 | 150x150x150 | 150φ x300 | 37.86 | 26.82 |
| Group-B | Solid beam | 150x150x150 | 150φ x300 | 30.83 | 21.08 |
| | CBB | 150x150x150 | 150φ x300 | 32.56 | 22.75 |
| | SBB2-1 | 150x150x150 | 150φ x300 | 31.89 | 20.74 |
| | SBB2-2 | 150x150x150 | 150φ x300 | 35.4 | 23.5 |
| | SBB2-3 | 150x150x150 | 150φ x300 | 36.77 | 24.87 |

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3.2.2 Cement

Cement is a material, generally in powdered form, which can be made into a paste usually by the addition of water and, when molded or poured, will set into a solid mass. Numerous organic compounds used for an adhering, or fastening materials, are called cements, but these are classified as adhesives, and the term cement alone means a construction material. The most widely used of the construction cements is Portland cement. It is bluish-gray powdered obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. Portland Slag Cement (PSC) Konark Brand was used for this investigation. It is having a specific gravity of 2.96.

3.2.3 Fine Aggregate

Fine aggregate/sand is an accumulation of grains of mineral matter derived from disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles, but is distinct from clays which contain organic material. Sand is used for making mortar and concrete and for polishing and sandblasting. Sands containing a little clay are used for making molds in foundries. Clear sands are employed for filtering water. Here, the fine aggregate/sand is passing through 4.75 mm sieve and having a specific gravity of 2.64. The grading zone of fine aggregate is zone III as per Indian Standard specifications IS: 383-1970.

3.2.4 Coarse Aggregate

Coarse aggregates are the crushed stone is used for making concrete. The commercial stone is quarried, crushed, and graded. Much of the crushed stone used is granite, limestone, and trap rock. The coarse aggregates of two grades are used one retained on 10 mm size sieve and another grade contained aggregates retained on 20 mm size sieve. The maximum size of coarse aggregate was 20 mm and is having specific gravity of 2.88 grading confirming to IS: 383-1970.

3.2.5 Water

Water fit for drinking is generally considered good for making the concrete. Water should be free from acids, alkalis, oils, vegetables or other organic impurities. Soft water produces weaker concrete. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement. Ordinary clean portable tap water is used for concrete mixing in all the mix.

3.2.6 Reinforcing Steel

High-Yield Strength Deformed (HYSD) bars conforming to IS 1786:1985. The longitudinal steel reinforcing bars were deformed, high-yield strength, with 20 mm and 10 mm diameter. The stirrups were made from deformed steel bars with 8 mm diameter.

Three coupons of steel bars were tested and yield strength of steel reinforcements used in this experimental program is determined under uniaxial tension in accordance with ASTM specifications. The proof stress or yield strength of the specimens are averaged and shown in Table 3.5. The modulus of elasticity of steel bars was 2×10^5 MPa.

IV. CONCLUSIONS

In this experimental investigation the shear behaviour of RC T-beams strengthened by GFRP sheets are studied. The test results illustrated in the present study showed that the external strengthening with GFRP composites can be used to

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increase the shear capacity of RC T-beams, but the efficiency varies depending on the test variables such as fiber orientations, wrapping schemes, number of layers and anchorage scheme.

Based on the experimental and theoretical results, the following conclusions are drawn:

1. The test results confirm that the strengthening technique of FRP system is applicable and can increase the shear capacity of T-beams.
2. The experimental verification of the flange anchorage system shows the effectiveness in increasing the shear capacity of RC beams.
3. Existing evidence clearly indicates that the anchorage system can make FRP strengthening even more attractive and economical for concrete repair and strengthening.
4. The test results indicates that the contribution of GFRP benefits the shear capacity to a greater degree for beams without steel shear reinforcement than for beams with adequate steel shear reinforcement.
5. The contribution of externally bonded GFRP reinforcement to the shear capacity is influenced by the shear span-to-depth ratio (a/d) and it increases with a decrease in a/d ratio.
6. The use of anchorage system eliminates the debonding of the GFRP sheet, and consequently results in a better utilization of the full capacity of the GFRP sheet.

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