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LEARNING OF TWISTED BEHAVIOUR OF STRENGTHEN CONCRETE

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ABSTRACT

Fiber Strengthen Polymer (FRP) as an external reinforcement is used extensively to deal with the strength requirements related to flexure and shear in structural systems. But the strengthening of members subjected to torsion is explored only recently. Torsion failure is an undesirable brittle form of failure which should be avoided specially in the earthquake prone areas. In the present work, the behaviour and performance of rectangular strengthen concrete beams strengthened with externally bonded Glass Fibre Strengthen Polymer (GFRP) fabrics subjected to combined flexure and torsion is studied experimentally.

Rectangular RC beams externally bonded with GFRP fabrics were tested to failure using an arrangement which transfer torque to the central part of the beam through two opposite cantilevers called moment arms. Each arm is subjected to equal static loading during the experiment. Total nine RC beams were cast and tested for the learning. All the beams were designed to fail in torsion. One of the beam was used as a control beam and eight beams were strengthened using different configurations and different types of GFRP fabrics. The learning is restricted to continuously wrapped GFRP fabrics.

Experimental data on ultimate & first cracking loads, angle of twist and failure modes of each of the beams were obtained. The effect of different types and configuration of GFRP on first crack load, ultimate load carrying capacity and failure mode of the beams were investigated.

The experimental results have been validated with finite element analysis by using ANSYS software and found to be in good agreement with analytical values. The experimental results show that externally bonded GFRP can increase the twisted capacity of the beam significantly. The results also indicate that the most effective configuration is the full-wrap of GFRP fabrics. In addition GFRP applied in 45^0 with axis of the beam gives more strength than GFRP applied in 90^0 with the axis

I. INTRODUCTION

1.1. Overview

During its whole life span, nearly all engineering structures ranging from residential buildings, an industrial building to power stations and bridges faces degradation or deteriorations. The main causes for those deteriorations are environmental effects including corrosion of steel, gradual loss of strength with ageing, variation in temperature, freeze-thaw cycles, repeated high intensity loading, contact with chemicals and saline water and exposure to ultra-violet radiations. Addition to these environmental effects earthquakes is also a major cause of deterioration of any structure. This problem needs development of successful structural retrofit technologies. So it is very important to have a check upon the continuing performance of the civil engineering infrastructures. The structural retrofit problem has two options, repair/retrofit or demolition/reconstruction. Demolition or reconstruction means complete replacement of an existing structure may not be a cost-effective solution and it is likely to become an increasing financial burden if upgrading is a viable alternative. Therefore, repair and rehabilitation of bridges, buildings, and other civil engineering structures is very often chosen over reconstruction for the damage caused due to degradation, aging, lack of maintenance, and severe earthquakes and changes in the current design requirements.

Previously, the retrofitting of strengthen concrete structures, such as columns, beams and other structural elements, was done by removing and replacing the low quality or damaged concrete or/and steel reinforcements with new and stronger material. However, with the introduction of new advanced composite materials such as fiber strengthen polymer (FRP) composites, concrete members can now be easily and effectively strengthened using externally bonded FRP composites

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Retrofitting of concrete structures with wrapping FRP sheets provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. In addition, FRP manufacturing offers a unique opportunity for the development of shapes and forms that would be difficult or impossible with the conventional steel materials. Although the fibers and resins used in FRP systems are relatively expensive compared with traditional strengthening materials, labour and equipment costs to install FRP systems are often lower.

FRP systems can also be used in areas with limited access where traditional techniques would be impractical.
Several investigators took up concrete beams and columns retrofitted with carbon fiber strengthen polymer (CFRP) glass fiber strengthen polymer (GFRP) composites in order to learning the enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these members. The results obtained from different investigations regarding enhancement in basic parameters like strength/stiffness, ductility and durability of structural members retrofitted with externally bonded FRP composites, though quite encouraging, still suffers from many limitations. This needs further learning in order to arrive at recognizing FRP composites as a potential full proof structural additive. FRP repair is a simple way to increase both the strength and design life of a structure. Because of its high strength to weight ratio and resistance to corrosion, this repair method is ideal for deteriorated concrete structure.

1.2. Twisted strenghtening of beams

Early efforts for understanding the response of plain concrete subjected to pure torsion revealed that the material fails in tension rather than shear. Structural members curved in plan, members of a space frame, eccentrically loaded beams, curved box girders in bridges, spandrel beams in buildings, and spiral stair-cases are typical examples of the structural elements subjected to twisted moments and torsion cannot be neglected while designing such members. Structural members subjected to torsion are of different shapes such as T-shape, inverted L–shape, double T-shapes and box sections. These different configurations make the understanding of torsion in RC members a complex task.

In addition, torsion is usually associated with bending moments and shearing forces, and the interaction among these forces is important. Thus, the behaviour of concrete elements in torsion is primarily governed by the tensile response of the material, particularly its tensile cracking characteristics. Spandrel beams, located at the perimeter of buildings, carry loads from slabs, joists, and beams from one side of the member only. This loading mechanism generates twisted forces that are transferred from the spandrel beams to the columns. Strengthen concrete (RC) beams have been found to be deficient in twisted capacity and in need of strengthening. These deficiencies occur for several reasons, such as insufficient stirrups resulting from construction errors or inadequate design, reduction in the effective steel area due to corrosion, or increased demand due to a change in occupancy.

Similar to the flexure and shear strengthening, the FRP fabric is bonded to the tension surface of the RC members for torsion strengthening. In the case of torsion, all sides of the member are subjected to diagonal tension and therefore the FRP sheets should be applied to all the faces of the member cross section. However, it is not always possible to provide external reinforcement for all the surfaces of the member cross section. In cases of inaccessible sides of the cross section, additional means of strengthening has to be provided to establish the adequate mechanism required to resist the torsion. The effectiveness of various wrapping configurations indicated that the fully wrapped beams performed better than using FRP in strips.

1.3. Advantages and disadvantages of frp

1.3.1. Advantages

There have been several important advances in materials and techniques for structural rehabilitation, including a new class of structural materials such as fiber-strengthen polymers (FRP). One such technique for strengthening involves adding external reinforcement in the form of sheets made of FRP. Advanced materials offer the designer a new combination of properties not available from other materials and effective rehabilitation systems. Strengthening structural elements using FRP enables the designer to selectively increase their ductility, flexure, and shear capacity in response to the increasing seismic and service load demands. For columns, wrapping with FRP can significantly improve the strength and ductility.

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A potent advantage of using FRP as an alternate external confinement to steel is the high strength to weight ratio comparisons. In order to achieve an equivalent confinement, FRP plates are up to 20% less dense than steel plates and are at least twice as strong, if not more. Manufacture of modern composites is, then, possible in reduced sections and allows composite plates to be shaped on-site. The lower density allows easier placement of confinement in application. Design of external confinement to a structure should be made with conservative adjustments to the primary structures dead weight load. Changes of the stiffness of members should be considered when redesigning the structure. The improved deportment of FRP wrapped members reduces the strains of internal steel reinforcement thereby delaying attainment of yielding. Much like internal steel confinement in longitudinal and lateral axes, external confinement exerts a similar pressure on the concrete as well as to the internal steel. Furthermore, FRP have high corrosive resistance equating to material longevity whilst within aggressive environments. Such durability makes for potential savings in long-term maintenance costs.

1.3.2. Disadvantages

With the above advantages FRP does also have some disadvantages as follows: The main disadvantage of externally strengthening structures with fiber composite materials is the risk of fire, vandalism or accidental damage, unless the strengthening is protected. As FRP materials are lightweight they tend to poses aerodynamic instability. Retrofitting using fiber composites are more costly than traditional techniques. Experience of the long-term durability of fiber composites is not yet available. This may be a disadvantage for structures for which a very long design life is required but can be overcome by appropriate monitoring. This technique need highly trained specialists. More over there is lack of standards and design guides.

II. REVIEW OF LITERATURE

2.1 Brief review

Externally bonded, FRP sheets are currently being studied and applied around the world for the repair and strengthening of structural concrete members. Strengthening with Fiber Strengthen Polymers (FRP) composite materials in the form of external reinforcement is of great interest to the civil engineering community. FRP composite materials are of great interest to the civil engineering community because of their superior properties such as high stiffness and strength as well as ease of installation when compared to other repair materials.

Also, the non-corrosive and nonmagnetic nature of the materials along with its resistance to chemicals made FRP an excellent option for external reinforcement.

Research on FRP material for use in concrete structures began in Europe in the mid 1950's by Rubinsky and Rubinsky, 1954 and Wines, J. C. et al., 1966. The pioneering work of bonded FRP system can be credited to Meier (Meier 1987); this work led to the first on-site repair by bonded FRP in Switzerland (Meier and Kaiser 1991).Japan developed its first FRP applications for repair of concrete chimneys in the early 1980s (ACI 440 1996).By 1997 more than 1500 concrete structures worldwide had been strengthened with externally bonded FRP materials. Thereafter, many FRP materials with different types of fibres have been developed. FRP products can take the form of bars, cables, 2-D and 3-D grids, sheet materials and laminates. With the increasing usage of new materials of FRP composites, many research works, on FRPs improvements of processing technology and other different aspects have been performed.

Though several researchers have been engaged in the investigation of the strengthened concrete structures with externally bonded FRP sheets/laminates/fabrics, no country yet has national design code on design guidelines for the concrete structures retrofitted using FRP composites. However, several national guidelines (The Concrete Society, UK: 2004; ACI 440:2002; FIB: 2001; ISIS Canada: 2001; JBDPA: 1999) offer the state of the art in selection of FRP systems and design and detailing of structures incorporating FRP reinforcement. On the contrary, there exists a divergence of opinion about certain aspects of the design and detailing guidelines. This is to be expected as the use of the relatively new material develops worldwide. Much research is being carried out at institutions around the world and it is expected that design criteria will continue to be enhanced as the results of this research become know in the coming years.

Several investigators like Saadatmanesh et al., (1994); Shahawy, (2000) took up FRP strengthened circular or rectangular columns learninging enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these columns.

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Saadatmanesh et al. (1994) studied the strength and ductility of concrete columns externally strengthen with fibre composite strap. Chaallal and Shahawy (2000) reported the experimental investigation of fiber strengthen polymer-wrapped strengthen concrete column under combined axial-flexural loading. Obaidat et al (2010) studied the Retrofitting of strengthen concrete beams using composite laminates and the main variables considered are the internal reinforcement ratio, position of retrofitting and the length of CFRP.

2.2 Literature review on twisted strengthening of rc beam

Most of the research projects investigating the use of FRP focused on enhancing the flexural and shear deportment, ductility, and confinement of concrete structural members. A limited number of mostly experimental studies were conducted to investigate torsion strengthening of RC members.

Ghobarah et al. (2002) conducted an experimental investigation on the improvement of the twisted resistance of reinforced concrete beams using fiber-reinforced polymer (FRP) fabric. A total of 11 beams were tested. Three beams were designated as control specimens and eight beams were strengthened by FRP wrapping of different configuration and then tested. Both glass and carbon fibers were used in the twisted resistance upgrade. Different wrapping designs were evaluated. The strengthen concrete beams were subjected to pure twisted moments. The load, twist angle of the beam, and strains were recorded. Improving the twisted resistance of strengthen concrete beams using FRP was demonstrated to be viable. The effectiveness of various wrapping configurations indicated that the fully wrapped beams performed better than using strips. The 45° orientation of the fibers ensures that the material is efficiently utilized.

Panchacharam and Belarbi (2002) experimentally found out that externally bonded GFRP sheets can significantly increase both the cracking and the ultimate twisted capacity. The deportment and performance of strengthen concrete member strengthened with externally bonded Glass FRP (GFRP) sheets subjected to pure torsion was presented. The variables considered in the experimental learning include the fiber orientation, the number of beam faces strengthened (three or four), the effect of number of FRP plies used, and the influence of anchors in U-wrapped test beams. Experimental results reveal that externally bonded GFRP sheets can significantly increase both the cracking and the ultimate twisted capacity. Predicted strengths of the test beams using the proposed theoretical models were found to be in good agreement with the experimental results.

Salom et al. (2004) conducted both experimental and analytical programs focused on the twisted strengthening of strengthen concrete spandrel beams using composite laminates.

The variables considered in this learning included fiber orientation, composite laminate, and effects of a laminate anchoring system. Current twisted strengthening and repair methods are time and resource intensive, and quite often very intrusive. The proposed method however, uses composite laminates to increase the twisted capacity of concrete beams.

Jing et al. (2005) made an experimental investigation on the response of strengthen concrete box beam under combined actions of bending moment, shear and cyclic torque, strengthened with externally bonded carbon fiber strengthen polymer sheets. Three strengthened box beams and one reference box beam were tested. The main parameters of this experiment were the amount of CFS and the wrapping schemes. The failure shapes, twisted capacities, deformation capacities, rigidity attenuations and hysteresis deportments of specimens were studied in detail. The experimental results indicated that the contribution of externally bonded CFS to the aseismic capacity of box beam is significant. Based on the text results and analysis, restoring force model of CFS strengthened R.C. box beam under combined actions of bending moment, shear and cyclic torque was established.

Al-Mahaidi and Hii (2006) focuses on the bond-deportment of externally bonded CFRP in an overall investigation of twisted strengthening of solid and box-section strengthen concrete beams. Significant levels of debonding prior to failure by CFRP rupture were measured in experiments with photogrammetry. Numerical work was carried out using non-linear finite element (FE) modelling. Good agreement in terms of torque-twist deportment, steel and CFRP reinforcement responses, and crack patterns was achieved. The addition of a bond-slip model between the CFRP reinforcement and concrete meant that the debonding mechanisms prior to and unique failure modes of all the specimens were modelled correctly as well. Numerical work was carried out using non-linear finite element (FE) modelling. Good agreement in terms of torque-twist deportment, steel and CFRP reinforcement responses, and crack patterns was achieved.

Very few analytical models are available for predicting the section capacity (Ameli and Ronagh 2007; Hii and Al-Mahadi 2006; Rahal and Collins 1995).

Santhakumar et al. (2007) presented the numerical learning on unretrofitted and retrofitted strengthen concrete beams subjected to combined bending and torsion. Different ratios between twisting moment and bending moment are considered. The finite elements adopted by ANSYS are used for this learning. For the purpose of validation of the finite element model developed, the numerical learning is first carried out on the un-retrofitted strengthen concrete beams that were experimentally tested and reported in the literature. Then the learning has been extended for the same strengthen concrete beams retrofitted with carbon fiber strengthen plastic composites with ±45and 0/90o fiber orientations. The present learning reveals that the CFRP composites with ±45 fiber orientations are more effective in retrofitting the RC beams subjected to combined bending and torsion for higher torque to moment ratios.

Ameli et al. (2007) experimentally investigated together with a numerical learning on strengthen concrete beams subjected to torsion that are strengthened with FRP wraps in a variety of configurations. Experimental results show that FRP wraps can increase the ultimate torque of fully wrapped beams considerably in addition to enhancing the ductility.

Chalioris (2007) addressed an analytical method for the prediction of the entire twisted deportment of strengthen concrete (RC) beams strengthened with externally bonded fibre-strengthen-polymers (FRP) materials. The proposed approach combines two different theoretical models; a smeared crack analysis for plain concrete in torsion for the prediction of the elastic deportment and the cracking twisted moment, and a properly modified softened truss theory for the description of the post-cracking twisted response and the calculation of the ultimate torque capacity. The contribution of the FRPs is implemented by specially developed (a) equations in a well-known truss model and (b) stress - strain relationships of softened and FRP-confined concrete. In order to check the accuracy of the proposed methodology an experimental program of 12 rectangular beams under torsion was conducted. Tested beams were retrofitted using epoxy-bonded Carbon FRP continuous sheets and discrete strips as external reinforcement. Strengthened beams with continuous sheets performed improved twisted deportment and higher capacity than the beams with strips, since failure occurred due to fibre rupture. Comparisons between analytically predicted results and experimental ones indicated that the proposed deportmental model provides rational torque curves and calculates the twisted moments at cracking and at ultimate with satisfactory accuracy. Hii and Al-Mahaidi (2007) briefly recounted the experimental work in an overall investigation of twisted strengthening of solid and box-section strengthen concrete beams with externally bonded carbon fiber-strengthen polymer (CFRP).

2.4 Objective and scope of the present work

The aim of present work is to learning deportment and performance of RCC rectangular beams strengthened with externally bonded Glass Fiber strengthen Polymer subjected to combined flexure and torsion. In the present work the deportment of rectangular strengthen concrete beams, strengthened with GFRP is observed to know the practical feasibility of its application in the construction industry. Nine numbers of rectangular strengthen concrete beams are cast. All these beams except one beam are bonded with GFRP fabrics using epoxy in different size and orientations. These beams are subjected to torsion by applying gradually increasing static loading at the two cantilever moment arm of the beam to evaluate the increase in the twisted strength due to retrofitting. And the results are validated analytically by using finite element software ANSYS.

The variables considered in the experimental studies include

(1) Fiber orientation (45^{o}, 90^{o} oriented uni-directional & bi-directional glass fiber fabrics)
(2) GFRP configuration (continuously fully wrapped and wrapped in strips)
(3) Fiber type (Unidirectional and Bi-directional GFRP woven fabrics)
The experimental results will be compared with the analytical results.

III. EXPERIMENTAL LEARNING

3.1 Materials

3.1.1 Concrete

Concrete is a composite construction material composed of aggregate, cement and water. There are many formulations that have varied properties. The aggregate is generally coarse gravel or crushed rocks such as

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limestone, or granite, along with a fine aggregate such as sand. The cement, commonly Portland cement, and other cementitious materials such as fly ash and slag cement, serve as a binder for the aggregate. Various chemical admixtures are also added to achieve varied properties. Water is then mixed with this dry composite which enables it to be shaped (typically poured) and then solidified and hardened into rock-hard strength through a chemical process known as hydration. The water reacts with the cement which bonds the other components together, eventually creating a robust stone-like material. Concrete has relatively high compressive strength, but much lower tensile strength. The ultimate strength of concrete is influenced by the water-cementitious ratio *(w/cm),* the design constituents, and the mixing, placement and curing methods employed. All things being equal, concrete with a lower water-cement (cementitious) ratio makes a stronger concrete than that with a higher ratio. The quality of the paste formed by the cement and water largely referred to as designing the mixture, and for most structural work the concrete is designed to give compressive strengths of 15 to 35 MPa.

3.1.2 Cement

Cement is a material, generally in powder form, that can be made into a paste usually by the addition of water and, when moulded or poured, will set into a solid mass. Numerous organic compounds used for 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 a bluish-gray powder obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. The chief raw material is a mixture of high-calcium limestone, known as cement rock, and clay or shale. Blast-furnace slag may also be used in some cements and the cement is called Portland slag cement (PSC). The colour of the cement is due chiefly to iron oxide. In the absence of impurities, the colour would be white, but neither the colour nor the specific gravity is a test of quality.

3.1.3 Fine Aggregate

Fine aggregate is natural sand which has been washed and sieved to remove particles larger than 5 mm and coarse aggregate is gravel which has been crushed, washed and sieved so that the particles vary from 5 up to 50 mm in size. The fine and coarse aggregate are delivered separately. Because they have to be sieved, a prepared mixture of fine and coarse aggregate is more expensive than natural all-in aggregate. Sand is used for making mortar and concrete and for polishing and sandblasting. Sands containing a little clay are used for making moulds in foundries. Clear sands are employed for filtering water. Sand is sold by the cubic yard (0.76 m3) or ton (0.91 metric ton) but is always shipped by weight. The weight varies from 1,538 to 1,842 kg/m3, depending on the composition and size of grain. The fine aggregate is passing through 4.75 mm sieve and had a specific gravity of 2.67**.**

3.1.4 Coarse Aggregate

Coarse aggregate 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 sizes are from 0.25 to 2.5 in (0.64 to 6.35 cm), although lager sizes may be used for massive concrete aggregate. Machine chorused granite broken stone angular in shape is use as coarse aggregate.

3.1.5 Water

In general water that is fit for drinking is considered fit for making concrete. Water should be free from acids, oils, alkalis, vegetables or other organic impurities. Soft water also produces weaker concrete. Water has mainly two functions in concrete mix. Firstly, it causes a chemical reaction with the cement to form cement paste in which the inert aggregate are held in suspension until the cement paste has hardened. And secondly it acts as a lubricant in the mixture of fine aggregate and cement.

3.1.6 Fiber Strengthen Polymer (FRP)

Fiber strengthen polymer (FRP) is a composite material made by combining two or more materials to give a new combination of properties. However, FRP is different from other composites in that its constituent materials are different at the molecular level and are mechanically separable. The mechanical and physical properties of FRP are controlled by its constituent properties and by structural configurations at micro level. Therefore, the design and analysis of any FRP structural member requires a good knowledge of the material properties, which are dependent on the manufacturing process and the properties of constituent materials. FRP composite is a two phased material, hence its anisotropic properties. It is composed of fiber and matrix, which are bonded at interface. Each of these different phases has to perform its required function based on mechanical properties, so that the composite system performs satisfactorily as a whole. In this case, the reinforcing fiber provides FRP composite with strength and stiffness, while the matrix gives rigidity and environmental protection. A great majority of

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materials are stronger ad stiffer in fibrous form than as bulk materials. A high fiber aspect ratio (length: diameter ratio) permits very effective transfer of load via matrix materials to the fibers, thus taking advantage of their excellent properties. Therefore, fibers are very effective and attractive reinforcement materials. They are widely used for strengthening of civil structures. There are many advantages of using FRPs: lightweight, good mechanical properties, corrosion-resistant, etc. Composites for structural strengthening are available in several geometries from laminates used for strengthening of members with regular surface to bidirectional fabrics easily adaptable to the shape of the member to be strengthened.

IV. RESULTS AND DISCUSSIONS

4.1 Results

This chapter includes all the experimental results of all beams with different types of configurations and orientation of GFRP. Their behavior throughout the test is described using recorded data on twisted behavior and the ultimate load carrying capacity. The crack patterns and the mode of failure of each beam are also described in this chapter. All the beams are tested for their ultimate strengths. Beam No-1 is taken as the control beam. It is observed that the control beam had less load carrying capacity and high deflection values compared to that of the externally strengthened beams using GFRP sheets.

All the eight beams except the control beam are strengthened with GFRP sheets in different patterns. In series-1 two beams were fully wrapped, one with unidirectional GFRP and other with bidirectional GFRP. In series-2 two beams were wrapped with 19cm wide GFRP sheets, one with unidirectional GFRP and other with bidirectional GFRP. In series-3 two beams were wrapped with 5cm GFRP sheets, one with unidirectional GFRP and other with bidirectional GFRP. In series-4 two beams were wrapped with 5cm GFRP sheets, one with unidirectional GFRP and other with bidirectional GFRP making 40^{0} with the main beam.

4.2 Failure modes

Different failure modes have been observed in the experiments of rectangular RC beams strengthened in torsion by GFRPs.

These include shear failure due to GFRP rupture .Rupture of the FRP strips is assumed to occur if the strain in the FRP reaches its design rupture strain before the concrete reaches its maximum usable strain. GFRP debonding can occur if the force in the FRP cannot be sustained by the substrate. In order to prevent debonding of the GFRP laminate, a limitation should be placed on the strain level developed in the laminate. Load was applied on the two moment arm of the beams which is 0.25m away from the main beam and at the each increment of the load, deflections at L/4, L/2 and 2L/3 is taken with the help of dial gauges. Mid section at L/2 was taken as sec-1 and section 300mm away from sec-1 was taken as section 2.The load arrangement was same for all the beams.

The control beam and GFRP strengthened beam are tested to find out their ultimate load carrying capacity. It is found that all the beams failed in twisted shear.

Beam-2 continuously fully wrapped with unidirectional fabric did not show any failure in the strengthen part but the unstrengthen cantilever arm transferring moment had failed. Similarly Beam-3 continuously fully wrapped with biidirectional fabric did not show any failure in the strengthen part but the unstrengthen cantilever arm transferring moment had failed. In both cases failure is partial. Beam-4 & Beam-5 continuously fully wrapped with strips of 12 cm of uni and bi directional fabrics failure occurred in the unstrengthen part. The failure is due to combination of shear and torsion in the region. The diagonal cracks initiated from the concrete portion in between the strips and propagated in the concrete below the fabrics. There was no deboning of GFRP fabrics.

V. CONCLUSIONS

The present experimental learning is made on the twisted deportment of rectangular RC beams strengthened by uni-directional and bi-directional GFRP fabrics. Nine rectangular RC beams having same reinforcement detailing and designed to fail in torsion and are cast and tested till collapse. During testing deflections and strain measurements are observed with the help of dial gauges and strain gauge. Following conclusions are drawn from the test results and calculated strength values:

- The ultimate load carrying capacity of all the strengthen beams were enhanced as compared to the Control Beam1.

- Twisted strengthen concrete beams strengthened with GFRP sheets exhibited significant increase in their cracking and ultimate strength as well as ultimate twist deformations.
- Initial cracks appear for higher loads in case of strengthened beams.
- The load carrying capacity of the strengthened Beam 2 fully wrapped with unidirectional fibre was found to be maximum of all the beams. The increase in load carrying capacity is 88.46% compared to control beam1.
- Both fully wrapped beams Beam 2 and Beam 3 had partially collapsed without achieving the ultimate load. The failure occurred in the unstrenghtened part of the specimens.
- Beam 8 and Beam 9 were giving the best results in terms of load carrying capacity and angle of twist respectively. And both are having same wrapping pattern of GFRP which is bonded in the torsion part at an angle 45^0 with the main beam.
- Less cracks appeared on the beams strengthened with bidirectional fabrics compare to unidirectional fabrics. This may be due to availability of fibre on diagonal compression side causing less stress in concrete face in bidirectional fabrics.
- Test result reveals that strengthening using bidirectional GFRP sheets had not enhanced the ultimate strength but had increased the ductility of the beam.
- The angle of twist obtained using ANSYS matches the experimental results for lower range of load value for the beam which are wrapped with GFRP in 90^0 angles with main beam. For higher loads there is a deviation with experimental results for these beams.
- The experimental results obtained for beams wrapped with GFRP at an angle 45^0 with axis of the beam are in good agreement with ANSYS results.

VI. SCOPE OF THE FUTURE WORK

This present experimental work can give great scope for future studies. Following areas can be considered for future research:

- Experimental learning on deportment of flanged RC section wrapped with FRP under combined loading.
- Effect of different types of FRP like CFRP (carbon fibre strengthen polymer) or hybrid FRP strengthening on twisted deportment of RC beams.
- Development of an analytical model to predict full deportment up to collapse for RC beams strengthens in torsion under combined loading
- Developing a non linear finite element model for the analysis of the strengthened rectangular RC Beams using various configurations with different orientation of fibres.

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