RETROFITTING OF REINFORCED CONCRETE PIER WITH GFRP

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by

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DECLARATION

I, **IRFAN ARIF BASHIR** (11507729), hereby declare that this submission is my own work and that to the best of my insight and conviction, it contains no material beforehand distributed or composed by other individual or office. No material which has been acknowledged for reward of some other degree or certificate of the college or other organization of higher learning with the exception of where due affirmations have been made in the content. It was arranged and displayed under the direction and supervision of **Ms. Mandeep Kaur** (Assistant Professor) and **Mr. Paramveer Singh** (Assistant Professor).

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This is to certify that **IRFAN ARIF BASHIR** under Registration No. **11507729** has prepared the dissertation report titled "**RETROFITTING OF REINFORED CONCRETE BRIDGE PIER WITH FRP**" under my direction. This is a bonafide work of the above competitor and has been submitted to me in fractional satisfaction of the prerequisite for the honour of Masters of Technology in Civil Engineering.

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Signature of Student

IRFAN ARIF BASHIR

ABSTRACT

The main aim of our study is modification or repair of reinforced concrete bridge piers that have been affected either by self weight or by other forces like dynamic forces that act due to unexpected earthquakes resulting loss in strength and stiffness. In order To attain maximum stiffness and strength to withstand the shear forces, bending moments and other related structural response parameters efficiently. Our project aims at studying the behavior of a pier based on variations in compressive strength due to replacement of cement by metakaolin in initial stage .To increase the load carrying capacity of a pier, cement is replaced by metakaolin up to 15%.The different specimens were prepared in circular and square moulds by replacing the plain concrete with metakaolin and these samples were tested after 7 and 28 days after that all the samples were retrofitted with GFRP to increase the load carrying capacity of pier. Our Study reveals that replacement at 10% of metakaolin in both circular as well as square moulds increases the load carrying capacity approximately to about 19% when compared with plain reinforced concrete moulds respectively after 28 days. The most important finding is that the replacement of cement by metakaolin upto 10% helped us to attain higher strength after 7 as well as 28 and by retrofitting with GFRP the overall compressive strength was increased by 18%, hence providing us a simple efficient method of preventing the pier failure attaining higher strengths. Based on the test results there is remarkable increase in the load carrying capacity of pier which enhances the rigidity of pier in terms of strength and stiffness.

Keywords: *retrofitting, stress-strain curve, compressive strength, Metakaolin, RC Square and Circular Pier, compression test, OPC 53*.

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LIST OF SYMBOLS

%	Percentage
min	Minutes
mm	Millimetre
cm	Centimetre
m	Meter
L	Litre
sec	Second
g/cm^2	Grams per centimeter square
cm^2/g	Centimetre square per gram
m^2/kg	Meter square per kilogram
w/c	Water/cement
Kg/m^3	Kilogram per meter cube
d	Days
MPa	Mega Pascal
h	Hour
^oC	Degree Celsius
c/c	Centre to centre
Φ	Diameter
N	Newton

CHAPTER 1

INTRODUCTION

1.1 General

Bridge structures considered as life line structures need to be strong and solid throughout the life expectancy. But as the time proceeds their strength and solidness diminish either due to self-load or various other acting loads or due to disasters like earthquakes, accidents, wind e.t.c. Because of a seismic tremor, dynamic powers prompt inertial stress into the structure resulting in damage to the members like columns or piers that are meant to support and transfer the load acting on a bridge. For such cases when longer stresses are developed column segments are required or taller piers are required or both. Since the columns or piers or both piers and columns are subjected to high dynamic or seismic forces, hence necessary to improve their load carrying capacity in order to make them seismic resistant. In this project FRP retrofitted RC pier section is figured in order to improve its load carrying capacity so that it can withstand the maximum load carrying capacity, in our project the model of circular and square pier is examined under partial replacement of cement by various percentages of metakaolin (a supplementary cementitious material). A delegate model measurement is to be set up from the accessible pier drawings and a scale down column model will be readied utilizing comparability examination. The model segment has been subjected to compressive failure. The failure model is then retrofitted by utilizing FRP wrap. The efficiency or we can say load carrying capacity of the model segment is computed and the retrofitted segment is subjected to different loads in cyclic testing. The compressive strength and flexural strength for each sample after each and every test is taken from the testing machine (UTM and CTM) .The readings have been taken from all the samples before and after retrofitting.

1.2 Why to retrofit

To maximize structural efficiency in terms of load carrying capacity and to decrease the mass commitment of the solid strengthened pier to seismic reaction, retrofitting of existing structures like bridges is a key issue in any seismic zone. Earthquakes of high to low intensity continue to hit, leading loss of many lives and cause of destruction to structures and its various members, effecting ordinary life and the economy. Retrofitting provides us an alternate method to repair the existing structures or a particular structural member that have been effected by the various factors or forces in order to improve their efficiency in terms of strength and stiffness. Not only this but there are many other things that can be overcome by retrofitting for example, harm by accidents and ecological conditions, correction of starting outline defects, change of use and numerous other imperative properties can be achieved by retrofitting. The methodology adopted is one of the most effective practice and procedure. As it provides us a choice whether to destroy a whole damaged structure or to reestablish the same by the increasing the load carrying capacity of that structure in order to reinstall the structure. Under some circumstances, the level of damage occurred to a structure is to such an extent that with least rebuilding measure the building structure can be repaired and again brought back to its commonality and in such circumstance retrofitting is favored. Existing bridge piers may for an assortment of reasons be found to perform weakly consequently inadmissible. This could show itself by poor execution under administration stacking, as unnecessary diversions, clasping and breaking or there could be lacking shear quality and extra sesmic loads. Bridges are among every present structure that manage more harm, under seismic burdens, as unmistakably said in a few reports of late tremors. Not withstanding for "direct extent" tremors, the outcomes in these structures are disturbing towards an unsafe circumstance, either driving their incomplete obliteration or aggregate fall, with comparing substantial expenses and loss of lives. Much of the time, the bridge security is constrained and represented by pier limits. A few studies and works have been completed on strong and can be connected to building structures. Nonetheless, for rc bridge piers a great deal less research is found in the writing. For the most part, piers have extensive section measurements, with support bars spread along all appearances. Not at all like normal strong area sections, frequently the shear impact has awesome significance on the pier conduct. Subsequently, exceptional consideration is given to this issue when the retrofit of RC segment pier is visualized. Also, modifications in auxiliary plan and stacking codes may render many structures already thought to be tasteful, rebellious with current arrangements. In the present financial atmosphere, restoration of harmed solid structures to meet the more stringent points of confinement on serviceability, solidness and quality of the present codes, and fortifying of existing solid bridge piers to convey higher admissible loads, appear to be a more alluring contrasting option to devastating and revamping. In developed nations, tremors may bring about extreme financial misfortune likewise at a national scale, assessments of the fiscal harm put the figure for direct expenses at a few focuses rate of the total national output , evaluations of aggregate costs, whole of immediate and backhanded expenses, show values twofold. To adapt to the issue, an assortment of specialized arrangement has been actualized for seismic retrofitting, going from reinforcing of parts of the structure to seismic separation and dynamic control. However a methodical use of retrofitting procedures on a national or even local, scale has not been attempted, as a result of the high costs included. Subsequently, if there should arise an occurrence of mediations on a regional scale, huge retrofitting of structures that have been distinguished as helpless has never occurred. This is genuine both for created and creating nations in which seismic hazard is a worry. In high ready seismic tremor zones, where the majority of the region is at hazard, no extraordinary open arrangement is received for quake assurance of existing structures, aside from transitory and fractional qualification of retrofitting expenses for monetary finding. Quake protection is in addition utilized by an irrelevant minority thus the expenses of repairing the seismic tremor harms have been up to now halfway footed by the State, just for the immediate part of the expenses. The harms brought about by many solid extensions under the impact of close blame ground movements have prompted to the usage of a few noteworthy upgrades to bridge configuration codes. Late advances in tremor building support execution based methodologies for the seismic plan of new structures and for the evaluation and restoration of existing structures situated in dynamic seismic zones. In the seismic outline of structures, it is critical to have a reasonable vision of the sought seismic execution. Essential basic leadership questions like, "What is the required execution for the structure amid and after a tremor?" are without a doubt vital. By and large, new seismic outline methods of insight for extensions prescribe that essential bridge subject to a close land-vast scale bury plate tremor or an inland quake close to the structure ought to have the capacity to manage the normal most extreme horizontal drive in the inelastic stage with restricted harms, to guarantee brisk recoverabil

CHAPTER 2

LITERATURE REVIEW

2.1 General

Pier being considered as a member of life line structure needs to be stiff and strong throughout the life expectancy. Being a region of complex stresses and prone to the heavy loads that may be acting on, it needs to be the strongest member of the structure hence requiring the special attention for the stability of structure .Reinforced solid bridge pier is a generally hardened individual from closed cross-areas round fit as a fiddle of high quality, unbending nature and more prominent capacity to withstand superstructure weight. They are viewed as protected and solid for bearing substantial load that might follow up on them. They are utilized as a part of segments, and subsequently are a piece of one of the vital individuals from a structure to which entire load following up on a structure is exchanged through different individuals .now and again these empty roundabout wharfs may lose their solidness and quality because of calamities or superstructure weight that may bring about disappointment or even fall of entire structure. In our study on retrofitting of reinforce or strengthened concrete bridge pier, our work is to retrofit a pier to make is stiffer and solid. Numerous tremor damage reports called attention to the staggering harm to overwhelming bridge structures in light of piers including the late seismic tremors. Because of numerous common catastrophes like seismic tremors, numerous old bridges developed before 50-60 years prior ailing in the correct building structure were harmed in fragile fall.

Rasool MA et al [2016] Pier being considered as a member of life line structure needs to be stiff and strong throughout the life expectancy. Being a region of complex stresses and prone to the heavy loads that may be acting on, it needs to be the strongest member of the structure hence requiring the special attention for the stability of structure.

Dogan M et al [2011] Retrofitting is modification of existing structures to make them more resistant towards the external loadings. Some of the retrofitting methods that has been applied in the past are steel plate bonding, jacketing, external post tensioning, addition of new structural elements, use of different types of FRP's, etc and these methods were successful.

Dai et al [2011] discussed that PET,FRP is a promising other option to traditional FRPs for the seismic retrofit of RC bridge sections. Notwithstanding the amazing flexibility of the jacketed RC square segments, favorable position offered by the substantial strain limit is that PET FRP does not burst at a definitive utmost condition of the jacketed segments.

De luca A et al [2010] There are a number of reasons that lead to retrofitting of RC structures, which are: seismic activity, higher load demand, higher strength demand, constructional errors, deterioration caused by environmental factors, change in use of the structures, etc. Due to the formation of cracks, there is decrease in strength of a structure. So to regain its strength, a structure needs to be retrofitted.

El hacha R et al [2010] In FRP's, the main load bearing component are the fibers. FRP products that are used in retrofitting of structures can be in the form of strips, sheets and laminates.

Promis G et al [2009] Use of FRP for retrofitting proves to be more efficient and economical. Glass Fiber-reinforced polymers (GFRP) are light weight in nature, easy for implementation and have high tensile strength and also are corrosion resistance

Antonio et al [2009] discussed that the strategy for fortifying and retrofitting of piers is settled by method for remotely fortified fiber-strengthened polymer (FRP) overlays. In this paper, both square and rectangular RC section examples were threw and after that the research center testing of these RC segments limited remotely with glass and basalt-glass fiber-strengthened polymer (GFRP) overlays was finished. In testing, the RC segments were subjected to hub stack. The study was led to examine how the outside imprisonment influences the pivotal quality and twisting of a RC section. The outcomes demonstrated that there was an expansion in the solid pivotal quality because of the outer GFRP restriction. Amid his examination a three arrangement of section examples were threw and shape variable and volume element of these examples was likewise mulled over. Arrangement S-1 cross segment compares to a shape component of 1.0 and a volume element of 1.0;

arrangement to a shape element of 1.43 and a volume element of 0.5. R-1 relates to a shape variable of 1.45 and a volume element of 1.0; arrangement R-0.5 relates

- In segments, the outer FRP repression is more huge as far as upgrade of cement hub disfigurement as opposed to the solid pivotal quality.
- FRP coats helps in balancing the clasping of the longitudinal bars by permitting a development in volume of the solid center.
- FRP jacketing likewise helps in deferring the flimsy split propogation.
- The state of the cross area impacts the viability of the constrainment. This viability is higher for square segments as opposed to for rectangular segments.
- The increment in quality is expected to the FRP confinemnet which depends on the compressive quality of a control solid barrel 'fc'.

Difference in the FRP material makers does not influence the execution while keeping materials are of similar quality.

Calvi et al [2009] examined that fall of under-planned piers is regularly administered by fragile systems because of lopsided flexural-shear quality, untimely bars clasping or loss of holding in lap-graft. keeping in mind the end goal to upgrade both quality and malleability and to potentially finish the limit plan criteria. A parametric study utilizing numerical reenactment considering carbon, glass or aramid filaments and diverse geometrical attributes of the FRP layers has been performed to set up the ideal fortifying for every dock typology. Experimental semi static cyclic tests were then performed and base shear versus horizontal removal bends and harm examples were contrasted and those acquired from the past research. The upgrade due to the FRP fortifying is assessed as far as flexural and shear quality and dispersed vitality.

Colomb F et al [2008] FRP composites are preferred solutions for strengthening of various reinforced concrete structural elements and are now extensively being used all over the world. Physical properties and mechanical properties of FRPs are governed by its basic properties and the structure at micro level

Binici F et al [2005] The variable forces that may be induced due to the vertical forces on the piers are not included in seismic codes. Due to major or minor earthquakes, the intensity of such forces can be so high that the compressive forces will be as large as thrice the dead load. Also severe tensile axial load can generate.

Monti G et al [2001] Compressive stresses due to direct tension leads to Vertical motion resulting failure in shear and flexure, hence reducing the moment capacity and ductility of RC columns or piers.

Yalcin c et al [2000] Designing of single-column type RC bridge piers as per the earlier IRC codes were investigated. In such cases, the load carrying capacities of short piers were found lower than the required shear demand for compressive and flexural strength conditions.

Seible F et al [1997] To maximize structure effectiveness as far as the quality/mass and stiffness/mass proportions and to lessen the mass commitment of the bridge to seismic reaction, it has been a prominent building practice to utilize bridge piers for column sections. Many existing RC piers don't satisfy the quality and ductility demands for seismic loading as they were designed in light of outdated codes of practice. Because of the lack of sufficient transverse reinforcement as well as appropriate seismic detailing, these substandard RC piers may encounter ductile shear failure (before or after the flexural yielding of longitudinal reinforcement),confinement failure of the flexural plastic hinge region and lap splice de-bonding of the longitudinal reinforcement during a major earthquake. As a result, they need large strength and ductility improvements in order to meet the requirements of modern earthquake-resistance regulations.

Priestley et al [1996] Talked about that to maximize structure effectiveness as far as the quality/mass and stiffness/mass proportions and to lessen the mass commitment of the bridge to seismic reaction, it has been a prominent building practice to utilize bridge piers for column sections.

Caldarone et al [1994] Utilizing material of efficient properties (e.g. steel with high strain hardening),improving the reinforcement provided and proper section design can be a efficient step to increase the yield stiffness for section.

Chai YH et al [1991] In seismic zones, the efficiency of new RC structures could be improved by weakening the rebar and concrete bond.

Fahmy et al [2009] A flowchart basically showing the required outline steps is given in fig, where the retrofit system is isolated into five noteworthy strides to get the correct FRP jacketing that would guarantee the required recoverability as indicated by the normal plan level of ground movement. In the initial step seismic reaction parameters of the current segment (yield quality, perfect hypothetical quality, and the relating removals) are resolved. The second step plans the FRP coat for plastic pivot repression, which fulfills the prerequisites of the outline level of ground movement. In the third step, leftover miss hapening record is connected to examine the end of the recoverable state. The fourth step incorporates check for the upgrade of segment shear quality. On the off chance that the section is lap-joined at the plastic pivot zone, the last stride checks the FRP coat thickness that gives the essential bracing weight.

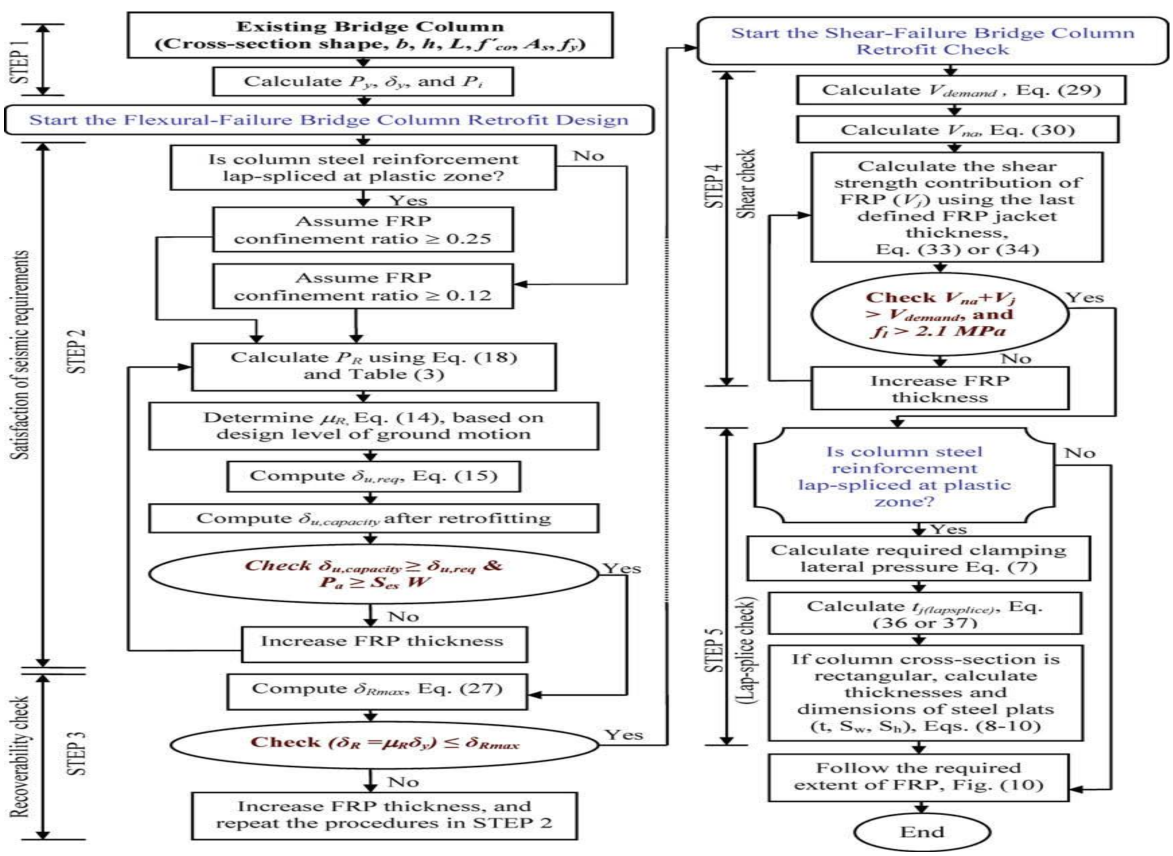


Figure 2.1:-Proposed chat for strengthening design guide Fahmy et al [2009]

Dubey et al [2008] Different specimens were cast with 10% supplementary cement material (MK). 15% increase in flexural strength is observed. MK incorporation served to increase toughness

Kennison et al [2005] Splitting tensile strength increases with the addition of MK. Splitting tensile strength for the MK mixtures generally show 15% increase in the tensile strength as compared ordinary concrete.

Brooks et al [2001] determined that conclusion of metakaolin as replacement of cement increased the compressive strength of concrete, but the replacement level of OPC by MK to give maximum strength enhancement was about 20%.

CHAPTER 3

RATIONALE AND SCOPE OF STUDY

The properties of reinforced or strengthened piers should be kept up for the duration of the life expectancy of bridge. Furthermore, to keep up these properties we have to number or follow up on the damage that is done to the structure of bridge and its members for the strength of structure. This damage might be brought about either by the major or minor seismic tremors or because of the superstructure weight and different catastrophes, that occur time in and time out creating serious damage to the structure and affecting the properties like firmness, quality, shear limit, durability, and other flexible properties or thus can in some cases prompt to fall of the entire structure, and coming about loss of many lives and property worth millions. With a specific end goal to evade the crumple of entire, our research will be very pertinent to the conditions which are pervasive in retrofitting those bridges which have been harmed by late tremors. As there are numerous zones on this planet that fall in high recurrence quake zones and thus are inclined to confront seismic load at whatever time. So our project can be very valuable to give some kind of restricting outline quality to these bridges so they can withstand the heaps securely even in the most noticeably awful conditions Notwithstanding, our project depends on reinforced piers and is exceptionally factor with the real conditions. Thus, a higher element of security must be utilized.

CHAPTER 4

OBJECTIVES OF THE STUDY

The main aim of the study is

- Study of compressive behavior of circular and square RC pier.
- Study of compressive behavior of RC pier by partial replacement of cement by metakaolin.
- Compressive behavior of RC pier by retrofitting with GFRP.
- Stress-Strain relationship for retrofitting.

CHAPTER 5

MATERIALS AND METHODOLOGY

5.1 General

The various materials used for retrofitting are listed below:

5.1.1 FRP

Lately, critical measure of research work has been done to create different fortifying and restoration methods to enhance the execution and life expectancy of a structure. A portion of the fortifying techniques that has been connected in the past are steel plate holding, jacketing, outside post tensioning, expansion of new basic components, and so on and these strategies were fruitful. Among every one of the techniques, retrofitting with Fiber Strengthened Polymers (FRP) materials has prompt to an awesome achievement in the field of structural building as of late. Fiber-fortified polymers (FRP) are light weight in nature, simple for execution and have high rigidity furthermore are consumption resistance. Because of these reasons, FRP composites are favored answers for fortifying strategy for different fortified cement auxiliary components and are currently broadly being utilized everywhere throughout the world.

FRP composites might be of different sorts:-

- Carbon FRP (CFRP)
- Glass FRP (GFRP)
- Aramid FRP (AFRP)

Following figure shows us some typical and stiffness values of some strengthening materials that are used for retrofitting

Table 5.1:-Typical strength and stiffness values for materials used in retrofitting

Material	Tensile strength (MPa)	Modulus of elasticity (GPa)	Density (kg/m^3)	Modulus of elasticity/density ratio (mm^2/s)
Carbon	2100-5500	235-820	1800-2150	130-175
Glass	3300-4700	75-90	2200-2450	31-33
Epoxy	50	2.5	1100-1350	1.7-2.2
CFRP	1400-3600	150-530	1400-1700	110-320
Steel	270-1800	195-215	7800	24-27

These FRP composites can be fortified together in a grid of epoxy, polyester and vinyl ester. In FRP's, filaments are the fundamental load conveying segment and the plastic grid exchanges shear. FRP items that are usually utilized as a part of retrofitting of auxiliary components can be as strips, sheets and covers.

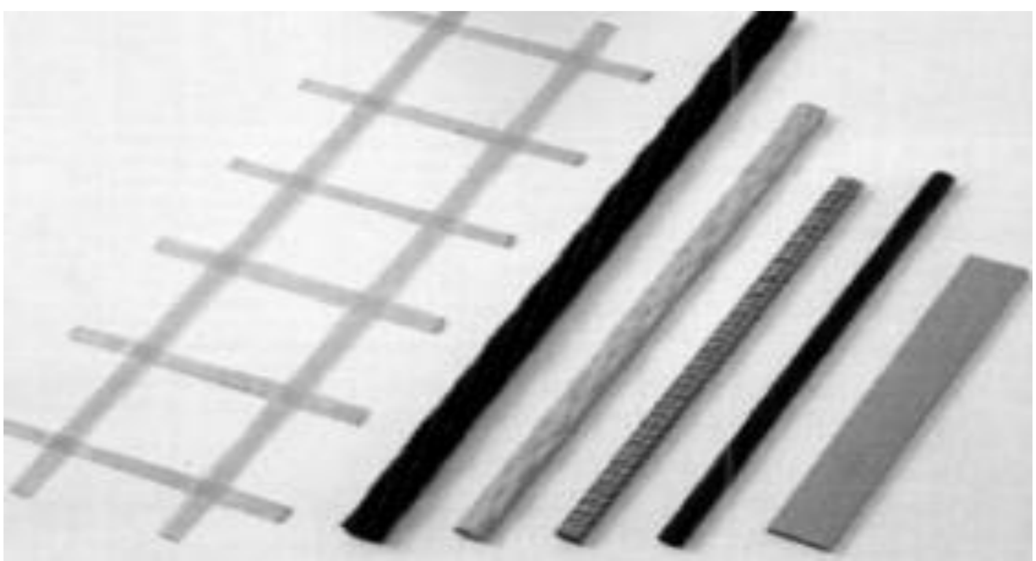


Figure 5.1:-FRP Sheets

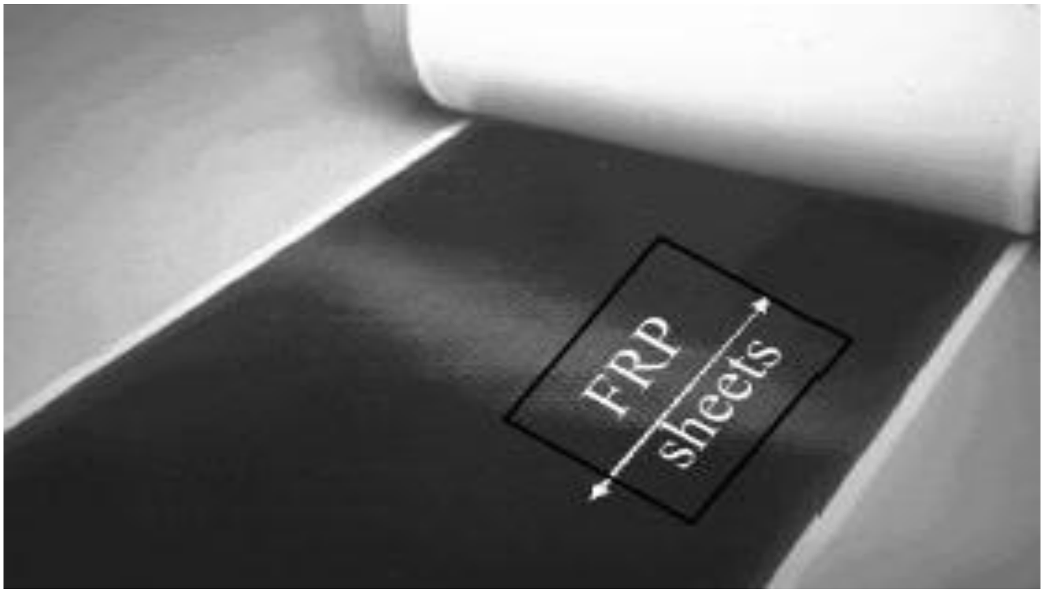


Figure 5.2:-FRP Sheets

Utilization of FRP has turned into a typical option over steel to repair, retrofit and reinforce structures and connects and different basic components. FRP materials may offer various points of interest over steel plates which incorporate High specific strength

- High stiffness
- High corrosion resistance
- Convenient in handling
- Ease of implementation
- Resistance to high temperature
- Resistance to mechanical as well as environmental conditions.

5.1.2 Metakaolin

Metakaolin was taken from one of the chemical plants.The metakaolin used was having following mechanical properties:

Table 5.2:-Properties of metakaolin

Property	Value
Specific Gravity	2.50
Bulk density	0.35
FORM	Powder
ORDER	White

5.1.3 Cement

The cement was taken from the nearest dealer of ACC Company and the cement used is OPC grade53 with consistency value (P) 28.9 %, Initial test observed on stopwatch was 40 minutes; Final setting observed as 3 hours and 35 minutes, soundness equal to 0.3cm and specific gravity of cement is equal to 3.15.

5.1.4 Aggregates

The coarse aggregates were 10-20mm crushed stone and the fine aggregate was river sand with fineness modulus equal to 2.45

5.1.5 Water

water one the main ingredients used to mix the concrete. The typical water cement ratio throughout the project work is 0.45.

5.2 Methodology

5.2.1 Methods of retrofitting:-

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.

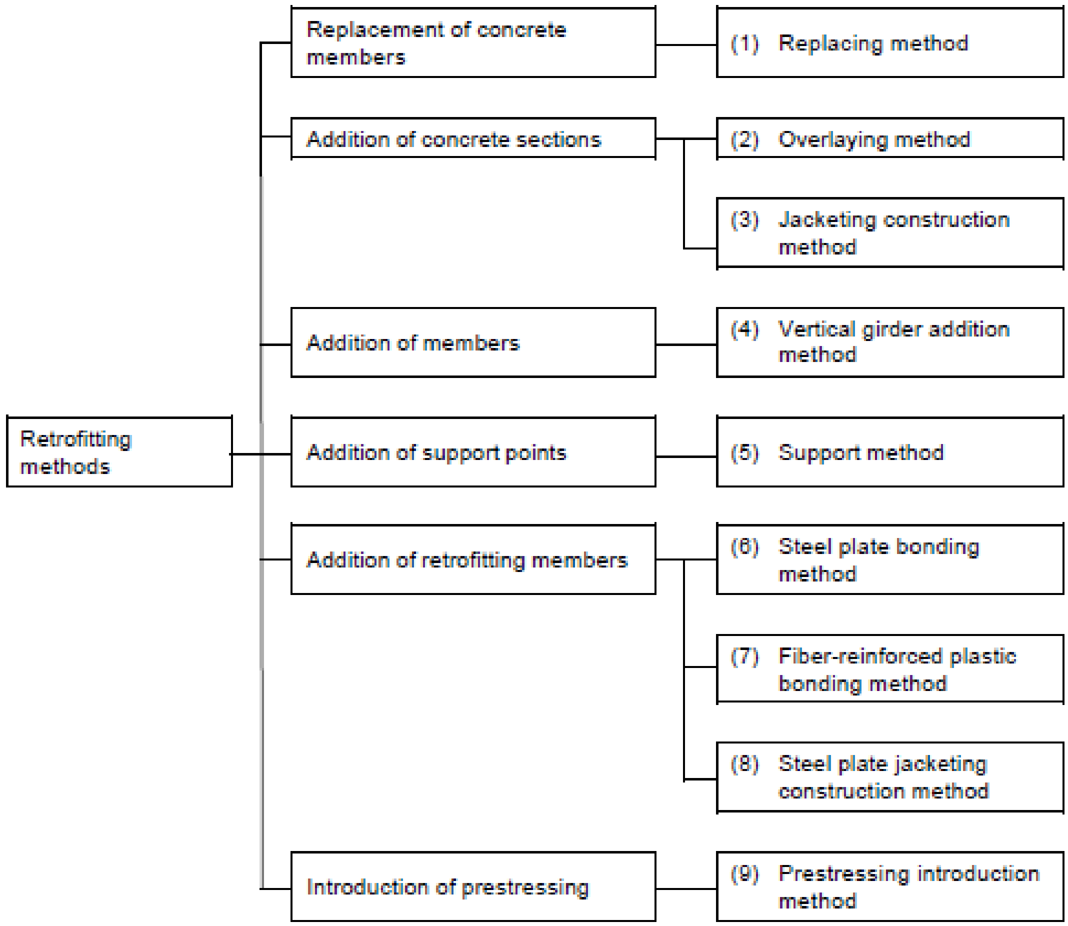


Figure 5.3:- Methods of retrofitting

5.2.2 Mix design

it may be defined as the selection of suitable ingredients of concrete in order to find the relative proportions materials in concrete of minimum strength and durability and as economical as possible.

Necessities of Mix design:- The prerequisites which frame the premise of determination and proportioning of blend fixings are:

a) The base compressive quality required from basic thought

b) The sufficient workability fundamental for full compaction with the compacting hardware accessible.

c) Suitable water-bond proportion as well as appropriate concrete substance to give satisfactory solidness for the specific site conditions

d) Suitable bond substance to keep away from shrinkage splitting because of temperature cycle in mass cement.

5.2.3 Mix Proportion assignment

The normal strategy for communicating the extents of elements of a solid blend is in the terms of parts or proportions of concrete, fine and coarse totals. For e.g., a solid blend of extents 1:2:4 implies that concrete, fine and coarse total are in the proportion 1:2:4 or the blend contains one a player in bond, two sections of fine total and four sections of coarse total. The extents are either by volume or by mass. The water-concrete proportion is typically communicated in mass. The normal water-bond proportion utilized as a part of this venture is 0.45

Firstly the cement type used is OPC 53 as per IS-12269-1987, The Maximum Nominal Aggregate Size used in design process is 20mm. The minimum cement content is 310 kg/m^3 with maximum Water Cement Ratio as 0.45. The Workability is 65 mm (Slump). The Exposure Condition is normal and the degree of supervision is good. The Type of Aggregate is in the form of Crushed Angular Aggregate. The Maximum Cement Content is 540 kg/m$^{3.}$The Chemical Admixture Type super-plasticizer used is Confirming to IS-9103. While performing test data for materials type of cement is OPC 53 grade. With Sp. Gravity of cement equal to 3.15, and the Sp. Gravity of Water used is equal to 1.00. The Chemical Admixture used is from and chemical plant. The Sp. Gravity of 20 mm Aggregate used for mix is 2.884, and the Sp. Gravity of 10 mm Aggregate is equal to 2.878. The Sp. Gravity of Sand used for the mix is 2.605. The Water Absorption of 20 mm Aggregate is equal to 0.97% and the Water Absorption of 10 mm Aggregate is equal to 0.83%. The Water Absorption of Sand is equal to 1.23%, The free (Surface) Moisture of 20 mm Aggregate is nill, also the Free (Surface) Moisture of 10 mm Aggregate is nill with nill Free (Surface) Moisture of Sand. The Sieve Analysis of Individual Coarse aggregates is done separately. The Sieve

Analysis of Combined Coarse Aggregates was also done separately. The Sp. Gravity of Combined Coarse Aggregates is equal to 2.882. The Sieve Analysis of Fine Aggregates is also done separately, while targeting Strength for Mix Proportioning, Target Mean Strength is at 36N/mm$^{2.}$. The Characteristic Strength for 28 days is at 25N/mm^2. While Selecting of Water Cement Ratio, the Maximum Water Cement Ratio is 0.45.Adopted Water Cement Ratio is equal to 0.43.For selecting water content Maximum Water content (10262-table-2) is 186 Lit. The Estimated Water content for 50-75 mm Slump is 138 Lit. The Super-plasticizer used in the process is 0.5 % by wt. of cement. While calculating cement content Water Cement Ratio is 0.43 with cement content of 320 kg/m^3 Which is greater then 310 kg/m$^{3.}$. The Proportion of Volume of Coarse Aggregate & Fine Aggregate Content as per the as per table 3 of IS 10262 = 62.00% with Adopted Vol. of Coarse Aggregate as 62.00% whereas the Adopted Vol. of Fine Aggregate (1-0.62) must be 38.00%.

5.3 Experimental setup

5.3.1 Structure of specimen

In order to study the behavior of pier, the specimens were prepared in both circular as well as rectangular form. Overall dimensions of test specimen are shown in Figure 5.4.1

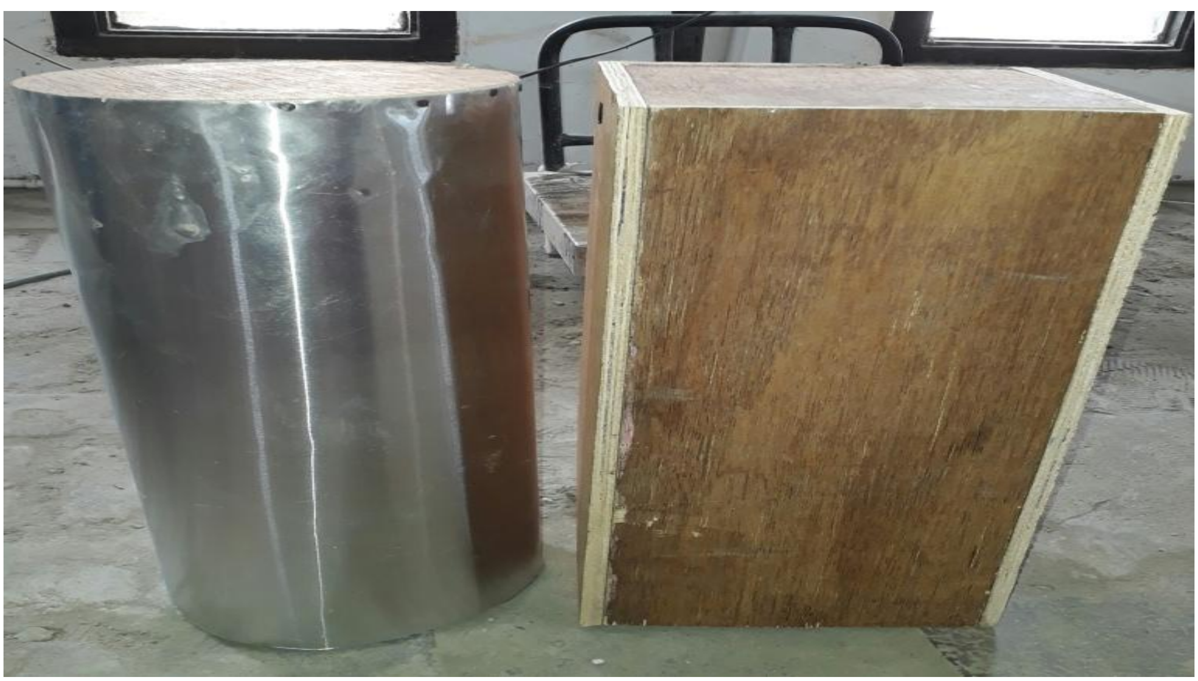


Figure 5.4.1:Circular mould=15cm×40cm, square mould=15cm×15cm×40cm

The experimental program consists of 8 samples 4 for circular pier and 4 for rectangular. These different samples consist of replacement level of metakaolin up to 15% and were tested after 7 days and 28 days on UTM and CTM. Grade of concrete used throughout the experiment was M-25.Piers of circular and rectangular shape being investigated. For Both cases compressive strength was investigated at various replacement levels of cement by metakaolin. In order to find out the compressive strength the tests were carried out by using CTM and UTM.A suitable arrangement is made at the time of testing for achieving the fixity condition as shown in Figure 5.4.2 and 5.4.3

Figure 5.4.2:Testing of square column on UTM Figure 5.4.3:Testing of circular column on CTM.

After performing the tests after 28 days the piers were retrofitted with GFRP sheets in order to improve their peak load capacity. The retrofitting was done by laminating the piers in order to cover the cracks that were developed during the loading process the following figure 5.5.4 shows retrofitting by laminating GFRP sheets

Figure 5.4.4:-Retrofitting of circular and square column with GFRP

The following table shows the detail of samples used during the research work. At a total 8 samples were used. The detail of sample is discussed in the below table:-

Table 5.4.1: Details of samples used

Sample	% age of metakaolin
Sample 1	For circular pier at 0% replacement of metakaolin
Sample 2	For circular pier at 5% replacement of metakaolin
Sample 3	For circular pier at 10% replacement of metakaolin
Sample 4	For circular pier at 15% replacement of metakaolin
Sample 5	For square pier at 0% replacement of metakaolin
Sample 6	For square pier at 5% replacement of metakaolin
Sample 7	For square pier at 10% replacement of metakaolin
Sample 8	For square pier at 15% replacement of metakaolin

CHAPTER 6

RESULTS AND DISCUSSION

Using metakaolin as a partial replacement of cement increased the load carrying capacity hence increasing the strength of pier. In our project work up to 15% of cement was replaced by 2metakaolin with results were taken after 7 and 28 days respectively. During the research work a total of 8 samples (4 each from square and circular cross section) were taken with cement being replaced up to 15%. At 10% replacement level of cement by metakaolin, the increase in compressive strength obtained was most efficient with the percentage increase of 19.23% in circular and 16.76% in square pier after 28 days. In order to find the compressive strength both compressive tensile machine (CTM) and universal testing machine (UTM) were used for tests performed. In order to calculate the compressive strength of both circular and square piers the peak load carrying capacity was calculated with the help of CTM and UTM. The peak load capacities of the samples are compared below:-

Table 6.1: Peak load comparison of samples after 7 and 28 days

Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Peak load after 7 days	385.73 KN	421.72 KN	450.33 KN	422.25 KN	453.15 KN	474.75 KN	519.07 KN	465.52 KN
Peak load after 28 days	612.27 KN	661.19 KN	728.47 KN	642.82 KN	719.32 KN	776.7 KN	857.7 KN	757.35 KN

After finding the peak load carrying capacity of piers by performing various tests on CTM and UTM respectively after 7 and 28 days, The following resulted were found out showing the compressive strength of each sample after 7 and 28 days:-

Table 6.2: Compressive strength of various samples after 7 and 28 days

Sample	Compressive strength for 7 days(N/mm^2)	Compressive strength for 28 days(N/mm^2)
Sample 1	21.84	34.67
Sample 2	23.88	37.44
Sample 3	25.50	41.25
Sample 4	23.91	36.40
Sample 5	20.14	31.97
Sample 6	21.10	34.52
Sample 7	23.07	38.12
Sample 8	20.69	33.66

From the above results significant increase in the compressive strength of both circular as well as square piers was after the partial replacement of cement by metakaolin. These readings were calculated after the peak load capacity of the pier was tested by performing compressive strength test.

The below graphs show the comparsion of compressive strength according to percentage of metakaolin after 7 and 28 days:-

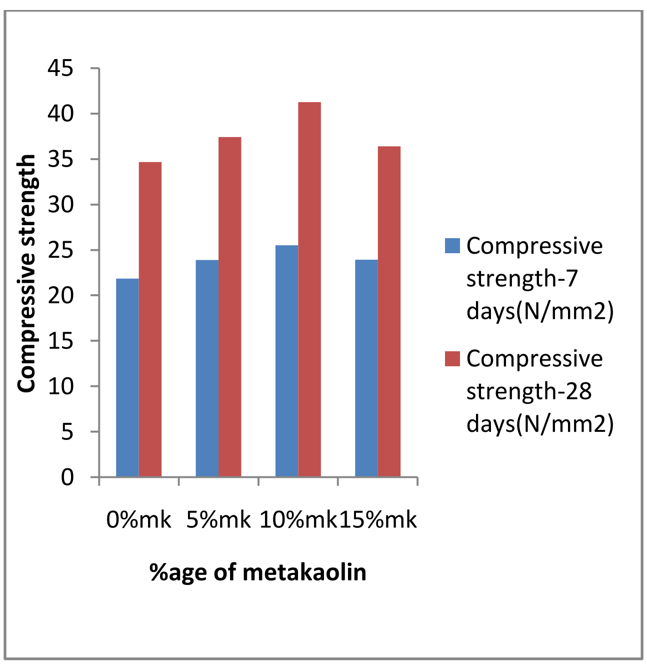


Figure 6.1: circular pier

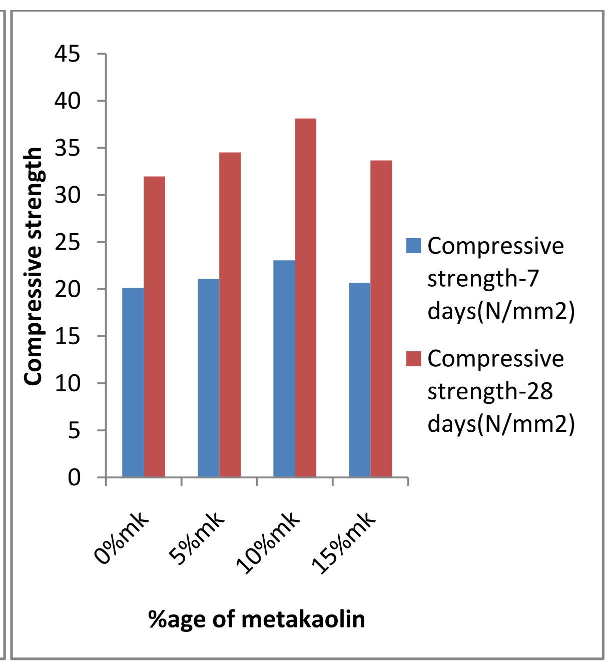


Figure 6.2: square pier

After calculating the compressive strength of each and every sample,in order to find the stress-strain relationship of circular and square piers after 7 and 28 days the following figures were plotted:

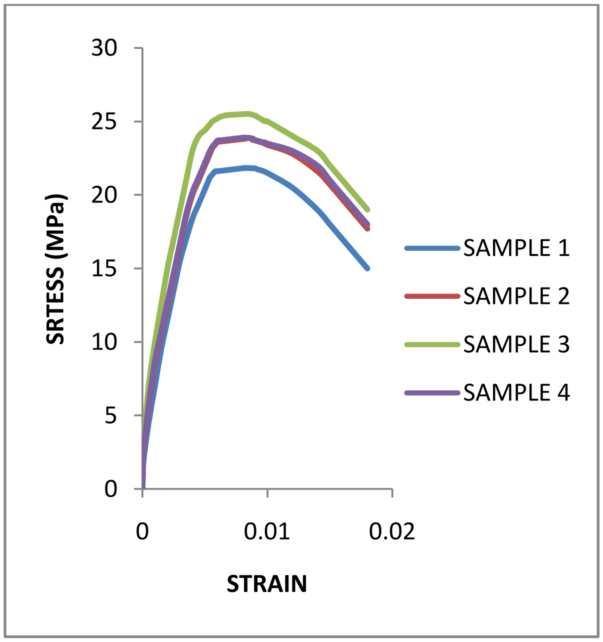


Figure 6.3: Stress-strain relation after 7days (circular pier)

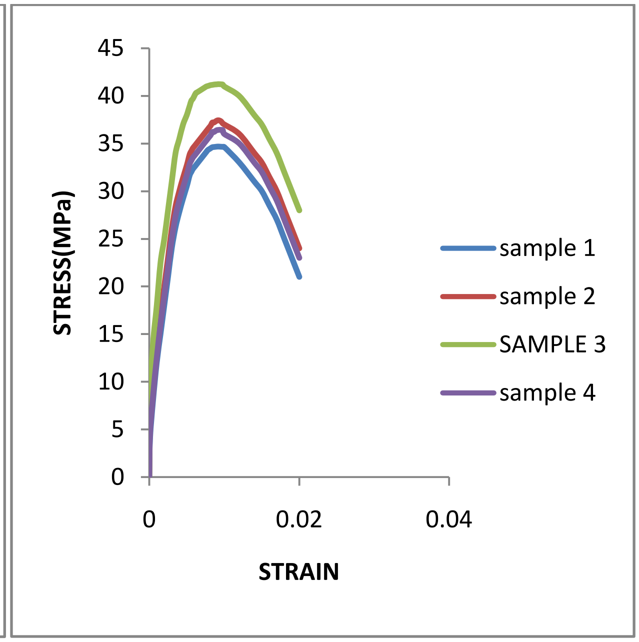


Figure 6.4: Stress-strain relation after 28days (circular pier)

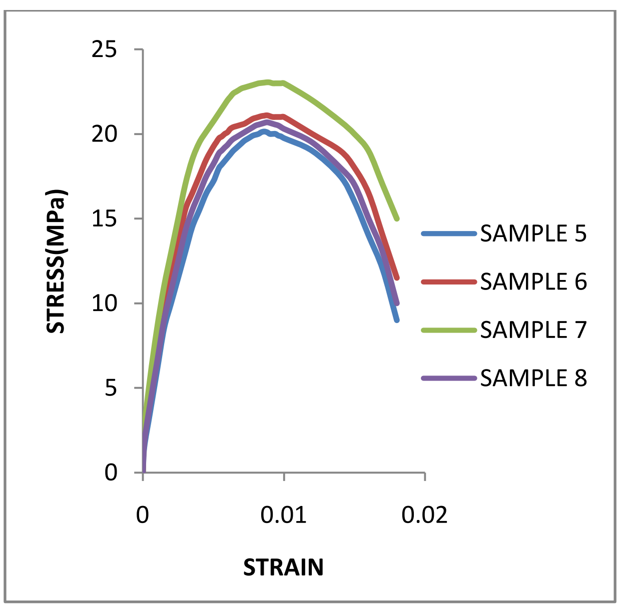


Figure 6.5: Stress-strain relation after 7days (Square Pier)

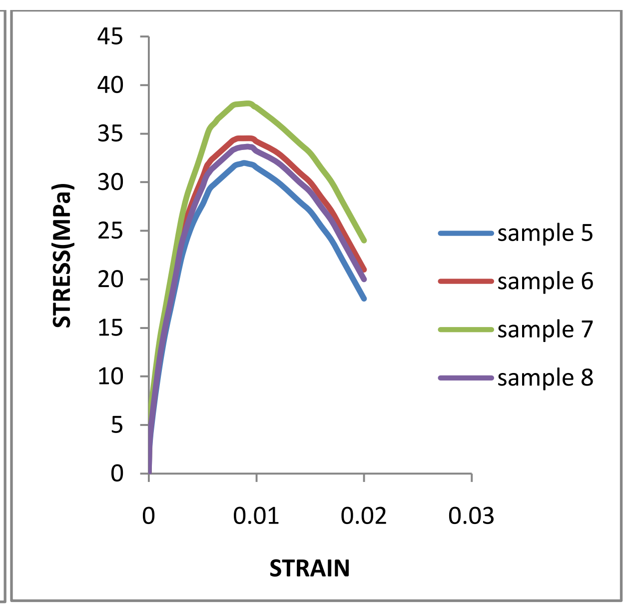


Figure 6.6: Stress-Strain relation after 28days (Square Pier)

The below table shows the peak load carrying capacity of all the samples after retrofitting with GFRP that was calculated with the help of CTM. The peak load carrying capacity is the maximum load carry capacity of the pier that it can withstand.

Table6.3: Peak load capacity of samples after retrofitting with GFRP

Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Peak load after retrofitting days	724.92 KN	780.19 KN	859.47 KN	757.82 KN	848.477 KN	915.7 KN	1000 KN	893.26 KN

After finding the peak load carrying capacity of piers by performing various tests on CTM and UTM respectively after 7 and 28 days, The following resulted were found out showing the compressive strength of each sample after 7 and 28 days:-

Table6.4: Compressive strength of various samples after retrofitting with GFRP

Sample	Compressive strength after Retrofitting (N/mm^2)
Sample 1	40.91
Sample 2	44.17
Sample 3	48.67
Sample 4	42.95
Sample 5	37.72
Sample 6	40.73
Sample 7	44.98
Sample 8	39.66

After calculating the peak load capacity of the pier before and after retrofitting both results were compared in order to calculate the variations in results. The below table shows the comparison of results of peak load capacity of all the samples before and after retrofitting

Table 6.5: Peak load comparison of samples before and after retrofitting

Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Peak load before retrofitting	612.27 KN	661.19 KN	728.47 KN	642.82 KN	719.32 KN	776.7 KN	857.7 KN	757.35 KN
Peak load after retrofitting	724.92 KN	780.19 KN	859.47 KN	757.82 KN	848.477 KN	915.7 KN	1000 KN	893.26 KN

After comparing the peak load capacity of piers, similarly there compressive strengths were compared in order to show the variation in compressive strength due to retrofitting. The given below table shows the comparison of compressive strength of various samples before and after retrofitting

Table 6.6: Compressive strength comparison of various samples before and after retrofitting

Sample	Compressive-strength before Retrofitting (N/mm^2)	Compressive-strength after Retrofitting (N/mm^2)
Sample 1	34.67	40.91
Sample 2	37.44	44.17
Sample 3	41.25	48.67
Sample 4	36.40	42.95
Sample 5	31.97	37.72
Sample 6	34.52	40.73
Sample 7	38.12	44.98
Sample 8	33.66	39.66

The following graph shows the graphical comparison of compressive strength before and after retrofitting :-

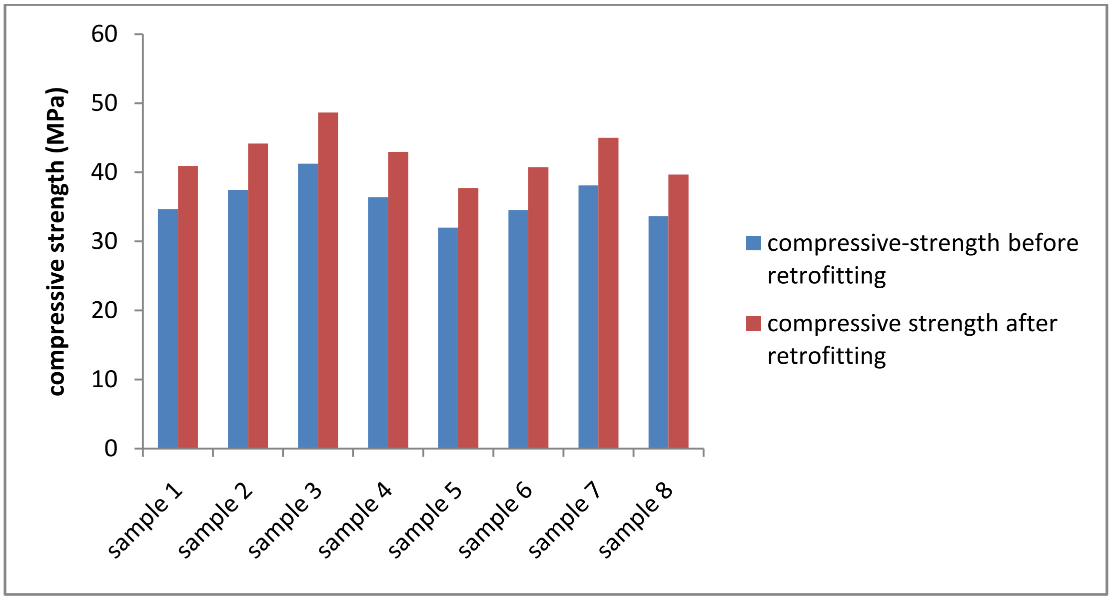
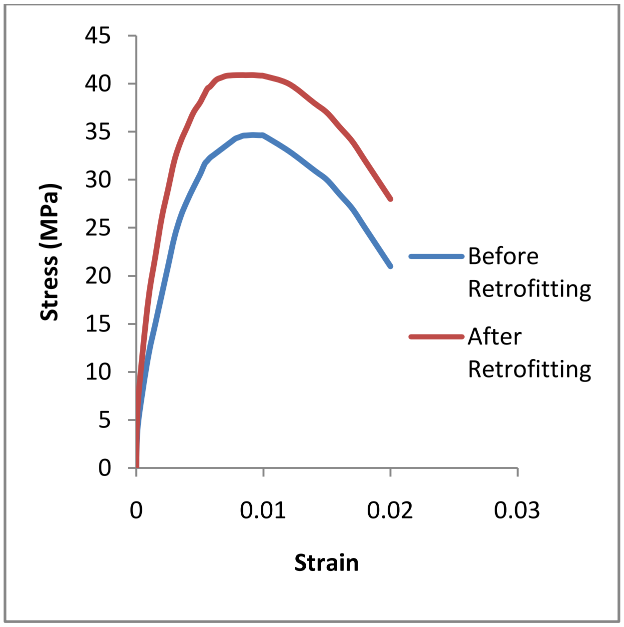


Figure 6.7: comparison of compressive strength before and after retrofitting

After calculating the compressive strength of each and every sample before and after retrofitting,in order to find the stress-strain relationship of every sample before and after retrofitting the following figures were plotted:



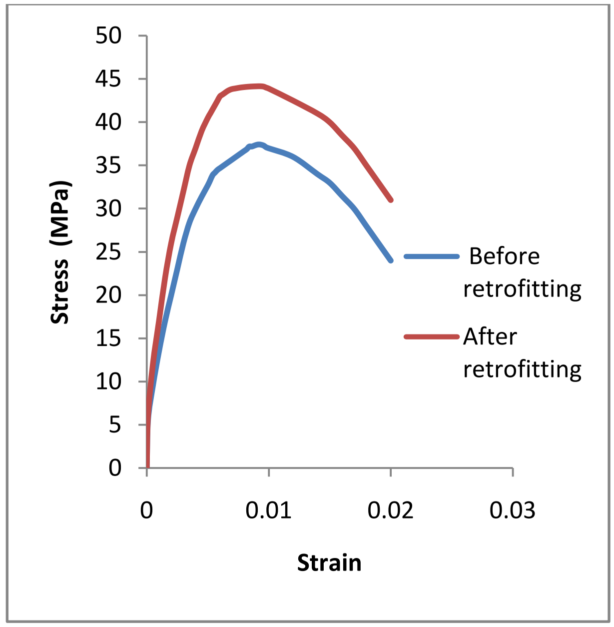
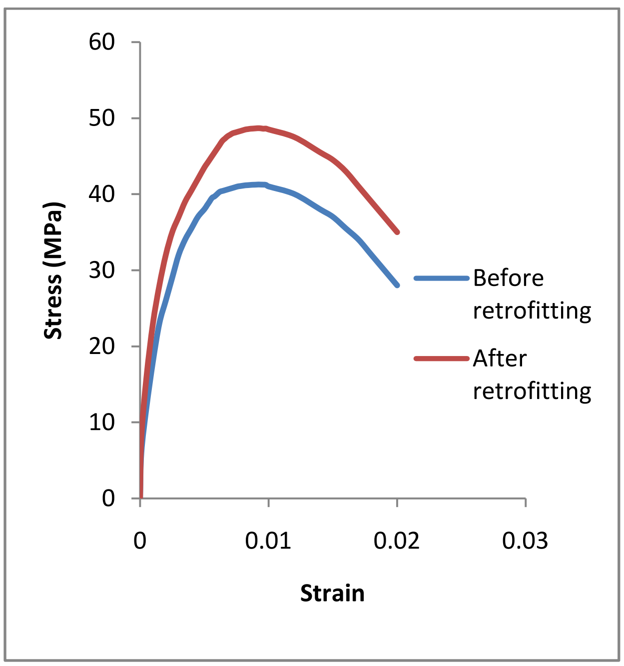


Figure 6.8: Sample 1

Figure 6.9: Sample 2



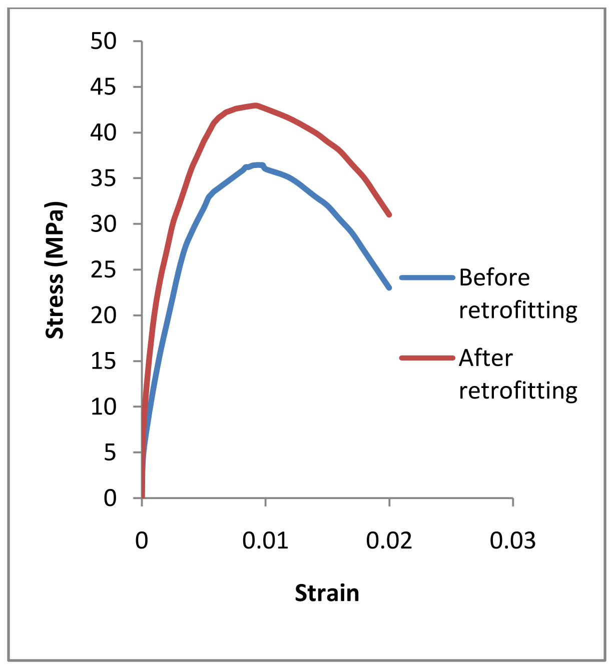


Figure 6.10: Sample 3

Figure 6.11: Sample 4

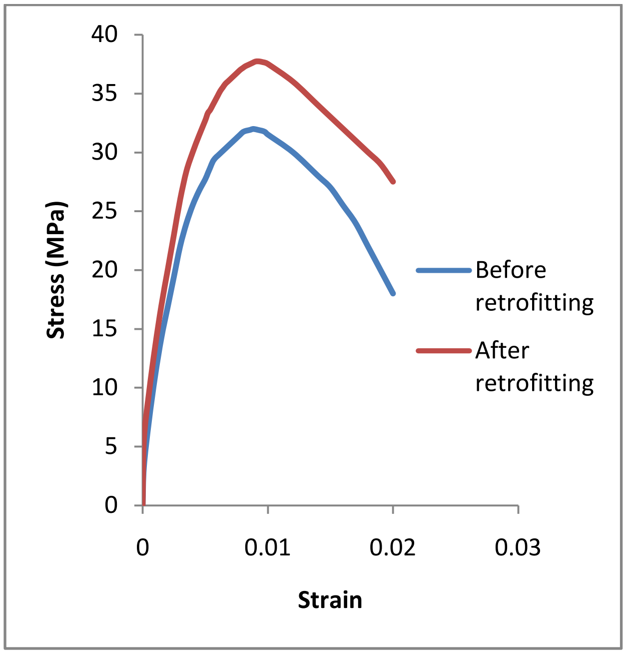


Figure 6.12: Sample 5

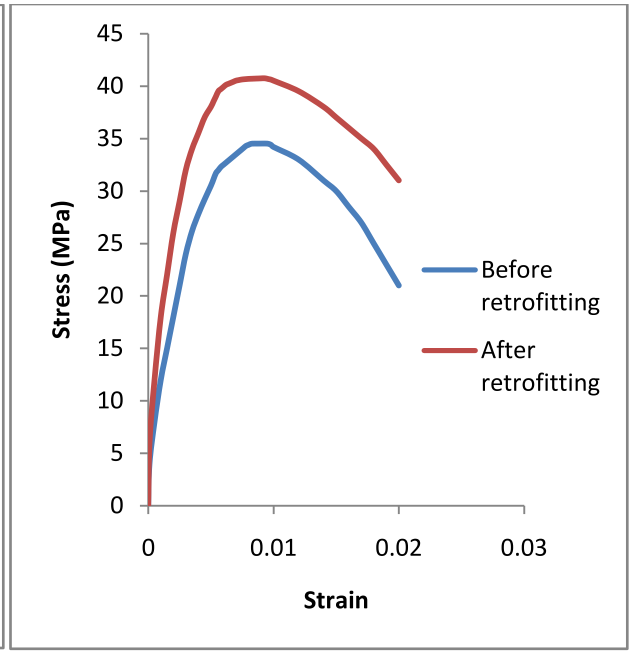


Figure 6.13: sample 6

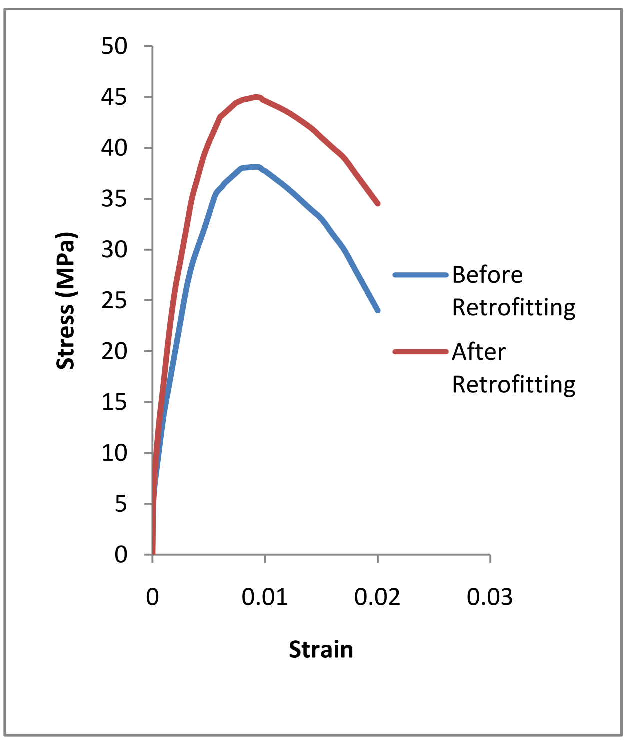


Figure 6.14: Sample 7

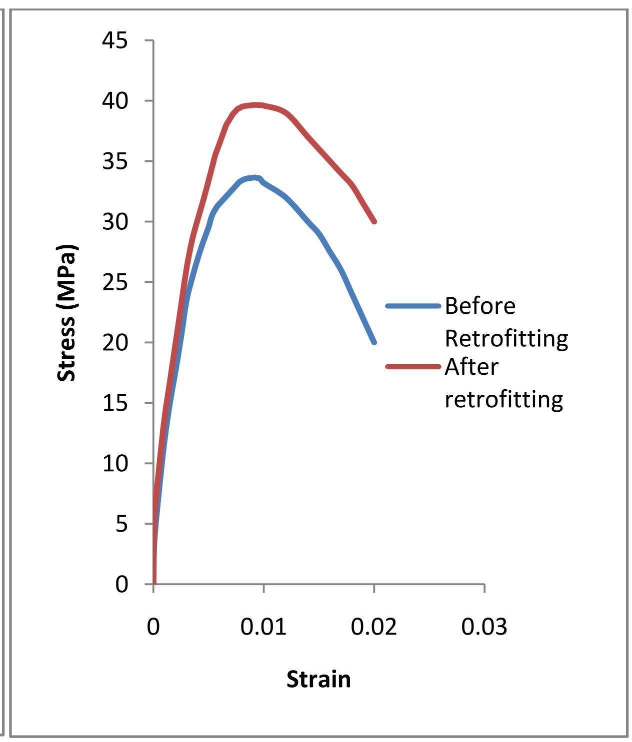


Figure 6.15: Sample 8

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

1. Sample 3 is having superior load carrying capacity which is 19.06% more as compared sample 1, 11%, more as compared to sample 2 and 13.98% more as compared to sample 4 after 28 days.
2. Sample 7 is having superior load carrying capacity which is 19.23% more as compared to sample 5,11.26% more as compared to sample 6 and 13.95% more as compared to sample 8 after 28 days.
3. Sample 3 is having superior load carrying capacity which is 16.76% more as compared sample 1, 7.4% more as compared to sample 2 and 7.42% more as compared to sample 4 after 7 days.
4. Sample 7 is having superior load carrying capacity which is 14.54% more as compared to sample 5, 9.78% more as compared to sample 6 and 10.89% more as compared to sample 8 after 7 days.
5. The maximum optimal increase in the compressive strength was obtained at 10% replacement of metakaolin after 7 and 28 days.
6. Addition of metakaolin improved the early strength as well as final strength by efficient amount.
7. Load carrying capacity of circular pier was much efficient as compared to square piers. Hence can with stand to more load.
8. After retrofitting with GFRP the peak load capacity or compressive strength of both circular and square increased in average upto 18%.

Future scope

In seismic prone areas our project can play a vital rule in improving the strength of buildings, bridges. Not limited to only this but in our project we have also worked with supplementary cementious material and the results are positive, hence giving us an option of replacement of cement in major projects in order to improve the strength in initial stages of new constructions.

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APPENDIX

7 days stress-strain values for circular pier

STRAIN	STRESS SAMPLE 1	STRESS SAMPLE 2	STRESS SAMPLE 3	STRESS SAMPLE 4
0	0	0	0	0
0.0001	2	2.5	3	2.6
0.0005	4.5	5.5	7	5.7
0.001	7	8.5	10	8.7
0.0015	9.5	10.5	12.5	10.7
0.002	11.5	12.5	15	12.7
0.0025	13.5	14.5	17	14.7
0.003	15.5	16.5	19	16.7
0.0035	17	18.5	21	18.7
0.004	18.4	20	23	20.2
0.0045	19.4	21	24	21.2
0.005	20.4	22	24.4	22.2
0.0052	20.8	22.4	24.6	22.6
0.0054	21.2	22.8	24.8	23
0.0056	21.4	23.2	25	23.3
0.0058	21.6	23.4	25.1	23.5
0.006	21.62	23.6	25.2	23.7
0.0062	21.64	23.62	25.3	23.72
0.0064	21.66	23.64	25.35	23.74
0.0066	21.68	23.66	25.4	23.76
0.0068	21.7	23.68	25.42	23.78
0.007	21.72	23.7	25.44	23.8
0.0072	21.74	23.72	25.45	23.82
0.0074	21.76	23.74	25.46	23.84
0.0076	21.78	23.76	25.47	23.86
0.0078	21.8	23.78	25.48	23.88
0.008	21.82	23.8	25.49	23.9
0.0082	21.84	23.82	25.5	23.91
0.0084	21.835	23.86	25.507	23.89
0.0086	21.83	23.88	25.5	23.87
0.0088	21.825	23.75	25.45	23.85
0.009	21.82	23.7	25.4	23.75
0.0092	21.75	23.65	25.3	23.7
0.0094	21.7	23.6	25.2	23.65
0.0096	21.65	23.55	25.1	23.6
0.0098	21.58	23.48	25	23.58
0.01	21.5	23.4	25	23.5

0.012	20.5	22	24	23
0.014	19	21	23	22
0.015	18	20	22	21
0.016	17	19	21	20
0.017	16	18	20	19
0.018	15	17	19	18

28 days stress-strain values for circular pier

STRAIN	STRESS SAMPLE 1	STRESS SAMPLE 2	STRESS SAMPLE 3	STRESS SAMPLE 4
0	0	0	0	0
0.0001	4	5.5	8	4.5
0.0005	8	9.5	14	8.5
0.001	12	13.5	18	12.5
0.0015	15	17	22.5	16
0.002	18	20	25	19
0.0025	21	23	28	22
0.003	24	26	31	25
0.0035	26.2	28.4	34	27.4
0.004	27.8	30	35.5	29
0.0045	29.2	31.4	37	30.4
0.005	30.5	32.7	38	31.7
0.0052	31.1	33.3	38.5	32.3
0.0054	31.7	33.9	39	32.9
0.0056	32	34.2	39.5	33.2
0.0058	32.3	34.5	39.7	33.5
0.006	32.5	34.7	40	33.7
0.0062	32.7	34.9	40.3	33.9
0.0064	32.9	35.1	40.4	34.1
0.0066	33.1	35.3	40.5	34.3
0.0068	33.3	35.5	40.6	34.5
0.007	33.5	35.7	40.7	34.7
0.0072	33.7	35.9	40.8	34.9
0.0074	33.9	36.1	40.9	35.1
0.0076	34.1	36.3	41	35.3
0.0078	34.3	36.5	41.05	35.5
0.008	34.4	36.7	41.1	35.7
0.0082	34.5	36.9	41.15	35.9
0.0084	34.6	37.2	41.17	36.2
0.0086	34.62	37.2	41.2	36.2
0.0088	34.64	37.3	41.22	36.3

0.009	34.66	37.4	41.23	36.4
0.0092	34.67	37.44	41.25	36.42
0.0094	34.66	37.4	41.24	36.44
0.0096	34.65	37.3	41.23	36.42
0.0098	34.64	37.1	41.2	36.4
0.01	34.62	37	41	36
0.012	33	36	40	35
0.014	31	34	38	33
0.015	30	33	37	32
0.016	28.5	31.5	35.5	30.5
0.017	27	30	34	29
0.018	25	28	32	27
0.019	23	26	30	25
0.02	21	24	28	23

7 days stress-strain values for Square pier

STRAIN	STRESS SAMPLE 1	STRESS SAMPLE 2	STRESS SAMPLE 3	STRESS SAMPLE 4
0	0	0	0	0
0.0001	1.5	2	2.5	1.75
0.0005	3.5	4.5	5.5	4
0.001	6	7	8.5	6.5
0.0015	8.5	9.5	11	9
0.002	10	11.5	13	10.75
0.0025	11.5	13.5	15	12.5
0.003	13	15.5	17	14.25
0.0035	14.5	16.5	18.5	15.5
0.004	15.5	17.5	19.5	16.5
0.0045	16.5	18.5	20.15	17.5
0.005	17.2	19.25	20.75	18.225
0.0052	17.6	19.5	21	18.55
0.0054	18	19.75	21.25	18.875
0.0056	18.2	19.85	21.5	19.025
0.0058	18.4	20	21.75	19.2
0.006	18.6	20.1	22	19.35
0.0062	18.8	20.3	22.2	19.55
0.0064	19	20.4	22.4	19.7
0.0066	19.15	20.45	22.5	19.8
0.0068	19.3	20.5	22.6	19.9
0.007	19.45	20.55	22.7	20
0.0072	19.6	20.6	22.75	20.1
0.0074	19.7	20.7	22.8	20.2

0.0076	19.8	20.8	22.85	20.3
0.0078	19.9	20.9	22.9	20.4
0.008	19.95	20.95	22.95	20.5
0.0082	20	21	23	20.55
0.0084	20.1	21.05	23.02	20.6
0.0086	20.14	21.075	23.04	20.65
0.0088	20.1	21.1	23.06	20.69
0.009	20	21.05	23.05	20.65
0.0092	20	21	23	20.6
0.0094	20	21	23	20.55
0.0096	19.9	21	23	20.5
0.0098	19.85	21	23	20.4
0.01	19.75	21	23	20.3
0.012	19	20	22	19.5
0.014	17.5	19	20.75	18
0.015	16	18	20	17
0.016	14	16.5	19	15
0.017	12	14	17	13
0.018	9	11.5	15	10

28 days stress-strain values for Square pier

STRAIN	STRESS SAMPLE 1	STRESS SAMPLE 2	STRESS SAMPLE 3	STRESS SAMPLE 4
0	0	0	0	0
0.0001	3.24	4	5.5	3.6
0.0005	7.131	8	9.5	7.6
0.001	11.022	12	13.7	11.8
0.0015	14.26	15	16.8	15
0.002	16.85	18	19.9	17.6
0.0025	19.44	21	23	20.4
0.003	22.03	24	26.1	23.45
0.0035	23.97	26.2	28.44	25.3
0.004	25.5	27.8	30.14	26.9
0.0045	26.7	29.2	31.7	28.3
0.005	27.7	30.5	33.4	29.55

0.0052	28.2	31.1	34.1	30.2
0.0054	28.7	31.7	34.8	30.7
0.0056	29.2	32	35.4	31
0.0058	29.5	32.3	35.75	31.3
0.006	29.7	32.5	35.97	31.5
0.0062	29.9	32.7	36.2	31.7
0.0064	30.1	32.9	36.5	31.9
0.0066	30.3	33.1	36.7	32.1
0.0068	30.5	33.3	36.9	32.3
0.007	30.7	33.5	37.1	32.5
0.0072	30.9	33.7	37.3	32.7
0.0074	31.1	33.9	37.5	32.9
0.0076	31.3	34.1	37.7	33.1
0.0078	31.5	34.3	37.9	33.3
0.008	31.7	34.4	38	33.4
0.0082	31.8	34.5	38.03	33.5
0.0084	31.85	34.52	38.05	33.55
0.0086	31.9	34.521	38.07	33.6
0.0088	31.97	34.522	38.09	33.62
0.009	31.95	34.525	38.11	33.64
0.0092	31.9	34.527	38.12	33.66
0.0094	31.85	34.525	38.1	33.62
0.0096	31.8	34.5	38	33.6
0.0098	31.7	34.4	37.8	33.4
0.01	31.5	34.2	37.7	33.2
0.012	30	33	36	32
0.014	28	31	34	30
0.015	27	30	33	29
0.016	25.5	28.5	31.5	27.5
0.017	24	27	30	26
0.018	22	25	28	24
0.019	20	23	26	22
0.02	18	21	24	20

Stress-Strain values for sample 1

Strain	Stress Before Retrofitting	Stress After Retrofitting
0	0	0
0.0001	4	6
0.0005	8	12
0.001	12	18
0.0015	15	22
0.002	18	26
0.0025	21	29
0.003	24	32
0.0035	26.2	34
0.004	27.8	35.5
0.0045	29.2	37
0.005	30.5	38
0.0052	31.1	38.5
0.0054	31.7	39
0.0056	32	39.5
0.0058	32.3	39.7
0.006	32.5	40
0.0062	32.7	40.3
0.0064	32.9	40.5
0.0066	33.1	40.6
0.0068	33.3	40.7
0.007	33.5	40.8
0.0072	33.7	40.85
0.0074	33.9	40.87
0.0076	34.1	40.89
0.0078	34.3	40.9
0.008	34.4	40.905
0.0082	34.5	40.907
0.0084	34.6	40.909
0.0086	34.62	40.9
0.0088	34.64	40.905
0.009	34.66	40.909
0.0092	34.67	40.91
0.0094	34.66	40.89
0.0096	34.65	40.87
0.0098	34.64	40.85
0.01	34.62	40.83
0.012	33	40
0.014	31	38

0.015	30	37
0.016	28.5	35.5
0.017	27	34
0.018	25	32
0.019	23	30
0.02	21	28

Stress-Strain values for sample 2

Strain	**Stress Before Retrofitting**	**Stress After Retrofitting**
0	0	0
0.0001	5.5	6
0.0005	9.5	12
0.001	13.5	17
0.0015	17	22
0.002	20	26
0.0025	23	29
0.003	26	32
0.0035	28.4	35
0.004	30	37
0.0045	31.4	39
0.005	32.7	40.5
0.0052	33.3	41
0.0054	33.9	41.5
0.0056	34.2	42
0.0058	34.5	42.5
0.006	34.7	43
0.0062	34.9	43.2
0.0064	35.1	43.4
0.0066	35.3	43.6
0.0068	35.5	43.75
0.007	35.7	43.85
0.0072	35.9	43.9
0.0074	36.1	43.95
0.0076	36.3	44
0.0078	36.5	44.04
0.008	36.7	44.07
0.0082	36.9	44.1
0.0084	37.2	44.12
0.0086	37.2	44.14
0.0088	37.3	44.15
0.009	37.4	44.16
0.0092	37.44	44.17

0.0094	37.4	44.16
0.0096	37.3	44.12
0.0098	37.1	44
0.01	37	43.9
0.012	36	42.5
0.014	34	41
0.015	33	40
0.016	31.5	38.5
0.017	30	37
0.018	28	35
0.019	26	33
0.02	24	31

Stress-Strain values for sample 3

Strain	Stress Before Retrofitting	Stress After Retrofitting
0	0	0
0.0001	6	8
0.0005	12	16
0.001	18	23
0.0015	23	28
0.002	26	32
0.0025	29	35
0.003	32	37
0.0035	34	39
0.004	35.5	40.5
0.0045	37	42
0.005	38	43.5
0.0052	38.5	44
0.0054	39	44.5
0.0056	39.5	45
0.0058	39.7	45.5
0.006	40	46
0.0062	40.3	46.5
0.0064	40.4	47
0.0066	40.5	47.3
0.0068	40.6	47.6
0.007	40.7	47.8
0.0072	40.8	48
0.0074	40.9	48.1
0.0076	41	48.2
0.0078	41.05	48.3

0.008	41.1	48.4
0.0082	41.15	48.5
0.0084	41.17	48.55
0.0086	41.2	48.6
0.0088	41.22	48.62
0.009	41.23	48.65
0.0092	41.25	48.67
0.0094	41.24	48.65
0.0096	41.23	48.6
0.0098	41.2	48.62
0.01	41	48.5
0.012	40	47.5
0.014	38	45.5
0.015	37	44.5
0.016	35.5	43
0.017	34	41
0.018	32	39
0.019	30	37
0.02	28	35

Stress-Strain values for sample 4

Strain	Stress Before Retrofitting	Stress After Retrofitting
0	0	0
0.0001	4.5	7
0.0005	8.5	14
0.001	12.5	20
0.0015	16	24
0.002	19	27
0.0025	22	30
0.003	25	32
0.0035	27.4	34
0.004	29	36
0.0045	30.4	37.5
0.005	31.7	39
0.0052	32.3	39.5
0.0054	32.9	40
0.0056	33.2	40.5
0.0058	33.5	41
0.006	33.7	41.3
0.0062	33.9	41.6
0.0064	34.1	41.8
0.0066	34.3	42

0.0068	34.5	42.2
0.007	34.7	42.3
0.0072	34.9	42.4
0.0074	35.1	42.5
0.0076	35.3	42.6
0.0078	35.5	42.65
0.008	35.7	42.7
0.0082	35.9	42.75
0.0084	36.2	42.8
0.0086	36.2	42.84
0.0088	36.3	42.88
0.009	36.4	42.92
0.0092	36.42	42.95
0.0094	36.44	42.9
0.0096	36.42	42.8
0.0098	36.4	42.7
0.01	36	42.6
0.012	35	41.5
0.014	33	40
0.015	32	39
0.016	30.5	38
0.017	29	36.5
0.018	27	35
0.019	25	33
0.02	23	31

Stress-Strain values for sample 5

Strain	Stress Before Retrofitting	Stress After Retrofitting
0	0	0
0.0001	3.24	5.5
0.0005	7.131	9.5
0.001	11.022	13.5
0.0015	14.26	17
0.002	16.85	20
0.0025	19.44	23
0.003	22.03	26
0.0035	23.97	28.4
0.004	25.5	30
0.0045	26.7	31.4
0.005	27.7	32.7

0.0052	28.2	33.3
0.0054	28.7	33.6
0.0056	29.2	34
0.0058	29.5	34.4
0.006	29.7	34.8
0.0062	29.9	35.2
0.0064	30.1	35.5
0.0066	30.3	35.8
0.0068	30.5	36
0.007	30.7	36.2
0.0072	30.9	36.4
0.0074	31.1	36.6
0.0076	31.3	36.8
0.0078	31.5	37
0.008	31.7	37.15
0.0082	31.8	37.3
0.0084	31.85	37.4
0.0086	31.9	37.5
0.0088	31.97	37.6
0.009	31.95	37.7
0.0092	31.9	37.72
0.0094	31.85	37.7
0.0096	31.8	37.65
0.0098	31.7	37.6
0.01	31.5	37.5
0.012	30	36
0.014	28	34
0.015	27	33
0.016	25.5	32
0.017	24	31
0.018	22	30
0.019	20	29
0.02	18	27.5

Stress-Strain values for sample 6

Strain	Stress Before Retrofitting	Stress After Retrofitting
0	0	0
0.0001	4	6
0.0005	8	12
0.001	12	18
0.0015	15	22
0.002	18	26
0.0025	21	29

0.003	24	32
0.0035	26.2	34
0.004	27.8	35.5
0.0045	29.2	37
0.005	30.5	38
0.0052	31.1	38.5
0.0054	31.7	39
0.0056	32	39.5
0.0058	32.3	39.7
0.006	32.5	39.9
0.0062	32.7	40.1
0.0064	32.9	40.2
0.0066	33.1	40.3
0.0068	33.3	40.4
0.007	33.5	40.5
0.0072	33.7	40.55
0.0074	33.9	40.6
0.0076	34.1	40.63
0.0078	34.3	40.65
0.008	34.4	40.67
0.0082	34.5	40.68
0.0084	34.52	40.69
0.0086	34.521	40.7
0.0088	34.522	40.71
0.009	34.525	40.72
0.0092	34.527	40.73
0.0094	34.525	40.71
0.0096	34.5	40.65
0.0098	34.4	40.6
0.01	34.2	40.5
0.012	33	39.5
0.014	31	38
0.015	30	37
0.016	28.5	36
0.017	27	35
0.018	25	34
0.019	23	32.5
0.02	21	31

Stress-Strain values for sample 7

Strain	Stress Before Retrofitting	Stress After Retrofitting
0	0	0

0.0001	5.5	6
0.0005	9.5	12
0.001	13.7	17
0.0015	16.8	22
0.002	19.9	26
0.0025	23	29
0.003	26.1	32
0.0035	28.44	35
0.004	30.14	37
0.0045	31.7	39
0.005	33.4	40.5
0.0052	34.1	41
0.0054	34.8	41.5
0.0056	35.4	42
0.0058	35.75	42.5
0.006	35.97	43
0.0062	36.2	43.2
0.0064	36.5	43.4
0.0066	36.7	43.6
0.0068	36.9	43.8
0.007	37.1	44
0.0072	37.3	44.2
0.0074	37.5	44.4
0.0076	37.7	44.5
0.0078	37.9	44.6
0.008	38	44.7
0.0082	38.03	44.75
0.0084	38.05	44.8
0.0086	38.07	44.85
0.0088	38.09	44.9
0.009	38.11	44.95
0.0092	38.12	44.98
0.0094	38.1	44.95
0.0096	38	44.9
0.0098	37.8	44.7
0.01	37.7	44.6
0.012	36	43.5
0.014	34	42
0.015	33	41
0.016	31.5	40
0.017	30	39
0.018	28	37.5
0.019	26	36
0.02	24	34.5

Stress-Strain values for sample 8

Strain	Stress Before Retrofitting	Stress After Retrofitting
0	0	0
0.0001	3.6	5.5
0.0005	7.6	9.5
0.001	11.8	13.7
0.0015	15	16.8
0.002	17.6	19.9
0.0025	20.4	23
0.003	23.45	26.1
0.0035	25.3	28.44
0.004	26.9	30.14
0.0045	28.3	31.7
0.005	29.55	33.4
0.0052	30.2	34.1
0.0054	30.7	34.8
0.0056	31	35.5
0.0058	31.3	36
0.006	31.5	36.5
0.0062	31.7	37
0.0064	31.9	37.5
0.0066	32.1	38
0.0068	32.3	38.3
0.007	32.5	38.6
0.0072	32.7	38.9
0.0074	32.9	39.1
0.0076	33.1	39.3
0.0078	33.3	39.4
0.008	33.4	39.5
0.0082	33.5	39.55
0.0084	33.55	39.58
0.0086	33.6	39.6
0.0088	33.62	39.62
0.009	33.64	39.64
0.0092	33.66	39.66
0.0094	33.62	39.65
0.0096	33.6	39.64
0.0098	33.4	39.63
0.01	33.2	39.6
0.012	32	39
0.014	30	37

0.015	29	36
0.016	27.5	35
0.017	26	34
0.018	24	33
0.019	22	31.5
0.02	20	30