Finite Element Simulation of Retrofitting of RCC Beam Using Coir Fibre Composite (Natural Fibre)

Mrs. Tara Sen and Dr.H.N.Jagannatha Reddy

***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., leading to cracking, spalling, loss of strength, deflection, etc. The recent developments in the application of the advanced composites in the construction industry for concrete rehabilitation and strengthening are increasing on the basis of specific requirements, national needs and industry participation. The need for efficient rehabilitation and strengthening techniques of existing concrete structures has resulted in research and development of composite strengthening systems. Fiber Reinforced Polymer (FRP) composite has been accepted in the construction industry as a promising substitute for repairing and in incrementing the strength of RCC structures. FRP composites possess some outstanding properties such as: resistance to corrosion, good fatigue and damping resistance, high strength to weight ratio, and electromagnetic transparency. 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. On the other hand natural fibres have their shortcomings, and these have to be solved in order to be competitive with glass and carbon. Natural fibres have lower durability and lower strength than glass fibres. However, recently developed fibre treatments have improved these properties considerably. We have enough natural resources and we must keep on researching on these natural resources.. Among the various natural fibres, Coir fibre reinforced composite is of particular interest as these composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocellulosic fibres. Hence encouragement should be given for the use of natural fibres, Here a nonlinear finite element analysis is carried out in order to evaluate the performance of Coir fibres in structural retrofitting by retrofitting a Plain Concrete Block by using Coir fibre reinforced polymer. It is seen that the strengthened specimens exhibit significant increase in strength, stiffness, and stability as compared to controlled specimens. It appears that the proposed simulation technique will have a significant impact in engineering practice in the near future.**

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

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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. That is why reinforced concrete structures often have to face modification and improvement of their performance during their service life. In such circumstances there are two possible solutions: replacement or retrofitting. Full structural replacement might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption of the function of the structure e.g. traffic problems. When possible, it is often better to repair or upgrade the structure by retrofitting.

Retrofitting of flexural concrete elements are traditionally accomplished by externally bonding steel plates to concrete. Although this technique has proved to be effective in increasing strength and stiffness of reinforced concrete elements, it has the disadvantages of being susceptible to corrosion and difficult to install. In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or fibre reinforced polymer (FRP) plates to the surface of the concrete. The plates then act compositely with the concrete and help to carry the loads. Also recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength good fatigue and corrosion resistance and ease of use, make them an attractive alternative to any other retrofitting technique in the field of repair and strengthening of concrete elements. FRP can be convenient compared to steel for a number of reasons. These materials have higher ultimate strength and lower density than steel. The installation is easier and temporary support until the adhesive gains its strength is not required due to the low weight. They can be formed on site into complicated shapes and can also be easily cut to length on site. Carbon Fiber Composites are the most frequently used system in previous research and retrofitting field applications. This material has superior properties which include very high tensile strength accompanied with a reasonable modulus of elasticity (almost equals that of steel). On the other hand, the Glass Fiber Composites (GFC) are comparatively cheap and have high tensile strength but with relatively low modulus of elasticity (about one-third that of carbon and reinforcing steel is also another sought after retrofitting material.

It is to be kept in mind that the materials chosen for structural upgradation must, in addition to functional efficiency and increasing or improving the various properties of the structures, fulfil some criterion, for the cause of sustainability and a better quality. For example, these materials should not pollute the environment and endanger bioreserves, should be such that they are self sustaining and promote self-reliance, should help in recycling of polluting waste into usable materials, should make use of locally available materials, utilise local skills, manpower and management systems, should benefit local economy by being income generating, should be accessible to the ordinary people and be low in monetary cost. Besides improving the strength of the structure using FRPs as the raw material, it is also necessary to make use of local materials in construction. So far the work on retrofitting of structures is confined to using of carbon, glass or aramid fibres etc, very little work is being imparted in improving structures using naturally available materials, or natural fibres. The application of composites in structural facilities is mostly concentrated on increasing the strength of the structure with the help of artificial fibres and does not address the issue of sustainability of these raw materials used for strengthening purposes. In an expanding world population and with the increase of the purchasing potentials, the need for raw materials required for structural strengthening, that would satisfy the demand on world market is rapidly growing. In times when we cannot expect the fibre reinforced polymer prices to come down, with the consumption growing day by day. Also waste disposal has become one of the major problems in modern cities. At present there are two major methods in practice to dispose wastes. One is land filling and the other is burning. First one requires more valuable land and second one pollutes the environment. So, alternate methods to dispose solid waste should be found.

New materials that would be cheaper and at the same time offer equal or better properties have to be developed. We have enough natural resources and we must keep on researching on these natural resources. Development of plant fibre composites has only begun. Among the various natural fibres, Coir fibre reinforced composite is ofparticular interest as these composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocellulosic fibres. Hence encouragement should be given for the use of natural fibres such as Coir fibres which are locally available materials, in the field of structural retrofitting. Also by considering the case of waste disposal, here an attempt is made to study the possibilities of reusing Coir fibre materials as Coir fibre reinforced polymer, in structural retrofitting concrete which not only tries to improve the structural properties but also helps to solve the problem of waste disposal atleast to a small extent. Economic and other related factors in many developing countries where natural fibres are abundant, demand that scientists and engineers apply appropriate technology to utilize these natural fibres as effectively and economically as possible for structural upgradation and also other purposes for housing and other needs etc.

II. Material Investigation

The use of natural fibres such as jute, Coir, banana, hemp, ramie, coir 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. Coir 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.

Coconut fibre that is coir fibre, is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre is Coir, Cocos nucifera and Arecaceae (Palm), respectively. There are two types of coconut fibres, brown fibre extracted from matured coconuts and white fibres extracted from immature coconuts. Brown fibres are thick, strong and have high abrasion resistance. White fibres are smoother and finer, but also weaker. Coconut fibres are commercial available in three forms, namely bristle (long fibres), mattress (relatively short) and decorticated (mixed fibres). These different types of fibres have different uses depending upon the requirement. In engineering, brown fibres are mostly used. According to official website of International Year for Natural Fibres 2009, approximately, 500 000 tonnes of coconut fibres are produced annually worldwide, mainly in India and Sri Lanka. Its total value is estimated at $100 million. India and Sri Lanka are also the main exporters, followed by Thailand, Vietnam, the Philippines and Indonesia. Around half of the coconut fibres produced is exported in the form of raw fibre. There are many general advantages of coconut fibres e.g. they are moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use, totally static free and easy to clean.

Coconut fibres were investigated by many researchers for different purposes. There is a huge difference in some properties, e.g. diameter of coconut fibres is approximately same and magnitudes of tensile strength are quite different,. Also, the range shown for a particular property is quite wide; some coir fibres have the density as 0.67-10.0 g/cm3. Where as some have 0.67-1.00 g/cm3. There are variations in properties of coconut fibres, and this makes it difficult for their frequent use as construction material. The purpose of compilation of data for the properties of fibres is to get a guideline, but after compilation, a huge variation is seen.

There should be some standards for such variations, just like we have standards for sand and aggregates.

For coir fibres, fibre dimensions of the various individual cells are said to be dependent on the type of species, location and maturity of the plant. The flexibility and rupture of the fibre is affected by the length to diameter ratio of the fibre and this also determines the product that can be made from it. The shape and size of central hollow cavity, lumen, depends on (i) the thickness of the cell wall and (ii) the source of the fibre. The hollow cavity serves as an acoustic and thermal insulator because its presence decreases the bulk density of the fibre. It is seen that the inner coconut fibre had a higher mechanical strength as compared to that of outer fibre, but the outer coconut fibre had a higher elongation property which could makes it to absorb or with stand higher stretching energy as compared to the inner coconut fibre. Coconut fibres contain cellulose, hemi-cellulose and lignin as major composition. These compositions affect the different properties of coconut fibres. The pre-treatment of fibres changes the composition and ultimately changes not only its properties but also the properties of composites. Some-times it improves the behaviour of fibres but sometimes its effect is not favourable.

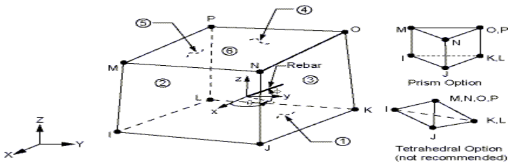
III. Finite Element Analysis

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.

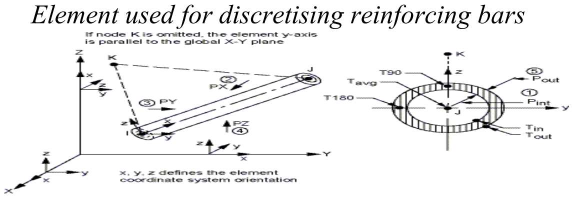
A. Elements used for discretisation

Element used for discretising concrete



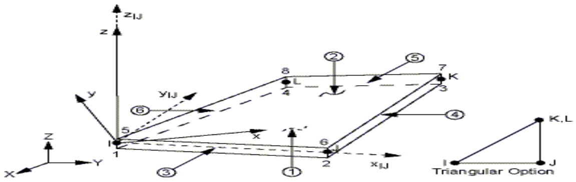
SOLID65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression.

Element used for discretising reinforcing bars



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

Element used for discretising Coir fibres



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

IV. Details of the Reinforced Concrete Model

The specimen that is the model frame is designed following the standards and provisions of Indian code of practice IS 456: 1958. The material chosen are concrete compressive strength Fck = 20 N/mm^2 . Hence forth the Young's modulus = 22361 N/mm^2 and the Poisson's Ratio is 0.15, and the reinforcing steel has a Young's Modulus of 200000 N/mm^2 and the Poisson's Ratio is 0.3. The Coir fibres used for retrofitting purpose has a Young's modulus = 20000 N/mm^2 and the Poisson's Ratio is 0.3, and also has a thickness of 5mm.

The dimensions of the concrete block is as shown in figure – below :

Details of Reinforced Concrete Beam dimensions :

Length = 500 mm, Width = 200 mm, Depth = 200 mm

Details of the Reinforcements :

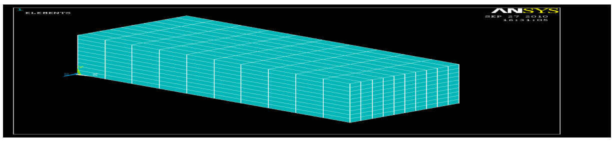
Longitudinal Bars at top : 2 nos of 10mm dia each

Longitudinal Bars at bottom : 2 nos of 10mm dia each
Stirrups : 6mm dia at 50 mm C/C.

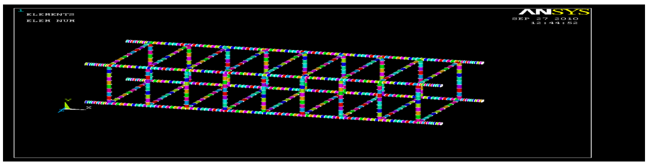
V. Analytical Results

A. Analysis of the Reinforced Concrete Beam

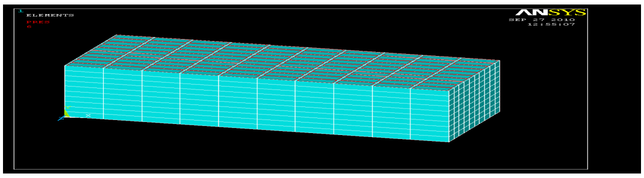
Finite element model of the reinforced concrete beam



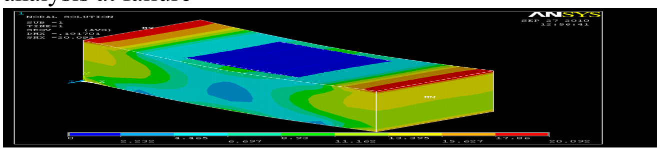
Finite element model of the reinforcement inside the reinforced concrete beam



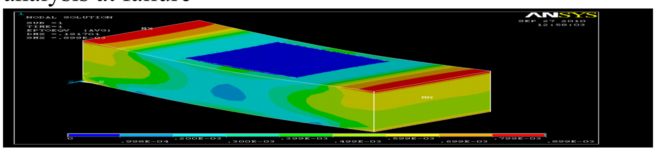
The finite element model with the given uniformly distributed load



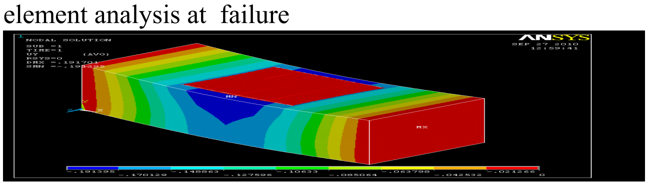
The stresses in the model after the nonlinear finite element analysis at failure



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

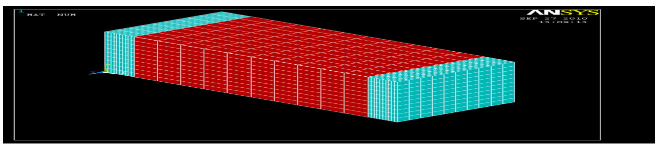


The deflections in the model after the nonlinear finite element analysis at failure

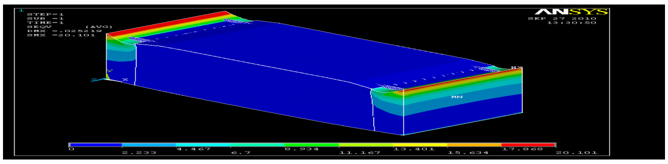


Retrofitting of the Reinforced Concrete Beam by full wrapping technique using Coir Fibres

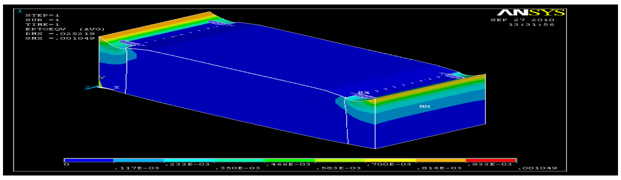
The meshed finite element model fully wrapped with Coir fibre around all four sides



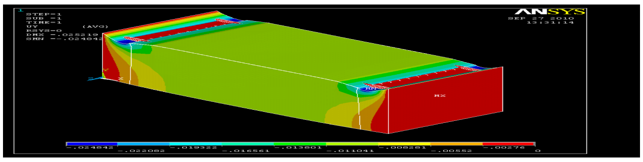
The stresses in the model after the nonlinear finite element analysis at failure after the retrofitting done by Coir fibres



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



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



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

Type of model	Failure Load (Uniformly Distributed Load) KN/m	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 Coir Fibres using full wrapping technique on all four sides	10.75	20.101	0.001049	0.024842	79.17 %

VI. Conclusions

The following conclusive details have been obtained from the analytical programme:

1) The reinforced concrete beam, when are retrofitted with Coir 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.
2) By providing different percentages of Coir fibres for retrofitting, the load carrying capacity of reinforced concrete beam models can be enhanced as compared to that of the controlled specimens.
3) The use of Coir fibres for retrofitting of reinforced concrete beams also minimizes the deflections in the beams.
4) 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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