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Analyse the effect of carbon fiber reinforced polymer (CFRP) strengthening of beams using ANSYS

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Abstract. This paper presents a nonlinear finite element model analysis to effect of carbon fiber reinforced polymer (CFRP) strengthening of beams using ANSYS, Finite element software ANSYS 12.0 has been used for modeling the beams by conducting nonlinear static analysis. The SOLID 65 and SHELL 181, LINK180 elements have been used to, respectively; model the 3D concrete beams and the composite layer, steel rebars. The results of the finite element were compared with the experimental data The results showed that the general behavior of the finite element models represented by the load-deflection curves shows good agreement with the test data from the previous researches.

Key words: Analysis, FEA, ANSYS, CFRP.

1. Introduction

The use of fiber reinforced polymer because of good corrosion resistance, low coefficient of thermal expansion and high chemical inertness. CFRP has been effectively used to strengthen concrete, many studies concerned with the flexural strengthening of RC reported that CFRP significantly increases the strength. Ashour et al. (2004) tested beams to study the "flexural strengthening of reinforced concrete continuous beams using CFRP laminates". The results showed that CFRP strengthened beams demonstrated Very higher load capacity. Ahmad et al. (2011) conducted an experimental investigation to evaluate the flexural performance of RC beams strengthened with CFRP sheets with different arrangement schemes. They reported that CFRP strengthening has greatly improved the load carrying capacity of reinforced concrete beams. Also, it is shown that increasing the number of CFRP laminate layers increases the flexural stiffness ultimate load. Dong et al. (2011) studied the flexural behavior of strengthened RC beams. They tested seven beams with different cross section depths, longitudinal reinforcement, and concrete cover thickness. They concluded that retrofitting reinforced concrete beams with CFRP sheets increased the strength by 41-125%.

Esfahani et al. (2007) tested reinforced concrete beams with different reinforcement ratios. The authors used CFRP sheets with different widths, lengths, and number of layers to strengthen RC beams and study their behavior. The study concluded that the flexural strength and stiffness of the strengthened beams were higher than un-strengthened beams. 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 as concret and steel bar. (Anthony and Wolanski, 2004) have studied reinforced and prestressed concrete beams using Finite Element Analysis. From this study it was concluded that the finite element 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, different phases of the behavior of the finite element model of a reinforced concrete beam were studied to failure of the beam. The entire load-deformation response produced correlated well with the analytical results. Banu et al (2007), 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. It has been 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 concrete beams while SOLID45 has been used to design the thick shells. They have conducted their results for load-deflection. Parandaman and Jayaram (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 capacity increased and the strength increase by using FRP laminates. Musmar et al (2014), have studied a shallow reinforced concrete beam using ANSYS. They study of shallow RC beam loading. They concluded the cracking increases with increment in the load. In this study An ANSYS finite element program used to study the behavior of four point bending analysis is carried out using concrete beam strengthened with externally bonded CFRP layers . Comparison between the experimental model from Hawileh et al. (2015). Load-deflection responses in comparison to the experimental data, the numerical method was seen to satisfactorily predict the behavioral responses of the beams.

2. Experimental program

Finite element method is a numerical method used for solving a differential or integral equations and obtaining an approximate solution to a wide variety of engineering problems. ANSYS is a general-purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. In this work, a three-dimensional finite element modeling by using (ANSYS12) software has been conducted.

2. 1. Element type

2.1.1 Concrete properties

The three-dimensional element Solid65 is used for modeling solid concrete beams. This element has eight nodes as shown in Figure 1 with three degrees of freedom at each node, which are translations in the x, y, and z directions. The Solid65 element is capable to estimate plastic deformation, cracking in three orthogonal directions, and crushing of concrete. Stress strain relationship for concrete is shown in Figure 2.

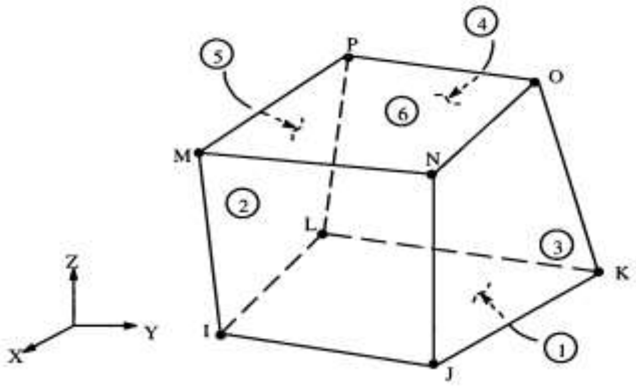


Fig 1. Solid65 element (ANSYS12)

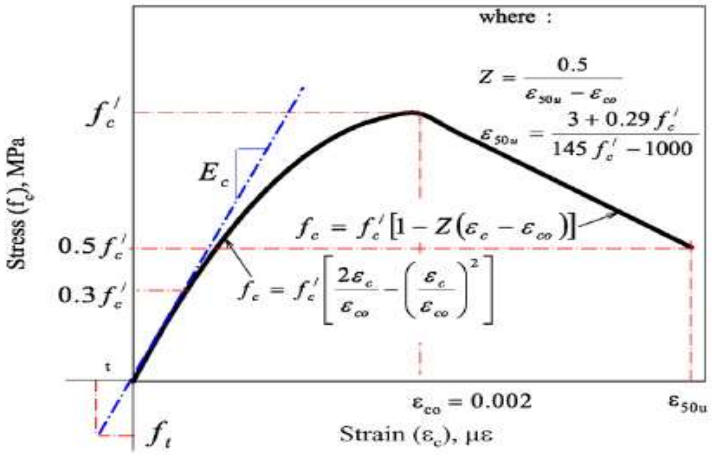


Fig 2. Concrete uniaxial stress-strain curve Darmansyah Tjitradi et al., (2017)

2.1.2 Composite layers

Modeling of composite layer has been done using Shell181 element, presented in the figure 3.

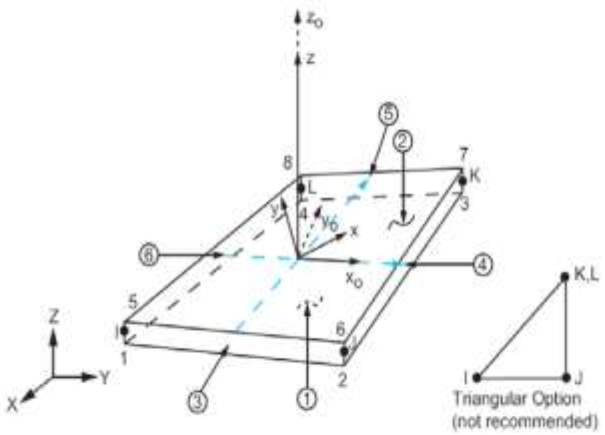


Fig3. Shell181 element(ANSYS12)

2.2.3 Steel Reinforcement

A Link 180 element was used to model steel reinforcement. The element is a uniaxial tension-compression element with three degrees of freedom at each node. The geometry, node locations, and the coordinate system for this element are shown in figure 4. Darmansyah Tjitradi et al (2017)

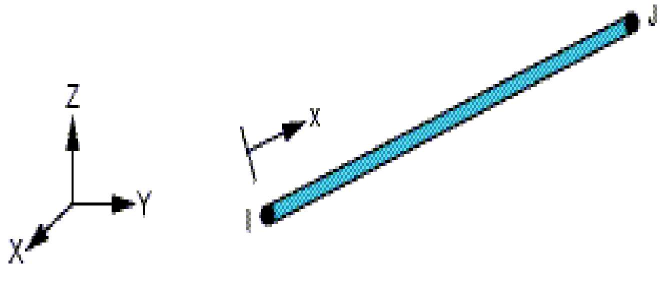


Fig 4. LINK 180 geometry (ANSYS12)

3. Beams geometry and material properties

Table1 summarizes the material properties assumed for reinforced concrete as used by Hawileh et al. (2015), in their experimental study. The beam has a 1840 mm long and 120 mm and125mm,.130mm width shown in figure 5. The concrete strength was 19MPa and 21 MPa.

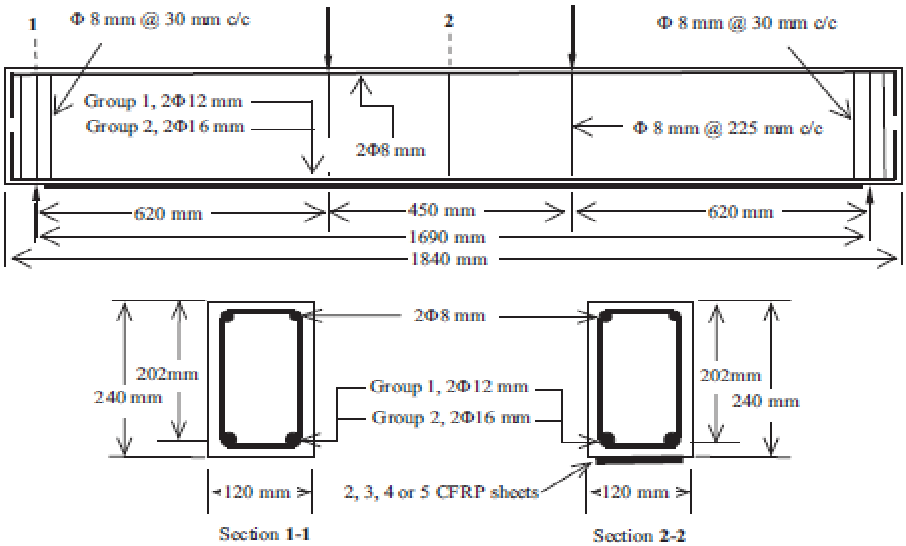


Fig 5. Details of concrete beams by CFRP. Hawileh et al. (2015)

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

Group 1	beams	Number of CFRP layers
1	B1	-
2	B1S2	2
3	B1S3	3
4	B1S3	4
5	B1S3	5
Group 2	beams	Number of CFRP layers
1	B2	-
2	B2S2	2
3	B2S3	3
4	B2S4	4

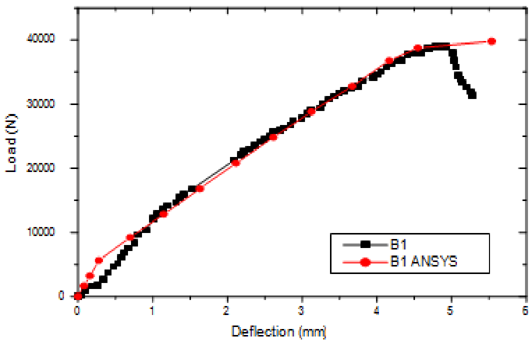
4. Modeling validation

For the validate the model, the results of ultimate load and deflection, obtained of beams, were compared with those of Hawileh et al. (2015). They are presented in tables 2-3. The finite element models' predictions to the load-deflection response are compared with the obtained experimental results. Figures (7-8) shows the predicted and measured load-midspan deflection response for the tested specimens of Groups (1-2). Tables (2-3) provides the predicted and measured data for the ultimate load and corresponding midspan deflection, respectively. It is clear from Figures (6-7) that there is a good correlation between the predicted numerical and experimental results at all phases of loading till beam failure. Thus, the finite element models are capable to precisely predict the load carrying capacity of the tested beams. This validates the accuracy of developed finite element models. Tables (2-3) shows that the difference percentage of the predicted failure loads to that of the obtained experimental data ranged from 2.04% to 7.91% Group1. Furthermore, the percentage difference for the predicted deflection from the experimental results ranged from 5.76% to 12.29% Group1 and, 2.37% to 7.80% (Difference

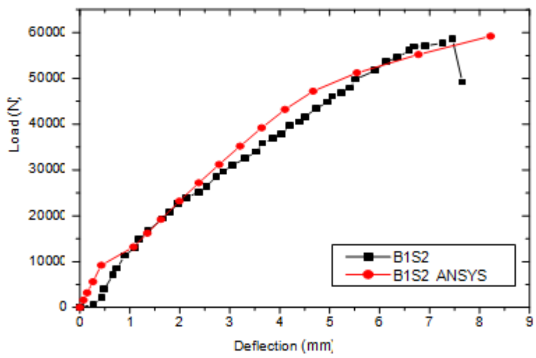
Load) Group2. Furthermore, the percentage difference for the predicted deflection from the experimental results ranged from 0.259% to 5.94% Group2, respectively.

Table. 2. Results between numerical modeling and experimentation Group 1

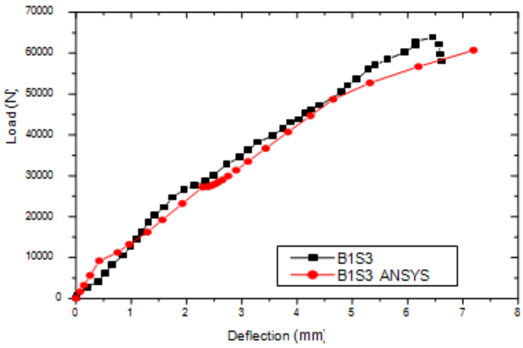
Reinforced concrete beams	Load (N)		% Difference	Ultimate Deflection (mm)		% Difference
	Exp	FE A		Exp	FEA	
B1	38986.4	39800	2.04	4.85	5.53	12.29
B1S2	58541.7	59200	1.11	7.45	8.22	9.36
B1S3	63853.2	60686	4.96	6.45	7.19	10.29
B1S4	65454.5	60679	7.29	5.72	6.35	9.92
B1S5	66461.5	61200	7.91	5.39	5.72	5.76



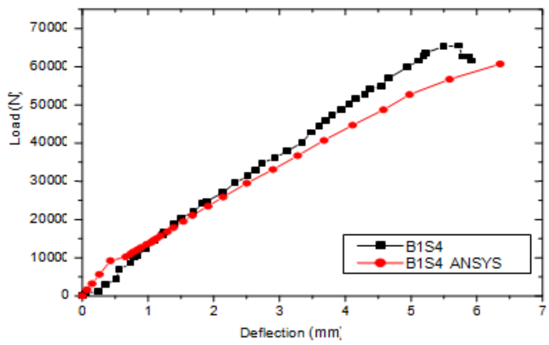
(a): beam B1



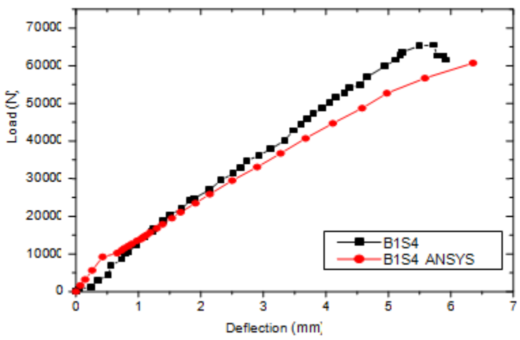
(b): case of 2 CFRP layers



(c): case of 3 CFRP layers



(d): case of 4 CFRP layers

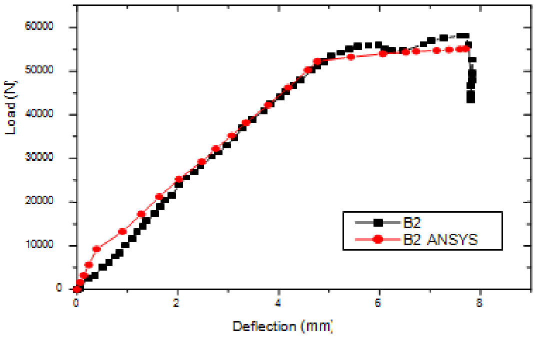


(e): case of 5 CFRP layers

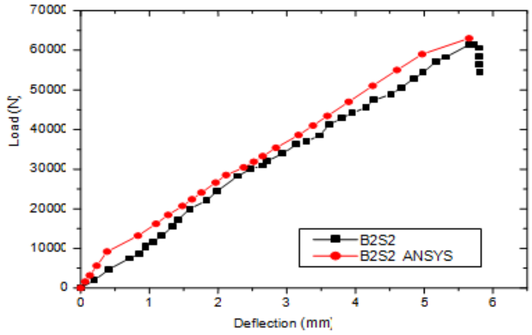
Fig 6. Load- deflection curves for different types of beams.
Comparison between experimental data and numerical results

Table. 3. Results between numerical modelling and experimentation Group 2

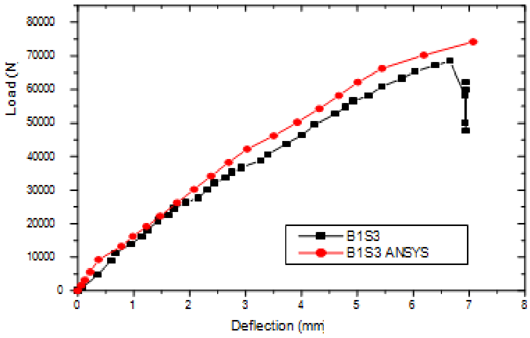
Reinforced concrete beams	Load (N)		% Difference	Ultimate Deflection (mm)		% Difference
	Exp	FE A		Exp	FEA	
B2	58020.2	55061	5.10	7.70	7.72	0.259
B2S2	61501	63000	2.37	5.66	5.65	0.176
B2S3	68410.5	74200	7.80	6.65	7.07	5.94
B2S4	72251.8	69200	4.22	5.22	5.33	2.06



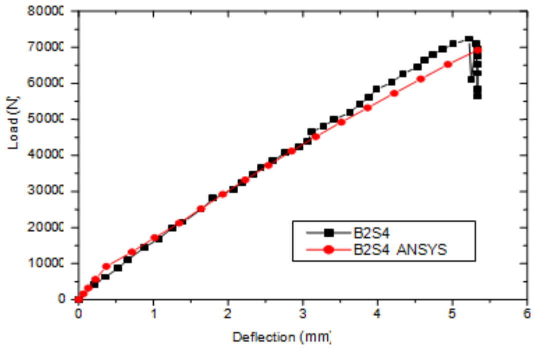
(a): beam B2



(b): case of 2 CFRP layers



(c): case of 3 CFRP layers



(d): case of 4 CFRP layers

Fig 7. Load- deflection curves for different types of beams.

Comparison between experimental data and numerical results

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 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.
- Good correlation is observed between the experimental and finite element values at all stages of loading for the four modeled specimens. It can be concluded that:
- The developed finite element models are valid to predict the response of concrete beams strengthened in flexure with externally bonded of CFRP sheets

- Finite element models can be used for carrying out parametric studies and further investigations to optimize the proposed hybrid system.

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