STRUCTURAL RETROFITTING OF RC COLUMNS USING GLASS FIBRE-REINFORCED POLYMER SHEETS

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by

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CERTIFICATE

This is to certify that this dissertation report entitled, "**STRUCTURAL RETROFITTING OF RC COLUMNS USING GLASS FIBRE-REINFORCED POLYMER SHEETS"** is a bonafide work done by "**OWIAS NAZIR, Reg. No.:- 11501317"** Student of Civil Engineering Department, Lovely Professional University, Phagwara, Punjab in partial fulfilment of the requirement for the Degree of Master Of Technology in Structural Engineering. This report has not been submitted to any other university or an institution for the award of any degree.

Signature of the Supervisor

Mr. Navaneethan

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DECLARATION

I, Owias Nazir (11501317), hereby declare that the dissertation report entitled, **"STRUCTURAL RETROFITTING OF RC COLUMNS USING GLASS FIBRE-REINFORCED POLYMER SHEETS"** is a bonafide and genuine research work carried out by myself under the guidance of **Mr. Navaneethan, Assistant Professor; Department of Civil Engineering, Lovely Professional University**, **Phagwara.**

Date: OWIAS NAZIR

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Signature of Student

Abstract

There are various strengthening and rehabilitation techniques to improve the performance, durability, load carrying capacity and life span of structure. Retrofitting of the damaged or week structure is the best way to improve the strength of that structure. In recent years, FRPs have been used for the purpose of retrofitting. In this experimental study, 18 number of circular columns and 18 rectangular will be casted and the diameter of each circular specimen is 150mm and height of 350mm. While as the cross section of rectangular columns is 150mm×150mm and height is 350mm. Both control and retrofitted columns of circular and rectangular shapes were tested on CTM to determine the compressive strength after 7 days, 14 days and 28 days.

From the experimental data, it is observed that there is increase in compressive strength in the retrofitted specimens, both in circular and rectangular columns. For retrofitted circular columns, there is 20.36% increase in compressive strength after curing period of 28 days. Also, there is an increase of 19.23% of compressive strength in rectangular retrofitted columns after curing period of 28 days. From the experimental findings, it is observed that retrofitting by GFRP is most efficient in circular columns. Retrofitting by GFRP can be employed in case when the structures are subjected to severe load combinations.

Keywords*: Retrofitting, GFRP, circular and rectangular columns, Compressive strength*

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LIST OF ABBREVIATIONS AND SYMBOLS

CA	Coarse aggregates
FA	Fine aggregates
FRP	Fibre reinforced polymer
GFRP	Glass fibre reinforced polymer
CFRP	Carbon fibre reinforced polymer
PPC	Pozzolana Portland cement
Min	Minutes
mm	Millimetre
Sec	Second
^{o}C	Degree Celsius
ml	Millilitre
kg	Kilogram
%	Percent
kg/m^3	Kilogram per metre cube
MPa	Mega-pascal
W/C	Water cement ratio

Chapter 1

Introduction

1.1 General

All the loads that are acting on the structure whether they are lateral loads, gravity loads, longitudinal loads, etc are transferred from beam to column and column then transfers it to the foundation. So the columns are very important in any structure for its stability and durability. Whenever there are higher loads acting on the structure, or there is an earthquake, structure gets damaged partially or fully and the structure loses its original strength. To regain its original strength, retrofitting is the best way chosen so far to improve the strength of that damaged structure.

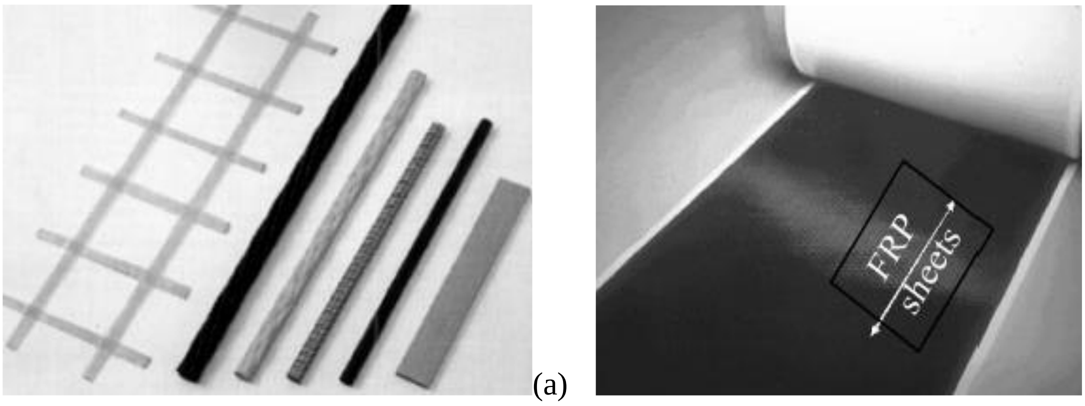
Retrofitting means improvements in strength to an existing structure. There are a lot of RC buildings and bridges and various RC structures that are in need of re-strengthening and therefore there is a need of retrofitting.[1] There are a number of reasons that lead to retrofitting which are: seismic activity, higher load demand, higher strength demand, constructional errors, deterioration caused by environmental factors, change in use of the structures, etc. Micro cracks are also developed in concrete due to thermal variations. Due to the formation of micro cracks, there is a decrease in strength of a structure. So it regain its strength, a structure needs to be retrofitted.[2]So to sum up, retrofitting is modification of existing structures to make them more resistant towards external loadings.

In past years, large research work has been done to make various strengthening and retrofitting techniques to improve the strength and lifespan of a structure. Some of the strengthening methods that has been applied in the past are steel plate bonding, jacketing, external post tensioning, addition of new structural elements, etc and these methods were successful. Among all the methods, retrofitting with Fibre Reinforced Polymers (FRP) materials has lead to a various achievements in the field of civil engineering in past one or two decades. Fibre-reinforced polymers (FRP) are light weight in nature, easy for implementation and have high tensile strength and also are corrosion resistant. Due to these reasons, FRP composites are preferred solutions for strengthening method of various reinforced concrete structural elements and are now extensively being used all over the world.[3]

FRP composites may be of various types:

- Carbon fibre-reinforced polymer (CFRP)
- Glass fibre-reinforced polymer (GFRP)
- Aramid fibre-reinforced polymer (AFRP)

In FRP's, the main load bearing component are the fibres. FRP products that are used in retrofitting of structures can be in the form of strips, sheets and laminates.



(a) (b)

Figure 1.1: FRP for retrofitting, (a) FRP Strips and (b) FRP Sheets

1.2. Fibre reinforced polymer:

FRP is a material made up of two or more materials to form a composite material which possess various combinations of properties. FRPs are widely used these days for retrofitting of damaged or weak structures. There are various advantages of fibre reinforced polymers (FRP) like they are light in weight, they bear high mechanical properties and they also are corrosion resistant.[4] Physical properties and mechanical properties of FRPs are governed by its basic properties and the structure at micro level. Before wrapping of FRP to the structural element, there should be proper analysis and design of FRP. FRPs are anisotropic in nature. In our experimental study, FRP provides strength and stiffness to the structural component on which it will be wrapped.

1.3 Methods of strengthening and retrofitting:

Various techniques are:

- Jacketing of steel to structural elements.
- External pre stressing for the bridge girders.
- Use of FRP composites wrapped to the surface of concrete.

- Chemical methods i.e filling up of cracks with some adhesives or cracks.

Retrofitting technologies for structures are at the research stage. So following figure shows us various types of methods for retrofitting which have been developed and are beneficial for the performance of the structure.[5]

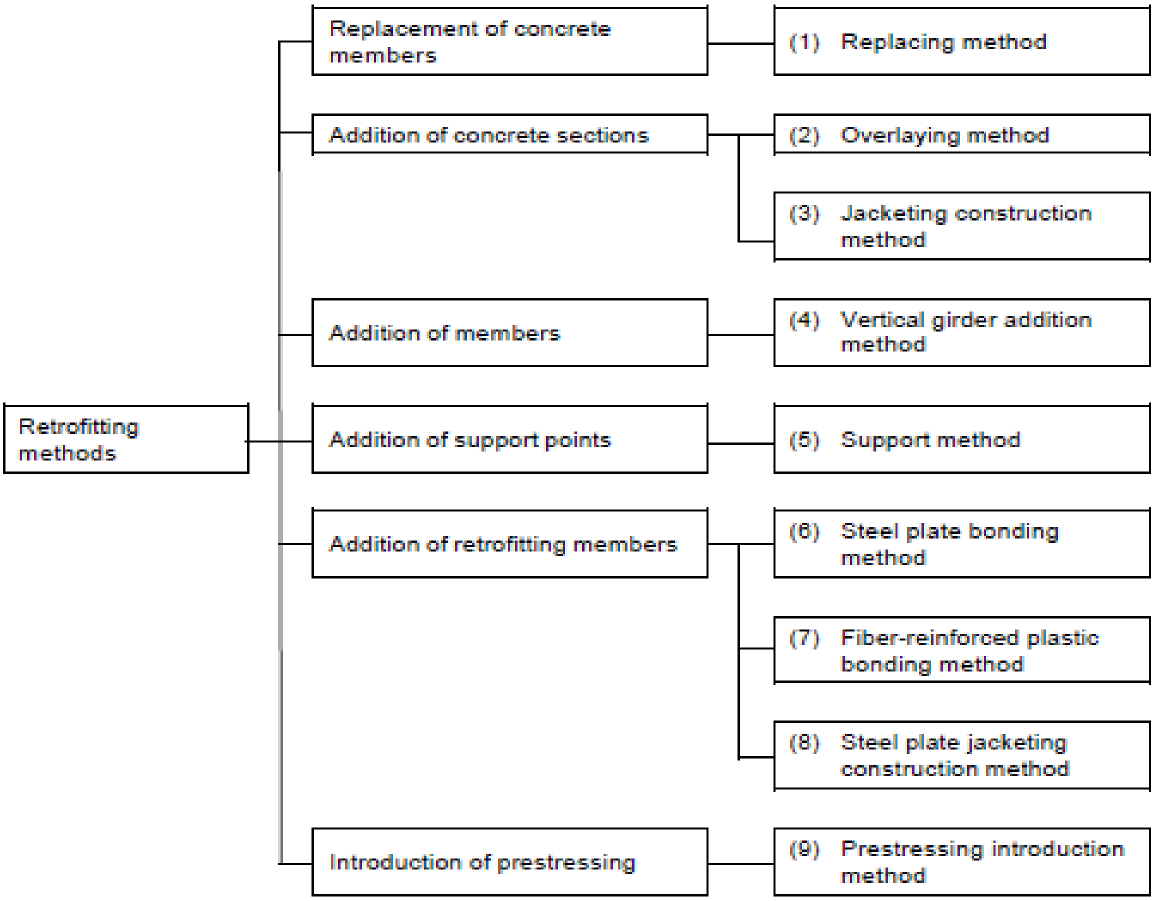


Figure 1.2: Methods of retrofitting

1.4 Advantages of FRP materials:

For repairing, retrofitting and re-strengthening of various structural elements, FRP is mostly used in place of steel. Various advantages of FRP materials are;

1. High strength;
2. High stiffness;
3. High corrosion resistance;
4. Convenient in handling;
5. Ease of implementation;
6. Resistance to high temperature;

7. Resistance to mechanical as well as environmental conditions.;
8. High tensile strength;
9. Light in weight;
10. Low cost of maintenance and repair.

1.5 Disadvantages of FRP composites:

1. Low compressive strength as compared to tensile strength.
2. Unstable at high temperature;
3. Anisotropic material i.e, it doesn’t have same properties in all directions.
4. Very high cost of some of the fibres like carbon fibres.
5. FRPs are not good resistant of fire.
6. Up to yield point, stress strain curve is linear but after that mode of failure is brittle.

Chapter 2

Literature Review

Antonio et al (2015): The well known technique for retrofitting and strengthening purposes for various damaged RC columns is by externally wrapped FRP laminates or sheets. In this paper, there is experimental study on various FRP materials like blast glass fibre laminates and glass fibre sheets on rectangular and square RC columns. These columns are tested under eccentric loading and axial loading and the design of columns was also done for the two loading conditions: axial loading and eccentric loading by referring ACI 318 code. This study was conducted to determine how FRP sheets effect on peak axial strength and deformation under the centric loading for FRP wrapped column. After studying this whole experimental program, it was concluded that the strength was increased in compression.

Yu-Fei Wul et al (2015): In this experimental program, different retrofitting techniques were demonstrated and it was determined that which technique in particular is effective for enhancement in the structural performance of the columns. This study identifies the key factors that affect the effectiveness and deficiencies of different retrofitting methods. various results were determined from this study, some of them are as follows:

1. Retrofitting by steel or FRP jacketing is very effective for circular as well as rectangular columns.
2. For axial retrofitting, circular shaped jackets can offer a reliable performance that can be both qualitatively and quantitatively found out and for flexural retrofitting, circular jackets can also be very effective for both lap splice failure and concrete crush failure.

G Promis et al (2013): In this experimental program, the main aim is to check the CFRP's contribution to the improvement in the strength of short columns. The columns were tested with the combined effect of compressive and flexural loadings. Total number of 8 columns were casted in this study, which are having longitudinal reinforcement higher than then the transverse reinforcement. Each of the 8 columns was wrapped with CFRP or GFRP sheets. After studying this whole experimentation, it was found out that Use of FRP has a good influence on ductility, stiffness and dissipated energy.

K.Galala et al (2013): During seismic activity, RC short columns are most likely to undergo shear failure. Therefore study of the behaviour of short columns is very important and also retrofitting of the short columns is important. In this paper, short reinforced columns were reinforced with transverse reinforcement and then they were retrofitted by using fibre reinforced polymer composites. Design of seven short RC columns was done and then they were tested under axial load. CFRP or GFRP was used for the purpose of retrofitting. From this experimental study, I can say that increase in the number of FRP layers in RC short column decreases the strains in both the transverse ties and fibre materials used. By retrofitting of CFRP sheets, shear force was improved and energy dissipating capacity was also improved.

Minho Kwon et al (2013): GFRP-infill panels were designed so that they can be used steel structures. The objective of this designing was to increase the strength of the steel structure and to give support to the week steel frames under seismic activity. After the studying of the test results, there was an increase in the strength of frames made up of steel structures. Also design procedure for GFRP-infill panels can be used to increase the strength and durability of a frame made up of infill-steel structure.

Dr. Gopal Rai et al (2010): New innovative construction materials are being used now-a-days to meet the requirements of any structure in advance. The use of FRP in strengthening of the structure are proven quite useful and also are used in various other applications. FRP can be used by applying epoxy on the laminates and that can be wrapped around the beams, slabs and columns to improve their strength in weak regions or damaged areas. Direction of application of FRP laminates or strips are parallel to the high tensile stresses. Therefore the compound of FRP are finding ways to test its affect on the structure and economical time.

Pedram Sadeghian et al (2010): In recent years, different studies on FRP confined column strengthened had been tested under concentrated loads. However most of the columns crack when there is eccentric loading with the combinations of axial compressive loads and bending moment. This study is done by experimenting tests on RC columns reinforced with carbon fibres and were being tested under axial force and bending moment. In this paper, number of specimens with cross section of 200mm × 300mm were casted and tested under eccentric loadings. FRP was applied in two, three and five layers on the columns. On determining the results, it was shown that increase in eccentricity decreases the moment carrying capability of the column. Also CFRP composites increases the load carrying capacity of column. FRP jacketing can enhance or improve the ductility of the columns.

Raafat El Hacha et al (2011): The deterioration of concrete structures by corrosion of reinforcements and rebars is due to sever environment conditions such as cold zones and coastal area zones. The objective of this study is to enhance the effectiveness of cylinders made up of concrete when it is exposed to extreme temperature differences. In this experimental paper, 36 plain cement concrete cylinders were tested and they were wrapped by 2 number of layers of unidirectional CFRP plates. These specimens were subjected to temperature differences of 23ºC and 45ºC heating and cooling and later these were put to cyclic freezethaw cycles. Some of the specimens were completely submerged into water. Then the specimens were subjected to the loading for failure under uni-axial compressive stress and axial and lateral deformations were calculated. Based upon the test results, 74% strength was increased in the cylinder which was made up of 43 cement grade and was wrapped by unidirectional carbon fibres. Significant strength was also increased in those samples which were subjected to temperature fluctuations. Axial load carrying capability of cylinder was increased up to 4 times.

Eslami et al (2011): In past years, there has been a lot of research in the field of retrofitting on a column beam joint arrangement by using fibre reinforced polymers (FRP) by various researchers. Most of the researchers have said that FRP jacketing should be done on the web of the beam column arrangement and corners which are fixed i.e, crossbeams and central slabs should be wrapped with FRP laminates in slabs because maximum strain has been determined in these portions only. In this paper, 9 no. of beam-column test specimens were castes in which two were control beams and rest were retrofitted. Cyclic loading were applied to the beam-column joint to check the effect of the seismic forces on these specimens. Various properties were determined like, moment carrying capacity, stiffness, displacement, ductility and dissipated energy and these were compared with the test results from the control mix beam-column joints and hence it was proved that the efficiency of new system of anchorage is beneficial in beam-column joints.

Dhanu M. N. Revathy et al (2006): In this study, experimental and numerical study was done by retrofitting of FRP laminates on the RC beams. Main motive of this experimental study is to check the improvement in the strength of RC beams by applying adhesive on the surface of the beam and then wrap it with the FRP laminate. FRP used in this experimental study is GFRP and coir fibres. After the wrapping of FRPs, moment carrying capacity and crack pattern were determined. It is concluded that the GFRP and coir fibre retrofitting increases the resistance of structure towards seismic forces.

Okan Ozcan et al (2009): In this research paper, rectangular RC columns were casted and they were retrofitted with CFRP anchorages. Only 5 rectangular Rc columns were casted with poor transverse rebars and also the strength of concrete was kept low. These columns were subjected to cyclic displacements and axial forces. Also wrapping was done on the surface of the columns by CFRP laminates and they were fixed with some adhesive so that laminates can be tightly wrapped. It was found out that an increase in the ratio of FRP laminates is very beneficial.

Mohammad R. Irshidat et al (2008): In this experimental study, carbon nanotubes (CNTs) were used to improve the strength of RC columns confined by carbon fibres/epoxy composites. Total number of 14 rectangular RC columns were casted and tested under concentric axial loading. Carbon fibres were coated with epoxy resins which were enriched with CNTs. For the experimentation, RC columns were tested with fully wrapped carbon fibres and partially wrapped carbon fibres. Different properties were determined like failure modes, axial load-displacement responses, etc. from the tests, it was proven that the axial load carrying capability and toughness of columns wrapped with carbon fibres was increased by 12% and 19% respectively.

Chapter 4

Rationale and Scope of the project

There are a lot of RC buildings and bridges and various RC structures that are in need of re-strengthening and therefore there is a need of retrofitting. There are a number of reasons that lead to retrofitting which are: seismic activity, higher load demand, higher strength demand, constructional errors, deterioration caused by environmental factors, change in use of the structures, etc.Micro cracks are also developed in concrete due to thermal variations. Due to the formation of micro cracks, there is a decrease in strength and stability of a structure. So to regain its strength, a structure needs to be retrofitted. As Fibre-reinforced polymers (FRP) are light weight in nature, easy for implementation and have high tensile strength and also are corrosion resistant, retrofitting with Fibre Reinforced Polymers (FRP) materials is one of the useful and economical methods to improve the average strength of the RC structures.

Chapter 4

Objective of the Study

Following are the objectives of this experimental work:-

1) To determine the compressive strength of the control and the retrofitted samples.
2) To calculate the average strength of the columns after the curing period of 7 days, 14 days and 28 days.
3) To make retrofit technique easy, practical and economic.
4) To detect and repair damage easily.

Chapter 5

Research Methodology

5.1 Materials

For the casting of columns, various construction materials are used like cement , fine aggregates and coarse aggregates and water. GFRP laminates will be used for the purpose of retrofitting.

- **Cement**: Portland pozzolana cement (PPC) is used for the casting of the columns. The cement has been checked for various properties and they are accurate taking IS:4031-1968 into consideration.
- **Coarse aggregates:** Size of the aggregates used in the making of concrete are 10mm and 20mm. This material has to satisfy IS:383-1970. Locally available aggregates and some basalt stone chips will be used in this study.
- **Fine aggregates**: Locally available riverbed sand is used and it should be confirming some zone which depends upon the sieve analysis of the sand.
- **Fibre:** The main role of the fibres is to carry load, provide stiffness, increase strength and give thermal stability to the structure. Fibres are made up of long filaments. There are basically three general types of fibres which are being mostly used in retrofitting i.e, glass fibre, carbon fibre and aramid fibres.
- **Glass fibres:** These fibres are generally made up of silicon. Their main property is high strength. After retrofitting, glass fibres enhance various properties of the structure.
- **Epoxy**: Epoxy is used as a resin and it will act as a binder for the purpose of wrapping of GFRP. Tensile strength and flexural modulus of epoxy is 37 MPa and 3680 MPa respectively, with elongation of 1.2%.
- **Steel:** HYSD bars of 8mm were used for main reinforcement and stirrups of 6mm were used for both circular and rectangular columns with a minimum cover of 10mm for main reinforcement.

5.2 Material testing

Various tests were performed on the cement and the aggregates. These tests were done in the laboratory under the supervision of our mentor. Various properties were determined with the help of these tests. These all tests were performed keeping IS 383:1970 in consideration.

5.2.1 Tests performed on the cement:

Various tests were performed on the cement to check its various properties and the calculated results are discussed below:

I. Consistency
II. Soundness test
III. Initial setting time
IV. Final setting time
V. Fineness of cement
VI. Specific gravity test

I. Consistency test:

Objective: To determine the standard consistency of cement paste.

Theory: The standard consistency of a cement paste is defined as that consistency which will permit a Vicat plunger (consistency apparatus) to penetrate to a depth of 33-35 mm from the top of the mould. Normally standard consistency is used to determine the quantity of water required to be added to cement to make it in the form of paste.

Apparatus required:

1. Vicat apparatus.
2. Balance.
3. Measuring cylinder.
4. Tray.
5. Glass plate.

Environmental conditions:

Table 5.1: Environmental conditions for consistency test.

Temperature	25^{o}C to 27^{o}C
Humidity	60^{o}C to 70^{o}C

Calculations:

Standard consistency is the ratio of quantity of water added (W) to the quantity of cement used(C).

Mathematically, consistency is represented as:

$$P = \frac{W}{C} \times 100$$

Figure 5.1: Consistency test

Figure 5.2: Vicat apparatus

Result:

Table 5.2: calculation of standard consistency.

S.No	Weight of cement (gms)	Percentage by water of dry cement (%)	Penetration (mm) (from the bottom of the mould)
1	300	25	41 mm
2	300	27	34 mm
3	300	29	31 mm
4	300	30.5	23 mm
5	300	32.5	11 mm
6	300	34.5	7 mm

Therefore the standard consistency for the cement is **34.5%**.

Test standard reference

The IS code used for the consistency of cement is IS:4031-PART 4-1988

II. Soundness of cement

Objective: To calculate the soundness of cement by Le- Chateliers method.

Theory: certain cements undergo large expansion after setting that causes failure in the structure. So the cement after setting should not have any expansion or there should be no change in the volume of the cement. Soundness of cement is determined to detect any expansion in the cement by boiling a hardened cement paste for a fixed time. The capability to resist any volume expansion is called as soundness of that material.

Apparatus:

1. Le-Chatelier test apparatus.
2. Water bath (100^0C).
3. Caliper.
4. Balance.
5. Trowel.
6. Tray.

Figure 5.3: le-chatelier's test apparatus.

Environmental conditions:

Table 5.3: Environmental condition for soundness test

Temperature	25^oC to 27^oC
Humidity	60^oC to 70^oC

Calculations:

L_1= Distance separating the two indicator points submerged in water bath at normal temperature for 24 hours.

L_2= Distance between the two indicator points submerged in water bath at 100^{o}C for three hours.

Soundness or expansion= **L_2-L_1**

Table 5.4: Results for soundness test.

S.NO	L_1 (mm)	L_2 (mm)	Soundness (mm)
SAMPLE 1	1.5	1.9	0.4
SAMPLE 2	1.5	1.85	0.35
SAMPLE 3	1.5	1.75	0.25

The soundness is calculated by taking the mean of the three samples and it comes out to be **0.33mm.**

Conclusion:

According to IS:1489-1991 (part 1), the expansion limit for Portland pozzolana cement is 10mm. Therefore, the given cement is said to be sound as the soundness or expansion is only 0.33 mm.

III. Initial setting time of cement.

Objective: To determine the initial setting time of the cement.

Theory:

Initial setting time: It is the time when the water is added to the cement to the time the cement paste starts losing its plasticity.

Final setting time: it is defined as the time when water is added to the cement to the time when the cement has completely lost its plasticity and has attained some firmness to resist any external load or pressure.

Apparatus:

Vicat apparatus, Balance, Trowel, Tray, Water, Stop watch.

Figure 5.4: Vicat apparatus

Figure 5.5: Assembly of test apparatus and test block

Calculations:

1. Weight of dry cement is 300 gm.
2. The standard consistency of cement is 34.5%.
3. Volume of water added = 0.85P

$0.85\times 34.5 = 29.325\%$

∴ volume of water added = 29.325× $(\frac{300}{100})$ = 87.97 ml

Initial setting time= $T_2 - T_1$.

Table 5.5: Result of initial setting time test.

Sample	**T_1 (min)**	**T_2 (mins)**	**Setting time (T_2-T_1)**
Sample 1	10:15	10:52	37
Sample 2	11:05	11:39	34
Sample 3	12:02	12:33	31

The initial setting is calculated by taking the average of the three reading and is equal to 34 minutes

The final setting time is taken as the average of the 3 samples and is 590 minutes.

Test standard reference

According to IS:1489 - part 1, the initial and final setting time of PPC should be 30 minutes and 600 minutes respectively. According to our test, the initial and final setting time is 34 minutes.

IV. Fineness of cement

Objective: To find out the fineness of Portland pozzolana cement by dry sieving.

Theory: Fineness is determined by sieving of dry cement on the standard sieve and the size of grains whose size is larger than the specified sieve size is determined. The fineness of cement has a good affect on the rate of hydration. Finer the cement more will be the rate of hydration and thus there will be increase in the strength.

Apparatus required:

90 micron sieve

Balance

Tray

Lid

Figure 5.6: 90 micron sieve

Calculations:

The fineness of cement is calculated by taking the average of the three samples.

Table no. 5.6: calculation of fineness of cement

Sample	Weight of dry cement (g)	Weight retained on the 90 micron sieve (g)	Fineness (%) $(X/200)\times 100$
Sample 1	200	11.5	5.75
Sample 2	200	10.9	5.45
Sample 3	200	10.7	5.35

Therefore the fineness of cement is calculated by taking the average of the three samples and is equal to 5.5%.

Test standard preference:

According to IS:4031-1996 (part 1) the fineness of PPC should not be more than 10%. So our sample is fine in nature as its fineness is 5.5%.

V. Specific gravity test

Objective: To find out the specific gravity of dry cement using Le-Chatelier's flask,

Theory: The specific gravity is defined as the ratio of the weight of a given volume of material and weight of an equal volume of water. Kerosene or diesel is used to determine the specific gravity of cement.

Apparatus :

Le-Chatelier's flask

Balance

Diesel

Dry cement.

Figure 5.7: Le-Chatelier's flask

Calculation:

The difference between the two readings represents the volume of liquid displaced by the equal amount of cement.

W= weight of cement.

W_1= weight of diesel in the flask.

W_2= weight of diesel and cement in the flask.

Specific gravity of cement = $\frac{W}{W-\{(W2-W1)\times 0.85\}}$

Specific gravity of diesel = 0.85

Here, W=50 gm

W_1= 240.35 gm

W_2= 279.352 gm

Therefore, specific gravity of cement = 2.967.

.**Reference:**

According to IS:4031-1988(part 11), the specific gravity of Portland pozzolana cement is around 3.10.

5.2.2 Tests performed on the coarse aggregates and fine aggregates.

I. Sieve analysis of coarse aggregates and fine aggregates.

Theory: Sieve analysis is commonly known as gradation test. The sieve analysis helps us in determining the gradation of particles i.e, the distribution of aggregate particles by size.

A). **Determination of sieve analysis for coarse aggregates:**

Objective: To determine the fineness modulus of coarse aggregates.

Apparatus: Sieves of size 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, Balance

Figure 5.8: coarse aggregate test

Calculations: Weight of coarse aggregates taken= 5kg.

Table no. 5.7: Fineness modulus of coarse aggregates.

S.NO	Sieve size (mm)	Weight retained (kg)	% weight retained	Cumulative % weight retained (X)	Cumulative percent passing
1.	80	0	0	0	100
2.	40	0	0	0	100
3.	20	0.400	8	8	92
4.	10	2.850	57	65	35
5.	4.75	1.480	29.6	94.6	5.4
6.	2.36	0.270	5.4	100	0
Total		5.000 kg		267.6	

Result:

Therefore, the fineness modulus of coarse aggregates = $\frac{X}{100}$= $\frac{267.6}{100}$= 2.676.

Also the given sample of coarse aggregates belong to graded aggregates taking IS:383:1970 into consideration (grading limits for coarse aggregates).

Standard reference:

IS : 2386 (Part I) – 1963,
IS: 383-1970,
IS : 460-1962

B). Determination of sieve analysis for fine aggregates.

Objective: to determine the fineness modulus of fine aggregates by sieve analysis.

Theory: With the help of fineness modulus, we can determine the fineness of sand, whether it is coarse sand, medium sand or fine sand.

Table 5.8: Types of fine aggregates and their range

Fine aggregate	Fineness modulus
Fine sand	2.2-2.6
Medium sand	2.6-2.9
Coarse sand	2.9-3.2

Fine aggregates having fineness modulus more than 3.2 will be unsuitable for preparing concrete.

Apparatus:

Test Sieves conforming to IS : 460-1962 having specification of 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron, 150 micron,
Balance,
Gauging Trowel,
Stop Watch etc.

Calculations:

Weight of fine aggregate taken = 1kg

Table 5.9: Fineness modulus of fine aggregates

S.NO	Sieve size	Weight retained (kg)	% weight retained	Cumulative % weight retained (kg)	% weight passing (kg)
1.	4.75 mm	0.02	2	2	98
2.	2.36mm	0.045	4.5	6.5	93.5
3.	1.18mm	0.092	9.2	15.7	84.3
4.	600 μm	0.177	17.7	33.4	66.6
5.	300 μm	0.492	49.2	82.6	17.4
6.	150μm	0.161	16.1	98.7	1.3
7.	Pan	0.013	1.3	100	0
Total		1 kg		X=238.9	

Result:

Therefore, the fineness modulus of the fine aggregates = $\frac{X}{100} = \frac{238.9}{100} = 2.389$

Also the given sample of fine aggregates belong to the Grading zone *III* taking IS:383:1970 into consideration (grading limit for fine aggregates).

II. Determination of specific gravity and water absorption of coarse aggregates.

Objective: To determine the specific gravity and water absorption of coarse aggregates.

Apparatus:

Wire basket,

Oven

Container for filling water and suspending the basket.

Air tight container

Balance

Tray and absorbent clothes.

Calculations:

W_1= weight of saturated dry sample.

W_2= weight of wire basket in water.

W_3= weight of wire basket + sample in water.

W_4= weight of oven dried sample.

Table 5.10: Specific gravity and water absorption of CA

SAMPLE	W_1 (kg)	W_2 (kg)	W_3 (kg)	W_4 (kg)
Sample 1	2	0.108	1.382	1.991
Sample 2	2.	0.637	1.910	1.995
Sample 3	2	0.177	1.432	1.994
Average	2	0.307	1.574	1.993

Average specific gravity= $\frac{W4}{W4-(W3-W2)} = \frac{1.993}{1.993-(1.574-0.307)}$=**2.74.**

Water absorption percentage= $\frac{W1-W4}{W4} \times 100 = \frac{2.000-1.993}{1.993} \times 100 = \mathbf{0.7\%}$

Result:

The average specific gravity of coarse aggregate is 2.74

The water absorption percentage is 0.7%.

Test reference:

IS : 2386-1963 (part III).

III. Specific gravity and water absorption of fine aggregates:

Objective: to determine the specific gravity and water absorption of a given sample of fine aggregates.

Apparatus:

Pycnometer, 1000-ml measuring cylinder, oven, Taping rod, Filter papers and funnel, balance, etc.

Figure 5.9: Pycnometer.

Calculations:

Table 5.11: specific gravity and water absorption of fine aggregates

Sample	Weight (g)
Weight of saturates and dry aggregates (W)	500
Weight of pycnometer, sample and water (W_1)	1896
Weight of pycnometer and water (W_2)	1584
Weight of oven dry sample (W_3)	494

Result:

Specific gravity = $\frac{W3}{W-(W1-W2)} = \frac{494}{500-(1896-1584)}$ = 2.62

Water absorption = $\frac{W-W4}{W4} \times 100 = \frac{500-494}{494} \times 100$ = 1.1 %

Test reference:

IS : 2386-1963 (PART III)

5.3 MIX DESIGN M20

Design mix is done by taking IS:10262-2009 into consideration.

Stipulation for proportionating:

I. Grade of concrete = M20

II. Type of cement = PPC 43 Grade.

III. Maximum size of coarse aggregates = 20mm

IV. Exposure condition = mild

V. Maximum cement content = 450 kg/m^3

VI. Type of aggregate = crushed.

Test data for material: All the data is based on the test results which were done in laboratory.

1. specific gravity of cement = 2.967
2. specific gravity of coarse aggregates = 2.74
3. specific gravity of fine aggregates = 2.626
4. Water absorption of CA = 0.7%
5. Water absorption of FA = 1.1%
6. Fineness modulus of FA = 2.389
7. Consistency of cement = 34.5 %
8. Initial and final setting time of cement = 34 minutes and 602 minutes respectively.

- **Mix design**

1. Target strength for mix design

$F_{ck} = f_{ck} + (t \times s)$

Where "F_{ck}" is target average compressive strength at 28 days and "f_{ck}" is the characteristic at 28 days, "s" is standard deviation and "t" is a statistic variable depending upon the accepted proportion of low results and the no. of tests.

[Table 1 IS:10262-2009]

$F_{ck} = 20 + (1.65 \times 4.6) = 27.59$ N/mm^2

2. Selection of water cement ratio

W/C ratio for corresponding F_{ck}value from IS:10262-2009 = 0.48

For mild exposure = 0.6

Take the min. water cement ratio = 0.48

[Table 5 IS:10262-2009]

3. Air content:

For maximum size of 20 mm aggregates, the entrapped air is 2% of the volume of concrete.

4. Water content and fine aggregate to total aggregate ratio

For nominal maximum size of 20 mm aggregates and concrete grade of M20, the water and sand content obtained are 186 kg/m^3 and 35% of total aggregate volume respectively.

Water content = 186 kg/m^3.

5. Adjustments of values in water content and sand percentages

No corrections are required since aggregates used are not rounded and there is no increase or decrease in w/c ratio and compaction factor.

6. Determination of cement content

W/C ratio = 0.48

Water content = 186 kg/m^3

Cement content = $\frac{186}{0.48} = 387.5$ kg/m^3

7. Check for minimum and maximum cement content

The calculated cement content of 387.5 kg/m^3 is adequate as per IS: 456:1978

8. Determination of coarse and fine aggregate content

Fine aggregates:

$V = (W + \frac{C}{Sc} + \frac{1}{p} \times \frac{\mathbf{fa}}{Sfa}) \times \frac{1}{1000}$

$0.98 = (186 + \frac{387.5}{2.967} + \frac{1}{0.35} \times \frac{\mathbf{fa}}{2.622}) \times \frac{1}{1000}$

Fa = 608.79 kg

Coarse aggregates:

$V = (W + \frac{C}{Sc} + \frac{1}{p} \times \frac{\mathbf{Ca}}{Sca}) \times \frac{1}{1000}$

$0.98 = (186 + \frac{387.5}{2.967} + \frac{1}{1-0.35} \times \frac{\mathbf{Ca}}{2.740}) \times \frac{1}{1000}$

Ca = 1181.50 kg.

9. Total quantities of ingredients and mix proportions

Table 5.12: proportion for mix design M20

Cement (kg)	**Fine aggregate (kg)**	**Coarse aggregate (kg)**	**Water (kg/m^3)**
387.5	608.79	1181.50	186
1	1.570	3.049	0.48

Therefore ratio of mix = 1 : 1.570 :3.049.

Chapter 6

Experimental setup

In this experimental study, total number of36 columns were casted in the laboratory. Out of these 36 columns, 18 specimens were circular and 18 specimens were rectangular. All the 36 specimens were tested under CTM to study the compression behaviour of columns with and without retrofitting.

6.1 Circular columns: In this study, total number of 18 circular columns were casted. The moulds were first formed at the carpenter shop having diameter and height of 150mm and 350mm respectively as shown in the figure 6.2.In these circular specimens, 6 bars of 8mm diameter was used as main reinforcement and the diameter of stirrups is 6mm. Spacing of stirrups is 75mm at the middle portion and its less than 50mm near the ends of each column. Every specimen was tested under CTM to determine the compressive strength. These columns were tested after 7 days, 14 days and 28 days. All the specimens were cured in the curing tank. For determining the average strength of the columns after 7 days, 3 sample columns and 3 retrofitted columns were tested and their average value was taken and same was done for the compressive strength after 14 days and 28 days. The size and reinforcement details are shown in the figure 6.1:

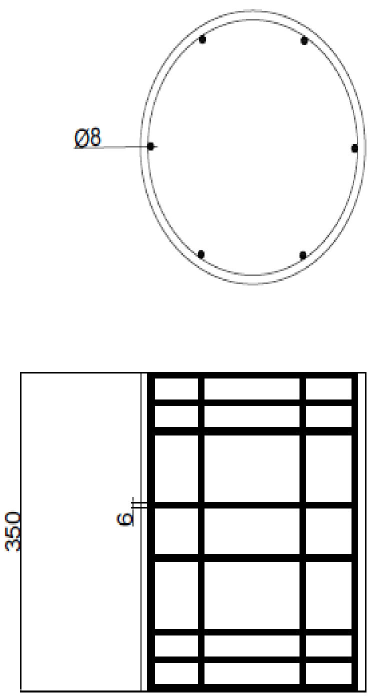


Figure 6.1: Diagram of Circular column

Figure 6.2: Mould for circular column

6.2 Rectangular columns: Total number of 18 rectangular columns were casted. The moulds were first formed at the carpenter shop having cross-section of 150mm×150mm and height of 350mm as shown in the figure 6.4. In these rectangular specimens, 4 bars of 8mm diameter was used as main reinforcement and the diameter of stirrups is 6mm. Spacing of stirrups is 75mm at the middle portion and its less than 50mm near the ends of each column. Every specimen was tested under CTM to determine the compressive strength. These columns were tested after 7 days, 14 days and 28 days. All the specimens were cured in the curing tank. For determining the average strength of the columns after 7 days, 3 sample columns and 3 retrofitted columns were tested and their average value was taken and same was done for the compressive strength after 14 days and 28 days. The size and reinforcement details are shown in the figure 6.3.

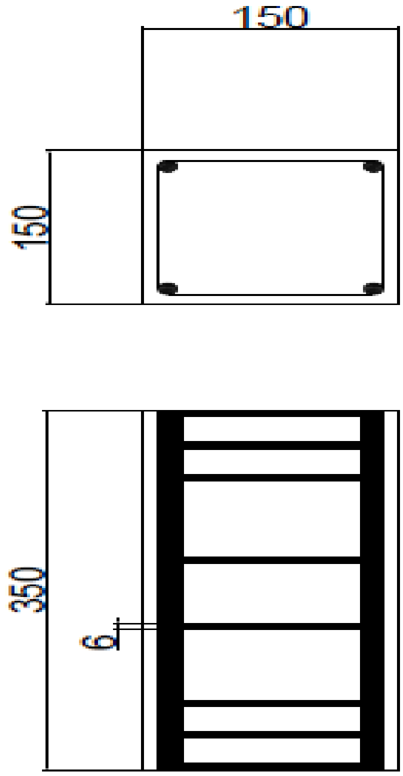


Figure 6.3: Diagram of rectangular column **Figure 6.4: Mould for rectangular column**

6.3 Retrofitted specimens: For the purpose of retrofitting, 9 circular columns and 9 rectangular columns were wrapped with GFRP at the top and bottom edges. Before wrapping of GFRP, epoxy resin was applied on the specimens, so that GFRP will be tightly wrapped along the outer surface of columns. Application of epoxy resin was done with a soft and fresh paint brush. After binding of GFRP laminates, compression behaviour of retrofitted was tested and was compared with the strength of sample columns.

Chapter 7

Results and discussion

To determine the accurate compressive strength of the columns, average of three samples was taken for every reading. The testing of specimens has been performed after curing period of 7 days, 14 days and 28 days for both control and retrofitted columns. From the experimental findings, it is clear that there is increase in load carrying capacity of retrofitted columns.

Table 7.1: Compressive strength of control and retrofitted circular columns after 7 days, 14 days and 28 days.

Specimen (curing period)	Samples	Strength (MPa)	Average strength (MPa)
Control (7 days)	S1	18.58	18.26
	S2	17.94	
	S3	18.26	
Retrofitted (7 days)	S4	23.37	23.05
	S5	22.73	
	S6	23.05	
Control (14 days)	X1	29.16	29.16
	X2	28.48	
	X3	29.84	
Retrofitted (14 days)	X4	34.51	35.90
	X5	36.19	
	X6	37.01	
Control (28 days)	Z1	34.70	33.91
	Z2	33.12	
	Z3	33.91	
Retrofitted (28 days)	Z4	44.07	42.58
	Z5	42.58	
	Z6	41.09	

Table 7.2: Compressive strength of control and retrofitted rectangular columns after 7 days, 14 days and 28 days.

Specimens (Curing period)	Samples	Strength (MPa)	Average strength (MPa)
Control (7 days)	S1	17.89	17.89
	S2	18.58	
	S3	17.22	
Retrofitted (7 days)	S4	23.83	22.83
	S5	21.76	
	S6	22.83	
Control (14 days)	X1	25.84	26.27
	X2	26.25	
	X3	26.66	
Retrofitted (14 days)	X4	32.78	33.32
	X5	33.32	
	X6	33.86	
Control (28 days)	Z1	31.48	32.41
	Z2	33.34	
	Z3	32.41	
Retrofitted (28 days)	Z4	38.76	40.13
	Z5	41.5	
	Z6	40.13	

From the table 7.1, there is increase of 20.78% and 18.77% of compressive strength in circular retrofitted specimens after 7 days and 14 days respectively. There is 20.36% of increase in compressive strength of circular retrofitted columns after 28 days as compared to control specimens.

From the table 7.2, there is increase of 21.63% and 21.15% of compressive strength in rectangular retrofitted columns after curing period of 7 and 14 days as compared to the control specimens. There is 19.23% of increase in compressive strength of rectangular retrofitted columns after 28 days. Therefore there is increase in the load carrying capacity of columns when they are retrofitted.

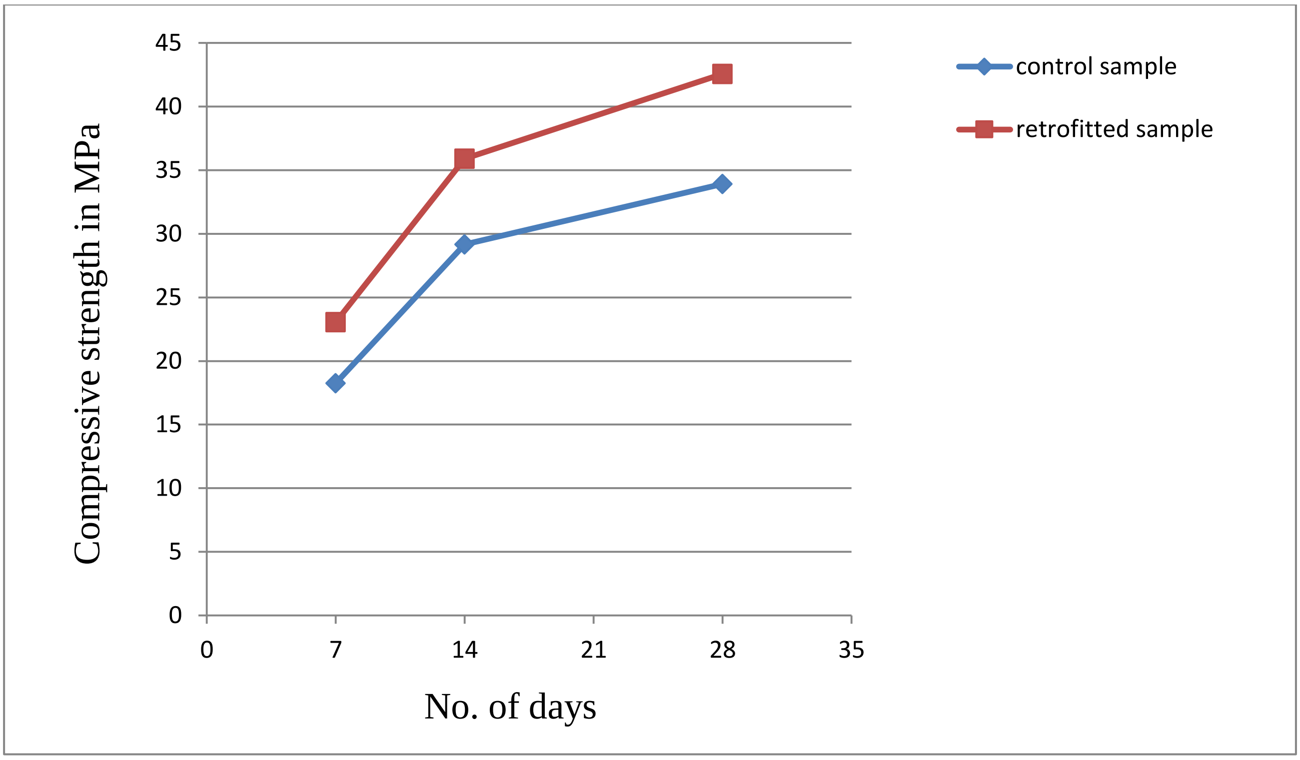


Figure 7.1: variation of compressive strength of circular specimens after 7days, 14 days and 28 days

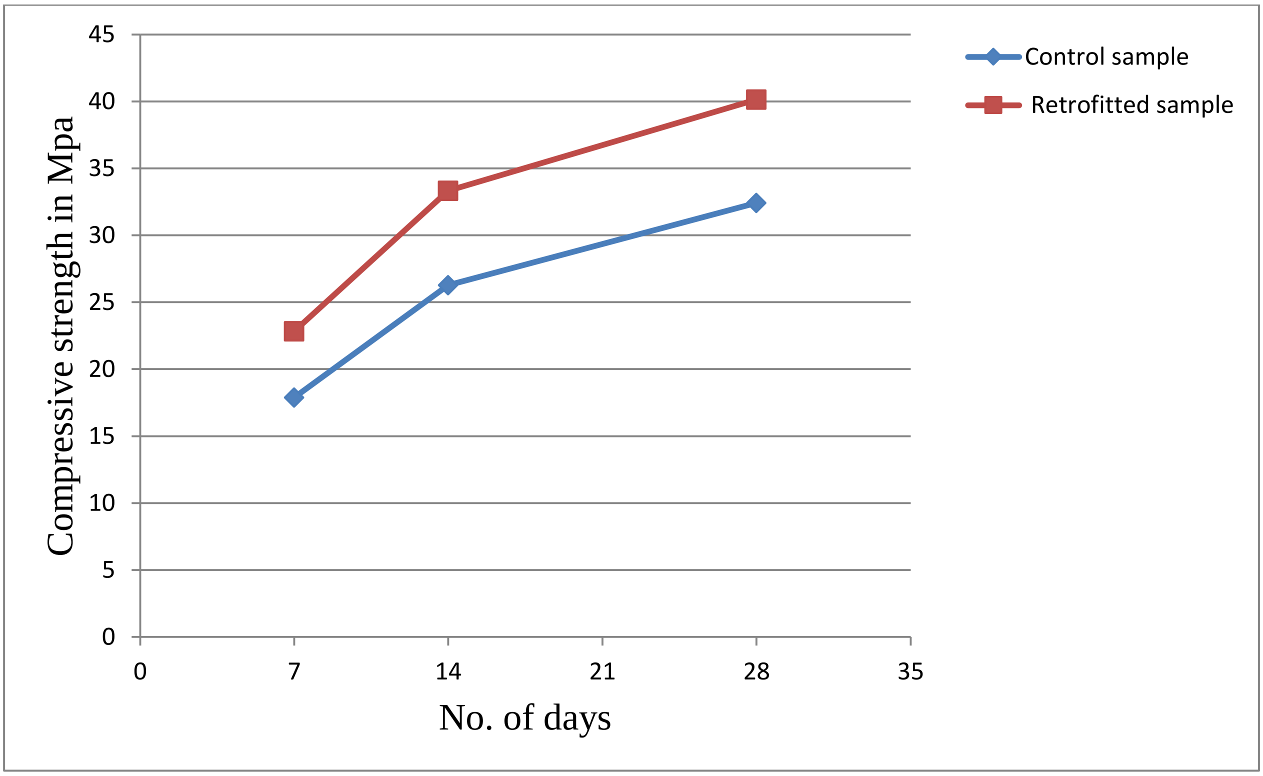


Figure 7.2: variation of compressive strength of Rectangular specimens after 7 days, 14 days and 28 days

The load carrying capacity of retrofitted columns is more than the control specimens. From figure 7.1 and figure 7.2, it is shown that circular retrofitted columns is having higher capacity to carry loads effectively than retrofitted rectangular columns. Load carrying capacity of retrofitted circular columns is 20.36% after 28 days, while as the compressive strength of retrofitted rectangular columns is 19.23% after curing period of 28 days. It is because of air entrapped in case of rectangular columns while wrapping the GFRP sheets, usually at the corners. Also the bond between the GFRP laminates/sheets at the edges is less strong as compared to circular columns. After curing period of 7 days, load carrying capacity of specimens is less than 20MPa for both circular and retrofitted columns, but after retrofitting with GFRP laminates, load carrying capacity has increased up to 23.05MPa and 22.83MPa for circular and rectangular columns respectively. From figure 7.1 and figure 7.2, it is clear that the compressive strength of retrofitted columns is always high than that of control columns.

Figure 7.3: Retrofitting of specimens

Chapter 8

Conclusions and Future Scope

Conclusions: The retrofitting plays an important role in enhancing the overall strength, stiffness and load carrying capacity of the structure. By the definition of retrofitting, there should be re-strengthening in the structure. Following are the outcomes from my experimental study:

1. GFRP sheets can provide improvement in the strength and stiffness of the RC columns. For curing period of 7 days, average strength of specimens gets increased by more than 20% for retrofitted columns. After curing period of 14 days, average strength of retrofitted columns has been increased by 18.77% and 21.15% for circular and rectangular columns respectively
2. For retrofitted circular columns, there is 20.36% increase in the load carrying capacity after curing period of 28 days. For retrofitted rectangular columns, there is 19.23% increase in the compressive strength after curing period of 28 days.
3. Epoxy is one of the best resins for the purpose of retrofitting because of its good tensile and adhesive properties.
4. Wrapping of GFRP laminates at the top and bottom edges is very beneficial for the purpose of retrofitting than wrapping of GFRP at the centre.
5. Crack formation of retrofitted specimens is very less after failure than the control columns.
6. Retrofitting technique is very easy for circular columns as compared to the rectangular columns.

To increase the strength and stiffness of a collapsed or damaged RC structure, technique of retrofitting is one of the best ways, because load carrying capacity of retrofitted columns is much more than that of control columns.

Future scope of study:

As a reasonable other option to tedious lab tests, numerical and analytical techniques have pulled in broad consideration in research group and also in industry. The most comprehensive approach is to model each column in a RC structure and this can be achieved by the application of finite element method. Important material properties of column subjected to various loading combinations can be analysed by the method of strain energy approach.

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