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International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 *Online ISSN 2812-5142*

Special Issue for ICASGE'19

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ASGE Vol. 04 (01), pp. 56-66, 2020

International Conference on Advances in Structural and Geotechnical Engineering

ICASGE'19

25-28 March 2019, Hurghada, Egypt

EFFECT OF DRILLING GEOMETRY ON THE BEHAVIOUR OF RC BEAMS STRENGTHENED WITH CFRP LAMINATES

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ABSTRACT

Recently, strengthening of reinforced concrete (RC) beams subjected to bending moments and shear forces is receiving increased and continuous attention. The bending and shear stresses are considered the main factors affecting on the strength of (RC) beams. Cracks around the opening in the beams occurs because of the stress concentrations generated ahead of openings, that leads to reduce the beam load capacity and stiffness and increase the deflection and crack widths of the beam.

In this work, a numerical program was designed to investigate the behavior of RC beams drilled with opening and strengthened with carbon fiber reinforced polymer (CFRP) sheets. The well-known finite element program named ANSYS with version 19 was used. The parameters which have been studied include the relative dimensions of the opening with respect to the dimensions of the beam. A 3-D finite element analysis with a steady state loading conditions has been considered to model and idealize the problem.

The results in the present work proved that using the suggested shape of strengthening for drilled RC beams improved its load bearing capacity, deflection and the modes of failure of the beams. It was also found that the height of the opening is more effective than its length in reducing the load bearing capacity of the beam.

Keywords: Strengthening; Drilled; CFRP; Finite element; Concrete; RC Beam; Opening.

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INTRODUCTION

Passage of ducts and pipes for heating, air-conditioning, sewage, water supply systems and electricity, telephone, and internet cables through transverse openings in beams is very important for engineers because it enables them with a lot of facilities that increase the design efficiency of building, by decrease the clear height of the story and increase the number of stories. Cracks around the beam opening occurs because of the stress concentrations around openings, that leads to reduce the beam load capacity and stiffness and increase the deflection and crack widths of the beam

A lot of studies have been carried out on (RC) beams with openings to predict the behavior of beams, effect of opening size and shapes, and mechanisms of crack initiation and propagation around these openings. The roles of fiber reinforced polymer (FRP) in strengthening of structural elements were, also, investigated [1,2]. Nie X.F, et al [3] studied a T-section beam with opening in the web and they used local carbon fiber reinforced polymer strengthening to increase the shear capacity of the post-weakening beam to obtain a ductile failure process. Two different dimensions of opening were considered, the first was 300 mm height, and 700 mm Length and the second was 280 mm height, and 800 mm length. Results show that strengthening of RC beams with CFRP increase the load capacity and decrease the deflection of the beams. The results, also, show that the height of the opening is more sensitive than its length and this finding was attributed to the significant effect of the height of the neutral axis that increase the tension area and consequently increase the area of cracks.

Ata El-kareim Shoeib and Ahmed El-sayed Sedawy, [4] studied fifteen RC beams with different opening size. Results in [4] show that the opening decrease the shear load capacity that a very dangerous because of the brittle mode of failure occur. About 35% and 65% from the yield strength of steel bars resist the shear force by the stirrups adjacent to the opening, and must be considered for shear resistance. Most of the cracks occurred around the opening in the shear zone and in the direction of the compression zone. Some cracks occur in moment zone and increased in length with increasing load to the failure of the beam.

Deep beams with variable opening dimension and strengthening with CFRP were studied in [5]. Results of this work show that the failure modes depend on the opening size. For the unstrengthened beam, the shear strength reduction was about 21% when the opening size increase from a/h= 0.3 to 0.4 and the shear strength reduction was about 51% when the opening size increase from a/h= 0.3 to 0.5. After strengthening RC beams with CFRP, the load capacity increase about 65 – 71 %. Strengthening of RC beams with opening was carried out using three types of CFRP schemes, first CFRP inside the opening, second CFRP around the opening, and third CFRP both inside and around the opening[6]. Results show that CFRP in both inside and around the opening is more effective than that around the opening and CFRP around the opening is more effective than that inside the opening.

Subhajit Mondal, et al, [7], studied nine beams with different opening dimensions. The results show that there are two type of FRP failure, the first mode was FRP ruptures and the second mode was debonding of FRP from concrete surface. To avoid debonding of FRP, FRP was wrapped around the opening keeping 80 mm from the opening side at least. The deflection increased about 50% and the load capacity decreased about 50% because of the opening existing. On the other hand, load capacity increased about 25% by strengthening the beam with FRP. The effect of small opening with circular shape on the shear and flexural behavior and ultimate capacity of beams for normal and high strength concrete were presented in [8]. Nine beams for normal strength concrete and five beams for high strength concrete have been studied. The results in [8] show that the increase in opening diameter reduced the ultimate strength of the beam. Deflection, strain and cracks increased when the load increased up to failure.

M S Latha and B M Naveen Kumar [9] studied RC Beams with different shapes and sizes openings using ANSYS program version 10.0. Results in [9] show that there is no effect on the behavior of the opening beam with circular opening with diameter about 24% of the depth of the beam. There is small effect on the behavior of the beam when the compression chord depth is more than the compressive stress block depth for the circular opening with diameter less than 44% of the beam depth. Five large rectangular beams damaged due to shear force strengthened and repaired with CFRP in [10]. The results show that strengthening and repair of damaged beams increase the stiffness of the beams and reduced deflection compared to the control beams. The load deflection curve show that the strengthened beams without steel stirrups have a very brittle failure by a sudden drop in the resisting load. The Ultimate Shear Capacity after strengthening of beams increased about 100%.

In this work, we study numerically the effect of openings on the structural behavior of strengthened and un-strengthened RC beams. Moreover, an evaluation of the present strengthening method is also given.

IDEALIZATION

A finite element analysis (FEA) using well known ANSYS computer program (Version 19.0) has been used to simulate and idealize the present model with three dimensional analyses under steady state loading conditions. Finite element models for reinforced concrete structures have generally been based on mesh discretization of a continuous domain into a set of discrete subdomains, usually called elements representing the concrete and the steel reinforcement. Currently, three alternative techniques are mainly used for modeling reinforcement in a three-dimensional finite element model of a concrete structure, the discrete model, the embedded model, and the smeared model. In the present analysis, a discrete model concept was used. Concrete was modeled using the solid element SOLID65 with 3-D 8-node solid elements, Fig. 1, while steel reinforcement was modeled using A LINK180 elements, Fig. 2.

The 28-day ultimate compressive strength of the idealized concrete in the present work was 30 MPa while the tensile strength was 4 MPa. The isotropic elastic constants were 29250 MPa for modulus of elasticity and 0.2 for Poisson's ratio. The steady state stress-strain behavior of concrete is given in Fig. 3. The behavior of the used reinforcing steel was considered as bilinear elastic-plastic condition with elastic modulus of 200000 MPa and post elastic regime of 540 MPa. The Poisson's ratio for steel was taken 0.3. The tensile yield strength of main steel was 350 MPa while the tensile yield strength for stirrup steel was 240 MPa. The elastic constants and mechanical properties of the idealized CFRP are given in Table 1.

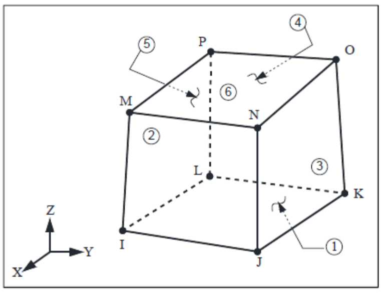


Fig. 1 SOLID65 concrete element

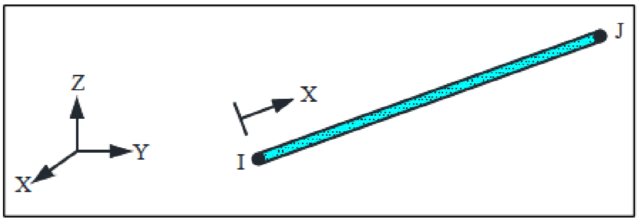


Fig.2 LINK 180 steel reinforcing element

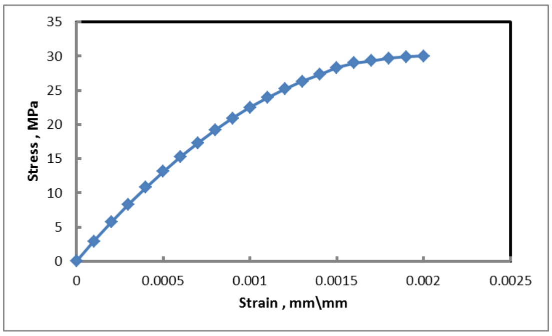


Fig. 3 Stress – Strain Curve for concrete

Table 1 Elastic constants of CFRP

	CFRP with thickness 1 mm for one layer								
	E_x (MPa)	E_y (MPa)	E_z (MPa)	Pr_{xy}	Pr_{yz}	Pr_{xz}	G_{xy} (MPa)	G_{yz} (MPa)	G_{xz} (MPa)
one layer	60114	4675	4675	0.22	0.3	0.22	3166	1803	3166
two layers	120228	9350	9350	0.22	0.3	0.22	6332	3606	6332
three layers	180342	14025	14025	0.22	0.3	0.22	9498	5409	9498

Where;

E = Modulus of elasticity of CFRP

Pr = Poission's ratio of CFRP

G = Shear modulus of CFRP

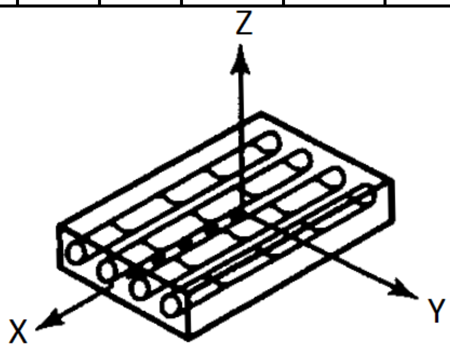


Fig. 4 CFRP directions

NUMERICAL PROGRAM

Five models were designed and idealized in this work for RC beam with relative dimensions and steel reinforcement percent, as shown in Fig. 5. The first model consider for control beam without opening. The other four models are as follows: two of them for opening beams and other two for strengthened beams as given in Table 2.

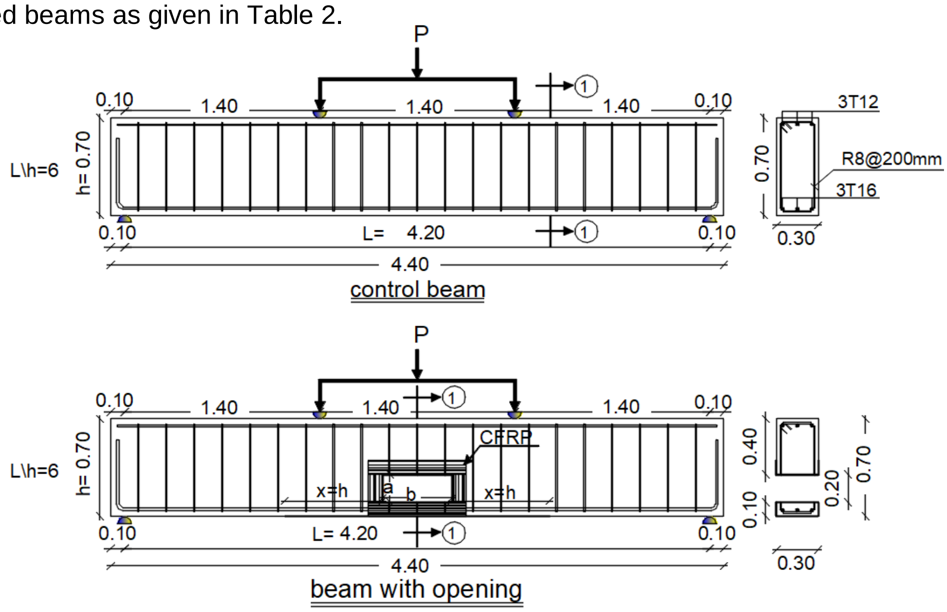


Fig. 5 Schemes for control RC beam and RC beam with opening

Table 2 Numerical Program

Model No.	1	2	3	4	5
Opening dimensions., mm	0	200 X 900	150 X 700	200 X 900	150 X 700
Relative dimensions	0	b/L = 0.21	a/h = 0.21	b/L = 0.21	a/h = 0.21
CFRP strengthening	NO	NO	NO	Yes	Yes

Control beam was idealized without opening and CFRP strengthening. The beam dimensions are 300 mm breadth, 700 mm depth and 4400 mm length. Fig.6 shows the generated mesh through 3-D analysis within the present finite element program for control RC beam, RC beam with opening and CFRP strengthening for drilled RC beam.

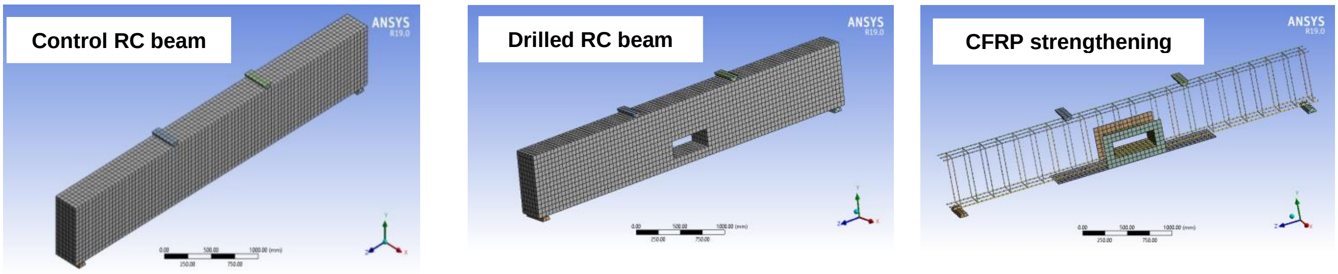


Fig. 6 Generated mesh for control RC beam, RC beam with opening and CFRP strengthening

RESULTS AND DISCUSSION

Behavior of Control RC Beam:

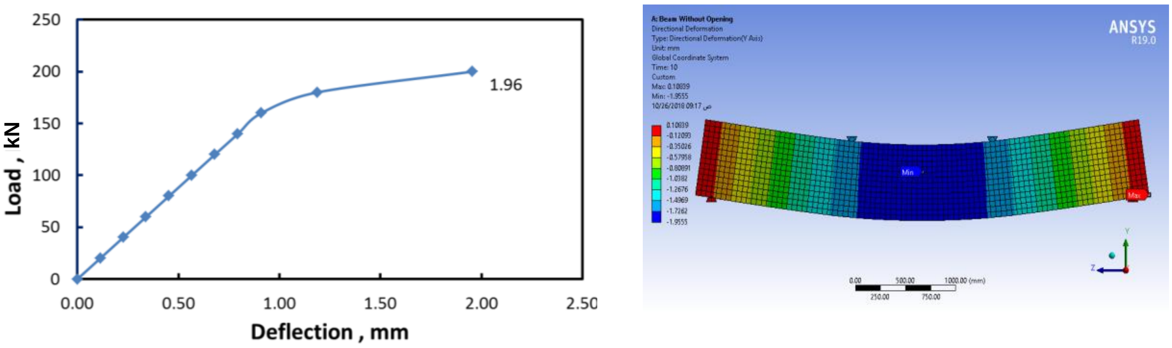


Fig. 7 Load - deflection of control RC beam and its pattern in numerical analysis

Fig. 7 presents load-deflection behavior and its pattern through numerical analysis for the control RC beam. The behavior starts linear up to the 1st crack load which equals to 145 kN, after that the behavior showed nonlinear relationship up to the beam failure load, which equals to 200 kN. The maximum deflection was 1.96 mm while the deflection at first crack was 0.8 mm. Four sections locations were chosen, as seen in Fig. 8, to evaluate the behavior of normal stress and strain along these sections for control beam.

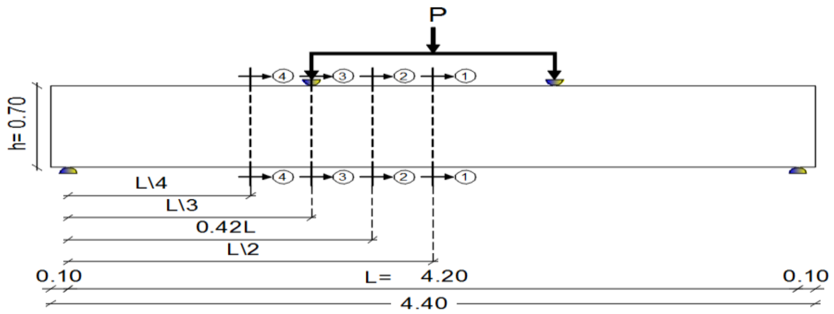


Fig. 8 Locations of the selected sections

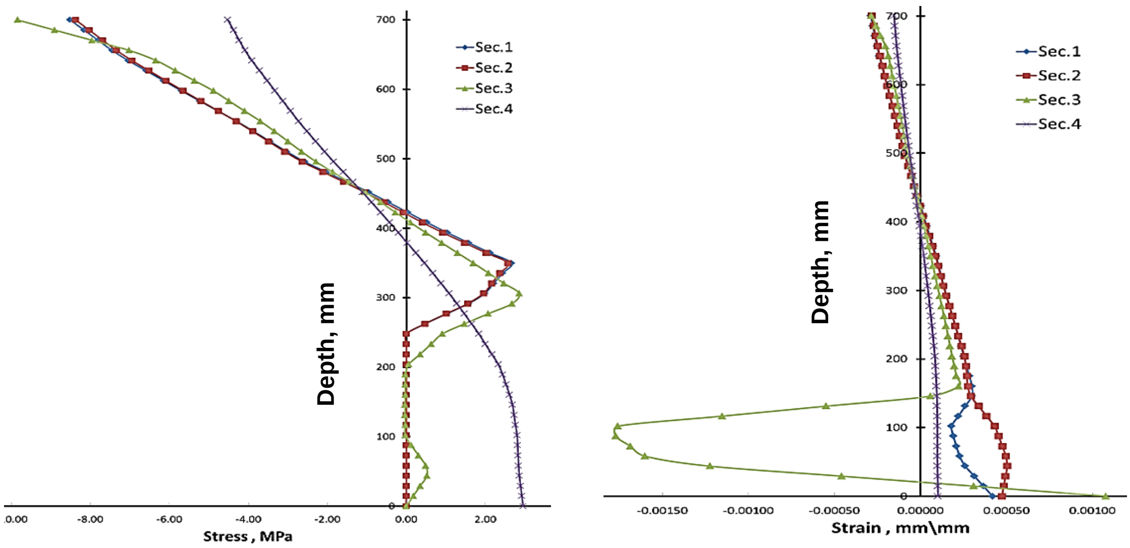


Fig. 9 Distribution of normal stress and normal strain for the selected sections in control RC beam

The data presented in Fig. 9 clearly show the behavior of normal stress and normal strain distribution along the beam depth at the selected four sections. The distribution was captured at the ultimate load of the beam. Through this Figure one can notice the location of the neutral axis for each section. At section 1 the neutral axis height is 435 mm, at section 2, the neutral axis height is 415 mm, at section 3, the neutral axis height is 420 mm, and at section 4, the neutral axis height is 380 mm. These results reflect the location and situation of each section with respect to cracking condition stat.

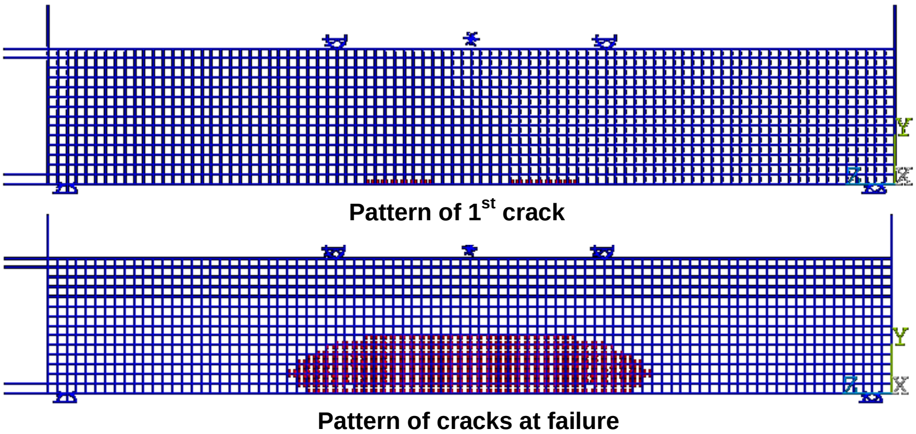


Fig. 10 Patterns of 1st crack and the cracks at failure for control RC beam

The patterns of the 1st crack and the cracks at the beam failure are shown in Fig. 10. The 1st crack start in the tension zone stresses. The cracks still propagated in this area up to the beam failure; finally the beam failure mode was tension failure. Similar results were found in [1, 2, 6, and 9].

Behavior of RC Beams with Opening:

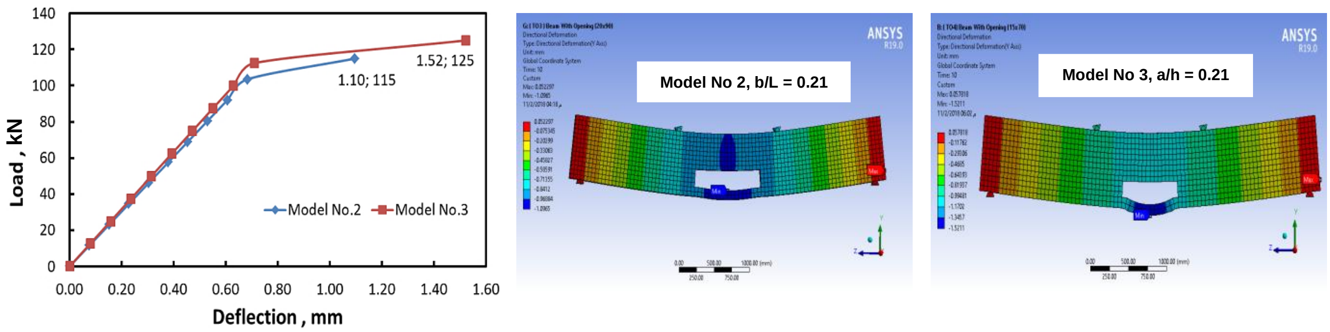


Fig. 11 Load - deflection of RC beams with opening and their patterns in numerical analysis

Load-deflection behavior and its pattern through numerical analysis for the RC beam with opening are given in Fig. 11. The behavior starts in linear pattern up to the 1st crack loads for the two models. The 1st crack load for model 2, b/L = 0.21, equals 95 kN while it is equal to 105 kN for model 3, a/h = 0.21. The relationship between load and deflection for two models exhibits nonlinear behavior after the first cracking up to the failure load. The beam failure load and maximum deflection for model 2 are 115 kN and 1.1 mm respectively. On the other hand, the beam failure load and maximum deflection for model 3 are 125 kN and 1.52 mm respectively. These results proved that the intensive effect of drilling height on the deformation behavior of RC beams containing openings. Also, four sections locations were chosen, as seen in Fig. 8, to evaluate the behavior of normal stress and strain along these sections for the two beams.

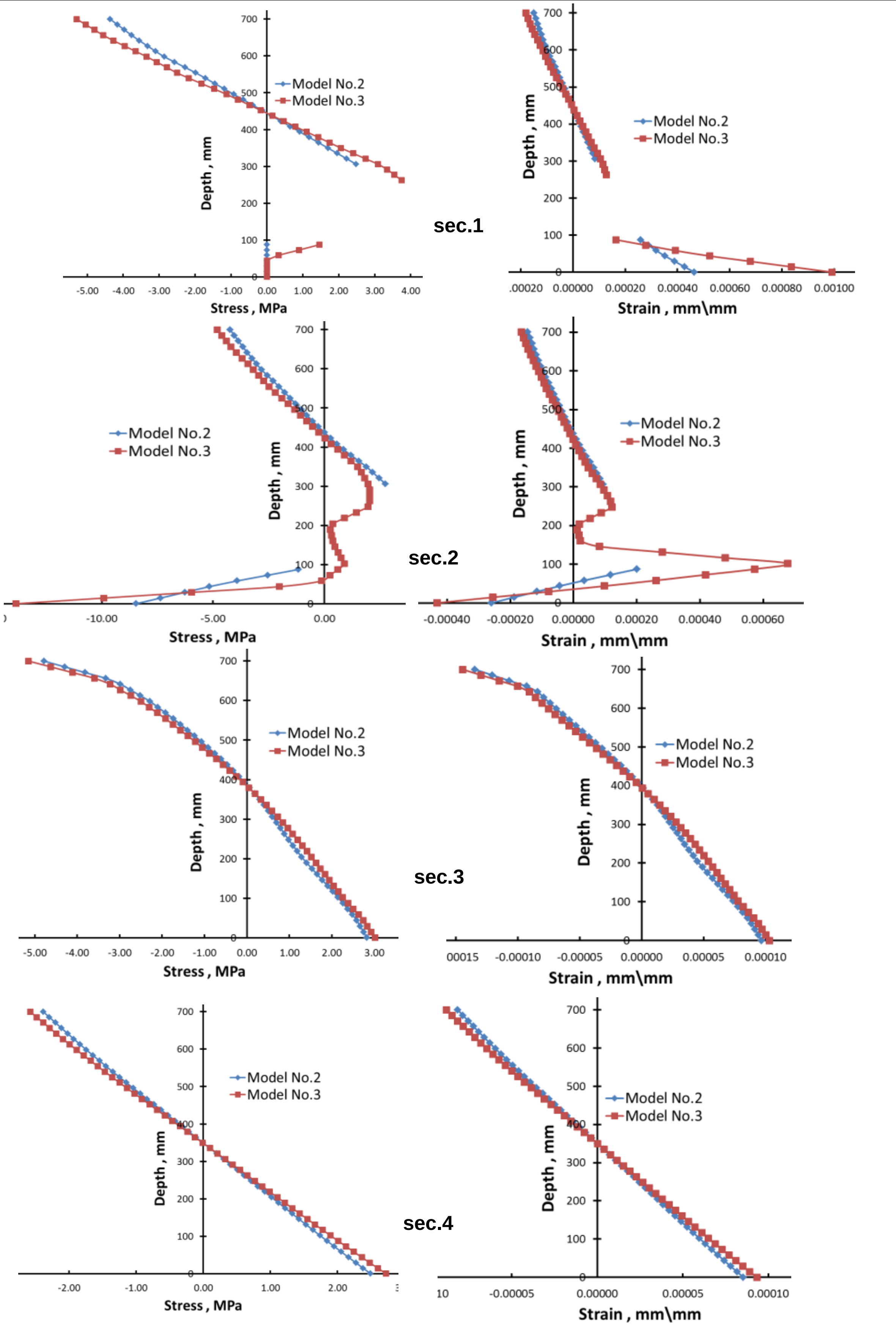
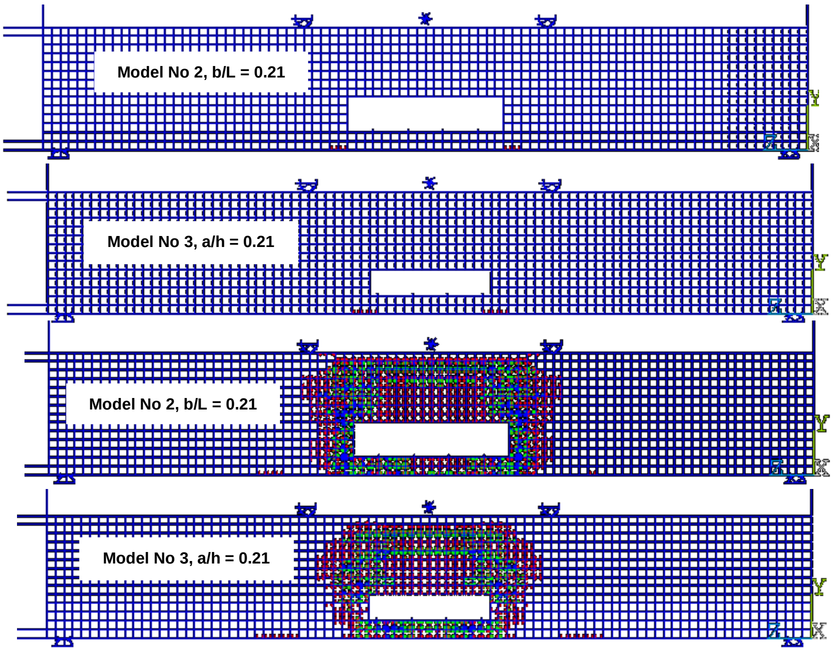


Fig. 12 Distribution of normal stress and normal strain for the selected sections in drilled RC beam

The distribution of normal stress and normal strain along the beam depth at the selected four sections are given in Fig. 12 for the RC beam with openings. The distribution was captured at the ultimate load of the model no. 2 and model no. 3. From the data in these Figures one can notice the location of the neutral axis for each section. At section 1 the neutral axis height is 445 mm for the two models. At section 2, the neutral axis heights are 438 mm for model no. 2 and 425 mm for model no. 3. At section 3, the neutral axis height is 385 mm for the two models and at section 4; the neutral axis height is 350 mm for the two models. These results, also, reflect the location and situation of each section with respect to cracking condition state. Moreover, these results clearly approved the intensive effect of drilling height on stress-strain distribution along beam sections.



1st crack for model no.2 and 3

Cracks at failure model no.2 and 3

Fig. 13 Patterns of 1st crack and the cracks at failure for drilled RC beam, model No.2 and 3

The patterns of the 1st crack and the cracks at the beam failure are shown in Fig. 13. The 1st crack start in the tension zone stresses. The cracks still propagated in this area up to the beam failure**.**

Behavior of RC Beams with Opening and Strengthened by CFRP:

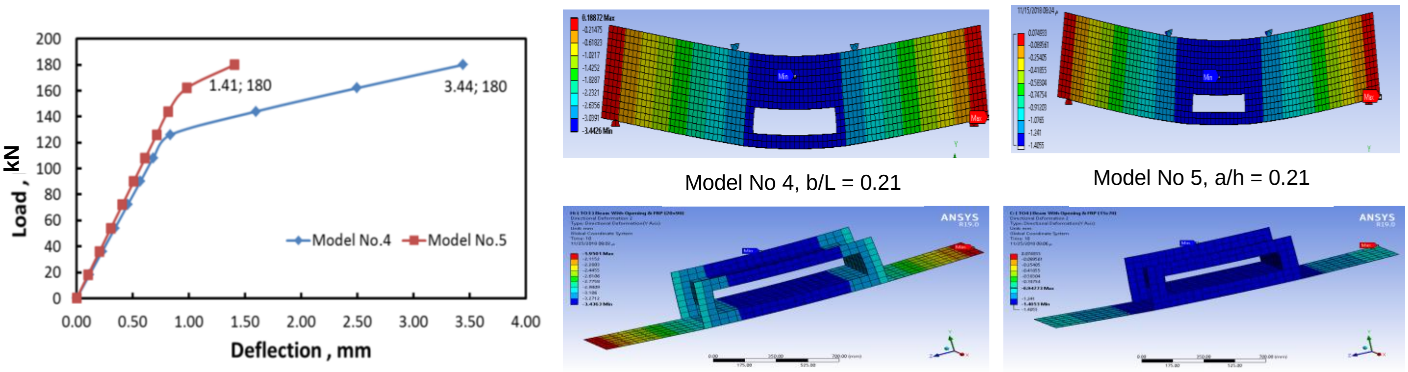


Fig. 14 Load deflections of RC beams with opening and CFRP and their patterns through numerical analysis

Fig. 14 shows the load-deflection behavior and its patterns in numerical analysis for the RC beam with opening and CFRP, model No. 4 and 5. The behavior starts in linear pattern up to the 1st crack loads for the two models. For Model No.4, b/L= 0.21, the 1st crack load equals to 120 kN. While For

Model No.5, a/h = 0.21 the 1st crack load equals to 125 kN. After that the relationship between the load and deflection for two models exhibits nonlinear behavior up to the failure loads. The maximum deflections are 3.44 and 1.41 mm at load 115 and 180 kN for Model No.4 and 5 respectively. These results proved that the intensive effect of drilling height on the deformation behavior of RC beams containing openings.

By comparing the load deflection behavior for the five models in this work one can notice that, at load equal to 115 KN, the deflections are 1.10 mm for model No. 2, 0.73 mm for model No. 3, 0.78 mm for model No. 4, and 0.68 mm for model No. 5. These results illustrated that as the drilling height increase the beam showed more deflection, model No. 2. In case of ultimate loads, the ultimate load for control beam is 200 kN. While the ultimate load for model No. 2 is 115 kN, and 125 kN. for model No. 3. As the beams were strengthened by CFRP, model No. 4 and 5, the ultimate load becomes 180 kN for model No.4 and 5. These results clearly indicated that the strengthening with CFRP decreases the deflection with 29% for model No. 2, and 6% for model No. 3, and increases the load bearing capacity to about 90% of that control beam.

The distribution of normal stress and normal strain along the beam depth at the selected four sections for the RC beam with opening and CFRP are given in Fig. 15 for model No. 4 and model No. 5. The distribution was captured at the ultimate load of each beam. The location of the neutral axis for each section can be noticed from the data in these Figures. At section 1, the neutral axis heights are 535 mm for model No. 4 and 430 mm for model No. 5. At section 2, the neutral axis heights are 535 mm for model No. 4 and 420 mm for model No. 5. At section 3, the neutral axis heights are 455 mm for model No. 4 and 380 mm for model No. 5. At section 4, the neutral axis heights are 357 mm for model No. 4 and 346 mm for model No. 5.

The patterns of the 1st crack and the cracks at the beams failure are shown in Fig. 16. The 1st crack start in the tension zone stresses. The cracks still propagated in this area up to the beam failure; finally the beam failure mode was tension failure. Similar results were found in [1, 2, 6, and 9]. It can be seen, clearly, that the amount of cracks in model No. 4 is more than that of model No. 5 which proved that the drilling height is more sensitive than the drilling length when the RC beam drilled in tension zone. Moreover, The CFRP is a well technique for strengthening the drilled RC beams. This may be attributed to the difference in the strain rate and stiffness between CFRP and RC beam that prevent the deflection of the RC beam which reduces the amount of cracks and increases the load beam capacity.

CONCLOUSIONS

Based on the numerical results of the RC beams in this work, the following conclusions can be drawn:

1. Drilling RC beams leads to stress concentration occurs around the opening and the cracks starts around the opening.
2. When the opening length and height increased, the ultimate load capacity decreased, but the opening height is more effective than the opening length on the beam capacity
3. Strengthening RC beams with CFRP increase the ultimate load carrying capacity to 90% of the ultimate load capacity of the original beam.
4. The strengthening with CFRP decreases the deflection with 29% for model No. 2, and 6% for model No. 3.

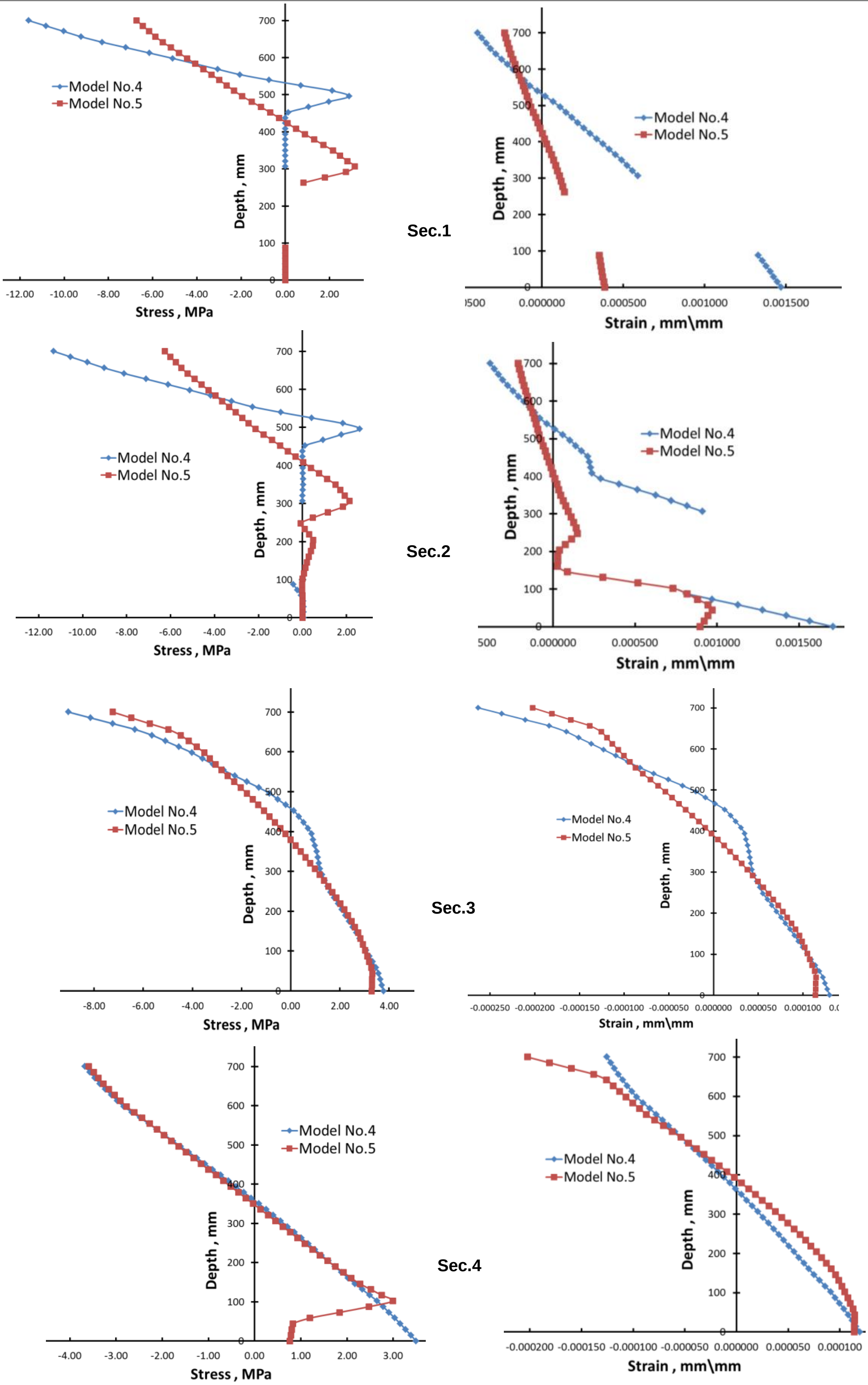
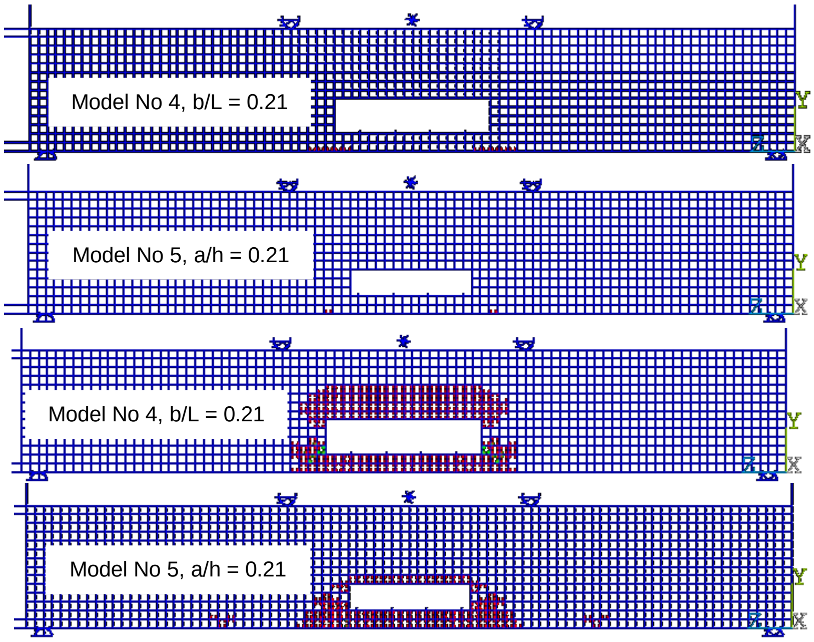


Fig. 15 Distribution of normal stress and normal strain for the selected sections in drilled RC beam



1st crack for model no.4 and 5

cracks at failure for model no.4 and 5

Fig. 16 Patterns of 1st crack and cracks at failure for RC beam model no.4 and 5

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