

**RETROFITTING OF FLEXURAL MEMBERS USING WOVEN  
NATURAL JUTE AS FIBRE REINFORCED POLYMER**

*A Thesis submitted in partial fulfillment of the requirement for the award of the degree of*

**MASTER OF ENGINEERING**

**IN**

**STRUCTURAL ENGINEERING**

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## DECLARATION

I, Rahul Batish hereby declare that the work presented in this thesis entitled **“RETROFITTING OF FLEXURAL MEMBERS USING WOVEN NATURAL JUTE AS FIBRE REINFORCED POLYMER”** in fulfilments of the requirement for the award of degree of **Master of Engineering in Structural Engineering** submitted at Civil Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of **Dr. Heaven Singh, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala** from January to July, 2018.

The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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## **Abstract**

The issue of upgrading existing structures has been of great importance over the last decades due to their deterioration; ageing, environmental induce degradation, lack of maintenance, natural hazards like earthquakes, etc. Hence, for maintaining the structural integrity, retrofitting techniques are to be developed, which ensures the safety and serviceability criteria of the structures. Retrofitting can also be classified as restoring the original structure shape and strengthening the damaged members with inadequate load bearing capacity; so that the load bearing capacity of the member is enhanced.

Up-gradation or strengthening in structures arises due to structural deterioration because of corrosion in steel caused by exposure to an aggressive environment and various accident events such as earthquakes, inadequate maintenance, excessive loading, change in use or in code of practice, and/or exposure to adverse environmental conditions, bad constructional practices, usage of poor quality construction materials, and faulty design practices. Inadequate performance of any type of structure is a major concern from public safety standpoint. That is the reason why repair and rehabilitation of existing structures is becoming a major part of constructional activities all over the world. Some estimates have indicated that, worldwide, in the years to come, the expenditure for maintenance and repair work will represent about 85% of the total expenditure in the construction field. Full structural replacement might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption in the function of the structure.

This study will help in reviewing the characteristics of the structures retrofitted with the material which is made using natural fibre i.e. jute.

It will also compare the results of various test performed on retrofitted members with natural fibre.

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# CHAPTER 1

## INTRODUCTION

### 1.1 GENERAL

Reinforced concrete is one of the most abundantly used construction material, not only in the developed world, but also in the remotest parts of the developing world. The RCC structures constructed in the developed world are often found to exhibit distress and suffer damage, even before their service period is over due to several causes such as earthquake, floods, fire, overloading, etc.

Such structures require attention, check of the cause of distress and suitable remedies to be adopted, so that structure could be used again.

In the recent years several researches are going on to increase the life of the structures by retrofitting and strengthening techniques. Among the retrofitting techniques, FRP jacketing is one of the most popular and convenient method of retrofitting is used nowadays. In FRP jacketing various FRPs are used to retrofit the distressed flexural members. But it is observed that using the FRPs is restricted. There is need to develop a technique, which is economical and could be executed at site with semi-skilled labour. Natural Fibre jacketing using jute fibre is found to be one such attractive technique due to its lightweight, overall economy, easy application and good tensile strength.

Some estimates have indicated that, worldwide, in the years to come, the expenditure for maintenance and repair work will represent about 85% of the total expenditure in the construction field. Full structural replacement might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption in the function of the structure, e.g. Traffic problems and also result in difficulty in its usage. When possible, it is often better to repair or upgrade the structure by retrofitting. Furthermore, it has been forecast that huge sum will be devoted for spending just on the restoration of deteriorated bridges and viaducts and other mass public usage constructional facilities. Most of the rehabilitation works consist of repairing old deteriorating structures, and structures damaged by earthquakes and natural disasters.

Hence the development of cost-effective and long-lasting repair/retrofit methods can greatly reduce maintenance requirements, increase life safety and increase the entire service life of concrete structures. Recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength good fatigue and corrosion resistance and ease of use, make these new composite materials an attractive alternative to any other retrofitting technique in the field of repair and strengthening of concrete elements

RC beams strengthened with externally bonded natural FRPs, when subjected to constantly increasing loads, faces three failures that are identified as flexure, debonding and shear.

Flexural failure of a beam is ductile in nature, i.e., it occurs gradually with large deflections and cracking, which provide a warning of incipient failure. Conversely, shear failure is brittle in nature and does not allow substantial redistribution of loads; thus, shear failure occurs without any prior warning and is often catastrophic. Poorly designed beams may fail in shear before reaching the flexural strengths. Hence, RC beams must have sufficient shear strength, higher than flexural strength, in order to ensure a ductile failure mode.

Shear failure in flexural members may be due to reduced shear reinforcement, overloading of the beams, etc. thus strengthening of the beams is required to increase the ultimate load bearing capacity of the beams.

Debonding of FRP is prevalent, however surface treatment is done using sand paper to roughen the surface before lamination. Roughened surface makes good bond with epoxy using which FRP is bonded with the surface of RCC beam.

## **1.2 Jute as Natural FRP**

India is the largest producer of raw jute since last two centuries. Jute is the second most important natural fibre after cotton due to its versatility. Jute is replacing many synthetic materials because it's biodegradable and eco-friendly behaviour.

In the context of materials which are eco-friendly and could be produced economically are to be used in the construction purposes also. Jute is produced abundantly in our country and also our country is developing so both the factors are in our favour. Using jute in the building purposes could be feasible if and if researchers are willing to develop such techniques using which threshold of both the factors could be reached. It would be beneficial to the farmers producing jute, jute industry of India as well as infrastructure companies using jute in construction purposes.

FRPs offer designers an excellent combination of properties not available from other materials and present a potential solution to civil infrastructure's crisis hence are suitable materials for structural retrofitting, FRP composite materials also offer an attractive alternative to any other retrofitting technique in the field of repair and strengthening of concrete elements.

The advantages of FRP are many such as high strength to- weight ratio, high specific tensile strength, good fatigue resistance, ease of installation and corrosion resistance characteristics, ease of repairing, high strength in the required direction, and higher ultimate strength and lower density than steel, etc. are some of the properties which make FRPs ideal for strengthening applications. But a good amount of theoretical knowledge and design guidelines is required to ensure a safe, reliable and cost-efficient use of FRP materials. The most widely used fibres, which are used as reinforcements in FRP, for the strengthening of concrete structures are artificial fibres which are carbon, glass, and aramid, etc.

Carbon fibre is one of the costliest of all the fibres, followed by aramid fibres, and although it comes with an advantage of increasing the structural potential by many folds, it also comes at an overhead of huge price and cost, and hence cannot be easily considered as a good outcome based market product. Although the requirement of structural strengthening is increasing day by day with the deterioration of increasing civil infrastructure, the cost of these artificial fibres is also increasing, with the increment of various environmental challenges that the fabrication of these fibres pose.

Although glass fibre is cheaper than carbon and aramid fibres, it has resulted in dermatitis problems in many workers dealing with glass fibre products and applications. Hence, innovative strengthening techniques, which uses user friendly as well as pocket friendly fibres, for the production and making of fibre reinforced polymer are becoming increasingly important to enable the extension of service life of deteriorated civil infrastructure.

Also it is to be kept in mind that the materials chosen for structural up-gradation must, in addition to functional efficiency and increasing or improving the various properties of the structures, fulfil some criterion, for the cause of sustainability and a better quality. For example, these materials should not pollute the environment and endanger bio-reserves, should be such that they are self-sustaining and promote self-reliance, should help in recycling of polluting waste into usable materials, should make use of locally available materials, utilise local skills, manpower and management systems, should benefit local economy by being income generating, should be accessible to the ordinary people and be low in monetary cost.

Besides improving the strength of the structure using FRPs as the raw material, it is also necessary to make use of local materials in construction. So far the work on retrofitting of structures is confined to the use of carbon, glass or aramid fibres, etc., and very little work is being imparted in improving structures using naturally available materials, or natural fibres. The application of composites in structural facilities is mostly concentrated on increasing the strength of the structure with the help of artificial fibres and does not address the issue of sustainability of these raw materials used for strengthening purposes.

In an expanding world population and with the increase in the purchasing potentials, the need for raw materials required for structural strengthening, that would satisfy the demand on world market is rapidly growing. In times when we cannot expect the fibre reinforced polymer prices to come down, with the consumption growing day by day, new materials that would be cheaper and at the same time offer equal or better properties have to be developed and be utilised for the up gradation of various engineering structural components.

New materials, apart from the conventional ones, should be developed and used for structural strengthening, and these materials have shown promise and good properties and enhancement in structural improvement. Economic and other related factors in many developing countries where natural fibres are abundant, demand that scientists and engineers apply appropriate technology to utilise these natural fibres as effectively and economically as possible for structural up gradation and also other purposes for housing and other needs, etc. We have enough natural resources and we must keep on researching on these natural resources. Development of plant fibre composites has only begun. Large number of various natural fibres, such as jute coir, banana and sisal, etc., mainly manufactured in India, are among those fibre reinforced composites which are of particular interest as these composites have high impact strength besides having moderate tensile and flexural properties compared to other fibres. Hence encouragement should be given for the use of natural fibres such as coir fibres, jute fibres and sisal fibres which are locally available materials, in the field of structural retrofitting. Here an attempt is made to study the possibilities of using jute fibre materials as jute fibre reinforced polymer, in structural retrofitting of reinforced concrete beams, which tries to improve the structural properties of the said beams.

Natural fibres such as jute fibres are recyclable and also they are produced from a source which is renewable, and are also carbon neutral since carbon dioxide (CO<sub>2</sub>) emitted during the production is reabsorbed by new plant growth.

They pose no risk to human health when fibre particles are inhaled, and at end of their life they are biodegradable. The environmental standing for natural fibre composites as compared to their counterparts, e.g. synthetic fibre composites is not as conclusive if only the production phase, i.e. the manufacturing phase is considered in the life cycle assessment. The situation improves dramatically when the use phase is included in LCA. The longevity of the product with several other environmental benefits introduces a great improvement in the LCA. Even the disposal phase also improves the environmental standing by giving back some energy, by being recyclable, and also by being re-usable and saving landfill spaces and by not conferring to environmental pollution as contributed by the incineration process by which artificial or synthetic fibres are disposed. Hence natural fibres and their utilization dispose a favourable score in environmental terms, with various positive environmental indicators.

## CHAPTER 2

### REVIEW OF LITERATURE

Much research has been done to assess effectiveness of FRP retrofitting technique during the last years. This section presents a brief review of research done related to the use of natural fiber reinforced polymers for repairing or strengthening purposes. The research done concerning retrofitting with this type of materials has two main motivations. By one side, it is aimed at solving durability or aging problems or prolonging service life of the structure and by the other side, it is aimed at solving strength or structural problems. The use of fiber reinforced polymer both for the strengthening and repairing of different types concrete and reinforced concrete elements like beams, columns, panels, joints, slabs and pavements has been extensively investigated during the last years. The reinforced concrete structures retrofitting technique using fiber reinforced polymer (FRP) avoids some of the problems that other systems present like the brittle failure of the interface retrofitting layer/concrete. Compared with fiber reinforced cement composites, fiber reinforced polymer present higher resistance against high temperature and ultraviolet radiation, more long term durability and fundamentally more compatibility with the substrate. Moreover, the use of fibers on the retrofitting concrete layer helps controlling shrinkage cracking.

Hence, innovative strengthening techniques, which uses user friendly and pocket friendly fibres, for the production and making of fibre reinforced polymer are becoming increasingly important to enable the extension of service life of deteriorated civil infrastructure.

Also it is to be kept in mind that the materials chosen for structural up-gradation must, in addition to functional efficiency and increasing or improving the various properties of the structures, fulfil some criterion, for the cause of sustainability and a better quality. For example, these materials should not pollute the environment and endanger bio reserves, should be such that they are self-sustaining and promote self-reliance, should help in recycling of polluting waste into usable materials, should make use of locally available materials, utilise local skills, manpower and management systems, should benefit local economy by being income generating, should be accessible to the ordinary people and be low in monetary cost. Besides improving the strength of the structure using FRPs as the raw material, it is so necessary to make use of local materials in construction.

So far the work on retrofitting of structures is confined to the use of carbon, glass or aramid fibres, etc and very little work is being imparted in improving structures using naturally available materials, or natural fibres. The application of composites in structural facilities is mostly concentrated on increasing the strength of the structure with the help of artificial fibres and does not address the issue of sustainability of these raw materials used for strengthening purposes. In an expanding world population and with the increase in the purchasing potentials, the need for raw materials required for structural strengthening, that would satisfy the demand on world market is rapidly growing. In times when we cannot expect the fibre reinforced polymer prices to come down, with the consumption growing day by day, new materials that would be cheaper and at the same time offer equal or better properties have to be developed and be utilised for the upgradation of various engineering structural components. New materials, apart from the conventional ones, should be developed and used for structural strengthening, and these materials have shown promise and good properties and enhancement in structural improvement

**Prem Pal Bansal et.al (2010)** studied the effect of fibre orientation and stress level on the strength of stressed beams retrofitted with GFRP jackets. The beams were initially stressed up to 60, 75 and 90% of their safe load and then retrofitted with GFRP jackets with fibres in different orientations. The results show that those beams which are retrofitted using Glass Fibre Reinforced Polymer (GFRP) jackets with fibres at 45 degree to the longitudinal axis yield an increase in the maximum load carrying capacity, i.e., approximately 30–35% in case of under-reinforced sections and 13–17% in case of balanced sections as compared to beams retrofitted using fibres at 0° to the longitudinal axis. A considerable increase in the ductility ratio is also observed for both the fibre orientations.

GFRP jackets used for retrofitting of the under-reinforced beams perform better with fibres at 45 degrees to the longitudinal axis of the beam.

The strength of the section decreased with an increase in the initial stress level. The maximum load carrying capacity of the beams decreased due to decrease in stiffness of the section with an increase in the initial stress level.

The initially stressed beams retrofitted with GFRP jackets had a lesser safe load carrying capacity. This is attributed to the fact that due to initial stress level the section loses its stiffness, hence deflects more when reloaded after retrofitting.

GFRP jacketing helps to improve the energy absorption capacity of all the beams, irrespective of the type of section and orientation of fibres in the jackets.

The under-reinforced sections with fibres oriented at 45° performed better within the group.

**Prem Pal Bansal et.al (2011)** effect of wire mesh orientation on the strength of stressed beams retrofitted with Ferro cement jackets has been studied. The beams after being stressed up to 75 percent of safe load are then retrofitted with Ferro cement jacket with wire mesh at various orientations. The results demonstrate that the increase in load carrying capacity percentage for beam retrofitted with Ferro cement jackets with wire mesh at degree angles of 0, 45, and 60 with longitudinal axis of beam, varies from 45.87 to 52.29 percent. Also a considerable increase in energy absorption is observed for all orientations. Also, orientation at 45 degree shows a higher percentage increase in energy absorption which is followed by 6 and 0 degree respectively.

The beams that are retrofitted with wire mesh at different orientations do not de-bond when loaded to failure.

The failure of the composite is characterized by development of flexural cracks over the tension zone. The reduced spacing of cracks for retrofitted beams indicates better distribution of stress. Wire mesh at 45 degree orientation for retrofitting the stressed beams has the highest load carrying capacity as compared to control beam as well as the other beams retrofitted using different orientations.

After retrofitting, all the test specimens showed reduced crack widths, large deflection at the ultimate load, a significant increase in the ductility ratio and considerable increase in the energy absorption as well, making the components better equipped to resist dynamic loads.

A vigorous cost analysis was done shown in the following Table 2.1:

**Table 2.1 :- cost analysis:-**

Material	Rate (Rs.)	Cost (Rs.) of Beam type			
		A++	B++	C++	D++
<b>Concrete Ingredients</b>					
Cement (kg)	215	215	215	215	215
Rebars (kg)					
10mm	30.10	148.724	148.724	148.724	148.724
8mm	30.75	97.14	97.14	97.14	97.14
6mm	33.75	111.52	111.52	111.52	111.52
Coarse Aggregates (cft)	14.0	50.89	50.89	50.89	50.89
Fine aggregates (cft)	17.0	29.56	29.56	29.56	29.56
Labour for control beams	Lump Sum	200	200	200	200
<i>Cost of Ingredients</i>		852.834	852.834	852.834	852.834
<b>Retrofitting Material</b>					
Welded Wire mesh	Lump Sum	-	330	420*	480*
Additional material like cement, Fine aggregates, screws etc.	Lump Sum	-	107	107	107
Labour	Lump Sum	-	192	192	192
<i>Cost of Retrofitting</i>		-	629	719	779
<b>Total Cost</b>		<b>852.834</b>	<b>1481.834</b>	<b>1572.834</b>	<b>1631.834</b>

<sup>++</sup> Beam Type A = Control un-retrofitted beam

Beam Type B = Beam retrofitted with welded wire mesh oriented at zero degree

Beam Type C = Beam retrofitted with welded wire mesh oriented at 45 degree

Beam Type D = Beam retrofitted with welded wire mesh oriented at 60 degree

The cost of the wire mesh at the orientation of 45 degrees and 60 degrees increases due to wastages at these angles.

**Tara Sena et.al 2013** studied Applicability of the jute textile FRP as a strengthening material was probed via many experimental works of mechanical characterisation of the FRP along with strengthening effects provided by bonding of jute textile FRP to beams over bonding of carbon textile FRP and glass textile FRP.

Ultimate Load and Deflection were observed as shown in Table 2.2 in the experimentation of RC beams strengthened in flexure by textile FRPs. The first set of beams that are group A, with no FRP failed in flexure which proved that the beams were deficient in flexure.

Beam Group	FRP used	Ultimate Load (KN)	Deflection(mm)	Deflection Comments
A (No Wrapping)	None	80	11.426	No warning Brittle Failure
B (U Wrapping)	Jute	130	23.211	Huge Deflection, Sufficient Warning
	Carbon	200	16.31	Least Deflection
	Glass	180	17.626	Less than Jute Retrofitted Beams but higher than Carbon FRP
C (Strip Wrapping)	Jute	100	17.863	Lower than fully wrapped beams, since failure occurs at lower loads.
	Carbon	120	10.126	
	Glass	110	10.854	

**Table 2.2**

Mid span which is the pure flexure zone suffered major vertical cracks. These cracks firstly developed at the lower face that is at the bottom side of the beam and extended from the bottom side towards the top face of the beam. The average ultimate strength of group A beams was 80 KN.

The second set of beams in group B with U wrapped FRP, it was seen that both these beams failed in flexure and their ultimate load carrying capacity was much higher than that of Group A beams. When load was applied on Jute FRP retrofitted beam, then firstly the matrix started cracking, then on further increment of load, the jute fibres in the textile jute FRP started to crack, then again on further load increment the cracks in jute FRP started to widen, then the RC beam showed a vertical crack in the flexure zone, and then this crack started slowly moving from the bottom face of the beam to the top face. The failure modes depicted by these beams were very ductile in nature and the beam carried huge deflections before reaching its ultimate load.

There was no de-bonding of jute FRP at all from the beam face in any direction even at very high load, only a single crack appeared in Jute FRP specimen at the flexure zone (near the beam mid span) and this crack started to widen with the increase in the load, without the development of any other cracks, these cracks were also observed in flexure zone of the beam and the ultimate load carrying capacity was reached by further widening of the crack at the centre, without generation of any other alternate cracks. The average ultimate strength of group B beams retrofitted with Jute FRP was 130 KN.

Testing on Group C beams, retrofitted with strip type U technique showed that their ultimate load carrying capacity was higher than that of Group A beams, but lower than that of group B beams, in which 3 sided that is U, full wrapping using different fibres were carried out. In all the beams of group C, it was observed that cracks first developed in the RC beams and not on the FRP, be it jute textile FRP, carbon FRP or glass FRP, this indicated that the presence of bonded FRP on RC beams, be it natural FRP like jute, or artificial FRP like carbon and glass, imparted additional strength to the beams, and there by enhanced the ultimate load carrying capacity of the beams.

Major vertical cracks developed in the mid span that is the pure flexure zone, and these cracks developed only in the beam area and not even a single flexural crack developed in the FRP, nor did the FRP undergo rupture, these cracks on the beam, firstly developed at the lower face that is the bottom side of the beam and extended from the bottom side towards the top face of the beam.

The load deflection behaviour of all the beams was noted. The mid-span deflection of each beam was compared with that of the group A controlled beams. Comparison between two wrapping schemes having the same reinforcement was made on the load deflection behaviour. It was noted that the behaviour of the group B beams when bonded with fully wrapped textile FRP were better than group A controlled beams. The mid-span deflections were higher when bonded externally with textile FRP because the ultimate load at failure was much higher.

**H.N. Jagannatha Reddy et.al 2014** have developed Sisal fabric reinforced polymer composite system and then its tensile and flexural behaviour was characterized and compared with that of carbon and glass fabric reinforced polymer composite. They have carried out the study of flexural cracking, effect on ultimate load carrying capacity and load deflection behaviour of RC beams bonded externally with SFRP, CFRP and GFRP.

When woven sisal fabric was subjected to heat treatment, then it increased the flexural as well as the tensile strength of woven sisal FRP composite. Hence it can be concluded that the performance of heat treated woven sisal fibre reinforced polymer (FRP) composites were superior than the untreated or raw woven sisal fibre reinforced composites. The heat treatment aided in enhancing the mechanical properties of woven sisal FRP composite, by the virtue of modification of cellulosic structure by enhanced cross-linking, increased amount of crystallinity in the fibres, and by de-moisturization, which improved the adhesion between the fibres and the natural rubber backing of the fabric.

The woven sisal FRP composite exhibited a tensile strength of 223.367 N/mm<sup>2</sup>, which was 24% of the tensile strength of carbon FRP (923.056 N/mm<sup>2</sup>) and 33% of the tensile strength of glass FRP (678.571 N/mm<sup>2</sup>). The woven sisal FRP composite exhibited a flexural strength of 350.034 N/mm<sup>2</sup>, which was 22% of the flexural strength of carbon FRP (1587.134 N/mm<sup>2</sup>) and 52% of the flexural strength of glass (E-glass) FRP (666.871 N/mm<sup>2</sup>).

The study showed that the reinforcement of woven sisal fibre reinforced polymer composites created a new alternate material with properties that were generally with superior mechanical properties.

Un-strengthened beams, i.e. controlled beams failed at 80 kN, whereas the beams strengthened by full wrapping technique by using heat treated woven sisal FRP, woven carbon FRP and woven glass FRP failed at 170 kN, 200 kN and 180 kN respectively. The beams strengthened by the strip wrapping technique by using heat treated woven sisal FRP, woven carbon FRP and lastly woven glass FRP failed at 130 KN, 120 KN and 110 KN respectively. This depicted the effect of flexural strengthening, provided by the use of natural woven sisal FRP, bonded to reinforced concrete beams of comparable magnitude of that provided by glass FRP. The load carrying capacity increased with an improvement in the load deflection behaviour due to the increase in degree of strength. The load deflection behaviour was better for beams retrofitted with FRP compared to the controlled beams.

A significant difference was observed in the failure pattern of woven natural fibre FRP strengthened beams and woven artificial fibre FRP strengthened beams. For SF1 and SF2, failure was observed by the development of single crack at the beam mid-span, firstly crack developed in the sisal FRP, followed by the development of large flexural cracks in the beam area, further failure took place by widening of these flexure cracks, this resulted in a ductile type of failure with high deflection and totally avoided any mode catastrophic failure of beams.

**Jayanarayanan Karingamanna et.al 2016** made an attempt to assess the potency of hybrid composite system as a potential choice for the retrofitting of reinforced concrete structures. The axial compressive behaviour and stress-strain response characteristics are studied. The combination of synthetic and natural fibres are used for the external confinement of concrete cylinders.

**Compressive behaviour:** - The axial compression test results of concrete specimens confined with different FRP's like CFRP, GFRP and natural sisal.

Compression Test results are shown in **Table 2.3**

<b>Specimen</b>	<b>Compressive Strength</b>	<b>Axial Compressive Strain</b>
Concrete Normal	21.1 MPa	0.32 %
Sisal Retrofitted	27.6 MPa	1.35 %
GFRP	38.5 MPa	0.72 %
CFRP	74.5 MPa	1.3 %

It is clear in the above Table that compared to plain concrete specimen FRP confined specimens has good efficiency in enhancing load carrying capacity. The highest increase in axial load carrying capacity was shown by carbon fibre (CFRP). CFRP confined specimens has shown an increase in axial load carrying capacity by 253%, followed GFRP where the axial load carrying capacity increased by 82.46% and then by sisal FRP which has shown an increase in axial load carrying capacity by 30.8%.

### **Stress-strain response**

In all the cases the concrete specimens are confined with single layer FRP. The curves of the confined specimens exhibit three different regimes. In the initial stage, the confined specimens exhibit a linear trend similar to behaviour of unconfined concrete. In the second stage a transition occurs where the strength of concrete exceeds the unconfined concrete strength and concrete starts expanding laterally which initiates the confining action of FRP. The third stage again shows a linear trend with reduced slope. The confinement effect of FRP's are manifested in the second and third stage of the curve. In the case of control specimen, the failure is occurring at the end of first stage itself. This is because the control specimens exhibits brittle failure whereas FRP strengthened specimens shows ductile mode of failure i.e. failure after yielding. Compared to synthetic fibre confinement the presence of natural fibre has shown reasonable improvement in ductility of the confined specimens. Hence, the possibility of catastrophic failure for FRP strengthened specimen is minimal, which makes it a suitable application for earthquake prone areas. The improvement in the axial strain improved the ductility of the structure which can be considered as a significant criterion for seismic resistant design of structures to avoid catastrophic failure.

**Li-Jun Ouyang et.al 2017** the researchers undertook a study of an experimental program in which carbon and basalt Fibre-Reinforced Polymer (FRP) sheets are used as confining jackets to increase the seismic performance of square reinforced concrete columns which have inadequate transverse reinforcement.

They studied seismic behaviour of square RC columns retrofitted with BFRP sheets. It is a new group of FRP composites characterized by low price and good mechanical properties. In totality, one un-retrofitted column and five FRP-retrofitted columns were tested under constant axial load and reversed-cyclic lateral load/ displacement excursions that simulated seismic loading. The effects of the amount and type of FRP jackets on the seismic performance of FRP-retrofitted columns were investigated and compared.

Ductility is an important parameter to determine the deformation capacity of structural members under seismic loadings. The displacement ductility factor is defined as the ratio of the ultimate displacement to the yield displacement is usually applied to describe the ductility capacity. The displacement ductility ratio of the un-retrofitted column is 2.5, whereas those for the retrofitted columns have significantly increased to 3.1–4.6.

According to the seismic design code NCSR-02 (reported in Caballero Morrison KE, Bonet JL, Navarro-Gregori J, and Serna-Ros P. An experimental study of steel fibre-reinforced high-strength concrete slender columns under cyclic loading. *Eng Struct* 2013; 57:565–77.), the levels of ductility can be classified as: high ductility ( $D > 4$ ), medium ductility ( $4 > D > 3$ ), low ductility ( $3 > D > 2$ ), and no ductility ( $2 > D > 1$ ). It can be seen that the reference column has a low ductility, whereas the retrofitted columns show medium levels or even high levels of ductility. Compared with the CFRP-retrofitted columns, their counterparts retrofitted with BFRP sheets possess better displacement ductility, despite having slightly lower ultimate displacement.

It was found out that the un-retrofitted RC column did not have sufficient shear strength to resist the maximum lateral load and thus failed in brittle shear failure, whereas the FRP jacket attenuated the effects of large transverse hoop spacing within the hinging zone alongwith the enhanced the shear strength in addition to enhancing the ductility performance and flexural strength.

The unretrofitted column with inadequate transverse reinforcement fails in a brittle manner because the load carrying capacity decreases rapidly after the yielding of the longitudinal steel reinforcement.

The confinement of FRP sheets significantly reduces the spalling of the cover concrete in retrofitted columns, and thus the displacement ductilities of these retrofitted columns are significantly improved by approximately 72– 112% compared with the unretrofitted column.

The energy dissipated by the columns retrofitted with FRP sheets is much higher than that evaluated for the unretrofitted column. Nevertheless, until the failure of the unretrofitted column is achieved, unretrofitted and retrofitted columns dissipate a comparable amount of energy.

The FRP jackets have also enhanced the damping behaviour of the columns as the retrofitted specimens have higher values of the equivalent viscous damping coefficient than that of the un-retrofitted column at the same lateral displacement.

The stiffness degradation of retrofitted columns is much slower at latter stages of the cyclic tests after the longitudinal steel rebars of the un-retrofitted column have yielded; however, this beneficial effect is independent of the number of layers of the applied FRP sheets.

## **CHAPTER 3**

### **EXPERIMENTAL PROGRAMME**

#### **3.1 INTRODUCTION**

At present there are a number of retrofitting materials like CFRP (Carbon fibre reinforced polymer), GFRP (Glass fibre reinforced polymer), Ferro-cement, cementitious materials etc. are being used for retrofitting of structure. Very few researchers had used natural materials for enhancing either the flexural or shear strength of the beam but in actual the beam may need strengthening in both shear and flexure. Thus in the present study 12 beams are casted and subsequently stressed to 25%, 50% and 75% of the ultimate load and are retrofitted with woven jute bonded to beam with epoxy in U-type configurations.

For the proposed work twelve beams (4100 x 230 x 130 mm) were casted. Out of these three beams are controlled beams tested to find out the safe load carrying capacity of beams and subsequently nine beams in group of 3 are stressed to 75%, 50% and 25% of the safe load and then retrofitted with natural fiber i.e. jute.

#### **3.2 TEST PROGRAMME**

The test programme is so devised so as to find out the properties of materials to be used for casting of beams and then the behaviour of retrofitted beams.

The test programme consists of:

Determination of basic properties of the constituent materials namely sand, cement, steel bars and coarse aggregates as per relevant Indian standard specifications.

2. Casting of twelve beams (4100 x 230 x 130mm) using M 25 grade concrete, the mix of which is designed with evaluated properties.

3. Computation of ultimate failure load of the beams according to maximum load carrying capacity of the sections.

4. The beams are stressed to 25%, 50% and 75% of failure load.

5. Finally beams are retrofitted with natural FRP material in U-type configuration.

#### **3.3 MATERIALS**

Coarse aggregates, cement, reinforcing bars and fine aggregates are used in designing and casting of beams. Jute in form of gunny bags and epoxy are being used for retrofitting of these beams. The specifications and properties of these materials are as under:

### 3.3.1 Portland Cement

Ultratech (PPC) cement from a single lot is used for the study. IS 8112:2013 provides the specification of cement to be used for casting. According to IS 8112 cement should be manufactured by closely mixing calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker to produce a cement that is capable of complying with this standard. No material shall be added after burning, other than gypsum (natural mineral or chemical), water, performance improver(s), and not more than a total of 1.0 percent of air-entraining agents or other agents including colouring agents, which have proved not to be harmful. It was fresh and without any lumps. The physical properties of the cement as determined from various tests conforming to Indian Standard IS: 8112: 2013 are listed in table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. The tests conducted on cement are specific gravity, initial and final setting time, compressive strength and fineness. The results of above said tests are shown in table

**Table 3.1: Properties of Cement**

Characteristics	Experimental Values Obtained	IS 12269:2013 Specified Values	Test Method Referred to
Specific Gravity	3.11	-	IS 4031 Part 11
Standard Consistency (in %)	33	-	IS 4031 Part 4
Setting Time (min)			
Initial	34	30 (Minimum)	IS 4031 Part 5
Final	320	600 (Maximum)	
Compressive Strength			
3 Days	24.5 N/mm <sup>2</sup>	23 N/mm <sup>2</sup>	IS 4031 Part 6
28 Days	33.5 N/mm <sup>2</sup>	33 N/mm <sup>2</sup>	

### 3.3.2 Coarse Aggregates

These are generally the aggregates which are the residue of the 4.75mm IS sieve and passed through 75mm IS sieve. Coarse aggregates consist of crushed gravel, uncrushed gravel and partially crushed gravel. These aggregates are formed by natural disintegration of rocks or by artificial crushing of rock or gravel. As per IS: 383-1970 standards quality of aggregates shall be hard, strong, dense, durable, clear and free from veins and adherent coating; and free from injurious amounts of disintegrated pieces, alkali, vegetable matter and other deleterious substances. As far as possible, flaky, scoriaceous and elongated pieces should be avoided. The coarse aggregates used in the present study, obtained locally, were a mixture of crushed stones of 20mm and 10mm sizes. The aggregates were thoroughly washed to remove dirt, dust and then dried to surface dry condition. They were then put into the oven for a period of 24 hours so as to remove the excess moisture present. The aggregates taken out were then cooled down to the room temperature to be used in the concrete mix.

**Table 3.2: Sieve Analysis of Coarse Aggregates (20mm)**

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	5	0.70	99.83	0.70
4	10	2982	99.40	0.43	99.57
5	4.75	13	0.43	0	100.00
6	2.36	0	0	0	100
7	1.18	0	0	0	100
8	600	0	0	0	100
9	300	0	0	0	100
10	150	0	0	0	100
11	Pan	0	0	<b>SUM</b>	<b>699.73</b>
<b>Total</b>		<b>3000</b>		<b>FM = 7.00</b>	

**Table 3.3: Properties of Coarse Aggregates**

Characteristics	Value	
Color	Grey	
Shape	Angular	
Maximum size	20mm	10mm
Specific Gravity	2.81	2.55

**Table 3.4: Sieve Analysis of Coarse Aggregate (10mm)**

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	80	0	0.00	100.00	0.00
2	40	0	0.00	100.00	0.00
3	20	0	0.00	100.00	0.00
4	10	1730	57.67	42.33	57.67
5	4.75	1270	42.33	0.00	100.00
6	2.36	0	0.00	0.00	100
7	1.18	0	0.00	0.00	100
8	600 $\mu$	0	0.00	0.00	100
9	300 $\mu$	0	0.00	0.00	100
10	150 $\mu$	0	0.00	0.00	100
11	Pan		0.00	<b>SUM</b>	<b>657.67</b>
<b>Total</b>		<b>3000</b>		<b>FM = 6.58</b>	

The specific gravity and other physical properties of coarse aggregates are shown in Table 3.2. The values obtained by the sieve analysis of coarse aggregate done in the laboratory for 20mm aggregate are shown in the Table 3.3 and for the 10mm aggregate in Table 3.4.

### 3.3.3 Fine Aggregates

According to size, the fine aggregate may be described as coarse, medium, and fine sands. The sand used for the experimental works is conformed to grading zone II (size less than 2.36 mm). IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV), depending upon the particle size distribution. The grading zones become progressively finer from grading zone I to IV. It was coarse sand light grey in colour. In this experimental program, fine aggregates which lie in grading zone II were collected from a local supplier in Patiala. The fine aggregates were washed to remove silt and clay and were then oven dried for a period of 24 hours. They were then brought down to room temperature and were then used in the concrete mix. Physical properties and sieve analysis of fine aggregates are tested as per IS: 383-1970 and results are shown in table 3.5 and table 3.6 respectively.

**Table 3.5: Physical Properties of Fine Aggregates**

Characteristics	Values
Type	Natural Sand
Specific Gravity	2.66
Fineness Modulus	2.73
Grading Zone	II

**Table 3.6: Sieve Analysis of Fine Aggregates**

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	4.75	8	0.8	99.20	0.80
2	2.36	103	10.30	88.90	11.10
3	1.18	200	20.00	68.90	31.10
4	600 $\mu$	222	22.20	46.70	53.30
5	300 $\mu$	261	26.10	20.60	79.40
6	150 $\mu$	182	18.20	2.40	97.60
7	Pan	24	2.40	-	-
<b>TOTAL</b>		<b>1000</b>		<b>SUM</b>	<b>273.30</b>
<b>Zone II</b>			<b>FM= 2.73</b>		

### 3.3.4 Epoxy

The success of the strengthening technique primarily depends on the performance of the epoxy resin used for bonding of woven jute to concrete surface. Numerous types of epoxy resins with a wide range of mechanical properties are commercially available in the market. These epoxy resins are generally available in two parts, a resin and a hardener. The epoxy resin used in this study was Dr. Fixit 211 epoxy bonding agent. The properties of the epoxy resin used in the experimental work are given in Table 3.7

**Table 3.7 - Properties of Epoxy resin (provided by manufacturer)**

Sr. no.	Physical properties	Value
1	Mix Density	1120 kg/m <sup>3</sup>
2	Colour	Grey
3	Pot Life @ 30° C	± 30-40 mins.
4	Cure time	7 days
5	Tensile strength, 7 days	10.4 N/mm <sup>2</sup>
6	Compressive strength, 7 days	60 N/mm <sup>2</sup>
7	Flexural Strength	28.1 N/mm <sup>2</sup>

### 3.4 Design of Concrete Mix

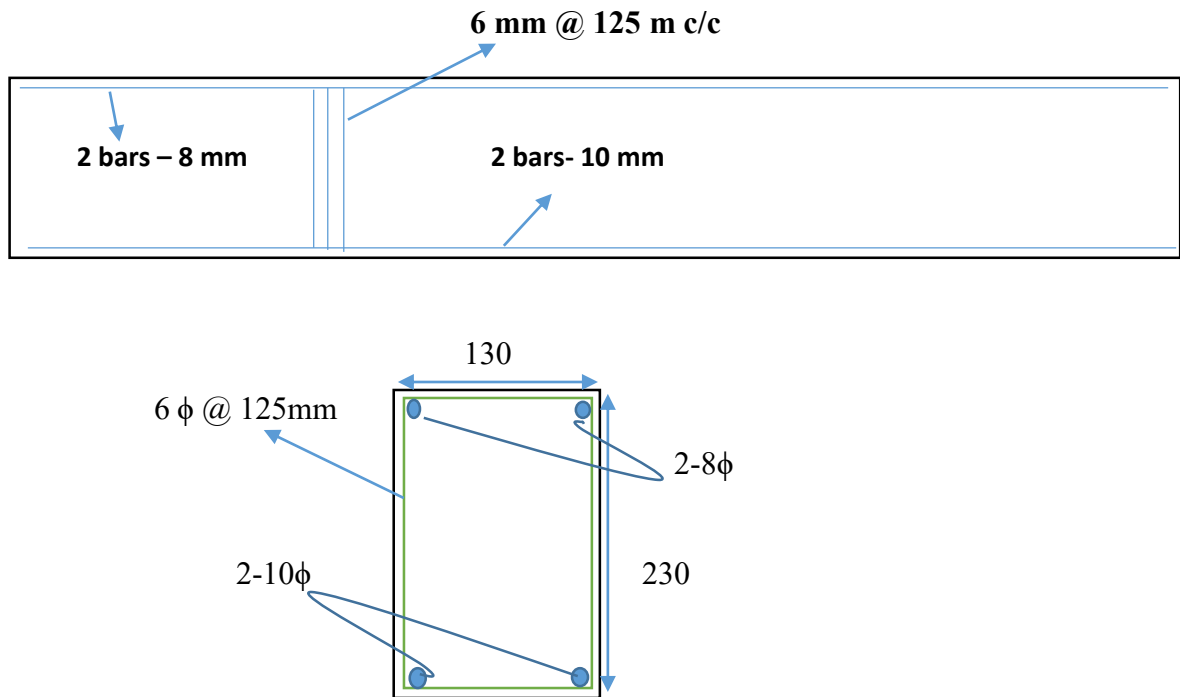
M25 concrete mix was designed by using the properties of cement, fine aggregate/sand and crushed stone coarse aggregates as per IS: 10262-2009 guidelines. The water/cement ratio was taken as 0.46. The mix proportions are given in Table 3.8 The cubes were prepared with this mix proportions and were tested at the age of 7 days and 28 days. The compressive strength of cubes (average of 3 cubes) at 7 days and 28 days was 20.9 MPa and 34.40 MPa respectively.

**Table 3.8- Mix Proportions for M25 grade concrete**

Water	Cement	Fine Aggregate/sand	Coarse Aggregates
192 kg	417.39 kg	544.38 kg	1190 kg
0.46	1	1.30	2.85

### 3.5 RCC BEAM DESIGN

In the present study RCC beam is designed using M25 grade concrete and Fe 500 steel. The RCC beam is designed using limit state method. The beam is designed having 2 steel bars of 8mm dia at compression face and 2 bars of 10mm dia at tension face; and the stirrups used are of 6mm diameter at the spacing of 125 mm.



**Figure 3.1 – Reinforcement Detailing**

### 3.6 CASTING OF RCC BEAMS

The beams are casted in a mould of size 130x 230 and of length 4100mm. First, the entire beam mould is oiled so that it can be easily removed from the mould after the desired period. Spacers of size 25 mm are used to provide uniform cover to the reinforcement. Concrete mix is poured in the mould and vibrations are given with the help of vibrator, once the bars have been placed in position as per the design. The vibration is done until the mould is completely filled and there is no gap left. The beams are then removed from the mould after 24 hours. After demoulding the beams are cured for 28days.

### 3.7 TESTING ARRANGEMENT

The beams were tested after 28 days from the date of casting. All the beam specimens were tested as simply supported beams subject to two-point loading with loads applied at  $L/3$  distance from the each end; where  $L$  is the effective span i.e.4000 mm. This load case was chosen because it gives constant moment and zero shear in the section between the loads, and constant maximum shear force between support and load. The moment was linearly varying between supports and load. The testing procedure for the entire beam specimens was same. The tests were performed using the setup as shown in the Figure 3.2.



**Figure 3.2- Two Point Loading Testing Arrangement**

### 3.8 RETROFITTING OF BEAMS

The beams are stressed up to a specified limits of the failure load and then retrofitted with woven jute using Epoxy as bonding agent between concrete and jute. The U-type retrofitting technique was used in which three sides of the flexural member are to be wrapped with the retrofitting material.

## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1 INTRODUCTION

The results of experimental work are discussed in this section. In the present study, the increase in strength of retrofitted beam is studied. For the purpose the beams were firstly stressed to predefined stress levels of 25%, 50% and 75 % of the failure load and then the beams were retrofitted as discussed earlier using epoxy and jute. The load deflection graphs of both controlled and initially stressed retrofitted beams were obtained. A comparative study on the strength variation of retrofitted beams and control beam is done with above parameters.

#### 4.2 TESTING METHODOLOGY

Firstly control beams were tested to failure and the data corresponding to it was recorded. Then three groups of three beams in each group were stressed to 25%, 50% and 75% of the failure load. The failure load was calculated from the load deflection curve of the control beams and the load so obtained was 15.90 KN. The corresponding load at 25%, 50% and 75% stress level was 3.970 KN, 7.95 KN and 11.92 KN respectively as shown in Table 4.2.1. Then the retrofitting of beams was done with woven jute using epoxy resin as bonding agent. The retrofitted beams were left to dry with jute and epoxy for 5 days and tested again with the same method as the control beam was tested initially and the corresponding results are recorded and shown in the sections to follow.

The beam designations were used as follow:-

**Table 4.1 – Beam Designations**

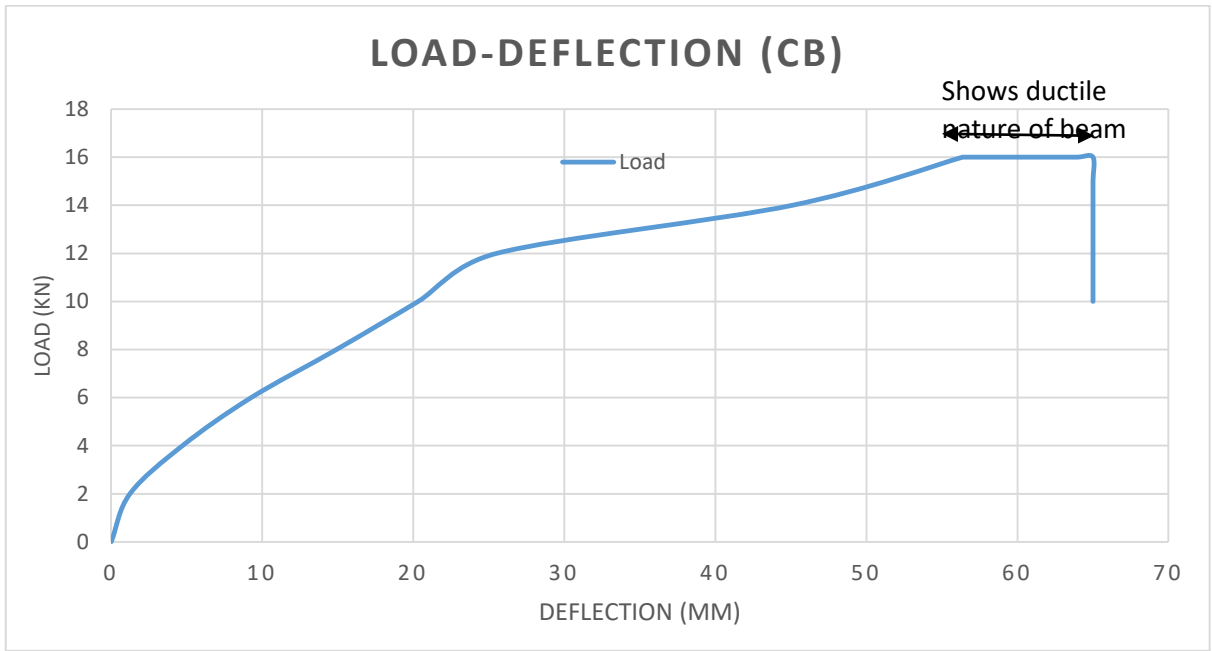
Control Beam	CB
Beams pre-loaded at 25% of Ultimate Failure Load of control beam	<b>Type I</b>
Beams pre-loaded at 50% of Ultimate Failure Load of control beam	<b>Type II</b>
Beams pre-loaded at 75% of Ultimate Failure Load of control beam	<b>Type III</b>

### 4.3 LOAD-DEFLECTION BEHAVIOUR OF CONTROL BEAM

From the graph shown in Figure 4.1 it is observed that on increasing loads at a constant rate the amount of mid-span deflection increased in the control specimen up to a load of 15.90 kN. The specimen behaved elastically till this load after which it entered the plastic range in which the deflection observed is very large as compared on the increase in the load carrying capacity of the beam. After the plastic range, there is a sudden drop in loads with zero deflection indicating that the beam has failed. Thus, the beam had an elastic range with a plastic range afterwards, indicating its ability to deflect permanently before failure that is its ductile behaviour. Figure 4.2 confirms the mode of failure of control beam which shows cracking at 90° in the beam.

**Table 4.2 Detail of Load vs Displacement of Control beam**

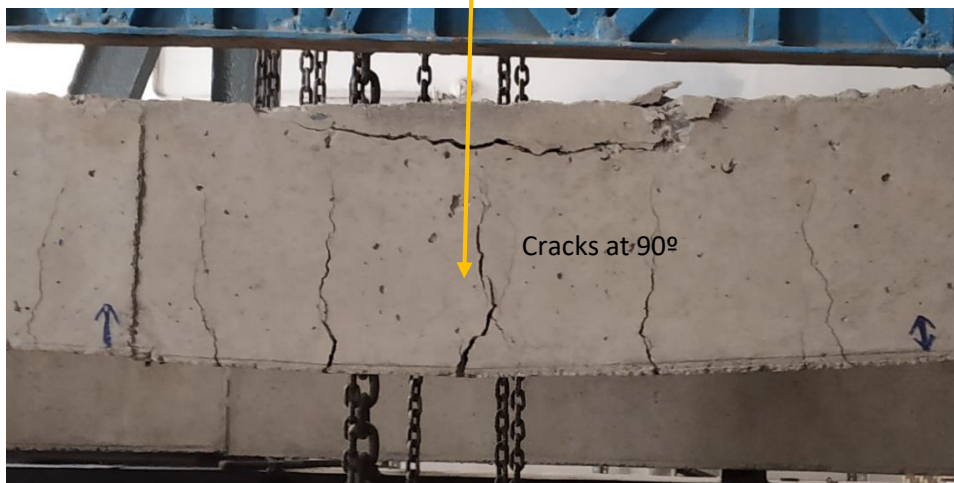
Load(KN)	Displacement (mm)
0	0.000
1	0.268
2	1.244
3	2.442
4	4.720
5	6.932
6	9.274
7	12.914
8	14.922
9	17.686
10	20.330
11	22.744
12	25.532
13	28.092
14	45.118
15	49.106
16	56.370



**Figure 4.1 load-deflection curve of CB**



**Figure 4.2 crack pattern in control beam**



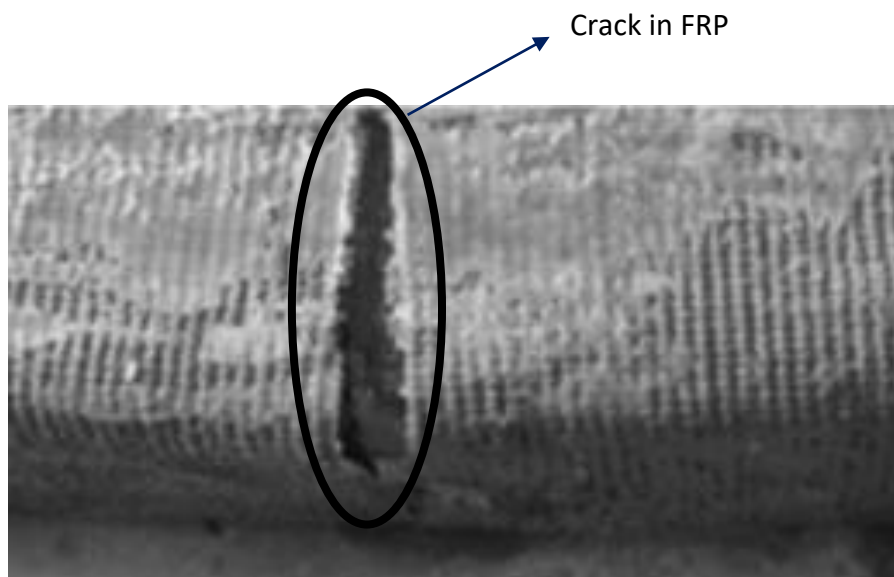
**Table 4.3 values at which beams were pre-loaded before retrofitting**

<b>Beams</b>	<b>Percentage of Failure Load</b>	<b>Load (KN)</b>
Type I	25 %	3.970
Type II	50%	7.950
Type III	75%	11.920

#### **4.4 LOAD-DEFLECTION BEHAVIOUR OF RETROFITTED BEAMS**

##### **4.4.1 BEHAVIOUR OF RETROFITTED BEAMS (Type I)**

There was no debonding of jute FRP at all from the beam face in any direction even at very high load, only a single crack appeared as shown in fig 4.3 at the flexure zone (near the beam mid span), and this crack started to widen with the increase in the load, without the development of any other cracks, and in another beam, two cracks appeared, which started to widen with the increase in the load without the development of any other cracks, these cracks were also observed in flexure zone of the beam, and the ultimate load carrying capacity was reached by further widening of the crack at the centre, without generation of any other alternate cracks. The average ultimate strength of three beams tested was 21.40 KN.

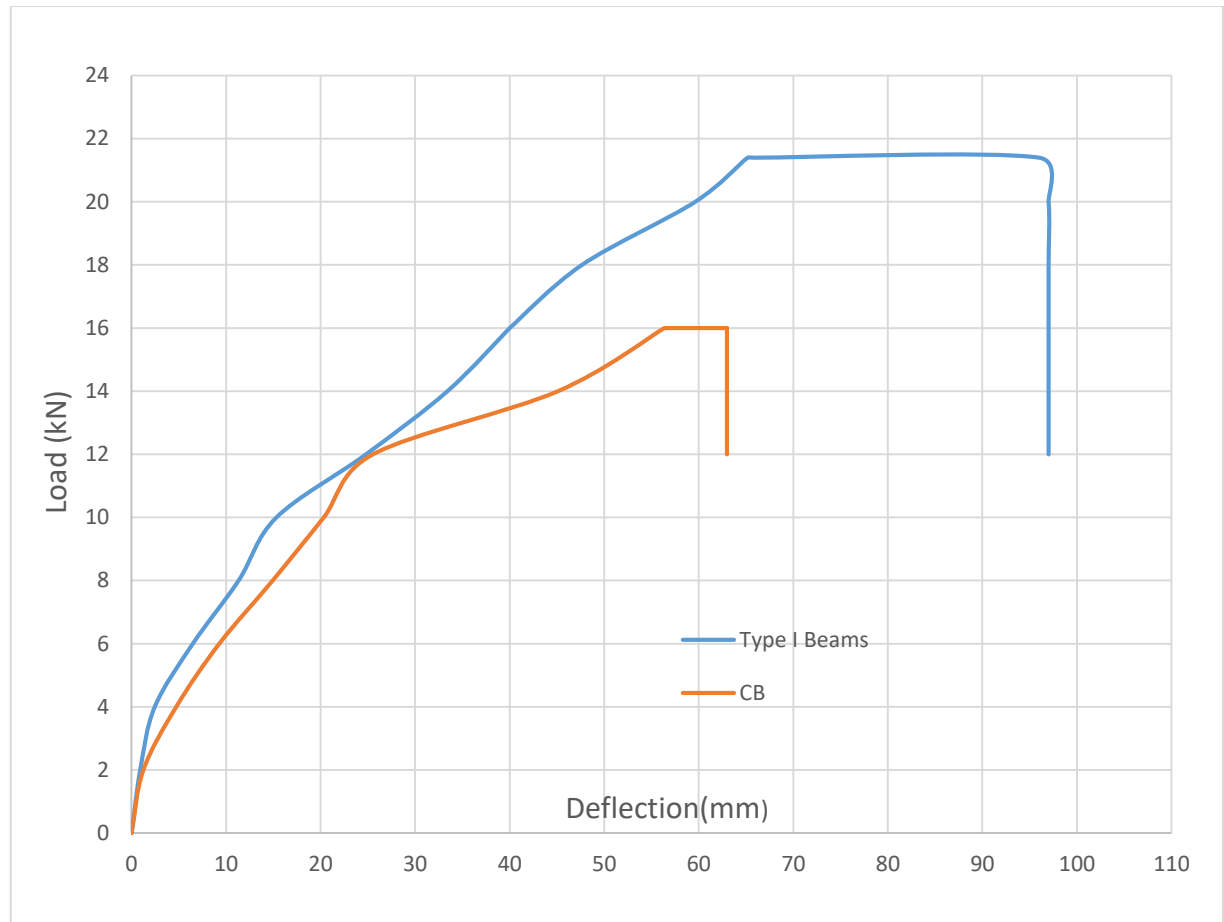


***Figure 4.3 crack in FRP***

**Table 4.4 Detail of Load vs Displacement of Type I Beams**

Load(KN)	Displacement (mm)
0	0.000
1	0.254
2	0.914
3	1.886
4	2.448
5	4.132
6	6.474
7	9.104
8	11.314
9	14.686
10	15.312
11	19.454
12	24.787
13	29.394
14	33.400
15	36.510
16	39.988
17	41.233
18	47.624
19	51.114
20	59.611
21.40	65.167

**Figure 4.4 comparison of load-deflection of control beams and Type I beams**

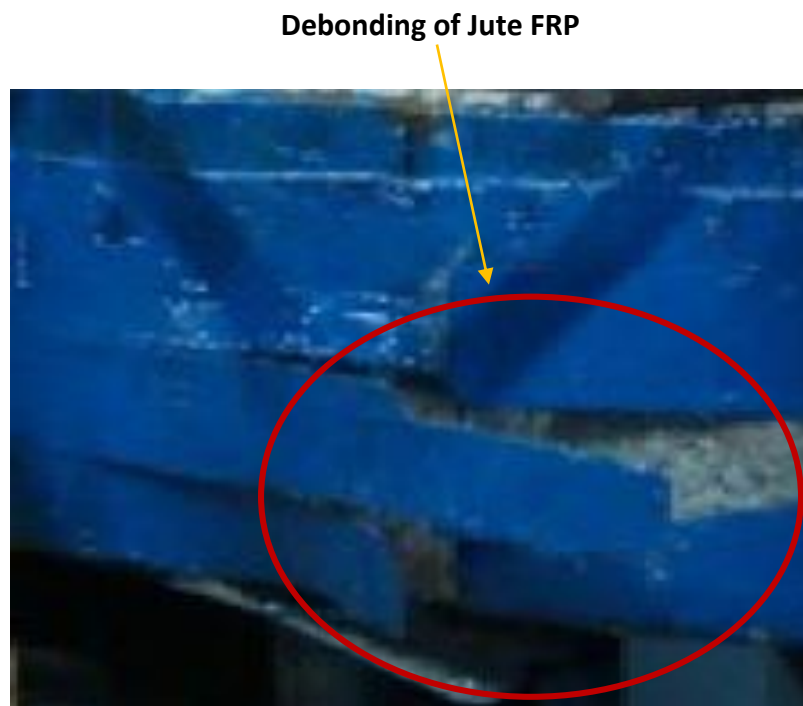


The failure modes depicted by retrofitted beams were very ductile in nature, and the beam carried huge deflections before reaching its ultimate load as shown in Figure 4.4.

Ductility characterises the deformation capacity of members (structures) after yielding, or their ability to dissipate energy. In general, ductility is a structural property which is governed by fracture of the structural member. The deformability index is defined as the ratio of ultimate deflection to yield or the first crack deflection. Here, it was observed that Type I beams have higher deformability index as compared to control beams. Higher deformability index marks more energy absorption and more plastic deformation before failure and hence forth a structure processing one would definitely be more ductile in nature.

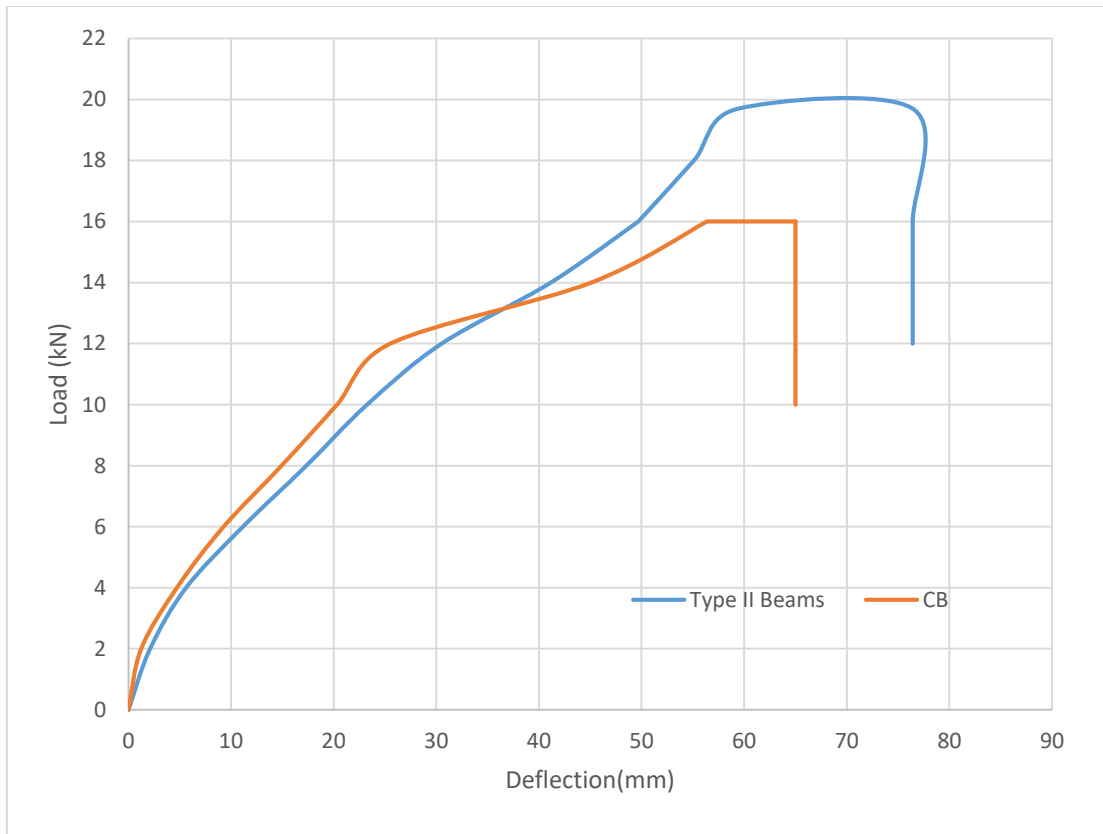
#### 4.4.2 LOAD-DEFLECTION BEHAVIOUR OF TYPE II BEAMS

When load was applied on Type II beams, firstly the rupture of jute FRP was observed at the centre followed by FRP debonding, that is in the flexure zone (at the beam mid span) jute FRP firstly cracked and secondly started debonding as shown in Fig. , debonding occurred at the bottom side as well as on the other two lateral sides of the beam, then on further increment of load, large number of cracks developed at the bottom side of the beam, and the ultimate load carrying capacity was reached by further widening of these cracks at the bottom with the generation of a large number of alternate cracks in the flexure zone. The average ultimate strength of three beams tested was 19.70 KN.



**Figure 4.5 debonding of FRP**

**Figure 4.6 Load-Deflection behaviour of Type II beams compared with control beams**

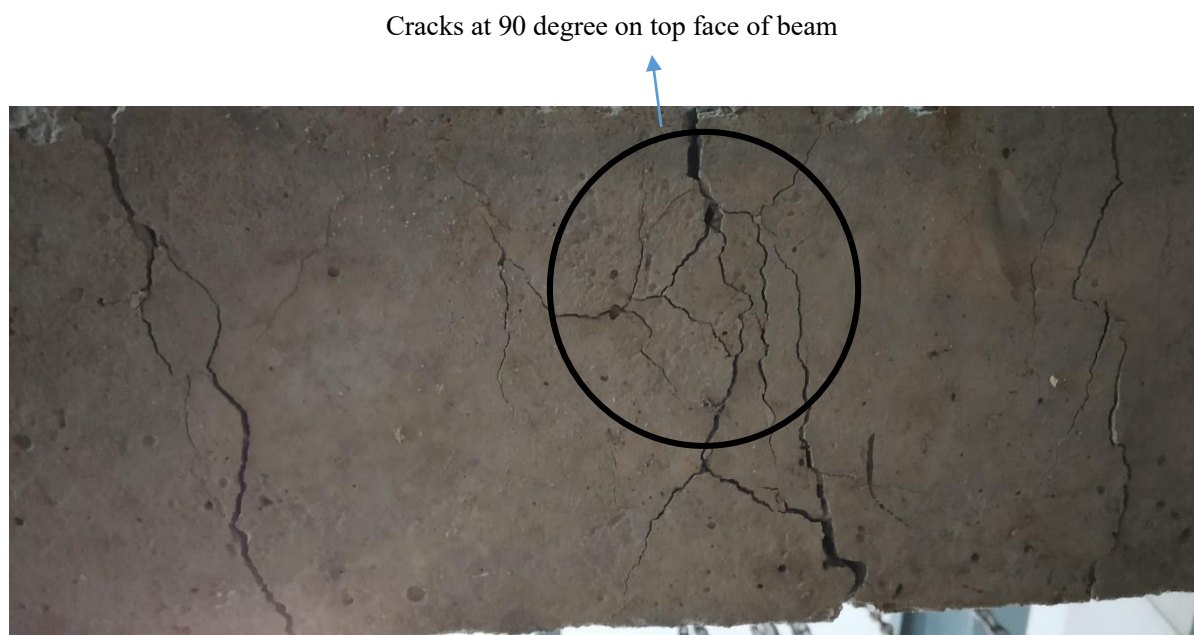


The debonding of the jute FRP exposed the cracks in the beam, all the type II beams showed vertical cracks in the mid span i.e. in the pure flexure zone, these cracks firstly developed at the lower face i.e. the bottom side of the beam and extended from the bottom side towards the top face of the beam. The ultimate load carrying capacity (Fig 4.6) was reached by further widening of these flexural cracks at the bottom with the generation of alternate cracks in the flexure zone.

For type II beams, failure was observed by rupture of FRP, followed by the debonding of FRP from the ruptured point, further by the development of multiple flexural cracks in the beam area.

#### 4.4.3 LOAD-DEFLECTION BEHAVIOUR OF TYPE III BEAMS

In Type III beams same kind of failure pattern as of Type II beams was seen. When load was applied on the beams, then firstly the FRP started debonding, then on further increment of load, the jute fibres in the textile jute FRP started to crack, then again on further load increment the cracks in jute FRP started to widen, then the beam showed a vertical crack in the flexure zone, and then this crack started slowly moving from the bottom face of the beam to the top face (Fig 4.7). The average ultimate strength of three beams tested was 17.10 KN.

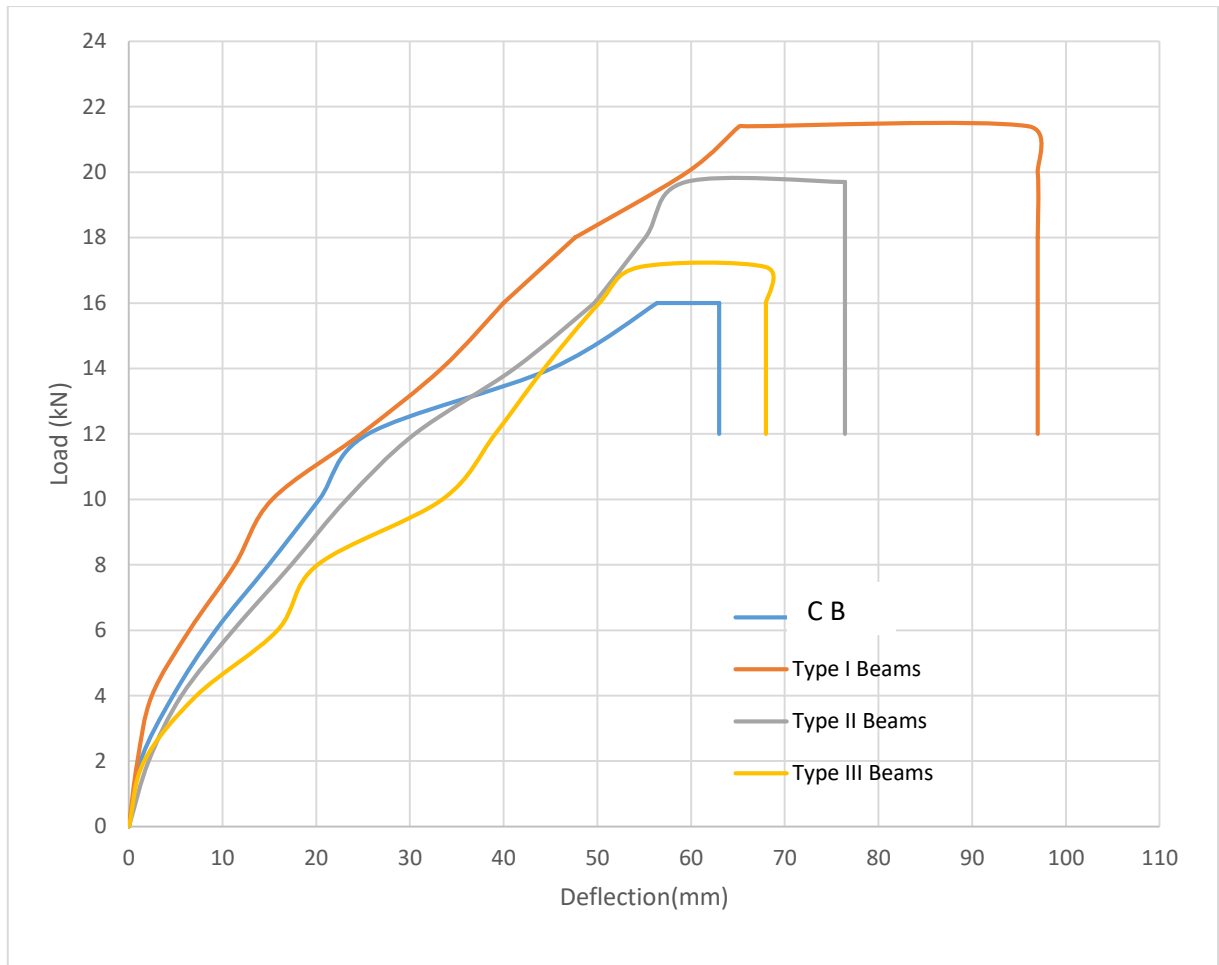


**Figure 4.7 top face of the type III beam**

**Table 4.5 shows the percent increase in ultimate load and change in deflection**

Specimen	Maximum Load (in kN)	Ultimate deflection (in mm)	% increase in load	% change in deflection
CB	15.90	56.370	-	-
Type I	21.40	65.167	34.5	15.60
Type II	19.70	59.430	23.89	5.42
Type III	17.10	54.500	7.54	3.31

**Figure 4.8** load-deflection comparison of control beam, type I, type II and type III beams



On analysing the **Figure 4.8** which is a comparative graph of the load-deflection for the all type of beams tested in the laboratory, it is obtained that the ultimate strength of the beam is increased by wrapping the beam with natural FRP i.e. Jute and this gain in strength is the maximum when pre-cracking done is minimum i.e. in 25% pre-loaded beam. Thus, if a healthy beam was wrapped instead of pre-cracked beams, it would have the highest strength. With increased load and strength, the deflection in the beam before failure also increased and is maximum with least pre-cracking.

## 4.5 Ductility

Ductility is an important parameter to determine the deformation capacity of structural members under seismic loadings. The displacement ductility factor is defined as the ratio of the ultimate displacement to the yield displacement is usually applied to describe the ductility capacity.

According to the seismic design code NCSR-02 (Spanish Code) the levels of Ductility could be defined as in the following table:-

**Table 4.6:- range defined for ductility**

<b>High ductility</b>	<b><math>&gt; 4</math></b>
<b>Medium ductility</b>	<b><math>4 &gt; D &gt; 3</math></b>
<b>Low ductility</b>	<b><math>3 &gt; D &gt; 2</math></b>
<b>No ductility</b>	<b><math>2 &gt; D &gt; 1</math></b>

**Table 4.7:- Ductility of tested beams**

<b>Beams</b>	<b>Ductility</b>
CB	2.54
Type I	3.87
Type II	2.95
Type III	2.72

It can be concluded from the table 4.6 and 4.7 that the control beam has a low ductility, whereas the retrofitted beams show medium levels or even high levels of ductility. Compared with the control beams, even the type III beams possess better displacement ductility, despite having slightly lower ultimate displacement than type I and type II beams.

## 4.6 ENERGY ABSORPTION

The energy absorption capacity of reinforced concrete elements is one of the crucial structural properties that define their seismic resistance. It is defined as area under the load-deflection curve of the beam. The energy absorbed by the beams tested as shown in the following table 4.8.

**Table 4.8 Energy absorption**

<b>Beam</b>	<b>Energy Absorbed at Ultimate Load (kN-mm)</b>	<b>Percent Increase in Energy Absorption</b>
CB	298.65	----
Type I	514.18	72.32
Type II	416.78	39.53
Type III	357.11	19.79

## **CHAPTER 5**

### **CONCLUSIONS**

#### **5.1 CONCLUSIONS**

Based upon the results of experimental study carried out the following conclusions can be drawn:-

1. The load carrying capacity of the Type I beams increases by 34.5% when the initially stressed (25%) beams are retrofitted with jute fibres in U-type retrofitting technique. These beams showed the 15.60 % increase in deflection before failure.
2. Even the Type II and Type III beams showed increase in ultimate strength i.e. 23.89% and 7.54 % respectively and also meagre change in deflection was also seen.
3. With the utilisation of jute wrapping, parameters such as ductility is enhanced such as Type I beams showed the value of ductility as 3.57 which showed the good ductile nature as compared to control beam, also type II and type III beams showed ductility value 2.95 and 2.72 respectively which shows that all type of retrofitted beams showed good ductile nature
4. 3 sided U wraps, improve the behaviour of the beam under flexure, by not only improving its behaviour in the tension zone but also additionally the energy absorbed by the beams is also increased, type I beams absorbed 72.32 % more energy as compared to control beams. In type II and type III beams although debonding took place, those beams also showed 39.53 % and 19.79 % respectively, showed more energy absorption then control beams.
5. The use of textile FRP, in continuous form had effect in delaying the growth of crack formation. It was evident from the load causing the initial cracks. The use of continuous textile FRP was able to avoid the brittle failure of the beams, as the beams carried huge deflections before failure and hence gave out sufficient warnings before it could collapse.
6. Hence, we can conclude that natural fibre in the textile form, like jute FRP can be regarded as a suitable strengthening material for flexural strengthening of concrete structures particularly, as a good alternative methodology among the fabric reinforcement in FRP considering economic and environmental aspects about FRP products.

## **5.2 Scope for the Future Study**

The following are some suggested areas for future studies on the retrofitting of beams using natural woven jute:

1. The effect of shear span to depth ratio ( $a/d$ ) on the failure mode and load carrying behavior of shear deficient beams retrofitted with jute can be explored. Beams of different lengths and cross-section may be cast to achieve this objective.
2. In this study, all the beams were initially stressed at some percent of the control beam failure load and subsequently retrofitted with jute. The stress level and layers of jute may be varied (both may be changed simultaneously or one at a time) and their effect on the behavior of beams may be studied.
3. The effect of different configurations used for retrofitting in this thesis on the behavior of beams may be studied in combination with the above mentioned points. Further, the researchers may also explore the effect of new retrofitting configurations and compare the efficiency of those methods with the contemporary rehabilitation techniques.
4. Jute fibre could be used with some other type of FRP to form any new composite retrofitting material and then its behavior could be checked.

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