A Numerical Study of Strengthening of RCC Beam Using Natural Bamboo Fibre

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***Abstract*—Many of the existing reinforced concrete structures throughout the world are in urgent need of rehabilitation, repair or reconstruction because of deterioration due to various factors like corrosion, lack of detailing, failure of bonding between beam-column joints, increase in service loads etc. FRP composite has been accepted as a promising substitute for repairing and in incrementing the strength of RCC structures. During the last decade there has been a renewed interest in the natural fibre as a substitute for conventional FRP materials such as glass fibres and carbon fibres, motivated by potential advantages of weight saving, lower raw material price, and 'thermal recycling' or the ecological advantages of using resources which are renewable, also natural fibres are sustainable materials. Among the various natural fibres, Bamboo fibre reinforced composite is of particular interest as these composites have high impact strength besides having moderate tensile and flexural properties. Here a nonlinear finite element analysis is carried out in order to evaluate the performance of Bamboo fibres in structural retrofitting by retrofitting a Plain Concrete Block by using Bamboo fibre reinforced polymer. It is seen that the strengthened specimens exhibit significant increase in strength, stiffness, and stability as compared to controlled specimens.**

***Index Terms*—Bamboo fibres, retrofitting, finite element analysis, reinforced cement concrete, beams.**

I. Introduction

There is a considerable number of existing concrete structures in India that do not meet current design standards because of inadequate design and construction or need structural upgradation to meet new seismic design requirements because of new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes . Inadequate performance of this type of structures is a major concern from public safety standpoint. Strengthening or upgrading becomes necessary when these structural elements cease to provide satisfactory strength and serviceability. Fiber Reinforced Plastic (FRP) composites can be effectively used as an external reinforcement for upgrading such structurally deficient reinforced concrete structures. One major application of composites to structural retrofit is to increase the flexure and shear capacity of the beams.

Strengthening of RC flexural and shear beams with external bonded FRP laminates and fabric has been studied by several investigators. Only recently, researchers have attempted to simulate the behavior of reinforced concrete strengthened with FRP composites using finite element method. Researchers used finite element method to simulate the behaviour and failure mechanisms of RC beams strengthened with FRP plates. The FRP plates were modeled using two dimensional plate elements. Few researchers in their study used truss elements to model the FRP composites. Some researchers used the finite elements adopted by ANSYS to model the uncracked

RC beams strengthened for flexure and shear with FRP composites. Solid 65 elements were used to model the FRP composites. It has been observed that comparisons between the experimental data and the results from finite element models showed good agreement. In this paper, using finite element method an attempt has been made to study the behaviour of retrofitted RCC beams and unretrofitted reinforced concrete beams that is the Control Specimens, subjected to Uniformly distributed loading producing bending as well as deformation.. The finite elements adopted by ANSYS were used for this study, that is for analyzing the RCC beams retrofitted using Bamboo Fibre Reinforced Composite, which is a natural fibre.

Composite materials from man-made fibres (i.e. glass fibre, carbon fibre etc.) are already available as products for consumer and industrial uses. A relatively newer concept is to consider natural fibres as a reinforcing material. Stringent environmental legislation and consumer awareness has forced industries to support long term sustainable growth and develop new technology based on renewable feedstock that are independent of fossil fuels. As the current status quo, the main reinforcement for the composite industry is glass fibres; 22.3 million tons (metric) are produced globally on an annual basis. Although glass fibre products have somewhat superior mechanical properties, their life cycle performance is very questionable. Manufacturing of these products not only consume huge energy but their disposal at the end of their life cycle is also very difficult since there is virtually no recycling option. Annual industrial crops grown for fibre, have the potential to supply enough renewable biomass for various bio-products including composites. The scope of possible uses of natural fibres is enormous. This is substantiated by the

Manuscript received January 27, 2011; revised September 25, 2011.

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declaration of United Nation for 2009 as International Year of Natural Fibres (IYNF).

All over the world, the bio-composite industry is developing at a significant pace to meet growing consumer awareness and follow new environmental regulations. A survey done by Canadian Agri-Food Research Council (CARC) in 2003 showed that the European automotive industry has already taken the lead and uses approximately 22,000 tons of natural plant fibre in low stress applications in cars. In 2005, 19000 tones of natural fibres were used in Germany for automotive composite. Lignocellulosic bio-fibre derived from various origins such as leaf, bast, fruit, grass or cane; contribute to the strength of bio as well as synthetic polymer composites in various applications. These fibres are renewable, non-abrasive to process equipment, and can be incinerated at the end of their life cycle for energy recovery as they possess a good deal of calorific value. They are also very safe during handling, processing and use. Major natural fibres of vegetative origin used as reinforcement are shown below.

Fibre	Type
Bagasse	Cane
Bamboo	Grass
Banana	Stem
Coconut husk	Fruit
Flax	Bast
Hemp	Bast
Jute	Bast
Kenaf	Bast
Sisal	Leaf
Wood	Stem

Advantages of natural fibre reinforced composites:

1. Reduction in density of products.
2. Acceptable specific strength, toughness and stiffness in comparison with glass fibre reinforced composites.
3. Ease of shaping into complex shapes in a single manufacturing process.
4. Lower energy consumption from fibre growing to finished composites
5. The manufacturing processes are relatively safe when compared with glass based reinforced composites.
6. Possibility of recycling the cuttings and wastage produced during manufacturing and moulding.
7. The production of natural fibres can be started with a low capital investment and with a lower cost.
8. Bast fibres exhibit good thermal and acoustic insulation properties.

Both thermoset and thermoplastic matrices are used for development of natural fibre reinforced composite, the comparative study of these two type of matrices

Property	Thermoset	Thermoplastics
Formulations	Complex	Simple
Melt viscosity	Very low	High
Fibre impregnation	Easy	Difficult
Prepeg stability	Poor	Excellent
Processing cycle	Long	Short to long
Processing temperature / pressure	Low to moderate high	High
Environmental durability	Good	Unknown
Solvent resistance	Excellent	Poor to good
Database	Very large	Small

Broadly defined bio-composite are composite materials made from natural fibre and petroleum derived non biodegradable polymers like polyester, phenolic, PP etc. These polymer matrices are becoming costlier because of the fluctuating price of petrochemicals. These resins could be made cheaper by modification with cheaper bio-resources. Bio-composite derived from plant fibre & crop / bio-derived plastic are likely more eco-friendly and such bio-composites are termed as green composite. Future attempt would therefore be to develop cheaper biodegradable matrix utilizing modification of bio-resources. Keeping in view the above mentioned, here in this paper, work have been carried out to use natural fibre such as bamboo for the purpose of structural upgradation.

II. Material Investigation

The use of natural fibres such as jute, Bamboo, banana, hemp, ramie, Bamboo etc. as composites in structural upgradation is increasing tremendously. Wood flour and other fibres are primarily used as fillers in thermoplastic decking, building materials, furniture & automotive components. Long agricultural fibres such as flax, kenaf, bast, hemp & jute are used as structural reinforcements in thermoplastic/thermoset composites as a replacement of glass fibre. Natural fibre composites can easily be recycled than glass or carbon composites. The usage of natural fibre composites is higher in Europe than other countries. Advantages of Natural fibre composites components includes weight reduction of 10-30%, excellent acoustical absorption properties, good impact properties with convenience of forming complex shaped parts in a single moulding process. Bamboo fibres have a diameter of 100 to 450mm, density of 1.15 gm/cc, elastic modulus of 4 to 6 GN/m^2, an elongation percentage of 15 to 40 %, cellulose/Lignin content of 43/45 %, and micro fibrillar angle of 30 to 49 degrees.

Bamboo has been one of the common materials in pre-industrial architecture in Asia and South American countries, employed as structural elements. The utilization of bamboo as construction component is motivated by its widespread availability in the tropical and subtropical climatic regions, its rapid growth and the combination o f elevated mechanical strength and low specific weight. However, at the present time, even the most modern construction where bamboo is used rely on a craft approach, with the know-how of construction techniques restricted to a small group of researchers, engineers and architects. Although bamboo has an immense potential, standardization and a definition of a correct construction practice still present some difficulties. Actually, there is an on-going research on bamboo with regards to special treatments leading to higher durability ,improved connectors and mathematical modeling for the structural analysis of bamboo structures, along with the micro, macro- and nano-structural properties shutter bamboo concrete slabs, application of bamboo segments as reinforcement of concrete beams, circular columns and pillars in quadratic form of concrete, double–layer spatial and plane truss bamboo structure and special joints between the bamboo elements, which can be easily used for plane and double-layer spatial structures. It is now well established that bamboo is a composite material of cellulose fibres, with an average tensile resistance of about 700 MPa. These cellulose fibres are immersed in a lignin matrix. Studies showed that bamboo is a material with the variation of its physical and mechanical properties in an optimized form, according to the stresses generated due to wind load and its own weight. It has been observed on a macroscopic scale that the distances between the nodes (stiffeners), the diameter and the thickness vary along the total length of the bamboo Culm. The thickness, size and volumetric fraction of fibres vary, becoming more concentrated as they approach the external shell. This is due to the higher forces applied to the external surface when the bamboo is subjected to bending by wind load. The determination of how the variation of volumetric fracture occurs in the thickness is necessary for applying the theory of composite materials to bamboo, which allows the optimized use of bamboo on engineering sites. This variation of the properties as well as the macro, meso and microscopic characterize the graduate functionality of bamboo. There is on-going research concerned with the structural analysis of bamboo frame structures commonly used by local people, improvement of the concrete permanent bamboo shutter slabs and reinforced concrete beams and columns, having in mind its improvement according to available knowledge. Fabrication of corrugated composite slabs based on cement paste reinforced with cellulose pulp of bamboo. The cement composites reinforced by bamboo pulps are produced by the vacuum pressure process, seeking to establish the characteristics of a material which can be easily fabricated, utilising the machinery of asbestos cement industry. The bamboo pulp is used in the paper industry on a large scale. There are studies underway to produce durable furniture and new geometrical structural forms, as well as bicycles, tricycles and car bodies using bamboo. The first aero plane which succeeded to fly was made with bamboo by the Brazilian Santos Dumont.

Properties of this fibre are as follows:

Specific gravity [Kg/m3]	1158
Density [g/cm^3]	1158
Water absorption [%]	145
Tensile strength [MPa]	73-505
Modulus of elasticity [GPa]	10-40

Available countries:-

India, Sri Lanka, Egypt, Guyana, Jamaica, Philippines, Malaysia

Advantages

1) It has elevated mechanical strength.
2) It has low specific weight too.
3) It has high tensile strength.
4) It has better modulus of elasticity than any other natural material.
5) Easily and locally available material.

Disadvantages

1) It is very much bad in torsion when it become mature.
2) Probability of decomposition in biological attack.

Applications

1) Bamboo segments are used as reinforcement of concrete beams, circular columns and pillars in quadratic form of concrete, double–layer spatial and plane truss bamboo structure and special joints between the bamboo elements, which can be easily used for plane and double-layer spatial structures.
2) Bamboo frame structures commonly used by local people for improvement of the concrete permanent bamboo shutter slabs and reinforced concrete beams and columns.

3) It has many uses which include erosion control, watershed protection, soil remediation, environmental greening and medicinal application.
4) Bamboo is a high-yield renewable natural resource: ply bamboo is now being used for wall paneling, floor tiles; bamboo pulp for paper making, briquettes for fuel.

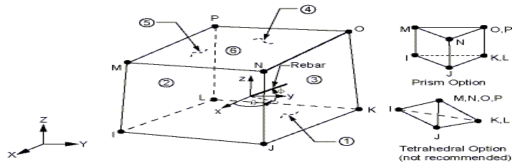
III. Finite Element Analysis

Almost all the structures exhibit a certain degree of nonlinearity at various load stages. This may be due to material nonlinearity or geometric nonlinearity. Geometric nonlinearity is associated with certain structures where large deflection may alter the configuration of the structure and affect the behaviour of the structure on further loading. The effect of displacement on the internal forces must be considered in the analysis of such structures. However , in concrete structures, the displacements are small compared to the dimensions of the structure and hence in the present study geometric nonlinearity is neglected. Since concrete is a non- homogeneous material and behaves linearly over a small percentage of its strength, material non linearity is considered. Nonlinear finite element analysis is a powerful tool in determining the internal stress strain distribution in concrete structures. With the aid of nonlinear finite element analysis it is possible to study the behaviour of composite layered concrete frames upto the ultimate load range, which leads to the optimum design of the concrete frames. The load deformation relationships can be used to realistically predict the behaviour of the structures. Nonlinear analysis gives better knowledge of serviceability and ultimate strength. The computational time and solution costs of nonlinear analysis are very high compared to linear analysis. Hence, the method should be as efficient as possible and the numerical technique adopted should reduce the computational requirements. The finite element analysis approach is adopted considering the various material nonlinearities such as stress strain behaviour of concrete ,cracking of concrete, aggregate interlock at a crack, dowel action of the reinforcing steel crossing a crack etc. Composite layered concrete being a composite material by itself, numerical modeling of this is still an active area of research. Nonlinear finite element analysis based on advanced constitutive models can be used well for the simulation of composite layered concrete Structures.

Computer simulation is a robust tool for checking the performance of concrete structures in design and development. Such simulation can be regarded as virtual testing and can be used to confirm and support the structural solutions with complex details and also serve to find an optimal and cost effective design solution. Hence, the aim of the present study is to conduct a finite element analysis for the nonlinear analysis of composite layered concrete through elastic, inelastic, cracking and ultimate load ranges. This chapter describes in detail the finite element simulation of the composite layered concrete frames.

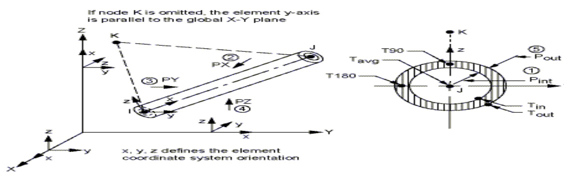
A. Elements used for discretisation

Element used for discretising concrete



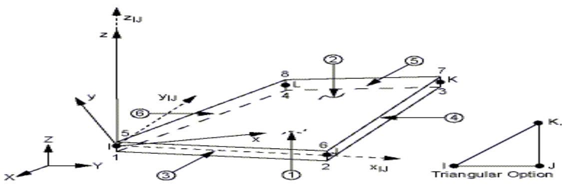
SOLID65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression.

Element used for discretising reinforcing bars



Pipe 16 is a uniaxial element with tension-compression, torsion, and bending capabilities.

Element used for discretising Bamboo fibres



SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The

IV. Geometry and Material Properties

The specimen that is the model frame is designed following the standards and provisions of Indian code of practice IS 456: 1958. The elastic modulus and tensile strength of the concrete were calculated from the established empirical relations given in ACI 318.

The compressive strength of Concrete Choosen: 20 MPa

Young's modulus of Concrete : 22361 N/mm^2

Poisson's Ratio of Concrete : 0.15

Length of the RCC Beam : 500 mm

Width of the RCC Beam : 200 mm

Depth of the RCC Beam : 200 mm

Details of the Reinforcements :

Longitudinal Bars at top : 2 nos of 10mm dia each

Longitudinal Bars at bottom : 2 nos of 10mm dia each

Stirrups : 6mm dia at 50 mm C/C.

The yield strength of these longitudinal reinforcements : 415 MPa

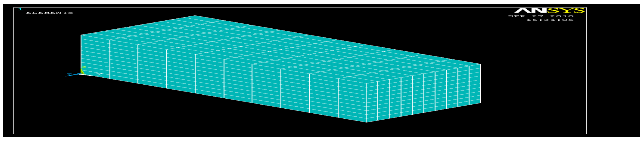
The yield strength of these Stirrup reinforcements : 415 MPa

Young's modulus of Steel Reinforcements : 200000 N/mm2
Poisson's Ratio of Steel Reinforcement : 0.3
The concrete cover for the reinforcements at top, bottom and sides was taken as : 25 mm

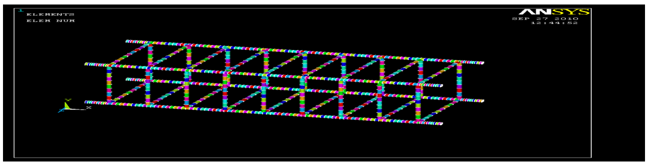
V. ANALYTICAL RESULTS

A. Analysis of the Reinforced Concrete Beam

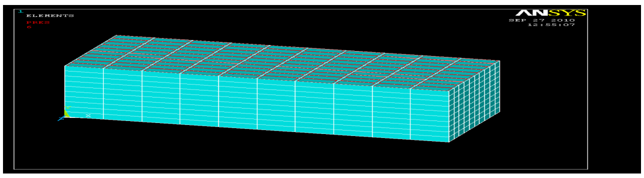
Finite element model of the reinforced concrete beam



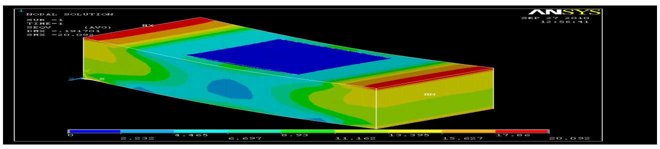
Finite element model of the reinforcement inside the reinforced concrete beam



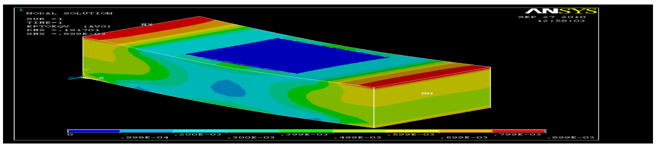
The finite element model with the given uniformly distributed load



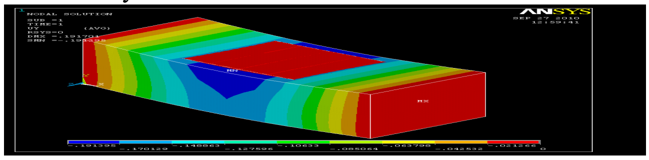
The stresses in the model after the nonlinear finite element analysis at failure



The strains in the model after the nonlinear finite element analysis at failure

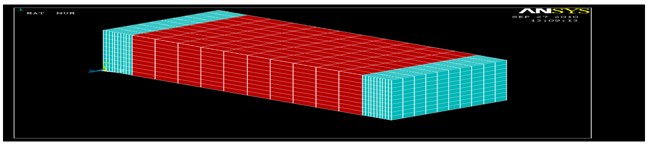


The deflections in the model after the nonlinear finite element analysis at failure

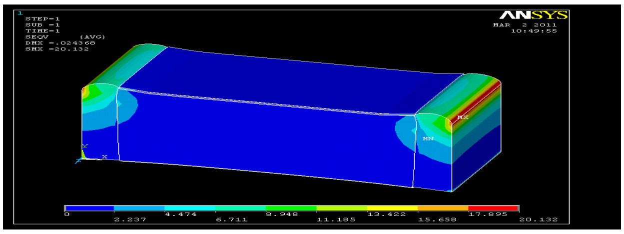


B. Analysis of the Retrofitted Reinforced Concrete Beam, Retrofitted by full wrapping technique using Bamboo Fibres

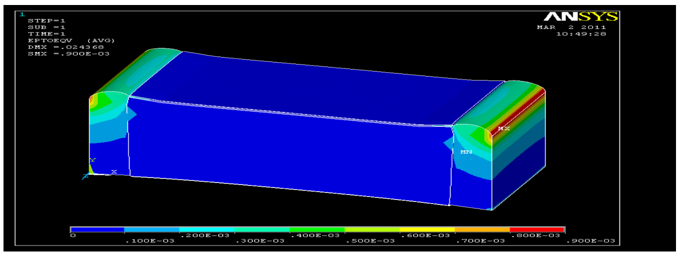
The meshed finite element model fully wrapped with Bamboo fibre around all four sides



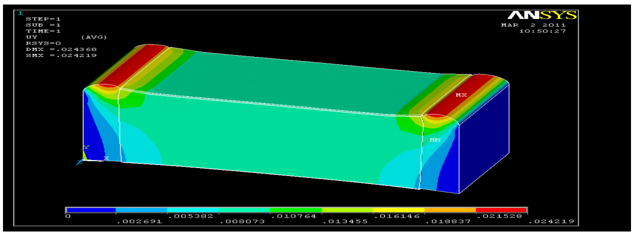
The stresses in the model after the nonlinear finite element analysis at failure after the retrofitting done by Bamboo fibres



The strains in the model after the nonlinear finite element analysis at failure after the retrofitting done by Bamboo fibres



The deflections in the model after the nonlinear finite element analysis at failure after the retrofitting done by Bamboo fibres



Comparison between the concrete model and the concrete model retrofitted by fully wrapped Bamboo fibre around all four sides

Type of model	Failure Load KN	Maximum Stress (N/mm2)	Maximum Strain	Maximum Deflection (mm)	Percentage increase in the load carrying capacity
Plain reinforced concrete model	6	20.092	0.899 X 10^{-3}	0.191395	
Reinforced concrete model retrofitted by bamboo fibres using full wrapping technique	11	20.132	0.900 X 10^{-3}	0.24219	83.33%

VI. Conclusions

The numerical study is extended to the reinforced concrete beams strengthened for bending The results obtained are presented and discussed. The flexural stiffness of strengthened reinforced concrete beams is compared with that of the corresponding control beams. The beams retrofitted with Bamboo composites have shown to undergo an increase in the flexural load carrying capacity. The stiffness of the control and strengthened beams remain unaltered in the initial stages of loading when the cracks are not developed. This observation suggests that in the case of strengthened beams, the addition of Bamboo Fibre laminates has no significant effect on the initial stiffness of the RC beams. It is seen that there is a progressive increase in the stiffness of the strengthened beams when compared with the control beam from the state of first cracking of concrete till the ultimate stage. This shows that any strengthening of the RC beams with Fibre composites will be effective after the initial cracking of

concrete. This is an interesting observation since such additional strengthening of the RC elements are required only after the beams have developed cracks and are to be rehabilitated. The following conclusive details have been obtained from the analytical programme:

- In strengthened beams, the addition of FRP laminate has no significant effect on the initial stiffness of beams.
- Strengthening of the RC beams with FRP is found to be effective only after the initial cracking of concrete.
- The reinforced concrete beam, when are retrofitted with Bamboo fibre using the full wrapping technique around all four sides, 83.33 % load carrying capacity is increased as compared to that of the controlled specimen.
- By providing different percentages of Bamboo fibres for retrofitting, the load carrying capacity of reinforced concrete beam models can be enhanced as compared to that of the controlled specimens.
- The use of Bamboo fibres for retrofitting of reinforced concrete beams also minimizes the deflections in the beams.
- From the above conclusions, it is concluded that depending upon the strength required for the reinforced concrete beam, the percentage of fibres, that is to be applied on to the reinforced concrete beam, can be varied so as to obtain different increments in strength.

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