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Retrofitting of RC Element-COLUMN by CFRP jacketing

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ABSTRACT: Retrofitting is the seismic strengthening of existing damaged or undamaged structures. It is a functional improvement, where Retrofitting means structural strengthening and enhancement of performance of deficient structural elements of a building to a pre-defined performance level whether or not an earthquake has occurred. It provides a number of ways to improve the damaged structure and allows to expand the lifespan of a structure, increasing its functioning and safety. Day to day, concrete structure to need retrofitting due to various factors like corrosion, lace of detailing, and failure of bonding etc. This report summarizes the scopes and uses of CFRP material in seismic strengthening of RC structures. Experimental study for investigation of compressive strength for without retrofitted column specimens and with retrofitted column specimens is carried out. The column specimens retrofitted using carbon fibre reinforced polymer compared to column specimens without retrofitting gave results to a significant margin. Failure modes of retrofitted column wrapped with CFRP is given in this paper along with future recommendations.

KEYWORDS: CFRP, column jacketing, compressive strength, Retrofitting, seismic.

I. INTRODUCTION

Retrofitting is the modification of existing structures to improve the performance and durability of the structure. Structural repairs and rehabilitation are process of reconstruction and renewal of a facility or its structural elements. This involves determining the origin of distress, removing damaged materials and causes of distress, as well as selecting and applying appropriate repair materials that extend a structure's life. Retrofitting is the seismic strengthening of existing damaged or undamaged structures. It is an improvement over the original strength when the evaluation of the building indicates that the strength available before the damage walls insufficient and restoration alone will not be adequate in future earthquakes. Retrofitting mainly depends upon the modern technology and the unique ideas of the engineers and may vary from place to place.

Rehabilitation

It is a functional improvement, where Retrofitting means structural strengthening and enhancement of performance of deficient structural elements of a building to a pre-defined performance level whether or not an earthquake has occurred.

Repairs

The main purpose of repairs is to bring back the architectural shape of the building so that all services start working and the functioning of building is resumed quickly. Repair does not pretend to improve the structural strength of the building and can be very deceptive for meeting the strength requirements of the next earthquake.

Restoration

This type of action must be undertaken when there is evidence that the structural damage can be attributed to exceptional phenomena that are not likely to happen again and that the original strength provides an adequate level of safety. The main purpose of restoration is to carry out structural repairs to load bearing elements. It may involve cutting portions of the elements and rebuilding them or simply adding more structural material so that the original strength is more or less restored.

1.2 AIM

To study the performance of RC-column retrofitted with CFRP under different distress percentage conditions.

1.3 OBJECTIVES

1. To study enhancement in compressive strength of column by using CFRP laminates before and after retrofitting.
2. To evaluate compressive strength results obtained from RC column without retrofitting and retrofitted RC column with two layers of wrapping using Carbon Fibre Reinforced Polymer.

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3. To compare compressive strength results obtained from without retrofitted column specimen with retrofitted column specimen after distressed by 50%, 60% and 70%.

II. COLUMN JACKETING

Strengthening by jacketing of columns improves the axial and shear strength of columns. A major advantage of column jacketing is that it improves the lateral load capacity of the building in a reasonably uniform and distributed way. Effectiveness of this method depends upon parameters like type of structures, material condition, amount of damage etc. Primary aim of strengthening a structure is to increase its load bearing capacity with respect to its previous condition.

i. FRP Jacketing

Fibre reinforced polymer composites consist of high strength fibres embedded in a matrix of polymer resin. Fibres typically used in FRP are glass, carbon and aramid. The primary functions of the matrix in a composite are to transfer stress between the fibres, to provide a barrier against the environment and to protect the surface of the fibres from mechanical abrasion.

a) Column Strengthening with CFRP

CFRP systems can be used to increase the axial compression strength of a concrete member by providing confinement with an CFRP jacket wrapping. CFRP jacket can also provide strength enhancement for a member subjected to combined axial compression and flexure. Confining a concrete member is accomplished by orienting the fibers transverse to the longitudinal axis of the member. The CFRP jacket can also serve to delay buckling of longitudinal steel reinforcement in compression and to clamp lap splices of longitudinal steel reinforcement. For seismic applications, CFRP jackets should be designed to provide a confining stress sufficient to develop concrete compression strains associated with the displacement demands. A composite with all fibres in one direction is designated as unidirectional. If the fibres are woven, or oriented in many directions, the composite is bi- or multidirectional. Since it is mainly the fibres that provide stiffness and strength composites are often anisotropic with high stiffness in the fibre direction.

i. The merits of CFRP material are:

1) Carbon fibre is flexible and can be made to contact the surface tightly for a high degree of confinement.
2) The carbon fibre has light weight as compared to other jacketing materials and rusting does not occur.
3) Thickness of CFRP is less than other retrofitting materials, hence dead load on structure is negligible after retrofitting.
4) Application of CFRP to structural elements is easy as it consumes less time compared to other materials.

III. EXPERIMENTAL WORK

3.1 INTRODUCTION

This chapter includes the parameter study on materials checking their physical and mechanical properties. It also includes calculation of concrete mix design, preparation of beam specimens, reinforcement detailing, casting, testing and results of the conventional grade of concrete and composite grade concrete.

3.2 MATERIALS USED

This chapter deals with the properties and significance of all the materials which used in this project work.

1) Cement
2) Coarse Aggregate
3) Fine Aggregate
4) Normal Water
5) Carbon Fiber reinforced polymer
6) sika Dur 30 epoxy resin

3.2.1 Cement: Ordinary Portland Cement (OPC) of grade 53 was used in concrete mixture. IS 8112-1989. Initial and Final setting time test to be conducted for ordinary Portland cement as per IS code 269-2015.

Sr.no.	Test	Result	Permissible limit as IS
1	Fineness modulus	6.6%	Max.10%
2	Consistency	34%	33to 35%
3	Initial setting time	26min	Not less than 30min.
4	Final setting time	560min	Not more than 600 min
5	Specific gravity	3.15	3.12 to 3.19
`6	Soundness test	1.5mm	<10 mm

Table no.3.1: Physical properties of cement

3.2.2 Coarse Aggregate: The coarse aggregate used were locally available. The maximum nominal size of aggregate was 20mm with confirming IS 2386-4(1963).

Sr.no	Parameter	Result	Permissible limit as per IS
1.	Shape	Angular	Angular, hard
2.	Size	20mm	20 mm stone aggregate = (85 to 100% should pass through 20mm IS sieve)
3.	Specific gravity	2.74	2.4 to 3.0
4.	Water absorption	0.5%	0.3 to 2.5 %
5.	Impact value test	19.8%	Should not be more than 30%
6.	Crushing value test	28.4%	Not more than 45 %
7.	Fineness modules	6.9	5.52 to 8.0

Table no.3.2: Physical properties of coarse aggregate

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3.3.3 Fine Aggregate: This is river sand which is locally available. It was clean and nearly free from impurities. Confirming IS 2386-3(1963).

Sr no.	Parameter	Result	Permissible limit as IS
1.	Silt content	6.3	It should not be more than 7%
2.	Zone	1	Sand conforming zone ;1,2,3 for concrete work and 2 for plaster work
3.	Fineness modules	3.1	2 to 4
4.	Specific gravity	2.74	2.6 to 2.8

Table no.4.3: Properties of fine aggregate

3.1.4 Normal Water: Any Natural water which is fit for drinking and has no taste or colour is generally accepted for concrete. The tap water is used for preparation of concrete.

3.1.5 Technical Data of SikaDur 30:

SikaDur – 30 is a two partadhesive with standard pot life and curing speed. It is designed to use for fabric installation by the dry application method. It has high mechanical properties and separate primer is not required.

Chemical Base	Epoxy Resin
Colour	Light Grey
Mixing (by volume)	Component 'A': 1 Component 'B': 3
Pot Life	Approximately 70 minutes @ 23°C (1 qt.)
Packing	6kg
Shelf Life	2 years in original, unopened containers.

Table no.3.4: SikaDur 30 epoxy resin

Figure no.3.1: SikaDur 30 epoxy resin

3.1.6 Technical Data of Carbon Fiber :

Carbon Fiber Reinforced Polymer (CFRP) is an advanced non-metallic composite material made of a polymer resin reinforced with carbon fibers.

Property	Method	Typical Test Value
storage condition	-	store dry at 4°-35°C
shelf life	-	10 years
colour	-	black
primary fibre direction	-	0°(unidirectional)
Tensile Strength	ASTM D-2343-85	4900MPa
Tensile Modulus	ASTM D-2343-85	234500MPa
Ultimate Elongation %	ASTM D-2343-85	1.7%
Density	ASTM D-3317 / D1505	1.8 g/cm^3

Table no.3.5: Carbon fibre polymer

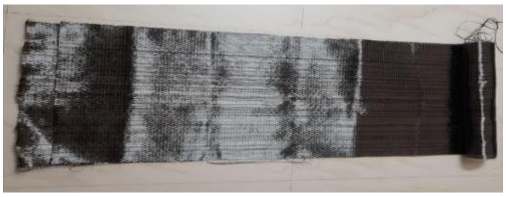

Figure no.3.2: Carbon fibre polymer

Sr no	Materials	Quantity
1	Cement	420kg/m^3
2	Sand	685kg/m^3
3	Coarse aggregate(20mm)	1170kg/m^3
4	Water	190L

Table no.3.6: Concrete mix

3.3 Specimen Design

A total no. of 12 column specimens were prepared in accordance with the need of the research and they were divided into 4 sets. The columns having dimension of 200 mm X 200 m X 600mm, which is a 2/3 scale of real short columns in buildings. These specimen sizes were selected as being representative of reality. The selected slenderness is equal to three (H/L = 3), which is the upper limit of the short column notion. Minimum eccentricity of column is less then minimum eccentricity permitted; hence no bending check is required. Four 12 mm steel rebars are used for the longitudinal reinforcement and three 6 mm stirrups separated by 200 mm for transverse reinforcement illustrated in figure no.3.3. Design is based on IS456 2000.

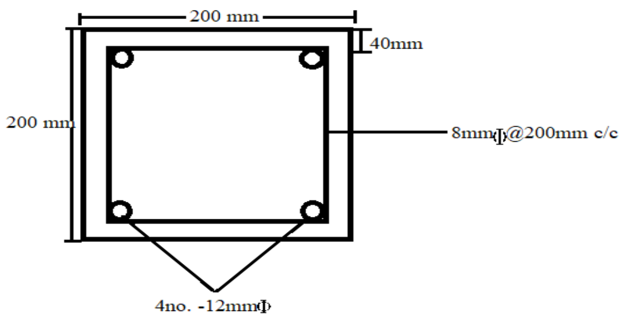

Figure no.3.3: C/S of column

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Set no.	Column specimen name	Distress %	CFRP strengthening
1	C-1, C-2, C-3	100	without
2	C-4, C-5, C-6	50	with
3	C-7, C-8, C-9	60	with
4	C-10, C-11, C-12	70	with

3.4 Casting of specimen :-

1) A total no. of 12 column specimens were prepared in accordance with the need of the research and they were divided into 4 sets. (set 1, set 2, set 3, set 4)
2) Casting and curing of the column specimens was done at RMC plant.

Figure no.3.4: Compacted concrete

Figure no.3.5: Concrete after 24hrs

3.5 Testing of column specimens:-

The column specimens were tested on a 2000kN capacity Universal testing machine (UTM) under uni-axial compressive load. Loading rate was maintained at 10kN and this rate was maintained constant up to cracks appeared on surface of the column specimen.

1) At first, a set of 3 column specimens (C-1, C-2, C-3) without CFRP wrapping were tested to find out average compressive strength.
2) Accordingly, 50%, 60%, 70% of the average compressive strength is calculated for further testing on column specimen. Column specimens set 2, set 3, set 4 were distressed at 50%, 60%, 70% of average compressive strength respectively shown in figure no.3.6
3) The 50%, 60% and 70% distressed specimen sets were given a corner radius of 5mm so as to apply CFRP sheet with ease and proper bonding.
4) The epoxy used for binding CFRP sheet with concrete is SikaDur 30. Then column specimens with 5mm radii were retrofitted by double wrapping with CFRP sheet and were kept in a dry place for 24hrs as shown in figure no. 3.7.

(a) **(b)**

Figure no.3.6: columns under uniform compressive loading

Figure no.3.7: column specimens with 5mm corner radii

Figure no.3.8: Retrofitted column specimens

5) Again, specimens were tests under uniform loading on UTM an extreme load at which the considerable

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ultimate failure of retrofitted column specimens was noted.

(a) (b)

Figure no.3.9: Retrofitted column specimens under uniform loading

3.6 Reasons of Failure :

1) Cracks formed parallel to the load application axis in both sets of specimens with and without externally-bonded CFRP confinement.
2) The failure mode of the columns confined with CFRP fabric of the specimens exhibited some degree of horizontal tearing, mainly at the edges of column specimens.
3) Upon inspection of the samples, a thin layer of concrete adhered to the CFRP fabric was observed, implying adequate bonding between concrete and the CFRP sheet.
4) Additionally, the CFRP wraps delayed core failure in the column.

Figure no.3.10: Failure under uniform loading

IV. RESULTS AND DISCUSSION

4.1 Introduction

This chapter represents the obtained results by experimental study and discusses causes for variation in results from standard result. The above test set up were used to produce the results of the research work. Every column specimen underwent the axial loading and their ultimate loads were noted down.

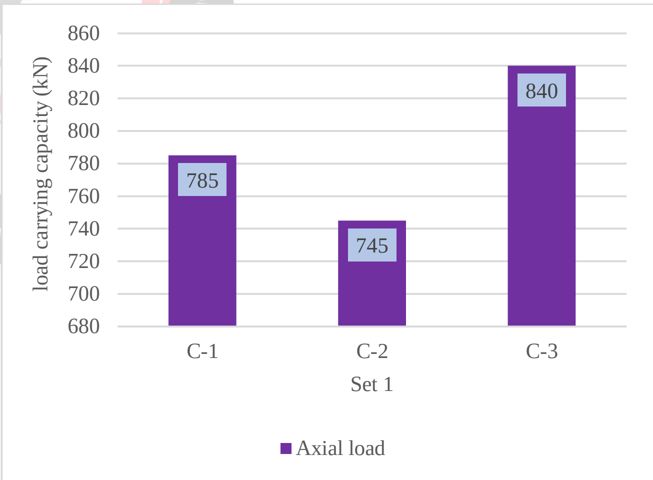
specimen no.	load at which cracks started to form	Avg load
	kN	kN
C-1	400	330
C-2	270	
C-3	320	

4.2 Results for control column:

Table no.4.1: Load at which cracks formed for set 1

specimen no.	axial load before CFRP wrapping	Compressive strength	Average Compressive strength
	kN	N/mm²	N/mm²
C-1	785	19.625	19.75
C-2	745	18.625	
C-3	840	21	

Table no.4.2: average compressive strength



Graph no.4.1: Axial load for set 1

4.2.1 Discussion:

Graph and result represent variation in load carrying capacity and flexural strength of concrete beam specimen after 28 days of curing. First set of 3 column specimens was tested under uniform loading. The average compressive strength was found out to be 19.75N/mm^2.

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distressing %	specimen no.	load at which cracks started to form	Avg load	Compressive strength
		kN	kN	N/mm²
50	C-4	250	270	6.75
50	C-5	250		
50	C-6	310		
60	C-7	200	210	5.25
60	C-8	180		
60	C-9	250		
70	C-10	270	270	6.75
70	C-11	250		
70	C-12	290		

4.3 Results for load at which cracks formed distressing column specimen and retrofitted column specimen:

Table no.4.3: For load at which cracks formed for specimen while distressing:

Table no.4.4: For load at which cracks formed for retrofitted specimen:

distressed %	specimen no.	load at which cracksstarted to form	Avg load	compressive strength
		kN	kN	N/mm²
50	C-4	800	790	19.75
50	C-5	760		
50	C-6	810		
60	C-7	600	593.33	14.83
60	C-8	550		
60	C-9	630		
70	C-10	600	543.33	13.58
70	C-11	500		
70	C-12	530		

Table no.4.5: Results for Retrofitted column specimens:

specimen no.	Distress % before wrapping CFRP	axial load after CFRP wrapping	Avg load	Compressive strength	% increase of ultimate strength over unconfined
		kN	kN	N/mm²	%
C-4	50	1160	1133.33	28.33	64
C-5	50	1100			
C-6	50	1140			
C-7	60	1000	996	24.9	51.31
C-8	60	1070			
C-9	60	918			
C-10	70	810	796.67	19.92	32.17
C-11	70	800			
C-12	70	780			

4.3.1 Discussion:

1. It has been observed that average compressive strength increased from specimen while 50% distressing to Retrofitted specimen after distressed by 34.177%.
2. It has been observed that average compressive strength increased from specimen while 60% distressing to Retrofitted specimen after distressed by 35.40%.
3. It has been observed that average compressive strength increased from specimen while 70% distressing to Retrofitted specimen after distressed by 49.70%.

4.2 Average axial load graph:

Graph no.4.2: average axial load

4.5.1 Discussion :

219.625N/mm² is average compressive strength calculated from initial set 1 and average compressive strength for retrofitted 50% distressed column specimens was 28.33N/mm² Similarly, for retrofitted 60% and 70% distressed column specimen it was 24.9N/mm² and 19.92N/mm². The % increase of ultimate load over unconfined came out to be 43% for 50% distress, 26% for

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60% distress and 0.84% for 70% distress. It has been observed that compressive strength increased after retrofitting. The difference between results of non-retrofitted set 1 column specimens and retrofitted sets of column specimen was at substantial level.

V. CONCLUSION

I. CFRP is a sustainable substitute to steel jacketing or other conventional materials as it consumes far lesser time and space than those conventional materials.

II. The ultimate load of the short column retrofitted with CFRP improved by 43% for 50% distressed column specimen as compared to control column specimens (C-1, C-2, C-3); similarly, 26% for 60% distressed retrofitted column specimen and 0.84% for 70% distressed retrofitted column specimen as compared to without wrapping column specimen (C-1, C-2, C-3).

III. 50% distressed retrofitted column specimen gives higher compressive strength by 13.7% as compared to 60% distressed retrofitted column specimen and by 42.2% compared to 70% distressed retrofitted column specimen.

IV. Higher load carrying capacity is obtained from doubly wrapped CFRP column.

V. Load carrying capacity of columns is very well enhanced by providing the corner radius of 5mm to edges of column. Hence CFRP wrapping with corner radii is strongly recommended for retrofitting of structural elements.

VI. Future recommendations

i. As percentage of distressed column varies, single wrapping or multiple wrapping of CFRP sheet to columns can be recommended.

ii. Types of CFRP wrapping such as top/bottom wrapping of column, middle wrapping or stripped wrapping can be done according to need of retrofitting.

iii. Corner radii can be increased for bonding of CFRP sheet with concrete column.

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