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Finite Element Modeling of Strengthened Beams Using CFRP

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Abstract: Deteriorating and damage of some structural elements influence negatively their strength and the bearing capacity. However, it is necessary to take some measures improve structural performance. In this context, the composite material is often used to strengthen the damaged parts. This paper presents a model to analyze the effect of carbon fiber reinforced polymer strengthening of beams under four point bending. Finite element software ANSYS 12.0 has been used for modeling the beams by conducting nonlinear static analysis. The SOLID 65 and SHELL 181 elements have been used to, respectively; model the 3D concrete beams and the composite layer. Constitutive properties of different components (concrete and FRP) have been incorporated. The predicted Finite element analysis results for the load-midspan deflection are compared to the measured experimental data. Close agreement was found between the predicted and measured results at all stages of loading for both models developed.

Key words: Finite element analysis, modeling, strengthened, FRP.

1. Introduction

Fiber Reinforced Polymer (FRP) can be used to improve the shear and flexural capacities RC structural elements, (Grace et al. 1999; Bruno et al. 2007; Arduini and Nanni 1997; Ross et al. 1999). Increasing capacity depends on such factors as concrete strength, FRP and steel mechanical properties and reinforcing steel and FRP ratios. An et al. (1991), Malek and Saadatmanesh (1998) and Ross et al. (1999) have done many studies. They have established analytical methods to evaluate the flexural capacity of reinforced concrete beam strengthened with FRP laminates.

Santhakumar and Chandrasekaran (2004) have studied the effect of CFRP on concrete beam with different fibre orientations. Their results have been useful in tracking propagation of the crack. Tăranu and Bejan (2005) have studied Mechanical modeling of composite ARAMIDE fiber. The carbon filaments have been observed to be more suitable in understanding the composite strips utilized for the basic restoration of strengthened solid twisted components.

In the last decades, Finite Element Analysis (FEA) is also used to determine the overall behavior of the structure. (Fanning, 2001), studied the experimental load-deflection response of ordinary and post-tensioned concrete beams with ANSYS. They have found that correlation of experiments and modeling depends on the values of the materials properties, such the Young's modulus of concrete and the yield strengths of the reinforcing bars.

Anthony (2004) have studied reinforced and prestressed concrete beams using Finite Element Analysis. They concluded that the finite element package could well model the failure mechanism of the beams. Dahmani et al. (2010) have conducted an investigation into the applicability of ANSYS software for analysis and prediction of crack patterns in RC beams and the advantage of performing numerical simulation instead of experimental tests. For this purpose, different phases of the behavior of the FE model of an RC beam was studied from initial cracking to failure of the beam. The entire load-deformation response produced correlated well with the analytical results.

Banu et al. (2012), have used ANSYS software to analysis the effect of FRP material as an external layer to see the effect of it on load carrying capacity. They studied the numerical modeling of two-way reinforced concrete slabs strengthen with carbon fibers reinforced polymer strips. They have used SOLI65 element to model the 3D concrete beams while SOLID45 has been used to design the thick shells. They have conducted their results for load-deflection and ultimate carrying capacity.

Parandaman and Jayaraman (2014), studied the Finite element analysis of reinforced concrete beam retrofitted with different fiber composites using Ansys. They have used three different composite layers. The Load carrying capacity and the strength increase by using FRP laminates.

Musmar et al.(2014), have studied a shallow reinforced concrete beams using ANSYS. They targeted their study towards the study of shallow reinforced concrete beam for transverse loading. They concluded that cracking initially occurs in the vertical flexural. It increases with increment in the load. The relationship between the load and deflection has been found to be linear elastic up to cracking moment strength then it inclines in horizontal plane.

In this paper, four point bending analysis is carried out using concrete beam strengthened with externally bonded FRP layers using ANSYS 12.0. Load-deflection responses and the crack patterns at critical stages of loading are studied. In comparison to the experimental data, the numerical method was seen to satisfactorily predict the behavioral responses of the beams.

2. Material properties

2.1. Geometry and material data

The geometry of the beam has a 1840 mm long and 120 mm width. The concrete strength was 21 MPa. A total of four types of beams are analysed depending on CFRP layers number (2 to 5) layers).Table1 and Table2 summarizes the material properties assumed for reinforced concrete as used by Hawileh et al. (2015), in their experimental study.

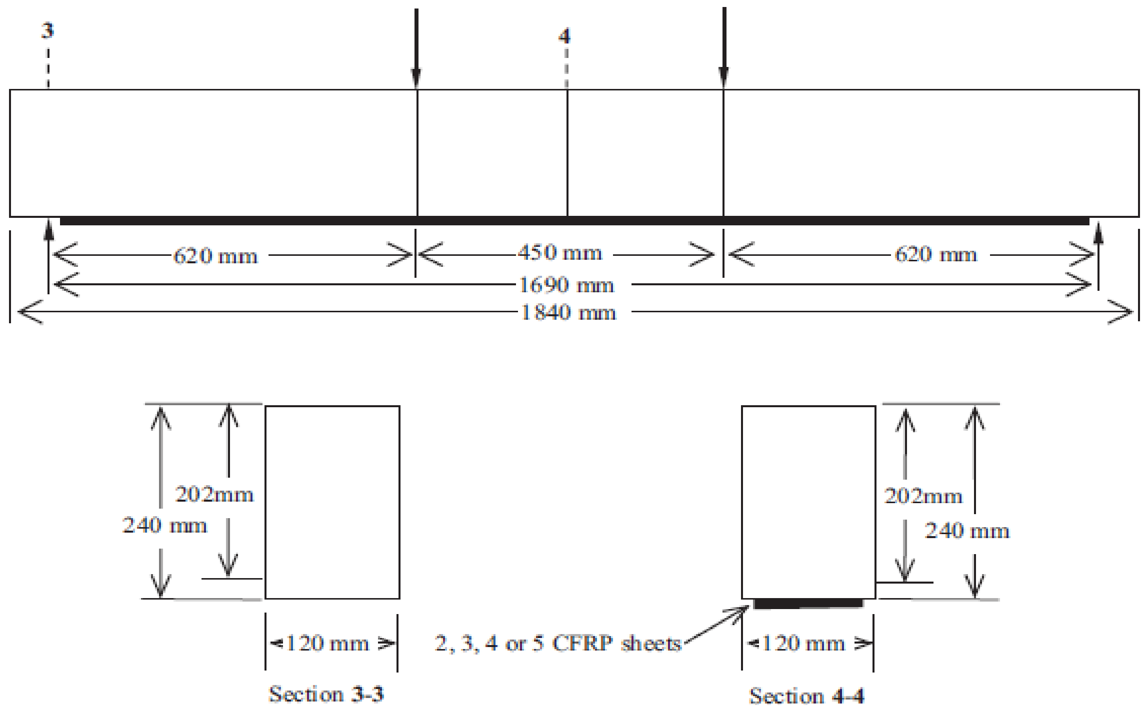


Fig. 1. Details of concrete beams by CFRP. Hawileh et al. (2015).

Table 1. Experimental program details Hawileh et al. (2015).

Group	beams	Number of CFRP layers
1	UBS2	2
2	UBS3	3
3	UBS4	4
4	UBS5	5

Table 2. Mmechanical properties of the CFRP sheets and epoxy adhesive Hawileh et al. (2015).

Material	Design thickness (mm)	Modulus of elasticity (GPa)	Ultimate tensile strength (MPa)	Elongation at failure (%)
SikaWra 300 C	0.17	230	3900	1.5
Sikadur 330	-	4.5	30	0.9

3. Samples preparation

ANSYS computer program has been used for the finite element modelling ANSYS computer program has been used for the finite element modelling

The finite element method is a numerical technique for obtaining approximate solutions to a wide variety of engineering problems. ANSYS is a software of finite elements modeling uses to solving a wide variety of problems, of which structural analysis (linear and nonlinear).

The strengthening of concrete beams and CFRP had been analyzed using finite elements models by ANSYS 12. In this work, using the finite element models ANSYS12. Multiple element types were used to model the five beams.

3.1. Concrete properties

Solid65 (ANSYS12) is used for the three-dimensional modeling of solids with or without reinforcing bars. The solid is capable of cracking in tension, crushing in compression, creep nonlinearity and large deflection geometrical nonlinearity. Here, the model without reinforcing bars was used. This element has eight nodes with three degrees of freedom at each node; translations in the nodal x, y, and z directions. Stress strain relationship for concrete is shown in Figure 2. Figure 3 shows Solid65 element in ANSYS

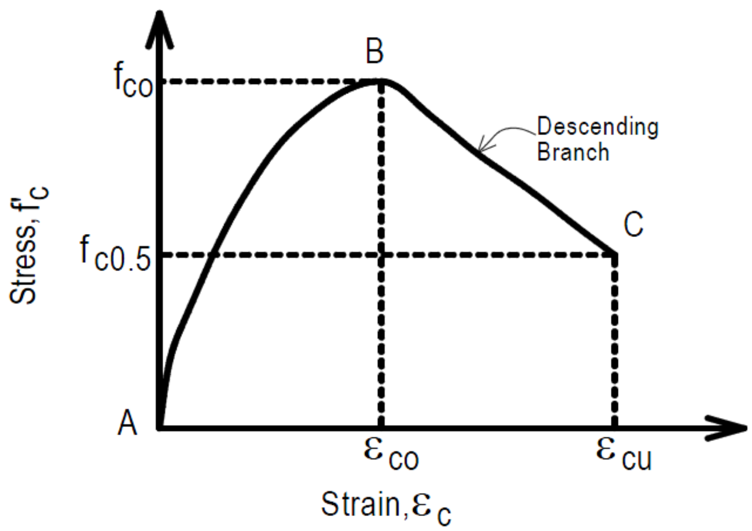


Fig. 2. Concrete uniaxial stress-strain curve.

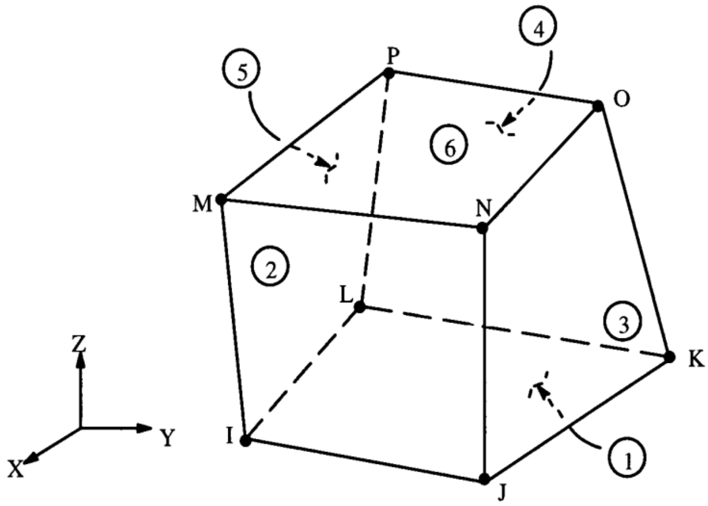


Fig. 3. Solid65 element (ANSYS12).

3.2. Composite layers

For CFRP using elements Shell181 (ANSYS12) it is an element of four-node with six degrees of freedom at each node:traductions in the x, y, directions and z, and rotations about the x, y, and z.

SHELL181 is well- suited for linear and large rotation, and/or large strain nonlinear applications. The geometry, node locations, and the coordinate system are shown in Figure 4.

Modeling of composite layer has been done using Shell181 element, presented in the figure 4.

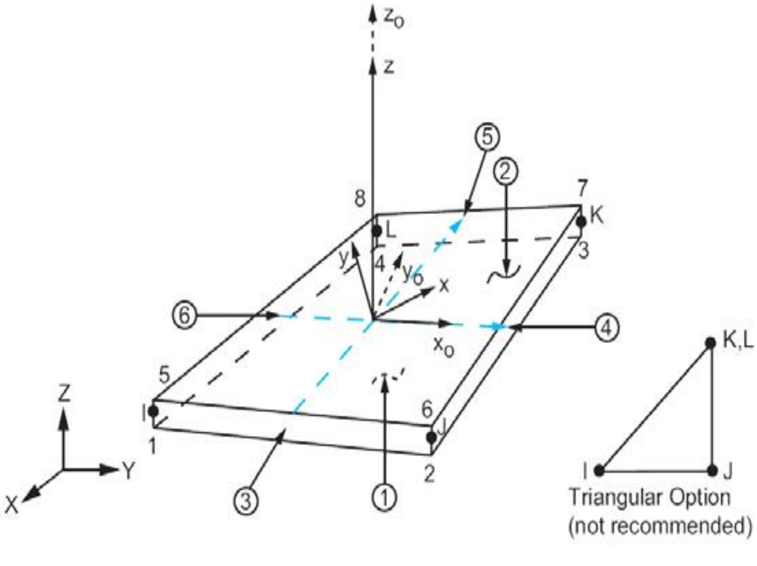


Fig. 4. Shell181 element (ANSYS12)

4. Results

The beam and CFRP layer were modeled using separate volumes. Figures 5 and 6 show, respectively, the meshed beam and the meshed CFRP in ANSYS. The supports were modeled such that roller and the external loads were applied as concentrated forces distributed equally among the nodes.

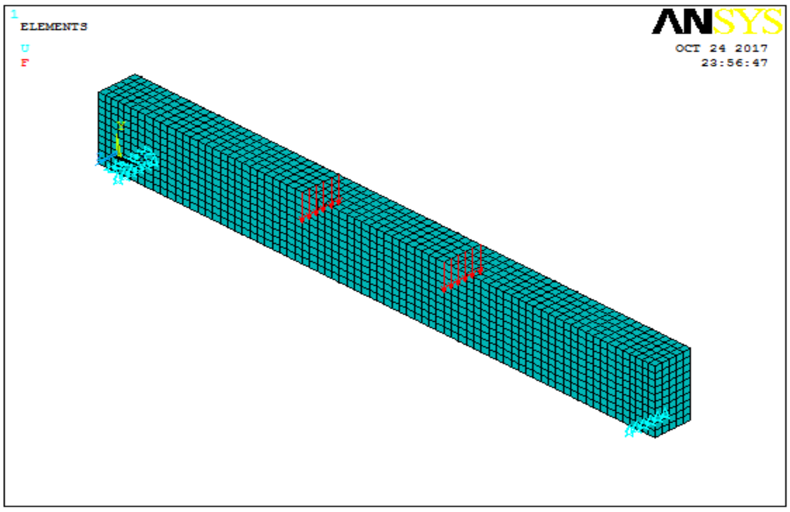


Fig. 5. The meshed beam.

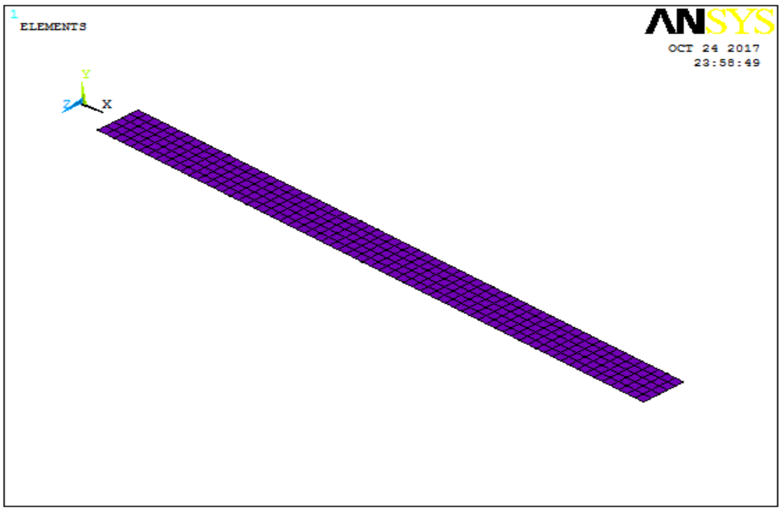


Fig. 6. The meshed CFRP.

4.1. Modeling validation

One of the most important parameters in structures strengthening is bearing capacity, ductility and deflection. To validate the model, the results of ultimate load and deflection, obtained in mid span of beams, were compared with those of Hawileh et al. (2015). They are presented in table 3. Numerical results show an increasing in bearing capacities and decreasing in deflection with increasing of composite layers. The relative differences between the numerical and experimental results are not greater than 15.88% for load capacity and not greater than 18.7% for ultimate deflection. It can be concluded that numerical results are in good agreement with the experimental one.

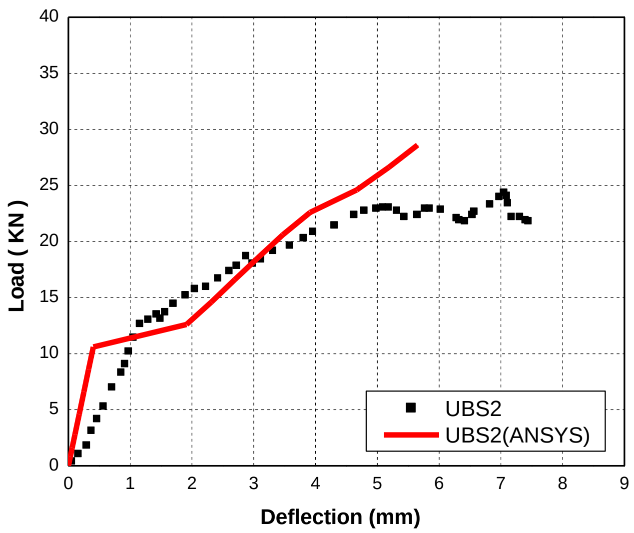
Table 3. Results between numerical modelling and experimentation.

Reinforced concrete beams	Load (KN)		% Difference	Ultimate Deflection (mm)		% Difference
	Exp	FE A		Exp	FEA	
UBS2	24.056	28.600	15.88	7.1005	6.05461	14.72
UBS3	34.299	34.600	0.87	6.0075	5.2472	12.65
UBS4	34.042	36.600	6.98	5.6292	4.57632	18.70
UBS5	33.409	38.600	13.44	3.5166	3.76819	6.67

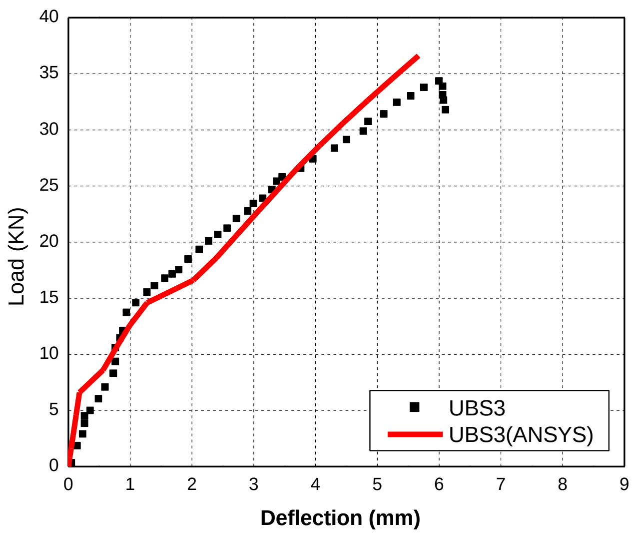
4.2. Comparison of the Load-Deflection Curves for different beams

Comparison of Load-Deflection curves are shown in figure 7. Firstly, it can be seen clearly that FE results are in good agreement with those of experiment. However, numerical curves are little stiffer, in linear zone, than those of experimental ones.

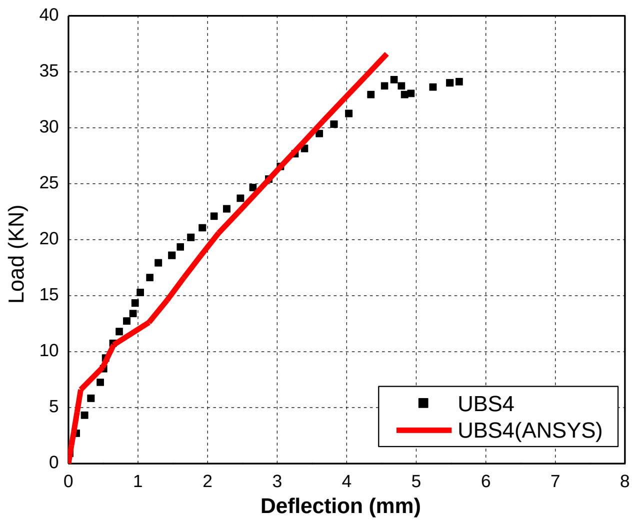
The deflections and stresses in the beams were seen to increase with loading. Comparison of the ultimate loads for strengthened beams according to the control beam has showed an increase of these loads, caused by the CFRP layer, ranging from 14 .89% to 1.46%.



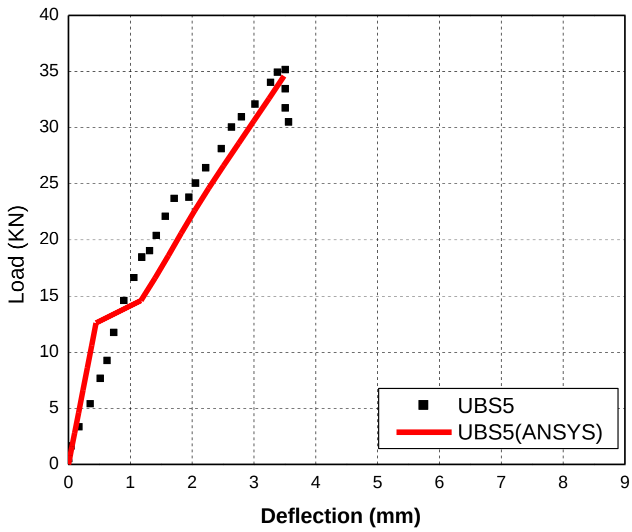
(a) case of 2 CFRP layers



(b) case of 3 CFRP layers



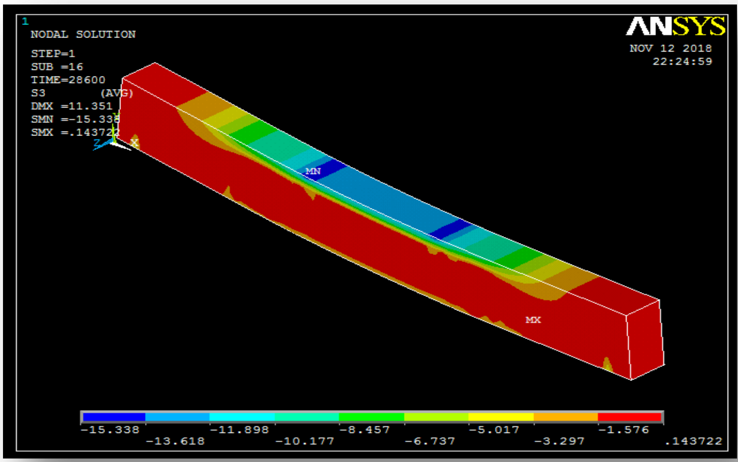
(c) case of 4 CFRP layers



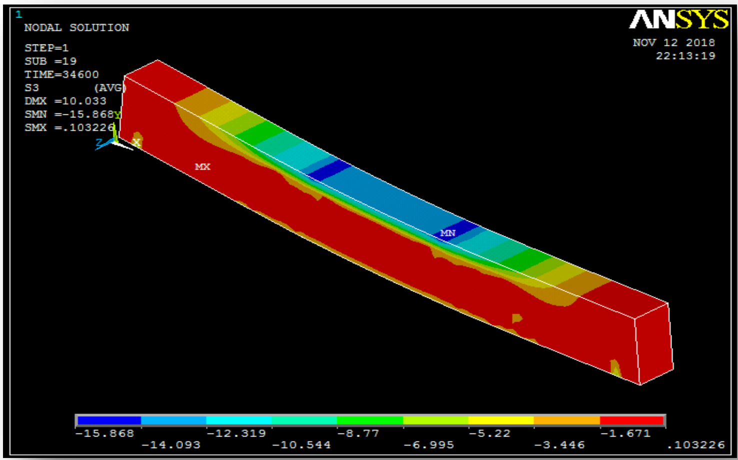
(c) case of 4 CFRP layers

Fig. 7. Load- deflection curves for different types of beams. Comparison between experimental data and numerical results.

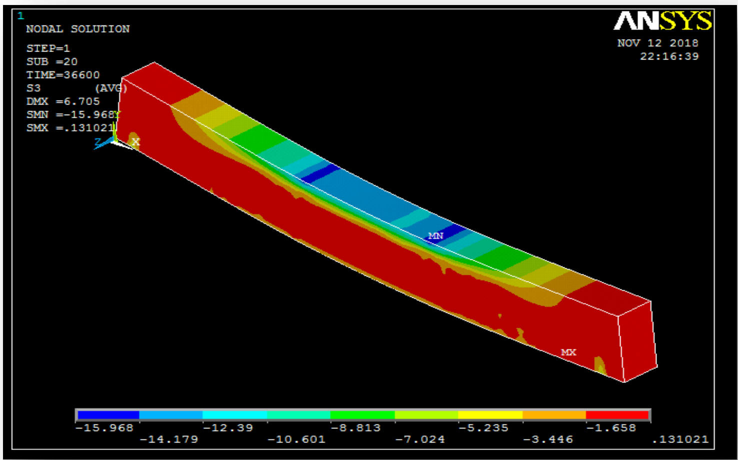
Having such a reliable and validated finite element model is advantageous over the experimentally measured data in many respects. The output of the experimental test are usually limited to that recorded by discrete number of strain gauges and LVDT at few points within the beam at specified time or load, while the finite element model provides predicted full deformation and stress results throughout the beam for the entire loading history. For instance, figure 8 shows the evolution Stress in concrete 3rd Principle stress (σ3)



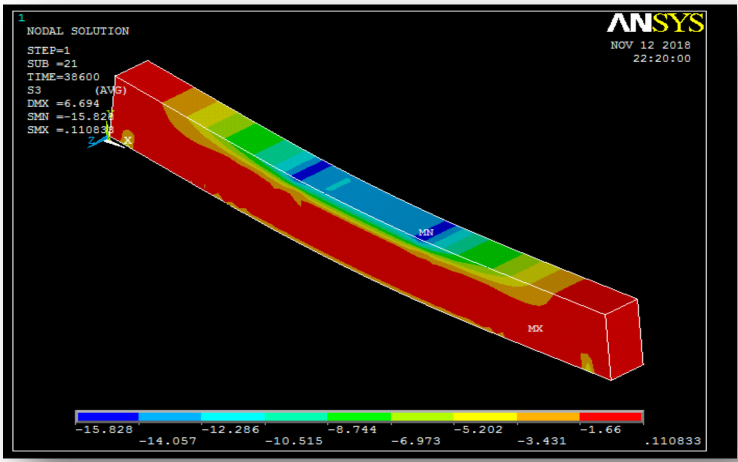
(a): case of 2 CFRP layers



(b): case of 3 CFRP layers



(c) : case of 4 CFRP layers



(d) : case of 5 CFRP layers

Fig. 8. Response and stress distribution3rd Principal Stress (σ3).

4.3. Distribution of cracks

The numerical cracks distributions are illustrated in figures 9 and 10. Fracture instability is affected by the Layers number. The first crack in the FE model was a flexural crack in the mid span region of the beam. It appears at about 20% of the ultimate load. They are deeper in the beam with two layers than those of the beam with 5 CFRP layers.

Cracking also progressed with loading progress. They have been observed to increase in the constant moment region before they spread out towards the supports at last stages. At the end of loading, they have become more extended on the beam and denser than those observed in the first loading stage.

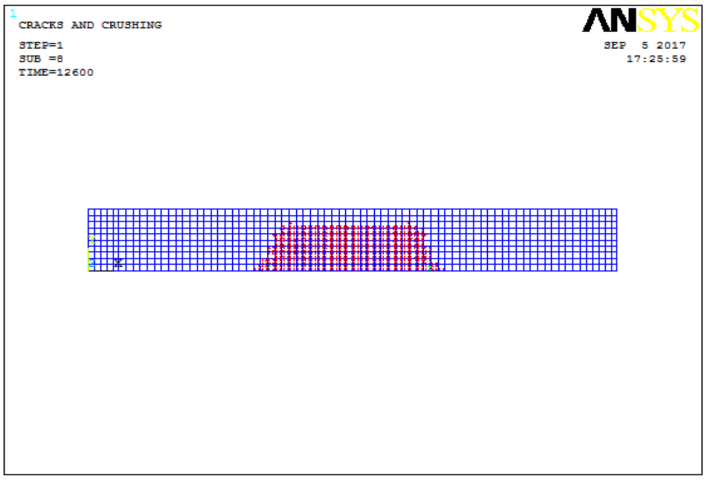
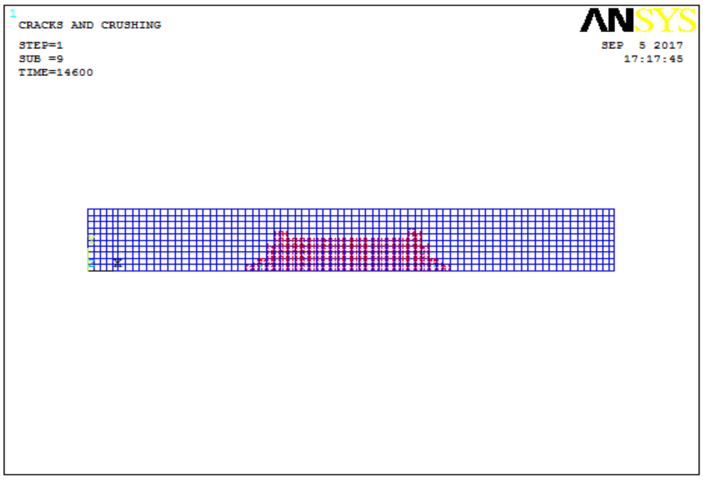
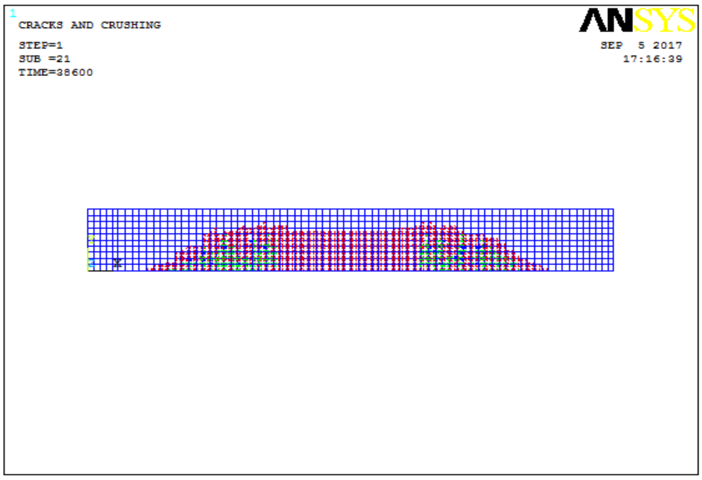


Fig. 9. Cracks at load of 10.000 K N. Case of 2 CFRP layers.



(a) Cracks at load of 10.000 KN. Case of 5 CFRP layers



(b) Cracks prior to fracture. Case of 5 CFRP layers

Fig. 10. Crack distribution at two loading stages. Case of beam with 5 CFRP layers.

5. Conclusions

In this study, the behavior of strengthened concrete beam was analyzed using finite element method. The results of load-displacement curves revealed that applying the CFRP layers, significantly improve beam performance. Such that it increased beam bearing capacity. The deflections and stresses in the beams were seen to increase with loading. It has been seen that CFRP layers increase the ultimate load of the beam which depends on the CFRP layer numbers.

The model allowed the tracking propagation of the cracks. The first crack in the FE model was a flexural crack. It appears at about 20% of the ultimate load. They are deeper in the beam with two layers than those of the beam with 5 CFRP layers. They also progressed with loading progress. They have been observed to increase in the constant moment region before they spread out towards the supports at last stages. At the end of loading, they have become more extended on the beam and denser than those observed in the first loading stage.

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