A COMPARATIVE STUDY ON EFFECT OF DIFFERENT MATERIALS FOR RETROFITTING OF CONCRETE COLUMN

Submitted in partial fulfillment of the

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In

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By

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DECLARATION

I, **MANDAKARUHI RYMBAI (11206511)**, hereby declare that this thesis report entitled **"A COMPARATIVE STUDY ON EFFECT OF DIFFERENT MATERIAL FOR RETROFITTING OF COLUMNS"** submitted in the partial fulfillment for the requirements in the award of degree of Master of Civil Engineering, in the School of Civil Engineering, Lovely Professional University, Phagwara, is my own work. The material included in this report has not been submitted to any other university or institute either in part or in full for the award of any degree.

Date: **MANDAKARUHI RYMBAI**

Place:

CERTIFICATE

Certified that this project report entitled "**A Comparative Study on Effect of Different material for Retrofitting of columns**" submitted individually by student of School of Civil Engineering, Lovely Professional University, Phagwara, under my Supervision has been carried out the work in order to obtain the Award of Degree. This Report has not been Submitted to any other university or institution for the award of any degree.

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ABSTRACT

Aged important structures are likely to be affected by the variable load or the change in the environment circumstances such as effect due to earthquake load, wind load and other unpredictable factors. Rehabilitation of such structure will cost a lot and the alternate way to reduce that cost is by choosing the structure to be strengthening with various type of strengthening technique using different material. One of the best technique used is by wrapping different material from the external surface. Retrofitting of material is a widely-used method and has been followed since long time back especially during this time period where natural calamities can happen anytime anywhere, so people are likely being aware with their structure condition. The retrofitting material being used here are steel jackets, elastic tapes, rubber tubes and glass fiber reinforced polymer(GFRP) with epoxy resin as adhesive. The concrete column used is having the dimension of 80mmX80mmX300mm a type of short column. The wrapping location tested at two specific places- first wrapping done at the distance 100mm from both edges of the columns and in the second the wrapping location done 100mm to 200mm distance of the column i.e.at the center of the column. The columns are both end fixed and two grade of concrete used for the tested columns i.e.M20 and M25. The cracking load that can be absorb by the columns were tested by using digital compressive testing machine. The rate of loading applied was 0.7KN/sec and each grade of columns tested on 28days curing into three category- first categories were the standard columns, the second category in which the columns were first subjected to the compressive load then retrofitting done after subjecting to load for the second-time testing and the third category in which the retrofitting of columns was directly followed after its 28days curing then the columns were subjected to the compressive load. The results obtained were being simulated into the ANSYS software and the finite element analysis is done which gives similar result as compared to the experimental values.

Keywords: *Retrofitting, cracking load, GFRP, steel jackets, elastic tapes, rubber tubes, epoxy resins, ANSYS.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Background

Today's generation where the earthquake is very prone to happen, it is very important to make sure that the building or any other important structure should be on the safe side. For safety purposes rehabilitation of such structure needs to be done which can cost a lot. To reduce the cost, Retrofitting is one of the best way adopted in civil engineering to strengthen the members of such structure which have deteriorated its strength due to relaxation with age or due to exposure to excess load and critical condition cause by manmade and natural calamities. Retrofitting, from the name suggest, means to add external material to the structural member which was not constructed initially with the members so as to strengthen the member of that structure. It can be done by wrapping the confinement material from the external surface fully or in part depends on requirement. The materials that were usually used for retrofitting are composite material of Steel jackets, Fiber Reinforced Polymer (FRP) of glass, carbon, aramid fiber; and concrete jacketing. Retrofitting using material like FRP and concrete jacketing need some adhesive material to form the bond between the concrete and the new material. In such cases, the adhesive that were usually used were resins such as epoxy resin, vinyl ester, unsaturated polyester, phenolic prepreg and inorganic binders. Some of these binders may be able to give strength in dry condition but not being able to work properly in wet condition. Therefore, depending on the condition of the environment that the structural member will be subjected resins need to be chosen wisely.

Base on the mentioned background the material chosen for retrofitting in this project are GFRP (Glass Fiber Reinforced Polymer), steel jackets, rubber tubes and elastic tapes with epoxy resins as interfacial binder. GFRP and Steel jackets have been chosen here in order to compare the properties of the newly introduced material elastic tape and rubber tubes. Since as we have seen from the previous study that GFRP and Steel jackets were among the best material for retrofitting. So, in this project with the properties of these highly material we would like to check whether the newly introduced material will be able to give comparable results or not.

1.2 About the retrofitting material

GFRP (Glass Fiber Reinforced Polymer)- Glass Fiber Reinforced Polymer or GFRP is fiber polymer sheet made up of glass fiber. These are possessing low modulus of elasticity and high stiffness. Its high stiffness properties strengthened the column but its low modulus decreasing the ductility of the concrete. It is one of the cheap and good material among the FRP family.

Steel jacket- Steel jackets is a plate sheet made up of steel plate by joining from three corner by welding/curving from three sides and bolt at the fourth side. It is a little bit costly, depending on its thickness, the more the thickness the higher will be the cost. It enhances the column strength better but need to be keep proper maintenance from the corrosion attack.

Elastic tape- Elastic tape is the material made up of nylon fiber. These are usually used for weaving and making chair, bed etc. This can add to the aesthetic purpose of the structural member if it will be able to produce a favorable strength enhancement of the deteriorated structure.

Rubber tubes- Rubber tubes are the air tube obtained from the wastage of wheel tire. Most of the time these materials are just dumped to the environment but they do not decompose as well. However, if these materials will be able to reach the favorable strength enhancement then the future used of these material in retrofitting will help recycle the material and reduce the cost of environmental pollution.

Epoxy Resins- The epoxy resin used here is the readymade resins sold in the market by the name Araldite. It is the standard Epoxy Adhesive whereby the resin come in one pack with the hardener in the ratio of 5:4 by weight or the mixture will be 1:1 by volume. The reason behind choosing this particular resin due its availability and cost effective.

Figure 1.1 Epoxy Resin

Figure 1.2 Steel jackets

Figure 1.3 GFRP

Figure 1.4 Elastic tape

Figure 1.5 Rubber tubes

1.3 Member Description

The structural member chosen in this project is the square column of size 80mmX80mmX300mm with fixed end condition from both side. The process of wrapping will be strip wrapping and there will be comparison between the two location. First location will be strip wrapped at the center (100mm to 200mm location of column) and the second location will be strip wrapped at both the edge (100mm from both end) of the column. The strip wrapping will be one layer for GFRP and steel jacket, whereas for rubber tubes and elastic tapes it will be done in two layers. The column will be tested in three ways, standard column, strengthened column and retrofitted column consisting two columns each for both grade of M20 and M25.

CHAPTER II

TERMINOLOGY

FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
CFRP	Carbon Fiber Reinforced Polymer
mm	Milli meter
ACI	American Concrete Institute
D	Diameter
%	Percentage
m	meter
TRM	Textile Reinforced Mortar
DFRP	Dyneema Fiber Reinforced Polymer
LVDT	Linear variable differentially transformer
KN	Kilo Newton
hrs	Hours
IS	Indian Standard
Kg	Kilogram
gm	gram
Kg/m^3	Kilogram per meter cube
MPa	Mega Pascal
ml	Milliliter

CHAPTER III

REVIEW OF LITERATURE

[1] P. Feng, X.Z. Lu & L.P. Ye, (June, 2002)

In order to check the property of retrofitted column wrapped with GFRP and CFRP, the author performed experimental analysis and finite element analysis with the help of ANSYS software. ANSYS software was found to be a good platform for checking the stress-strain property as well as other results as it can create various models subjected to various condition. The results obtained from experimental test have been compared with that of the finite element analysis and the comparison was able to put the contrast for plotting the required graph. In this research, the experimental test was performed on five specimens which were of control column, columns wrapped with GFRP of different layer and CFRP. Full surface wrapping was done with the help of resin and the reinforcement used was 10mm diameter longitudinal bars and three 6mm diameter hoop bars which were placed at an interval of 200mm. To measure the compression load and the axial deformation, forced sensor was placed at the top of the specimen and two symmetrically placed extensometers fixed at two sides of column together with ten strain gauge on the fiber sheet surface respectively. The load-displacement curve obtained was divided into three phases base on the state of stress. After that the model was design in ANSYS using SOLID65, LINK8 and SHELL41, column fixed at both end and uniform compressive load which was applied with the condition that the column satisfy displacement coordination at all joints of element. After the comparison of result it was found that the contrast in all cases of columns were less than 10%. Towards the end, the author performed the Stress-Strain analysis and concluded that the radius at the corner of the column was the parameter which can determined the constrain and the stress zone. Moreover, it was concluded that the finite element analysis using ANSYS proves to be good for studying the behavior of the column.

[2] Yan Xiao, M. ASCE, and Hui Wu (June 1,2003)

For the structure consisting various size of columns, to stay safe from shear failure and to enhance its ductility, the experimental test was conducted by the author in this paper using different method of retrofitting with partially stiffened steel jackets. The samples were constructed base on the design done with the help of ACI 318 code (1999). Five samples were made, first one was control specimen, the second was retrofit with rectilinear steel jacket, third, fourth and fifth specimens were retrofitted with thick steel plate, angle plate and square tubes respectively, in addition to rectilinear steel jacket. Columns were of 1,016mm height and 254mmX254mm cross section. D16 and D6 longitudinal bar and hoop bar were used respectively with hoop spacing 254mm. The load was applied in such a way that the axial load remains constant and the lateral forced was applying in a cycle of different drift ratio at max 8%. On doing the test it was found that all the columns with rectilinear steel jacket enhance the shear strength as compared to that of control column. But when it comes to ductility the column that was retrofitted with only rectilinear steel jacket fails to improve the ductile behavior and it can bear the cycle load only up to 4% drift ratio whereas those with additional plates, angle plate and square tubes enhance the ductile behavior of column to greater extend. In this paper, the author has also derived the equation for finding thickness of confinement element.

[3] Guoqiang Li, Samuel Kidane, Su-Seng Pang, J.E. Helms, Michael A. Stubblefield (2003)

In this paper, the parametric study of column retrofitted with FRP was done with the help of finite elemental analysis using ANSYS. Parameters such as the effect of thickness, stiffness, fiber orientation and interfacial bonding of FRP with the concrete surface were studied. The analytical model was constructed by using SOLID65 and SHELL99 with bottom surface lie on the x-y plane and extend in the z direction. The load was applying in such a way that it started from zero and gradually increase up to predefined load. Nonlinear analysis was performed and there was a sharp break at the failure of the concrete. The experimental model used two types of bonding material- epoxy and E-glass fabric reinforced phenolic prepreg which took 24hrs at room temperature and 1.5hrs at 135^{o}C to cure respectively. 8columns were casted, cured and tested on 28days. Split tensile test was performed on 6 columns before retrofitting so as to control the damage in a better way. The columns then retrofitted by using epoxy and E-glass fabric reinforced phenolic prepreg which then subjected to compressive loading to check for its compressive strength and modulus of elasticity. The results obtained was then compared with that from the analytical model and it was found that the result were very close to each other therefore finite element analysis was then chosen to perform the parametric analysis. With this analysis, it was found that stress strain curve was divided into three parts, the first part where the effect of interfacial bonding is minimal the load was taken by the concrete and the effect of confinement was insignificant, the second part was the transition part in which the concrete continues to damage with the increase in load till it reach the third part where the load was fully taken by the confinement until it reaches its ultimate point. In addition to this, it was observed that the interfacial bonding and the modulus of elasticity of FRP has a greater impact on strength and stiffness of columns. Also, with a strong interfacial bonding the thickness of FRP will further create an impact on strength and stiffness enhancement. From this, it was concluded that the fiber orientation in axial direction is better than hoop direction.

[4] D.A. Bournas and T.C. Triantafillou (October ,2008)

Apart from FRP the author want to find an alternative material in order to compensate for the weakness cause by FRP like when there's a need to retrofit in wet area, at high temperature and post-earthquake assessment. For this purpose, the study in this paper used two material TRM (textile reinforced mortar) and FRP for comparison. Textile reinforced mortar is a fabric made of woven or knitted in two direction impregnated in inorganic base such as cement mortar. In this paper, the author used column structural member of cantilever type dominated in flexure. With cross section of 250mmX250mm and point of application of load at a height of 1.6m supported upon the base of 1.2mX0.5m of depth 0.5m deep such that the longitudinal bar anchored at a 90^o hook from the bottom with the base. The experiment used 13samples, 6 of them with lap slice bar and 7 with continuous longitudinal bar, out of these 3continuous bar sample used smooth bar and 4continuous bar sample used deformed bar. Two specimen were tested as control specimen, the next pair were retrofitted with two layers CFRP, the other pair were retrofitted with an equal strength and stiffness TRM as compared to CFRP and the last specimen was retrofitted with low stiffness and strength glass fiber TRM jackets. The specimens were subjected to the constant axial load which was 28% of the member compressive strength and to a lateral cyclic load which was test by using MTS actuator placed horizontally. Strain gauge was used to measure the strain distribution of the longitudinal bars and rectilinear displacement transducer was used to measure the strain at the plastic hinge region and the displacement. The test was performed and it was found that the ability of TRM to handle the cyclic deformation and the energy dissipation was comparable to that of FRP which the author concluded that TRM could be the other alternative of FRP for strengthening the weak structure to prevent from seismic failure.

[5] Ahmed EI-Badawy Sayed (May 2009)

To improve the method of jacketing confinement the author here used steel jacket in a new way to retrofit the column and that was by retrofitting using sheets of steel jacket to confine the column from the outside. In this paper, the author used three shapes of column circular, rectangular and square of 1:2:4 concrete ratio with 8mm longitudinal bars and 6mm stirrups. The columns were categorized into three groups, the first group consisted of 8 control columns out of which 2 for rectangular control column, two for square control column, two for spiral circular control column and two for closed loop circular control column. Similarly, the second group was the retrofitted group consisted of 8columns two for each type and in this group the columns were first subjected to the cracking load then confinement was done to retrofit the crack obtain then again, the columns were subjected to the second-round load whereas the third group was the strengthened group in which the column was directly retrofitted with steel jacket without subjecting to prior load. In the same way third group as well consisted of 8columns with two columns of each types The columns here were subjected to direct axial load and the capacity to handle more crack load and deformation was evaluated. From here, it was observed that the retrofitted and strengthened columns with rectangular and square geometry was able to enhance the strength of control column up to 20-30% respectively. Also, those of circular strengthened column was able to enhance the control up to 50%. With the results obtained from the experiment the author concluded that the used of steel jackets for retrofitting brought a marvelous enhancement in the strength and stiffness of the aged columns which can be used for further requirement.

[6] Dong-Sheng Gu, Gang Wu, Zhi-Shen Wu and Yu-Fei Wu (October 1,2010)

With the advancement of retrofitting technique using FRP the author here wanted to check the effectiveness of FRP retrofitted subjected to simulated seismic load. In this paper, the author was doing experiment on 17 concrete circular columns which were subjected to constant axial load and cyclic lateral load displacement. Two types of circular used with two different diameter 360mm and 300mm. Two types of FRP used CFRP (Carbon Fiber Reinforced Polymer) and DFRP (Dyneema Fiber Reinforced Polymer) having different thickness and different number of layers. Lateral force was applied using the MTS actuator and the lateral displacement was measured by using LVDT (Linear variable differentially transformer). On performing the experiment, it was observed that the axial load was effected by the drift ratio and aspect ratio. The more the aspect ratio the higher is the ultimate drift ratio. As the number of cyclic load increase it can affect the deformation capacity of column to a greater extend. The amount of energy dissipation increase with the increase in the number of confinement layer however after exceeding the critical value the increase in confinement layer would decrease the energy dissipation capacity of the column.

[7] Tara Sen, H.N Jagannatha Reddy, Shubhalakshmi B.S (2012)

Different matrix could be used to make GFRP and for this to check the efficiency of resins the author in this paper was doing researched on two types of bonded FRP and those were Vinyl Ester bonded GFRP and Epoxy bonded GFRP. These materials were used as composite for retrofitting the RC beam in order to check the enhancement in shear strength property using these materials. 12samples were constructed, four were used as control specimen and four samples for each type of GFRP bonded out of which two samples were fully wrapped and two were strip wrapped. The samples were subjected to shear test under simply supported condition and it was observed that both type of GFRP bonded enhanced the shear strength of the control column to a better extend. In comparison between the type of wrapping it was observed that strip wrapping give better results as compare to that of the full wrapping the reason behind was that incase of strip wrapping the wrapping was able to exhibit the growth of crack as it was specifically wrapped at a particular location. Moreover, the study of comparison shows that the vinyl ester bonded GFRP samples enhance the strength more than that of epoxy bonded GFRP which was concluded that vinyl ester was better than epoxy but in term of cost analysis vinyl ester is a bit costly compared to epoxy.

[8] Jinsup Kim, Minho Kwon, Wooyoung Jung, Suchart Limkatanyu (2013)

To prevent the aging structure from collapse at the time of earthquake attack, column due to its weak point in shear failure needs to be studied for enhancing its shear strength. In this paper, the author was trying to enhance the shear strength of column by retrofitting with the GFRP strip having aluminum clip connector. The composite was designed in such manner that it will failed at the composite portion rather than at the aluminum part. Five sample of 1000mm length with 300mmX380mm cross section area was constructed. The specimens were attached by the loading block of size 400mmX380mmX400mmfrom the top and 900mmX980mmX600mm stub from the bottom end which were constructed monolithically. Out of these five samples, two samples were of control specimen, one of which subjected to axial load and the other was subjected to the cyclic lateral load. The other three samples were strengthened with different width of GFRP. Linear variable differential transformer(LVDT) with strain gauge was attached to each specimen to measure the lateral displacement. After performing the test, it was found that the two control samples were able to satisfy the target shear strength and flexural capacity of the designed column, and for the retrofitted specimen, as the strip of GFRP width increase the shear strength of the column was enhance to a greater extend and the columns were able to absorb more cyclic lateral load as compared to that of the control specimen. Numerical analysis was performed with the help of ABAQUS software and it was found that the experimental values and the analytical values give close result which leads to the conclusion that the proposed composite of GFRP with aluminum clip connector was found to be satisfactory and for further analysis improve analytical model need to be study.

[9] Ugale Ashish B and Raut Harshalata R (2014)

To check the superiority of FRP, the author chose another part of structural member to test the effectiveness of FRP and that member was the beam column joint. In this paper, the author was trying to check the effectiveness of FRP for strengthening beam column joint. For this, both experimental and analytical test was performed by using prototype beam and column of size 305X460 and for testing model the size of beam used was 120X170mm with length 450mm and column of size 120X230mm with height 600mm. the load applied in forward and reverse cycle and out of every 3KN cycle load, deflection was checked by using LVDT. After testing with the cyclic load the crack was filled by the glass paste mixed with the unsaturated polyester resin then later on the GFRP was cut into a definite shape and it was paste on the surface of the beam-column joint right after the applying of resin. Finite element analysis was performed using STAAD Pro.

and ANSYS software. The model and load was simulated into the software and it was observed that similar to the experimental study, the maximum stresses occurred at the junction. From here, it was concluded that the analytical result was given similar values with that of experimental study and it was found that the load carrying capacity of retrofitted column is 6% more than that of control column. However, it was observed that on applying seismic load the control specimen failed at the column portion of the specimen which needs to be avoided whereas the retrofitted specimen failed at the beam portion which will prevent the structure from progressive collapse and this proves the enhancement of FRP retrofitting at another structural member as well.

[10] Prof. Ankush R Pendhari, Udayan Doifode (2015)

A part from studying the effect of confinement stiffness and orientation, one more important condition needs to be study is the layer of wrapping. In this paper, the author studied the effect of singly and doubly wrapping of GFRP for retrofitting the M30 grade column. The GFRP used was of E-glass material and the resin used was epoxy polyamine. Two aspect ratio columns were used, square and rectangular or in other word 1:1 and 1:1.5 aspect ratio. In 1:1 aspect ratio 6 columns were casted 3 for singly wrapping and 3 for doubly wrapping. Similarly, for 1:1.5 aspect ratio 3 columns were tested for singly wrapping and three columns for doubly wrapping. On doing the compressive strength test, it was observed that the wrapping-column give better results to control-column and the square column was more effective as compared to rectangular column. Moreover, the column with doubly wrapping gives more strength as compared to that of singly wrapping. From here it was concluded that the column decrease its strength when the aspect ratio increase from 1 to 1.5 and also the layer increase the strength of column with the increase in number.

[11] Vikrant S Vairagade, Dr. ShriKhrishna Dhale, Dr. Patel Rakesh (February 2016)

As we study further, comparative study in between two types of FRP needs to be check and in this paper the author was trying to check the efficiency of CFRP and GFRP with a parametric study using ANSYS software. In this paper, the author was doing experiment on a circular column of 300mm diameter and 3m length. Grade of concrete chosen was M25 with poison ratio of concrete 0.2 and that of steel reinforcement 0.3. Fe415 was using with 8no 16mm diameter longitudinal bars, thickness of FRP was 0.5mm throughout. The model chosen used SOLID65 for control column and SOLID 46 for FRP retrofitted column. The thickness of CFRP was varying from 3mm to 6mm and it was found that CFRP of thickness 4mm gives the optimum strength. Beyond that the strength start decreasing due to the fact, that the brittleness of CFRP increase with the increase in thickness. It was observed that the load was maximum at the top and decrease to zero at the bottom due to fixed end condition at the bottom. From this paper, it was concluded that the used of CFRP and GFRP are both effective depending on the area required. This means CFRP can be used in the field where higher strength is the key requirement as compared to ductility and GFRP can be used in the field where higher ductility is consider more important than the strength. The reason behind was that, GFRP enhance more ductility as compare to strength due to its low modulus whereas CFRP enhance more strength as compared to ductility. Despite of the enhancement of FRP, their used need to be taken into precaution since they possess brittle nature.

[12] Anurag Chaturvedi & R.D. Patel (May ,2016)

Considering other retrofitting method with other structural member, here the author was applying jacketing method on beam in order to enhance the flexural strength of the beam. In this paper, the author used epoxy resin as the adhesive material and retrofitting is done by concrete jacketing. Three samples were tested as control sample and three samples as retrofitted samples. The size of beam used was 1800mm length 150mm height and 100mm width with effective length of 1675mm. Control samples were tested for 3days ages and 28days age whereas retrofitted samples were tested for 28days age only. The retrofitted samples were prepared by placing the beam inside the mould and removing the concrete 430mm length from the central part of the beam and then the surface was clean to be free from all the loose material then was applied by epoxy resin. After the epoxy resin dries up new concrete material was placed into three layers with the help of plane table vibrator. The samples were allowed to settle for 24hrs and then curing was done. Testing was done by applying gradual increase load on compression testing machine and the load deflection curve was plotted which was observed that the retrofitted beam was able to carry out only 75% load of that carried by control beam. The reason behind was the applying of epoxy as adhesive and therefore, the bond form between the old and new concrete took time to fully recover its flexural strength.

CHAPTER IV

RATIONALE AND SCOPE OF THE STUDY

Apart from the chosen view, the process of retrofitting can be done in many other ways. The effect of wrapping location, the shape of the structural member, the layer of confinement, the strength of retrofitting material, the ability to form strong interfacial bond, the orientation of fiber material, the cost of the retrofitting material, the point of application of loads, the finite element analysis using other software and many more parameters, all of these needs to be checked separately. With the ability to study all these parameters it will be beneficial for the society to have more alternatives of retrofitting material as well.

CHAPTER V

OBJECTIVES OF THE STUDY

- Determination of the compressive strength of column retrofitted with GFRP, Steel jackets, Elastic tapes and rubber tubes.
- To compare the compressive strength obtained by retrofitting using the above four materials with the standard column.
- To check the effective location for retrofitting.
- To compare the effective result obtained among the four materials.

CHAPTER VI

MATERIALS AND RESEARCH METHODOLOGY

To study about the impact on material by any additional material, it is very important to know its original properties. Same thing followed here, before analyses the impact of retrofitting and strengthening on the column, the original properties of material need to be investigated properly. The properties and the methodology of the research material used here, have been studied into two heads (a)Physical Properties and (b)Mechanical Properties

6.1. Physical Properties: Various physical properties of cement, sand, aggregate have been studied according to Indian Standard Code. For cement the physical properties studied were soundness properties, consistency and setting time, fineness and specific gravity. For aggregate the properties investigated were sieve analysis, water absorption and specific gravity whereas that for sand were sieve analysis and specific gravity.

6.1.1. Properties of Cement

The cement used in this project is Portland pozzolana cement and according to IS 1489 (part 1) the properties of this cement shall be test in accordance to its mentioned IS code. The test have been done accordingly and the results have been compared with the mention IS code as follows:

Consistency and setting time test of cement: The main aim of this test is to check the percentage of water which give the standard paste to the cement. This test was performed according to IS 4031(part 4)-1988 using Vicat apparatus. The percentage of water tested was taken starting from 28% then increasing 2% at a time till we get the percentage of water which will give 5-7mm penetration of plunger from bottom of the gauge. According to IS 4031(part5)-1988 after getting the consistency of the cement new sample was taken and mixed with 0.85times consistency water to give a standard paste. The stopwatch starts from the point where water was added to the cement till the needle give a penetration of around 5mm penetration from bottom of the mould and then noted as initial setting time and the time up to which the needle make only impression on the surface was noted as final setting time. The needle used for initial setting time was different from the needle used for final setting time followed according to IS code.

Figure 6.1 consistency test

Figure 6.2 Initial setting time

Figure 6.3 Final setting time

Soundness: soundness test shows how much contraction the cement may exhibit. According to IS 4031(part 3):1988 in which the apparatus confirmed to IS 5514:1969, the test performed by gauging the cement with 0.78times the water consistency of the specific cement. The test used Le-Chatelier apparatus in which the cement paste formed were put into it by covering with glass cover from top as well as bottom together with a heavy metal cover from top and it was kept in water for 24hours and then was taken out to measure the distance d1 and again was submerge in water bath of 25 to 30 degree boiling for 3hours then the again taken out to measure the distance d2. The soundness of cement will be calculated by the formula (d2-d1). According to the code it should be less than 10mm.

Figure 6.4 soundness test

Fineness test: Fineness test of a cement was performed according to IS 4031(part 1):1996. Here the cement taken was sieve through a 90micron sieve for about 15minutes.After sieving the weight of the retained material was measured. According to the code the percentage weight retained should be less than 10%.

Figure 6.5 Fineness test

Specific gravity: The specific gravity of cement was test by using Le Chatelier flask and the nonpolar solvent used was diesel of specific gravity 0.82 confirming to IS 1489 (part 1):1991.

Figure 6.6 Specific gravity test of cement

6.1.2. Properties of coarse aggregates

Sieve Analysis of aggregates: The aggregate was allowed to pass through sieves size of 31.5mm, 25mm, 20mm, 26mm, 12.5mm, 10mm, 6.3mm, 4.75mm after drying in oven at a temperature of $110^{o}+5^{o}C$. Then the cumulative weight was calculated according to IS 2386(part I)-1963.

Figure 6.7 sieve analysis test of coarse aggregate

Specific gravity and water absorption: These properties of aggregate were check by following the code IS 2386(part III)-1963.

Figure 6.8 water absorption test of coarse aggregate

6.1.3. Properties of fine aggregates

Fineness modulus: This property was check by doing sieve analysis test according to IS 2386(part I)-1963. The fine aggregate was allowed to pass through the sieve size of 4.75mm, 3.35Mm, 2.36mm, 1.18mm, 600micron, 300micron, 180micron, 90micron and 75micron.

Figure 6.9 Fineness test of fine aggregate

Specific gravity: This property was check by using pycnometer apparatus followed according to IS 2386(part III)-1986.

6.1.4 Properties of retrofitting material

The properties of retrofitting material GFRP, Steel jackets, Rubber tubes and Elastic tapes have been taken from the standard value according to the previous researched paper. The properties of epoxy resins used was given from the manufacturer.

Figure 6.10 Samples with GFRP, elastic tapes, rubber tubes and steel jackets

6.2. Mechanical Properties: The mechanical properties to be test for concrete are the workability test, compaction factor test which were followed according to IS 1199-1959 and the compressive test according to IS 516-1959 to check the ultimate load carried by the standard column and the effect of retrofitting by different materials confine from the external surface of the column. The test is also for the purpose of comparing the impact of location of wrapping.

6.2.1 workability test: workability test was done by using slump-cone test which was performed according to IS 1199-1959. The mould used was according to the code specification where the mould was placed on a smooth nonabsorbent surface cleaned and applied with oil from its internal surface and concrete was filled into four layers, tamped 25strokes each layer and the mould were removed immediately just after the top layer was levelled and the difference in the height of mould and the highest point of the concrete was measured in term of mm which gives the workability of concrete.

Figure 6.11 workability test

6.2.2 Compaction Factor Test : This test was performed according to IS1199-1959 by which the concrete was placed in the top hopper up to the brim by the closing the trap door then right after filling it up the trap door was opened and the concrete was allowed to fall into the second hopper in the same way which then finally make the concrete to fall into the cylinder. The excess above the top of cylinder was removed and the cylinder was weighted which is term as partially compacted concrete. Then the fresh sample was again placed to the cylinder was in layers and vibration to obtain full compaction in which the cylinder was again weighted and this is term as fully compacted concrete. The ratio obtained between partially compacted concrete to fully compacted concrete is term as compacting factor.

Figure 6.12 compaction factor test

6.2.3 Sample casting : Two grades of sample was casted, M20 and M25. In total 70 samples were there, 35 samples of M20 and 35 samples of M25, each grade contained 3 standard columns, 2 retrofitted columns for each material and each location of wrapping (centre and edge) with each grade and 2 columns strengthened columns for each material and each location of wrapping (centre and edge) with each grade. The column were casted according to the mixed design ratio and the size of column casted was 80mm X80mm X300mm using wooden moulds. The concrete was mixed using rotating machine,placed and compacted manually and then left to set for morethan 10hrs. After the column was set curing was done for 28days and then allowed it to go through the required test.

Figure 6.13 casting of columns

Figure 6.14 setting of columns

Figure 6.15 Before curing

Figure 6.16 curing of columns

6.2.4 Cracking load testing: The test were performed in three category of columns. First category were the standard columns. This column were tested after 28days curing and was marked as the control specimen. Second category were the retrofitted columns. In this category the column was subjected to the axial load till the crack appear in the column then retrofitting was done in two ways, retrofitting at the two edge of columns at a distance 100mm from the end point and retrofitting at the centre of column at a distance 100mm to 200mm. Retrofitting using four material wasdone in the same way, the only different was that when retrofitted with GFRP and Steel jackets the layer was single but when retrofitted with Rubber tubes and Elastic tape the layer was double. Similarly, in the third category the strengthened column retrofitting of four material was done as the retrofitted category and the difference in this category was that the column subjected to axial load directly after wrapping with material without letting it crack at the first place.

Figure 6.17 control column, column with steel jackets at edge and centre

Figure 6.18 GFRP edge and centre column

Figure 6.19 Columns with elastic tape and rubber tubes at edge and centre

CHAPTER VII

CONCRETE MIX DESIGN

With the experimental value of concrete material obtained, the concrete mix design has been derived for two grade of concrete M20 and M25 according to IS 10262:1982. The calculation for the two grade will be shown in separate head as follows.

Table 7.1. Concrete Material

Material	Consistency	Setting time		Soundness	Fineness	Specific gravity	Fineness modulus	Water Absorption
		Initial	Final					
Cement	32%	30mins	510mins	3mm	1.3%	3.13	-	-
Fine aggregate	-	-	-	-	-	2.64	2.11	-
Coarse aggregate 10mm	-	-	-	-	-	2.58	3.5	1.01%
Coarse aggregate 20mm	-	-	-	-	-	2.58	3.5	1.01%

7.1 M20 Mix calculation

Target mean strength = (20+4.6×1.65)

= 27.59 MPa

Selection of water cement ratio: the target mean strength was compared with the graph from figure1 of IS code and from there the water cement ratio obtained was 0.48.

Calculation of water content: Approximate water content for 20mm maximum size of aggregate = 186 kg/m^3

Calculation of Cement content: W/C=0.48

Cement Content = 186÷0.48=387kg/m^3.

Correction table

Description	Adjustment water content (%)	Required % of Sand in total Aggregate
For decrease in w/c ratio (0.6-0.48)		-3
For sand confirming Zone III		-1.5
Increase in compacting Factor	+3	
	+3	-4.5

Assume degree of workability (0.9-0.8) =0.1

The required sand content as percentage of total aggregate by absolute volume =35%-4.5%=30.5%

There is an entrapped air in wet concrete which is 2%.

So, actual volume of concrete after deduction=$1m^3-2\%\times1m^3=1-0.02=0.98$

Now, value of $\rho=30.5\%=30.5\div100=0.305$

For fine aggregates

$V= (w + C/S_c +1/\rho \times f_a/S_{fa}) \times 1/1000$

$0.98= (149 +387/3.13 +1/0.305\times fa/2.6) \times 1/1000$

fa= 561kg/m^3

For coarse aggregates

$V= (w + C/S_c +1/1-\rho \times C_a/S_{ca}) \times 1/1000$

$0.98= (149 +387/3.13 +1/1-0.305\times Ca/2.51) \times 1/1000$

Ca=1234kg/m^3

water	cement	Fine aggregate	Coarse aggregate
149	387	581	1234
0.38	1	1.5	3.2

Again, coarse aggregate id divided into 20mm and 10mm

For 20mm=40% of 1234= 493.6kg

For 10mm=60% of 1234= 740.4kg

Calculation of actual mass of different materials for the sample

Volume of sample taken = 300×80×80

=0.00192

As per 1m^3 calculation

Mass of cement for 1m^3= 387kg

Mass of water for 1m^3= 149kg

Mass of fine aggregate for 1m^3=581kg

Mass of coarse aggregate(10mm) for 1m^3=740.4kg

Mass of coarse aggregate(20mm) for 1m^3=493.6kg

For sample calculation

We take wastage= 2%

Total wastage = 102= 1.02

Therefore, quantity of cement for 1mould= [(387×0.0019) +(1.02) (387×0.00192)] =1.5kg

Quantity of water for 1mould = 0.6kg

Quantity of fine aggregate= 2.25kg/m^3

Quantity of coarse aggregate(10mm) =2.87kg

Quantity of Coarse aggregate (20mm) =1.914kg

7.2 M25 Mix calculation

Target mean strength = (25+5.3×1.65)

= 33.74 MPa

Selection of water cement ratio: the target mean strength was compared with the graph from figure1 of IS code and from there the water cement ratio obtained was 0.43.

Calculation of water content: Approximate water content for 20mm maximum size of aggregate = 186 kg/m^3

Calculation of Cement content: W/C=0.48

Cement Content = 186÷0.43=432kg/m^3.

Correction table

Description	Adjustment water content (%)	Required % of Sand in total Aggregate
For decrease in w/c ratio (0.6-0.48)		-4
For sand confirming Zone III		-1.5
Increase in compacting Factor	+3	
	+3	-5.5

Assume degree of workability (0.9-0.8) =0.1

The required sand content as percentage of total aggregate by absolute volume =36%-5.5%=29.5%

There is an entrapped air in wet concrete which is 2%.

So, actual volume of concrete after deduction=1m^3-2%×1m^3=1-0.02=0.98

Now, value of ρ=29.5%=29.5÷100=0.295

For fine aggregates

$V= (w + C/S_c +1/\rho \times f_a/S_{fa}) \times 1/1000$

0.98= (149 +432/3.13 +1/0.295×fa/2.6) ×1/1000 fa= 532kg/m^3

For coarse aggregates

V= (w + C/S_c +1/1-ρ ×C_a/S_{ca}) ×1/1000

0.98= (149 +432/3.13 +1/1-0.295×Ca/2.51) ×1/1000

Ca=1226kg/m^3

water	Cement	Fine aggregate	Coarse aggregate
149	432	532	1226
0.34	1	1.23	2.8

Again, coarse aggregate id divided into 20mm and 10mm

For 20mm=40% of 1234= 490.4kg

For 10mm=60% of 1234= 735.6kg

Calculation of actual mass of different materials for the sample

Volume of sample taken = 300×80×80 =0.00192

As per 1m^3 calculation

Mass of cement for 1m^3= 432kg

Mass of water for 1m^3= 149kg

Mass of fine aggregate for 1m^3=532kg

Mass of coarse aggregate(10mm) for 1m^3=735.6kg

Mass of coarse aggregate(20mm) for 1m^3=490.4kg

For sample calculation

We take wastage= 2%

Total wastage = 102= 1.02

Therefore, quantity of cement for 1mould= [(432×0.0019) +(1.02) (432×0.00192)] =1.68kg

Quantity of water for 1mould = 0.575kg

Quantity of fine aggregate= 2.06kg/m^3

Quantity of coarse aggregate(10mm) =2.84kg

Quantity of Coarse aggregate (20mm) =1.89kg

Table 7.2. Quantities of material for concrete specimen

Material	Standard specimen		Both Edge wrapping (no of layers X Length X Height X thickness)		Middle wrapping (no of layers X Length X Height X thickness)	
	M20	M25	M20	M25	M20	M25
cement	1.5Kg	1.68kg	1.5kg	1.68kg	1.5kg	1.68kg
Fine aggregate	2.25kg	2.06kg	2.25kg	2.06kg	2.25kg	2.06kg
Coarse aggregate 10mm	2.87kg	2.84kg	2.87kg	2.84kg	2.87kg	2.84kg
Coarse aggregate 20mm	1.914kg	1.89kg	1.914kg	1.89kg	1.914kg	1.89kg
GFRP	-	-	1 X 320mm X100mmX1mm	1 X 320mm X100mmX1mm	1 X 320mm X100mmX1mm	1 X 320mm X100mmX1mm
Steel jackets	-	-	1 X 320mm X100mmX0.2mm	1 X 320mm X100mmX0.2mm	1 X 320mm X100mmX0.2mm	1 X 320mm X100mmX0.2mm
Rubber tubes	-	-	2 X 320mm X100mmX1mm	2 X 320mm X100mmX1mm	2 X 320mm X100mmX1mm	2 X 320mm X100mmX1mm
Elastic tapes	-	-	2 X 320mm X100mmX1mm	2 X 320mm X100mmX1mm	2 X 320mm X100mmX1mm	2 X 320mm X100mmX1mm

CHAPTER VIII

RESULTS AND DISCUSSION

8.1 Result of physical properties of cement

Table 8.1: Consistency of PPC Cement

Percentage of water	Water in ml	Drop measure from bottom
28%	70	23mm
30%	75	17mm
31%	80	10mm
32%	85	7mm
		Cement Consistency =32%

Weight of cement taken initially=250gm

Table 8.2: Setting time of cement

Serial No.	Time taken	Penetration measure from bottom (in mm)
1	0-10	3
2	10-20	4
3	20-25	4.5
4	25-30	6
		Initial setting time=30minutes
		Final setting time =510minutes

Table 8.3: soundness of cement

Serial number	Initial distance(d1)	Final distance (d2)	Soundness(d2-d1) in mm
1.	13	16	3

Table 8.4: Fineness of Cement

Serial Number	Weight taken	Weight retained	Percentage weight retained
1	3oogm	4gm	1.3

Table 8.5: Specific gravity of Cement

Sr. No	Weight of Empty flask(w1)	Weight of flask+ cement(w2)	Weight of flask +Cement +diesel (w3)		Weight of flask + diesel (w4)	Specific gravity= (w2-w1)/((w2-w1) (w2-w4) x0.82)
1	111gm	169gm	400gm		358.5gm	3.13

8.2 Result of physical properties of coarse aggregate

Table 8.6: Specific gravity of coarse Aggregate

Sr No	Weight of basket in water (w1)	Weight of basket +aggregate in water(w2)	Surface dry Weight of aggregate after immersion in water for 24hours(w3)	Oven dry weight of aggregate after 24 hours at 110ºC (w4)	Specific gravity of aggregate =(w3/(w4(w1-w2)))
1	850gm	3250gm	3981.5gm	3941.5gm	2.58

Table 8.7: water absorption of coarse aggregate

Sr No	Weight of basket in water (w1)	Weight of basket + aggregate in water(w2)	Surface dry Weight of aggregate after immersion in water for 24hours(w3)	Oven dry weight of aggregate after 24 hours at 110ºC (w4)	Water absorption = ((100x(w 3-w4) /w3)
1	850gm	3250gm	3981.5gm	3941.5gm	1.01%

Table 8.8: Sieve Analysis of coarse aggregate

Serial no	Sieve size31.5	Weight retained (in gram)	Percentage weight retained	Cumulative percentage passing	Maximum weight allowed as per IS 2386(part I)-1986
1	31.5	0	0	100	2500
2	25	0	0	100	2500
3	20	3	0.75	99.25	2000
4	16	593.5	14.84	84.41	1500
5	12.5	1400	35	49.41	1500
6	10	849.5	21.24	28.17	1000
7	6.3	712	17.8	10.37	750
8	4.75	415	10.38	0	500

8.3 Result of physical properties of fine aggregate

Table 8.9: Fineness modulus of sand

Serial no	Sieve size	Weight retained in gram	% weight retained	Cumulative weight retained	Cumulative percentage of sand retained
1	4.75mm	1	0.05	1	0.05
2	2.36mm	1	0.05	2	0.10
3	1.18mm	15	0.75	17	0.85
4	600micron	1	0.05	18	0.900
5	300micron	1	0.05	19	0.950
6	180micron	640	32	659	32.97
7	90micron	850	42.5	1509	75.49
8	75micron	490	24.5	1999	100
		Total =1999			Total =211.31
					Fineness modulus=(211.31/100) =2.11 Very fine sand

Table 8.10: Specific gravity of Sand

Weight of dry pycnometer=639gm				
Serial No	**Weight of sand+ weight of pycnometer (w)in gm**	**Weight of pycnometer + weight of water (w1) in gm**	**Weight of sand after drying 24hours in oven (w2) in gm**	**Specific gravity= (w2/ (w2- (w-w1)))**
1	1842.5	1459.9	495.5	2.64

DISCUSSION OF CONCRETE MATERIAL

The properties of cement, sand and aggregate obtained is matching with that provided by the specific Indian Standard Code. Therefore, the above material can be utilized for further investigation to make the columns of M20 and M25 of size 80mmX80mmx300mm for the purpose of checking the effect on mechanical properties by retrofitting with different materials.

8.4 Result of physical properties of retrofitting material

Table 8.11 Physical properties of retrofitting material

Material	Young's modulus
GFRP	43GPa
Steel jacket	200GPa
Elastic tapes [13]	13.5GPa
Rubber tubes	5MPa
Epoxy Resin [14]	2GPa

8.5 Result of workability of concrete

Table 8.12 Workability of concrete

Concrete Grade	Height of the cone, H1 (in mm)	Height of the slump, H2 (in mm)	Workability, (H1-H2) (in mm)
M20	300	250	50
M25	300	256	54

8.6 Result of compaction factor of column

Mass of cylinder=720gm

Table 8.13 compaction factor of concrete

SL No.	Water-cement ratio	Mass with partially filled concrete, W2 gm	Mass with fully compacted, W3 gm	Mass of partially compacted concrete, (W2-W1) gm	Mass of fully compacted concrete, (W3-W1) gm	Compaction factor = (W2-W1)/(W3-W1)
1	M20	16.5	18.74	8.95	15.54	0.77
2	M25	17.2	19.1	10	11.9	0.84

8.7 Result of cracking load of column

The specimens have been tested where the average load of control column for M20 was found to be 70.4KN and that of M25 was 86.8KN. Some specimens as shown in the table were directly retrofitted right after 28th day curing whereas some specimens were allowed to be subjected to the load just after their 28th day curing then retrofitting were done after applying load.

Table 8.14 Cracking load of columns

Material	Location of wrapping	Load for directly retrofitted specimen M20 (KN)	Load for retrofitting specimen after applying load M20 (KN)		Load for directly retrofitted specimen M25 (KN)	Load for retrofitting specimen after applying load M25 (KN)	
			Before retrofitted	After retrofitted		Before retrofitted	After retrofitted
GFRP	Middle	85.1	50	24.1	96.1	44.5	31.2
	Both edge	57.5	58.3	50.7	99.8	92.7	69
Steel jackets	Middle	71.9	41.1	18.6	60.7	61.1	45.8
	Both edge	64.7	49.2	35.2	66	86.8	63.2
Rubber tubes	Middle	54.3	36.7	36.2	61.8	53.5	17.5
	Both edge	65.4	30.2	22.5	73.2	47.2	21.8
Elastic tapes	Middle	64.6	61.9	48.3	29.5	53.3	29.8
	Both edge	70.4	57.8	30.6	45.9	57	37.9

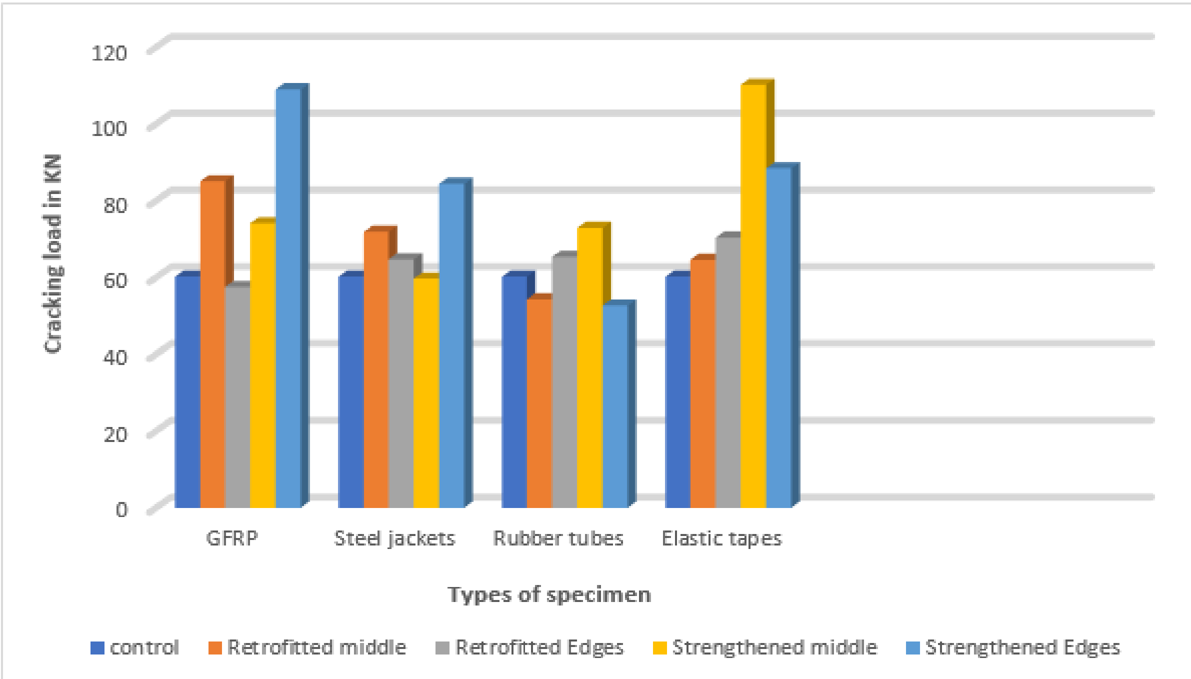

Figure 8.1 Comparison between different material used with control column of grade M20

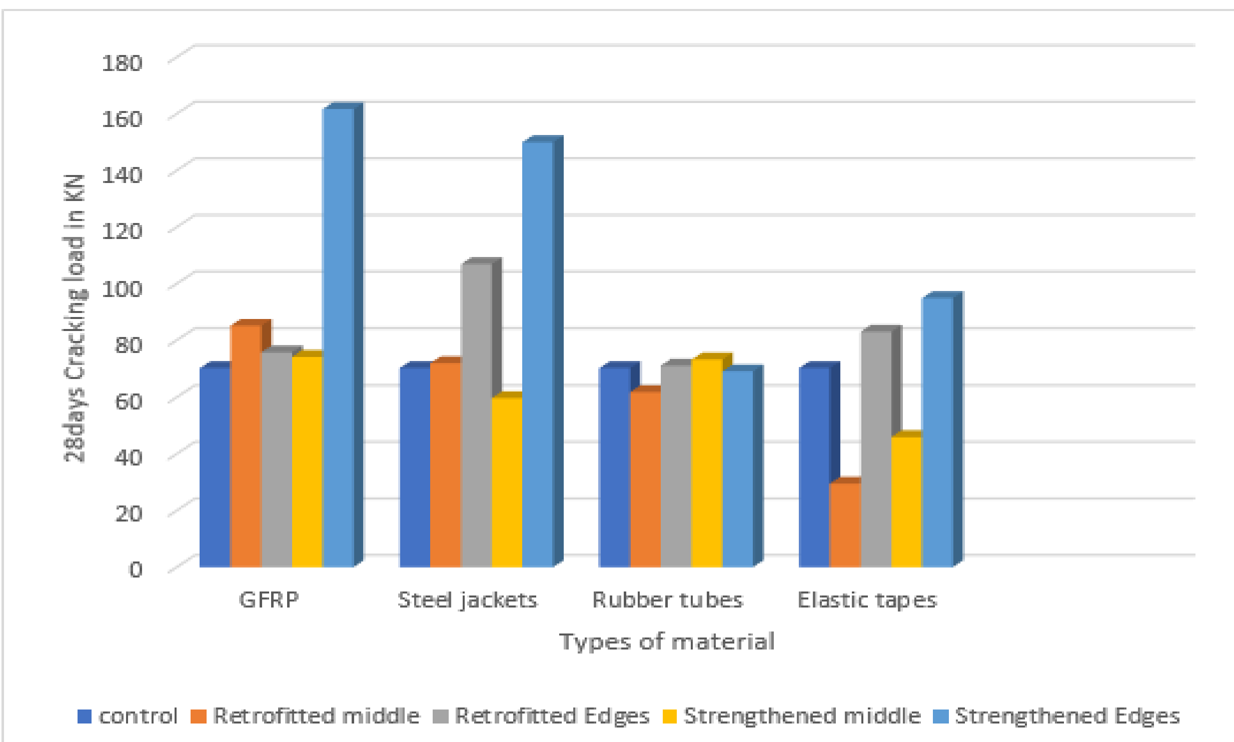

Figure 8.2 Comparison between different material used with control column of grade M25

The results of 28 days cracking load absorb by control column, retrofitted column and strengthened column are shown in Table 4. The comparison of variation of load absorb by different material with control column of M20 and M25 have been shown in figure1 and figure2 respectively. From these figure, we can see that the load absorbs by strengthened columns are comparatively high to retrofitted and control column. The reason behind is due to the extension of the load carrying capacity of column by adding external material to it. Whereas retrofitted column is also enhancing the strength of control column to a better extend and the reason for lesser value compare to strengthened is due to the crack formation which already formed and decrease loosen the interfacial bond when wrapped with the external material at the later stage. However, the retrofitted column did not fail to carry the extra load for the already cracked column which shows the effectiveness of the retrofitting material. Regarding the four types of material as discuss earlier GFRP and steel jackets are two widely used retrofitting material which have already proved to be effective but with the other two material like rubber tubes and elastic, they are newly introduce material towards retrofitting. From the results obtained, it is seen that elastic tapes can be used for retrofitting whereas rubber tubes can carry up to approximately 85% of the load carried by control column. The variation of results obtained in M20 and M25 may cause due to the reason of using wooden mould which may lead to lose capacity, manual compaction which leads to lose density and the casting weather condition since it was winter condition. Apart from these, if we compare on the location of wrapping for steel jackets and GFRP the middle wrapping give better results in retrofitted specimen and the edges wrapping give better results in strengthened column. The reason behind is in retrofitted specimen the crack usually occurs at the center, so when that crack has been retrofitted then h column obtained better strength. But if directly strengthened then the edges give better results due to the reason that it is able distribute and absorb uniform load at edges than at center which inhibit the formation of cracks. However, further study need to be done in rubber tube and elastic tapes as these two gives reverse result to that of steel jackets and GFRP. These results have been simulated in ANSYS and similar results were shown by the stress deformation.

It is clearly seen that the results of compressive strength have not discussed. This is because target compressive strength was not able to attained, reason behind may be due to the used of wooden mould which gives weak support and weak foundation, manual compaction which can cause less density, cold weather condition since casting was done during winter therefore while curing it may cause freezing condition in morning hours and the used of small rate load that is 0.7KN/sec.

CHAPTER IX

CONCLUSION AND FUTURE SCOPE

Conclusion: In this study since the target compressive strength was not able to attained due to the above mention reason therefore, the conclusion will be based on the cracking load absorb by the columns.

- As per the cracking absorb, both the strengthened column and the retrofitting column were able to absorb more load as compare to the control column which can conclude that retrofitting using the above four material can be able to enhance the strength of column.
- Of all the four materials only rubber tubes were not able to carry more load than control load as it carries only 85% of that carried by control load. Hence it can be concluded that more experimental study need to be check regarding rubber tubes.
- Elastic tapes proofs to be useful when compare with GFRP and steel jackets as it was able to attained the comparative cracking load. From here, it can be concluded that elastic tapes may be helpful for retrofitting but needed further study regarding its binding method.
- It can be concluded that Edges wrapping location is best for strengthened column and middle wrapping or wrapping at crack location is best for retrofitting column.

Future Scope: Further study about the efficiency of elastic tapes and confirmation of rubber tubes utilization as retrofitting material can be done. In addition to this the effective location and wrapping style can also be explore in further ways.

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APPENDIX

Compressive strength: It is the capacity of the structural member to withstand compressive load or load which tend to suppress the material inwards. This strength is generally measured by compression testing machine or universal testing machine. If calculated manually the load obtain from the compression testing machine should be divided by the area of load in the unit N/mm^2. The strength obtained will be the compressive strength.

Cracking Load: The maximum load obtained just prior to the crack formation in the structural member refer to as cracking load. It is this load that we consider to calculate compressive strength of the member.