International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-3, Issue-11, November 2017
ISSN: 2395-3470
www.ijseas.com

Finite Element Analysis on the behavior of Strengthened RC Shallow T- Beams with Large Openings at Shear Zone Using CFRP and BFRP sheets

Hamdy K. Shehab El-Din [1], Mohamed M. Husain [2], Mahmoud A. Khater [3], Mahmoud Y. A. Zaghlal [4]
[1-4] Faculty of Engineering, Zagazig University, Zagazig, Egypt

Abstract
Finite Element Modeling FEM using ANSYS v.15 program was performed to explore the efficiency of strengthening using carbon Fiber Reinforced Polymer CFRP and basalt Fiber Reinforced Polymer BFRP sheets for RC T-beams having shear zone large rectangular opening. Four strengthening schemes were discussed. It was concluded that introducing CFRP or BFRP sheets resulted in great increase in load carrying capacity and stiffness of the strengthened beams. Crack patterns and failure loads for the tested models were compared with experimental study carried out by the authors and FEM results were in good agreement with experimental results.
Keywords: *CFRP, BFRP, T-beams, Opening, FEM*

1. Introduction

Transverse openings through RC are used sometimes to pass water and sewage pipes, air conditioning ducts and electricity wires in our buildings as shown in fig. 1. However creating an opening in the beam results in stress concentration around opening and degrades its load carrying capacity if not reinforced [1-6, 30]. Choosing the location of web opening in mid span of the beam where the shear stresses are very low can solve this problem and reduce the effect on the total behavior of the beam [7], but sometimes we need to open in the shear zone near the columns.

The application of Fiber Reinforced Polymers FRP as external reinforcement to strengthen RC beams has been widely used [15–18]. The well-known types of FRP in the concrete strengthening is carbon, aramid or glass fibers [16]. Basalt fibers have strength higher than GFRP and lower than CFRP with very good durability and fire resistance [35], however, they have not the same popularity and not included in most design codes. Strengthening of RC shallow Rectangular beams containing web openings in shear zone using External Bonded Reinforcement EBR FRP or Steel plates was discussed by many researchers [3, 19-23, 25-27, and 31]. Strengthening proved to be effective in increasing beam capacity and limiting cracking at the opening corners. Strengthening of deep beams with transverse square opening using FRP composites also was studied [24,32] and % increase in shear capacity was in the range of 35–73%. An experimental investigation on the performance of RC T-beams with and without small circular opening strengthened in shear using mechanically anchored bi-directional U-wrap GFRP fabrics was also studied [28, 33] .The use of anchorage system eliminated the debonding of the GFRP sheet, and consequently results in a better utilization of the full capacity.

Fig. 1 Photograph for the garage of cultural center in Port Said City, Egypt

Behavior of RC rectangular beams with large opening under pure torsion moment and strengthened using CFRP sheets was also discussed [29]. It is observed from literature that large number of researchers studied the strengthening of rectangular beams with openings but very few studies are found on strengthening of shallow T-beams.

The main Objectives of this study are to investigate using FEM the effectiveness of strengthening using CFRP and BFRP sheets for T-beams containing large rectangular web openings in shear zone with different schemes, and compare the results with experimental results carried out by the authors in a companion paper.

2. Finite element analysis

In this study, a three dimensional nonlinear finite element analysis was carried out using the finite element package, ANSYS v.15.

2.1 Analysis models

The FE analysis includes seven reinforced concrete shallow T-beams. They were divided into two main groups. The first group consists of two beams, of which, one solid control beam and one beam with non-strengthened rectangular opening at shear zone. The second group includes five T-beams with web openings at critical shear zone, of which, four were strengthened by CFRP sheets with different schemes and one was strengthened using BFRP sheets with the maximum efficient scheme from the previous four beams. These beam models were tested by the authors (companion paper) experimentally. Dimensions and reinforcement details of tested beams are shown in fig. 2 and fig. 3. Average compressive strength of concrete cubes at 28 days f_{cu} is 44 MPa. Average yield stress of steel bars is 550 MPa for 10mm and 12mm bars and 340 MPa for 6mm bars. The commercial name for carbon fiber is sikawrap-230 from SIKA EGYPT for construction chemicals[37]. The ultimate stress, ultimate strain, and modulus of elasticity for a cured laminate of CFRP sheet were 360 MPa, and 1.1%, 33.5 GPa, respectively from experiment. The commercial name for the basalt fiber is BJ30 from Anjie Company, CHINA. The ultimate stress, ultimate strain, and modulus of elasticity of a cured laminate of this BFRP sheet were 171 MPa, 1.9%, and 9.0 GPa, respectively from experiment.

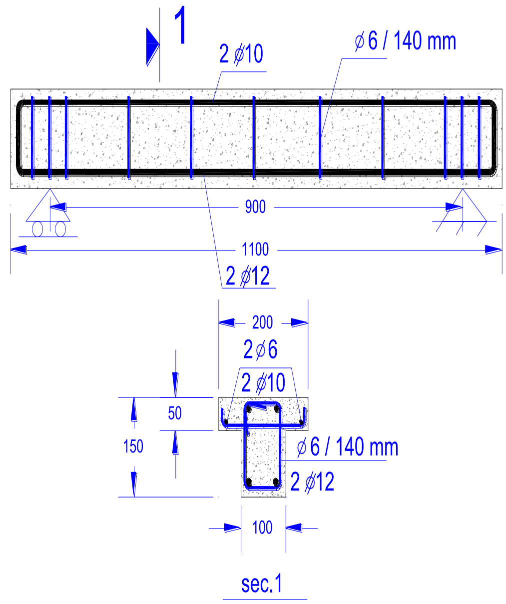

Fig. 2 Reinforcement of solid beam (dimensions are in mm)

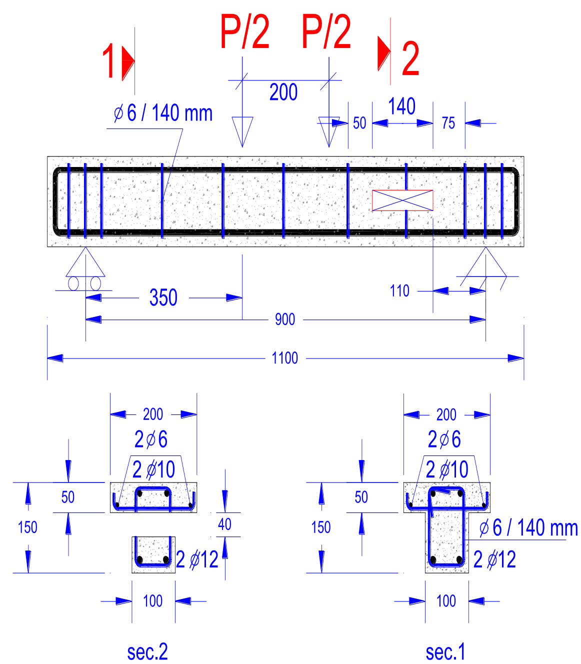

Fig. 3 Reinforcement of Beam with web opening at shear zone (dimensions are in mm)

Table 1: Test specimens

Specimen designation	***Strengthening scheme***	
B1(Solid beam)	NO	
B-O-NS	NO	
B-O-S-CFRP-1	**CFRP** sheets	Scheme1
B-O-S-CFRP-2		Scheme2
B-O-S-CFRP-3		Scheme3
B-O-S-CFRP-4		Scheme4
B-O-S-BFRP	**BFRP** sheets	Scheme4

2.2 strengthening schemes

Different Strengthening schemes are illustrated in figures (4 to 7). **B-O-S-CFRP-1** is strengthened by wrapping of the bottom cord only using one layer of CFRP sheet. **B-O-S-CFRP-2** is strengthened by applying two horizontal side CFRP strips at bottom cord and confining of the bottom cord using one layer of CFRP, In addition 50 mm U-strips are applied to right and left of the opening for the beam stem only (not complete wrap).

B-O-S-CFRP-3 is similar to **B-O-S-CFRP-2** but additional longitudinal CFRP strip with 100 mm width was applied to the slab top surface above the opening.

B-O-S-CFRP-4 is typically as **B-O-S-CFRP-3** but additional horizontal strip with 100 mm width was applied to the beam soffit under the opening and extended 100 mm right and left. Also the side vertical strips were completely wrapped around the web through pre-cut slots through the slab.
B-O-S-BFRP was strengthened as **B-O-S-CFRP-4** but with **BFRP** instead of **CFRP**.

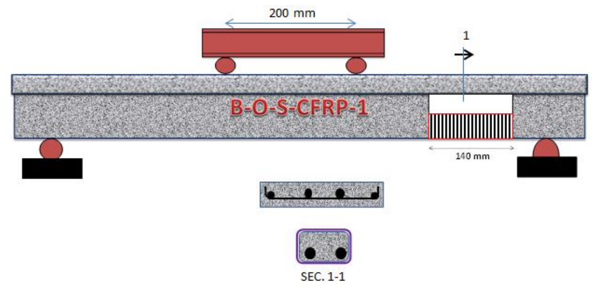

Fig. 4 strengthening scheme (1)

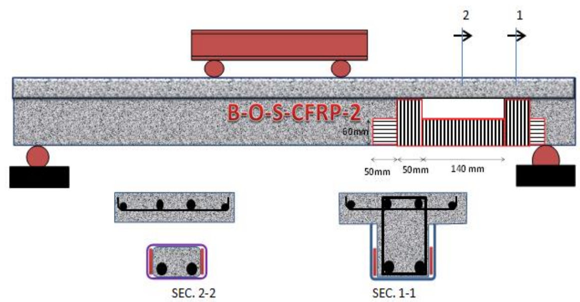

Fig. 5 strengthening scheme (2)

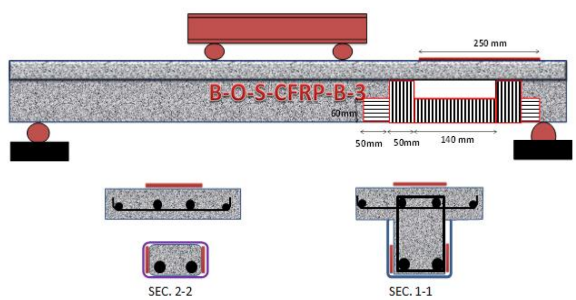

Fig. 6 strengthening scheme (3)

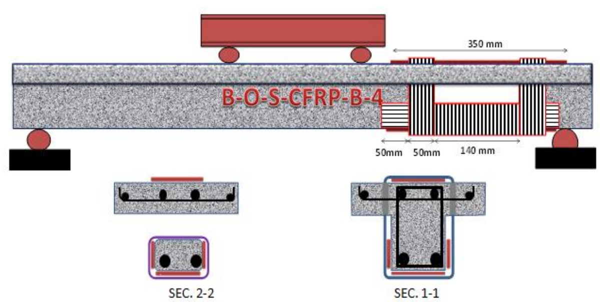

Fig. 7 strengthening scheme (4)

2.3 Element types

There are a lot of elements in ANSYS package to simulate different structure parts[34]. SOLID65 element was used to model Concrete and epoxy. A LINK180 element was used to model the stirrups. A Beam188 element was used instead of link180 to model the Longitudinal steel bars to account for dowel action in shear resistance. The spreader beam was also modeled using Beam188. The SOLID185 element is used for the modeling of loading and supporting plates.

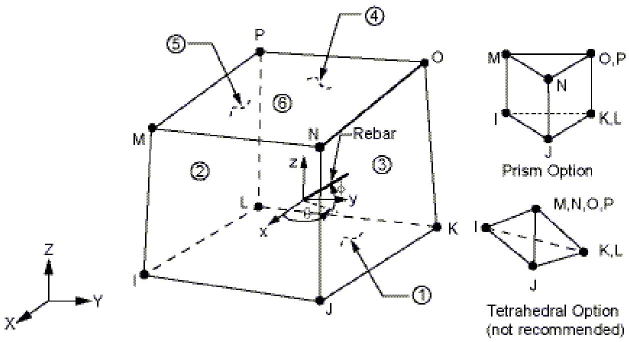

Fig. 8 SOLID65 3D-reinforced concrete solid element, ANSYS 2013, [34]

The CFRP and BFRP sheets were modeled using layered SHELL181 element with elastic orthotropic material properties. It is a four-node element with six degrees of freedom at each node and suitable for analyzing thin to moderately-thick shell structures [34].

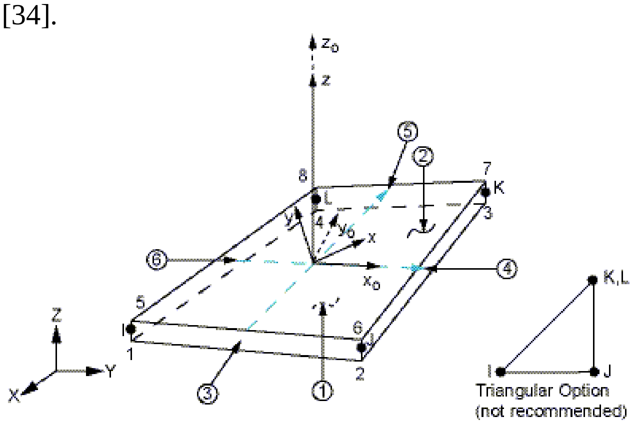

Fig. 9 Shell181 element geometry, ANSYS 2013, [34]

2.4 Material properties

2.4.1 Concrete

Simplified Compressive Uniaxial stress-strain curve was adopted and stress versus strain values are listed in table 2. Cracking and crushing capability were turned on. The default tension stiffening model after cracking was considered in the program. Also a crushed stiffness factor for the concrete after crushing was set to 0.05 to help convergence. The material input data for concrete material in ANSYS are summarized in table 3.

Table 2: Stress-strain values for concrete material

Stress (MPa)	***Strain***
0	0
10.56	0.00037
24.3	0.001
31.0	0.0015
33.5	0.002
34.5	0.0025
35.2	0.0035

Table 3: Concrete Material input data in ANSYS

Property	***value***
E_c (young's modulus)	29186 MPa
f_c (Crushing stress)= 0.8 f_{cu}	35.2 MPa
f_t (cracking stress) = 0.1 f_{cu}	4.4 MPa
vxy (Poisson's ratio)	0.2
βt Shear transfer coefficients for open crack	0.25
βc Shear transfer coefficients for closed crack	0.9

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-3, Issue-11, November 2017
ISSN: 2395-3470
www.ijseas.com

Young's modulus is calculated according to Egyptian code [36] using equation 1.

$$Ec=4400\sqrt{fcu} \quad \text{MPa} \qquad (1)$$

2.4.2 Steel

The reinforcement is assumed to be a bilinear isotropic elastic-perfectly plastic with poison's ratio of 0.3.

2.4.3 FRP system

The epoxy used to bond the CFRP sheets to the concrete surface has been modeled as the concrete but with a cracking stress of 22 MPa, modulus of elasticity of 2 GPa, and Crushing capability was set to off. An assumed layer of epoxy having a thickness of 1mm was used. The cured CFRP strip is assumed to be an elastic orthotropic material. The elastic orthotropic material properties used are [Ex = 33.5GPa, Ey,z= 5GPa, νxy,yz = 0.25, νyz = 0.3, Gxy,xz= 2.5GPa, and Gyz = 2GPa]. The elastic orthotropic material properties for BFRP sheets are [Ex = 9.0 GPa, Ey,z= 3 GPa, νxy,yz = 0.25, νyz = 0.3, Gxy,xz= 2.5GPa, and Gyz = 2GPa].

2.5 Finite element mesh

Finite element mesh was produced for different element types with max edge size of 20 mm as shown in fig.10. Only one half of the beam was simulated to reduce the time of processing so symmetry boundary conditions were taken as shown in fig. 11. Loading of the beam was by applying vertical displacement at the top mid span of a steel spreader beam. Loading steps were divided into very small sub-steps to get converged solutions.

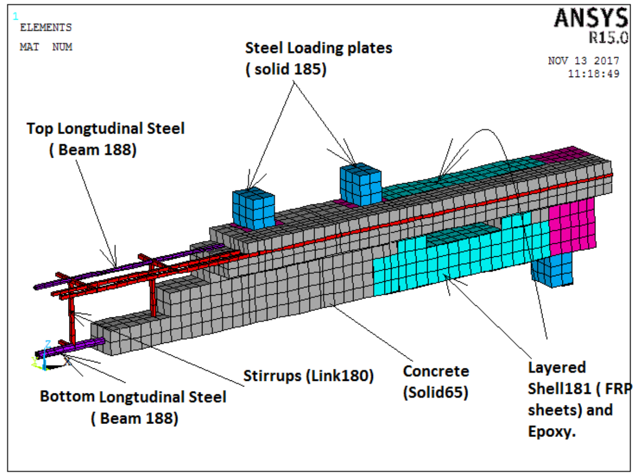

Fig. 10 FE mesh (B-O-S-CFRP-4)

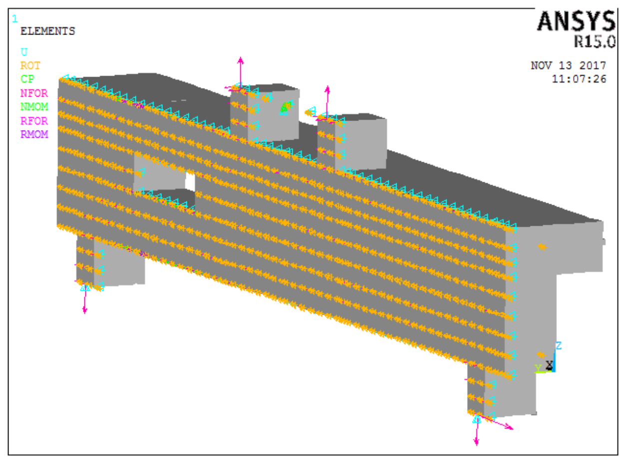

Fig. 11 Symmetry boundary conditions

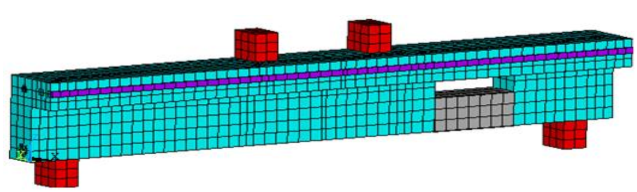

Fig. 12 FE mesh for (B-O-S-CFRP-1)

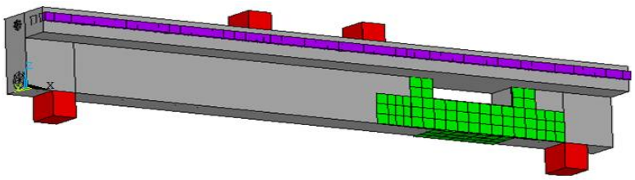

Fig. 13 FE model for (B-O-S-CFRP-2)

2.6 Finite element results and discussions

Behavior of the tested models such as crack patterns and mode of failure, load versus deflection curves, von-mises concrete strains were obtained. Crack patterns from experiments, FEM crack patterns , and von-mises strain for concrete elements at ultimate loads are illustrated in figures (19 to 39).The finite element results were compared with the experimental. It is observed from the comparison that they agree with each other in failure mode and crack patterns. Ultimate loads are also close to those were obtained from experiments as listed in table 4 and illustrated in fig.14. Load versus mid span deflection responses are shown in figures (15 to 18) for the different beams. It is clearly observable from these relationships that the behavior of all finite element models are stiffer than the experiments especially after cracking and at higher loads. This may be because the assumption of full bond for reinforcement with concrete. Also Tension stiffening and residual stresses after cracking or crushing of some concrete elements may be reasons for lower deflections and higher stiffnesses at higher loads.

The beam that has un-strengthened opening failed in brittle manner with very low absorbed energy compared with the solid beam . It is noted that all strengthed beams gain higher loads and ductility than un-strengthend but all of them failed by shear in the opening location except the properly confined beam B-O-S-CFRP-4 that behaves as a solid beam with high ductility and stiffness.

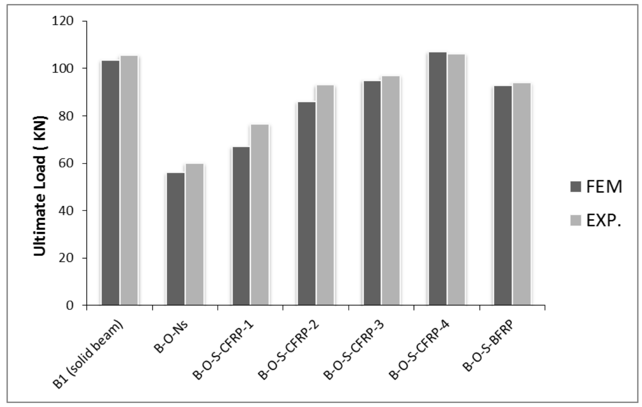

Fig. 14 Comparison between models according to ultimate loads (Exp. And FEM).

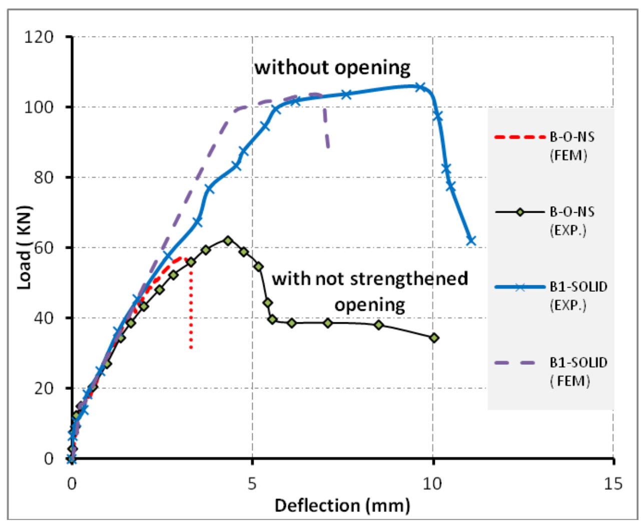

Fig. 15 Load- Mid span deflection responses for control beams

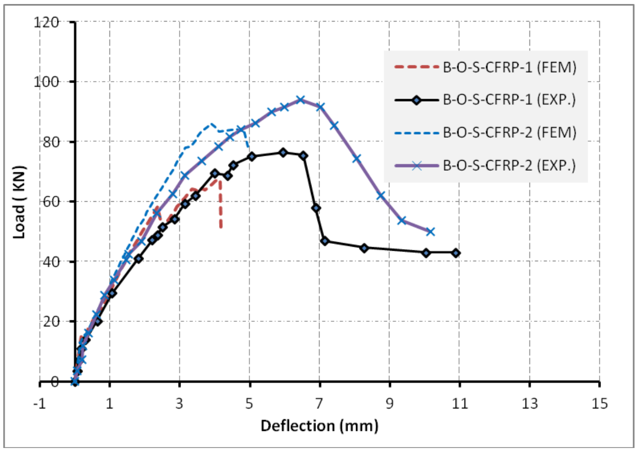

Fig. 16 Load- Mid span deflection responses for **B-O-CFRP-1** and **B-O-CFRP-2**

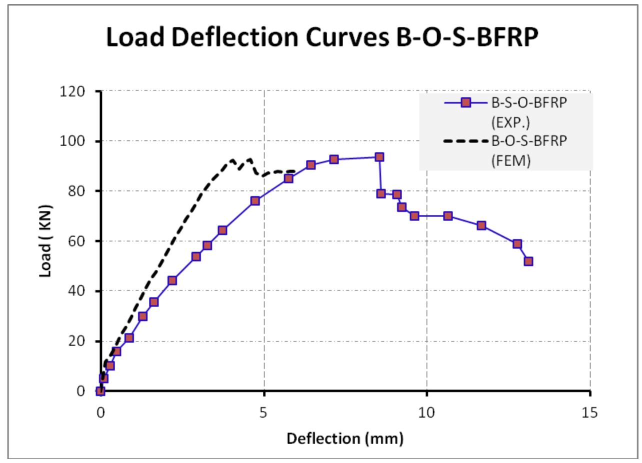

Fig. 18 Load- Mid span deflection response for **B-O-BFRP**

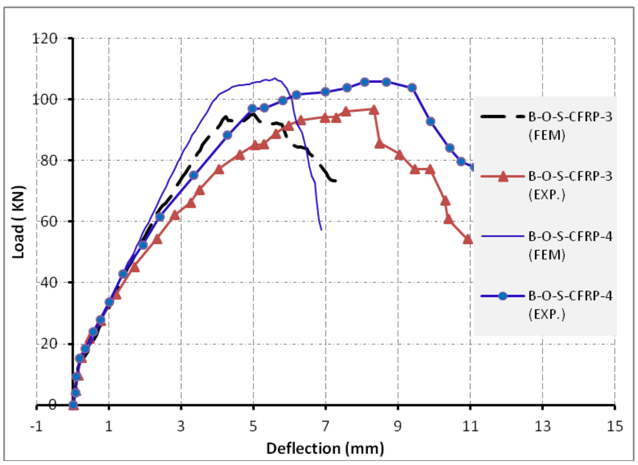

Fig. 17 Load- Mid span deflection responses for **B-O-CFRP-3** and **B-O-CFRP-4**

Table 4: Ultimate loads and failure modes

Beam model	***P_u (KN) ANSYS***	***P_u (KN) Exp.***	***Failure Mode***
B1 (solid beam)	103.5	105.5	Flexure-shear
B-O-NS	56	60	Shear across the opening
B-O-S-CFRP-1	67	76.5	Shear across the opening
B-O-S-CFRP-2	86	93	Shear across the opening
B-O-S-CFRP-3	95	97	Shear across the opening
B-O-S-CFRP-4	107	106	Flexure-Shear at solid part.
B-O-S-BFRP	92.7	93.9	Shear across the opening

Fig. 19 Cracks for solid beam-B1

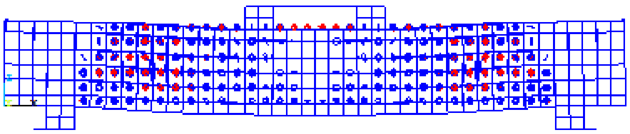

Fig. 20 Crack patterns for solid beam-B1 (ANSYS)

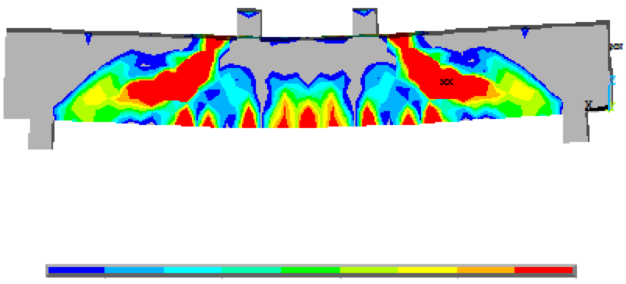

Fig. 21 Von-mises strains for solid beam-B1

Fig. 22 Crack patterns for B-O-NS

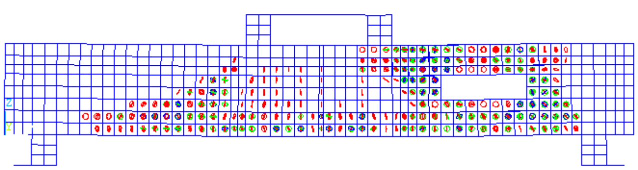

Fig. 23 Crack patterns for B-O-NS (ANSYS)

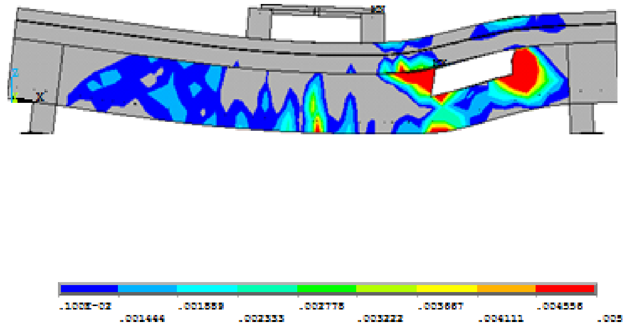

Fig. 24 Von-mises strains for B-O-NS

Fig. 25 Crack patterns for B-O-S-CFRP-1

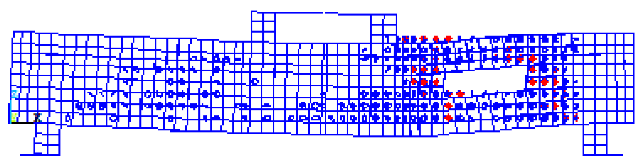

Fig. 26 Crack patterns for B-O-S-CFRP-1 (ANSYS)

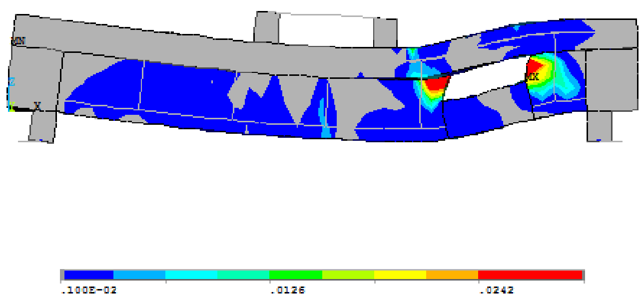

Fig. 27 Von-mises strains for B-O-S-CFRP-1

Fig. 28 Crack patterns for B-O-S-CFRP-2

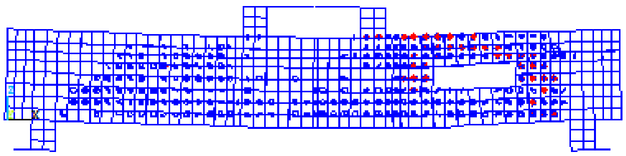

Fig. 29 Crack patterns for B-O-S-CFRP-2 (ANSYS)

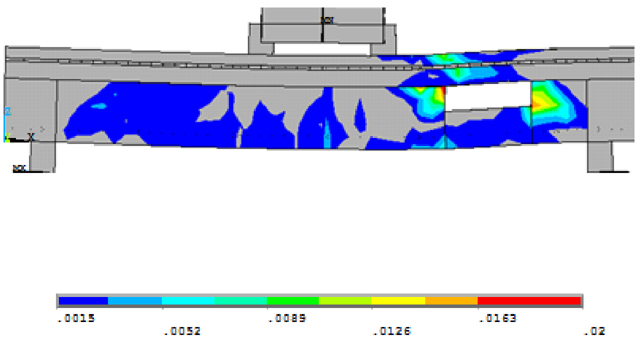

Fig. 30 Von-mises strains for B-O-S-CFRP-2

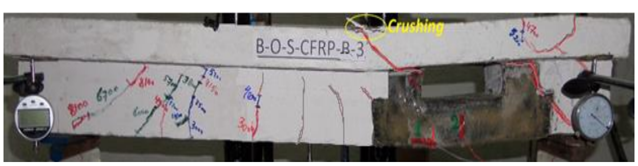

Fig. 31 Crack patterns for B-O-S-CFRP-3

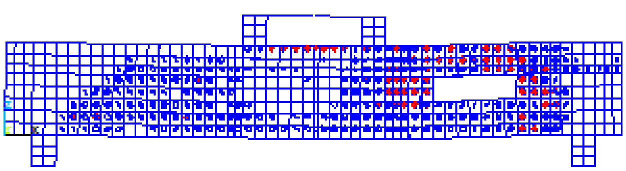

Fig. 32 Crack patterns for B-O-S-CFRP-3 (ANSYS)

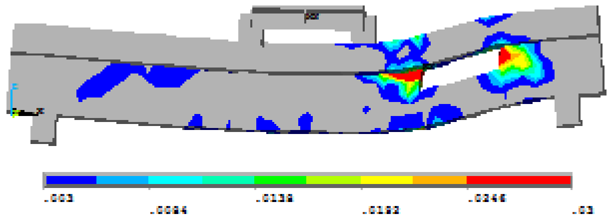

Fig. 33 Von-mises strains for B-O-S-CFRP-3

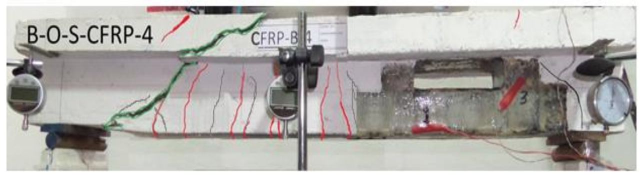

Fig. 34 Crack patterns for B-O-S-CFRP-4

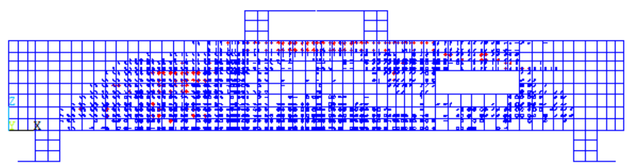

Fig. 35 Crack patterns for B-O-S-CFRP-4 (ANSYS)

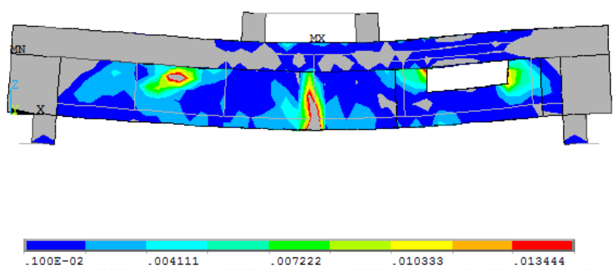

Fig. 36 Von-mises strains for B-O-S-CFRP-4

Fig. 37 Crack patterns for B-O-S-BFRP

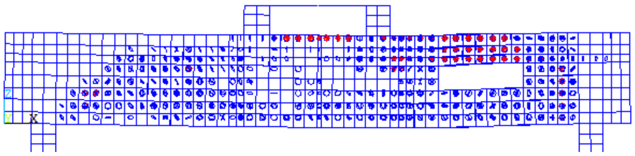

Fig. 38 Crack patterns for B-O-S-BFRP (ANSYS)

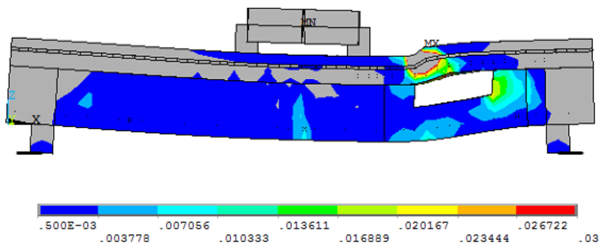

Fig. 39 Von-mises strains for B-O-S-BFRP

3. Conclusions

The behavior of shallow RC T-beams containing shear zone large opening and strengthened with CFRP and BFRP sheets were studied using FEM. Also two not strengthened control specimens were analyzed (one Solid beam and another one with opening). In the end, Finite element results were compared with experimental results.

Conclusion results are as follows:

1- Introducing a large opening that is not well reinforced in Shallow beams largely weakens the beam.

2- It is not efficient to wrap only the bottom cord of the opening with FRP sheets as the shear cracks start from the opening corners.

3- Application of CFRP and BFRP sheets with complete wrapping scheme for the opening location results in increase in stiffness, ductility, and load carrying capacity for the strengthened beams.

4- The RC shallow T-beams with openings can behave as solid beams if they are properly strengthened.

5- Finite element modeling can predict reasonably the ultimate load and mode of failure for the analyzed beams and can be used instead of the very costly experimental work.

6- Modeling of longitudinal steel bars in ANSYS using beam elements is better than modeling them with link elements so that it can consider the dowel action in shear resistance.

7- CFRP is more efficient than BFRP due to high modulus of elasticity and tensile strength; max % increase in ultimate load over control opened beam was 76.5% and 56.5% for CFRP and BFRP strengthened beams respectively.

References

[1] M. A. Mansur, and K. H. Tan, Concrete Beams with Openings: Analysis and Design, Florida, USA, CRC Press, 1999.

[2] M. A. Mansur , L. M. Huang, K. H. Tan, and S. L. Lee, "Deflections of reinforced concrete beams with web openings", ACI Structural Journal, Vol. 89, No. 4, 1992, pp.381-389.

[3] H. A. Abdallaa, A. M. Torkeya, H.A. Haggagb, and A. F. Abu-Amira, "Design against cracking at openings in reinforced concrete beams strengthened with composite sheets", Composite Structures, Vol. 60, 2003, pp. 197-204.

[4] M. A. Mansur, "Design of Reinforced Concrete Beams with Web Openings", in Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006), 2006, Kuala Lumpur, Malaysia, PP. 104-120.

[5] S. Mondal, J. N. Bandyapadhya, Chandra Pal Gautam, "Strengthening and rehabilitation of reinforced concrete beams with opening", International Journal of Civil and Structural Engineering, Vol. 2, No. 1, 2011, PP.127-137.

[6] M. A. Mansur, "Effect of openings on the behavior and strength of R/C beams in shear", Cement and Concrete Composites, Elsevier Science Ltd., Vol. 20, No. 6, 1998, PP.477-486.

[7] S. A. Al-Sheikh, “Flexural Behavior Of Rc Beams With Opening”, Concrete Research Letters, Vol. 5, No. 2, 2014, PP.812-824.

[8] E. G. Prentzas, "Behaviour and reinforcement of concrete beams with large

rectangular apertures",Ph.D. Thesis, Structural Engineering, University of Sheffield, U.K., 1968.

[9] J. M. Hanson, "Square openings in webs of continuous joists", PCA Research and Development Bulletin RD 100.01D, Portland Cement Association, 1969, pp.1-14.

[10] N. F. Somes, and W.G. Corley, "Circular openings in webs of continuous beams. Shear in Reinforced Concrete", Special Publication SP-42, American Concrete Institute, Detroit, 1974, pp. 359-398.

[11] S. A. Salam, "Beams with openings under different stress conditions", in 3rd Conference on Our World in Concrete and Structures, 1977, CI-Premier, Singapore, pp.259-267.

[12] W. Weng "Concrete beams with small openings under bending and shear", M. Eng. Thesis, National University of Singapore, 1998, 92 p.

[13] M. A. Mansur, K. H. Tan, Y. F. Lee, and S.L. Lee, "Piecewise linear behavior of RC beams with openings", Joumal of Structural Engineering, ASCE, Vol. 117, No. 6, 1991, pp. 1607-1621.

[14] W. B. Siao, and S. F. Yap, "Ultimate behavior of unstrengthened large openings made in existing concrete beams", Journal of the Institution of Engineers, Vol. 30, No. 3, 1990, pp.51-57.

[15] M. Breveglieri , A. Aprile, J. A. Barros, "Shear strengthening of reinforced concrete beams strengthened using embedded through section steel bars", Engineering Structures, Vol. 81, 2014, pp. 76–87.

[16] ACI Committee 440, Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures, American Concrete Institute; 2002, p. 118.

[17] fib-Bulletin 14. Externally bonded FRP reinforcement for RC structures, Technical report by Task Group 9.3 FRP (Fiber Reinforced Polymer) reinforcement for concrete structures. Féderation Internationale du Béton fib; 200. p. 130.

[18] C. E. Bakis, L.C. Bank, V. L. Brown, E. Cosenza, J. F. Davalos, JJ Lesko, et al. "Fiber reinforced polymer composites for construction – state-of-the-art review" Journal of composites for construction, vol. 6, No. 2, 2002, pp. 73–87.

[19] S. M. Allam, "Strengthening of RC beams with large openings in the shear zone", Alexandria Engineering Journal, Vol. 44, No. 1, 2005, PP. 59-78.

[20] H. Madkour, "Non-linear Analysis of Strengthened RC Beams with Web Openings" , Proceedings Of The Institution Of Civil Engineers, Structures and Buildings, Vol. 162, 2009, pp. 115-128.

[21] A. Pimanmas, "Strengthening R/C beams with opening by externally installed FRP rods: Behavior and analysis", Composite Structures, vol. 92, Jul. 2010, pp. 1957-1976.

[22] K. Fawzy, "Strengthening of Opening R.C. Beams in Shear Using Bonded External Reinforcements" International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 4, No. 2, 2015, pp. 11-23.

[23] N. Z. Hassan et al., "Finite element analysis of reinforced concrete beams with opening strengthened using FRP", Ain Shams Eng J, 2015, http://dx.doi.org/10.1016/j.asej.2015.10.011

[24] R. A. Hawileh, T. A. El-Maaddawy, and M. Z. Naser," Nonlinear finite element modeling of concrete deep beams with openings strengthened with externally-bonded composites", Materials & Design, Vol. 42, December 2012, pp. 378-387.

[25] S. C. Chin, N. Shafiq, and M. F. Nuruddin, "Strengthening of RC Beams with Large Openings in Shear by CFRP Laminates: Experiment and 2D Nonlinear Finite Element Analysis", Research Journal of Applied Sciences, Engineering and Technology, Vol. 4, No. 9, 2012, pp. 1172-1180.

[26] A. M. Mahmoud, "Strengthening of concrete beams having shear zone openings using orthotropic CFRP modeling", Ain Shams Engineering Journal,Vol. 3, No. 3, 2012, pp.177–190.

[27] D. Jayalin, A. G. Prince, V. Karthika, "ANALYSIS OF COMPOSITE BEAM USING ANSYS", IJRET: International Journal of Research in Engineering and Technology, Vol., 04, No. 09, 2015, pp. 11-15.

[28] S. Vuggumudi, "Experimental Study on Shear Strengthening of RC T-Beams With Web Openings Using FRP Composites", Ph.D. thesis, Department of Civil Engineering, National Institute of Technology, Rourkela , India, 2013.

[29] A.M. Elnady, "Torsional behaviour of RC beams with opening retrofitted with FRP material", M. Sc. Thesis, Structural Engineering Department, Faculty of Engineering Zagazig University; Egypt, 2015.

[30] B. H. Osman, E. Wu, B. Ji, and S. S. Abdulhameed, "Shear behavior of reinforced concrete (RC) beams with circular web openings without additional shear reinforcement", KSCE Journal of Civil Engineering, Vol. 21, No. 1, 2017, pp. 296-306.

[31] B. H. Osman, E. Wu, B. Ji, and S. S. Abdulhameed, "Repair of Pre-cracked Reinforced Concrete (RC) Beams with Openings Strengthened Using FRP Sheets Under Sustained Load", International Journal of Concrete Structures and Materials, Vol.11, No.1, 2017, pp.171–183.

[32] T. El-Maaddawy, and S. Sherif, "FRP composites for shear strengthening of reinforced concrete deep beams with openings", Composite Structures, Vol. 89, No.1, 2009, pp.60–69.

[33] A. K. Panigrahi, K. C. Biswal, and M. R. Barik, "Strengthening of shear deficient RC T-beams with externally bonded GFRP sheets", Construction and Building Materials, Vol. 57, 2014, pp.81–91.

[34] ANSYS, (2013), Release 15.0 Documentation. ANSYS Inc., http://www.ansys.com.

[35] S. S. Choobbor, "Flexural performance of reinforced concrete beams externally strengthened with carbon and basalt FRP sheets", M. Sc. Thesis, Department of Civil Engineering, College of Engineering, American University of Sharjah, United Arab Emirates, 2015.

[36] ECP 203, (2007), "The Egyptian Code for Design and Construction of Concrete Structures", Ministry of Housing, Cairo, Egypt, (In Arabic).

[37] Sika. SikaWrap Hex 230C: Carbon Fiber Fabric for Structural Strengthening System Product Data Sheet, Edition 04.2005, 2005.

Hamdy Shehab, Professor of concrete structures, member of Egyptian concrete Code committee,

Degrees

Ph.D Leeds university, England, 1990

Ms.C Cairo University, Cairo, Egypt, 1984

Bs.C Cairo University, Cairo, Egypt, 1978

Employment: Structural Engineering Department, Faculty of Engineering, Zagazig University 1979 - Now.

Research of interest: Nano materials, Structural dynamics, prestressed concrete, and evaluation and repair of existing structures.

Mohamed Husain, Professor of concrete structures, member of Egyptian concrete Code committee and consultant engineer

Degrees

Ph.D Catholic university of America, Washington D.C, USA, 2001

Ms.C Zagazig University, Zagazig, Egypt, 1988

Bs.C Zagazig University, Zagazig, Egypt, 1983

Employment: Structural Engineering Department, Faculty of Engineering, Zagazig University 1983-Now.