Retrofitting of Concrete Beams using Externally Bonded GFRP Wraps - an Overview

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Abstract— The research work related to retrofitting of building and civil structural elements had been done by many engineers. It is an essential medicine required to be applied for enhancing the structural health of a structural element over a serviceability period of life. In general a beam or slab needs to carry an additional load as the purpose of occupancy has been changed over a period of time for a specified area in a building and it needs to be replaced for a very short difference in its load carrying capacity; in such case the application of the externally bonded Glass Fibre Reinforced Polymer (GFRP) wraps can be a remedy or solution over the problem. There are many new types of Glass Fibre Reinforced Polymer (GFRP) wraps available recently for the effective use in enhancing the load carrying capacity and mainly meant for the retrofitting of the various structural elements. Non Crimped Fibres (NCF) had been evolved as a result of rigorous research and new technology in the area of GFRP over crimped fibres used in routine practice. These new fabrics are woven as unidirectional, bi-directional and multi-directional forms. This paper focuses on the new material i.e. Non crimped fibres and the various pattern, thickness i.e. number of layers and results of the previous attempts made to strengthen the beams by the application of externally bonded GFRP wraps, mats etc.

Key words: Glass Fibre Reinforced Polymer, GFRP Wraps, Concrete Beams, Resins, Strengthening, Shear Capacity and Retrofitting

I. Introduction

The Glass Fibre Reinforced Polymer (GFRP) is used in various ways for many applications to achieve the desired results from past experiences from experimental trails and testing. The GFRP can be simply used along with concrete in some percentage to enhance the compressive strength in the form of chopped strand fibres.

Fig. 1: Chopped strand glass fibres

And, there are many more applications of GFRP in its advanced forms. It can be used in the externally bonded form for enhancing shear capacity of beam and for retrofitting. The reasons include up-gradation of the design standards, changing the use of the structure and committing mistakes in design or in construction.

In other way it can be stated that the flexural strength of a reinforced concrete beam can be extensively increased by the application of GFRP plates/sheets adhesively bonded to the tension face of the beam. It is being used widely for rehabilitation and retrofitting due the lower cost of GFRP as compared with other available types of FRPs.

II. Literature review

The externally bonded GFRP wraps are widely used since many years in retrofitting work of various structural elements like bridges, bottom slabs, beams and columns. But, there is no such rational formula established to find the strength that GFRP application will impart. This is due to the dependency of the relation on the extent of deterioration of the member which has led the reduction in the strength of the member.

Sherif F. Kansouh, M. Basil H. Emara [1] makes use of GFRP fabrics to enhance the shear capacity of High Strength Concrete (HSC) beams. HSC is being used in the construction of the high-rise reinforced buildings. Through the use of HSC the size of the beams can be reduced, which may help to satisfy special architectural requirements. His paper discusses experimentally and theoretically the behavior of strengthened HSC beams. The effect of strengthening HSC beams with web bonded glass fibre fabrics is investigated at the ultimate state, where inclined shear cracks might develop in the beam. The effect of fibre orientation angle, concrete strength, tension reinforcement ratio and web reinforcement ratio are investigated. Eight high strength concrete beams were designed and prepared for this study. These beams were tested up to failure where their failure mode was monitored and ultimate load capacity is recorded. Besides, the strains were measured in both concrete and steel reinforcement at different load levels. Theoretical analysis was made and its results were compared to the experimentally measured results. Thus, the feasibility of using glass fibre fabric wraps as external strengthening to increase the shear capacity of HSC beams is investigated. It is also found that strengthening high strength concrete beams in shear switches the failure mode from the undesirable, brittle shear mode to the ductile flexural one.

M.A.A. Saafan [2] investigates the efficiency of GFRP composites in strengthening simply supported reinforced concrete beams designed with insufficient shear capacity. Using the hand lay-up technique, successive layers of a woven fibreglass fabric were bonded along the shear span to increase the shear capacity and to avoid catastrophic premature failure modes. The strengthened beams were fabricated with no web reinforcement to explore the efficiency of the proposed strengthening technique using the results of control beams with closed stirrups as web reinforcement. The test results of 18 beams were reported, addressing the influence of different shear strengthening schemes and variable longitudinal reinforcement ratios on the structural behavior. The results indicated that significant increases in the shear strength and improvements in the overall structural behavior of beams with insufficient shear capacity could be achieved by proper application of GFRP wraps. He presents a study focused on performing a comprehensive experimental work to explore the efficiency of GFRP composites as external shear reinforcement. The cost effectiveness of the system makes it a very attractive alternative in strengthening and repair works as the material are commercially available at a convenient price. The results indicated that significant increase in shear strength could be achieved by the application of GFRP to concrete beams deficient in shear capacity. When jackets are properly applied over the shear span, the failure mode of the beam may be altered from that of a brittle shear failure to a ductile flexural failure mode. Also, the strengthened beams were able to achieve the strength and stiffness levels of web reinforced beams. The results also show that the serviceability performance of strengthened beams is expected to be superior with regard to increased cracking loads and the limited number of cracks and small cracking width.

N. Pannirselvam, V. Nagaradjane and K. Chandramouli [3] had undertaken study to investigate the impact of externally bonded chopped strand mat (CSM), woven roving (WR), CSMWR GFRP and Unidirectional (UD) GFRP laminates on strength, deformation and ductility of the test beams and examined the composite action of the GFRP laminates at all loads. They also studied the associated cracking and failure mechanism. The experimental study shows that the performance of GFRP plated RC beams increased with regards to strength and deformation capacity. Deflection ductility values for beams showed increase up to 64.48% over the corresponding reference beam and energy ductility values increased upto 118.90% for 3.5 mm thick GFRP plated beams.

K. L. Muthuramu, A. Chandran, S. Govindarajan and S. Karunanidhi [4] also performed the experiment to strengthen the beam using GFRP. The study revealed that the performance of the epoxy resin/ general purpose resin used to bond the GFRP sheets to the RC beams was found good upto two layers and the GFRP sheets do not debond from the concrete surface during the flexural testing of RC beams upto two layers of GFRP sheets. And, increasing the number of GFRP sheet i.e. more than two sheets is found to be brittle failure. Also, sudden and undesirable debonding of GFRP sheets is the major failure mode of the strengthened beams when tested.

Deepa Raj S. and Surumi R. S. [5] executed work based on studying the behavior of various types of glass fibre reinforced polymer like strips, rods and sheets on shear strengthening of reinforced concrete beams. The use of various forms of GFRP like strips, rods and sheets showed effectiveness inn shear strengthening of RC beams. The use of NSM reinforcement was more efficient than externally bonded reinforcement in terms of exploitation of the FRP tensile strength. This is due to the early debonding of the externally bonded reinforcement from concrete.

Sandeep G. Sawant, A.B. Sawant, M.B. Kumthekar [6] did conducted the experiment and the data on load, deflection and failure modes of each of the beam is obtained. The detailed procedure and application of GFRP sheets for strengthening of RC beams is also included. The effect of number of GFRP layers and its orientation on ultimate load carrying capacity and failure mode of the beams are investigated. The experimental study consists of casting of four sets of reinforced concrete (RC) beams of grade M30, Total 30 no. of RC beam are casted and cured for 28 days. The cross-sectional dimensions of 150mm x 200mm and1000mm length, provided 2-12mm Ø bottom reinforcement and 2-8mm Ø top with 6mm Ø vertical stirrups @ 160mm c/c. All the specimens are tested in Universal testing machine (UTM). The experimentally obtained values are then compared with the control beam GFRP is provided to increase the strength and stiffness of existing concrete beams when bonded to the both side, bottom side and U-Shape by using single mat, double mat and woven roving wrap as compare to control beam, however the mode of failure associates with application of GFRP was more ductile and preceded by warning signs such as snapping sounds or peeling of the GFRP. Yet the results of this study show that GFRP can be used to increase the strength and stiffness of beams without causing catastrophic brittle failure associated with this strengthening technique. With reference to the experimental result strength and cost comparison are made. It is cleared that U-Shape wrap and bottom wrap was good for improving shear strength as well as for reducing deflection of RC member as compared to both side wrap. Even if initial cost of U-Shape wrap is more then also comparing to high strength results, the strength of U-Shape wrap beam was increased by 46% as compare to both side wrap beam. Cost of woven roving wrap was more as compare to single mat and double mat wrap but load carrying capacity also increases as compare to single mat and double mat wrap. It was indicated that woven roving U-Shape wrap is more beneficial and preferable for Retrofitting. Retrofitting is always affordable to strengthen the structure than replacement. It avoids excess time required for replacement and reduces cost of material and labour.

Dipesh K. Rathod, Prof. Tarak P. Vora [7] presents a research study to Study the Effect of Different Strengthening Patterns Using GFRP on shear capacity of the beam. Total twelve rectangular beams having 700 mm x 150 mm x 150mm were casted. The variables considered includes three different grades of concrete i.e. M20, M30, M40 and three different strengthening schemes were adopted (i.e. U shape vertical strip wrap “UVS”,U-wrap-“U” Vertical strip at 50°“VS50°”).Shear test, using simple beam with two-point loading was adopted in UTM testing Machine to study for the performance of GFRP wrapped beams in terms of increase in shear capacity and deflection and it was compared with the blank beams. The test results show that the beams strengthened with GFRP laminates exhibit better performance. The shear strength is increased by applying different pattern of GFRP strengthening scheme. The ultimate shear strength is increased by35%, 34% and 11% in U-shape wrapping beam inM20, M30 and M40 respectively.

Mettu Bhaskara Rao, P. J. Rao, M.V.S. Rao and K. J. Rao [8] studied the behavior of GFRP RC beams under shear. In this investigation the GFRP flats were used as shear reinforcement and GFRP bars as flexural reinforcement. The beams reinforced with plain GFRP bars as shear reinforcement have taken more shear than the control specimen with no shear reinforcement, which indicates that the GFRP bars are able to take shear and are comparable to mild steel (FE250) reinforcement. And, the failure of beams was not sudden though the failure of GFRP bars was sudden and associated with splitering of fibres in direct tension.

P.G.R.V. Sarath and Rama Mohan Rao P. [9] retrofitted the beams by two processes as by casting laminates of 20 mm thickness and attaching them to the beams and the other by directly pasting the fibre mat to the beam surface. The laminates with volume fraction of 5% were made. The substantial enhancement in the flexural strength was observed when fibre laminates properly bonded to the tension face of RC beams. On comparing beams applied with laminates and beams applied with fibre mats having equivalent area; laminates have taken more load than mats. A flexible epoxy system will ensure that the bond line does not break before failure and participate fully in the structural resistance of the strengthened beams.

Ghogare V. P. and Dr. M. B. Varma [10] an overview literature depicts the newly developed technique of Near Surface Mounted (NSM) GFRP reinforcement used for the strengthening of structures has attracted a wide attention as a feasible and economical alternative to the former techniques of strengthening of structures. This paper has provided a detailed and critical review of existing research on the flexural behavior of concrete structures strengthened with NSM GFRP reinforcement.

III. MATERIALS AND PROPERTIES

A. *GFRP Complexes*

A new material form Saertex India Pvt. Ltd. is getting wider attention which is known as NCFs (Non-Crimp Fabrics), are characterised by stretched fibres within the individual layers.

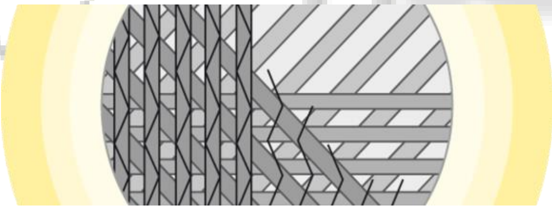

Fig. 2: Non Crimp Fiber

It is then divided into following categories:

1) *Unidirectional Complexes:*

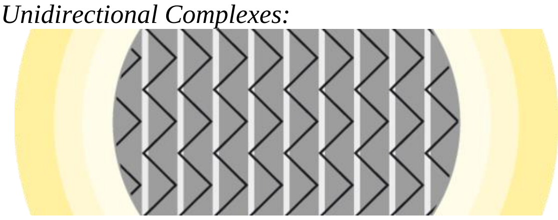

Fig. 3: Unidirectional Complexes

The composite components manufactured from non-crimp fabrics (NCFs) permit the ideal transmission to the component of the generated forces – in the direction of loading – by specifically adjusting the fibre orientation. And, the same is only possible in only one direction using such fibre. So, it is named as unidirectional complexes.

In comparison with standard reinforcement textiles (woven fabrics etc.) this delivers either reduced component weight for identical mechanical characteristic values, or a higher component loading for the same component weight.

The unidirectional complexes are available in both 0° and 90° orientations. They are produced optionally with reinforcement threads, a mat or a non-woven fabric.

2) *Multi-axial Complexes*

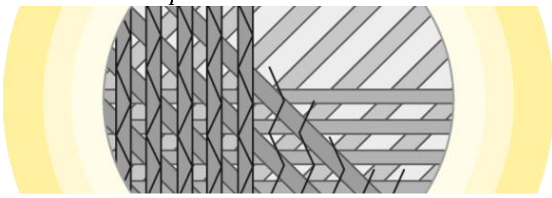

Fig. 4: Multi-axial Complexes

Multi-axial interlaid complexes (NCFs) of variable orientation and individual layer arrangement always exhibit the best mechanical characteristic values. The greatest degree of freely selectable angularity of the individual layers allows the component to absorb the forces in a manner that is adapted and optimised to suit the particular loading condition. The bidirectional complexes are available in orientations of 0°/90°. And, the multi-axial complexes are available in various weights, variable orientations and individual layer arrangements. Angles of between 22.5° and 90° are possible.

The design of the reinforcement textile is a major factor here. In this context, the fundamental characteristics of composites are dependent on:

- The type of fibre (glass, carbon, aramid)
- The fibre diameter/weight
- The width of the fabric
- The design of the layer structure
- The stitching

The greatest degree of freely selectable angularity of the individual layers allows the component to absorb the forces in a manner that is adapted and optimised to suit the particular load condition. The designer therefore has two options in comparison with woven textiles:

- Higher mechanical characteristic values for the same weight
- Lower weight and minimized use of reinforcement material for the same mechanical characteristic value

The use of our multi-axial interlaid complexes also offers further benefits:

1) Reduced lay-up time (fewer layers are required thanks to the higher weight per unit area of the individual layers)
2) This results in faster lamination cadence
3) With associated time savings
4) And cost savings.

IV. PROPOSED MIX DESIGN AND EXPERIMENTAL STUDY

A. *Mix Design*

A concrete mix of M20 grade shall be designed as per IS 10262:2009 and shall be used to prepare the test beams of size (150 × 150 × 700) mm.

B. *Experimental Study*

The control beams shall be casted as the details given below:

1) A plain cement concrete beam without any reinforcement.

2) A concrete beam with longitudinal reinforcement at bottom only and without shear reinforcement.
3) A concrete beam with longitudinal reinforcement at top and bottom along with shear reinforcement

The all other beams will be casted with longitudinal reinforcement at bottom. The beams will be applied with the externally bonded Bi-directional (0^0-90^0) GFRP wraps in single, double and triple layer thickness with three different patterns of the wrapping as below.

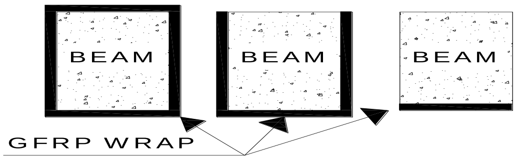

Fig. 4: Patterns of externally bonded GFRP wraps

The experimental study will comprises of the comparative study with regards to the various aspects like enhancement of the shear capacity of the beams, cracking pattern on loading and deflection of beams with externally bonded GFRP wraps on one side and control beams on the other side through four point load testing.

V. CONCLUSION

The method of using externally bonded GFRP wraps is much popular in the construction industry for retrofitting work as it has made possible to strengthen the beam in shear their by enhancing the capacity to resist the imposed load. The results in most of the experimental study has revealed that the use of GFRP wraps applied in more than single layer also helps to increase the shear capacity. But, it also states that the use of GFRP wraps for more than two layers will result in brittle failure and debonding of the wraps occurs at early stage.

So, the externally bonded GFRP wraps helps to strengthen beams and proves its applicability in the retrofitting work much effectively in construction industry.

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