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EXPERIMENTAL INVESTIGATION ON REHABILITATION OF REINFORCED CONCRETE STRUCTURES

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ABSTARCT:
Concrete is recognized to be a relatively brittle material when subjected to normal loads and impact loads, since tensile strength of conventional concrete is roughly about one tenth of its compressive strength. Steel reinforcement is used to overcome highly potential tensile stresses and shear stresses at critical locations in a concrete member. There is a keen need all over the world for strengthening and repairing of the damaged reinforced concrete structures. Recent advanced research proved that Fibre Reinforced Polymer (FRP) composites are attractive alternate to other traditional techniques in the field of strengthening and repairing of concrete elements.Fibre Reinforced Polymer (FRP) composites helps in improving the load carrying capacity, impact resistance and for arresting crack growth in the structural members. Fibre Reinforced Polymers (FRPs) have been extensively used as internal reinforcing material as well as external wraps for the strengthening and rehabilitation of structural elements. Synthetic Fibre Reinforced Polymers such as AFRP/CFRP/GFRP have been used for strengthening and retrofitting activity for the past 30 years. This Fibre Reinforced Polymers (FRP) wrapping improves the integrity of the structure there by acts as an outer strengthening layer to the structural elements.The main objective of the present experimental research is to access the behaviour of the flexural member which is strengthened and rehabilitated using different types of FRP materials wrapped in various patterns and layers. This research work was carried with the help of E-Glass fibre which is used as fibre reinforced polymer reinforcement for structural application to enhance the strength and stability of the different structural members. Based upon the fabric, the GFRP are classified as woven type (Woven Roving Mat Fibre - WRM) &Non-woven type (Chopped Strand Mat Fibre- CSM). Woven rovingmat & chopped strand mat were used in different layers and patterns to find the optimized method for strengthening and retrofitting.The behaviour of reinforced concrete beams strengthened and rehabilitated using concrete jacketing technique is also studied.In this experimental study, concrete confirming to M20 grade is used. To maintain the same quality of concrete throughout the study, various test specimens were cast and standard tests like compression test, split tensile test, modulus of rupture and modulus of elasticity on hardened concrete were carried out, confirming to Indian Standards.In order to find the structural properties of flexural elements subjected to static loading, using various FRP wraps & RC jacketing, reinforced concrete beam specimens

including control specimen were cast. Beams were wrapped with woven roving mat in single layer and double layer at bottom and sides to find the effect of wrapping in various layers and patterns to strengthen and rehabilitate the beam. Similarly, beams were wrapped with chopped strand mat in the same pattern as that of woven roving mat to find the behaviour of beam. Concrete Jacketing method is also done. These tests were done in two aspects such as strengthening and rehabilitation. To find the effects on rehabilitation, the beam is subjected to initial crack load, which is obtained by testing the control specimen.The test results carried out throughout this study has proved that, the beam wrapped with woven mat provided at the bottom as double layer to ensure better performance under the static load and also the deflection at yield in linear form, ultimate and breaking loads are in good profile. This ensures the improvement in the ductility.

INTRODUCTION

Rehabilitation of structures to higher seismic zones of several cities and towns in the country has also necessitated in evolving new strategies. Recent earthquakes have demonstrated that most of the reinforced concrete structures were severely damaged during earthquakes and they need major repair works. One of the techniques of strengthening the RC structural members is through external confinement by high strength fibre composites which can significantly enhance the strength, ductility and will result in large energy absorption capacity of structural members. Fibre materials are used to strengthen a variety of reinforced concrete elements to enhance the flexural, shear and axial load carrying capacity of elements. Beam-column joints, being the lateral and vertical load resisting members in reinforced concrete structures are particularly vulnerable to failures during earthquakes and hence their rehabilitation is often the key to successful seismic rehabilitation strategy. FRPC based strengthening strategy could be an attractive option in order to restore joints.

In addition to being lighter, thinner and easier to implement FRPC reinforced joints have the virtue of making the joints more ductile. This property is extremely desirable for seismic rehabilitation of structures. However, a direct extension of the strategies adopted for beams and columns are difficult as such the behavior of beam-column connections are complex and still not completely understood. Survey of existing constructions reveals that rehabilitation of structures is necessary in three conditions. The structure is inadequately designed for the present load conditions. The inadequately detailed for the present loading. This also includes those structures that are found deficient under seismic conditions. The structure is damaged and requires rehabilitation. The motivation behind this program is to examine the performance of fibre reinforced polymer composites (FRPC) in rehabilitation of damaged joints. Concrete is recognized as a brittle material and has relatively high compressive strength. It has tensile strength roughly about one tenth of its compressive strength. As a result of these feature, concrete flexural members cannot support more tensile loads that usually takes place during their life time. Hence, concrete has to be reinforced with materials that are strong in tension like, continuous reinforcing bars to withstand tensile stresses and to compensate the lack of ductility and strength.The steel reinforcement in concrete absorbs tensile stress, shear stress and even compressive stress in the reinforced concrete structures. The compressive strength of concrete and tensile strength of steel, works together in reinforced concrete member to sustain various stresses that come across its life time for considerable span.Fibre reinforced Polymer (FRP) is used as a structural engineering material in Civil Engineering field such as strengthening of structures made of concrete, masonry, steel and even timber. Many researches proved that the use of FRP in RCC flexural members has tremendous improvements in flexural strength.FRP materials are well recognized as vital constituents of the modern concrete structures. The FRP materials, have improved structural performance, in terms of stability, stiffness, strength (including improved resistance to fatigue loading) and durability (Mandell 1982, Machida 1993, 1997, Hayes et al.2000, Katz 1999, Nanni 2000, Dejke 2001). Other factors include convenience in mass production with high quality control and relative economy.The environmental deterioration in recent days, urges the need to improve the life span of the existing structures. The study on different methods of repair and rehabilitation techniques, methods of its application, its performance after rehabilitation over reinforced concrete structures is being carried out in an extend spread manner. In the recent years, the use of fibre wrapping over the reinforced structural members seems to be the most competitive method for all the structural elements. Thus Fibre Reinforced Polymers (FRP) wrapping improves the integrity of the structure there by the acts as an outer strengthening layer to the structural elements.The major objective of the present research is to experimentally find the most suitable method to strengthen and rehabilitate the flexural member using different wrapping strategies such as Woven Roving Mat, Chopped Strand Mat and Jacketing techniques under static load conditions

ADVANTAGES OF SYNTHETIC FIBRE REINFORCED POLYMER COMPOSITES

- Synthetic FRP composites exhibit high tensile strength and higher strength to weight ratio.
- The lower weight of FRP composites make easy handling and installation.
- FRP sheets are available in long lengths (avoid laps and joints and also permit overlapping).
- They are moulded to any shape and size with required mechanical properties.
- They exhibit corrosion resistance and electrically non- conductive.
- FRP sheets do not alter the overall dimensions of the concrete.

FLEXURAL STRENGTHENING OF FRP COMPOSITES

- Flexural strengthening is an important factor for structural

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members subjected to a bending moment larger than the corresponding flexural capacity. Flexural strengthening with FRP materials may be carried out by applying one or more layers of laminates/fabric/sheets to the tension side of the member to be strengthened as an external reinforcement. Perfect bond exists between FRP and concrete as well as steel and concrete. For flexural members, ductility is a measure of the member capable of evolving in the plastic range, it depends on both section behaviour and the actual failure modes of the overall structural member. In FRP strengthened members, greater ductility is ensured when failure takes place due to crushing of concrete.

LITERATURE REVIEW:

- The first use of composites dates back to the 1500 BC, when early Egyptian and Mesopotamian settlers used a mixture of mud and straw to create strong and durable buildings. Straw continued to provide reinforcement of ancient products including pottery and boats (Balaguru& Shah 1992).
- The growth of the structural composite industry started in the 1940's and the 'synthetic Composite Materials Age' was thrust upon then. In the earlier days, composites were mostly used in aerospace and automobile applications. Fibre development had been accelerated since the 1950's with the introduction of E-glass, R-glass, S-glass and special acid and alkali resistant glass. After this phase in 1963 carbon fibres and in 1965 aramid fibres were introduced and they had considerable performance advantagesover glass fibres. With the invention of different fibres, the hybrid composites were developed where the optimum properties of different fibres were used at optimum cost (Leonard Hollaway 1994).
- Even though synthetic FRP composites were developed in early 1960's, their application for strengthening and rehabilitation of structures started in the year 1990 when Meier used carbon FRP's for strengthening a bridge in Lucerne in Switzerland. Over 30 bridges and other structures in UK had been strengthened during 1997 with carbon sheets. After this an army of Civil Engineers in European countries such as Italy, Greece, Poland and Turkey applied FRP composites successfully for strengthening their existing structures (MasoudMotavalli& Christoph Czaderski 2007).
- Meier & Kaiser (1991) undertook a study of rectangular reinforced concrete beams with 2m span that was strengthened with 0.3mm thick CFRP sheets. Investigation was also done with RC beams with 7m span strengthened with 1mm thick CFRP sheets. The former beam showed double times the ultimate

flexural capacity of the beam, compared to the control beam. But the latter beam with 1mm thickness showed an increase in ultimate flexural capacity of only 22%. Despite providing higher ultimate flexural capacity, the crack width also reduced by 40% that was shown by the control beam.

- Ritchie et al. (1991) conducted experiments with a series of 16 under reinforced beams, to study the effectiveness of external strengthening using FRP plates which were bonded to the tension side of the beams with epoxy. The results indicated an increase in stiffness from 17% to 99% and anincrease in strength from 40% to 97% that was achieved for the strengthened beams.
- Saadatmanesh&Ehsani (1991) explored the static strength of R.C beams strengthened by gluing GFRP plates to their tension flanges. It was concluded that flexural strength of RC beams could significantly increase by using GFRP plates. It was also cited that beams strengthened with FRP plates experienced less flexural cracking, reduced crack widths and a delay in the formation of the flexural cracks. However, bonding of the FRP plates reduced the ductility of the beam compared to that exhibited by the conventionally reinforced beam.
- Triantafillou &Plevris (1992) carried out investigations with beams strengthened with FRPs. They analysed the failure mechanism such as steel yield-FRP rupture, steel-yield concrete crushing, compressive failure and de- bonding. They also obtained equations describing each failure mechanism using the strain compatibility method, concepts of fracture mechanism and a simple model for the FRP peeling off de-bonding due to the development of shear cracks. Seven beams strengthened with FRP plates were tested under four point loading. The experimental results showed that the ultimate flexural capacities of the FRP strengthened beams were superior to that of the control beam. Out of the seven beams, five of the repaired beams failed due to de- bonding and subsequent peeling off of the composite.
- Chajes et al. (1994) conducted a study with series of reinforced concrete beams to find the ability of FRP strips such as aramid, E-glass and graphite in improving the flexural behaviour of the beams. It indicated that external composite fabric bonding showed 36% to 57% increase in flexural capacity and 45% to 53% increase in flexural stiffness. They also presented an analytical study based on stress-strain relationships of concrete, steel and composite fabrics.
- Shahawy et al. (1996) observed the flexural behaviour of reinforced concrete beams with epoxy bonded Carbon Fibre Reinforced Polymer

(CFRP) laminates. The observation of the study included first crack load, cracking behaviour, deflections, serviceability loads, ultimate strength and failure modes. A theoretical analysis was also carried out to compare with the experimental results.

- Challal et al. (1998) had carried out an investigation to study the performance of reinforced concrete beams externally bonded with CFRP strips. Three kinds of beams, one designed with full strength in shear, the other designed for under shear and finally strengthened beams were used in the study. After the experimental investigations, it was reported that the external bonding helped in improving the shear strength thereby reducing the shear cracks. The beams with diagonal side strips gave good results compared to the beams wrapped with vertical side strips.
- El-Mihilmy& Tedesco (2000) performed analytical investigation to study flexural behaviour of FRP strengthened flexural members. The procedure was derived from equilibrium equations and compatibility of strains and related to singly, doubly reinforced as well as flanged sections. Experimental results were taken from the open literature for comparison. The investigation provided the upper and lower limits of FRP that may be bonded to R.C section to have ductile behaviour.

METHODOLOGY

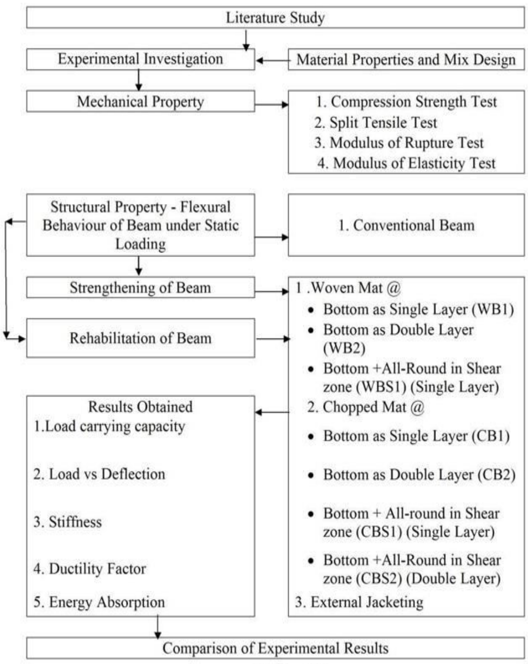

FIG: Methodology

EXPERIMENTAL INVESTIGATION

It includes the materials used for the concrete work, FRP used and its physical properties, specimen details and mix design used. The details of the test carried out to determine the basic properties of materials used and experimental method to determine the properties of hardened concrete are included

MATERIALS AND MIX

The materials used in this investigation were, Ordinary Portland cement of 43 grade, coarse aggregates obtained from crushed rock in local quarry with a maximum size of 20mm and fine aggregate from natural source. HYSD bars were used for main reinforcement and hanger bars in the reinforced beam. For external wrapping in reinforced concrete beam, commercially available E-Glass fibre in the form of woven roving mat and chopped strand mat were used. Also

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commercially available epoxy and hardener were used. The properties of all these materials are furnished in the successive sections.

CEMENT

Ordinary Portland cement of 43 grade, compliance to IS 8112-1989 was used in this study. Cement used was tested for its physical properties in accordance to Indian Standard specifications. The properties of cement used are given in Table 3.1.

Table 3.1 Properties of cement

S. No.	Physical Properties	Values
1	Specific gravity	3.18
2	Normal Consistency	29.6%
3	Initial Setting Times	38 minutes
4	Final Setting Times	350 minutes
5	Compressive strength at 3 days	31.30 N/mm^2
6	Compressive strength at 7 days	45.50 N/mm^2
7	Compressive strength at 28 days	51.10 N/mm^2

FINE AGGREGATE

The fine aggregate from natural source passing through 4.75mm sieve was used. The grading zone of fine aggregate is zone II as per Indian Standard specifications. The property of fine aggregate used is given in Table

Table 3.2 Properties of fine aggregate

S. No.	Physical Properties	Values
1	Specific gravity	2.56
2	Fineness Modulus	2.20
3	Water Absorption	0.75%
4	Bulk Density	1654 kg/m^3
5	Free Moisture Content	0.10%

COARSE AGGREGATE

Coarse aggregate of crushed granite stones from the local quarries were used. The maximum size of coarse aggregate used was 20mm. The properties of coarse aggregate were determined as per Indian Standard specifications. The property of coarse aggregate used is given in Table 3.3.

Table 3.3 Properties of coarse aggregate

S. No.	Physical Properties	Values
1	Specific Gravity	2.75
2	Fineness Modulus	7.73
3	Water Absorption	0.50%
4	Bulk Density	1590 kg/m^3
5	Free Moisture Content	0.20%
6	Aggregate Impact Value	11.20%
7	Aggregate Crushing Value	25.12%

WATER

Potable water free from salt was used for casting and curing of concrete as per IS: 456 - 2000 recommendations.

FIBRE REINFORCED POLYMERS

Commercially available E-glass woven roving mat fibres and chopped strand Mat fibres were used for the study. The woven

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roving mat used in this study is shown in Figure 3.1 and the chopped strand mat used is shown in Figure 3.2.

Figure 3.1 Woven Roving Mat

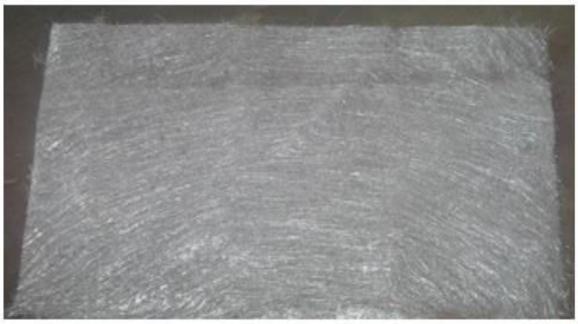

Figure 3.2 Chopped Strand Mat

MIX PROPORTION

A concrete mix was designed as per IS 10262 - 2009 to achieve a concrete grade of M20. A constant water cement ratio of 0.45 was used. The ratio of different ingredients used in concrete mix is given in Table.3.4

Table 3.4 Ratio of Ingredients used in Concrete Mix

Materials required	Cement	Fine Aggregate	Coarse Aggregate	Water/ Cement	Super Plasticizer
Weight in kg/m³	372	675	1235	167	3
Proportion	1	1.80	3.30	0.45	1% of weight of cement

CASTING OF SPECIMENS

A laboratory type concrete mixer machine was used to mix the various ingredients of concrete. First, fine aggregates, coarse aggregates and cement were placed inside the mixer and allowed to mix thoroughly, after that water is added and the materials were allowed to mix thoroughly to obtain uniform batching. The concrete was collected from trolley and manually placed in the respective moulds. All the specimens were well compacted. The specimens were demoulded after 24 hours, after that the specimens were kept under water for 28 days curing.

TESTING PROCEDURE

It is most important to evaluate properties of concrete used for the study. This section gives the testing procedures for finding the compressive strength, split tensile strength, modulus of rupture and modulus of elasticity of concrete as per IS standards.

COMPRESSIVE STRENGTH TEST

The most common of all tests on hardened concrete is the compressive strength test because of the intrinsic importance of the compressive strength of concrete in construction.

As per IS 456- 2000 concrete cubes were tested in compression to find their strength at 28 days.

This test was performed over cube specimens of size 150mm X 150mm X 150mm.

SPLIT TENSILE STRENGTH

The split tension strength is the indirect method to find the tensile strength of the concrete. The split tensile strength test was

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carried out on the compression testing machine on cylinder specimen. The casting and testing of the specimens were done as per IS 5816: 1999.

Split tensile strength = $2P/\pi dl$

Where P = Compressive load on the cylinder

L = Length of the cylinder

D = Diameter of the cylinder

MODULUS OF RUPTURE

The extreme fibre stress calculated at the failure of specimen is called as Modulus of rupture. It is also an indirect method to find the tensile strength of concrete. The Flexural strength test was conducted as per IS: 516 – 1959 recommendations.

MODULUS OF ELASTICITY

The modulus of elasticity of concrete is the most important one among all the mechanical properties of concrete, since it is having impact on the serviceability and the structural performance of reinforced concrete structures. The closest approximation to the theoretical modulus of elasticity derived from a truly elastic response is its initial tangent modulus

CONCLUSIONS

Based on the results of the above experimental investigation, it is generally concluded that the FRP wrapping techniques adopted for strengthening and rehabilitation of reinforced concrete beams is much better than external jacketing.The external jacketing results in modification of the size of the structure (enhancement in the size of the structure), which looks very odd while considering the aesthetic point of view.

SCOPE OF FUTURE WORK

- This research work has been carried out with the M20 grade concrete. In future, this work will be carried out with the high strength concrete.
- Woven mat and Chopped GFRP mats were used in this work and in the rehabilitated specimen, this mats were torn out due to its less bonding. So in future, the bonding between the cracked surface and the mat can be increased using superior quality of epoxies.
- The mats provided at the shear zone did not make any impact on the test results, due to rib up from the surface of the concrete, so the future work should be carried out with the pure tension zone.
- Studies may be carried out for enhancing the shear strength of the beams by using GFRP/CFRP mat wrapping.
- In future, investigations can be carried out to explore the behaviour of other structural elements such as columns and beam-column joints that are externally wrapped with GFRP/CFRP mats.
- In future, the durability aspects on the beam and beam column can be done. Also, the hybrid mats can be used for the further studies.

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