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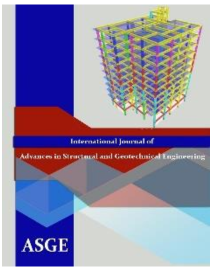

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NUMERICAL SIMULATION OF RC STRENGTHENED BEAMS USING NEAR-SURFACE MOUNTED GFRP BARS

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ABSTRACT

In recent years, the near-surface mounted, NSM, strengthening technique has been used to increase the load carrying capacity of concrete structures. This study focused on the development of a numerical modeling that can predict the behavior of reinforced concrete, RC, beams strengthened with NSM FRP rods. A three dimensional finite element, FE, analysis computer program ANSYS was conducted to obtain the response of the strengthened beams. The eight–node elements, solid 65, were used for the idealization of concrete while the reinforcement steel was idealized by using LINK 180. In this research, A nine different models were developed and implemented added to a control beam in the ANSYS to study effect of different parameters of such as GFRP bars length, tensile steel reinforcement ratios on the collapse behavior as observed from first crack load to fully collapse. The result obtained from the 3D FE analysis used in this study was the load-deflection curves simulating the behavior of reinforced concrete beams. Moreover the results indicated an increase in the first cracking load of reinforced beams by 17% compared with that of the control beam and improved the deflection due to different lengths and tensile reinforcement steel ratios.

Keywords: Reinforced concrete, strengthening, near surface, 3D finite elements.

INTRODUCTION

Through the past twenty years, applications for the use of fiber reinforced polymers, FRP, have been widespread. There were focused of near-surface mounted, NSM, technique of the researchers and structural engineers in the strengthening of slabs and beams and conduct much research to study the behavior and characteristics of structural elements after the strengthened. The NSM technique requires grooves to be cut in the concrete cover then the FRP reinforcement to be bonded to the concrete and, finally, the grooves to be filled with epoxy or cement grout. The NSM FRP rods technique is considered to have some other advantages compared with other strengthening techniques. De Lorenzis and Teng [1] mentioned some of those advantages. Firstly, NSM bars are protected by the concrete cover so they are less exposed to accidental damage like fire. Secondly, much less time and work is needed to fix and install the NSM FRP rods than others techniques.

In most engineering problems, solutions can be obtained explicitly only if regular geometry and simple loads are involved. Numerical methods are therefore required to solve practical problems. Many different numerical techniques have been developed, including finite difference methods, boundary element methods, finite volume methods, spectral methods and mesh less method. Nevertheless, the FEM (Finite Element Method) remains dominant among numerical methods for solving problems in solid mechanics. Majid A. Al-Jurmaa [2] used an ANSYS finite element program to study behavior of four reinforced concrete beams strengthened by CFRP in shear. Parametric studied influence of variation property of CFRP; length, thickness and width of CFRP on the ultimate load capacity and deflection. Faruk Ortes et al. [3] present the development of a numerical modeling that can predict the behavior of reinforced concrete, RC, beams strengthened with NSM CFRP technique subjected to bending loading and the efficiency of various parameters such as CFRP rod size and filling material type is evaluated using prepared models.

Numerical analysis and investigation of the behavior of strengthened beams with three kinds of FRP, carbon fiber bar, aramid fiber bar and glass fiber bar are presented in [4] by Mohamed Husain et al. [4]. Three dimensional finite element beam models are created on the finite element software ANSYS to study the flexural response of the investigated models. Darmansyah Tjitradi et al. [5] studied and discussed about ANSYS modeling of the failure behavior of structural reinforced concrete beam element. The capacity of the bending moment, deformation, stress, strain and fracture patterns are, also, determined that occurs on a single reinforced concrete beams with different types of collapsed mechanisms.

Ahmed Khene et al. [6] through this study the numerical FE simulations were compared with experimental measurement tested by other investigators on beam strengthened with NSM CFRP strips. S. Shabana et al. [7] in part of their study on a numerical investigation utilize the non-linear finite element (FE) modeling was also performed using ANSYS. Progressive continuum damage mechanics along with the fracture concepts were employed to simulate the damage initiation and propagation at the epoxy-concrete interface.

This paper presents numerical analysis and modeling that can predict the behavior of reinforced concrete beams strengthened with NSM GFRP bars technique subjected to bending loading for normal strength concrete, about 35 MPa. The efficiency of various parameters such as length of GFRP bars, concrete cover depth and area of steel reinforcement were investigated on ten different models of RC beams by ANSYS software.

NUMERICAL MODEL

The materials used to prepare the FE model consisted of concrete, steel bars, GFRP bars and epoxy resin. Table (1) presents the physical and mechanical properties of the materials used in the numerical modeling. Details of the modeled specimens in the numerical program are presented in Table (2). For all specimens the beam cross section dimensions are 200mm x300 mm with 2 Φ 8 mm top reinforcements

Table 1: Material properties of the control beam and NSM-GFRP strengthened RC beams

Material	Density (*kg/m3*)	Modulus of elasticity (*MPa*)	Tensile strength (*MPa*)	Poisson ratio
Concrete, 35MPa	2300	29250	2.9	0.2
Steel deformed bar	7850	200000	480	0.3
GFRP bar	2100	56000	750	0.2
Epoxy resin	1160	3780	30	0.35

Table 2: Specimens details

Specimen No.	Bottom steel	GFRP	Length of GFRP	Cover, mm
Beam 1	2-Φ10mm	N/A	N/A	50
Beam 2	2-Φ10mm	Φ12mm	0.8L	50
Beam 3	2-Φ10mm	Φ12mm	0.8L	30
Beam 4	2-Φ10mm	Φ12mm	0.5L	50
Beam 5	2-Φ10mm	Φ12mm	0.5L	30
Beam 6	2-Φ10mm	Φ12mm	0.25L	50
Beam 7	2-Φ10mm	Φ12mm	0.25L	30
Beam 8	4-Φ16mm	Φ12mm	0.8L	50
Beam 9	4-Φ16mm	Φ12mm	0.5L	50
Beam 10	4-Φ16mm	Φ12mm	0.25L	50

Concrete was modeled using ANSYS workbench 19.0 as shown in Fig. 1-A through solid element of SOLID 65. The element is defined by eight nodes having three translation degrees of freedom at each node in the x, y and z directions. The steel reinforcement was defined in the numerical models by LINK 180. A body sizing command was used to mesh all volumes to 40 mm as shown Figure (1-B and C). The beams were tested in four points bending. Details of the modeled strengthened beam illustrating the position of CFRP rod are shown in Figure (2).

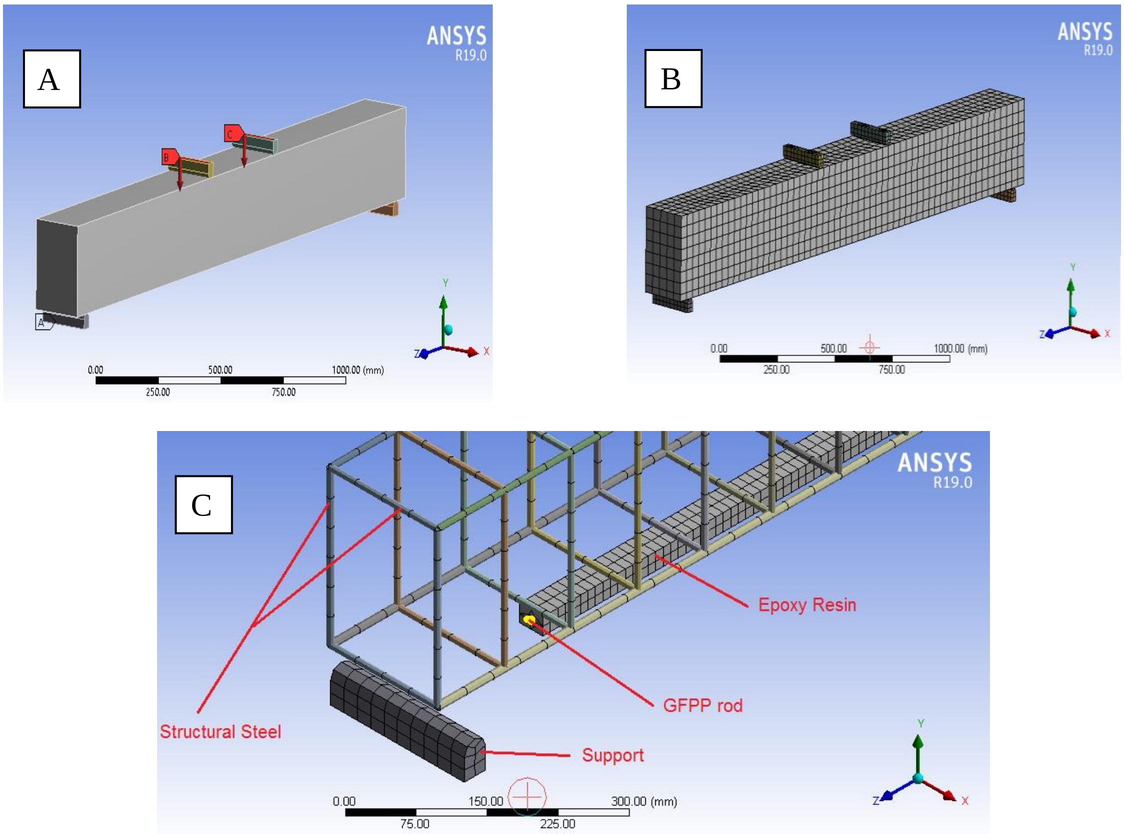

Fig. 1: Patterns of concrete beam, reinforcing steel and FRP and their meshing in ANSYS

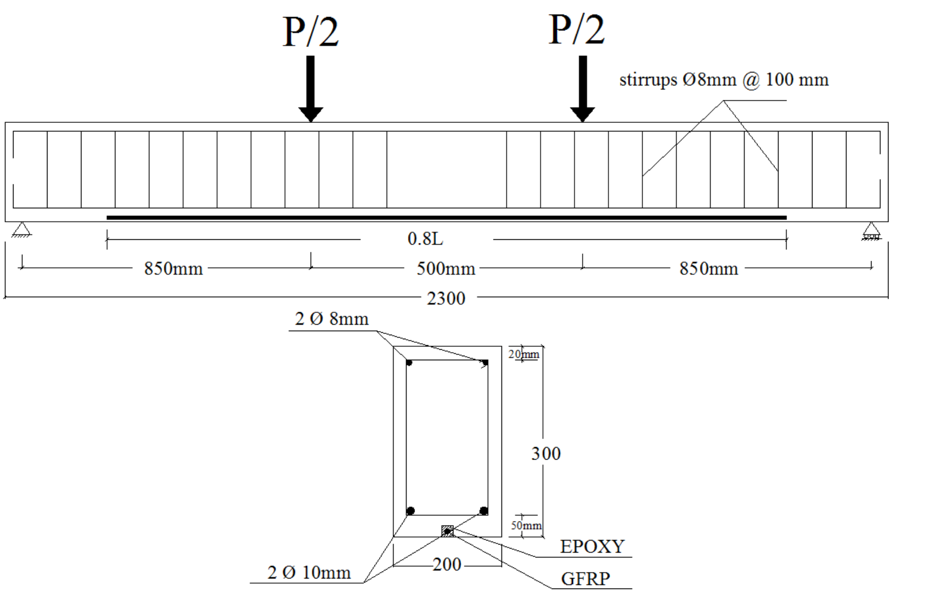

Fig. 2: Detailing of RC strengthened beams

RESULTS AND DISCUSSION

The beams were modeled using ANSYS and the obtained results are presented and discussed subsequently in terms of the observed modes of failure and load-deflection curves All the beams were tested under load control condition.

Loads – Deflection Behavior

Fig.3 shows the numerically deflected pattern shape for control beam, B1, through ANSYS. The numerically deflected pattern shape for the reinforcing steel bars and for the strengthening GFRP bar is given in Fig. 4. The load-deflection results for B1, B2, B4 and B6 are presented in Fig. 5-A. The data for B2, B4 and B6 were plotted again in Fig. 5-B for comparison. We observe the increase of the ultimate load by strengthening for the numerical modeling beams until they reach to failure of the beams. From Fig. 5 A and B, one can notice that the load-deflection relationship starts in linear manner up to first crack load for all beams. The values of first crack load for tested models are presented in Fig. 6. In beam B4 there is increase in the value of first crack load reaching to 20.70 kN by strengthening the beam with GFRP rod having length ratio equal to 0.5 length of beam (0.5L). This result clearly indicates a higher efficiency for strengthening by GFRP rod with length ratio 0.5L compared with other lengths of GFRP bars ratios of 0.25 L and 0.8 L.

As the cracks initiated in each beam, the load-deflection relationship exhibits non-linear behavior up to maximum deflection. The maximum deflection in control beam is equal to 79.73 mm at ultimate load of 35 kN. In B2, B4 and B6 the maximum deflections are equal to 8.98 mm, 7.51mm and 6.90 mm at ultimate loads 83 kN, 65 kN and 54 kN for strengthened beams respectively.

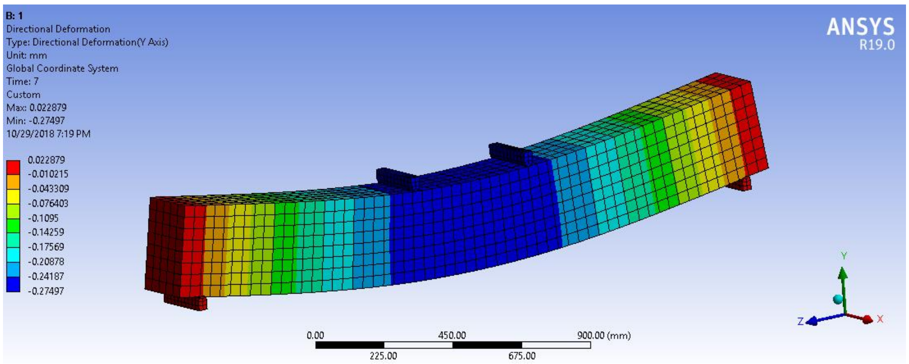

Fig. 3: Deflected pattern of B1 in ANSYS program

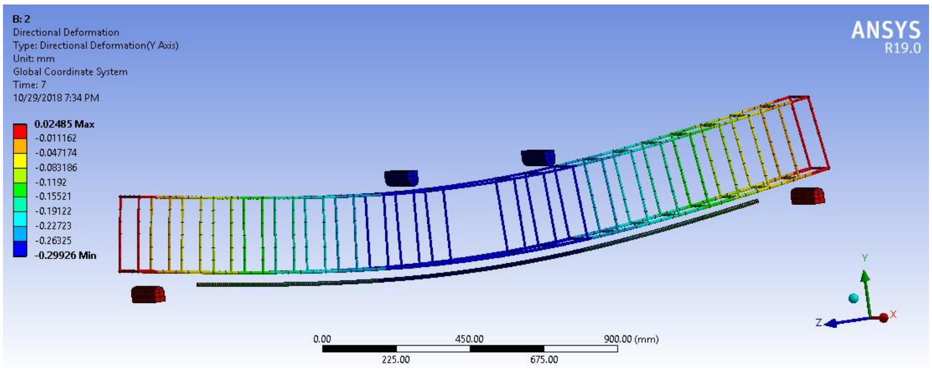

Fig. 4: Deflected pattern of strengthened B2 in ANSYS program

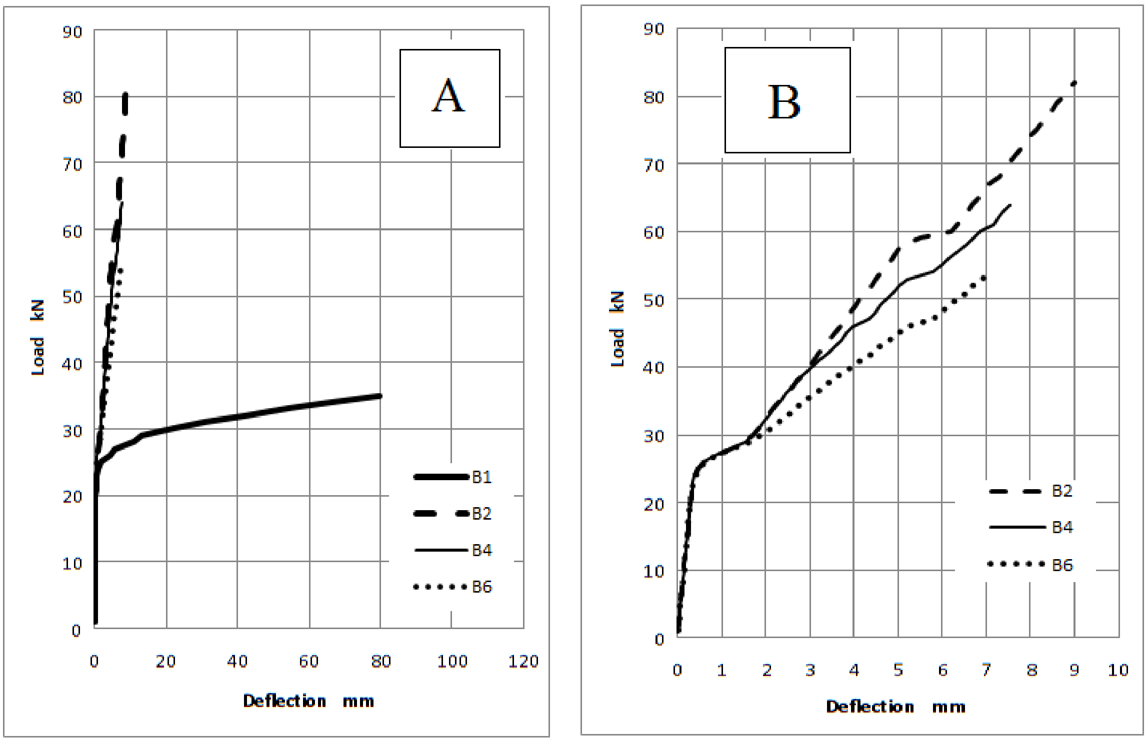

Fig.5: Load-deflection curve at mid – span for B1, B2, B4 and B6

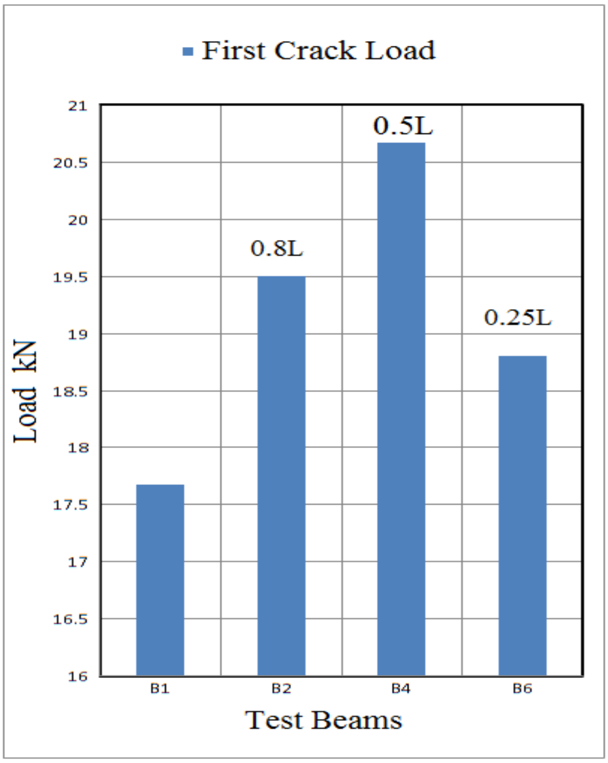

Fig.5: First crack load for tested beams

Effect of Reinforcement Ratio

Variation in tension steel reinforcement ratio of strengthening beams by GFRP bars from $\rho = \rho_{min}$ (2 Φ 10 mm), B2, to $\rho = \rho_{max}$ (4 Φ16 mm), B10, increased the first crack load and decreased the deflection of the strengthened beams. In Fig.7 an improvement in the value of the deflection and an increase in the first cracking load of strengthened beams B8, B9, and B10 are observed. We can observe, also, the response of the modeling simulation to the behavior of concrete beams, cracking load, maximum load, and deflections is controlled by tension steel reinforcement ratio, Under Reinforced /Over Reinforced, and length of GFRP bars.

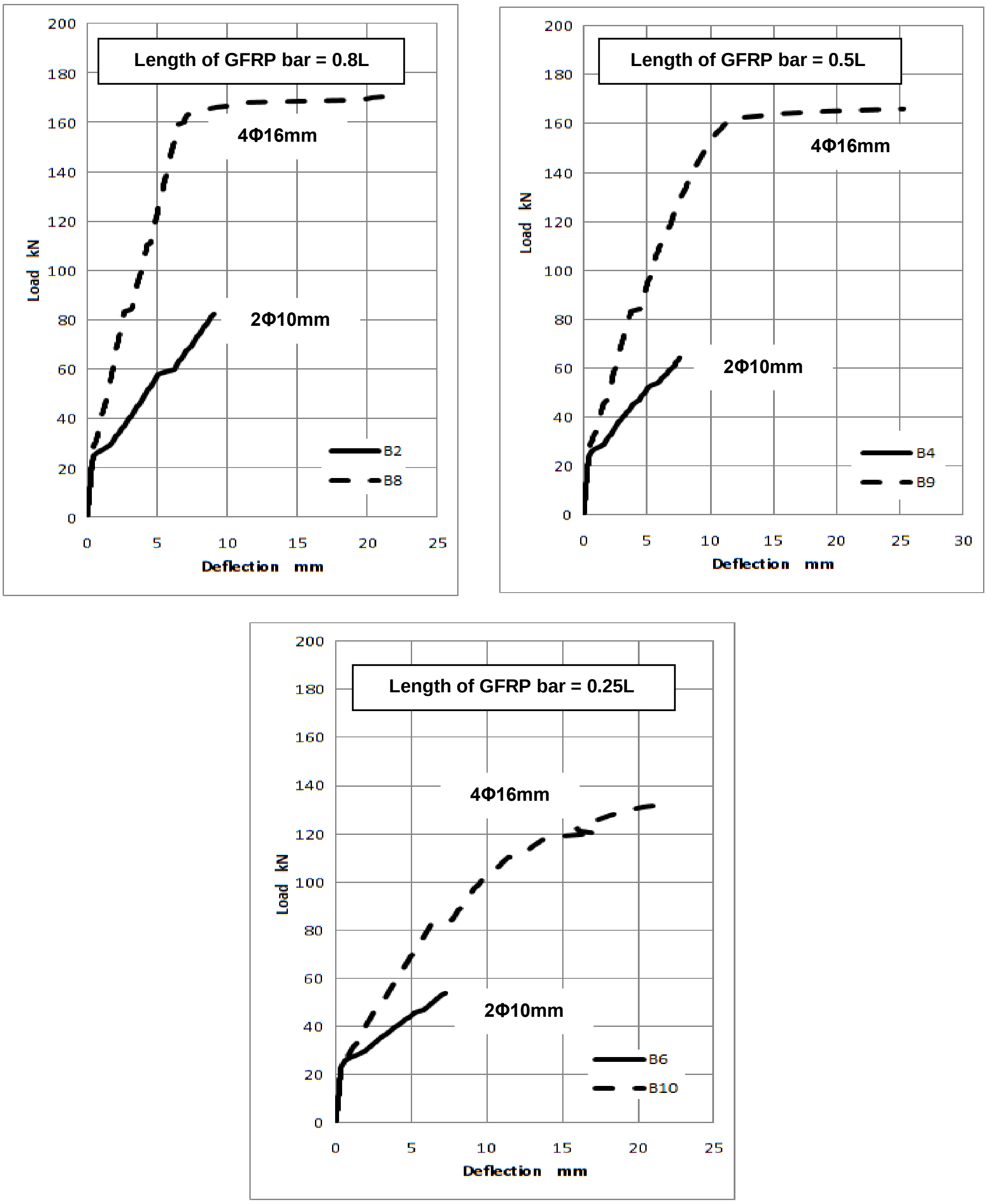

Fig.7: Effect of reinforcement ratio on load - deflection behavior at different lengths of strengthening bar

Effect of Concrete Cover Depth

Fig. 8 shows the effect of concrete cover depth on load deflection behavior of all strengthened beams by GFRP bars having different lengths. It is clear that, at certain applied load, the deflection increases with increasing concrete cover depth. Also, Numerical results show that, the concrete cover depth seems to have little influence on the first crack load of the strengthened beams by NSM GFRP bars as shown in Fig. 8.

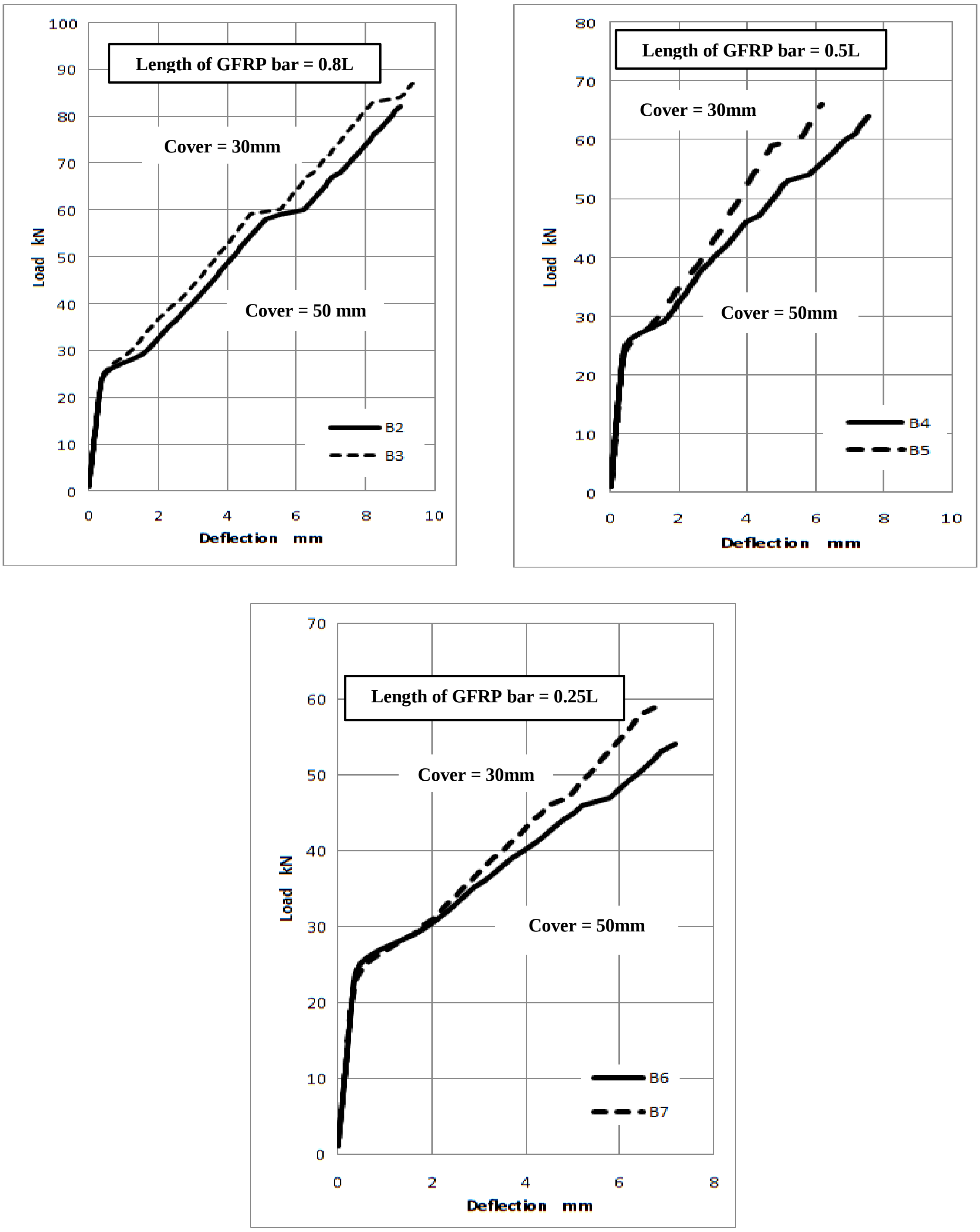

Fig. 8: Effect concrete cover on load - deflection behavior at different lengths of strengthening bar

Distribution of Normal Stress

The data presented in Fig. 9 clearly show the normal stress distribution along the depth at mid span of the simulated control beam and for strengthened beam B2. The sections in Figs. 9a and 9b show numerical pattern of normal stress distribution on width section before and after strengthening at load 12 kN. In Fig.10, there is an increase in the tensile stress in the GFRP bars as compared with the last case. Thus increase step load to first crack load, the tensile stress transfer from concrete to GFRP bar. While in Fig.11, we observe the shift of neutral axis to the upper and the collapse of the concrete in Fig.11a, unlike beam strengthened where the GFRP bars transfers of tensile stresses to increasing flexural strength.

Cracking Patterns

The cracking patterns for the control beam and strengthened beam B2 are shown in Fig. 12 at first crack loads and different load steps. The first crack was observed at load of 17.68 kN for the control beam, compared with 19.5 kN for strengthened beam. At step load of 35 kN we observe the spread of flexural cracks for both of beams. While at the ultimate load of the control beam of 35kN, we observe the crushing of the concrete in the middle of beam compared with strengthened beam at the same load. The spread of flexural cracks with the crashing in little parts with increasing load up to 83 kN, the strengthened beam fails and the concrete is completely crushed.

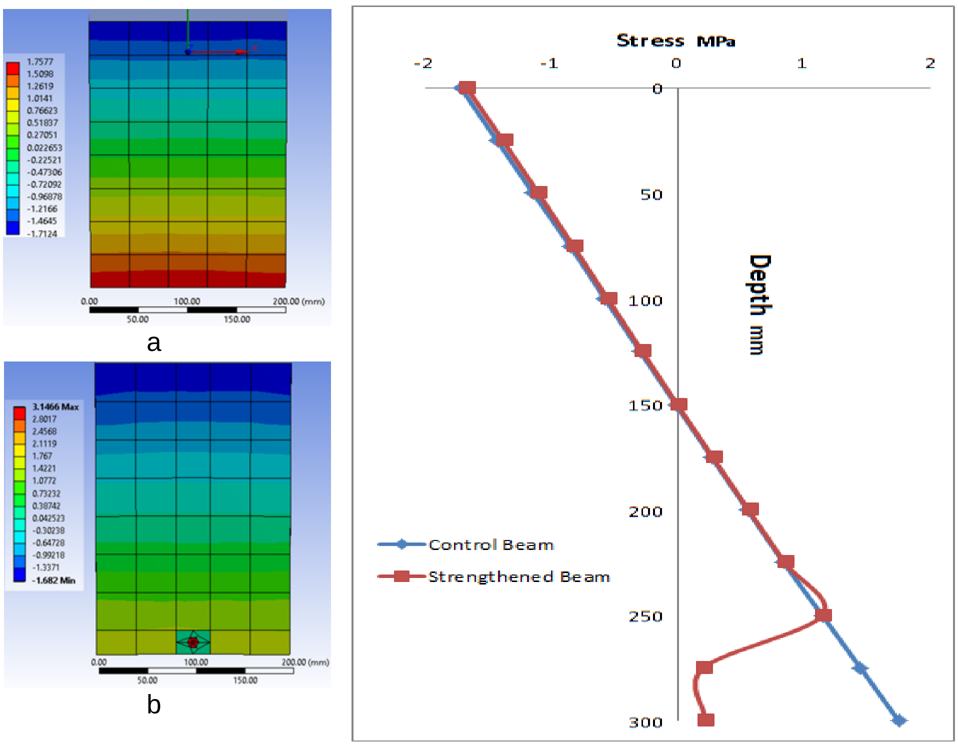

Fig. 9: Distribution of normal stress on cross section at mid span by 12.0 kN

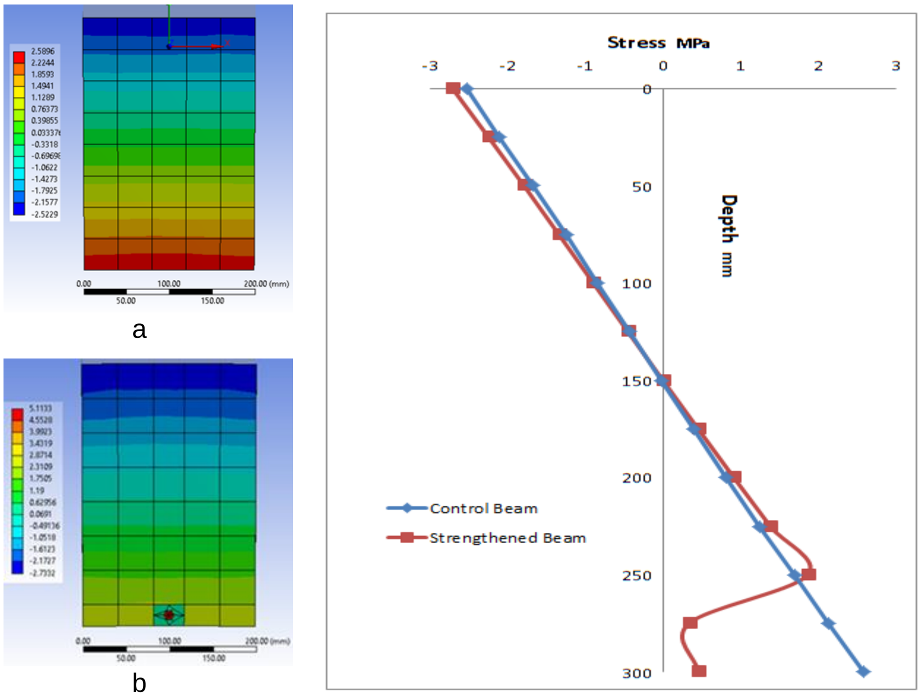

Fig. 10: Distribution of normal stress on cross section at First Crack Loading

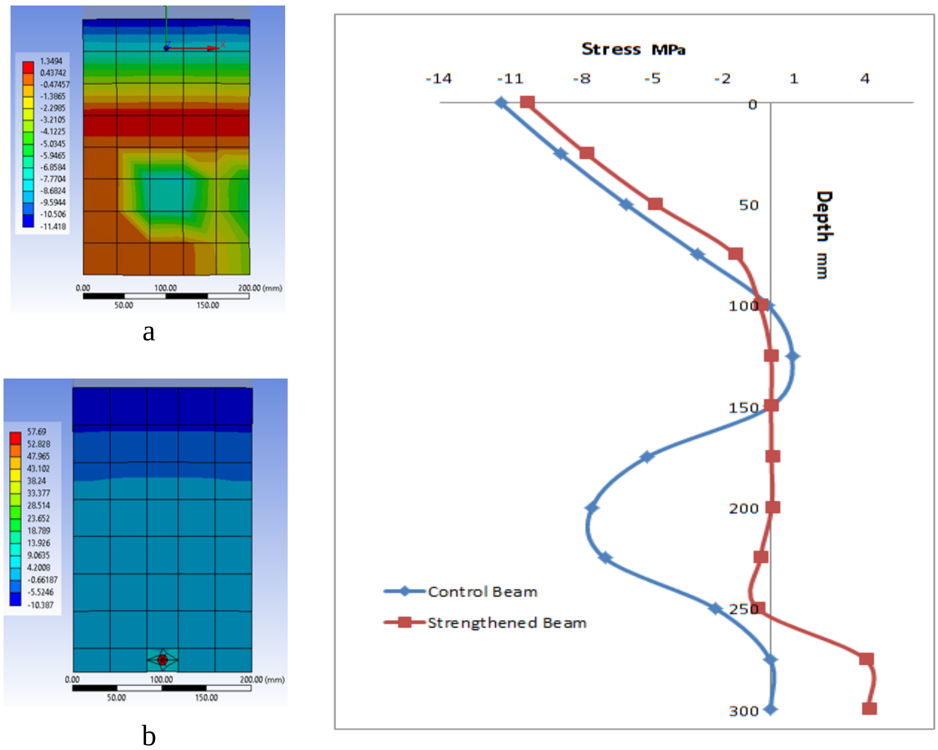

Fig. 11: Distribution of normal stress on cross section at mid span by 35.0 kN

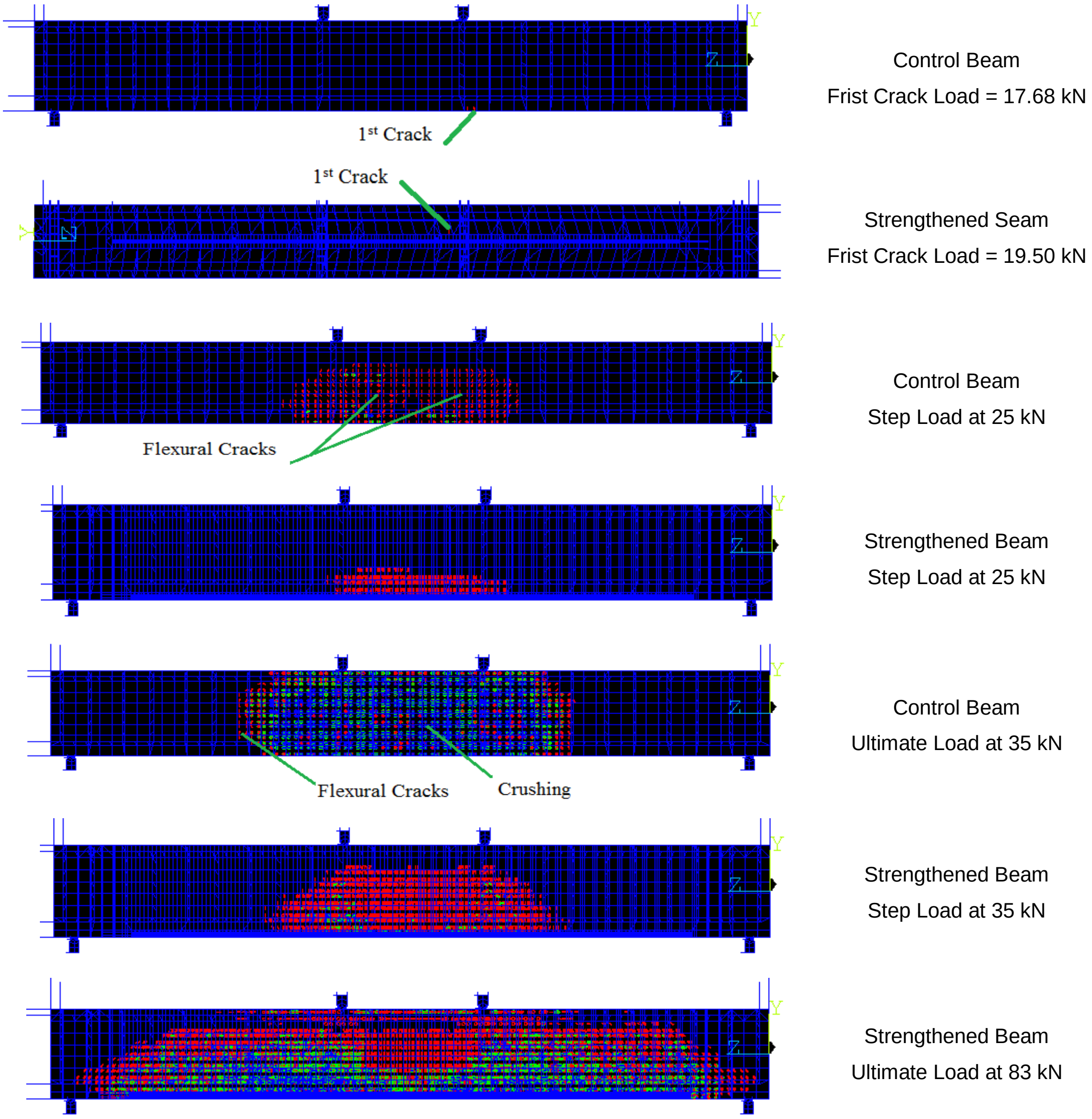

Fig.12: Evaluation of crack patterns with steps load

CONCLUSIONS

In this study, the behavior of the NSM GFRP-strengthened RC beams was investigated numerically. In this scope, nine models in addition to the control beam model were prepared and subjected to four points loading in ANSYS. The main conclusion that can be drawn from the present study is that the GFRP bars of different lengths and reinforcement ratio parameters affected maximum deflection, first cracking loads and stress values along the cross section of RC beams strengthened with NSM GFRP bars.

1. Based on the results obtained from the numerical models, as three different lengths 0.8 L, 0.5L and 0.25L of GFRP for effects on maximum deflections compared to control beam.

2. The best result of first crack load was with strengthening 0.5L of NSM GFRP of increase first crack load value of 6% on others lengths and 17% compare to control beam.
3. Increasing the ratio of tensile steel to improve deflection and first crack load.
4. The B2 given the ultimate load at 83 kN by GFRP bar length at 1800mm compared with B4 and B6 increased by 27.7% and 53.7% respectively
5. The technique of NSM - GFRP strengthened showed the decrease of stresses produced by increased loads at bottom faces and improves value of first crack load.

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