BEHAVIOUR OF RC BEAMS RETROFITTED WITH COMBINED JUTE AND GLASS FIBRE WOVEN FABRICS IN FLEXURE

A Thesis Report submitted in the partial fulfillment for the award of the degree of

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IN

STRUCTURAL ENGINEERING

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DECLARATION

I, Amitpal, hereby declare that the work which is presented in this thesis entitled "**BEHAVIOUR OF RC BEAMS RETROFITTED WITH COMBINED JUTE AND GLASS FIBRE WOVEN FABRICS IN FLEXURE**" in partial fulfilment of requirements for the award of the Master of Engineering in Structural Engineering, submitted in the Civil Engineering Department, Thapar Institute of Engineering and Technology, Patiala, is an authentic record of the work carried out by me under the guidance of Dr. Heaven Singh, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala.

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

Dated: 10/09/2019

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CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct to the best of my knowledge and belief.

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ABSTRACT

Strengthening/retrofitting of existing structures now days has become a common practice in construction industry. It is also known that many structures in present world are currently in need of up gradation due to many factors such as increase in traffic volume, inadequate design procedures, increase in loads, structures exceeding their design life and many other environmental factors such as earthquake, floods, etc. Therefore, effective methods are required for structural strengthening of existing structures as well as structural retrofitting of preloaded structural elements. Out of many retrofitting methods, fabric jacketing is one of the most popular and easy method of retrofitting now a days. This study deals with the method of fabric jacketing as a retrofitting technique. Fabric jacketing is found to be suitable technique of retrofitting due to its light weight, easy application and good tensile strength. It has been found from the previous studies that natural fibres alone, when used as a wrapping material in retrofitting of beams are incapable of withstanding high loads and stresses. In this study jute fibre as a natural and glass fibre as a synthetic woven fabric is used as a retrofitting material. A total of fourteen beams were casted in this study, out of which two beams were control beam and remaining twelve beams were retrofitted with suitable layering technique. Two types of wrapping schemes and three types of layering system was adopted in this study which includes Side Wrapping and three side U-Wrapping with Type-1 layering, Type-2 layering and Type-3 layering systems in each wrapping scheme. Type-1 layering system consisted of “one glass-one jute” layer, Type-2 layering system consisted of “two glass-one jute layer” and Type-3 layering system consisted of “two glass-two jute layers” bonded to the beams alternatively. Firstly, two control beams were tested under UTM to their failure load and the ultimate failure load was noted. Then all the remaining twelve beams were preloaded to 60% of the ultimate failure load. Six beams, in group of two beams, for each wrapping scheme were retrofitted and were tested under UTM to find their ultimate failure load and study their load deflection behaviour. It was found that beams wrapped with three side U-Wrapping schemes showed a better load deflection behaviour and higher ultimate failure load than the beams wrapped with Side Wrap scheme. Out of three types of layering system, Type-3 layering system which consisted of two glass-two jute fabric layers in alternate manner showed more failure load as compared to other two layering systems.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Generally most of the construction work from past few decades is done by using concrete as the major constructional material. Along with concrete many more materials are being used to increase the strength and durability of the structural members. The second most used material along with concrete is steel. The RCC structures constructed by using these materials have limited period of service because of many environmental factors. Also these structures are found to suffer damages even before their service period due to factors such as earthquake, fire , harsh environmental conditions, floods , overloading, etc. also many structures in world are presently in want of upgradational requirement due to several factors, for example inediquate design standards, inediquate procedures, increase in traffic volume, increase in traffic loads, human error at time of construction in design and at time of placing reinforcement as per structural detailing , inadequacy of quality control of constructional materials, corrosion of steel used in RCC structures due to prolonged exposure to an aggressive environmental conditions, etc.

With many considerations from the past experiences it is also found that many seismic zones are being revised world wide so as to ensure safety and also this revision is always on upward side. Therefore , there is a great need of attention to check for the distress caused to the structures and find suitable methods to repair the structure and bring them to be used at their full capacity.

Now a days retrofitting and strengthening of current structures has become one of the considerable part of construction industry. There is a developing demand of continued advancement of urbanization and modern life therefore the structures continued to increase at a high pace. Thus, it has become important to upgrade or repair the current structures due to many factors such as, environmental factors, structures exceeding their design life, loading on the structure changes due to some reason and to make the structure to be used for more than its design life. Therefore, many methods of strengthening/retrofitting and many materials have been developed for both shear and flexural strengthening of the structural members. So, it has become very important to strengthen the most essential parts of the structures i.e. load carrying elements of the structure, such as columns and beams. As construction of new structures by demolishing the old ones is a huge task and requires lots of manpower, energy, resources and economy, therefore it is always preferred to upgrade or repair the current structures because of its low cost.

It is also to be noted that in coming years, the cost of retrofitting and maintenance works will carry about 80% of the overall spending in the construction industry. It is preferred to repair or upgrade the existing structure by retrofitting/strengthening rather than fully replacement of the structure which might have various disadvantages such as high cost of material and labour, harmful impact on environment, disruption in the usage of structure due to construction process, etc.

Many researches have been done and some are going on to increase the design life of a structure by various methods of strengthening and retrofitting. Out of the various strengthening/retrofitting techniques, FRP (Fibre Reinforced Polymer) jacketing is one of the most popular and easy method of retrofitting used now a days. In this technique many different types of FRP are used to repair or retrofit the existing structural members. It has been observed that the use of Fiber Reinforced Polymer is restricted to only developing and developed nations due to its high initial investment and demand of skilled labour for the application of the work. Therefore there is a need to develop a technique which is convenient as well as cost-effective and can be carried out at site with semi-skilled labour.

Hence there is a need of developing cost effective and persistent retrofitting technique that can greatly lower the maintenance needs, increase in safety of life and also increase the total design service life of the structure. Recent developments in the field of composite materials, along with their intrinsic properties such as their good fatigue behavior, high tensile strength and good corrosion resistance and ease of application, makes these new materials a good substitute to other retrofitting techniques for strengthening and repair of concrete structures.

Fabric jacketing is found to be suitable technique of retrofitting due to its light weight, easy application and good tensile strength. In past few years, many research works have been carried out to develop eco-friendly biodegradable materials to be used as construction materials. Also the need of the world to become environment friendly had made the natural fibre reinforced material growing very rapidly. Moreover, the availability of natural fibres in asia is of great advantage which promotes the use of natural occurring materials in construction industry.

When externally bonded natural FRPs are used to strengthen RC beams subjected to constantly increasing loads, three types of failures are identified; these are flexure, de-bonding and shear. It is desirable that ductile failure of the beam occurs so that there is a considerable warning of the incipient failure. This type of ductile failure is accompanied by flexure failure. Contrarily, shear failure is brittle in nature and does not allow much redistribution of loads, thus shear failure occurs without any prior warning and is catastrophic. Therefore RC beams must have sufficient shear strength, higher than flexural strength so as to ensure ductile failure mode.

1.2 JUTE AS NATURAL FRP

Many research works have been done from past few years to make use of more environment friendly and biodegradable natural materials in construction industry. From the research works carried out, it was evident that NFRP composites provides a good alternative to the use of synthetic fibre composites and also Natural Fibre Reinforced Polymers have been used as a strengthening and repairing materials for structural elements in civil works. The world needs to become environment friendly, therefore the use of NFRP composites is growing at a high pace. Also it is found that the accessibility of natural fibres in Asia is much more as compared to other continents, and along with some advantages of NFRPs over traditional reinforcement materials such as renewability, recyclability, less cost, less density and bio-degradability, etc. moreover this material possess high specific stiffness and high specific strength of the structural material, which makes it a better possible alternative to synthetic fibres. Natural fibres exists in many different varieties and not every variety can be used in industrial application. The most common natural fibres used in construction industry are baste fibres which are obtained from the outer cell layer of plants stems, such as jute, kenaf, sisal, hemp and flax, etc. This study utilizes jute woven fabric as Natural Fibre Reinforced Polymer for retrofitting of the beams. Jute is known to be second most demanding and important natural fibre after cotton due to its wide range of use. It has been replacing many synthetic fibres from past few years due to its eco-friendly and biodegradable nature.

Figure 1. 1: Jute fibre woven fabric

Fiber reinforced polymers (FRPs) gives a wide scope to designers for customizing the composites to meet the specific need. Also it presents a huge potential solution to the various problems encountered during construction and repair work. As compared to other methods of retrofitting, FRP retrofitting technique proves to be a better alternative.

1.3 GLASS FIBRE WOVEN FABRIC

Glass fibre woven fabric as the name suggest is a fabric made up of glass fibres woven into fabric. GFRP is a synthetic material which has gained huge recognition in construction industry and has a vast range of application. Its high tensile strength, non-corrosive nature, high temperature resistance, good bonding ability, high strength to weight ratio, etc has made it one of the most used materials for repairing/retrofitting of the existing structural elements. Also Glass Fibre Reinforced Polymer (GFRP) are cheaper material than any other synthetic fibre. Glass fibres have relatively less modulus of elasticity when compared to carbon and steel fibres. The most widely used fibres which can be used as reinforcement in FRP are artificial fibres such as glass, carbon, aramid, etc. Out of all these synthetic fibres, carbon fibre is the most costliest, followed by aramid. Glass fibre is the cheapest one. Carbon fibre have many advantages over all other synthetic fibres, one of such is high strength. Despite of all the advantages of carbon fibre, it comes with a huge price and cost, which makes it less common and is cannot be used readily in construction industry. As now a days the requirement of strengthening of existing structure is increasing, therefore the cost of the fabrication of the fabrics from these fibres is also increasing, which poses a requirement of cheap materials. This requirement can only be fulfilled by using cheap fibre fabrics such as glass fabrics as FRP for retrofitting of the structural members.

Figure 1. 2: Glass fibre woven fabric

1.4 JUTE FIBRE IN COMBINATION WITH GLASS FIBRE FABRIC

It has been found that natural fibres alone, when used as a wrapping material in retrofitting of beams are incapable of withstanding high loads and stresses. Therefore, it has become important to use synthetic materials in combination with natural materials to meet the present need of the construction industry. It has been found by researchers, from various experiments, that natural fibres cannot fully replace synthetic fibres where strength is the main requirement. Therefore it will be more beneficial to use natural and synthetic fibres in combination. Natural fibres have their own advantages as discussed earlier, and also synthetic fibres have its own advantages which can serve the purpose of the construction industry. In this study woven jute fibre fabric is used as a natural FRP and woven glass fibre fabric is used as a synthetic FRP to be used as a combination to produce a hybrid FRP which can be used for retrofitting of beams and other structural members. Both the fibres have their own advantages, which were used in this study to accomplish the need of retrofitting. The high tensile strength of glass fibre combined with high extensibility of jute fibre made a good combination to be used as a retrofitting material. Also both the fibres have almost same aspect ratio when the length is taken same, which makes them idol to be used in combination with each other.

CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

Many researches has been carried out during the past few years to assess the effectiveness of FRP retrofitting technique. This chapter presents the brief review of various research works done by various researchers related to the use of natural and synthetic FRP for retrofitting and strengthening of structural elements. There are two main purpose of these researches related to retrofitting using natural and synthetic materials. The first and more important aim of retrofitting is to provide strength and solve structural related problems. The second aim of these research works is to solve durability aging difficulties and to increase the service life of the structure. During the past few years the use of fibre reinforced polymers for repairing and strengthening of various types of concrete and reinforced concrete structural elements such as slabs, columns, panels, beams, joints and pavements, is a major part in the study of retrofitting. The use of FRP as a retrofitting technique provides various advantages over the use of conventional way of retrofitting by using concrete layer. Using Fibre Reinforced Polymer as a retrofitting technique prevents the problem of brittle failure of the interface retrofitted with concrete layer. FRP is being widely used now a days for retrofitting because of its various advantages such as high strength, light weight, corrosion resistance, design flexibility, etc. FRP is a composite material which can be designed to meet the required strength. FRP can be customised to meet the requirements of the structure and also we have flexibility to use various combinations of reinforcement and resin to meet the physical and mechanical properties of the structure. The second most important advantage is that FRP are light weight. Composites can be designed for both high strength and light weight to meet the need of strength to weight ratio of the structure. We can choose material of FRP composites which are corrosion and temperature resistant so that they can provide a long lasting service to the structure. We can also control the orientation of fibres in FRP Composites so as to provide more strength in some specific directions.

Moreover, now a days it has become very important to use user friendly and economical materials in construction industry. So it is a great need to use environment friendly composite materials as FRP to be used for repairing and strengthening of deteriorated civil infrastructure.

From the research work carried out, it was observed that NFRP composites provide a better alternative to the use of synthetic fibre composites. The world needs to become environment friendly, therefore the use of natural fibre reinforces composites is growing very rapidly. It is to be kept in mind that the materials chosen for structural retrofitting must, in addition to the structural requirement should possess sustainability and promote self-reliance. More importantly the materials chosen for FRP should make use of locally available materials and should make use of local skills, manpower and should also benefit local economy.

2.2 REVIEW OF EXISTING LITERATURE

Table 2. 1: List of papers used in this study along with the properties studied and material used.

Name of Author	Year of publication	Name of paper	Material used	Properties studied
Sen & Reddy	2013	Strengthening of RC beams in flexure using natural jute fiber textile reinforced composite system and its comparative study with CFRP strengthening systems	Jute fabric, Carbon fibre, Glass fibre, Epoxy resin	Load deflection behavior, ultimate load, flexural strength.
Sen	2016	Shear strengthening of Reinforced concrete beams with various natural and artificial reinforced composite system	Jute fibre, sisal fibre, carbon fibre, epoxy	Load deflection behavior, ultimate load, flexural strength.
Alam & Riyami	2017	Shear strengthening of reinforced concrere beam using natural fibre reinforced polymer laminates	Knef fibres, jute fibres	Load deflection behavior, ultimate load, yield strength
Huang et al.	2016	Reinforced concrete beams strengthened with externally bonded natural flax FRP plates	Jute, flax, sisal, hemp, E-glass, carbon	Tensile strength, ultimate load, load deflection behavior, energy absorption
Biradar & Kumar	2017	Strengthening of RC Beam Using Polypropylene Fibre Sheet And Rubberized Coir Fibre Sheet.	Polypropylene sheets and Rubberized coir fibre sheet	Ultimate load, ultimate defection, load deflection curve
Anumol Raju et al	2013	Retrofitting of RC beam using FRP	Polypropylene fibres, steel fibres, glass fibres, coir fibres, carbon fibres	Ultimate load, ultimate deflection, load deflection curve

(Tara Sen and Jagannatha Reddy 2013) conducted experiments and studied tensile and flexure behavior of jute fiber reinforced polymer textile composite and compared the results with synthetic fiber textile such as Carbon Fiber Reinforced Polymer(CFRP) and Glass Fiber Reinforced Polymer (GFRP) system. The effectiveness of Jute Fiber Reinforced Polymer (JFRP) in flexural strengthening of RC beams was compared to Glass Fiber Reinforced Polymer(GFRP) and Carbon Fiber Reinforced Polymer(CFRP) by conducting flexural test on RC beams. The tests were conducted of fourteen beams in groups of three beams. This study deals with the study of the effect of flexural strengthening on ultimate load and ultimate deflection of the beam and hence studied its load-deflection behavior of the beams strengthened with externally bonded CFRP, JFRP and CFRP single layer wrapping with U-Type and strip type configuration along full length of the RC beam. Failure modes as well as deflection ductility of the RC beam was also studied in this experiment. After carrying out experimental program it was found that JFRP, CFRP and GFRP strengthened RC beams increased their ultimate flexural strength by 62.5%, 150% and 125% repectively when full U-Wrapping technique was used and when strip wrapping technique was used, the increase in flexural strength were found to be 25%, 50% and 37.5% respectively. It was also evident from the results that the beams strengthened with Jute Fiber Reinforced Polymer (JFRP) showed highest deformability index. Hence, it was concluded that Jute Fiber Reinforced Polymer textile can be used as a retrofitting and strengthening material.

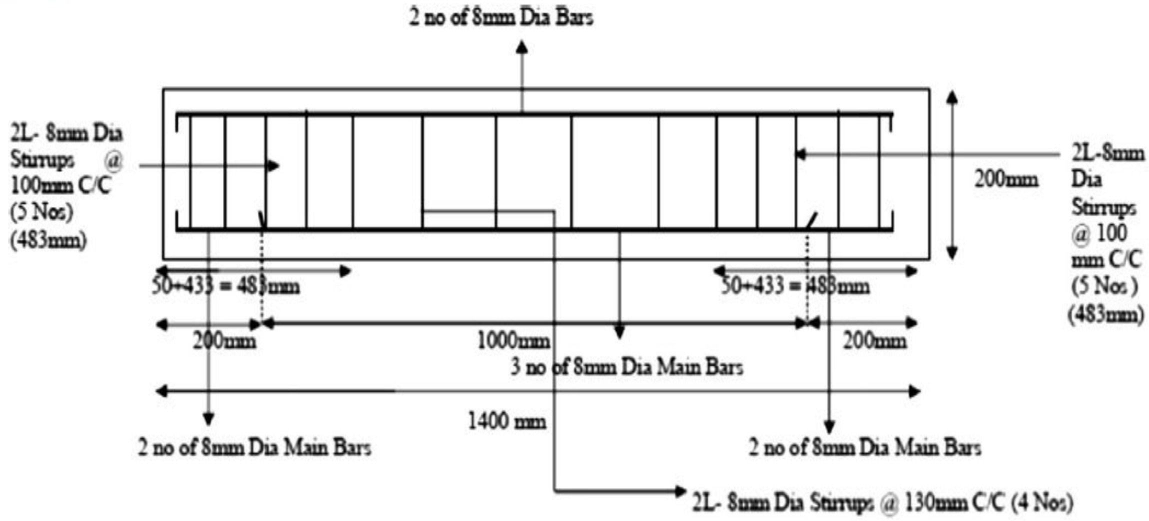

Figure 2. 1: Reinforcement detailing of the beam (Sen, Reddy, 2013)

Table 2. 2: Summary of the test beams (Sen, Reddy, 2013)

Beam group	Wrapping configuration	Strengthening material	Model beam designation with two number of sample models in each group	Type of strengthenin g	Strengthen ing scheme	Number of FRP layer bonded to the RC beams
Group A	Nil	Nil	Control Specimen Con1,Con2	No strengthenin g	Nil	Nil
Group B	Full length wrapping 90L, single layer Jute FRP	Jute FRP	JF1,JF2	Flexural strengthenin g using jute FRP	U – Wrap, three sided wrap	one layer
		Carbon FRP	CF1,CF2	Flexural strengthenin g using carbon FRP	U – Wrap, three sided wrap	one layer
		Glass FRP	GF1,GF2	Flexural strengthenin g using glass FRP	U – Wrap, three sided wrap	one layer
Group C	Strip wrapping 90L, single layer 62 mm strips at 124 mm C/C (at a clear gap of 62 mm) so as to achieve 50% of total area strengthening, with end clear gaps of 49 mm	Jute FRP	JF3,JF4	Flexural strengthenin g using jute FRP	U – Wrap, three sided wrap	one layer
		Carbon FRP	CF3,CF4	Flexural strengthenin g using carbon FRP	U – Wrap, three sided wrap	one layer
		Glass FRP	GF3,GF4	Flexural strengthenin g using glass FRP	U –Wrap, three sided wrap	one layer

(T. Sen 2016) conducted experiments and studied the effect of shear strengthening of beams retrofitted with natural fiber reinforced polymer and artificial fiber reinforced polymer composite system. In this study three group of beams were considered for experimental purpose. The first group of beams was group-A beams. These beams of group-A were designed as control beams and were not strengthened with any FRP material. Two specimens ConS1 and ConS2 were designated as control specimens. In group-B beams, two beams of each retrofitting material were considered. These beams were retrofitted with full U-wrapping technique in which 3 sides of beams were wrapped throughout the full length of the beam so as to evaluate the shear strengthening of the retrofitted beams. Four types of natural and synthetic FRP were used for shear strengthening of beams, these are jute fiber reinforced polymer (JS1,JS2), sisal fiber reinforced polymer(SS1,SS2), carbon fiber reinforced polymer(CS1,CS2) and glass fiber reinforced polymer(GS1,GS2). Similarly in group-C beams, two beams of each retrofitting material were considered. These beams were shear strengthened with strip U-Wrapping technique in which three sides of the beams were wrapped with strips of FRP material throughout the length of the beam so as the FRP material covers 50% of the beam area. FRP strip of 62 mm placed at 124mm C/C with a clear gap of 49 mm at the free ends were used. Similarly as in group-B beams, group-C beams were also strengthened with four types of natural and synthetic materials. Beams of group-C were designated as JS3,JS4(jute fiber reinforced polymer), SS3,SS4(sisal fiber reinforced polymer), CS3,CS4(carbon fiber reinforced polymer) and GS3,GS4 (glass fiber reinforced polymer). This study utilizes 1.4 m long beam with cross-section as 140 X 200 mm. all the beams had same reinforcement detailing as shown in the below figure. The experiment consisted of two point loading test and deflections at mid span was noted at each increment of load. Results from the experiment showed that there is a considerable increase in shear strength of the retrofitted beams. SS1,SS2 showed an increase in ultimate shear strength by 77 % by providing only single layer of FRP. These beams of group-B showed a more ductile failure in which no sudden FRP failure was observed and no debonding of FRP observed even at higher load. Jute fiber specimens JS1,JS2 also showed similar behavior and showed increase in ultimate shear strength by 66% with 1 layer of FRP. No debonding of FRP was observed and the failure was pure ductile in nature.CS1,CS2 and GS1,GS2 showed an increase in ultimate shear strength of 89% and 83% respectively. The results from beams retrofitted with strip wrapping technique showed increase in ultimate shear strength by 33%, 22%, 44% and 33% for beams retrofitted with sisal FRP, jute FRP, carbon FRP and glass FRP respectively. The load deflection behavior of strengthened beams was observed to be better than control beams. The beams which were strengthened with natural jute, sisal fibres and synthetic carbon and glass fibres all showed higher stiffness than control beam. It was concluded from the test results that both jute and sisal fiber reinforced polymer can be used for shear strengthening of the concrete structural members and they provide a good alternative to all other FRPs, by keeping in mind economy and environmental aspect of the fiber reinforced product.

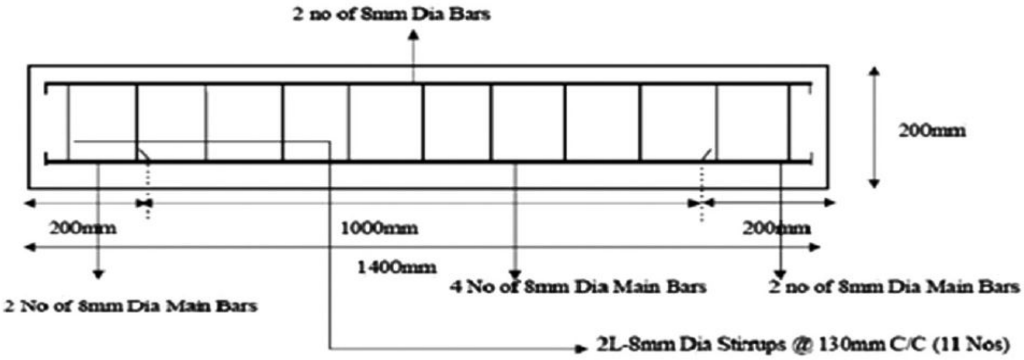

Figure 2. 2: Reinforcement detailing of the beam (Sen, 2016)

Table 2. 3: Summary of the test beams (Sen, 2016)

Beam group	Wrapping configuration	Strengthening material	Beam designation	Type of strengthening	Strengthening scheme
Group A	Nil	Nil	Control specimen ConS1,ConS2	No strengthening	Nil
Group B	Full wrapping 901, single layer	Sisal FRP	SS1, SS2	Shear strengthening using sisal FRP	U – Wrap, three-sided wrap
		Jute FRP	JS1, JS2	Shear strengthening using jute FRP	U – Wrap, three-sided wrap
		Carbon FRP	CS1, CS2	Shear strengthening using carbon FRP	U – Wrap, three-sided wrap
		Glass FRP	GS1, GS2	Shear strengthening using glass FRP	U – Wrap, three-sided wrap
Group C	Strip wrapping 901, single layer 62 mm strips at 124 mm C/C (at a clear gap of 62 mm) so as to achieve 50% of total area strengthening, with end clear gaps of 49 mm	Sisal FRP	SS3, SS4	Shear strengthening using sisal FRP	U – Wrap, three-sided wrap
		Jute FRP	JS3, JS4	Shear strengthening using jute FRP	U – Wrap, three-sided wrap
		Carbon FRP	CS3, CS4	Shear strengthening using carbon FRP	U – Wrap, three-sided wrap
		Glass FRP	GS3, GS4	Shear strengthening using glass FRP	U – Wrap, three-sided wrap

(Huang et al. 2016) reported an experiment which investigated the usage of Natural Flax Fabric Reinforced Polymer (FFRP) composite laminates for repairing and as a strengthening/retrofitting material for RC beams. Beam specimens of two meter length were used to test the flexural behaviour. Beams strengthened with externally bonded FFRP plates and without FFRP plates (control beams) were tested under four point loading test to assess the flexure nature of the beams. The experiment was conducted including two variables. First variable being thickness of FFRP i.e. 4 and 6 layers are used and second variable being the internal steel reinforcement ratio of 0.223% and 0.503%.

In this experimental program, eight beams were made which includes 2 control reinforced concrete beams without FFRP plates and remaining six RC beams were strengthened with FFRP plates. Cross section of the beams used was 150mm width to 300mm depth having length of beam equals to 2000mm. Two types of FFRP layers/thickness arrangements for strengthening of beams i.e. four and six layers of FFRP were used in this study. Also two types of internal reinforcement variation were considered i.e. 0.223% and 0.503%. Further two beams were pre-cracked at 80% of yield load of the control specimens.

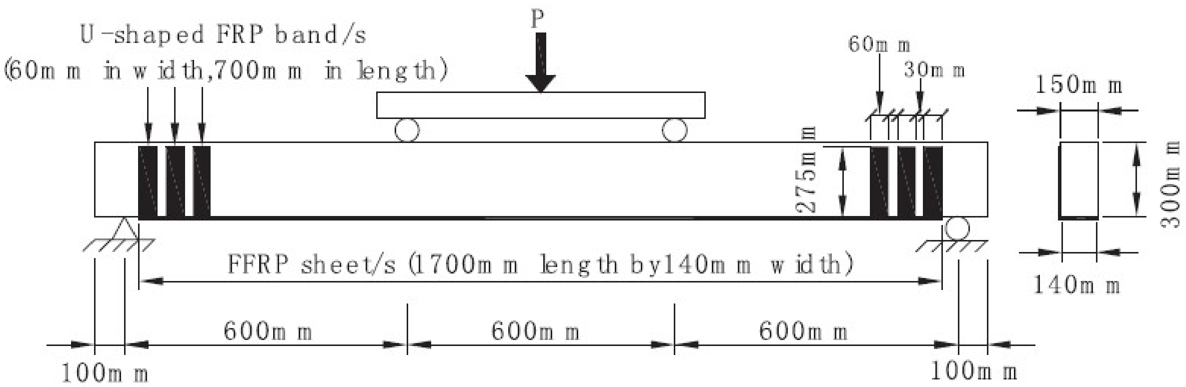

Figure 2. 3: Experimental setup of the test beams (Huang et.al, 2016)

The results from experiments showed that the FRP plates enhanced the ultimate load, ductility and ultimate deflection of the beam specimens significantly. Moreover, it was evident from the experiment that the increase in the ultimate load and deflection was more in case of RC beams having lower steel reinforcement ratio. Also it was found that beams with more FFRP layers showed higher ultimate load as well as ultimate deflection. Strengthening using FFRP plates increased the ultimate load ranging from 15.4% to 112.3% as compared to the control beams. It was also evident from the experiments that both energy absorption capacity and ductility increases notably with the increase in FFRP strengthening layers. Similarly it was also found that both ductility and energy absorption comes out to be higher for low steel reinforcement ratio as compared to beams with higher steel reinforcement ratio. It was also evident from the results that the two beams which were pre-cracked at 80% yield load of control beam showed slight increase in deflection at failure, ductility, but the failure mode, energy absorption and ultimate load capacity remains unchanged as compared to non pre-cracked beams. Also it was found that as compared with control beams; wider cracks at failure were present in beams strengthened with FFRP plates.

The conclusion of the experiment carried out by the author was that the Natural Flax Fabric Reinforced Polymer (NFFRP) composite is an eco-friendly and biodegradable external reinforcing material that can be efficiently and economically used for repairing and strengthening of existing structures.

Table 2. 4: Summary of beam specimens (Huang et.al, 2016)

Specimen	Steel reinforcement	Reinforcement ratio (%)	No. of fabric layers	FFRP reinforcement types
CB-1	2 C8	0.223	-	-
CB-2	2 C12	0.503	-	-
FB-1	2 C8	0.223	4	Type 1
FB-2	2 C8	0.223	6	Type 1
FB-3	2 C12	0.503	4	Type 1
FB-4	2 C12	0.503	6	Type 1
FB-5	2 C8	0.223	4	Type 2
FB-6	2 C8	0.223	6	Type 2

NOTE: CB: Control beam, FB-Fibre reinforced beams, Type 1: strengthening with FFRP prior to applying load; Type 2: strengthening with FFRP after applying 80% of the yield load of the control beam.

(Alam and Al Riyami 2018) did their research work which aimed at developing high strength composite plates made up of natural fibres that can be possibly used in shear strengthening/retrofitting technique for RC structures. The experimental study in this research consisted of laminates which were made by using jute, kenaf and jute rope fibres. Alam and Riyami also studied the effect of treated and untreated fibres by using them in two conditions i.e. treated and untreated.

Beams specimens were fabricated with size 150mm X 130mm X 2300mm embedded with 2-16mm flexural reinforcement and shear reinforcement of 6mm diameter with 130 mm spacing. The test length of the beam was kept two meters i.e. the beam was supported over roller spaced at two meters. The beams were tested under two point load system having shear span 550mm. The experimental programme consisted of total 8 beam specimens which were fabricated to examine their behaviour under load applied. The beams were reinforced externally in shear by using composite plates which were fabricated by using natural fibres such as jute, kenaf and jute rope in treated and untreated conditions. They also eliminated debonding failure during testing by providing embedded connectors.

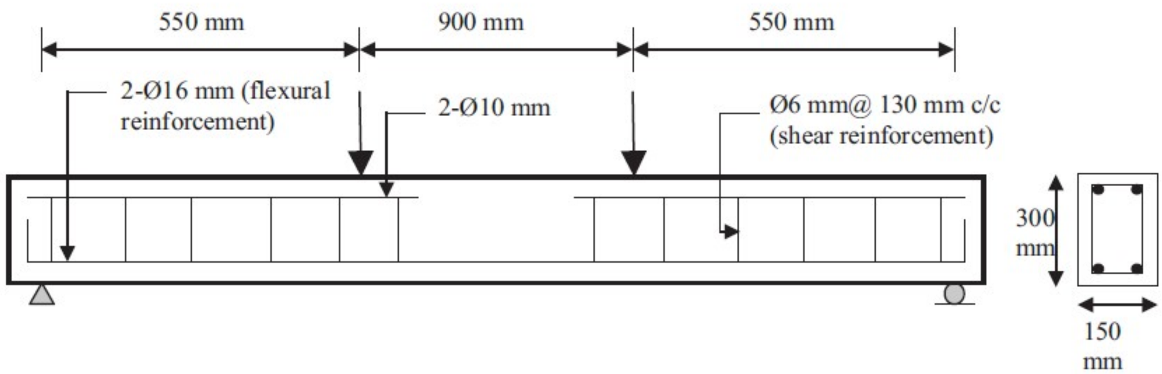

Figure 2. 4: Reinforcement detailing and experimental setup of test beams (Alam and Riyami, 2017)

It was seen from the test results that the beams which were shear strengthened by using untreated jute, kenaf and jute rope laminates had shown increase in ultimate failure load by 35%, 36% and 34% in comparison with control beams respectively. The beams which were strengthened with treated composite plates did not showed much increase in failure loads when compared to the untreated beams. As the test results showed, the mid-span deflection of the beams which were strengthened were found to be lesser when compared to control specimens. The maximum mid-span deflection of beam specimens UK, UJ and UJR were found to be nearly 43%, 87% and 26% lower than control beams respectively. Flexure failure was observed in the strengthened beams with further collapse, whereas the control beam collapsed in shear and was catastrophic in nature. Also it was found from the experiment that not more than 45% of fibre content can be used while fabricating composite plates. Out of the three materials used for making natural fibre composite plates, jute rope showed lesser tensile strength and modulus of elasticity as compared to jute fibre and kenaf fibre.

Table 2. 5: Specimen names and type of NFRP laminates (Alam and Riyami, 2017)

Fibre	**Specimen**	**Specimen ID**	**Description of Specimens**
Untreated fibre	Kenaf	UK	Untreated kenaf fibre
	Jute	UJ	Untreated jute fibre
	Jute rope	UJR	Untreated jute rope fibre
Treated fibre	Kenaf	TK	Treated kenaf fibre with 6% NaOH
	Jute	TJ	Treated jute fibre with 6% NaOH
	Jute rope	TJR	Treated jute rope fibre with 6% NaOH

Table 2. 6: Table showing failure load, shear crack load, and deflection at failure of test specimens (Alam and Riyami, 2017)

Beam ID		Failure load(KN)		Shear crack load (KN)		Deflection at failure load (mm)	
untreated	treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
CB	CB	156	156	55	55	11.5	11.5
UK	TK	211	171	71	65	8	8.7
UJ	TJ	213	192	62	64	6	6.9
UJR	TJR	209	204	67	89	9	8.6

(Biradar and Kumar 2017), reviewed the effect of wrapping of geo-textiles on the surface of the beam and compared the results with control beam. In this study a total of 12 beams of size

150mm X 150mm X 1200mm were casted. Beams were wrapped in two ways i.e. at bottom of the beams and in U shape up to neutral axis of the beam. These retrofitted beams were tested and were compared of flexural strength. This study involved casting of 12 beams out of which two beams were control beams, one beam was retrofitted by using polypropylene fibre sheet of 2mm at the bottom of the beam from one end to other end, two beams were retrofitted by using Polypropylene Fibre sheet of 4mm at the bottom full length of the beam, two beams are retrofitted by using polypropylene fibre sheets of 4mm at the bottom full length of the beam up to neutral axis, one beam was retrofitted by using rubberized coir fibre sheet of 2mm at the bottom full length of the beam, two beams were retrofitted by using rubberized coir fibre sheet of 4mm at the bottom full length of the beam, two beams were retrofitted by using rubberized coir fibre sheet of 4mm at the bottom full length of the beam up to neutral axis. This study involved the testing of beams under two point loading and load vs. deflection behaviour of the beam was studied up to failure. Moreover, maximum load, stress strain behaviour and complete crack patterns were also studied during the experiment.

The beams casted in this experiment were embedded with three bars of twelve mm dia in bottom tension zone and two hanger bars of twelve mm diameter in upper compression zone. Vertical stirrups of 10mm diameter equally spaced were used in the beam. The load deflection curve of the control beam showed that the from 0 KN load to 20KN load, deflection was very minor, but when the load exceeded 20 KN the deflection increased suddenly till load of 40 KN and then it showed gradual increase in deflection till it failed at 47 KN load.

The results showed that the ultimate load of two control beams were 45 and 47 KN. Two beams strengthened with a strip of 4mm PP sheets at bottom of the beam showed failure at 60 and 53 KN load. But when the PP sheet of 4mm thick was used up to neutral axis of the beam, two beams also showed 60 and 53 KN of load. From the result of these beams it can be concluded that strengthening of beams by applying sheet at bottom only serves the purpose of strengthening. Other material used was rubberized coir fibre sheets. Two beams were retrofitted with 4mm RC sheet at bottom of the beam and two beams were retrofitted by applying RC sheets up to neutral axis of the beams. The results from these beams showed that ultimate load of beams retrofitted with 4mm RC sheet at bottom of the beam were 59 and 57 KN, and ultimate load of beams retrofitted applying RC sheets up to neutral axis of the beams were 55 and 60 KN. From the results of these beams it can be concluded that second type of wrapping (up to neutral axis of beam) does not provide any extra strength to the beam. At last, two beams retrofitted with 2mm thick PP sheet at bottom of the beam showed the ultimate load of 60KN each. This concludes that 2mm thick sheet is sufficient to strengthen the beams rather than using 4mm or more thickness which does not provide extra strength to the beam.

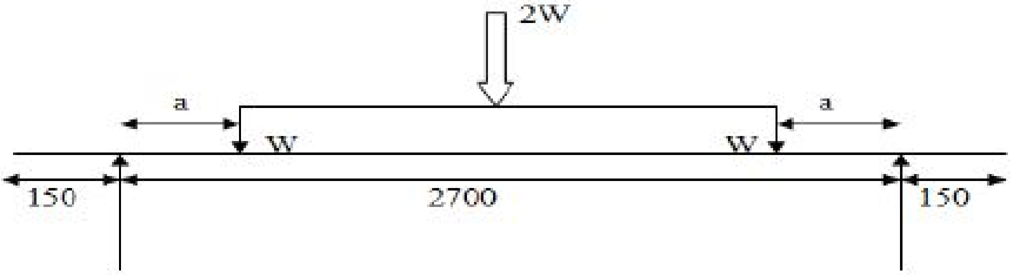

Figure 2. 5 :Experimental setup of test beam.

Table 2. 7 :Details of control beams and retrofitted beams.

BEAM DESIGNATION	SIZE OF BEAM (BXD)	STRENGTHENING BY PP AND RC SHEETS
B1	150 X 260	Control specimen
B2	150 X 260	Control specimen
B3	150 X 260	Strip of 4mm PP sheet at bottom of the beam
B4	150 X 260	Strip of 4mm PP sheet at bottom of the beam
B5	150 X 260	Strip of 4mm PP sheet at bottom of the beam up to neutral axis
B6	150 X 260	Strip of 4mm PP sheet at bottom of the beam up to neutral axis
B7	150 X 260	Strip of 4mm RC sheet at bottom of the beam
B8	150 X 260	Strip of 4mm RC sheet at bottom of the beam
B9	150 X 260	Strip of 4mm RC sheet at bottom of the beam up to neutral axis
B10	150 X 260	Strip of 4mm RC sheet at bottom of the beam up to neutral axis
B11	150 X 260	Strip of 2mm PP sheet at the bottom of the beam
B12	150 X 260	Strip of 2mm PP sheet at the bottom of the beam

(Anumol raju et al., 2013) studied the behaviour of the beams after retrofitting with different types of natural and manmade fibres such as steel fibres, glass fibres, polypropylene fibres, coir fibres, carbon fibres, etc. This study involved casting of total 30 beams out of which five beams were control beams and 25 beams were retrofitted. All the beams were of same dimensions. The length of the beams was 1000m and cross sectional dimension was 150mm X 150mm. These beams were reinforced with three 8 mm diameter bars in tension zone at the bottom of the beam and two bars of 8 mm diameter as hanger bars in compression zone. Shear reinforcement of two legged 8 mm dia bars spaced at 300mm c/c were used. Following figure shows the reinforcement detailing of the beam.

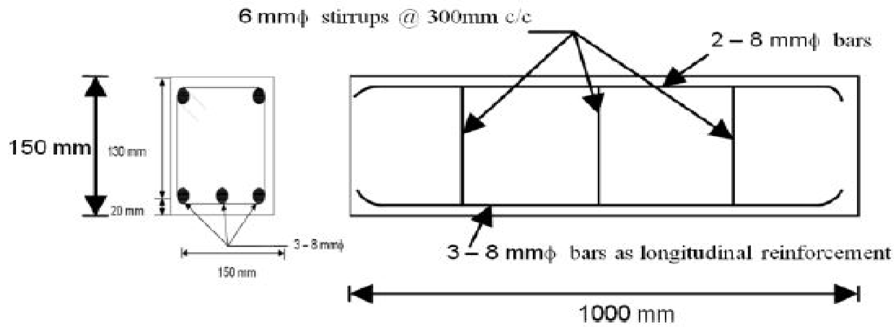

Figure 2. 6: Reinforcement detailing (Anumol raju et al., 2013)

All the beams including control specimens and strengthened specimens were tested to find their bending strength. All the beams were tested with same procedure. The casted beams were thoroughly cured for 28 days. All the beams were tested under two point loading arrangement in which load was transmitted through a load cell. The test beams were simply supported having 50 mm of overhang from both ends of the beam. The loading points were kept at an equal distance of 300 mm from the two supports, dividing the beam in three equal parts of 300 mm each. All the beams were tested in UTM. Load deflection curve of beams were plotted and average of five beams was taken to make final load deflection curve.

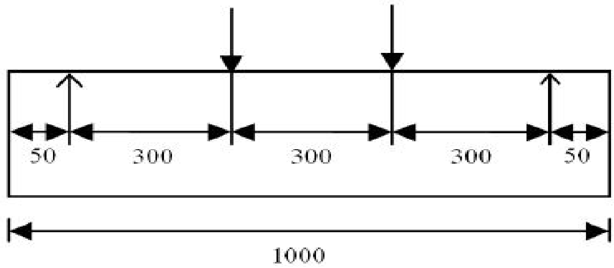

Figure 2. 7: Test setup of beam (Anumol raju et al., 2013)

When the beams were tested it was observed that all the retrofitted beams failed in flexure. It was observed that control beam has lower ultimate load capacity and deflections were large at failure when compared with the test results of beams strengthened with FRP sheets. Also it was evident from the test results that the load-deflection behaviour was different for beams retrofitted with different FRP sheets. It was observed that beams retrofitted with CFRP sheet wrapping showed better load deflection behaviour than any other retrofitted beams. The results from this study showed that retrofitting of beams enhances the ultimate load capacity of the beams. It was evident from the results that the ultimate load of control specimen was 63.3 KN, whereas the ultimate load of all the retrofitted beams were greater than 80 KN.

CFRP retrofitted beams showed 125% increase in ultimate load capacity than the control specimen and is the highest of all beams retrofitted. Beams retrofitted with GFRP showed ultimate load of 120 KN, which is 89.6% greater than control specimen. SFRP retrofitted beams showed 45.02% increase in ultimate load and coir fibre sheet retrofitted beams showed 37.9% increase in ultimate load capacity of beam. Among all the retrofitted beams PFRP retrofitted beams showed least ultimate load of 87.74 KN, which is 37.03% higher than ultimate load.

2.3 OBJECTIVES OF THE STUDY

The study of existing literature indicates that there is limited data available on the behaviour of RC beams retrofitted with the combination FRP like jute fibres and man made fibres like glass fibre.

The present study aims at:

1. To study the effect of different number of layers of jute and glass fibres in composites used for retrofitting of RC flexure elements.
2. To study the effect of side wrap and 3side U- wrap configurations with different number of layers in the behaviour of damaged RC beams
3. To study the effect of different types of retrofitting on the ductile behaviour of beams.

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 INTRODUCTION

Now a days retrofitting and strengthening of current structures has become one of the considerable part of construction industry. There is a developing demand of continued advancement of urbanization and modern life therefore the structures continued to increase at a high pace. Thus, it has become important to upgrade or repair the current structures due to many factors such as, environmental factors, structures exceeding their design life, loading on the structure changes due to some reason and to make the structure to be used for more than its design life. Therefore, many methods of strengthening/retrofitting and many materials have been developed for both shear and flexural strengthening of the structural members. Among the various retrofitting techniques, FRP jacketing is the most popular and easy method of retrofitting used now a days. In this technique many different types of FRP are used to repair or retrofit the existing structural members. Now days there are a number of materials used for retrofitting such as GFRP, CFRP, Ferro-cement, etc.

Moreover, there is a great need for the world to become eco-friendly has made the natural fibre reinforced material growing very rapidly. Therefore, now days more eco-friendly and biodegradable materials are being used in construction industry. The use of natural fibres for retrofitting and repairing work has become major part of the study now a days. But the use of only natural fibres cannot meet the strength and structural requirement of the structure, therefore in this study both natural and synthetic fabrics are used as a hybrid composite for retrofitting of the beams.

In this study both flexure and shear strengthening of beams is done by using jacketing as retrofitting technique. In the present study, 14 beam specimens of size (130mm X 230mm X 1000mm) are casted out of which two beams are control beams. Two schemes of wrapping are done in the study i.e. Side Wrapping and U-Wrapping. Further three different types of layers of jute and glass fabric is used for retrofitting. Two beams for each type of layer are tested for accuracy. Therefore, the remaining 12 beams are divided into two groups. Six beams in group of two are retrofitted with side wraps and remaining six beams are retrofitted with U-Wrapping scheme. Firstly control beams were tested to the ultimate failure load and the yield load is calculated and noted. Then all the beams to be strengthened are stresses to 60% of the failure load of the control beams and then they are retrofitted by applying different layers of jute and glass fabric with the help of epoxy.

3.2 TEST PROGRAMME

The main objective of the test programme was to figure out the properties of the materials which are to be used for fabrication of specimens and after that finding the behavior of the retrofitted beams.

The test programme involved following steps:

1. Figure out the basic properties of the materials such as cement, coarse aggregates, sand and steel bars conforming to Indian standard specifications.
2. Casting of fourteen reinforced concrete beams (1000 x 230 x 130mm) having grade of concrete as M25 and steel Fe500. The mix is designed as per the properties of the constituent materials.
3. Finding out the ultimate failure load of the control beams by stressing them to their ultimate failure load.
4. The remaining beams are loaded to 60% of the ultimate failure load.
5. At final stage, the beams are retrofitted with jute fabric and glass fabric in layers with Side-Wrap type configuration and U-Wrap type configuration.

3.3 MATERIALS

Materials used in this study for casting of the beams are cement, fine aggregate, coarse aggregate, reinforcing steel bars, and portable water. Jute fabric and Glass fabric is used as a retrofitting materials and epoxy as a bonding agent is used for bonding of FRP to the surface of the beams. The properties of these materials and their specifications are mentioned as under:

3.3.1 Cement

Shree (Ordinary Portland Cement) cement from a single batch is used for the experiment. IS 8112:2013 named "ORDINARY PORTLAND CEMENT, 43 GRADE- SPECIFICATION" is the Indian standard which provides the specifications such as manufacturing, chemical and physical requirements of the OPC 43 Grade. The specifications of cement used in this study complies with IS 8112:2013. According to IS 8112:2013 OPC 43 grade should be manufactured by thoroughly mixing together argillaceous and calcareous and/or silica, alumina or iron oxide bearing materials. Then burning them at high temperature so that clinkers are formed, then these clinkers are grinded to produce cement of standard specifications as laied down by IS 8112:2013. Other than gypsum, performance improver(s) and water no other material is to be added after burning of clinkers. The cement used was stored in cool and dry place to prevent any contact with moisture so that its properties are not altered. Cement used was fresh and free form any lumps. The physical properties of the cement are determined form various tests such as initial setting time and final setting time, specific gravity, fineness and compressive strength conforms to Indian Standard IS 8112:2013. These properties are listed in following tables

Table 3. 1: Properties of cement used in the study.

Properties	Values obtained	Test method referred from
Grade of cement	OPC 43	-
Specific gravity	3.12	IS 4031 Part 11
Initial setting time(min)	123	IS 4031 Part 5
Final. setting time(min)	270	IS 4031 Part 5
Consistency (%)	28	IS 4031 Part 4

3.3.2 Fine Aggregates

Fine aggregates are further divided in accordance with their respective size, into three categories i.e. coarse, medium and fine sand. In this study the sand used conforms to grading zone II i.e. size less than 2.36 mm. On the basis of the distribution of particle size, IS 383-1970 divides the fine aggregates into 4 grading zones. The size of the sand progressively becomes finer from grading zone I to IV. Sand used in this experimental study was obtained locally from Patiala.

Firstly the sand was sieved through 4.7 mm sieve so as to remove large size particles and then it was washed with clean water to remove any clay and silt. Then the wet sand was sundried for few days to remove the moisture. The sand then obtained was ready to be used in concrete mix. IS 383-1970 lays down the specifications of fine aggregate, thus all the tests related to fine aggregate are done in accordance of this Indian standard (IS 383:1970). The physical properties and sieve analysis of fine aggregate used in this study are shown in table.

Table 3. 2: Properties of fine aggregate used in the study.

Name of Property	Observed Value
Maximum size of aggregate	4.75 mm
Specific Gravity	2.63
Net Water Absorption	0.80
Fineness Modulus	3.92
Grade of Sand	Grade II

Table 3. 3: Sieve analysis of fine aggregate used in the study.

Sieve No.	Mass Retained (gm)	Percentage Retained (%)	Passing (%)	% Retained Cumulative
4.75	28	2.8	97.2	2.8
2.36	186.5	18.65	81.35	21.45
1.18	177.5	17.75	82.25	39.2
600	130	13.0	87.0	52.2
300	291	29.1	70.9	81.3
150	138	13.8	86.2	95.1
Pan	49	4.9	95.1	100
				$\sum$ % retained = 292.5

Weight of sample taken = 1000g

Fineness Modulus = 292.5/100 = 2.925

3.3.3 Coarse Aggregate

Aggregates can be classified as coarse aggregate when they pass through 75mm Indian Standard sieveaand are retained over 4.75 mm IS sieve. Coarse aggregate can be crushed gravel, partially crushed gravels and uncrushed gravels. Coarse aggregates are formed from the natural fragmentation of rocks or by artificially crushing of gravels or rock. IS 383-1970 gives standard specifications of coarse aggregate to be used for construction. This standard specifies that the aggregates should be dense, hard, strong, clear , durable and free from any type of coating , alkali , organic matter and any other deleterious substance. The coarse aggregates utilized in this study conform to Indian Standard specification (IS 383-1970). These aggregates utilized in the present study were free from any flaky and elongated pieces. Crushed stone aggregate having maximum nominal size of 12.5 mm was used in the study. These aggregates passed through 12.5mm sieve and were retained on 10mm sieve. Physical properties and their sieve analysis of the coarse aggregate is given as below:

Table 3. 4 : Properties of coarse aggregate used in the study

Name of Property	Observed Value	
Maximum size of aggregate	10mm	20mm
Specific Gravity	2.69	
Net Water Absorption	0.85	
Fineness Modulus	6.10	
Bulk Density	1550 kg/m^3	

Table 3. 5 : Sieve Analysis of coarse aggregate (10mm)

IS Sieve	Mass retained (gm)	Mass Retained (%)	Cumulative % Retained	% Passing
20 mm	0	0	0	100
10 mm	379	18.95	18.95	81.05
4.75 mm	1442.5	72.125	91.075	8.95
Pan	178.5	8.925	100	0
			∑% Retained =110.025	

Weight of sample taken = 2000 g

Fineness Modulus = (110.025+500)/100 = 6.10

Table 3. 6 :Sieve Analysis of coarse aggregate (20mm)

IS Sieve	Mass retained (gm)	Mass Retained (%)	Cumulative % Retained	% Passing
20 mm	160	3.2	3.2	96.8
10 mm	4410	88.2	91.4	8.6
4.75 mm	360	7.2	98.6	1.4
Pan	70	1.4	100	0
			∑% Retained = 193.2	

Weight of sample taken = 2000 g

Fineness Modulus = (193.2+500)/100 = 6.93

3.3.4 Epoxy

Epoxy is one of the most important part of retrofitting in this study as it behaves as a bonding agent between concrete surface and jute/glass fabric and also between jute and glass woven fabric. The strength of these fabrics can only be utilized if they are properly bonded with the surface. There are a wide variety of epoxy resins available in market with different mechanical properties. Usually epoxy resins consists of two parts i.e. a resin and a hardener. This study uses Dr. Fixit 211 epoxy bonding agent which also consists of two parts, one is a resin and other is a hardener. These two parts are to be mixed in some proportions to get a uniform mixture which can be used as a bonding agent for retrofitting of beams. It is used for bonding of new concrete to old concrete and also works for bonding fibres to the concrete surface.

3.3.4.1 Features and Benefits

Table 3. 7 : Features and benefits of Dr. Fixit bonding agent.

S.NO	BENEFITS	DISCRIPTIONS
1.	Ease of application	
2.	Adhesion	Excellent adhesion to almost all building materials
3.	Strength	Bond strength exceeds the tensile strength of concrete hence no failure of concrete due to high degree of movements
4.	Open time	comfortable open time to complete the work easily
5.	Shrinkage	Very low shrinkage as compared to polymer modified cementitious bonding agent
6.	Water resistance	Excellent water resistance and sealing property prevents leakage.
7.	Toxicity	Non-toxic.
8.	Moisture tolerant	It is moisture tolerant hence provides strong bond
9.	Durability	very high durable bond.
10.	Chemical resistance	Resistant to chemical attack.

The properties of Dr. Fixit bonding agent used in the experimental study is as follows:

Table 3. 8 : Properties of Epoxy used in the study

S.no.	Properties	units	value
1.	Mix density	Kg/m^3	1120
2.	colour		grey
3.	Pot Life @30°C	min	± 30-40
4.	Tack Free Time@30 °C	hrs	1-2
5.	Shear bond strength		Concrete failure
6.	Tensile strength	N/mm^2	10.4
7.	Cure time	days	7
8.	Mixing ratio, B:H parts by weight		100:87
9.	Application temp.	°C	15-35
10.	Compressive strength	N/mm^2	7 days- 60
11.	Flexural strength	N/mm^2	28.1

Figure 3. 1 : Package of Epoxy bonding agent used in the study

3.4 DESIGN OF CONCRETE MIX

The mix design of concrete is done to achieve a particular compressive strength with proper workability. Workability of concrete is an important parameter to be kept in mind while designing of concrete mix, so that it can be easily carried, placed and compacted easily. Current study uses M25 grade concrete which is designed by taking into consideration all the properties of cement, fine aggregate(sand), and coarse aggregate(crushed stones) . The design of M25 grade concrete is done as per guidelines provided by IS : 10262-2009. Water to cement ratio was taken 0.45. The initial data of the materials required for M25 concrete design was found and is stated as below. The quantities of materials required per cubic meter volume of concrete are found out and the quantities per batch of the concrete were calculated by multiplying the calculated data with the batch volume. The mix proportions of the concrete is given in table below. Required number of cubes were prepared with the calculated mix proportions and were then tested after 7 days and 28 days of age. Preliminary data required for the mix design of the concrete is recognized and stated as below.

3.4.1 M25 Mix Design Data

Table 3. 9 : Data required for M25 Mix Design.

S.NO.	DATA REQUIRDED	VALUE
1.	Grade designation	M25
2.	Type of cement	OPC 43
3.	Maximum nominal size of aggregate	20mm
4.	Minimum cement content	300 kg
5.	Maximum water cement ratio	0.45
6.	Maximum water cement ratio	50-75 mm
7.	Exposure condition	Medium (RCC)

Table 3. 10 : Mix proportion of M25 grade concrete used in the study

Water	Cement	Fine aggregate/Sand	Coarse aggregate/Crushed stone
191.5 kg	425.55 kg	655.87 kg	1148.6 kg
0.45	1	1.54	2.70

3.5 RCC BEAM DESIGN

Present study uses M25 Grade concrete and Fe 500 steel for the design of RCC beam (1000mm x 130 mm x 230 mm). In this study limit state method is used for designing of RCC beam as an under-reinforced section. After designing, the reinforcing steel comes out to be 2 bars of 8 mm diameter at top compression face and 2 bars of 12 mm diameter at bottom tension face. The stirrups comes out to be 8 mm dia @ 90 mm c/c. The longitudinal section and cross-section of the beam is shown as below.

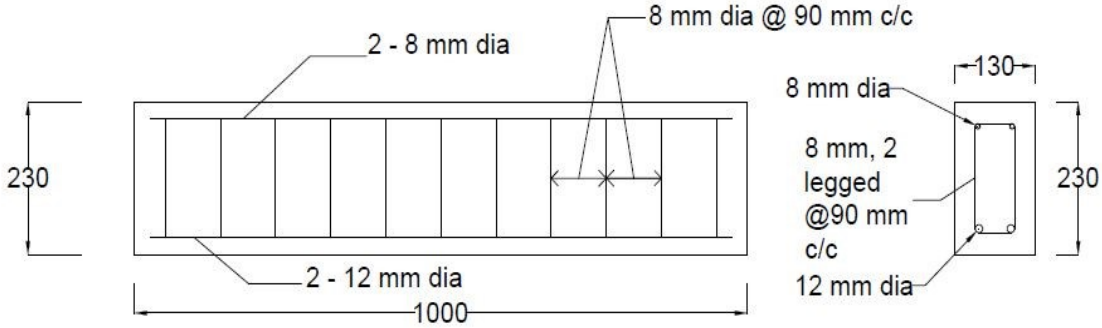

Figure 3. 2 :Cross-section and reinforcement detailing of the beam used in the study

3.6 CASTING OF RCC BEAMS

Casting of the beams was done in a single stage. The beams were casted in the mould of 130x 230x 1000mm size. First stage involves the preparation of the mould by tightening all the nuts and bolts of the mould and making sure that no gap is left from where concrete can flow outside. Then the entire mould is oiled thoroughly covering all the three faces and corners so that the beams can be easily detached from the mould after the desired period of time. Covers to the reinforcement is provided by using spacers of 25 mm. Second step for casting of beams is placing the reinforcement in mould over the spacers. When the bars have been kept at proper position keeping in mind proper spacing and covers, the designed concrete mix is poured in the mould. The concrete is compacted by providing vibrations with the help of needle vibrator so that no gap is left. The concrete is filled up to the brim of the mould and is smoothened from its top surface with the help of a trowel. The beam is then left undisturbed for 24 hours. Then, after

24 hours the beam is ready to be removed from the mould. After demoulding, the beams are cured for 28 days with the help of jute bags.

Figure 3. 3 : Figure showing filling of concrete in mould and vibrating with needle vibrator

3.7 TESTING ARRANGEMENT

The beams are tested after a curing period of 28 days. All the beam specimens were tested in Universal Testing Machine (UTM) with simply supported end conditions. All the beam specimens were subjected to three point loading test with load applied at L/2 distance from either support. A dial gauge was setup at the center of the beam to note down the central deflection of the beam corresponding to the load applied. The loading rate was kept 0.1 KN/sec so as to note down the reading of deflection in dial gauge corresponding to the load value, accurately. The testing arrangement is shown below.

Figure 3. 4 : Testing arrangement for the test beams in UTM

3.8 PREPARATION OF SURFACE OF BEAM BEFORE RETROFITTING

The beams to be retrofitted are cleaned and prepared before applying retrofitting material to the surface to make sure that the retrofitting material is properly bonded to the surface. After a curing period of 28 days of the beams, they are stressed up to certain load, as described in the study. After this, the surfaces of the beams are prepared for further retrofitting. The surfaces of the beams to be retrofitted are made free from any loose material like dust, loose concrete, etc. This is done with the help of sand paper and wire brush. Sand paper was grinded with the surface to be wrapped. This is done to remove the lose material and also to make the surface rough so as to ensure proper bonding of FRP to the surface of the beam. After grinding, all the surfaces prepared were cleaned with the help of water jet and were wiped to get a clean surface. The beam was left to dry for some time. Now, the beams were ready to be retrofitted.

Figure 3. 5 : Showing rubbing of beam surface with sand paper and then washing with water jet.

3.9 RETROFITTING OF BEAMS

In the present study the beams were preloaded to 60% of the ultimate failure load of the control beams and are then retrofitted with woven glass and jute fabric with the help of epoxy to make good bond between concrete to fabric and fabric to fabric.

Three different types of layers with two type of wrapping scheme is used as a retrofitting technique in the present study. Each wrapping scheme utilizes six beams with three different types of layers, having two beams for each type of layer.

Figure 3. 6 : Retrofitting of beams with side and U wrapping technique by applying epoxy over jute and glass fabrics

Table 3. 11 : Showing the wrapping schemes and type of layers used for retrofitting

S.NO.	BEAM NAME	WRAPPING SCHEME	LAYER CONFIGURATION
1.	CON.1	-	-
2.	CON.2	-	-
3.	$SW\text{-}B_1^A$	Side Wrap	1-Glass 1-Jute
4.	$SW\text{-}B_1^B$	Side Wrap	1-Glass 1-Jute
5.	$SW\text{-}B_2^A$	Side Wrap	2-Glass 1-Jute
6.	$SW\text{-}B_2^B$	Side Wrap	2-Glass 1-Jute
7.	$SW\text{-}B_3^A$	Side Wrap	2-Glass 2-Jute
8.	$SW\text{-}B_3^B$	Side Wrap	2-Glass 2-Jute
9.	$UW\text{-}B_1^A$	U-Wrap	1-Glass 1-Jute
10.	$UW\text{-}B_1^B$	U-Wrap	1-Glass 1-Jute
11.	$UW\text{-}B_2^A$	U-Wrap	2-Glass 1-Jute
12.	$UW\text{-}B_2^B$	U-Wrap	2-Glass 1-Jute
13.	$UW\text{-}B_3^A$	U-Wrap	2-Glass 2-Jute
14.	$UW\text{-}B_3^B$	U-Wrap	2-Glass 2-Jute

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter discusses the results of the experiments of this study. This study aims at increasing the strength of the preloaded beams and studying the behaviour of the retrofitted beams in comparison to control beams. Firstly, the failure load of the beams was found by stressing the control beams to its ultimate load, alternatively obtaining its load deflection curve. Then all the remaining beams were stressed to 60% of the failure load and were then retrofitted with jute and glass woven fabrics with the help of epoxy as a bonding agent. Then the retrofitted beams were tested after a proper curing period of 7 days. The retrofitted beams were tested under UTM to find out their ultimate load and correspondingly obtaining their load deflection graphs. Finally, a comparative study on the ultimate load capacity and their load-deflection behaviour of the retrofitted and control beams is done.

4.2 TESTING METHODOLOGY

Firstly, the failure load of the specimen was found by stressing the control beams to its ultimate load, alternatively obtaining its load deflection curve. Then all the remaining beams were stressed to 60% of the ultimate failure load and were then retrofitted with jute and glass woven fabrics with the help of epoxy as a bonding agent. The failure load of the two control beams was found to be 123 KN and 127 KN, and the average was calculated to be 125KN. Then all the remaining beams were stressed to 60% of the ultimate failure load of the control beam i.e. 70 KN. Then the retrofitting/strengthening of the beams was done with jute and glass woven fabric in layers and with different types of wrapping schemes as discussed in the previous chapters. Then the retrofitted beams were left to dry for 7 days for proper curing and were tested again with the same method as was done for control beams. The data was recorded and compared with the data obtained for control beams.

Table 4. 1 : The beam designations showing wrapping scheme and layer configuration used in the study

S.NO.	BEAM NAME	WRAPPING SCHEME	LAYER CONFIGURATION

1.	CON.1	-	-	
2.	CON.2	-	-	
3.	SW-B_1^A	Side Wrap	1-Glass 1-Jute	TYPE-1
4.	SW-B_1^B		1-Glass 1-Jute	
5.	SW-B_2^A		2-Glass 1-Jute	TYPE-2
6.	SW-B_2^B		2-Glass 1-Jute	
7.	SW-B_3^A		2-Glass 2-Jute	TYPE-3
8.	SW-B_3^B		2-Glass 2-Jute	
9.	UW-B_1^A	U-Wrap	1-Glass 1-Jute	TYPE-1
10.	UW-B_1^B		1-Glass 1-Jute	
11.	UW-B_2^A		2-Glass 1-Jute	TYPE-2
12.	UW-B_2^B		2-Glass 1-Jute	
13.	UW-B_3^A		2-Glass 2-Jute	TYPE-3
14.	UW-B_3^B		2-Glass 2-Jute	

4.3 LOAD-DEFLECTION BEHAVIOUR OF CONTROL BEAM

Two control beams were tested on UTM to their failure load and average of the data from the two beams was obtained. Deflections for each increment of load were noted from dial guage attached at the bottom centre of the beam. The beam showed no crack till the load reaches 42 KN. First crack when the load reaches 42 KN. First crack observed was at right angle from the bottom face of the beam i.e. it was a flexure crack. The crack propagated towards the top of the beam when the load was increased. When the load reaches 61 KN more cracks were observed. From the load deflection behaviour of the control beam, it is observed that the mid-span deflection of the beam increases at a constant rate up to a load of 73 KN. After this load the deflection increases at a high rate as the load was increased. This shows that the beams behaves elastically till the load of 73 KN and after that it enters into plastic range in which the deflection increases at a higher rate as compared to the increase in load. At the end of the plastic range the beam shows very higher deflections with no further increase in load, this shows that the beam has collapsed. The ultimate load at which the beam failed was found to be 125 KN. Thus, the beam shows a large range of elastic behaviour before entering into plastic range. This shows the ductile behaviour of the beam. Fig shows the crack pattern of the tested control beams.

Figure 4. 1 : Showing crack pattern at 60% of failure load

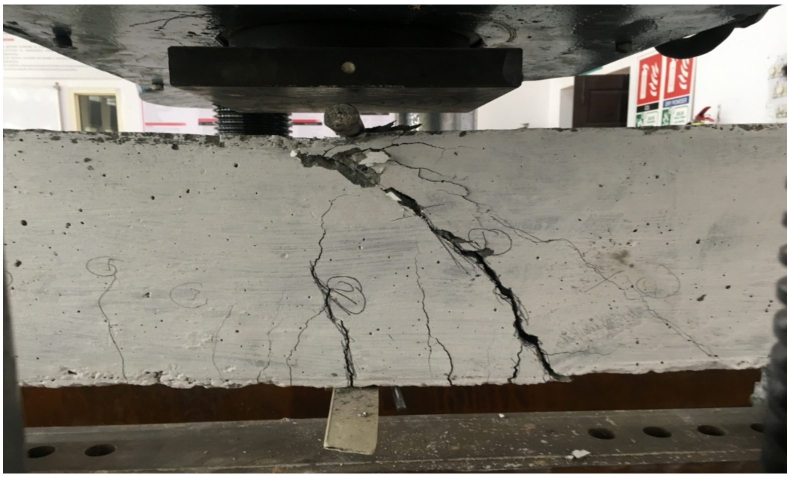

Figure 4. 2 : Showing ultimate failure crack of the control beam.

Table 4. 2 : Details of load vs. deflection of control beam

LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)
0	0	32	0.841	74	1.781	116	2.992
0.5	0.007	33	0.861	75	1.827	117	3.018
1	0.015	34	0.884	76	1.869	118	3.045
1.5	0.021	35	0.912	77	1.898	119	3.078
2	0.032	36	0.934	78	1.937	120	3.099

2.5	0.044	37	0.955	79	1.971	121	3.122
3	0.059	38	0.971	80	1.999	122	3.143
3.5	0.079	39	0.988	81	2.034	123	3.168
4	0.103	40	1.007	82	2.068	124	3.191
4.5	0.12	41	1.025	83	2.099	125	3.217
5	0.134	42	1.047	84	2.134	120	3.357
5.5	0.152	43	1.063	85	2.176	115	3.487
6	0.174	44	1.088	86	2.214	110	3.487
6.5	0.189	45	1.105	87	2.247	100	3.487
7	0.211	46	1.131	88	2.276		
7.5	0.232	47	1.157	89	2.308		
8	0.257	48	1.171	90	2.331		
8.5	0.283	49	1.194	91	2.358		
9	0.314	50	1.218	92	2.382		
9.5	0.331	51	1.235	93	2.409		
10	0.356	52	1.259	94	2.437		
11	0.384	53	1.284	95	2.468		
12	0.409	54	1.307	96	2.497		
13	0.421	55	1.328	97	2.526		
14	0.443	56	1.361	98	2.552		
15	0.462	57	1.384	99	2.577		
16	0.486	58	1.408	100	2.599		
17	0.508	59	1.432	101	2.634		
18	0.529	60	1.454	102	2.658		
19	0.553	61	1.478	103	2.684		
20	0.574	62	1.499	104	2.709		
21	0.597	63	1.518	105	2.725		

22	0.619	64	1.551	106	2.749		
23	0.643	65	1.574	107	2.771		
24	0.666	66	1.596	108	2.794		
25	0.689	67	1.617	109	2.827		
26	0.708	68	1.639	110	2.851		
27	0.726	69	1.662	111	2.876		
28	0.751	70	1.681	112	2.897		
29	0.774	71	1.698	113	2.919		
30	0.796	72	1.717	114	2.941		
31	0.818	73	1.738	115	2.968		

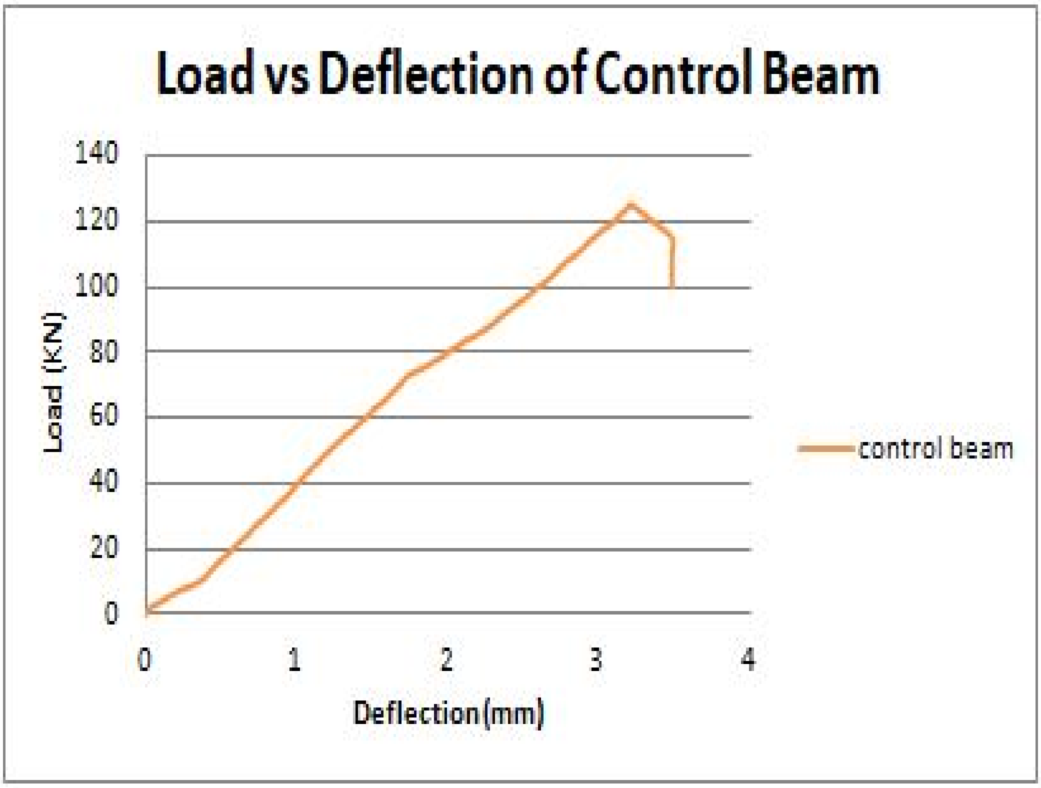

Figure 4. 3 : Graph showing load-deflection behaviour of the control beam

4.4 LOAD DEFLECTION BEHAVIOUR OF BEAMS RETROFITTED WITH SIDE WRAPS

4.4.1 BEHAVIOUR OF BEAMS RETROFITTED WITH TYPE 1 LAYERING

Two beams of each type of layering were tested on UTM to their ultimate load and average of the data from two beams was obtained. Deflections for each increment of load were noted from the dial gauge attached to the bottom middle of the beam, as was done for control beams. The load vs. deflection curve was built from the data obtained. Crackling sound of the crack was herd at a load of 48 KN. The crack became more visible when the load was increased. There was no sign of de-bonding of the jute and glass FRP from the surface of the beam even at ultimate load.

It was seen that only one crack appeared in the middle flexure zone during the whole testing, which gets widened with the increment of load, without the development of any other cracks. As the load increases to the ultimate load, the crack gets wider and no more cracks appeared.

From the load deflection behaviour of this beam it was observed that with the increase in load, the mid-span deflection increases at a constant rate up to the load of 85 KN. After this load the deflection increases at a higher rate as compared to the increase in load. This shows that, after behaving elastically till the load of 85 KN, beam enters into plastic range till it reaches ultimate load of 135 KN.

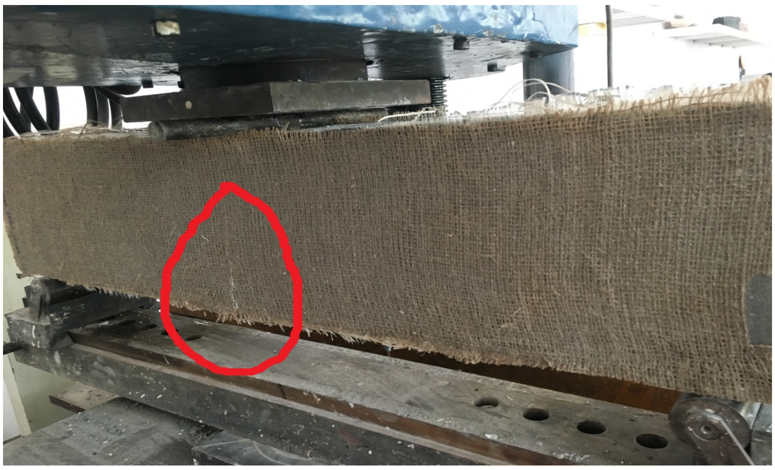

Figure 4. 4 : Showing single ultimate load crack of SW-B1 with Type-1 layering scheme

Table 4. 3 : Details of load vs. deflection of SW-B1 beam.

LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)
0	0	32	0.5185	74	1.487	116	2.7705
0.5	0.008	33	0.5475	75	1.5155	117	2.8025
1	0.0125	34	0.5665	76	1.5395	118	2.8355
1.5	0.017	35	0.5925	77	1.5545	119	2.872
2	0.0235	36	0.611	78	1.5705	120	2.908
2.5	0.0295	37	0.6325	79	1.5825	121	2.9235
3	0.033	38	0.654	80	1.598	122	2.9515
3.5	0.0395	39	0.672	81	1.612	123	2.98
4	0.0545	40	0.6915	82	1.627	124	3.017
4.5	0.071	41	0.723	83	1.6485	125	3.0485
5	0.084	42	0.746	84	1.67	126	3.078
5.5	0.0955	43	0.7735	85	1.682	127	3.104
6	0.117	44	0.793	86	1.701	128	3.1315
6.5	0.129	45	0.8295	87	1.74	129	3.1595
7	0.139	46	0.8525	88	1.771	130	3.1945
7.5	0.1535	47	0.87	89	1.803	131	3.2305
8	0.164	48	0.893	90	1.8445	132	3.2575
8.5	0.18	49	0.9205	91	1.8745	132.2	3.267
9	0.1905	50	0.945	92	1.9015	132.4	3.2825
9.5	0.207	51	0.9715	93	1.9355	132.6	3.299
10	0.219	52	0.989	94	1.9625	132.8	3.313
11	0.2295	53	1.015	95	2.0005	133	3.3215
12	0.2395	54	1.038	96	2.0395	134	3.286
13	0.25	55	1.0635	97	2.0765	134.2	3.301
14	0.26	56	1.0845	98	2.1215	134.4	3.316

15	0.275	57	1.1085	99	2.1625	134.6	3.331
16	0.286	58	1.1325	100	2.1935	134.8	3.346
17	0.299	59	1.1505	101	2.242	135	3.378
18	0.3145	60	1.1745	102	2.279	134	3.421
19	0.3325	61	1.2025	103	2.318	132	3.449
20	0.347	62	1.2315	104	2.3625	128	3.5435
21	0.3595	63	1.2625	105	2.394	125	3.6275
22	0.375	64	1.281	106	2.429	120	3.7205
23	0.388	65	1.301	107	2.4715	115	3.811
24	0.4025	66	1.323	108	2.51	110	3.881
25	0.417	67	1.345	109	2.546	100	3.858
26	0.429	68	1.367	110	2.5825		
27	0.4445	69	1.381	111	2.6215		
28	0.459	70	1.395	112	2.6455		
29	0.471	71	1.42	113	2.68		
30	0.486	72	1.442	114	2.7095		
31	0.5025	73	1.465	115	2.738		

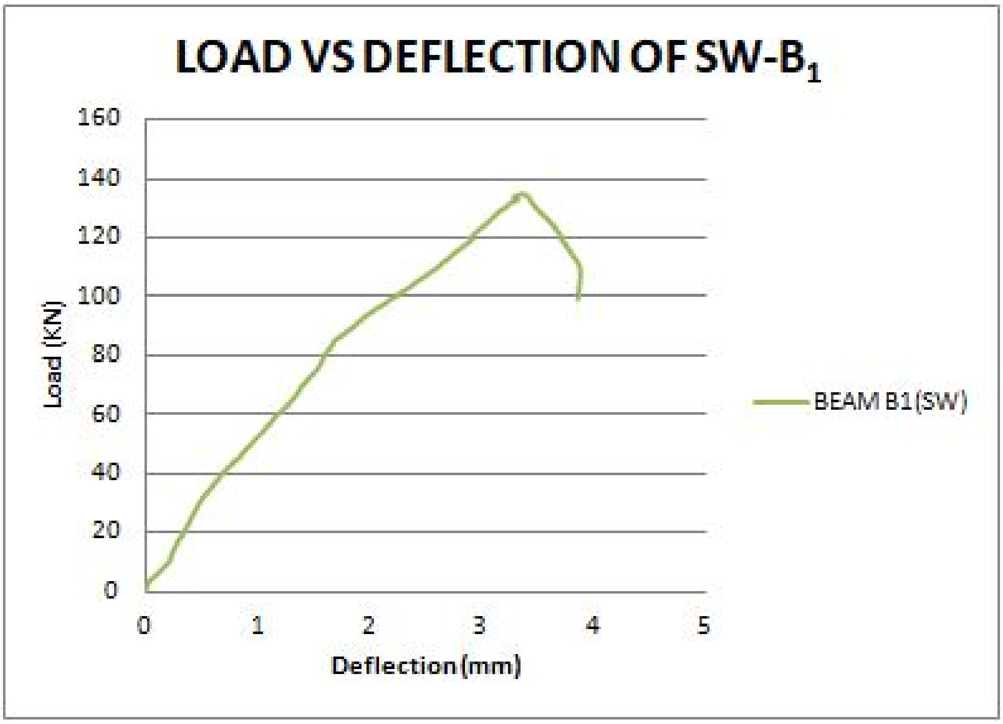

Figure 4. 5 : Graph showing load-deflection behaviour of SW-B1 beam.

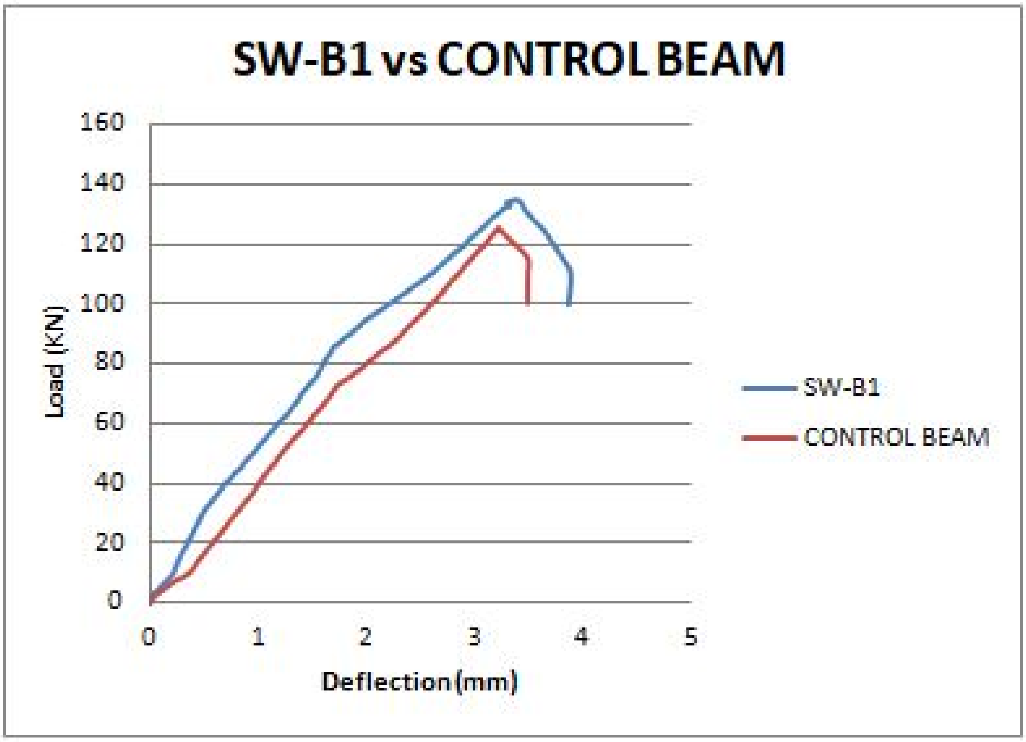

Figure 4. 6 : Comparative graph of load-deflection curves of control and SW-B1 beam.

In comparison to control beam, this beam retrofitted with Type-1 layering shows more ductility. This is evident from the load vs. deflection behaviour that the beam has carried huge deflections before failure.

This shows that the beam retrofitted with Type-1 layering is more ductile than control beam, this means that this beam have more deformation capacity after yielding and have higher ability to dissipate energy than control beam. The deformability index is defined as the ratio of ultimate load deflection to the yield load deflection. Therefore, it was observed that the deformability index of the beams retrofitted with Type-1 layering is more when compared to control beam. This shows that the retrofitted beams are improved version of the control beams in a way that they shows more plastic deformation and energy absorption before failure.

4.4.2 BEHAVIOUR OF BEAM RETROFITTED WITH TYPE-2 LAYERING

As mentioned earlier that two beams of each type of layering technique were utilised for testing and the average of the data obtained from two beams was calculated and considered. The testing method was same as that of control beam. Deflections were noted at proper intervals of load increment, which served as the data for Load v/s Deflection curve of this retrofitted beam. There was no sign of any crack sound till the load reaches 54 KN. When the load reaches 54 KN a crackling sound was herd, which shows the development of crack. The crack became more visible when load was increased further. One of the two beams tested, showed two cracks originating from the bottom middle of the beam. These cracks started to propagate towards the top of the beam as the load was increased. Other beam showed only one single cack at flexure zone of the beam. There was no sign of de-bonding of the FRP from the surface of beam even at very high load, this showed that whole strength of the FRP is utilised in the experiment.

From the load deflection curve of the retrofitted beam it was observed that with increase in load, the mid-span deflection increases at a constant rate till the load reaches 103 KN. After this load is reached, the deflection increases at a high rate as compared to the load increment. This shows that the beam behaves elastically till the load reaches 103 KN and after this load the beam enters into plastic range till the load reached its ultimate load capacity of the beam i.e. 140 KN.

Figure 4. 7 : Showing flexural failure of SW-B2 beam.

Figure 4. 8 : Showing clear view of crack pattern of SW-B2 beam at failure

Table 4. 4 : Details of load vs. deflection of SW-B2 beam.

LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)
0	0	32	0.5295	74	1.3845	116	2.336
0.5	0.006	33	0.5495	75	1.4	117	2.3705
1	0.0095	34	0.568	76	1.427	118	2.396
1.5	0.014	35	0.5885	77	1.4555	119	2.436
2	0.017	36	0.604	78	1.4765	120	2.473
2.5	0.024	37	0.6265	79	1.498	121	2.5185
3	0.034	38	0.654	80	1.516	122	2.592

3.5	0.047	39	0.6755	81	1.537	123	2.6425
4	0.059	40	0.689	82	1.5515	124	2.7025
4.5	0.0715	41	0.7035	83	1.568	125	2.758
5	0.08	42	0.7285	84	1.5935	126	2.8065
5.5	0.0915	43	0.752	85	1.6095	127	2.865
6	0.111	44	0.7735	86	1.627	128	2.915
6.5	0.126	45	0.797	87	1.641	129	2.9745
7	0.136	46	0.835	88	1.659	130	3.0355
7.5	0.1485	47	0.856	89	1.6805	131	3.078
8	0.1605	48	0.871	90	1.6955	132	3.1285
8.5	0.1765	49	0.887	91	1.7175	133	3.2045
9	0.183	50	0.9075	92	1.732	134	3.2605
9.5	0.1935	51	0.9255	93	1.747	135	3.309
10	0.2045	52	0.954	94	1.7585	136	3.368
11	0.2135	53	0.9715	95	1.7715	137	3.413
12	0.2265	54	0.9895	96	1.789	138	3.467
13	0.237	55	1.019	97	1.803	139	3.541
14	0.2505	56	1.04	98	1.8175	140	3.7005
15	0.2715	57	1.06	99	1.8285	141	3.961
16	0.283	58	1.0785	100	1.847	140	4.1115
17	0.2965	59	1.0975	101	1.8725	140	4.3105
18	0.3095	60	1.122	102	1.894	140	4.429
19	0.322	61	1.1435	103	1.917	140	4.635
20	0.3325	62	1.1585	104	1.9425	140	4.7005
21	0.35	63	1.179	105	1.973	140	4.806
22	0.3685	64	1.1985	106	2.019	140	4.8675
23	0.386	65	1.214	107	2.0615	135	4.8675

24	0.3955	66	1.2325	108	2.0925	130	4.8675
25	0.4105	67	1.2525	109	2.122	125	4.8675
26	0.425	68	1.2755	110	2.1545	115	4.912
27	0.44	69	1.289	111	2.1835	110	4.912
28	0.461	70	1.3085	112	2.2045	100	4.912
29	0.481	71	1.3315	113	2.241		
30	0.495	72	1.3535	114	2.28		
31	0.5115	73	1.365	115	2.303		

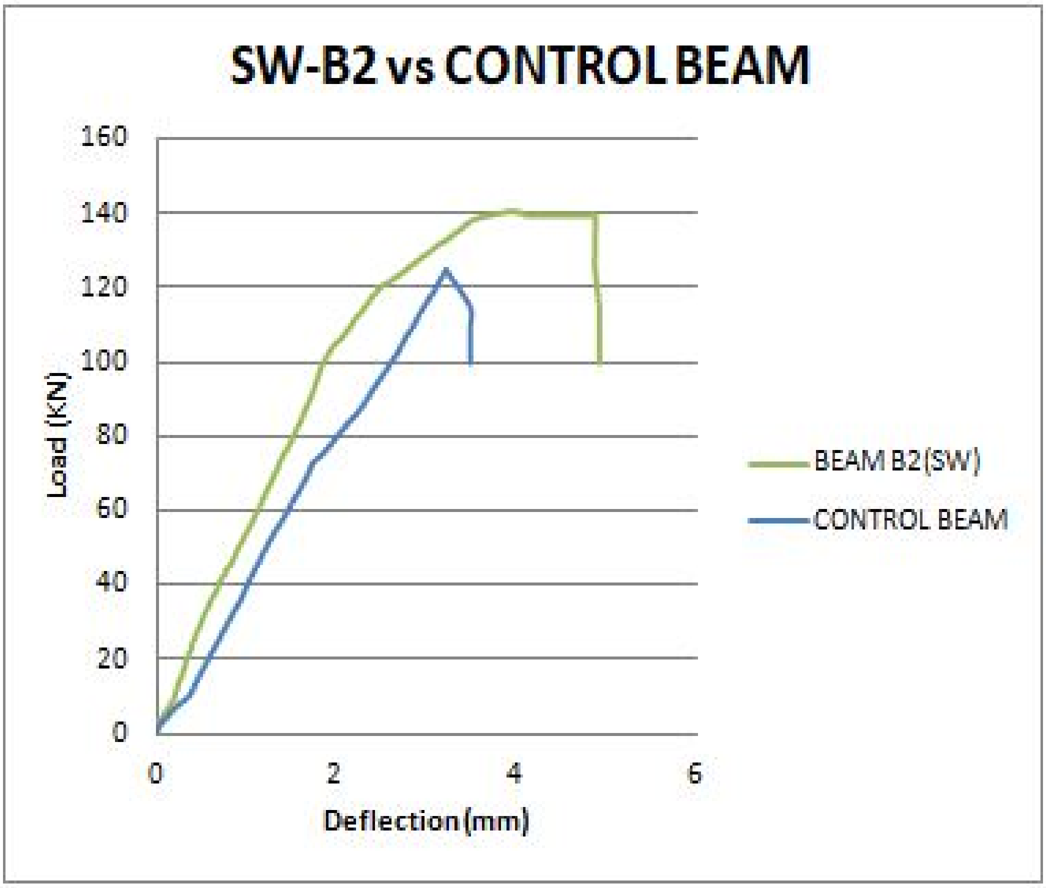

Figure 4. 9 : Comparative graph of load-deflection behaviour of control beam and SW-B2 beam.

In comparison with the control beam, this beam retrofitted with Type-2 layering technique shows more ductility. This is evident from the load vs. deflection curve that the beam has carried larger deflection than control beam before failure.

This shows that this retrofitted beam is more ductile than control beam. But when this beam was compared to the beam retrofitted with Type-1 layering, it was found that there was not any considerable increase in ductility. The deformability index as defined earlier is a structural property, therefore this retrofitted beam is structurally sounder than the control beam and the beam previously retrofitted. Also, the energy absorption before failure, of this beam is more as compared to control and previously retrofitted beam.

4.4.3 BEHAVIOUR OF BEAMS RETROFITTED WITH TYPE-3 LAYERING

As discussed earlier, two beams were retrofitted with Type-3 layering and were tested with the same procedure as discussed earlier. The results from the two beams were obtained after testing them on UTM. Deflections at proper interval of load increment were noted from the dial gauge attached at the mid-span of the beam. Single data of results from two beams was obtained after calculating their average values. Load deflection curve from the data was obtained for this retrofitted beam. There was no sign of any cracking sound until the load reached 57 KN. When the load reached 57 KN a cracking sound was herd due to little de-bonding of the fabric layer from the bottom of the beam. When the load was increased, the crack started to appear. The crack was vertical and positioned at the central portion of the beam, showing pure flexure failure of the beam. Only a single crack appeared, originating from centre bottom of the beam. This crack widens and propagates to the top of the beam with the increase in load. Both the beams showed single wide crack at the central portion of the beam at failure.

The load-deflection curve of this beam showed that the mid span deflection increases at a constant rate with the increase in load, till the load reached 112 KN. After this load, the deflections increased at a higher rate as compared to the load increment. This showed that the beam behaved elastically before reaching 112 KN and after this load the beam entered into plastic zone in which the mid-span deflections increased at a very high rate. The retrofitted beam continues to be in plastic zone till it reaches its ultimate load capacity of the beam. The ultimate load capacity of this beam retrofitted with side wrapping of jute and glass fabric (Type- 3 layering) was found to be 147 KN. Plastic zone indicates the zone in which if the beam is unloaded, it cannot regain its original configuration, i.e. it gains permanent deformation.

Figure 4. 10 : Showing cracks in FRP at failure load of SW-B3 beam

Figure 4. 11 : Showing de-bonding of FRP at bottom of the beam.

Table 4. 5 : Details of load vs. deflection of SW-B3 beam.

LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)
0	0	32	0.498	74	1.125	116	2.159
0.5	0.006	33	0.512	75	1.152	117	2.199
1	0.008	34	0.525	76	1.184	118	2.245
1.5	0.012	35	0.539	77	1.221	119	2.289
2	0.014	36	0.551	78	1.252	120	2.34

2.5	0.018	37	0.584	79	1.286	121	2.391
3	0.026	38	0.596	80	1.302	122	2.436
3.5	0.036	39	0.612	81	1.316	123	2.487
4	0.048	40	0.625	82	1.331	124	2.526
4.5	0.061	41	0.638	83	1.356	125	2.568
5	0.075	42	0.651	84	1.374	126	2.603
5.5	0.084	43	0.664	85	1.398	127	2.654
6	0.098	44	0.684	86	1.423	128	2.697
6.5	0.117	45	0.696	87	1.458	129	2.742
7	0.126	46	0.71	88	1.488	130	2.789
7.5	0.135	47	0.721	89	1.512	131	2.812
8	0.148	48	0.743	90	1.543	132	2.861
8.5	0.164	49	0.756	91	1.571	133	2.897
9	0.176	50	0.772	92	1.593	134	2.943
9.5	0.188	51	0.791	93	1.624	135	2.987
10	0.201	52	0.806	94	1.646	136	3.023
11	0.209	53	0.823	95	1.669	137	3.065
12	0.215	54	0.836	96	1.678	138	3.115
13	0.228	55	0.852	97	1.691	139	3.165
14	0.239	56	0.867	98	1.711	140	3.221
15	0.254	57	0.881	99	1.723	141	3.274
16	0.275	58	0.896	100	1.746	142	3.354
17	0.286	59	0.912	101	1.761	143	3.396
18	0.302	60	0.921	102	1.784	144	3.476
19	0.316	61	0.936	103	1.794	145	3.521
20	0.329	62	0.95	104	1.818	146	3.586
21	0.342	63	0.962	105	1.835	147	3.869

22	0.364	64	0.978	106	1.856		
23	0.375	65	0.988	107	1.875		
24	0.388	66	0.999	108	1.891		
25	0.405	67	1.01	109	1.913		
26	0.412	68	1.022	110	1.931		
27	0.422	69	1.034	111	1.958		
28	0.434	70	1.047	112	1.974		
29	0.449	71	1.061	113	2.021		
30	0.462	72	1.078	114	2.064		
31	0.484	73	1.096	115	2.112		

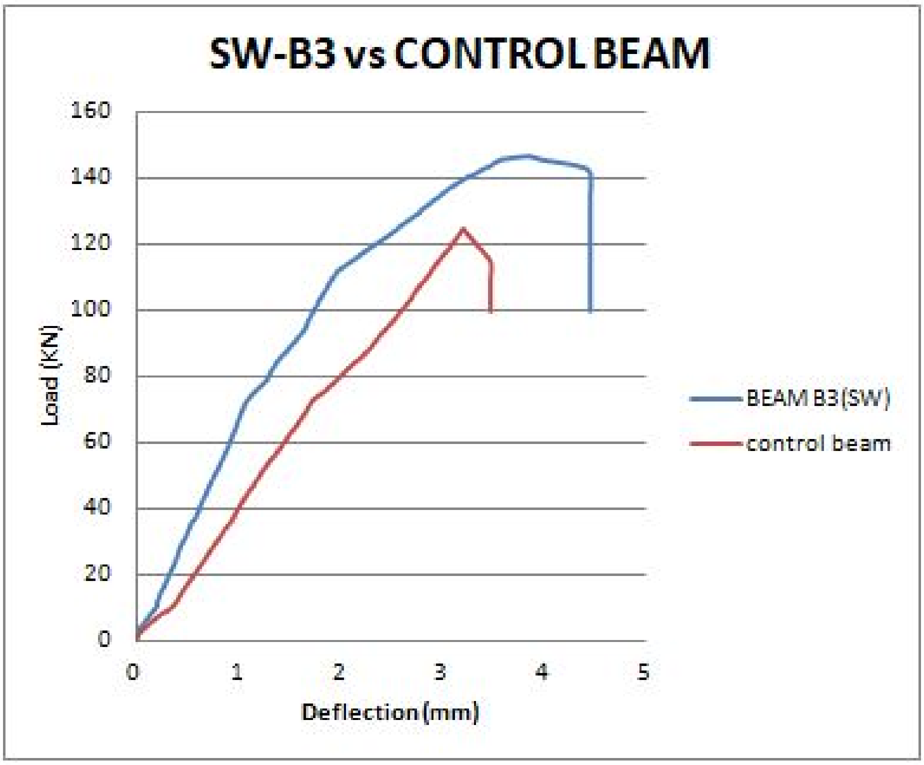

Figure 4. 12 : Comparative graph of load- deflection curve of control and SW-B3 beam.

In comparison to the control beam, this beam retrofitted with Type-3 layering technique show much more high ductility. The load vs. deflection curve shows that the beam carries large deflections at failure in comparison to the previously retrofitted beam and the control beam.

It is evident from the graph shown above that the beam is more ductile and have higher deformability index when compared to the previously retrofitted beams and control beam. The ultimate load of this retrofitted beam is more when compared with the control beam and beams retrofitted with Type-1 and Type-2 layering schemes.

Table 4. 6 : Shows %age increase in ultimate load and change in ultimate deflection.

Beam	Ultimate load (KN)	Ultimate deflection (mm)	%age inc. In load	% change in deflection
CB	125	3.217	-	
SW-B_1	135	3.378	8	5
SW-B_2	140	3.700	12	15.01
SW-B_3	147	3.869	17.6	20.26

4.4.4 COMPARISON OF LOAD-DEFLECTION BEHAVIUR OF ALL SIDE WRAPPED BEAMS AND CONTROL BEAM

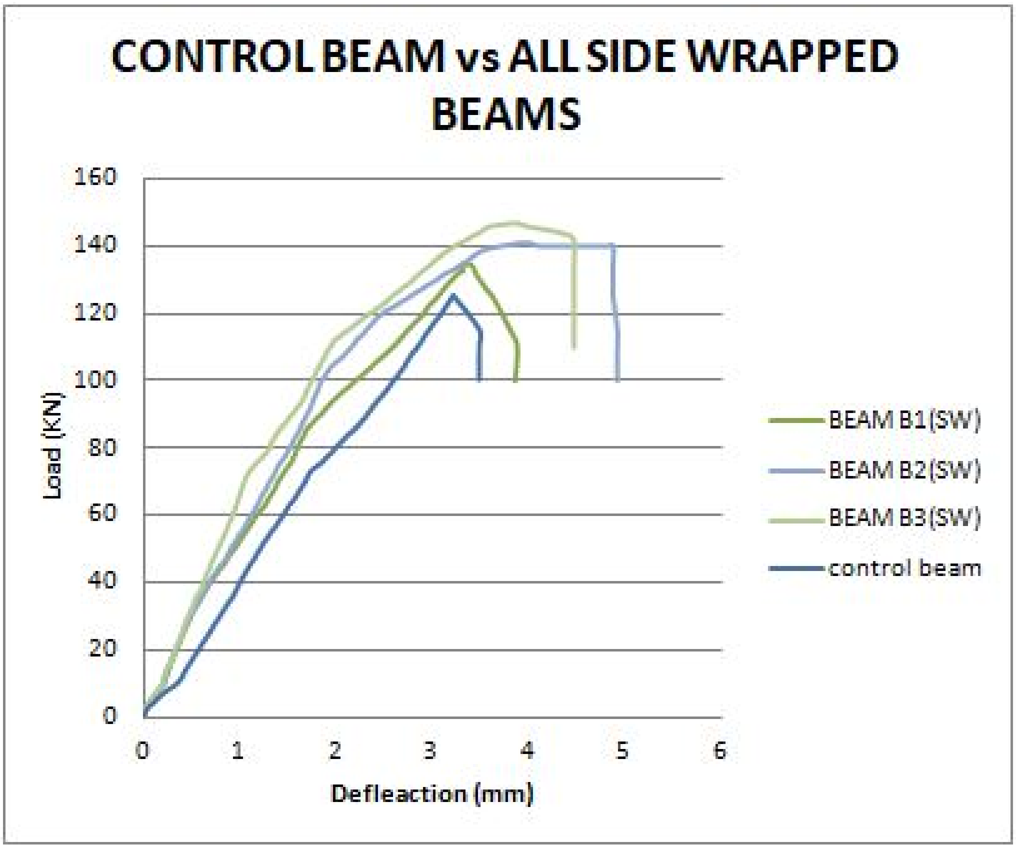

Figure 4. 13 : Comparative graph of load-deflection curves of all side wrapped beams and control beam.

The above graph is a comparative graph of load deflection curve of all the side wrapped beams and control beam. It can be concluded that the load deflection behaviour of the beam improved when retrofitted with jute and glass woven fabrics as a wrapping materials. The failure load of the retrofitted beams was increased when compared to control beam as shown in above graph. Moreover, the ultimate load capacity of the beam increases as the number of layers of jute and glass fabric increased. The beam wrapped with Type-3 layering system showed highest increase in ultimate load capacity in comparison to control beam. The deflection of the beams also increased when load at failure of the retrofitted beams increased.

4.5 LOAD-DEFLECTION BEHAVIOUR OF BEAMS RETROFITTED WITH FULL U-WRAPPING

4.5.1 BEHAVIOUR OF BEAMS RETROFITTED WITH TYPE-1 LAYERING

As discussed in earlier section, two beams were retrofitted with Type-1 layering and were tested in UTM to observe the behaviour of the retrofitted beams. These beams were wrapped with one glass - one jute woven fabric on three sides of the beam with the help of epoxy as a bonding agent. After a proper curing period, these two beams were tested in UTM and the data obtained was combined to calculate the average values. These average values are used for further obtaining the results and conclusions. The beams were tested with same method as was done for testing of control beams. Mid-span deflections were noted at proper interval of load increment from the dial guage attached at the middle of the beam at the bottom. Then the load def lection curve was obtained as discussed earlier.

It was observed that there was no sign of any crack till the load has reached 57 KN. After the beam was stressed to load greater than 57 KN, cracking sound of FRP was heard. The crack started initiating at this stage, but was not easily visible. As the load increased the crack started to become visible. Only a single crack appeared, originating from bottom central zone of the beam. The position of the crack showed pure flexure crack. As the load was increased further, this crack widened and breached towards the top of the beam. Both the beams showed only single crack till failure.

It was evident from the load vs. deflection curve of the beam that the mid-span deflection increased at a constant rate with load increment till the load reached 103 KN. After reaching 103 KN, when the load was increased further, the mid-span deflection of the beam increased at a very high rate as compared to the load increment. This shows that the beam behaves elastically before reaching 103 KN and after this load it enters into a plastic zone and continues to be in plastic zone until the beam has failed. The ultimate load capacity of beam retrofitted by 3 side U-Wrapping with Type-1 layering scheme of jute and glass woven fabric was found to be much higher as compared to Side-Wrapping technique of same layering scheme. This beam failed at an ultimate load of 143 KN.

Figure 4. 14 : Showing pattern of crack at failure load of UW-B1 beam.

Figure 4. 15 : Clear view of crack showing flexure failure of UW-B1 beam at failure.

Table 4. 7 : Details of load vs. deflection of UW-B1 beam.

LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)
0	0	32	0.4865	74	1.244	116	2.4915
0.5	0.0045	33	0.5	75	1.2655	117	2.539
1	0.0075	34	0.5145	76	1.2805	118	2.587
1.5	0.0115	35	0.528	77	1.3015	119	2.627
2	0.016	36	0.539	78	1.3245	120	2.667
2.5	0.0225	37	0.551	79	1.3455	121	2.704
3	0.03	38	0.564	80	1.373	122	2.741
3.5	0.04	39	0.579	81	1.391	123	2.7785

4	0.048	40	0.5935	82	1.411	124	2.8175
4.5	0.0545	41	0.607	83	1.4395	125	2.858
5	0.0625	42	0.6205	84	1.463	126	2.8885
5.5	0.07	43	0.6345	85	1.4915	127	2.9265
6	0.0795	44	0.6485	86	1.5175	128	2.967
6.5	0.091	45	0.661	87	1.5375	129	3.001
7	0.111	46	0.6785	88	1.562	130	3.0465
7.5	0.125	47	0.696	89	1.587	131	3.0855
8	0.139	48	0.719	90	1.6125	132	3.119
8.5	0.151	49	0.743	91	1.6305	133	3.158
9	0.1585	50	0.765	92	1.653	134	3.203
9.5	0.17	51	0.7855	93	1.6775	135	3.238
10	0.185	52	0.802	94	1.6955	136	3.276
11	0.1975	53	0.8185	95	1.718	137	3.317
12	0.2185	54	0.835	96	1.74	138	3.3605
13	0.233	55	0.852	97	1.763	139	3.4025
14	0.242	56	0.866	98	1.789	140	3.4495
15	0.2535	57	0.8865	99	1.8125	141	3.594
16	0.264	58	0.9045	100	1.8295	142	3.617
17	0.277	59	0.9225	101	1.8525	143	3.631
18	0.289	60	0.938	102	1.884		
19	0.303	61	0.957	103	1.9215		
20	0.318	62	0.978	104	1.9555		
21	0.3345	63	0.998	105	1.995		
22	0.347	64	1.0205	106	2.0375		
23	0.363	65	1.0375	107	2.083		
24	0.375	66	1.0545	108	2.1215		

25	0.3895	67	1.075	109	2.16		
26	0.404	68	1.0965	110	2.208		
27	0.424	69	1.1205	111	2.248		
28	0.435	70	1.146	112	2.295		
29	0.4485	71	1.1705	113	2.3365		
30	0.461	72	1.197	114	2.3905		
31	0.474	73	1.2205	115	2.441		

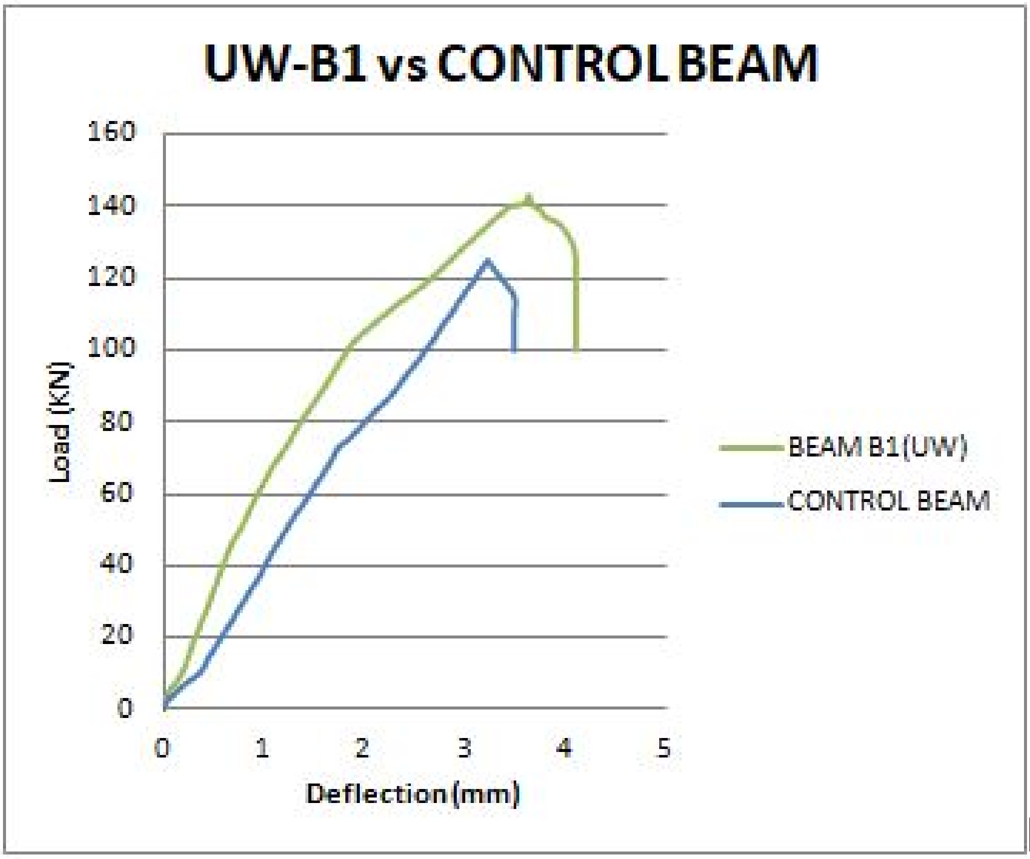

Figure 4. 16 : Comparative graph of load-deflection curve of control and UW-B1 beam.

It can be noted from the above graph that, the retrofitted beam shows large deflection before failure as compared to control beam, therefore shows higher ductility. This beam carries large plastic zone, this means that the beam undergoes large deflection before failure. The deformability index of this beam is somewhat comparable with the control beam.

4.5.2 BEHAVIOUR OF THE BEAM RETROFITTED WITH TYPE-2 LAYERING

This type of retrofitting method involves glass-jute-glass type of layering bonded with the 3 surfaces of the beam in U shape with the help of epoxy as a bonding agent. As discussed earlier, two beams were retrofitted and tested in UTM study the behaviour of the retrofitted beams. The data obtained from the two beams was combined to obtain the average values. Further these values were used to obtain results and conclusion. The retrofitted beams were tested with the same method as that of the control beam. Mid-span deflections were noted from dial guage at proper interval of load increment. These values were utilised for obtaining load deflection curve of this retrofitted beam.

It was observed that there was no sign of any crack till the load has reached 62 KN. after the beam was stressed to load greater than 62 KN, cracking sound of FRP was herd. The crack started initiating at this stage, but was very difficult to examine. When the load was increased further, the crack started to appear clear and distinct. It can be seen from the figure that only a single crack appeared. This crack was positioned at bottom mid-span of the beam, therefore showed pure flexure failure. As the load was increased further, this crack widened up and propagated towards the top leaving a single line of crack. The beam showed little debonding of the outer glass fabric layer at higher loads.

It was evident from the load vs. deflection graph of this retrofitted beam that the mid-span deflection increases at a constant rate with the increment of load till the load reached 118 KN. After reaching 118 KN load, when the load was further increased, the deflection at mid-span of the beam increased at a high rate than the load increment. This behaviour of the beam shows that it behaves elastically before reaching 118 KN load and after this load when the load is increased, the beam enters into plastic zone and it continues to be in plastic zone until the beam has failed. The ultimate load capacity of this beam was found to be more as compared to the previously retrofitted beam and also it was found to be more when compared to beams retrofitted with side wrapping technique using type-2 layering system. The ultimate load capacity of this beam was found to be 153 KN.

Figure 4. 17 : Showing crack pattern at ultimate load of beam UW-B2 beam.

Figure 4. 18 : Showing clear view of the only flexure crack at ultimate load of UW-B2 beam.

Table 4. 8 : Details of load vs. deflection of UW-B2 beam.

LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)
0	0	32	0.454	74	1.1795	116	2.03
0.5	0.002	33	0.4665	75	1.196	117	2.0435
1	0.0045	34	0.482	76	1.2235	118	2.078
1.5	0.0065	35	0.4945	77	1.248	119	2.125
2	0.0095	36	0.512	78	1.28	120	2.166
2.5	0.0135	37	0.5235	79	1.309	121	2.21
3	0.0175	38	0.5385	80	1.33	122	2.2455

3.5	0.024	39	0.553	81	1.3575	123	2.2755
4	0.031	40	0.572	82	1.3755	124	2.299
4.5	0.0425	41	0.585	83	1.3905	125	2.344
5	0.054	42	0.6005	84	1.41	126	2.3875
5.5	0.0655	43	0.6195	85	1.4315	127	2.4165
6	0.075	44	0.6355	86	1.4575	128	2.47
6.5	0.0845	45	0.6575	87	1.487	129	2.5185
7	0.097	46	0.677	88	1.5075	130	2.597
7.5	0.115	47	0.697	89	1.5265	131	2.65
8	0.1265	48	0.715	90	1.5575	132	2.7285
8.5	0.1375	49	0.73	91	1.5885	133	2.8025
9	0.1525	50	0.7415	92	1.6185	134	2.8535
9.5	0.1655	51	0.758	93	1.6315	135	2.9285
10	0.1795	52	0.773	94	1.6485	136	3.0465
11	0.1915	53	0.787	95	1.6755	137	3.123
12	0.205	54	0.801	96	1.691	138	3.191
13	0.219	55	0.828	97	1.7095	139	3.2535
14	0.23	56	0.845	98	1.727	140	3.293
15	0.2425	57	0.861	99	1.741	141	3.343
16	0.257	58	0.881	100	1.7605	142	3.398
17	0.265	59	0.898	101	1.78	143	3.451
18	0.2755	60	0.9135	102	1.7965	144	3.5455
19	0.288	61	0.9305	103	1.8135	145	3.618
20	0.2965	62	0.9445	104	1.8305	146	3.694
21	0.309	63	0.9695	105	1.8425	147	3.743
22	0.3205	64	0.988	106	1.855	148	3.803
23	0.3315	65	1.0135	107	1.8745	149	3.89

24	0.3455	66	1.0265	108	1.8915	150	3.96
25	0.3585	67	1.0415	109	1.91	151	4.1205
26	0.3745	68	1.0575	110	1.924	152	4.2345
27	0.389	69	1.0765	111	1.944	153	4.467
28	0.4045	70	1.095	112	1.9665		
29	0.415	71	1.1195	113	1.979		
30	0.427	72	1.1405	114	1.995		
31	0.4395	73	1.1575	115	2.0165		

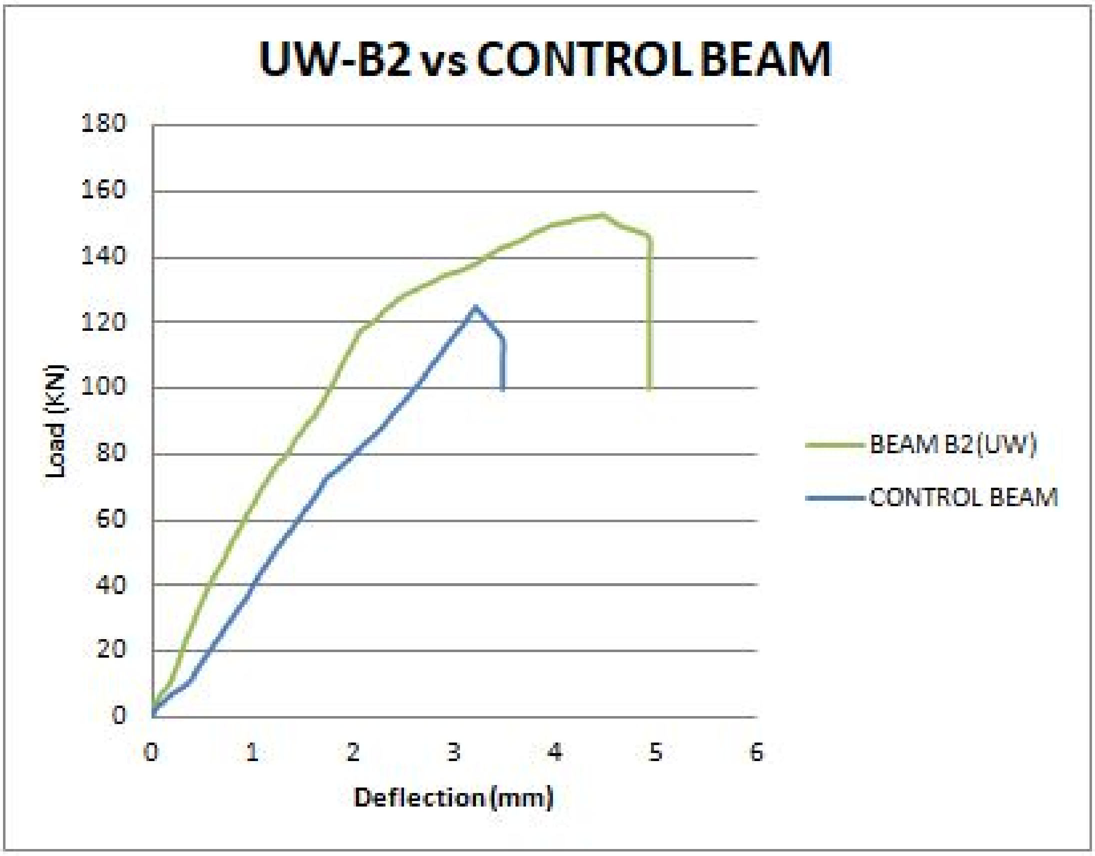

Figure 4. 19 : Comparative graph of load-deflection curve of control and UW-B2 beam.

It is evident from the load-deflection curve of this beam that it shows more ductility in comparison to the control beam. This beam showed large deflections before failure than the control beam and previously retrofitted beams.

Also this beam has higher deformability characteristics than any other beam previously tested. This shows that this beam is structurally more sound. Deformability index of the beams is defined as the ratio of deflection at ultimate load to the deflection at yield load. Hence, this beam have higher deformability index than control beam and any other previously retrofitted beam. The ultimate load of this beam retrofitted with 3 sides U-Wrap is higher as compared to control beam and beams retrofitted earlier.

4.5.3 BEHAVIOUR OF BEAM RETROFITTED WITH TYPE-3 LAYERING

This type of retrofitting involves two layers of glass fabric and two layers of jute fabric, combined alternatively to be wrapped against three sides of the beam using epoxy as a bonding agent. As discussed earlier, two beams were retrofitted and tested under UTM after a certain period of curing. The data obtained from two beams were combined to obtain the average values, and these average values were further used for purpose. The beams were tested using the same method which was used for testing control beams. Mid-span deflections were noted at proper interval of load increment from the dial guage attached to the bottom mid-span of the beam. This data is used further for making load deflection curves as discussed earlier.

It was observed that there was no sign of any crack before reaching 66 KN of load. After the beam was stressed to load greater than 66 KN, a cracking sound was heard. This cracking sound was due to the cracking of FRP attached to the concrete surface. The crack started to initiate at this stage, but the crack was very minor and was not properly visible through the FRP. When the load was increased, the crack started to become visible. Only one single crack appeared during the whole testing, and this crack was positioned at central zone of the beam, showing pure flexural behaviour of the beam. This crack widened and propagated through the beam to reach top edge of the beam as the load was further increased. Both beams tested showed only single crack at same position as discussed above.

It was observed from the load-deflection behaviour of the beam that the deflection at mid-span of the beam increased at a constant rate with load increment till the load reached 127 KN. After reaching 127 KN load, when the load was increased further, the mid-span deflection increased at a high rate as compared to the load increment. This shows that when the beam was stressed less than 127 KN of load, its behaved elastically but when the load was further increased the beam entered into plastic zone and it remained in plastic zone until the beam has reached its ultimate load capacity.

Mainly, the ultimate load capacity of this beam was found to be maximum when compared to all the cases. This beam failed at an ultimate load of 162 KN.

Figure 4. 20 : Showing crack pattern of UW-B3 at ultimate failure load.

Figure 4. 21 : Showing no de-bonding of FRP even at ultimate failure load.

Table 4. 9 : Details of load vs. deflection of UW-B3 beam.

LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)
0	0	36	0.4815	82	1.2035	128	2.2375
0.5	0.0015	37	0.494	83	1.231	129	2.269
1	0.003	38	0.5075	84	1.248	130	2.305
1.5	0.005	39	0.5205	85	1.262	131	2.357

2	0.0065	40	0.5325	86	1.276	132	2.398
2.5	0.0095	41	0.546	87	1.291	133	2.4545
3	0.012	42	0.557	88	1.314	134	2.523
3.5	0.015	43	0.57	89	1.3305	135	2.587
4	0.0245	44	0.5835	90	1.347	136	2.6435
4.5	0.0355	45	0.598	91	1.3705	137	2.7015
5	0.0475	46	0.6135	92	1.391	138	2.7745
5.5	0.059	47	0.6265	93	1.418	139	2.8385
6	0.0685	48	0.6405	94	1.4425	140	2.889
6.5	0.0795	49	0.653	95	1.478	141	2.959
7	0.091	50	0.6655	96	1.503	142	3.0285
7.5	0.1055	51	0.678	97	1.528	143	3.093
8	0.1195	52	0.6925	98	1.549	144	3.1495
8.5	0.134	53	0.706	99	1.567	145	3.206
9	0.146	54	0.7215	100	1.5895	146	3.268
9.5	0.159	55	0.735	101	1.6125	147	3.33
10	0.17	56	0.75	102	1.631	148	3.3935
11	0.181	57	0.764	103	1.6555	149	3.448
12	0.195	58	0.78	104	1.6855	150	3.517
13	0.2055	59	0.793	105	1.7085	151	3.578
14	0.2165	60	0.8105	106	1.7305	152	3.655
15	0.2295	61	0.8245	107	1.746	153	3.7315
16	0.244	62	0.8385	108	1.771	154	3.792
17	0.2565	63	0.855	109	1.7935	155	3.866
18	0.2705	64	0.8695	110	1.8155	156	3.9305
19	0.281	65	0.885	111	1.835	157	3.991
20	0.292	66	0.9005	112	1.851	158	4.0795

21	0.3045	67	0.9235	113	1.8795	159	4.1555
22	0.318	68	0.94	114	1.904	160	4.21
23	0.33	69	0.9555	115	1.923	161	4.287
24	0.337	70	0.9755	116	1.942	162	4.602
25	0.3485	71	0.987	117	1.963		
26	0.359	72	1.0025	118	1.987		
27	0.372	73	1.0235	119	2.013		
28	0.3845	74	1.0405	120	2.0355		
29	0.3985	75	1.0615	121	2.0505		
30	0.4165	76	1.082	122	2.0825		
31	0.428	77	1.1025	123	2.104		
32	0.4395	78	1.124	124	2.1185		
33	0.4495	79	1.1425	125	2.1455		
34	0.4595	80	1.163	126	2.1625		
35	0.47	81	1.1805	127	2.193		

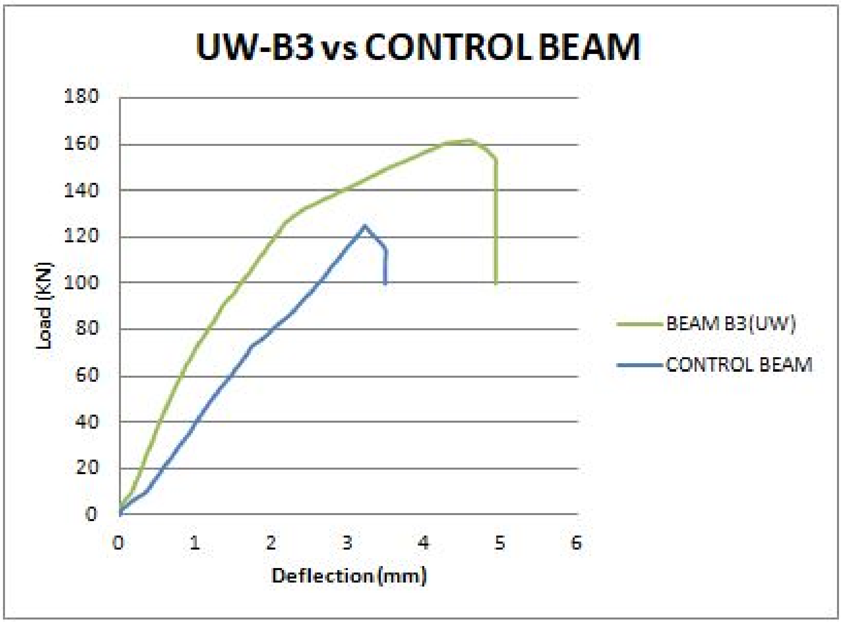

Figure 4. 22 : Comparative graph of load-deflection curve of control and UW-B3 beam.

As it is evident from the load-deflection graph of this beam that the beam undergoes large deflection before failure as compared to any other retrofitted beam in previous discussions. This shows that the beam is more ductile than any other beam in this study. Another term which comes here is deformability index. It is defined earlier in this study itself, and from the load deflection curve it is evident that this beam has higher deformability index than any other beam in this study.

Mainly, the ultimate failure load of this beam was found to be the highest of all the beams studied in this experiment. This is due to the method and type of retrofitting used in this beam. Four layered system of glass and jute fabric, layered alternatively poses huge benefit in increasing the failure load of the pre-cracked beams.

Table 4. 10 : Shows the %age increase in ultimate load and change in deflection of U-Wrapped beams.

Beam	Ultimate load(KN)	Ultimate deflection (mm)	%age inc. In load	%age change in deflection
CB	125	3.217	-	-
UW-B_1	143	3.631	14.4	12.86
UW-B_2	153	4.467	22.4	38.85
UW-B_3	162	4.602	29.6	43.05

4.5.4 COMPARISON OF LOAD-DEFLECTION BEHAVIOUR OF ALL THE RTEROFITTED BEAMS AND CONTROL BEAM

The graph is a comparative graph showing load-deflection behaviour of all the retrofitted beams (U-Wrapped and Side Wrapped) and control beam. From the above graph, it can be observed that at same deflection the load have higher values as the no. of layers of jute and glass fabric increases for retrofitting. Also, it is observed that for same type of layering scheme, U-Wrapping technique showed larger load carrying capacity than Side-Wrapping technique. As compared to the control beam the maximum %age of load increase was found in beams strengthened with full U-Wrapping technique with Type-3 layering system.

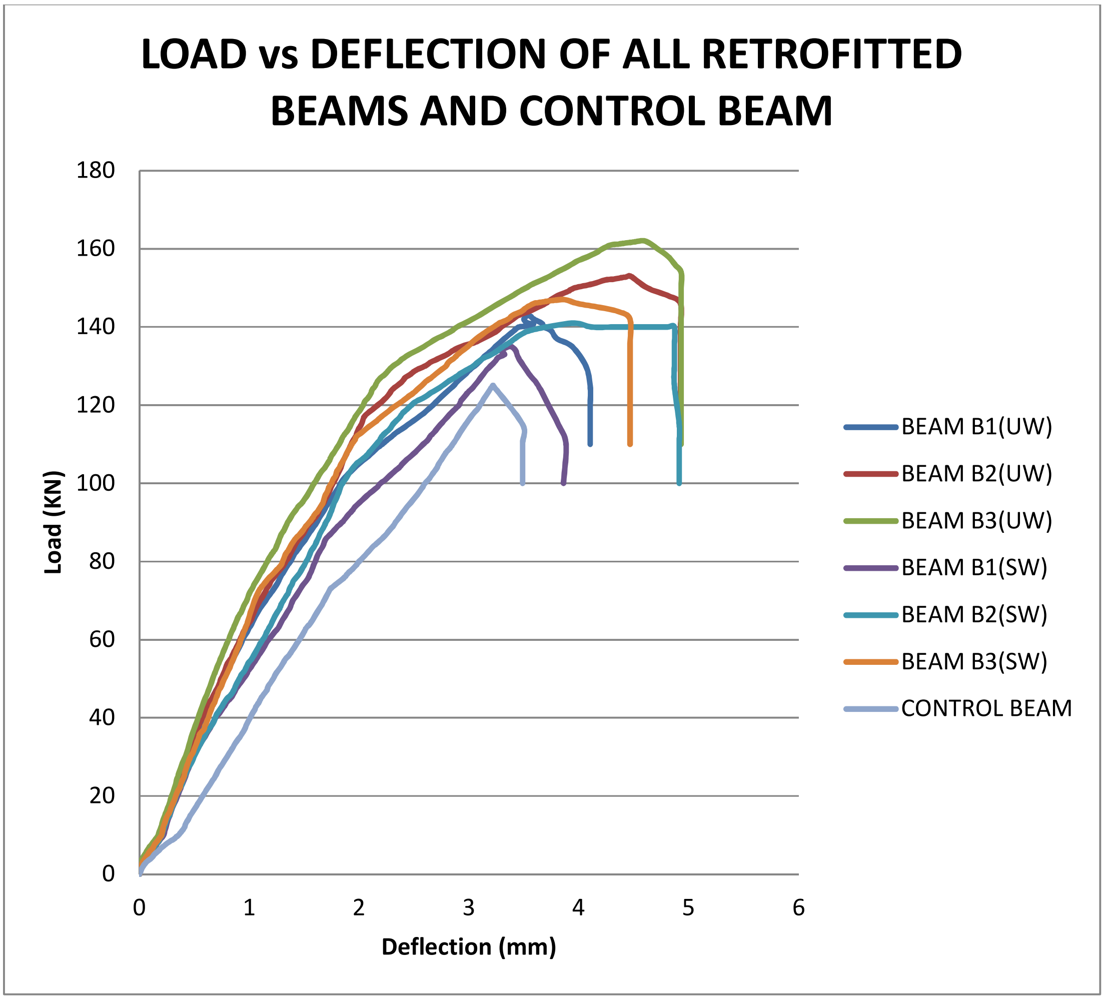

Figure 4. 23 : Comparative graph of load-deflection behaviour of all retrofitted beams and control beam.

. Not only this beam showed maximum load capacity but also it has undergone maximum deflection before failure, this shows good ductile behaviour of the beam. It can be concluded from the experiment that U-Wrapping technique of retrofitting shows better results than Side Wrapping technique. Moreover, number of layers of FRP also affects the strengthening effect of the beams. As the no. of layers increased, the ultimate load was also increased when the beams were tested under UTM. It was observed from the results that the strengthening effect increased considerably from Type-1 layering to Type-2 layering, but Type-3 layering did not provided much increase in strength than Type-2 layering, therefore it can be concluded that it is not much profitable to use more than 4 layer system of retrofitting.

4.6 DUCTILITY

Ductility of a structural member is an important factor which determines its deformation capacity. Ductility is determined by a ductility factor which is defined as the ratio of the ultimate load deflection to the yield load deflection of the beam.

The level of ductility can be defined by following table as described in seismic design code NCSR-02 (Spanish Code).

Table 4. 11 : Shows different ranges of ductility level.

DUCTILITY LEVEL	RANGE
High ductility	>4
Medium ductility	4>D>3
Low ductility	3>D>2
No ductility	2>D>1

Table 4. 12 : Shows ductility factor of all the retrofitted beams and control beam.

BEAMS	DUCTILITY
CB	1.71
SW-B_1	1.58
SW-B_2	1.36
SW-B_3	1.31
UW-B_1	1.39
UW-B_2	1.29
UW-B_3	1.27

It is evident from the above table that the ductile behaviour of the retrofitted beam decreases as the number of layers of retrofitting material increases. Also the ductility decreased for the beams retrofitted with U-Wrapping scheme. All the beams showed no ductility when referred to table.

CHAPTER 5

CONCLUSION

5.1 CONCLUSIONS

Results from the experimental study showed following conclusions :-

1. All the beams retrofitted with jute and glass fibre woven fabrics showed increase in ultimate load capacity as well as improved deflection behaviour of the beams when compared with the results from control beam.
2. The beams named SW-B_{Q1}, SW-B_2 and SW-B_3 retrofitted with side wrapping technique with Type-1, Type-2 and Type-3 layering respectively, showed increase in ultimate load capacity of 8%, 12% and 17.6% respectively. These beams also showed increase in ultimate deflection by 5%, 15.01% and 20.26% respectively when compared with control beam.
3. The beams named UW-B_1, UW-B_2 and UW-B_3 retrofitted with three side U wrapping technique using Type-1, Type-2 andType-3 layering scheme respectively, showed increase in ultimate load capacity of 14.4%, 22.4% and 29.6% respectively. These beams also showed increase in ultimate deflection by 12.86%, 38.85% and 43.05% respectively when compared with control beam.
4. It can be concluded that U-Wrapping technique showed better load deflection behaviour than Side-Wrapping technique. Also, the use of textile jute and glass FRP in continuous full length U-wrapping had helped in delaying the growth of crack formation, as it is evident from the experiment that the first crack appeared at much higher load when compared to control beam. The retrofitted beams carried huge deflection before failure, this showed their ductile behaviour and provided sufficient warning before failure.
5. It is evident from the experiment that with the increase in number of layers of jute and glass woven fabric, the strengthening effect increased. Hence, it can be concluded that using jute fabric and glass fabric in alternate layers as retrofitting material for retrofitting of damaged or weak existing beams, is very much capable of increasing the flexural as well as shear strength of the beam.

5.2 SCOPE FOR FUTURE STUDY

1. In this study jute and glass fabric were used as a composite FRP for retrofitting of beams, but other combinations of natural and synthetic fibres can also be used. Natural fibres such as kenaf, hemp, flax , and coir fibres can be used in combination with synthetic fibres such as carbon, aramid, glass fibres, etc.
2. In this study, all the beams were initially stressed to a particular percentage of the control beam failure and were then retrofitted with jute glass fabric. The stress level of the beams may be varied and their effect on the behaviour may be studied.

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