Application of FRP Composites In Flexural Strength Enhancement Of RC Slabs – A Review

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Abstract*- The service life of Reinforced Concrete slabs mainly depends on three parameters, satisfactory design, use of appropriate and quality construction materials, and least effect of environment on the existing component. Any flaw in these three leads to early degradation and deterioration of the structure. Replacement of such structures is not always possible due to the high operational expenditure and their usage limitations. The only way to retain the structure in a safe working mode is to repair, strengthen and maintain the structure. Consequently, the strengthening of deficient structures needs a complete understanding of the material and the adopted strengthening techniques. Researchers have been working on the repair and strengthening of RC slabs since decades utilizing various materials for performance enhancement. Objective of this research paper is to present a review of these works, which aimed at increasing the efficiency of strengthened slabs by using various materials and mechanisms to evaluate currently available and popular FRP strengthening techniques.*

Keywords- RC Slabs, Strengthening, FRP, Mechanisms, Epoxy Bonding, Debonding/Delaminating, Performance.

I. INTRODUCTION

There are a number of situations where it may become necessary to increase the load-carrying capacity of a structure in service. These include change of loading or use, and the cases of structures that have been damaged as a result of impact or material deterioration.

In the past, the increase in strength has been provided by casting additional reinforced concrete, dowelling in additional reinforcement or externally post-tensioning the structure. More recently, attaching steel plates to the surface of the tension zone by use of adhesives and bolts has been used to strengthen concrete structures. Even more recently, the use of fibre reinforced plastic (FRP) sheets/strips/rods has been developed using the same basic techniques.

FRP sheets have many advantages over steel plates in this application, and their use can be extended to situations where it would be impossible or impractical to use the steel. In addition to sheets, various types of fibres are available in the form of fabrics, which can be bonded to the concrete surfaces. An effort has been made here to evaluate several existing as well as newly evolved strengthening mechanisms for RC Slabs which can be adopted on field to yield least number of challenges encountered for strengthened components.

Structural strengthening is generally needed due to following reasons:

- Error in load calculation during design
- Change in functionality of structure
- Deficiencies led by deterioration
- Error in structural design and detailing
- Damages due to earthquake
- Change in loading condition
- Exhaustion of land

Identify the constructs of a Journal – Essentially a journal consists of five major sections. The number of pages may vary depending upon the topic of research work but generally comprises up to 5 to 7 pages. These are:multi-label learning, more than one class can be assigned to an instance. With the increase in the number of data

II. FRP TECHNOLOGY AND ITS ADVANTAGES:

Worldwide interest is being given to the use of fiber reinforced polymer (FRP) materials in various structures. Their chemical resistance to the effects of de-icing salts and marine environments represents an attractive feature for civil engineers. Three types of commercially available composites namely; glass (GFRP), aramid (AFRP) and carbon (CFRP)have the necessary combination of strength and stiffness needed to replace steel. FRP products are made from continuous, unidirectional and/or bidirectional fibers bonded to a polymer or resin matrix and formed into rods, grids, sheets, shapes and winding strands. Fibers make up between 40 and 70% of the volume and are the principal load carrying elements. The polymer matrix, on the other hand, acts as a load transfer medium and protects fibers from environmental damage.

The chief advantage of fabrics over plates is that they can be wrapped around curved surfaces, for example around columns and chimneys, or completely around the sides and soffits of beams, which offers a cost-effective technique for the strengthening of reinforced concrete slabs as well. As far as technical properties and market survey are concerned, best materials for flexural strengthening are laminates and wraps. Below are the types of FRP wraps and laminates used popularly for flexural strengthening of RC slabs.

GFRP (Glass fibre reinforced polymer) –Bi-directional:

First developed in the mid 1930's, Glass Fiber Reinforced Plastic (GFRP) has become a staple in the building industry. Glass is a super cooled liquid. It possesses neither a crystalline structure, nor flow properties. Following are the properties of Bi-Directional GFRP material.

- High Strength
- Lightweight
- Resistance
- Seamless Construction
- Able to mould in Complex Shapes
- Low Maintenance, High Durability

CFRP (Carbon fibre reinforced polymer):

Carbon fibres have been commercially available since 1959. Carbon is made from either PAN (polyacrylonitrile), pitch (a petroleum-processing by product), or rayon fibre precursors. The individual fibres are produced by stripping off hydrogen and other side groups from a carbon- carbon backbone polymer under tension, and thus a crystalline carbon matrix is formed. These are of two types, based on their stitching pattern i.e. straight stitched and zig-zag stitched. Although these are available in various grades based on their GSM's (Gram per square meters). Following are the properties of CFRP Wraps.

- Superior durability and fatigue characteristics
- Used in weight/modulus critical applications
- Significantly higher cost than glass

CFRP Laminates

CFRP laminates are carbon fibre reinforced polymers produced by a pultrusion process to have precisely defined properties and performance; all in accordance with tight specifications and quality control procedures. The materials are widely used for the flexural strengthening of dynamic and statically loaded buildings and other structures including bridges, beams, ceilings and walls, for both negative and positive moments.

Non-corrosive

- Very high strength and Excellent durability
- Light weight, Unlimited lengths, No joints required
- Low overall thickness, can be coated
- Easy transportation
- Simple plate interactions or crossings
- Very easy to install especially overhead
- Outstanding fatigue resistance
- Minimal preparation of plate
- Applicable in several layers
- Combinations of high strength and modulus of elasticity available
- High alkali resistance
- Clean edges without exposed fiber tends to the pultrusion process
- Approvals from many country worldwide

III. TECHNIQUES FOR FLEXURAL STRENGTHENING OF RC SLABS

1) Strip bonding method
2) Wrapping method
3) Near surface mounting method (NSM)
4) Shear strengthened by concrete (micro concrete, ferrocement, SCC etc.)
5) Jacketing etc.

IV. FRP COMPOSITE AS CONFINEMENT MATERIAL

Here comes the most crucial step for your research publication. Ensure the drafted journal is critically reviewed by your peers or any subject matter experts. Always try to get maximum review comments even if you are well confident about your paper.

M. A. Shahawy et.al in 1995 investigated a flexural behaviour of regular RC beam with epoxy bonded CFRP laminates with experimental and theoretical analysis. Four RC beams of the dimension 203 x 305x 2744 in mm were cast according to ACI 318-89 code provisions and tested under four-point static loading to analyse first crack load, cracking behaviour, deflections, serviceability loads, ultimate strength and failure modes by using Vibrating wire strain gauges and LVDT. The increase in strength and stiffness provided by the bonded laminates is assessed by increasing the number of laminates such as bonding of one, two and three CFRP laminates increased ultimate flexural capacity by 13, 66 and 92%, respectively. Theoretical analysis is presented by non-linear finite element program to predict the ultimate strength and moment deflection behaviour of the beams and compared with experimental results.

Koji Takeda and Hiromichi Sakai in 1996 performed an experiment on flexural behaviour of RC beams strengthened with CFRP sheets. Six medium-sized 150 x 200 x 2400 in mm RC beams were tested in bending by applying CF sheets in concrete surface to evaluate reinforcing effects and A large-sized 250 mm x 400 mm x 4800 mm RC beam which was initially Crack-damaged by pre-loading and subsequently repaired by injection of epoxy resin was also tested to simulate the performance in real structures under four-point static loading. The yield strength and ultimate strength of the strengthened beams were about 1.4 to 1.9 and 1.9 to 2.4 times respectively higher than that of the virgin beam, proportionally increasing with increase in number of sheets.

Rota V. S. GangaRao in 1998 evaluated the improvements in flexural strength of reinforced concrete beams after wrapping them with carbon fabrics. Four different carbon wrap configurations were used in 24 RC beams and tested for evaluation and comparison of experimental data to beams strengthened by bonded steel plates and also analysed by considering conventional force equilibrium equations. Static responses of all the concrete beams were evaluated in terms of strength, stiffness, compositeness between wrap and concrete, and associated failure modes and resulted in improved performance than the control beam and beam strengthened by steel plates.

P. Alagusundaramoorthy, I. E. Harikand C. C. Choo in 2003 studied the effectiveness of externally bonded CFRP sheets in increasing the flexural strength of concrete beams by application of different layouts of CFRP sheets and fabrics on nine beams and anchored CFRP sheets on three beams tested by Four-point bending flexural tests of all 230 x 380 x 4880 in mm sized beams. Variations in width, thickness and nos. of FRP in strengthened beams shows behaviour changes in beams both by experimental and analytical analysis resulted in increasing of flexural strength and failure load of anchored CFRP sheets higher than CFRP fabric and sheet on concrete surface.

W. Wenwei and L. Guo in 2005 examined the effects of initial load and load history on the ultimate strength of strengthened RC beams by externally bonded CFRP laminates with the help of strain gauges. To define the preloading condition of the damaged beams, one control beam was tested to failure for evaluating cracking, yielding, and ultimate loads and then other beams were preloaded at expectable constant load for 1 week to permit CFRP laminate application and curing. The stiffness of strengthened beams at different levels of sustaining load is weaker than that of virgin beam strengthened with CFRP laminates when initial load is same.
H. Toutanji, L. Zhao and Y. Zhang in 2005 analysed beams of dimensions 108 x 160 x 1800 mm reinforced with three to six layers of carbon fiber sheets bonded by an inorganic epoxy subjected to a four-point bending test to evaluate load, deflection, mid-span strain and failure mode up to failure. As the amount of CFRP reinforcement increased from three layers up to six, the failure mode of the strengthened beams transferred from FRP rupture to FRP delamination as shown in figure.

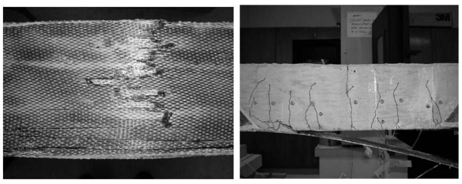

Figure 1 FRP rupture to FRP delamination

L. Bouazaouia, B. Jurkiewiezb and Y. Delmasa in 2008 investigated bonding connection in steel–concrete composite beams in the case of 3-point static loading and high-strength concrete confirms an efficient bonding in elastic domain with noticeable ductility. Navier's assumption also verified on elastic and plastic domain which confirms efficient bonding of high strength concrete so that ordinary connectors can be replaced.

N. Attari, S. Amziane and M. Chemrouk in 2012 examined efficiency of external strengthening systems for RC beams using FRP fabric like Glass and Carbon by different strengthening configurations such as use of (i) separate unidirectional glass and carbon fibres with some U-anchorages (ii) bidirectional glass–carbon fibre hybrid fabric on 100 x 160 x 1500 in mm sized beam. The use of a twin layer Glass–Carbon fibres increases strength without brutal ductility loss and the U-anchorage strengthening mechanism leads to a greater deformations where combination with hybrid composite improves ductility and gives good elongation at rupture. The analytical model based on the classical flexural theory of concrete correlates with experiment when no premature failure of the strengthening composite material takes place.

Mufti Amir Sultana, Rudy Djamaluddinb, WihardiTjarongeb and Herman Parungb in 2015 examined the property of FRP such as it is corrosion less in marine environment and chloride. For that a series of specimen of RC beams with dimensions 150 x 200 x 3300 mm were cast tested under different duration of the immersion of sea water as 1,3 and 6 months strengthened with GFRP sheets ,instrumented by strain gauges on concrete surface, steel bar and FRP sheet. All specimen gives same flexural behaviour up to failure-which occur sudden after GFRP sheet apart from beam and the flexural capacity will decrease with the time immersion.

Peng Gao, Xianglin Gu and Ayman S. Mosallam in 2016 studied evaluation of flexural behaviour of preloaded 12 RC beam of 150 x 300 x 2600 mm strengthened with pre-tensioned CFRP laminates and tested under monotonic three-point loading up to failure further compared with control beam and non-tensioned CFRP laminated beams. The behavior ofsuch beams was simulated using FEM and both results were compared and analyzed which shows delay in cracks. Use of anchorage system prevented debonding of FRP and pre-tensioned strengthenedbeams failed in laminates tensile rupture.However, the imposed sustained load washigher than 40% of ultimate capacity of control beam, the capacityof strengthened specimens would be notably reduced when concretecrushing failure mode controls.

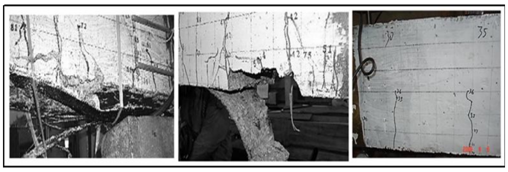

Figure 2 Failure pattern of FRP Strengthened RC Slabs

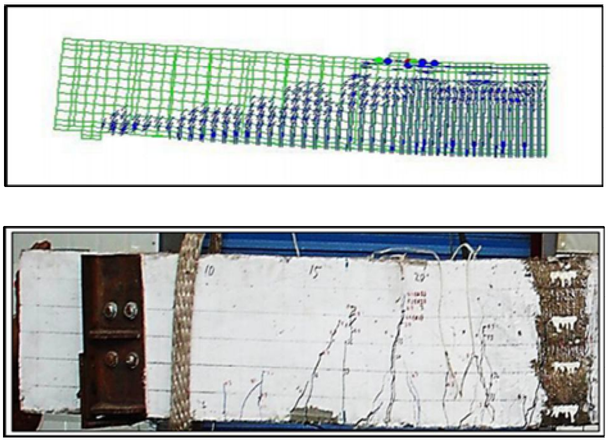

Figure 3 Failure of Strengthened RC Slabs in FEA Based Software v/s Experimental

V. RESEARCH GAPS

The experimental investigation for all mechanisms includes evaluation of deflections, load at first crack, Strain in Main reinforcement, Strain in Concrete and Ultimate load carrying capacity. The work accomplished till date, covered the evaluation of one mechanism for strengthening of RC beams in flexure. A wholesome work consisting of evaluation of strengthening by all major mechanisms is missing. A work comprising of detailed study in terms of real-time load, deflection, strains in steel, strains in concrete compression and strain in strengthening material is the need of time. This will provide guidance to practicing engineers, in terms of which mechanism and material to adopt in which situation.

Usama Ebead, Kshitij C. Shrestha and Muhammad S. Afzal in 2017 reported on the efficiency of fabric-reinforced cementitious matrix (FRCM) in enhancing the flexural capacity and deformational characteristics of under reinforced RC beams of 150 x 260 x 2500 mm with different steel reinforcement ratios. Two FRCM systems, six beams were externally strengthened using one, two, and three layers of carbon FRCM system where four beams with one and two layers of polyparaphenylenebenzobisoxazole (PBO) FRCM system. Testing results showed higher flexural capacity of carbon FRCM than PBO FRPM system.

VI. CONCLUSION

1. Adaptability of the strengthening material solely depends on the compatibility of the material with parent concrete. Selection of the strengthening mechanism/technique plays a vital role, as the feasibility of adopting the mechanism varies from component to component.
2. Strengthened beam element shows a reduction in ductility, which is purely dependent on the ductility of the material used for strengthening. A marginal decrease in ductility can be permitted, keeping in view the fact that loss of ductility must not invite catastrophic failure.
3. A mechanism which enhances the load carrying capacity without having major effect on the ductility of the element, and at the same time preventing de-bonding of the strengthening material, there by averting possibility of catastrophic failure, is ideally suited for strengthening of any structural element.
4. Important is the selection of strengthening material, which must possess adequate tensile strength to offer bending resistance, as well to impart ample ductility to the element, so as to prevent catastrophic failure. Equally important is the selection of strengthening technique.

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