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Nonlinear Finite Element Analysis of Retrofitting of RCC Beam Column Joint using CFRP

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***Abstract*—Many of the existing reinforced concrete structures throughout the world are in urgent need of strengthening, 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., Direct observation of these damaged structures has shown that damage occurs usually at the beam-column joints, with failure in bending or shear, depending on geometry and reinforcement distribution type. .A nonlinear finite element analysis that is a simulation technique is used in this work to evaluate the effectiveness of retrofitting technique called "wrapping technique" for using carbon fibres (FRP) for strengthening of RC beam-column connections damaged due to various reasons. After carrying out a nonlinear finite element analysis of a reinforced concrete frame (Controlled Specimen) and reinforced concrete frame where carbon fibres are attached to the beam column joint portion in different patterns ,the measured response histories of the original and strengthened specimens are then subsequently compared. 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*—Carbon fibres, retrofitting, finite element analysis, beam column joints.**

I. INTRODUCTION

There is a large need for strengthening of concrete structures all around the world and there can be many reasons for strengthening, increased loads, design and construction faults, change of structural system and so on. The need exists in flexure as well as shear. Epoxy plate bonding with carbon fiber reinforced polymers, CFRPs has shown to be a competitive for strengthening of existing concrete structures and increasing the load bearing capacity. Since the first structures were formed, whether by nature or by early human beings, they have plagued by destruction or detoriation. Detoriation and destructions are laws of nature that affect even the most modern of structures. Modern structures like skyscrapers, bridges are costly to build and the construction period may sometimes be disturbing the people and society. So it is of interest to have durable structures with long life and low maintenance costs, maintenance is not only of coats but also a necessity to keep a structure at a defined performance level. The definition of performance includes load bearing capacity, durability, function and aesthetic appearance. A structure which fulfills all the load carrying capacities might at the same time not satisfy durability demands or please the society demands for aesthetic appearance. Absence of, or incorrect maintenance will in most cases increase the speed of degradation process and therefore lower the performance of the structure. If the performance level has become too low, then repair is required to restore the structure to its original performance. Structures with long life span, which most of the civil and building structures should have, will meet changed demands placed on them from the owners, users, or surrounding society. A structure wilt satisfactory load bearing capacity, aesthetic appearance and Durability might not fulfill the function demands. To meet a changed demand, a structure might be upgraded, which furthermore can be a way to increase life, durability and reliability of the structure. It is often more complicated to strengthen an existing structure than erecting a new one. Concerns must be taken to existing materials, often in deteriorated condition, loads during strengthening and to existing geometry. In some cases it is also difficult to reach the areas that need to be strengthened. When strengthening is to be undertaken all failure modes must be evaluated. Strengthening a structure for flexure may lead to a shear failure instead of giving the desired increased load bearing capacity. It is to be noted that not only the failure mode of strengthened material is important. If a critical member in the structure is strengthened, another member can be a critical one. Because of changed stiffness in an undetermined structural system the whole structure must be investigated. The strengthening should also be designed with consideration to minimize the maintenance and repair needs. Furthermore the existing documentation of the structure is often very poor and sometimes even wrong. It might be necessary to redesign the structure with the probable former codes that were active when the structure was built. This can give enough knowledge about the structural mode of action. The design of strengthening however must fulfill requirements in codes today. It is not only the structural and financial aspects that should form the basis for decisions of strengthening and choice of strengthening method, but environmental and aesthetic aspects must also be considered. The research carried out here by the process of Nonlinear finite element analysis aids us to predict the responses of the beam column joints through elastic, cracking, and ultimate load ranges, to design an innovative and economical technique for retrofitting , to understand the Behavior of beam – column joints after retrofitting done by using carbon fibres, to study the ultimate load carrying capacity of the beam column joints

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retrofitted with CFRP wrapped by different techniques such as composite wrapping, strip wrapping for beam only and strip wrapping for both beam and column, to make suitable recommendations for practicing engineers.

II. Review of Previous Works

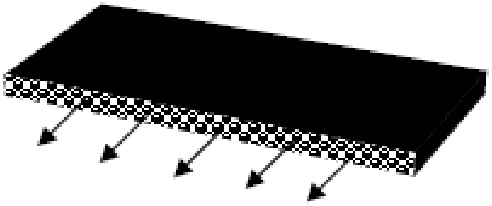
During the two decades considerable amount of research effort was devoted to the development of numerical models for the nonlinear behaviour of reinforced concrete structures. Most of these numerical models were conceived by coupling a displacement formulation of the finite element model together with a set of partial constitutive models for the aspects of nonlinear behaviour such as the stress strain relationship, the initiation and propagation of cracks, bond between steel and concrete, and time dependent phenomenon such as creep and shrinkage of concrete. The prevalent finite element models, which are adopted for the nonlinear finite element analysis of reinforced concrete structures are discussed below.

Hand, Pecknold and Schnobrich (1973) presented nonlinear finite element analysis including the elasto-plastic behaviour of steel, bilinear-elasto-plastic behaviour of concrete and the tension stiffening of concrete. They used the incremental variable elasticity technique to obtain the load deflection for any general RCC problem.They also demonstrated the need for a shear retention factor to provide the torsional and shear stiffness for cracked concrete. Lin and Scordelis (1975) in their paper presented a nonlinear finite element analysis of reinforced concrete structures in general form. The analysis was done to trace the load-deflection response, the crack-propagation through the elastic, in-elastic, and ultimate load ranges. They adopted a layered approach with an incremental tangent stiffness solution technique. They found in their study that the tension stiffening effect of concrete between cracks has a significant influence in the post cracking load deflection response of under reinforced concrete structures. The importance of the failure criteria was also investigated. Scordelis (1989) gave a brief review of the research in development of nonlinear analytical models, methods of analysis and computer programs to trace the structural behaviour of reinforced concrete structures under increasing loads through their elastic, cracking, inelastic and ultimate load ranges. Crisfield and Wills (1993) in their paper described the application of a series of different concrete models to the analysis of a number of reinforced concrete panels tested by Vecchio and Collins at the university of Toronto. Duraiswamy (1994) proposed a degenerated nine node, two dimensional, curved isoparametric element with five degrees of freedom at each node, for the modeling of reinforced concrete structures. He used the layered approach, dividing the concrete and the reinforcing steel into layers. Foster, Budino and Gilbert (1996) formulated a rotating crack finite element model for the analysis of reinforced concrete structures. They used discrete element to model the concrete and steel with bond slip incorporated into the formulation of the bar element used to model the steel reinforcement. Paramasivam et al (1997) developed layered shell elements for the modeling of reinforced concrete structures which are moderately thick and are made up of composite materials. The element consists of a number of bonded layers of orthotropic materials. In the nonlinear analysis, due to bending, different sandwhich layers will be in different states of strain. So, a layered approach can be adopted assuming the sandwhich layer to have constant strain across its thickness even though the strain varies in the thickness direction of the whole lamina.

III. Material Investigation

Composites are combinations of two materials in which one of the materials, called the reinforcing phase, is in the form of fibres, sheets, or particles, and is embedded in the other materials called the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. Composites are used because overall properties of the composites are superior to those of the individual components. For example: polymer/ceramic composites have a greater modulus than the polymer component, but aren't as brittle as ceramics. The following are some of the reasons why composites are selected for certain applications: high strength to weight ratio (low density high tensile strength), high creep resistance, high tensile strength at elevated temperatures, and high toughness. The strength of the composite depends primarily on the amount, arrangement and type of fibre (or particle) reinforcement in the resin. Typically, the higher the reinforcement content, the greater the strength. In some cases, glass fibres are combined with other fibres, such as carbon or aramid, to create a "hybrid" composite that combines the properties of more than one reinforcing material. In addition, the composite is often formulated with fillers and additives that change processing or performance parameters. The fibre is an important constituent in composites. A great deal of research and development has been done with the fibres on the effects in the types, volume fraction, architecture, and orientations. The fibre generally occupies 30% - 70% of the matrix volume in the composites. The fibres can be chopped, woven, stitched, and/or braided. They are usually treated with sizing such as starch, gelatin, oil or wax to improve the bond as well as binders to improve the handling. The most common types of fibres used in advanced composites for structural applications are the fibreglass, aramid, and carbon. The graphite or carbon fibre is made from three types of polymer precursors -- polyacrylonitrile (PAN) fibre, rayon fibre, and pitch. The tensile stress-strain curve is linear to the point of rupture. Although there are many carbon fibres available on the open market. They have lower thermal expansion coefficients than both the glass and aramid fibres. The carbon fibre is an anisotropic material, and its transverse modulus is an order of magnitude less than its longitudinal modulus. The material has a very high fatigue and creep resistance. Carbon fibres have high modulus of elasticity, 200-800 GPa. The ultimate elongation is 0.3 – 2.5 % where the lower elongation corresponds to a higher stiffness and vice-versa. Carbon fibres do not absorb water and are resistant to many chemical solutions. They withstand fatigue excellently, do not stress corrode and do not show any creep or relaxation, having less relaxation compared to low relaxation high tensile prestressing steel strands. Carbon fibre is electrically conductive and, therefore, might give galvanic corrosion in direct contact with steel. Figure below show the carbon fibre, fibre orientation and stress carried by carbon fibre.

(b)



A continuous roll of Carbon fibre sheet, and Close view of orientation of strands in carbon fibre

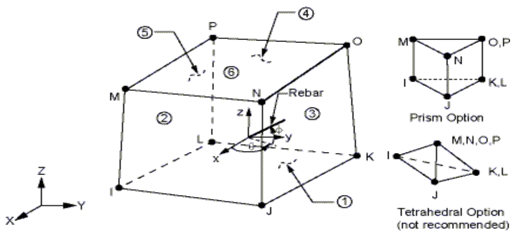
Since its tensile strength decreases with increasing modulus, its strain at rupture will also be much lower. Because of the material brittleness at higher modulus, it becomes critical in joint and connection details, which can have high stress concentrations. As a result of this phenomenon, carbon composite laminates are more effective with adhesive bonding that eliminates mechanical fasteners.

IV. 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 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. Currently, the concrete frames are being designed based on the analysis considering concrete to be a linearly elastic, homogeneous and isotropic continuum or based on yield line theory. This method of analysis is insufficient to strictly establish the required safety level and serviceability requirements, together as required by the design codes. Hence the behaviour of the concrete frames needs to be determined through elastic, inelastic and ultimate load ranges. The finite element method is the most suitable method for this analysis. 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

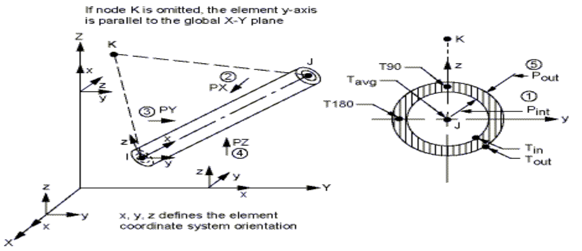
Structures. Computer simulation is a robust tool for checking the performance of concrete structures in design and development. Such simulation can be regarded as virtual testing and can be used to confirm and support the structural solutions with complex details and also serve to find an optimal and 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*



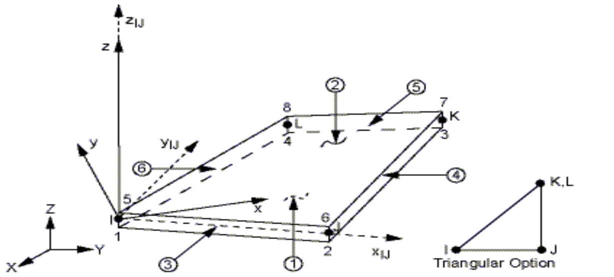
Element used for discretising concrete

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. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions and we have added another three degrees of freedom that is rotations about the nodal x, y, and z axes. Hence forth the element used has been provided with totally six degrees of freedom. The concrete element is similar to the solid 45 (3-D Structural solid) with the addition of special cracking and crushing capabilities. The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking, crushing, plastic deformation, and creep. They are also capable of plastic deformation and creep.



Element used for discretising reinforcing bars

Pipe 16 is a uniaxial element with tension-compression, torsion, and bending capabilities. The element has six degrees of freedom at two nodes: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. This element is based on the 3-D beam element (BEAM4), and includes simplifications due to its symmetry and standard pipe geometry. This element has various special features such as stress stiffening, large deflection and birth and death of elements.



Element used for discretising carbon fibres

SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses. This element has various special features such as stress stiffening, large deflection and birth and death of elements.

B. Constitutive modelling of concrete

The modeling of reinforced cement concrete structures poses a problem of different kind when compared to a homogeneous material like steel. This is because of the complexity in the modeling of concrete. The complexity arises due to its nonhomogeneity because of plain concrete constituents and steel. The complexity is also due to the different properties in tension and compression. The macroscopic behaviour of concrete depends on its constituent materials, their properties and the way in which it is made and is loaded. Its strength in tension is low unlike steel. Also , the stress strain curve is linear and brittle in tension but it is nonlinear and ductile in compression. Because of the low tensile strength, concrete cracks at very low loads and gives rise to highly nonlinear behaviour of structures. The need for safe and economical structures can be satisfied to the fullest only when the behaviour of the structure is adequately understood. One tool for improving the understanding of the behaviour is the analytical model. For any finite element analysis the constitutive laws governing the load response behaviour of the materials of which the material is composed of form a very important input for the formulation of the analytical procedure.

The nonlinear material properties of reinforced cement concrete can be represented by the constitutive laws. These laws are discussed in details in this section. A reasonable assumption would be to take plain concrete as a homogeneous mixture in the macroscopic sense and to consider steel separately as a homogeneous material effective only in the direction of the reinforcement. Any model which considers the nonlinear effects due to the material properties inclusive of cracking will be a reasonably good model. With the rational approach, it is possible to trace the structural response of the reinforced concrete structures through out their service load history , by increasing loads through their elastic, cracking, inelastic, and ultimate load stages.

Since the aim of the present study is to conduct a finite element analysis for studying the behaviour of composite layered reinforced concrete structure, the emphasis is mainly here for the material modeling of the composite layered reinforced concrete structure taking into account the stress strain behaviour of concrete, tension stiffening and the cracking of concrete.

C. Nonlinear stress strain relationship of concrete

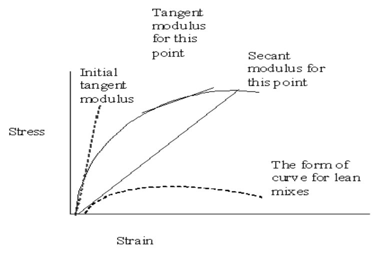
In the theory of reinforced concrete it is assumed that concrete is elastic, isotropic, homogeneous and that it confirms to Hooke’s law. Actually none of these assumptions are strictly true and concrete is not a perfectly elastic material. Concrete deforms when load is applied, but this deformation does not follow a strictly set rule. The deformation depends upon the magnitude of load, the rate at which the load is applied, and the elapsed time after which the observation is made. In other words, the rheological behaviour of concrete that is the response of concrete to the applied load is quite complex.

The Knowledge of the rheological properties of concrete is necessary to calculate the deflections of the structures, and design of concrete members with respect to their sections, quantity of steel and stress analysis. When the reinforced concrete is designed by elastic theory it is assumed that a perfect bond exists between concrete and steel. The stress in steel is m times the stress in concrete where m is ration between modulus of elasticity of steel and concrete, known as modular ratio. The accuracy of design will naturally dependent on the value of the modulus of elasticity of concrete , because the modulus of elasticity of steel is more or less a definite quantity.

It is further to be noted that concrete exhibits very peculiar rheological behaviour because of its being a heterogeneous, multiphase material whose behaviour is influenced by the morphology of the gel structures. The modulus of elasticity of concrete being so important and at the same time so complicated, we shall see this aspect in further more details.

The modulus of elasticity is determined by subjecting a cube or cylinder specimen to uniaxial compression and by measuring the deflections through dial gauges fixed between certain guage length. Dial guage reading divided by the guage length will give the strain and the load applied divided by the area of cross section will give the stress. A series of readings are taken and the stress strain relationship is established. The modulus of elasticity can also be determined by subjecting a concrete beam to bending and then using the formula for deflection and substituting other parameters. The modulus of elasticity so found out from actual loading is called the static modulus of elasticity. It is seen that even under short term loading concrete does not behave as an elastic material. However upto 10% to 15% of the ultimate strength of concrete, the stress strain graph is not very much curved and hence can give more accurate value. For higher strsses the stress strain relationship will be greatly curved and as such it will be inaccurate.

In view of the peculiar complex behaviour of the stress strain relatioship , the modulus of elasticity of concrete is defined in somewhat arbitary manner. The modulus of elasticity of concrete is designated in various ways and they have been illustrated on the stress strain curve below.

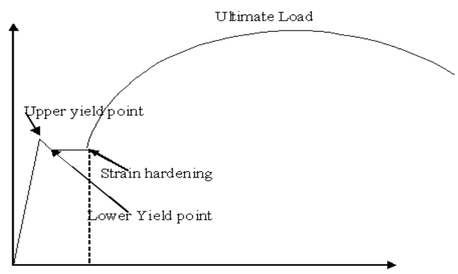


Stress strain curve illustrating the modulus of elasticity of concrete

The term young's modulus of elasticity can be strictly applied only to the straight part of the stress strain curve. In case of concrete since no part of the graph is straight, the modulus of elasticity is found out with reference to the tangent drawn to the curve at the origin. The modulus found from this tangent is referred to as initial tangent modulus. This gives satisfactory results only at lower stress values. For higher stress values it gives a misleading picture. Tangent can also be drawn at any other point in the stress strain curve. The modulus of elasticity calculated with reference to this tangent is then called tangent modulus. The tangent modulus also does not give a realistic value of the modulus of elasticity for the stress level much above or much below the point at which the tangent is drawn. The value of the modulus of elasticity will be satisfactory only for stress levels in the vicinity of the point considered. A line can be drawn connecting a specified point on the stress strain curve to the origin of the curve. If the modulus of elasticity is calculated with reference to the slope of this line, then the modulus of elasticity is referred as secant modulus. If the modulus of elasticity is found out with reference to the chord drawn between two specified points on the stress strain curve then such values of the modulus of elasticity is known as chord modulus. The modulus of elasticity most commonly in practice is the secant modulus. There is no standard method of determining the secant modulus. Sometime it is measured at stresses ranging from 3 to 14 Mpa and sometime the secant drawn to the point representing a stress level of 15, 25, 33, or 50% of ultimate strength. Since the value of secant modulus decreases with the increase in stress, the stress at which the secant modulus has been found should always be stated. The modulus of elasticity may be measured in tension, compression, or shear. The modulus in tension is usually equal to the modulus in compression. It is interesting to note that the stress strain relationship of aggregate alone fairly shows a straight line. Similarly the stress strain relatioship of cement paste alone also shows a fairly good straight line. But the stress strain relationship of concrete which is a combination of aggregate and cement paste together shows a cueved relationship. Perehaps this is due to the development of microcracks in the interphase of the aggregate and the paste. Because of the failure of bond at the interface increases at a faster rate than that of the applied stress, the stress strain curve continues to bend faster than increase of the stress.

D. Stress starin relationship of steel

Steel is a ductile material. The ductility of steel is an unique property in this material. This property does not exist in any other structural material in the same manner, as it exists in steel. The concept of ductility of structural steel forms the basis for the plastic theory. The structural steel is capable to withstand large deformations beyond the elastic limit without fracture. The ductility property of the structural steel is evident from the stress strain diagram shown in the figure below.



Stress strain curve depicting the ductility property of structural steel

It is seen that the stress strain curve is linear within the elastic range. Firstly the stresses go on linearly increasing with respect to the strains upto the upper yield point. From the upper yield point the stress in the material drops down without elongation to the lower yield point. This is followed by the sudden stretching of the material at constant stress from the lower yield point upto the strain hardening. It is seen that the yield stress is reached at a strain of about 0.11 %. At the constant stress the material elongates upto a strain of about 1.5 % . The portion of the stress strain curve from the lower yield point to the strain hardening represents the plastic range. But here we have considered the design of the structural member upto the elastic range only, henceforth we are modeling the steel in a linear fashion and not considering the nonlinear characteristics of steel. The elastic strain is about 1/12 to 1/15 of the strain at the beginning of the strain hardening. Beyond the strain hardening the stress increases with the increase of strain. However the strain increases more rapidly. The portion of the curve beyond strain hardening represents the strain hardening range. The elastic strain is about 1/200 of the maximum strain. Some of the structural steel do not show the upper yield point in the stress strain curve, however even when an upper yield point exists it can be avoided by cold working. In the simple plastic theory of bending the upper yield point and the strain hardening range are neglected. This simplifies the calculations.

E. Input Data

The input data consists of properties of steel, concrete and the material used for retrofitting that is carbon fibres such as Young's Modulus, Poisson's Ratio, Yield Stress, Density. Also, the concrete specimen's (in one of the model) and the composite that is carbon fibre layered concrete specimen's(in the retrofitted and the rehabilitated models) face on which the uniformly distributed force is acting will be given as an input. The boundary conditions such as fixity ,to be introduced at the ends of the columns etc are also to be given.

F. Output Information

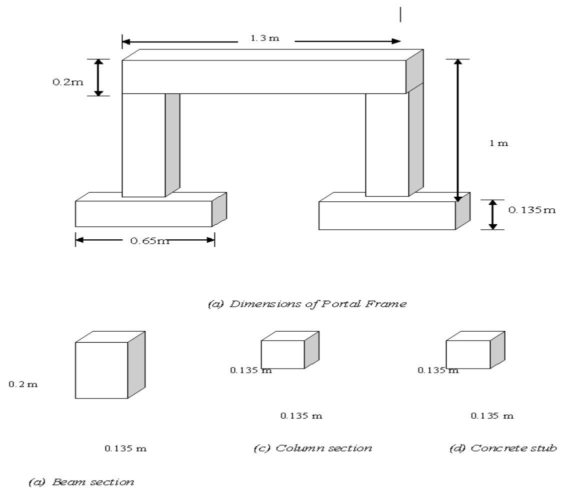
The output includes stresses, strains, translations, rotations, reaction forces and moments. Section forces, moments, and transverse shear forces are available for elements with displacement degrees of freedom.

The nodal displacements, the support reactions and the normal stresses σ_{x}, σ_{y}, and σ_{z} and the shear stresses such as τ_{xy}, τ_{yz} and τ_{zx} as well as the normal strains such as ε_{x}, ε_{y}, ε_{z} and the shear strains such as γ_{xy}, γ_{yz} and γ_{zx} are obtained. The displacement in all the directions that is x,y and z directions are obtained. And lastly a contour plot of all the output parameters mentioned above are obtained.

V. DESIGN AND DETAILS OF THE RC FRAME

The specimens 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 and Fe 415 steel

The specimens were reinforced in the joint region for bond to increase the strength in the joint region. In order to make the specimen strong in flexure an additional steel reinforcement was provided in the mid section of the beam. The dimensions of the portal frame are as shown in figure – below :



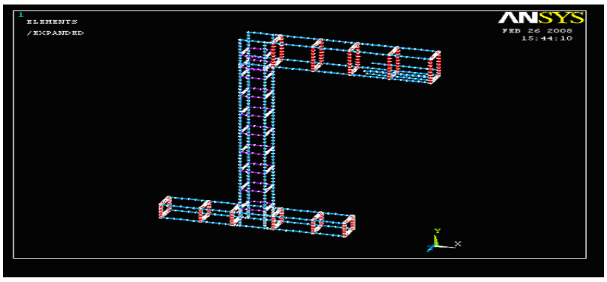
Details of Portal frame dimensions

A concrete stub of nominal size pertaining to the portal frame is designed in order to provide fixity to the portal frame. The nominal reinforcement is provided for the bottom stub portion. A basic requirement in RC structures is that the steel and surrounding concrete act together and there should be no slip of the bar relative to its surrounding concrete. Slippage of the bar may or may not result in overall failure of the beam. A beam may continue to carry loads as long as the bars are anchored at the ends. The concept of development length and anchorage of reinforcement replaces the old practice of satisfying the permissible flexure bond stress. The force in any reinforcing bar must be transmitted to the surrounding concrete by bond before the bar may be terminated. A brief review of reinforcement provided for all the frames are summarized in Table below.

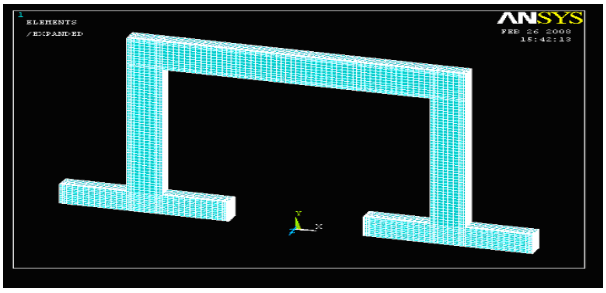
SECTIONS	MAIN REINFORCEMENT	STIRRUPS / LATERAL TIES
Beam	In tension • 2 – 8 mm Φ bars throughout the length • 2 – 8 mm Φ bars at center span • 2 – 8 mm Φ bars at center span as second layer In compression • 2 –8 mm Φ bars throughout the length of the beam	2 legged 6mm dia bars @ a spacing of 130 mm c/c at supports and gradually increasing to 200 mm at center.
Column	• 2 – 8 mm Φ bars on each column face	6 mm Φ lateral ties at a spacing of 120 mm c/c throughout the column
Stub	• 2 – 8 mm Φ bars on top and bottom faces	2 legged 6mm dia bars @ a nominal spacing

VI. ANALYTICAL RESULTS

Finite element model of the reinforcement according to the design

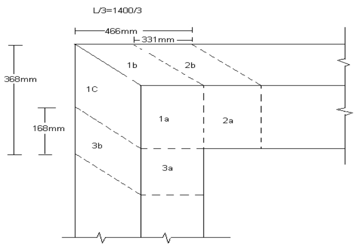


Finite element model of the reinforced concrete frame



A. Strengthening of beam column joints by full wrapping technique.

The joint area calculated, which is to be wrapped fully with carbon fibre is as under :



FRP WRAPPING AREA AROUND THE BEAM COLUMN JOINT

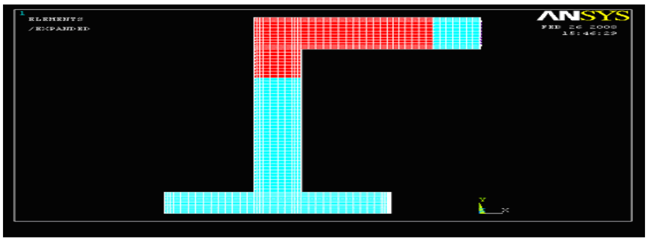
1.	(135x200) x 2	$= 0.054m^2 \times 2$	$= 0.108m^2$
	(135x135) x 1	$= 0.018m^2 \times 2$	$= 0.036m^2$
	(135x200) x 1	$= 0.027m^2 \times 2$	$= 0.054m^2$
2.	(331x200) x 2	$= 0.1324m^2 \times 2$	$= 0.265m^2$
	(331x135) x 2	$= 0.0894m^2 \times 2$	$= 0.179m^2$
3.	(135x168) x 2	$= 0.0454m^2 \times 2$	$= 0.09m^2$
	(135x168) x 2	$= 0.0454m^2 \times 2$	$= 0.09m^2$
	Total	$= 0.4116m^2 \times 2$	$= 0.823m^2$

After the area for FRP Wrapping is calculated, the carbon fibers are cut for split wrapping technique with 50mm width and 25mm spacing between each strip. The area for split wrapping of carbon fiber is calculated as below

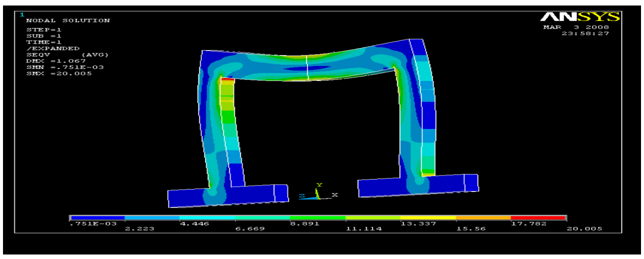
1. Column wrapping
   - Total column area $= 0.344m^2$
   - Total column area wrapped $= \underline{0.230m^2}$
   - Unused area $= \underline{0.114m^2}$

2. Beam Wrapping
   - Total beam area $= 0.354m^2$
   - Total beam area wrapped $= \underline{0.214m^2}$
   - Unused area $= \underline{0.140m^2}$
   - Therefore total area $= 0.698m^2$
   - Total area wrapped $= 0.444m^2$
   - % unused area $= (100 \times 0.444)/0.698$ $= 63.61\%$

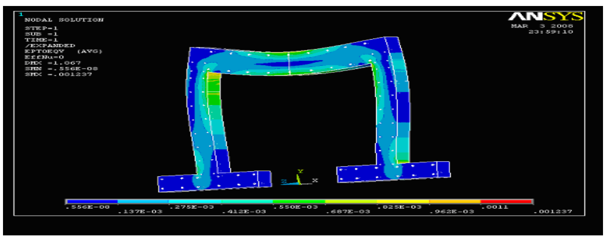
The meshed finite element model fully wrapped with carbon fibre



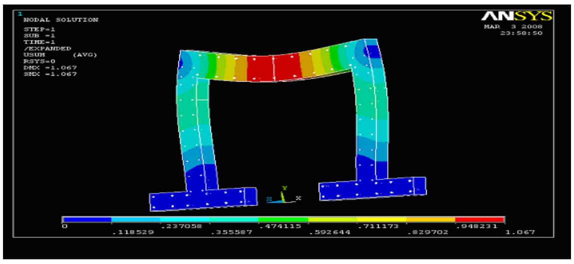
The stresses in the model after the nonlinear finite element analysis



The strains in the model after the nonlinear finite element analysis



The deflections in the model after the nonlinear finite element analysis

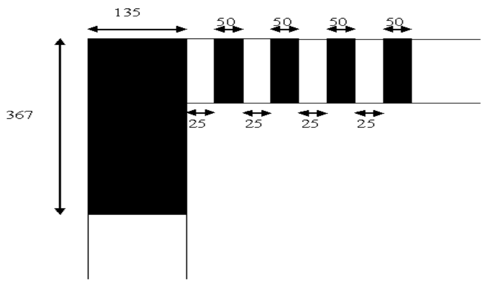


Comparison between the RC model and the RC model wrapped fully by carbon fibres in the beam column joint area

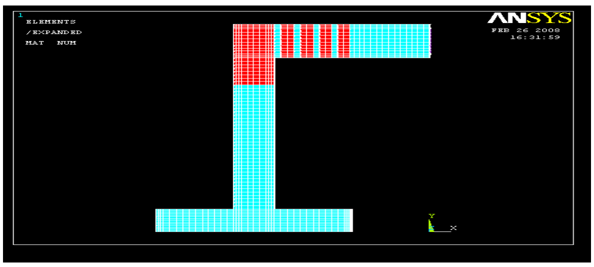
Type of model	Failure Load KN	Maximum Stress (N/mm2)	Maximum Strain	Maximum Deflection (mm)
Plain reinforced concrete model	118	20.077	0.001033	0.786851
Reinforced concrete model retrofitted by carbon fibres using full wrapping technique	170.44	20.005	0.001237	1.067

B. Strengthening of beam column joints by full wrapping technique for column and strip wrapping technique for beam.

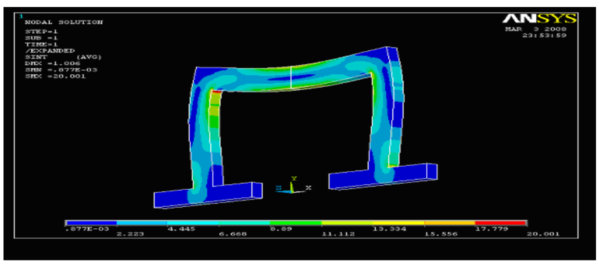
Details of the layout of carbon fibres in the beam and column region .



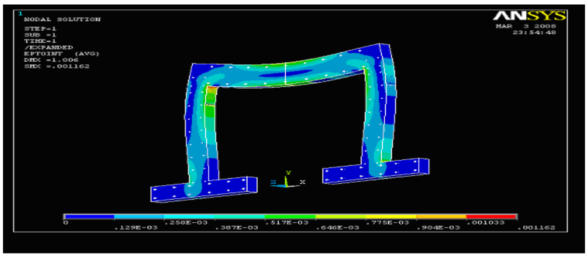
The meshed finite element model fully wrapped with carbon fibre in the column and strip wrapped in the beam



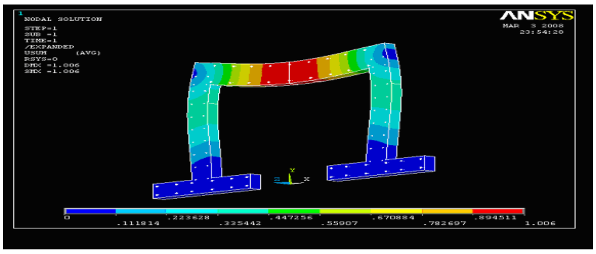
The stresses in the model after the nonlinear finite element analysis



The strains in the model after the nonlinear finite element analysis



The deflections in the model after the nonlinear finite element analysis

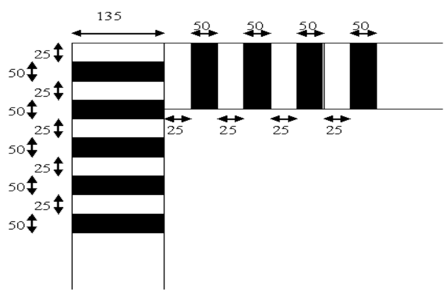


Comparison between the RC model and the RC model fully wrapped with carbon fibre in the column and strip wrapped in the beam

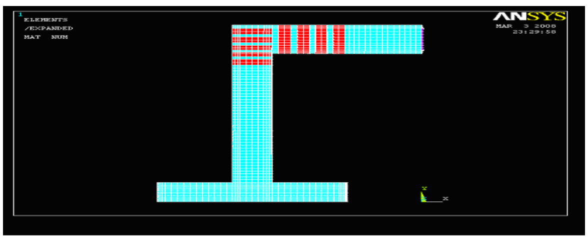
Type of model	Failure Load KN	Maximum Stress (N/mm2)	Maximum Strain	Maximum Deflection (mm)
Plain reinforced concrete model	118	20.077	0.001033	0.786851
Reinforced concrete model retrofitted by carbon fibres using strip wrapping technique for beam	156.1	20.001	0.001162	1.006

C. Strengthening of beam column joints by strip wrapping technique for both beam and column

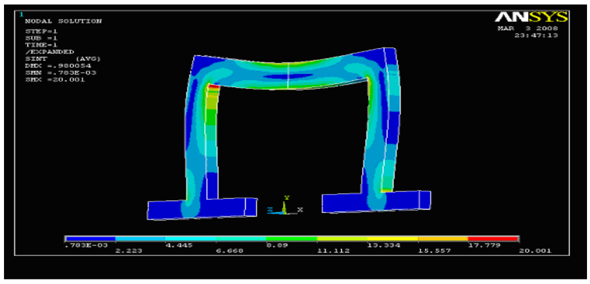
Details of the layout of carbon fibres in the beam and column region .



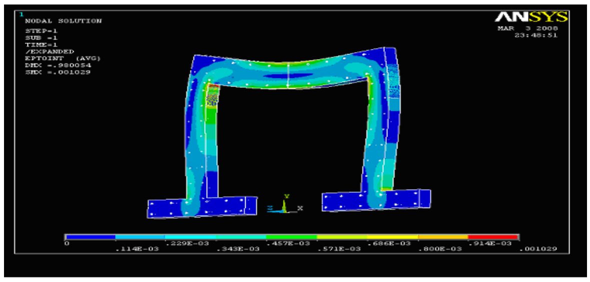
The meshed finite element model strip wrapped with carbon fibre in both the beam and the column region.



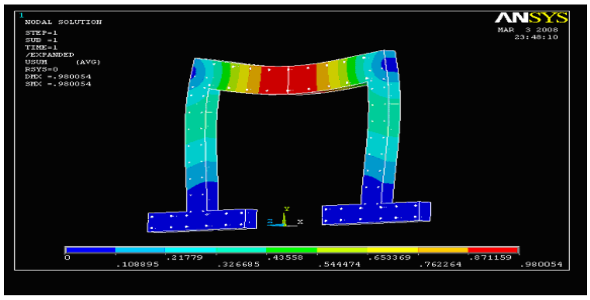
The stresses in the model after the nonlinear finite element analysis



The strains in the model after the nonlinear finite element analysis



The deflections in the model after the nonlinear finite element analysis



Comparison between the RC model and the RC model strip wrapped with carbon fibre in both the beam and the column region.

Type of model	Failure Load KN	Maximum Stress (N/mm2)	Maximum Strain	Maximum Deflection (mm)
Plain reinforced concrete model	118	20.077	0.001033	0.786851
Reinforced concrete model retrofitted by carbon fibres using strip wrapping technique for beam and column	149.74	20.001	0.001029	0.980054

Comparison of various parameters between the different techniques of retrofitting

Type of Model	Failure Load (KN)	Maximum Stress (N/mm^2)	Maximum Strain	Maximum Deflection (mm)
Reinforced concrete model retrofitted by carbon fibres using full wrapping technique (100 % of the beam column joint is wrapped)	170.44	20.005	0.001237	1.067
Reinforced concrete model retrofitted by carbon fibres using strip wrapping technique for beam (67.8 % of the beam column joint is wrapped)	156.1	20.001	0.001162	1.006
Reinforced concrete model retrofitted by carbon fibres using strip wrapping technique for both beam and column (53.95 % of the beam column joint is wrapped)	149.74	20.001	0.001029	0.980054

VII. CONCLUSIONS

The analytical programme confirmed that the externally bonded Fibre Reinforced polymer (FRP) using Carbon fibre with a new technique called STRIP WRAPPING TECHNIQUE is a promising and a viable solution towards enhancing the strength and stiffness characteristics of beam-column joints strengthened by design of bonding in joint zone subjected to uniformly distributed loads for the model designed portal frames. The retrofitted and the rehabilitated portal frames exhibited more strength than controlled frames.

The analysis of the specimens allowed for an investigation of several variables, details of which are described previously. The following conclusive details have been obtained from the analytical programme:

- The beam column joints, when are retrofitted with carbon fibre, using the full wrapping technique, it is seen that 44.44 % load carrying capacity is increased as compared to that of the controlled specimen.
- The beam column joints, when are retrofitted with carbon fibre, using the strip wrapping technique for beam portion only of the beam column joint, 32.3 % load carrying capacity is increased as compared to that of the controlled specimen.
- The beam column joints, when are retrofitted with carbon fibre using the strip wrapping technique for both beam and column portion of the beam column joint, 26.9 % load carrying capacity is increased as compared to that of the controlled specimen.
- In any case, by providing different percentages of carbon fibres for retrofitting ,it has been observed that the retrofitted and as well as the rehabilitated models exhibit much more strength as compared to that of the controlled specimens.
- From the above conclusions, it is concluded that depending upon the strength required for the reinforced concrete frame, the percentage of carbon fibres, that is to be applied on to the reinforced concrete frame, can be varied so as to obtain different increments in strength.

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