STRENGTHENING OF RC BEAMS BY USING FRP SURFACE MOUNTED TECHNIQUE

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ABSTRACT

In the present scenario almost all the structures such as buildings, bridges or other structure, etc. are constructing by using reinforced cement concrete. Basically structures of concrete exhibits better durability but it needs strengthening, repair or rehabilitation and it has become an increasingly important challenge for the reinforced concrete structures, because of many problems like cracks due to environmental effect, damage due to increasing load, earthquake and many other natural disasters, toxic emitted in the surrounding area and to rectify these structures, etc. Now a day it becomes a major growth in research area in the field to strengthening of RC structure or members by various strengthening techniques. In this research work, a 3D nonlinear finite element analysis model has made by using ANSYS software to know the behaviour of strengthening of reinforced concrete beam by using Carbon Fibre Reinforced Polymer (CFRP) laminate which is applied to the tension face of a concrete beam for flexural strengthening of the beam. The beam is designed based on IS 456: 2000, to a size of 200mm x 300mm x 2400mm. In ANSYS modelling for concrete was done as 3-dimensional solid element i.e. solid-65 of 8-noded brick element, reinforcing steel was modelled by using Link-8 spar element, CFRP laminate was modelled as 2D shell element of shell-63. There are two beams were modelled one is control beam for reference and other is with externally bonded CFRP laminate i.e. strengthened beam. After analysing in the software the results of the both beam models were compared such as load-deflection behaviour, load-stress behaviour and loads at first crack and at failure points. Evaluation is carried out and it is found that the load carrying capacity of strengthened beam is high compare to the beam without strengthened. All the results of analytical work of this report is compared with the same work experimentally carried out, it show a good agreement with experimental work.

Key Words: Reinforced concrete beam, Strengthening, Carbon fibre reinforced plastic (CFRP) laminate, finite element modelling, ANSYS

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1. INTRODUCTION

It has been seen that reinforced concrete structures requires so many repair, improvements and strengthening for its performance during his working span. There are so many factors some of them are change of using type, design standards were change, because of so many factors concrete gets deteriorate such as change in environment condition, steel gets corroded etc.. In these conditions there are two solutions i.e. retrofitting or replacement. Replacement of whole structure might have determine more disadvantage because of high cost for labour and material, a great impact on environment and so much of problems get arises during replacement operation of structure such as problems in traffic control. So when possible it is often better to repair of upgrade the particular structure.

Recently the development of strong epoxy adhesive has made a new development in the field of strengthening and upgrading of structures. In this technique basically it involves gluing of Fibre reinforced polymer (FRP) laminate to the concrete surface. This laminate then act compositely with concrete material.

Many material has been used for strengthening of concrete beam, such as Steel plates, this material has been used form many years and it has showed a great strengthening and bonding with concrete. Drawback of this is that they are heavy in weight hence difficulty in transportation and the plate length is also limited. Therefore FRP is convenient compared to steel plates. FRP has very high ultimate strength then steel, density is lower than steel and its non-corrosive property Therefore fixing is very easy and it does not requires temporary supports also because of lesser weight.

In this paper also it has focus on the use of FRP for flexural strengthening and repair of RC beams. Flexural strengthening of beams is one of the relatively more challenging applications of Externally bonded FRP because of the need to guard against unwanted failure modes and ensure ample deflection capacity, while still retaining the desired advantage of increased strength. This is because of the properties of FRP materials and the fact that performance potentials are dependent on properties of the existing member, designers must have a good focus on the interrelationships between strength, failure mode, and deflection capacity of beams with FRP reinforcement in flexure. Conventionally RC beams are designed so that they would fail in only flexure after developing significant tensile strain in steel reinforcement. It is a general expectation that strength gain and deflection capacity will show opposing trends with the amount of FRP and it is also expected that deflection capacity would be related to
the failure mode.

ANSYS is an analytical tool which will done the retrofitting modelling and calculate the nonlinear behaviour of structure is Finite element method (FEM). This method helps in investigating the structural behaviour during pre and post loading condition, behaviour of load deflection and crack pattern. Research provides the information for FEM model i.e. properties of materials. In addition the analytical study has evaluated by comparing with the experimental full scale model of beam.

2. MATERIAL PROPERTIES

For beam strengthening program material used are Concrete, Reinforcing steel and CFRP laminates. All of the material used in this strengthening work has been discussed in detail below.

2.1 Internal reinforcement

The internal reinforcement is of a grade of Fe 500 steel. The main reinforcement is provided as12 mm diameter of 4 bars. The hanger bars are provided for minimum reinforcement and that is of 2 bars of 8 mm diameter. The stirrups are provided as 8 mm diameter bars of 2 legged at 125mm centre to centre.

2.2 External reinforcement (A study on fibre reinforced polymer composite)

The external reinforcement used in this work is the Carbon Fibre Reinforced Polymer (CFRP) laminates. It is pre-cured plate with a surface texture on one face, with the structural adhesives which helps in improve bond.

The structures which are deficient due to either a structural flaw, Because of a change in use of CFRP laminates can often be brought to a useful capacity. FRP strengthening which is externally bonded is analogous to steel plate bonding. Implementation of CFRP plate bonding which is successful is dependent on proper surface preparation, to the concrete levelling and bond of the structural adhesive and interfaces CFRP plate. It is best in overhead applications of externally bonded CFRP Laminates work for flexural strengthening and there were sufficient bond and development lengths be achieved.

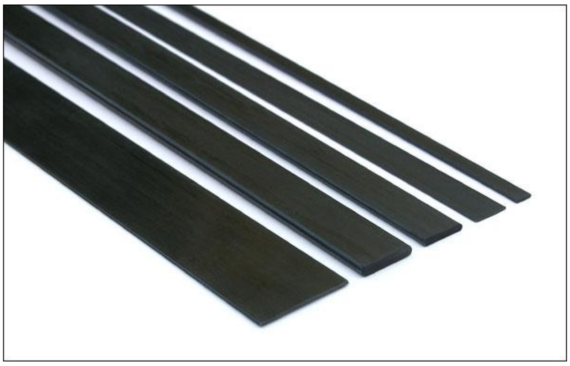

Fig. 1: CFRP laminates of varying widths and sections

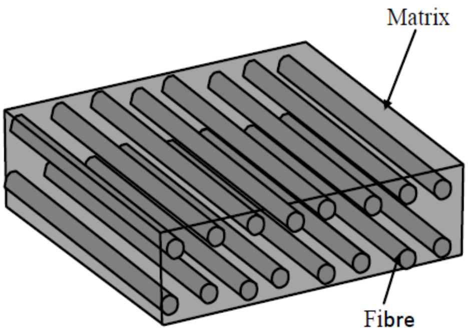

Fig. 2: A schematic diagram showing a typical unidirectional FRP plate.

2.2.1 Fibres

Fibre will provide stiffness and strength to FRP, Because the fibres used continuous most structural FRP applications are used and they oriented in a particular specified directions, they are much stronger and stiffer in the fibre direction, FRPs are orthotropic.
fibres selected should have the following properties.

a. Stiffness should be high.
b. It should have higher young‘s modules of elasticity
c. It should have high ultimate strength.
d. Variation of strength is low between individual fibres.
e. During handling stability should be there
f. Diameter should be uniform.

For the applications of structural engineering, fibres are also characterized by length-to-diameter ratios extremely large and small by diameters. Molecular structure of the material along the length of the fibres is aligned giving them high tensile strength and higher the young modules of elasticity. Also since the probability of a sample of material flaw large enough containing to cause brittle failure which is decreases with its volume, than the bulk fibre material microscopic fibres have fewer defects and hence strengths are higher. Under the event of a single fibre break within the FRP, force transfer will be takes place to adjacent fibres, in the polymer matrix through shear stresses it will develop and prevents failure of the overall composites of FRP. Overall failure it is important to note that the force transfer required to prevent the FRP that depends primarily on the matrix’s shear strength.

Up to failure these fibres are all linear elastic, compared to steel with no significant yielding. The matrix's primary functions are that the composite to transfer stress between the all fibres, against the environment to provide a barrier and from mechanical abrasion surface should be protect by the fibres.

The composite's mechanical properties are depend on the fibre properties, properties of matrix, bond properties of fibre-matrix, amount and orientation. With all fibres in one direction a composite is designated as unidirectional. If the fibres oriented in many directions are woven or the composite is multidirectional. Since the fibres mainly that provide strength and stiffness in composites are often anisotropic in the fibre directions with high stiffness.

Adhesives should be used to attach the composites to the surfaces such as concrete. Adhesives which are most common are acrylics, epoxies and urethanes. Epoxies provide high temperature resistance and high bond strength with, whereas acrylics provide with good strength a moderate temperature resistance and rapid curing. In applying adhesives effectively several considerations are involved such as careful surface preparation i.e. removing the cement paste, grinding by using a disc sander to the surface, by surface grinding using air blower removing the dust generated and careful curing are critical to bond performance.

3. DESIGN OF BEAM

In this study, beam is designed to carry a load of 100KN and Fe 500 grade steel as internal reinforcement, M 25 grade concrete. The full scale beam is designed and no scale down factors is used in the case of the design. As two point loads of 50 KN each that is a load of 100 KN is applied on the beam at a distance of one-third of the span from either side of the supports.

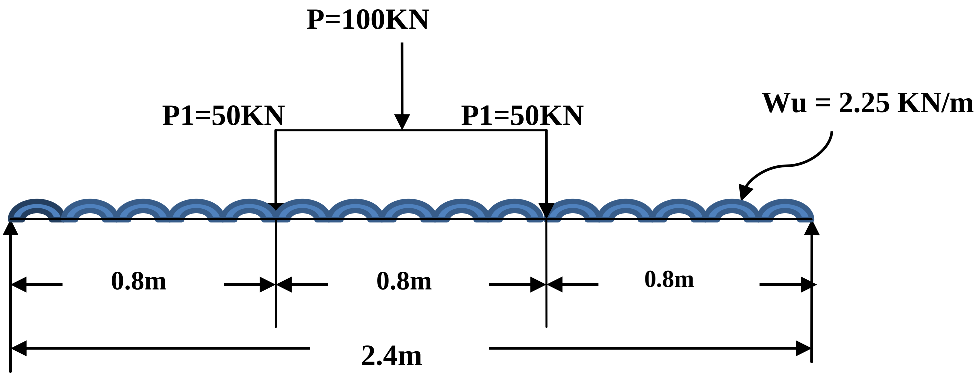

Fig. 3: Beam loading diagram

Clear span of beam L is 2.55 m
Effective span is L= 2.4 m (c/c distance b/w supports)
Span to depth ratio is L/d = 12, therefore d=200 mm. taking d=260 mm
Effective cover as of 40 mm and therefore Overall depth of beam, D = 300 mm
Assuming the width of beam, B = 200 mm and supports projections is 50 mm

- **Calculation of load:**
  Beams factored Self weight of the = w = 0.2 X 0.3 X 25 X 1.5 = 2.25 KN
  Reaction due to self-weight = 2.7 KN
  Reaction due to applied load = 50KN
  Total reaction = 52.7 KN
- **Moment under the point load is** = 52.7(0.8)-(2.25X0.8X0.4)
  = 41.44 KN-m

- **Factored Ultimate shear force is**= Vu = P* /2
  = 105.4 / 2
  = 52.7 KN
- **Tension reinforcement calculation:**
  $Mu, lim = 0.133\ f_{ck}\ B\ d^2$ ------(4.1)
  $= 0.133 \times 25 \times 200 \times 260^2$
  = 44.95 KN-m (< Mu, under reinforced section)
  $Mu = 0.87\ fyA_{st}\ d\ (1- (A_{st}fy) / bdf_{ck}))$ ---------(4.2)
  After solving we get, A_{st}= 441.3 mm^2
- **Checking for moment at mid span:**
  Mid span moment (M^*) = $52.7(1.2)-(2.25X(1.2^2/2))-50(0.4)$
  =41.62 KN-m
  Reinforcement for mid span moment A_{st}^*= 443.7 mm^2
  Provide 4# 12mm diameter bars as tension steel (A_{st}= 452 mm^2)
- **Compression reinforcement calculation:**
  Minimum reinforcement = $A_{st\ min}$
  = ((0.87bd)/fy) --------(4.3)
  = 90.48 mm^2
  Provide 2# 10 mm dia bars as compression reinforcement i.e. (A_{sc} = 157 mm^2)
- **Shear reinforcement calculation:**
  τ_v= Vu / bd ---------(4.4)
  = 1.013 N/mm^2
  Percentage of tension steel, Pt = (100 $A_{st)}$ / bd
  = 0.435 % (A_{st} = 226 mm^2)
  from IS: 456-2000, table 19, τ_c = 0.4562 N/mm^2($<\tau_v$)
  Balance shear $V_{us} = V_u - \tau_c bd$ --------(4.5)
  = 28.978 KN
  Assuming 2 legged 8mm dia bars as shear reinforcement (A_{sv} = 100.53 mm^2)
  Spacing = Sv = $0.87fy\ A_{sv}d / V_{us}$ ------(4.6)
  = 392 mm
  But Sv should not be greater than 0.75d = 195 mm.
  Provide 2 legged 8 mm dia @ 125 mm c/c spacing as shear reinforcement and in the flexure zone increase the same to 200mm.
- **Deflection Control check:**
  $(L/d)_{max}= (L/d)_{basic} \times K_t x K_c x K_f$ -------(4.7)
  =12 X 0.9 X 1.05 X 1
  =11.34
  (L/d) provided = 2.4 / 0.26 = 9.23 (SAFE).

3.1 BEAM SPECIMEN:

BEAM DETAILS:

Span	:	2.55m
Section	:	0.2m X 0.3m
Compression rft	:	2# 10mm ϕ diameter bars
Tension rft		
At mid-span section	:	4# 12mm ϕ diameter bars
At support sections	:	2# 12mm ϕ diameter bars
Shear reinforcement	:	2L 8mm ϕ diameter at 125mm c/c

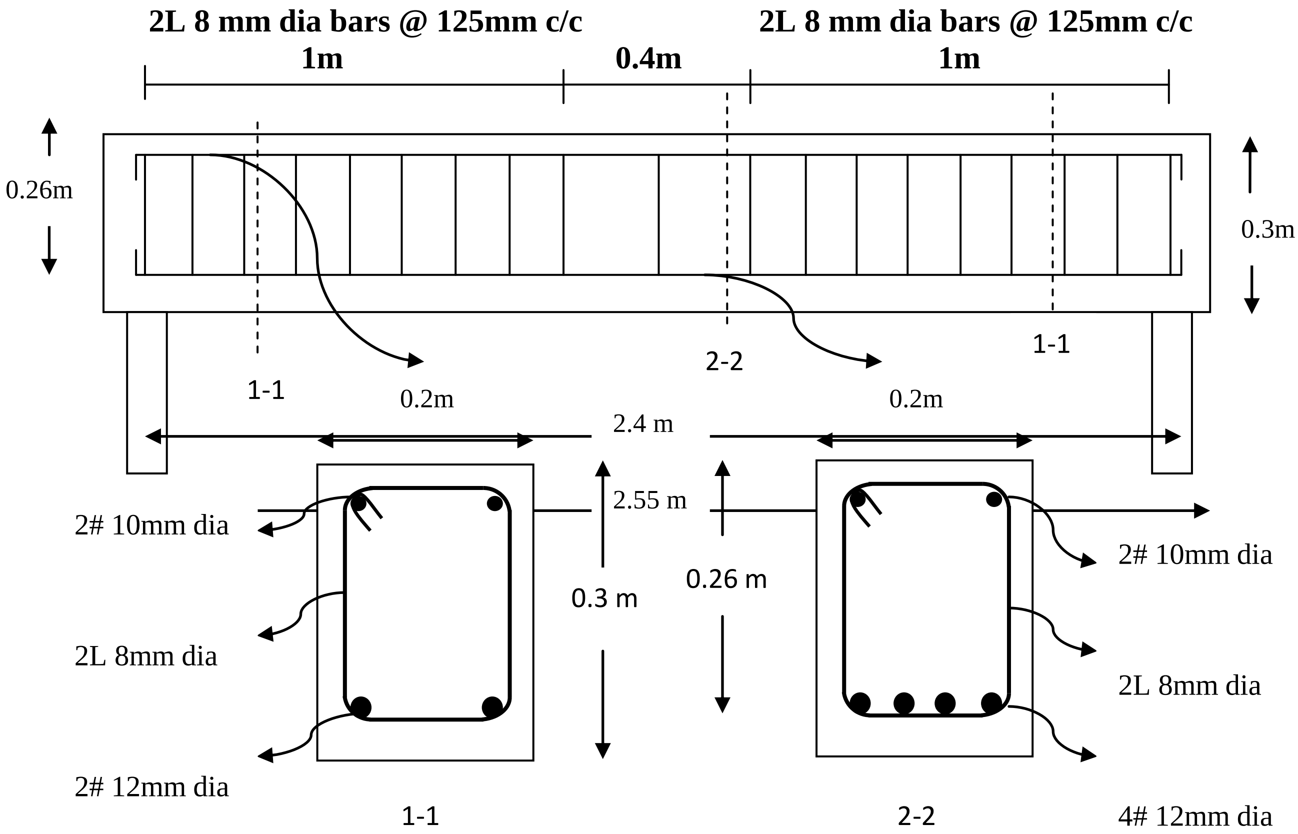

Fig. 4: Beam size and reinforcement details- Span, Support section, Mid span section

4. NON LINEAR ANALYSIS

Many engineering problems solution of is based on linear approximations. These approximations in structural analysis are represented by consideration the following points

- Displacements in this are very small therefore generally they will be neglected in equilibrium equations.
- Stress is proportional to strain that obeys Hook's law,
- Loads will be conservative therefore independent on displacements,
- During loading supports of the structure remain unchanged.

Consequently, there has a set of equations in the Finite Element Analysis (FEA), that describes the behaviour of structural is linear

$$\textit{i.e.}\quad K\,d = F \qquad \text{-------(5.3)}$$

where K = Stiffness matrix of the structure, d = Nodal displacements vector and F = External nodal force vector. This linear problem has a characteristics that

- To the loads the displacements will be proportional,
- On the value of the load the stiffness of the structure is independent.

In reality, structural behaviour is nonlinear, but in most practical problems divergences from linear response are usually small and may be neglected. On other hand, many engineering problems solution's solution needs abandonment of linear approximations. For example, slender structures displacements (like crane towers, masts etc.) will be so large that changes of the shape of structure (or configuration changes) cannot be neglected. So many materials be nonlinearly or if stress exceeds some value then linear material model cannot be used. Moreover, according to displacements and supports loads may change their orientations may change during loading. Consequently, structure comes to behave as nonlinear. If FEA will includes these phenomena, the set of equations of equilibrium becomes nonlinear and instead of set of the linear equations we will obtain a set of nonlinear algebraic equations.

i.e. **R(d) = F** ---------- (5.4)

Types of the structural nonlinearities

Structural nonlinearities will be specified as

Geometrical nonlinearities: The effect of large the displacements on the whole geometrical configuration of structure.

Material nonlinearities: Behavior of material is nonlinear. These material models are:

i. nonlinear elastic,
ii. elastoplastic,
iii. viscoelastic,
iv. viscoplastic.

Boundary nonlinearities, i.e. displacement will be depending on boundary conditions. Most of the boundary nonlinearities which are encountered in contact problems.

Consequences of nonlinear behavior of structural that will have to be recognized are:

i. The superposition principle cannot be applied. Thus, for example, several load cases results will not combined. they cannot be scaled the Results of the nonlinear analysis.
ii. At a time there will be only one load case can be handled.
iii. The sequence of load application (loading history) may be important. Especially, on a manner of loading plastic deformations will depend. This is a reason for which dividing the loads into small increments in nonlinear FE analysis.
iv. To the applied load the structural behavior will be non-proportional.
v. The initial state of stress (e.g. from the heat treatment the residual stresses, the welding, cold forming etc.) will be important.

5. MATERIAL SPECIFICATION:

5.1 STEEL

- Material : Structural Steel Fe 500Mpa
- Young's Modulus E=200Gpa
- Poison's ratio v=0.3
- Density p=7800kg/m3.

5.2 CONCRETE

- Grade of Concrete: M25
- Young's Modulus E=25000Mpa
- Poison's ratio v=0.16-0.3
- Density p=2400kg/m3

6. SPECIMEN GEOMETRY

The numerical model is done only for one fourth of the beam by taking symmetrises. The symmetry boundary conditions are used in order to simulate the tested joint sub assemblages adequately. The beam was modelled in ANSYS 12.0 with Solid 65, shell 63 and Link 8 elements. The Solid 65 element was used to model concrete and laminate. The concrete elements have eight nodes. The Link 8 element was used to model the reinforcement

6.1 Models of Control Beam

The beam was modelled by using two materials that is concrete and steel in the CFRP was not applied. In the modelling with ANSYS the concrete was taken as solid 65 and for steel Link-8 have used. Quarter beam was modelled by the advantage of symmetry.

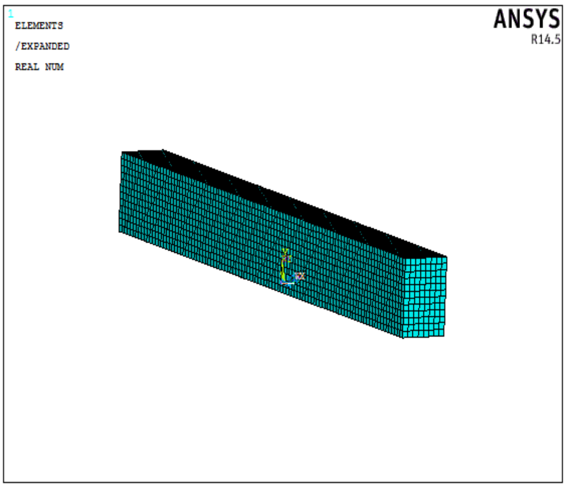

Fig. 5: Meshed RC beam model

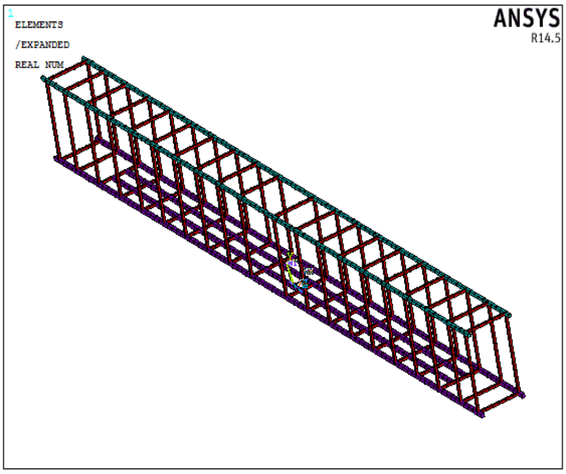

Fig. 6: Reinforcement model

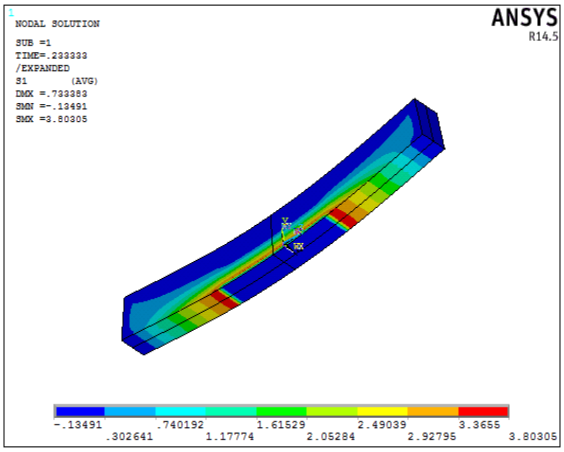

Fig. 7: Principle stress intensity

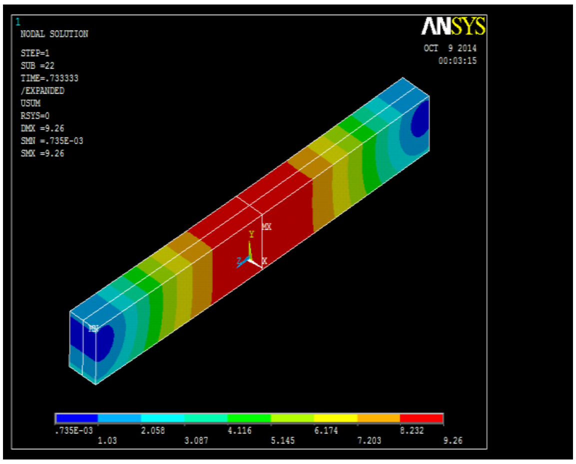

Fig. 8: Deflected beam model

6.2 MODELS OF EXTERNALLY BONDED LAMINATES BEAM (EBL):

In this, models of beam strengthened with CFRP laminates to the tension face of the beam by means of adhesives, the bonding of the laminates to the concrete was done. In the modelling with ANSYS the concrete was taken as solid 65 and for steel Link-8 have used and CFRP laminate has taken as shell 43. Quarter beam was modelled by the advantage of symmetry.

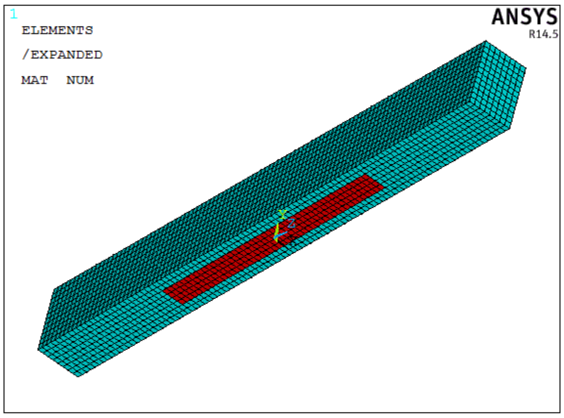

Fig. 9: Ansys Specimen showing

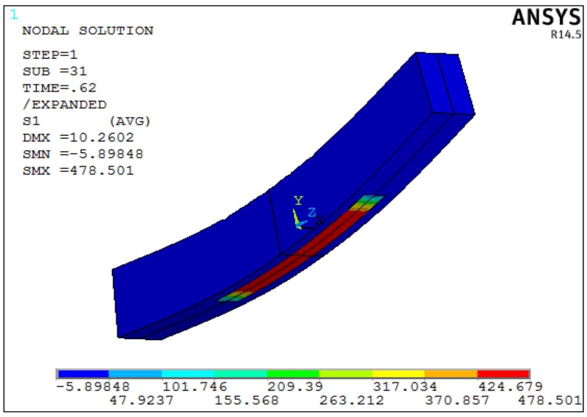

Fig. 10: Stress in beam (EBL)

Laminate application

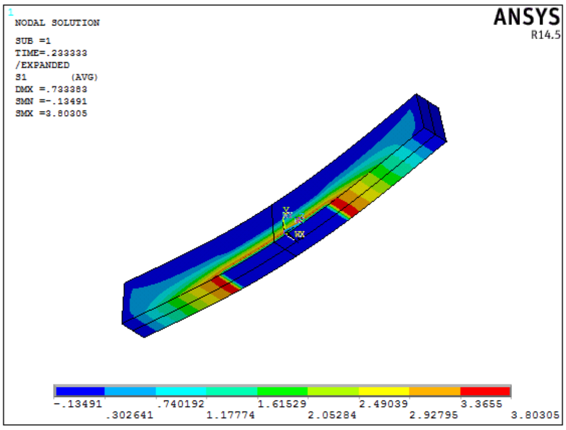

Fig. 11: Principle Stress (EBL)

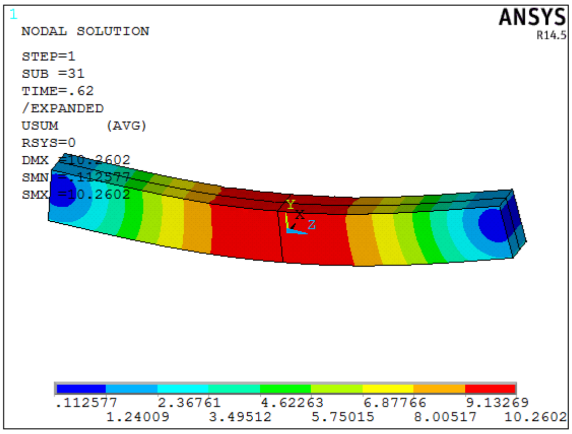

Fig. 12: Final displacement of beam (EBL)

6.3 Graphical representation of Load, Deflection, Stress, Strain values obtained from ANSYS analytical tool.

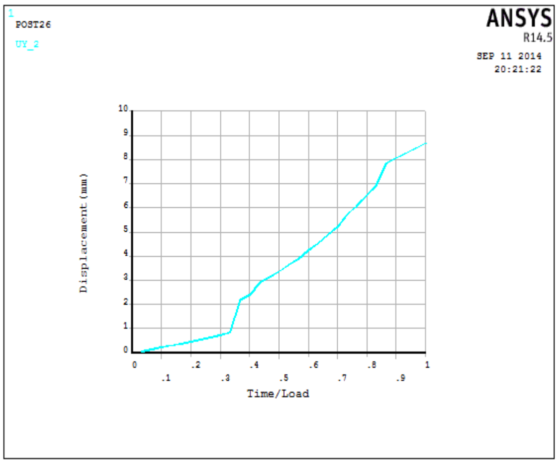

Fig. 13: Deflection v/s Time-load graph

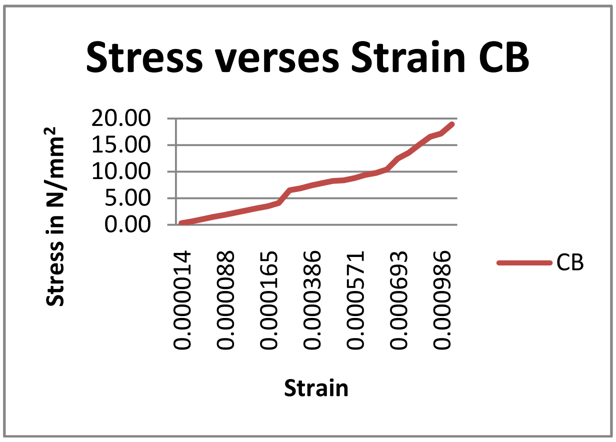

Fig. 14: Stress v/s Strain graph (CB)

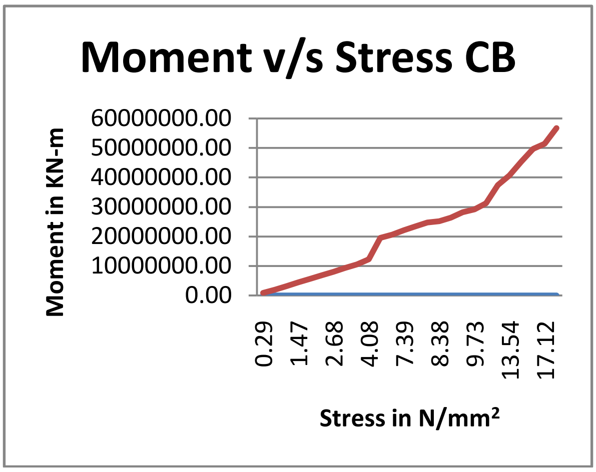

Fig. 15: Moment v/s Stress graph (CB)

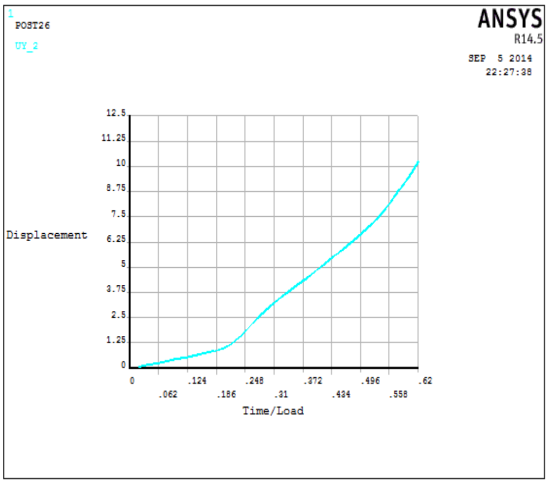

Fig. 16: Load deflection curve of (EBL)

Table 1: Showing the Beam deflections at Initial Crack load and ultimate load

Beam designation	Experimental results			
	P_s(KN)	Δ_s (mm)	P_u (KN)	Δ_u(mm)
CB	35	2.5	117.33	10.26
EBL	41.05	2.58	146.66	8.66

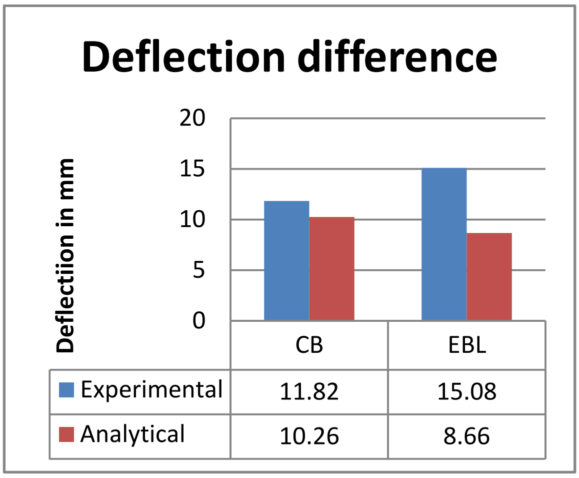

Fig. 18: Difference in deflection at ultimate load

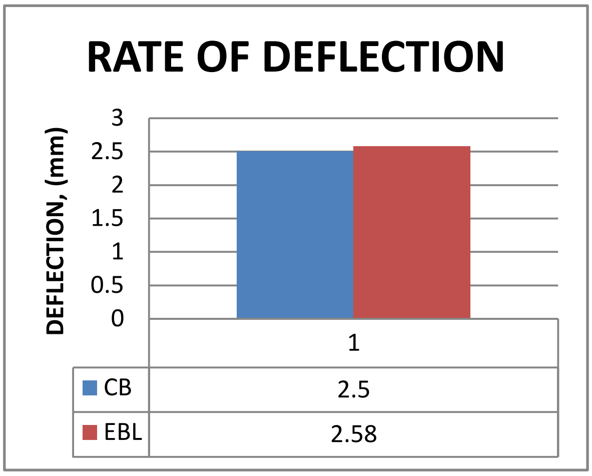

Fig. 19: Difference in deflection at initial crack load

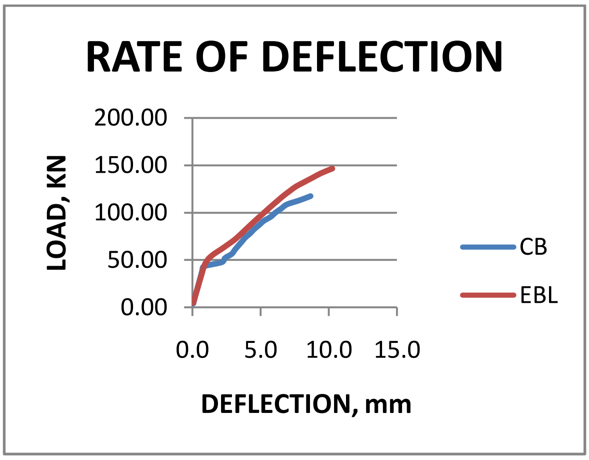

Fig. 20: Effect of strengthened beams on rate of deflection of CB and EBL

7. COMPARISON OF STUDY, ANALYTICAL WITH EXPERIMENTAL:

Comparison of Analytical and Experimental Results beams which includes controlled beams, and strengthened beams using CFRP laminates has been presented in this chapter. Beams were tested by using ANSYS software and compared with experimental results obtained from other M.Tech thesis and evaluation is made.

7.1 Comparison of Moments at different locations in analytical and experimental results

Table 2: Table showing comparison of Cracking Moments in analytical and experimental results

Beam designation	Moment at first crack(exp), M_e Experimental (KN-m)	Moment at first crack(exp), M_a Analytical (KN-m)	Moment at first crack(codal), IS:456-2000 (KN-m)	Ratio M_e/M_a
CB	16.3	9.27	10.5	1.75
EBL	23.4	11.00	10.5	2.12

Table 3: Comparison of experimental and analytical ultimate moments

Beam designation	Average ultimate load (Expt.) (KN)	Average ultimate load (Anayt.) (KN)	Average Ultimate moment, $M_{u,e}$ Experimental (KN-m)	Average Ultimate moment, $M_{u,a}$ Analytical (KN-m)	Average Ultimate moment, IS 456: 2000(KN-m)	Ratio $M_{u,e}/M_{u,a}$
CB	144.6	117.33	57.84	56.66	43.42	1.02
EBL	175.3	146.65	70.12	72.74	43.42	0.96

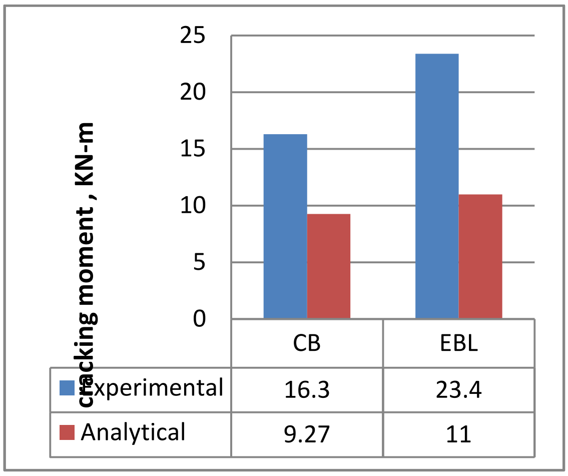

Fig. 21: Effect of Strengthening of beams on cracking moment

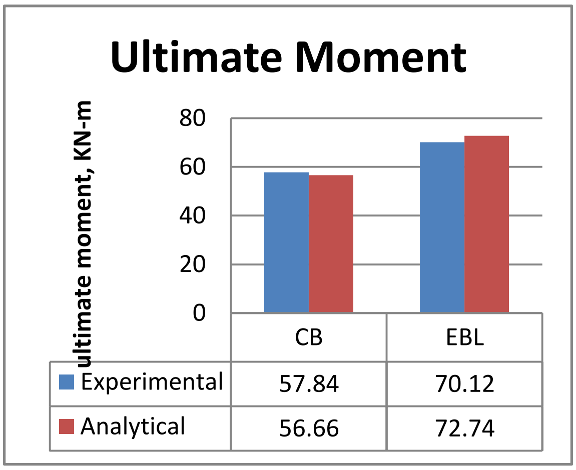

Fig. 22: Effect of strengthening of beams on Ultimate moment of experimental and analytical results

7.2 CRACK PATERNS

The crack pattern of the experimental and analytical is almost same as shown in the figure. Cracks gets taken place in flexure regionas well as flexure –shear cracks also developed. No horizontal cracks were observed at the level of reinforcement. The cracks originated adjacent to the flexure zone and propagated to the compression zone intersecting the flexural zone as it can be seen from the crack patterns from figs. The cracks started at the bottom of tension fibers and gradually moved to the top of the beam as the load increases.

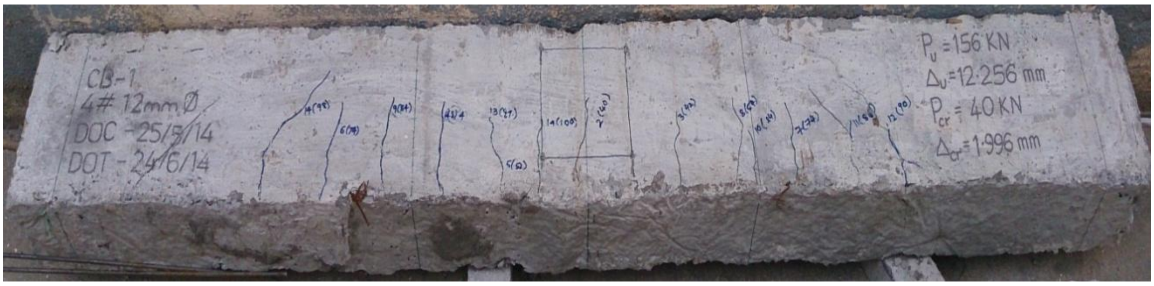

Fig. 23: Crack pattern of CB experimental

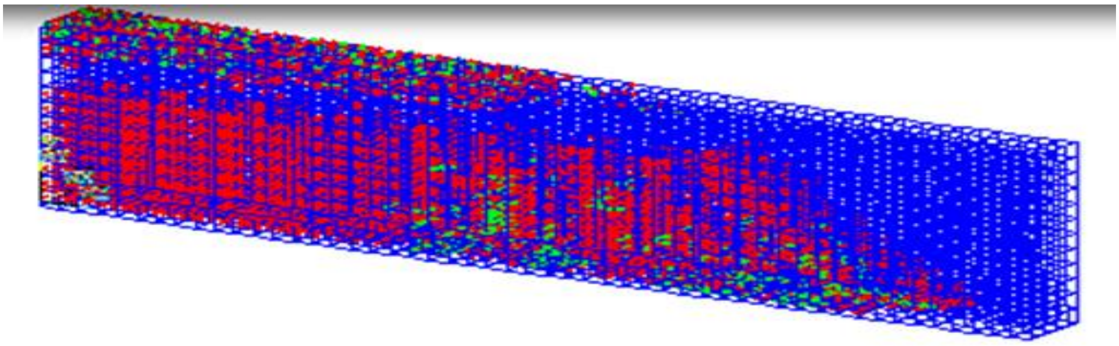

Fig. 24: Crack pattern of CB Analytical

The first crack in the analyticalcontrol beam specimen is occurred at the load of 35 KN while the first crack in case of experimental is occurred at an average load of 96.44 KN. It shows that experimental value more conservative than analytical. This is because of several reasons such as actual properties of constituent material may higher than the specified value of properties or other reasons such as more compaction of concrete, increase density of material etc.

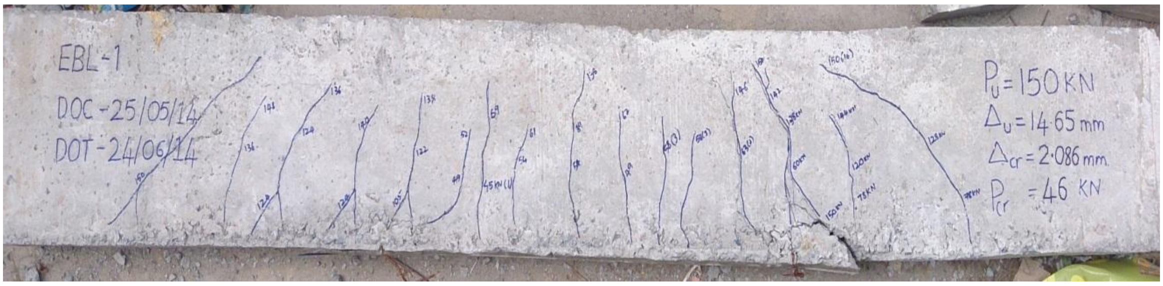

Fig. 25: Crack pattern of EBL (Experimental)

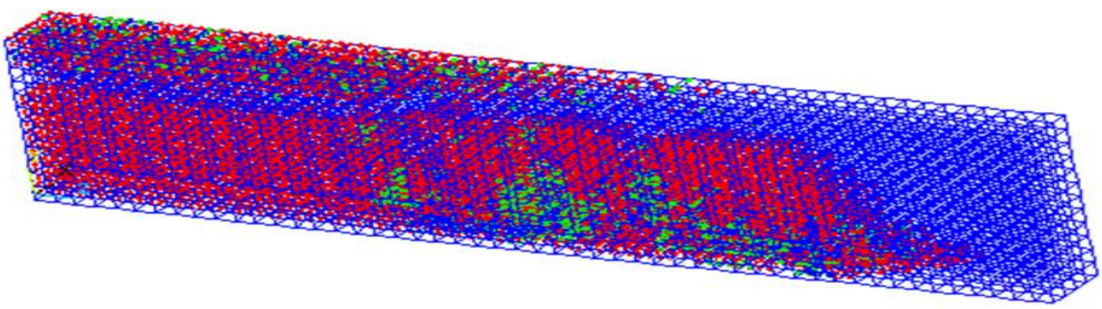

Fig. 26: Crack pattern of EBL (Analytical)

The first crack in the analytical externally bonded FRP beam specimen is occurred at a load of 41.05 KN while in case of experimental the first crack is occurred at an average load of 116.88 KN. It shows that experimental value more conservative than analytical. This is because of actual properties of constituent material is higher than the specified value of properties or other reasons such as more compaction of concrete, increase density of material etc.

7.3 DEFLECTION

The deflections recorded in the experimental were compared with the analytical values and also with the codalprovision at service load. The deflections recorded were also studied to see the variation with the strengthening techniques in the flexure zone.

Table 4: Comparison of Deflection of beams at initial service load and ultimate load of beams with a strengthened specimen of analytical with experimental

Beam designation	Service load P_s (KN)	mid span deflection, Δ_e, mm	Maximum deflection as per IS: 456-2000, mm $\Delta_s= I_c/250$
CB (Experimental)	96.44	6.325	9.6
CB (Analytical)	35	2.50	9.6
EBL (Experimental)	116.88	6.59	9.6
EBL (Analytical)	41.05	2.58	9.6

Table 5: Comparison of Experimental and Analytical beam deflections at Crack load

Beam designation	Corresponding Deflection at Service load Experimental (mm)	Corresponding Deflection at Service load Analytical (mm)	Maximum deflection as per IS: 456-2000, mm $\Delta_s= I_c/250$
CB	6.325	2.5	9.6
EBL	6.59	2.58	9.6

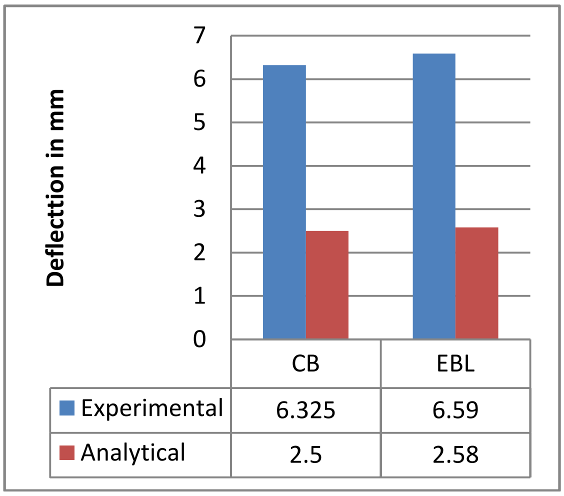

Fig. 28: Deflection at ultimate load Experimental v/s Analytical

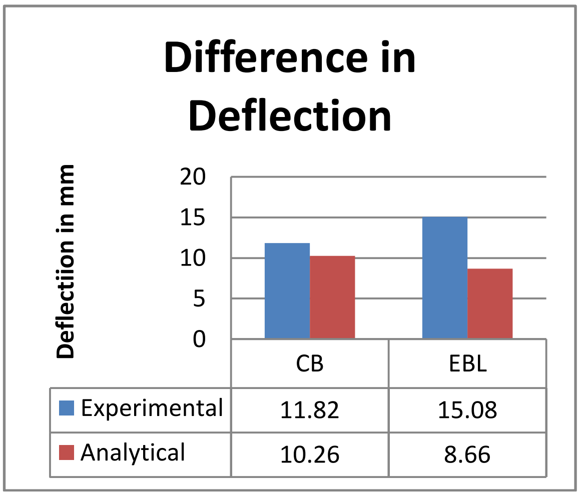

Fig. 29: Comparison of effect beams on rate of deflection

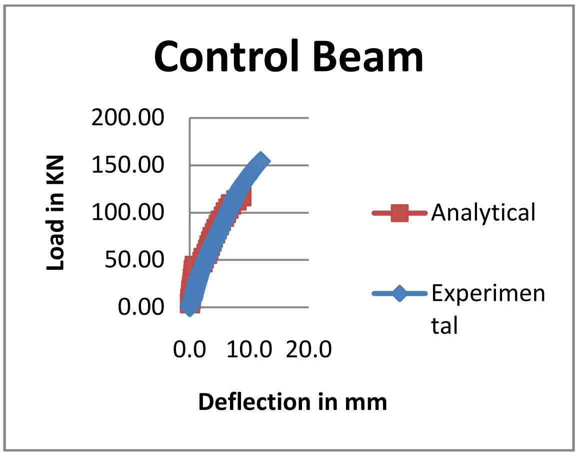

Fig. 30: Comparison of effect of strength on deflection of experimental and analytical only Control Beam

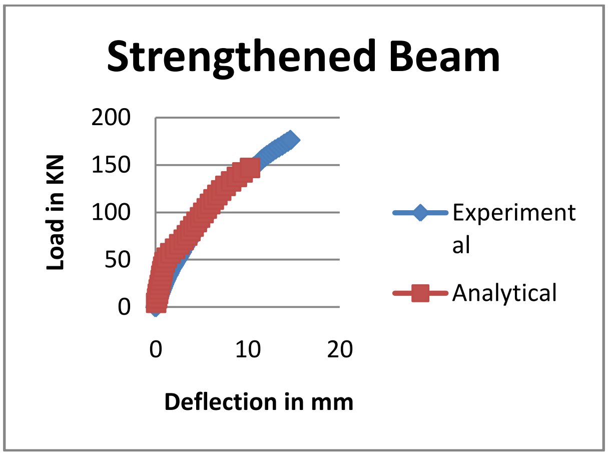

Fig. 31: Comparison of effect of strength on deflection of strengthened Beam in both experimental and analytical only

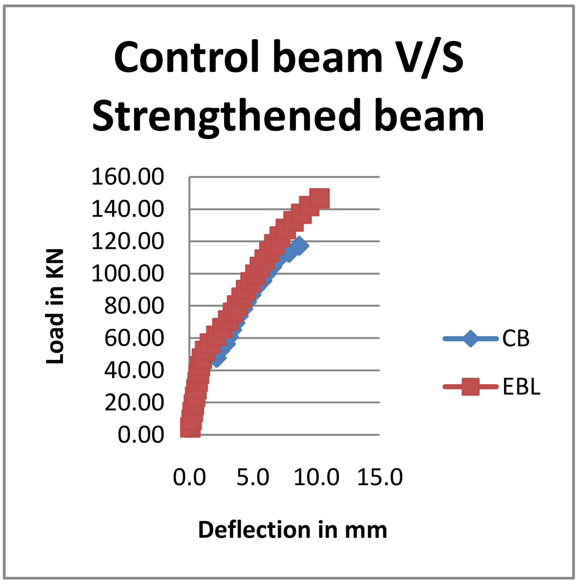

Fig. 32: Comparison of only analytical effect of strength on deflection of control and strengthened Beam

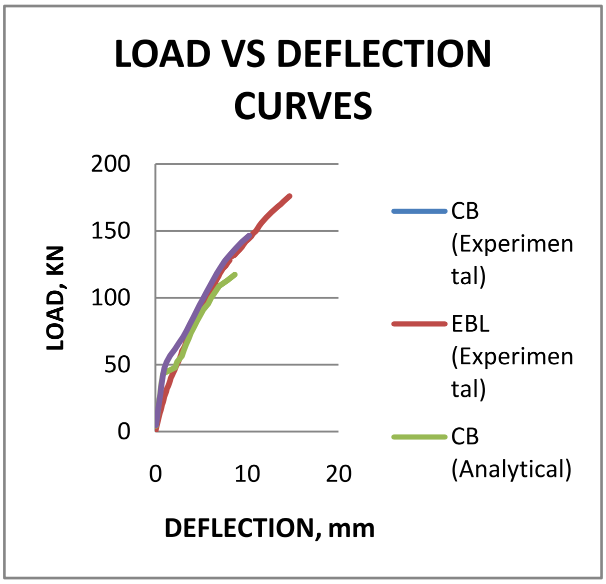

Fig. 33: Comparison of effect of strength on deflection of experimental and analytical

8 CONCLUSION:

- Beams which will strengthened with CFRP laminates in single layer were capable to take more load than the beams without strengthening (control beams).
- The behaviour of the finite element models which is represented by the load-deflection plots at mid span show good agreement with the test data from the full-scale beam tests
- ANSYS modelling can be used to predict the behaviour of strengthened reinforced concrete beams more precisely by assigning appropriate material properties.
- The average Load carrying capacity of the EBL beams were increased by 20% when compared to Control beams.
- Development of horizontal cracks formed at the flexural zone were prevented due to the laminate provided at the zone, which led the beam to fail by the formation of cracks in the shear zone.

- Though the ultimate load and the corresponding deflection of the strengthened beams were higher when compared with the control beams, the rate of deflection for the constant application of load was less which indicated that the strengthened beams were tending to be stiffer than the control beams.
- Up to30kN both the beams (control and strengthened) obey the same path of deflection. From this we can be conclude that strengthen material (CFRP) taken the load after 30kN.

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