Improvement of Compressive Strength of Reinforced Cement Concrete Elements using CFRP wrapping

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Abstract – Experiments were conducted on the distressed reinforced cement concrete compressive elements and on the same after they have been retrofitted for rehabilitation. Presently, FRP materials are also been started use in construction field in the form of wrapping to enhance the load carrying capacity, shear and flexural strengths as well as ductility. This is an experimental based project which deals with strengthening and load – deformation relationship of reinforced cement concrete compressive elements of square cross section using carbon fibre reinforced polymer (CFRP) wrapping. Mix design is done for M 20 grade of concrete as per IS: 10262-2009 for preparation of structural elements. Compressive test has been conducted on the fresh and distressed compressive elements for obtaining the load carrying capacity of the elements and the load – deformation relationship. From the results it is noticed that, there is an increase in load carrying capacity of the compressive elements having square cross section due to the CFRP wrapping when compared with the elements without CFRP wrapping. Further, it is observed that larger deformations in case of CFRP wrapped reinforced cement concrete compressive elements.

Keywords – Distressed, Strengthening, CFRP wrapping, Retrofitting, Rehabilitation etc.

I. INTRODUCTION

Construction activities in India took strides after its Independence, particularly after 60's. The structures built in early time after Independence are now aged around 40 to 50 years. Due to lack of Design Philosophies, materials quality, range, construction practice availability etc., some aged structures now showing distressed condition. Age old buildings / structures which are in distressed condition need to be diagnosed its strength and serviceability capabilities. Repair and Retrofitting are the possible techniques to bring back the structure to the serviceable condition, thus rehabilitation to the desired extent. Repair is a process of restore the durability of the damaged structure using additional materials. Retrofit is a technique of strengthen the distressed structure using certain additional components.

The retrofit strategies of reinforced concrete buildings are grouped into global and local strategies. A global retrofit strategy targets the seismic resistance of the building. A local retrofit strategy targets the seismic resistance of a member, without significantly affecting the overall resistance of the building. It may be necessary to combine both local and global retrofit strategies under a feasible and economical retrofit scheme. Local retrofit strategies refer to retrofitting of columns, beams, joints, slabs, walls and foundations. The Local retrofit strategies fall under three types. They are Concrete Jacketing, Steel Jacketing and Fibre reinforced polymer (FRP) sheet wrapping.

Concrete jacketing involves addition of a layer of concrete, longitudinal bars and closely spaced ties. The jacket increases both the flexural strength and shear strength of the column or beam. Steel jacketing of column refers to encasing the column with steel plates and filling the gap with non-shrink grout. Fibre reinforced polymer (FRP) sheets are used in similar manner to steel plates or sheets. The shear strength of column can be enhanced by wrapping FRP sheets around it. The wrapping also enhances the behaviour under flexure due to confinement of concrete. The confinement refers to the enclosing of concrete which has a beneficial effect in terms of increase in compressive strength and ductility. Several advantages are observed in using FRP wraps compared to the most common other techniques based on the use of steel reinforcements such as: the high-mechanical properties of the material (tensile strength and elasticity modulus) compared with its lightness; its insensitivity to corrosion; the ease of applying the reinforcing material, etc.

According to Karbhari, M and Douglas [1], the most common method of strengthening was to install reinforced steel jackets around circular sections. The use of a steel encasement to provide the lateral confinement to concrete in compression has been extensively studied and has been shown to be able to significantly increase the compression load-carrying capacity and deformation of the columns. However, the major disadvantages of using steel jackets are low resistance to corrosion, high cost and high dead-weight.

According to Mirmiran, A., et al [2], fibre reinforced composites, due to their high strength-to-weight and stiffness-to-weight ratios, large deformation capacity, corrosion resistance to environmental degradation and tailor ability, present an attractive option as an alternative and extremely efficient retrofitting technique in such cases through the use of composite jackets or wraps around a deteriorated column.

According to Bogdanovic, A. [3], carbon sheets have been applied to increase the concrete confinement and loading resistance of reinforced concrete columns. The confinement effectiveness of externally bonded FRP jackets depends on different parameters, namely, the type of concrete, steel reinforcement, thickness of the FRP jackets (number of layers) and stiffness (type of FRP) and loading conditions. Also, the shape of the cross sections and sharp edges in the cross sections of columns can directly affect the confinement effectiveness of externally bonded concrete. The efficiency of FRP confinement is higher for circular than square sections.

According to Ţăranu et al. [4], the structural strengthening and rehabilitation of deficient structures to restore or enhance load bearing performance, to improve the structural behaviour and repair of damaged framing systems have become current practices.

According to Sun & Wang [5], currently, strengthening of RC columns with externally bonded FRP composite products is a commonly accepted and widespread technique. The numerous studies developed over the last three decades have proven that lateral confinement of concrete can substantially increase its compressive axial load bearing capacity and ultimate axial strain. The use of FRP materials can improve significantly the behaviour of the RC columns. The efficiency of the RC columns confined with CFRP membranes is reduced if the load eccentricity and slenderness are increased. During the experimental program, it was noticed that the failure of the eccentrically loaded elements occurred at the compressed side. Failure of the FRP confined RC elements depends on the failure of the FRP composite membrane. Further research programmes are required for determining the efficient form of confining eccentrically loaded RC columns.

II. MATERIALS

Materials used are Cement, fine aggregate, coarse aggregate, water, HYSD steel, Carbon fibre fabric and adhesive. Ordinary Portland Cement of 43 grade is used as binding material and confirms to the Indian standards [6]. In this experimental program, the locally available river sand is used as Fine Aggregate. The fraction of sand passes through 4.75 mm to 150 micron sieves were used as Fine Aggregate. Fine Aggregate confirms to Zone II is collected from sieve analysis for preparation of concrete mix [7]. Crushed granite stone of size 20 mm and 12 mm are used as Coarse Aggregate and it have been tested as per the Indian Standards [7]. Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Since it helps to form cement gel which contributes to the strength, the quantity and quality of water are required to be viewed very carefully. In this experimental program, potable tap water available in the laboratory was used for mixing and curing of concrete [8]. The reinforcement used is of steel bars (VIZAG Steel) with nominal diameter 12 mm for longitudinal reinforcement. The average elastic modulus was 209 GPa. The stirrups were fabricated using steel with nominal diameter 8 mm. Material properties for the reinforcing steel have been tested as per the Indian Standards [9].

Carbon fibre fabric (HCU202H) used for the experimental work has been purchased from M/s. Hindoostan Technical Fabrics, Mumbai. The Characteristics and properties of the CARBON WOVEN REINFORCEMENT FABRIC (HCU202H) obtained from the manufacturer [10].Adhesive (HINPOXY) used for the experimental work has been purchased from M/s. Hindoostan Technical Fabrics, Mumbai. HINPOXY C RESIN is a Bisphenol-A based liquid epoxy resin. HINPOXY C HARDENER is a colorless, low viscosity, modified amine hardener [10].

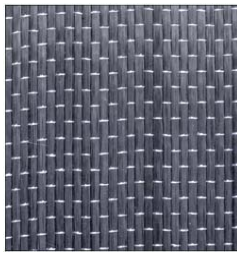

Fig 1 (a) Carbon fibre fabric

Fig 1 (b) Adhesive

M20 grade concrete was designed as per IS: 10262-2009 [11]. The proportions of ingredients for the M20 grade concrete were shown in Table 1.

III. MIX DESIGN

Table 1 : Mix proportions of M 20 grade design mix concrete

	Water	Cement	Fine Aggregate	Coarse Aggregate	20 mm CA	12 mm CA
By Weight (kg)	182	350	692	1111	667	444
By Volume (m^3)	0.52	1	1.52	3.18	1.91	1.27

IV. METHODOLOGY

Cement used for the study was tested for the parameters specific gravity, fineness, consistency, setting time, soundness and compressive strength. Aggregates were tested for Fineness Modulus, Specific Gravity and Water Absorption as per IS codes. Steel used for the experimental program has been tested for its mechanical properties. Manufacturer's data has been considered for the Carbon fibre fabric and adhesive. Reinforced cement concrete compression elements of square cross section are casted with M20 grade concrete reinforced with 4 Nos. of 12 mm dia deformed rebars as longitudinal reinforcement and 8 mm dia bars as stirrups.

In the present experimental program the wet lay-up technique was applied in order to obtain a full CFRP confining system. The CFRP wrapping process included surface preparation and unidirectional CFRP application. An overlap of 100 mm has been maintained wherever got necessary. In the process of CFRP application, first the specimen corners were rounded and the concrete surface was grinded. Then, using a vacuum cleaner, dust and any foreign particles have been removed from the concrete surface. The CFRP fabrics were pre-cut at the desired dimensions and were impregnated into the resin.

The epoxy resin consists of resin and Hardener in a mixed ratio of 100:30 was then applied straight on the prepared substrate. It has to be dried for 24 hours. After 24 hours, any cavities and cracks are filled with plaster of paris paste. On drying the surface, undulations are made smooth using sand paper. Then, one more coat of epoxy has been applied on the surface of the element. When the surface is in tacky condition, the CFRP fabric has been placed on the element. Adequate pressure was applied until the resin squeezed out between the fabrics.

The square cross sectional compression elements of 150x150x350 mm with M20 grade concrete are mentioned in table 2, which are designated as M20SC1 to M20SC12 based on the confinement condition.

Table 2 : Designation of elements.

Structural Element	Shape of the element	Cross Section (mm)	Grade of concrete	Specimen	Confinement condition
Compression elements	Square	150 x 150 x 350	M20	M20SC - 1	Ultimate strength at 28 days without wrapping.
				M20SC - 2	
				M20SC - 3	
				M20SC - 4	Ultimate strength at 28 days with wrapping.
				M20SC - 5	
				M20SC - 6	
				M20SC - 7	First crack strength at 28 days & ultimate strength at (28 + 21) days without wrapping.
				M20SC - 8	
				M20SC - 9	
				M20SC - 10	First crack strength at 28 days & ultimate strength at (28 + 21) days with wrapping.
				M20SC - 11	
				M20SC - 12	

All elements were subjected to concentric compression. The universal testing machine has been used for the testing the elements with safety precautions. On completion of 28 days curing, three specimens without CFRP wrap and three specimens with CFRP wrap were tested out of twelve for ultimate strength. Dial gauge has been attached to the specimens for measuring the displacement.

Balance six cubes have been tested to obtain the distress condition. The specimens were loaded until the first crack appears on the surface. These six specimens kept for development of further crack in normal room temperature for 21 days. After 21 days, three distressed specimens without CFRP wrap and three distressed specimens with CFRP wrap were tested for ultimate strength. Dial gauge has been attached to the elements for measuring the displacement. All the safety precautions have been followed during testing of the specimens.

V. RESULTS AND DISCUSSIONS

The various tests done on cement are shown in table 3. All the parameters are within the permissible limits.

Table 3 : Tests Results of Cement

Physical Properties	Test Result	Test method/ Remarks	Requirement
Specific gravity	3.15	IS 4031 (Part II) : 1988	-----
Fineness (m^2/Kg)	311.5	IS 4031 (Part II) : 1988	Min. 225
Normal consistency	30%	IS 4031 (Part IV) : 1988	-----
Initial setting time (minutes)	90	IS 4031 (Part V) : 1988	Min. 30
Final setting time (minutes)	220	IS 4031 (Part V) : 1988	Max. 600
Soundness Lechatlier Expansion (mm) Autoclave Expansion (%)	 0.8 0.01	IS 4031 (Part III) : 1988	 Max. 10 Max. 0.8%
Compressive strength (MPa) 3 days 7 days 28 days	 21 32 47	IS 4031 (Part VI) : 1988	 23 MPa 33 MPa 43 MPa

The results of tests conducted on aggregates are shown in table 4, and all the parameters were within the permissible limits.

Table 4 : Tests Results of Aggregates

Type of Tests	Coarse Aggregate	Fine Aggregate
Fineness Modulus (%)	6.99	2.61
Specific Gravity	2.65	2.58
Water Absorption (%)	0.5	1

The results of tests conducted on steel are shown in table 5.

Table 5 : Mechanical properties of Steel

Grade	Tested as per	Yield Strength (N/mm^2)	Ultimate Tensile Strength (N/mm^2)	% Elongation	Elastic Modulus (N/mm^2)
Fe 415	IS 1786 : 2008	425	485	19.0	2.09×10^5

The mechanical properties of Carbon fibre fabric provided by the manufacturer are shown in table 6.

Table 6 : Mechanical Properties of Fibre

Mechanical Properties of Fibre	
Density (g/cm^3)	1.81
Filament Diameter (μm)	7
Tensile Strength (Mpa)	4900
Tensile Modulus (Gpa)	250
Elongation Percentage (%)	2.0

The Characteristics of Hinpoxy C Resin and Hardner provided by the manufacturer are shown in table 7 and 8.

Table 7 : Characteristics of Hinpoxy C Resin

Characteristic	Test Method	Unit	Specification
Viscosity at 25^o C	ASTM-D 445	mPas	9,000 – 12,000
Epoxy Content	ASTM-D 1652	g/eq	185 - 192
Density at 25^o C	ASTM-D 4052	g/cc	1.15 - 1.20
Flash Point	ASTM-D 93	^{o}C	> 200
Storage life		Years	3

Table 8 : Characteristics of Hinpoxy C Hardner

Characteristic	Test Method	Unit	Specification
Consistency	Visual		Colourless to pale yellow liquid
Viscosity at 25^o C	ASTM-D 445	mPas	< 50
Flash Point	ISO 2719	^{o}C	>123
Density at 25^o C	ASTM-D 4052	g/cc	0.94 – 0.95
Storage life (2–40^o C)		Years	1

Results of the concrete cubes of size 150x150x150 mm of M20 grade concrete tested for 7 days and 28 days are given in table 9.

Table 9 : Test results of M20 grade concrete cubes

Sl. No.	Compressive strength of concrete at 7 days (N/mm^2)	Compressive strength of concrete at 28 days (N/mm^2)
Sample 1	19.10	26.00
Sample 2	17.50	26.80
Sample 3	18.00	27.90
Average	18.20	26.90

Results of the Reinforced cement concrete compressive elements of square cross section of M20 grade concrete tested for 28 days are given in table 10 below.

Table 10 : Ultimate load of Compression elements without and with CFRP wrap of M20 grade

Sl. No.	Type of elements	Status of Specimen	Specimen designation	Ultimate load (kN)	Average Ultimate load (kN)
I	Compression	Concrete elements without CFRP wrapping	M20SC-1	920	**860.00**
			M20SC-2	810	
			M20SC-3	850	
II	Compression	Concrete elements with CFRP wrapping	M20SC-4	1070	**1046.67**
			M20SC-5	1040	
			M20SC-6	1030	

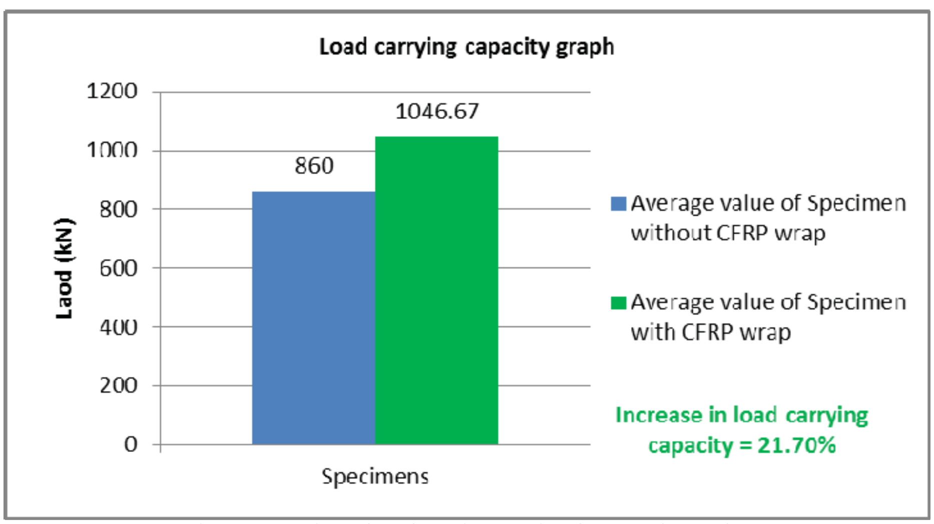

Fig. 2 : Comparison of Load carrying capacity of M20 grade Samples

From the Table 10 and Fig. 2, it is observed that average load carrying capacity of the compression elements without CFRP wrapping and with CFRP wrapping are 860 kN and 1046.67 kN respectively. There is an increase of 21.70 % in load carrying capacity with CFRP wrapped compression elements.

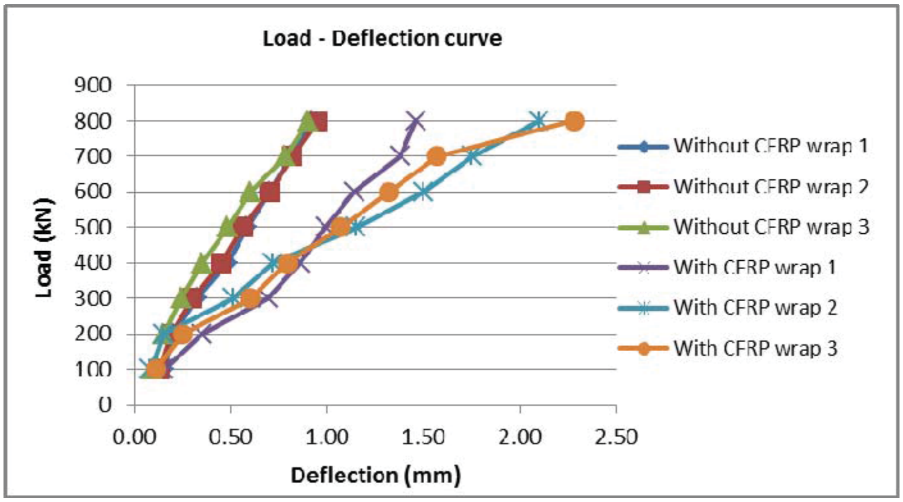

Fig. 3 : Comparison of Load Vs Deflection curve for Samples of M20 grade

From the Fig. 3, it is observed that the larger deflections were occurred in case CFRP wrapped compression elements when compared with compression elements without CFRP wrapping.

Results of the Reinforced cement concrete compressive elements of square cross section of M20 grade concrete tested after 21 days of the distressed condition are given in table 11 below.

Table 11 : Ultimate load of Distressed Compression elements without and with CFRP wrap of M20 grade

Sl. No.	Type of elements	Status of Specimen	Specimen designation	Ultimate load (kN)	Average Ultimate load (kN)
I	Compression	Distressed elements without CFRP wrapping	M20SC-7	1080	**1013.33**
			M20SC-8	950	
			M20SC-9	1010	
		First crack strength = 500 kN			
II	Compression	Distressed elements with CFRP wrapping	M20SC-10	1230	**1193.33**
			M20SC-11	1150	
			M20SC-12	1200	
		First crack strength = 500 kN			

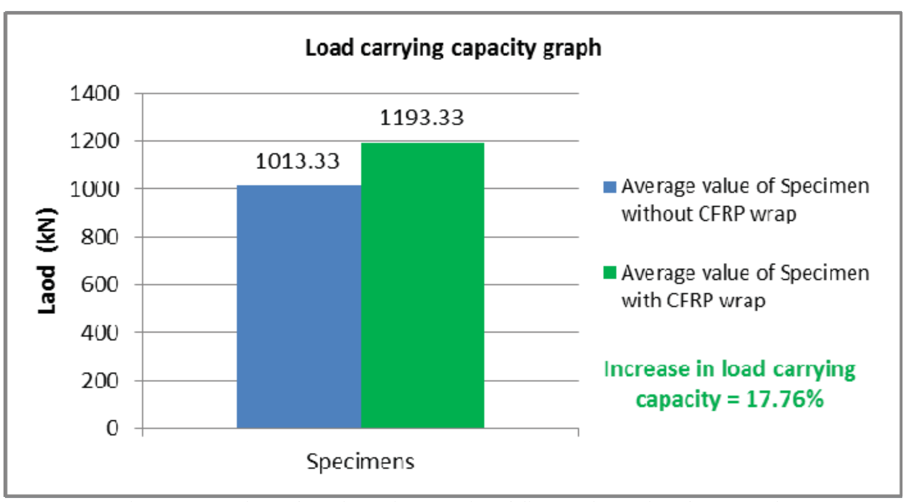

Fig. 4 : Comparison of Load carrying capacity of distressed Samples of M 20 grade

From the Table 11 and Fig. 4, it is observed that average load carrying capacity of the distressed compression elements without CFRP wrapping and with CFRP wrapping are 1013.33 kN and 1193.33 kN respectively. There is an increase of 17.76 % in load carrying capacity with CFRP wrapped compression elements.

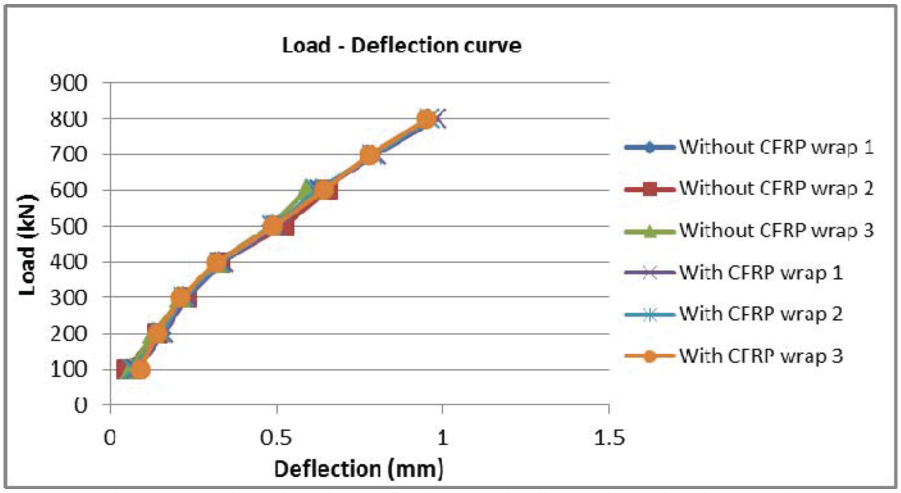

Fig. 5 : Comparison of Load Vs Deflection curve for distressed Samples of M20 grade

From the Fig. 5, it is observed that the larger deflections were occurred in case CFRP wrapped compression elements when compared with compression elements without CFRP wrapping.

The following conclusions can be drawn from this experimental study

1. CFRP wrapping technique can be used as one of the local retrofit strategy.
2. CFRP wrapping technique is a most efficient due to its several advantages.
3. The load carrying capacity of CFRP wrapped compressive elements of square cross section at 28 days is found about 22 % more than the load carrying capacity of compressive elements without CFRP wrapping.
4. Initial crack is observed at about 60 % of the Ultimate load of the compressive elements tested at 28 days without CFRP wrapping.
5. The load carrying capacity of CFRP wrapped distressed compressive elements of square cross section at 49 days (28 + 21) are found about 18 % more than the load carrying capacity of distressed compressive elements without CFRP wrapping.
6. Larger deformations were observed while testing the CFRP wrapped compressive elements than the compressive elements without CFRP wrapping.

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