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A STUDY OF STRENGTHENING OF CONCRETE USING CARBON FIBER REINFORCED POLYMER FOR RETROFITTING PURPOSE

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ABSTRACT: The rehabilitation of existing reinforced concrete (RC) bridges and building becomes necessary due to ageing, corrosion of steel reinforcement, defects in construction/design, demand in the increased service loads, and damage in case of seismic events and improvement in the design guidelines. Carbon Fiber-reinforced polymers (CFRP) have emerged as promising material for rehabilitation of existing reinforced concrete structures. The rehabilitation of structures can be in the form of strengthening, repairing or retrofitting for any type of deficiencies. Study has been carried on repair mechanism for the concrete beams with a particular percentage of damage. Carbon Fiber-reinforced polymers (CFRP) which is a well-accepted and efficient material for repair and rehabilitation is studied. The reinforced concrete beams has been tested and performance under two point loading setup. Studies has been carried for Carbon Fiber-reinforced polymers (CFRP) sheet bounded to the beams with different configuration in order to increasing the service life load capacity. In order to enhance stability, experimental program consisting of testing beams should be carried out. The specimen size of beams is 100 mm x 100 mm x 500 mm. Unidirectional Carbon Fiber-reinforced polymers (CFRP) sheets having cross section (500 mm x 1.0 mm) are used for wrapping the beams. The adhesive used for bonding Carbon Fiber-reinforced polymers (CFRP) sheets with concrete is a compatible epoxy resin. All the beams except the BEAM-1 were strengthened with CFRP sheets. The beam designated as BEAM-2 was strengthened with one layers of uni-directional CFRP sheets having U-wrap on the beam.
Keywords: Carbon fiber, concrete, reinforced polymer, beam and retrofitting

I. INTRODUCTION

Reinforced concrete (RC) is an extremely popular construction material. It has proven to be successful in terms of both durability and structural performance. Because of the nature and role of concrete in the creation, rehabilitation and regeneration of the infrastructure system of any country, Reinforced concrete plays a very important part in a nation’s economic development. Lack of durability of Reinforced concrete structures has thus not only massive economic implications to a nation’s well-being, but it is also one of the greatest threats to sustainable growth of concrete and construction industries. In reinforced concrete, the steel is embedded in concrete in such a manner that the two materials act together in resisting forces. The reinforcing steel-rods, bars, or mesh absorbs the tensile, shear, and sometimes the compressive stresses in a concrete structure. Plain concrete does not easily withstand tensile and shear stresses caused by wind, earthquakes, vibrations and other forces and are therefore unsuitable in most structural applications. In reinforced concrete, the tensile strength of steel and the compressive strength of concrete work together to allow the member to sustain these stresses over considerable spans. The invention of reinforced concrete in the 19th century revolutionized the construction industry, and concrete became one of the world’s most common building materials. 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 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 because of the complete replacement of such deficient structures leads to incurring a huge amount of public money and time. Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge Industries worldwide. The deterioration is mainly due to environmental effects, which includes corrosion of steel, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze-thaw cycles, contact with chemicals and saline water and exposure to ultra-violet radiations. This problem, coupled with revisions in structural codes needed to account for the natural phenomena like earthquakes or environmental deteriorating forces, demands development of successful structural retrofit technologies. The structural retrofit problem has two options, repair/retrofit or demolition/reconstruction.

Traditionally, the trend within the construction industries has been towards the latter option. This solution has become increasingly unacceptable due to changing economic and social attitudes concerning existing structures. This fact leads to the necessity for development of appropriate structural retrofit/repair systems. Traditionally, the retrofitting of reinforced concrete structures, such as columns, beams and other structural elements, involved a time consuming and disruptive process of 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 reinforced polymer (FRP) composites, concrete members can now be easily and effectively strengthened using externally bonded FRP composites. 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, labor 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. However, the use of these materials for retrofitting the existing concrete structures cannot reach up to the expectation due to lack of the proper knowledge on structural behavior of concrete structures retrofitted by fiber reinforced polymers (FRP) composites. Successful retrofitting of concrete structures with FRP needs a thorough knowledge on the subject and available user-friendly technologies/ unique guidelines. Beams are the critical structural members subjected to bending, torsion and shear in all type of structures. Similarly, columns are also used as various important elements subjected to axial load combined with/without bending and are used in all type of structures considering from building to bridge as piers or abutments. Therefore, extensive research works are being carried out throughout world on retrofitting of concrete beams and columns with externally bonded FRP composites. Several investigators took up concrete beams and columns retrofitted with carbon fiber reinforced polymer (CFRP)/ glass fiber reinforced polymer (GFRP) composites in order to study 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 study 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 due to exposure to de-icing salts and other environmental factors by encasing concrete members. FRP protects from existing salts and other environmental factors.It is noted that in many bridges the majority of corrosive damage occurred on exterior girders. This indicates that deleterious effects may be direct results of surface exposure, to spray of water, de-icing agents and environmental effects. Encasement of these girders not only increases design life, but also protects the members from surface attacks. FRP is a versatile material.

FRP can be applied to wide range of structures. FRP sheet can be cut and easily bonded to any concrete members. It is highly cost effect method of maintaining or upgrading existing structures. Quick application results in lower disruption and shorter contact periods. Reasons for strengthening of structures may include upgrading to accommodate higher (such as traffics), loss of pre-stress in existing reinforcement, or degradation of structures (e.g. corrosion of reinforcement). The technique may allow continued usage of structures or facility during strengthening works. Higher material cost of Carbon/Glass fiber is outweighed by numerous advantages over steel such as low self-weight and less requirement for plate surface preparation. Glass or Aramid fibers offer lower cost alternative, in some instances, to carbon fibers. FRP plates are an alternative to other forms of strengthening such as use of steel plates, or provision of additional support members. Column wrapping with FRP can be an alternative to jacketing additional reinforced concrete, or complete replacement of structures, with obvious saving in materials energy. It increases the capacity with minimal addition of dead load to the structure. Materials are easy to transport and handle no lifting gear required. It is easy to use at height. It increases the ability to work in confined areas and in situations with difficult access (e.g.tunnel and basements). This technique is relatively quick with reduced disturbance and installation time.

II. LITERATURE REVIEW

The state of deterioration of the existing concrete structures is one of the greatest concerns to the structural engineers worldwide. The renewal strategies applied to existing structures comprise of rehabilitation and complete replacement. A brief review of the existing literature in the area of reinforced concrete (RC) beams strengthened with epoxy-bonded FRP.

Norris et al.(1997) examine the behavior of damaged or under strength concrete beams retrofitted with thin carbon fiber reinforced plastic (CFRP) sheets, epoxy bonded to the tension face and web of the concrete beams to enhance their flexural and shear strengths. Author concluded that there is increase in strength and stiffness of the existing concrete structures after providing CFRP sheets in the tension face and web of the concrete beam depending upon the different orientation of fiber. Khalifa et al.(2000) studied the shear performance and the modes of failure of reinforced concrete (RC) beams strengthened with externally bonded carbon fiber reinforced polymer (CFRP) wraps experimentally. The experimental program consisted of testing twenty-seven, full-scale, RC beams. 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 3 versus 4), CFRP amount and distribution (i.e., Continuous wrap versus strips), bonded surface (i.e., lateral sides versus U-wrap), fiber orientation (i.e., 90°/0° fiber combination versus 90° direction), and end anchor (i.e., U-wrap with and without end anchor).

Khalifaet al.(2000) studied the improving shear capacity of existing reinforced concrete (RC) T-section beams using carbon FRP (CFRP) composites. Different configurations of externally bonded CFRP sheets were used to strengthen the specimens in shear. The experimental program consisted of six full-scale, simply supported beams. Design algorithms in ACI code format as well as Euro code format are proposed to predict the capacity of referred members. Alex et al.(2001) studied experimentally the effect of shear strengthening of RC beams on the stress distribution, initial cracks, crack propagation, and ultimate strength. Five types of beams with different strengthening carbon-fiber-reinforced plastic sheets are often strengthened in flexure. The results of tests performed in this study indicate that stiffness increases while increasing the CFRP sheet area at the flanks. Wang et al.(2001) examine the behavior of reinforced concrete T-beams retrofitted with carbon-fiber-reinforced polymer (CFRP) plates which were bounded to the underside of the beams to increase the service life load capacity. The beams were subsequently loaded to failure. The results shows that beam with full length or staggered CFRP plates behave in a similar manner at the service load range so that the use of staggered CFRP plates instead of full length CFRP plate is much economical to increase service live load capacity of the beam.

Sheikh et al.(2002) studied the damage sustained by foundation walls and large beams in a building simulated in full-size to near-full-scale model specimens in the laboratory. The damaged specimens were repaired with carbon and glass fiber-reinforced polymer (CFRP and GFRP) sheets and wraps, and tested to failure. Test results showed that fiber-reinforced polymers (FRP) were effective in strengthening for flexure as well as shear. Various analytical techniques were used to simulate experimental behaviour of the specimens. Both carbon and glass composites provided significant.Bousselhamet al.(2006) analyzed the behavior of reinforced concrete (RC) T-beams strengthened in shear with externally bonded carbon fiber reinforced polymer (CFRP) experimentally. The parameters investigated were as follows: (i) the CFRP ratio (that is, the number of CFRP layers); (ii) the internal shear steel reinforcement ratio (that is, spacing); and (iii) the shear length to the beams depth ratio, a/d(i.e. deep beam effect). The results showed that the contribution of the CFRP to the shear resistance is not in proportion to the CFRP thickness (that is, the stiffness) provided, and depends on whether the strengthened beam is reinforced in shear with internal transverse steel reinforcement.

Balamuralikrishnan (2009) has studied the flexural behaviour of RC beams strengthened with Carbon Fiber Reinforced Polymer (CFRP) fabrics. For flexural strengthening of RC beams, total ten numbers of beams were casted and tested over an effective span of 3000 mm up to failure under monotonic and cyclic loads. The beams were designed as under-reinforced concrete beams. The theoretical moment-curvature relationship and the load-displacement response of the strengthened beams and control beams were predicted by using software ANSYS. Comparison has been made between the numerical (ANSYS) and the experimental results. The results show that CFRP fabric properly bonded to the tension face of RC beams can enhance the flexural strength substantially. The strengthened beams exhibit an increase in flexural strength of 18 to 20 percent for single layer and 40 to 45% for two layers both static and compression cyclic loading respectively.Deifallaet al.(2010) have studied several 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. Failure of a structural element under combined shear and torsion is brittle in nature. 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.

III. MATERIAL AND METHODS

The experimental studies were carried based on the effect of externally bonded (EB) Carbon Fiber Reinforced Polymer (CFRP) sheets on the load bearing capacity of reinforced concrete beam. Twenty four number of reinforced concrete rectangular-beams were casted and tested up to failure by applying Two-point loading system. Out of twelve numbers of beams, six beamswere not strengthened by CFRP, whereas all other eighteen beams were strengthened with externally bonded CFRP sheets. The variables investigated in this research study included 7 days and 28 days strength of beams with externally bonded Carbon fiber Reinforced Polymer sheets.

Cement

Ordinary Portland cement of 43 Grade is used for the present investigation. The cement is of uniform colour i.e. grey with a light greenish shade and is free from any hard lumps. All the tests are carried out in accordance with procedure laid down in IS: 8112-1989.

Fine Aggregate

The sand used for the experimental program was locally procured and conformed to grading zone II. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust

Coarse Aggregate

Locally available coarse aggregates with maximum size of 20 mm mad 10mm was used in the present work. The aggregates used were first sieved and then they were washed to remove dust and dirt and were dried to surface dry condition.

Water

Fresh and clean tap water is used for casting the specimens in the present study. The water is relatively free from organic matter, silt, oil, sugar, chloride and acidic material as per Indian standard.

Reinforcing Steel

High-Yield Strength Deformed (HYSD) bars confirming to IS 1786:1985. The reinforcements of FE-500- 8 mm diameterwas used for the longitudinal reinforcement and the stirrups of FE-500-8 mm diameter. The Modulus of Elasticity of steel bars was 2 × 105MPa.

Carbon Fiber Reinforced Polymers

Continuous fiber reinforced materials with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behaviour up to failure. Normally, Glass and Carbon fibers are used as reinforcing material for FRP. Epoxy is used as the binding material between fiber layers.

Epoxy Resin

The adhesive used for bonding CFRP sheets with concrete is a compatible Epoxy system provided by the manufacturer. It is transparent pigmented Epoxy resin for saturation of Embraced fiber sheet to form in-situ CFRP Composite. It is made by mixing base saturant and hardener in ratio 100:42. Mixing of saturant and hardener is done thoroughly for five minutes until components are thoroughly dispersed.

IV. RESULTS AND DISCUSSION

The main objective of testing was to know the behaviour of RC beams with different configuration of CFRP wrapping. All the beams except the BEAM-1 were strengthened with CFRP sheets. The beam designated as BEAM-2was strengthened with one layers of uni-directional CFRP sheets having U-wrap on the beam.

In this study 12 beams and 6 cubes were casted to observe the behaviour of concrete. the main parameters studied were Flexural Strength of beams and Compressive Strength of Cubes for the nominal mix design of concrete.

Casting of the specimens

For conducting experiment, the proportions in the concrete mix are tabulated in Table 1 as per IS: 456-2000. The water cement ratio was fixed at 0.5. The mixing was done by hand mixing. The beams were cured for 7 and 28 days.

Table 1 Nominal Mix Proportions of Concrete

Description	Cement	Sand (Fine Aggregate)	Coarse Aggregate	Water
Mix Proportion (by weight)	1	1.5	3.0	0.5
Quantities of materials for one specimen beam (kg)	2.016	3.024	6.048	1.008

Concrete is a material composed of cement and water combined with sand, gravel, crushed stone, or other inert material such as expanded slag or vermiculite. A strong stone-like mass is formed from chemical reaction of the cement and water. The concrete paste can be easily moulded into any form or trowelled to produce a smooth surface. Hardening starts immediately after mixing, but precautions are taken, usually by covering, to avoid rapid loss of moisture since the presence of water is necessary to continue the chemical reaction and increase the strength. Too much of water, however, produces a concrete that is more porous and weaker. The quality of the paste formed by the cement and water largely determines the character of the concrete.

The size of specimen was (100 mm x 100 mm x 500 mm). The water cement ratio was fixed at 0.5 and the mixing was done by hand mixing. The beams were cured for7 and28 days.

Form work

Fresh concrete being plastic in nature requires good form work to mould in to the required shape and size. So the form work should be rigid and strong to hold the weight of wet concrete without bulging anywhere. The joints of the form work were sealed to avoid leakage of cement slurry. Mobil oil was then applied to the inner faces of form work.

Mixing of concrete

Mixing of concrete was done thoroughly by hand mixing. The concrete batch was mixed on a water-tight, non-absorbent platform with a shovel, trowel or similar suitable implement, using the following procedure:

- The cement and fine aggregate was mixed dry until the mixture is thoroughly blended and is uniform in colour,
- The coarse aggregate was then added and mixed with the cement and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch, and
- The water was then added and the entire batch mixed until the concrete appears to be homogeneous.

Compaction

All specimens were compacted by tamping rod, and sufficient care was taken to avoid displacement of the reinforcement cage inside the form work. Finally, the surface of concrete was leveled and smoothened by metal trowel. After seven hours, the specimen detail and date of concreting was written on top surface to identify it properly.

Curing of concrete

Curing is done to prevent the loss of water which is essential for the process of hydration and hence for hardening. Usually, curing starts as soon as the concrete is sufficiently hard. Here, curing is done by spraying water on the jute bags or by spending wet hessians cloth over the surface for a period of 28 days.

Strengthening of beams with CFRP sheets

All the loose particles of concrete surface at the bottom sides of the beam were chiseled out by using a chisel. Then the required region of concrete surface was made rough using a coarse sand paper texture and cleaned with an air blower to remove all dirt and debris particles.

Once the surface was prepared to the required standard, the Epoxy resin was mixed in accordance with manufacturer’s instructions. The mixing was carried out in a glass beaker and was continued until the mixture was in uniform. After their uniform mixing, the fabrics were cut according to the size then the epoxy resin was applied to the concrete surface. Then the CFRP sheet was placed on top of epoxy resin coating and the resin was squeezed through the roving of the fabric with the roller. Air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface were eliminated.

The composite laminate was attached starting at one end and applying enough pressure to press out any excess epoxy from the sides of the laminate. During hardening of the Epoxy, a constant uniform pressure was applied on the composite fabric surface in order to extrude the excess epoxy resin and to ensure good contact between the epoxy, the concrete and the fabric. This operation was carried out at room temperature. Concrete beams strengthened with carbon fiber fabric were cured for minimum of 72 hours at room temperature before testing.

Experimental setup

The test procedure for all specimens was same. First the beams were cured for a period of 7 and28 days then its surface was cleaned with the help of sand paper for clear visibility of cracks. The two-point loading arrangement was used for testing of beams. Two-point loading is conveniently provided by the arrangement shown in Figure 1.

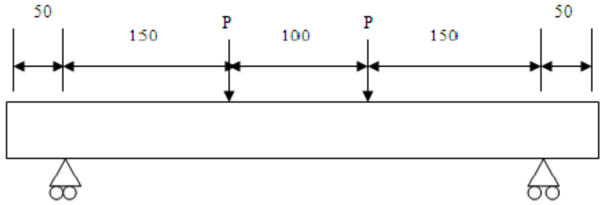

Figure 1: Two-Point Loading Experimental Setup

Description of specimens

The experimental program consistsoftwentyfournumbers of RC rectangular-beams of same longitudinal reinforcement of four numbers of 8mm φ out of which six beams weretaken as beams without CFRP and other six beams were strengthened using carbon fiber reinforced polymer (CFRP) sheets. Experimental data on loadof the beams were obtained. The changes in load carrying capacity of the beams were investigated as the configuration of CFRP is altered.

Beam - 1

Concrete beamwithout CFRP Coating - Beam 1

The reinforcement consists of 4 numbers of 8 mm φ HYSD bars. This beam was not strengthened with CFRP sheet. It was an un-cracked beam. It was checked for its ultimate load bearing capacity under two point loading setup.

Beam - 2

Concrete Beam with CFRP Coating (U-wrap) - Beam 2

The beam was strengthened with one layer of CFRP sheet having U-wrap on bottom and web portions and then checked it to its ultimate load capacity under two point loading setup.

Six beams without CFRP and eighteenbeams strengthened with CFRP sheet tested in this experimental investigation. The detail descriptions of above mentioned beams are presented in Table 2.

Table 2 Beam Test Parameters and Material Properties

Beam ID	Reinforcement	Strengthening material	Sheet Thickness (mm)	Strengthening system with FRP sheets
BEAM-1	4 Nos. – 8mmφ	----------	--------	Concrete Beam (No sheets)
BEAM-2	4 Nos. – 8mmφ	CFRP	1	One layer bonded to the bottom and sides of beam (U-shape)

V. CONCLUSIONS

From the studies the conclusions with drawn are desired as the ultimate load carrying capacity of the CFRP coated beams is enhanced as compared to the beam without CFRP. The load carrying capacity of the CFRP U-wrap increased 26 % more than the beam without CFRP. The flexural strength of the CFRP U - wrap beam is increased as compare to the beams without CFRP. The load carrying capacity of the beams after 28 days without CFRP is 53 KN. It is observed BEAM-2 (U-wrap) the load carrying capacity is 67 kN .

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