Effect of BFRP Sheets on Strengthening Deep Beams with Openings

[a] Hala Mamdouh, [b] Hoda A. Awad, [c] Mostafa A. Osman,
[a] Associate Professor, Civil Engineering Department, Faculty of Engineering at Mataria, Helwan University, Cairo 11718, Egypt. Hala_mamdouh@m-eng.helwan.edu.eg
[b] Ph.D. Student, Civil Engineering Department, Faculty of Engineering at Mataria, Helwan University, Cairo 11718, Hoda_awad89@yahoo.com (corresponding author)
[c] Professor, Civil Engineering Department, Faculty of Engineering at Mataria, Helwan University, Cairo 11718, Egypt. m_osman62@yahoo.com

Abstract
In this study, the Basalt fibers from basalt rocks are used to strengthen openings in deep beams where this fiber is an environmentally friendly material that doesn't produce any toxic reactions with air or water, and its surface is anti-explosion. Also, it doesn't produce chemical reactions that may damage the environment or human health When it contacts other chemicals, it is safe for use in industry and has no pollution, the effect of strengthening deep beams with openings vertically by using these basalt fiber sheets is studied. A practical program has been developed to study the behavior of deep beams strengthened with basalt fiber-reinforced polymer (BFRP) sheets. The practical program consists of 6 beams designed as American code, with various types of openings. The results of the tested sheets and results of beams such as deflection, cracking load, crack propagation, ultimate load, and failure character, are recorded. Also, nonlinear analysis and mathematical equations are used in this study. This research can achieve that the basalt fiber sheets could affect slightly on the behavior of the deep beam with openings in cracking loads, deflections, stiffness, energy capacities, and ultimate loads.
Keywords: Basalt fiber-reinforced polymer (BFRP) sheets, Deep beams, Openings, Strengthening, vertically, nonlinear analysis, mathematical equations

1. Introduction

using basalt fiber sheets instead of other fibers such as carbon saves the environment from pollution because it doesn't produce any toxic reactions with air or with water and, its surface is anti-explosion. Also, it doesn't produce chemical reactions that may damage the environment or human health When it contacts with other chemicals, so it is safe for use in industry and have no pollution, and it also saves natural resources which can be recycled and reused in buildings so that, it is an advantage to use it as a strengthening material to enhance the behavior of the structure elements Also, basalt fiber is easy to handle and process, so there is no need for special processing equipment, and it is convenient with a lot of resins like epoxy, it has excellent shock resistance as it is good for ballistic applications(1,2). so, we choose this fiber trying to solve the problems which happen due to existing of openings in deep beams such as the reduction in strength of the beam, more cracks, and deflection in addition to that, openings disrupt the normal stresses flow, resulting in concentration of stress at the openings' sides and early cracking of concrete by strengthening these openings with basalt fiber reinforced polymer sheets. And also trying to solve the problem of pollution due to carbon fiber.

The last searches of BFRP were about its behavior individually, as a ratio of concrete mix, BFRP bars, and as a strengthening material (3-12). Hannibal Ólafsson et al (3) made a review on basalt fiber, the different methods of production, and tests done on it as a strengthening material for R.C. members. Cheng Yuan et Al (4) investigated the aggregate size effect on the bond between BFRP sheets and concrete. John-Sebastian Branston et al (5) evaluated mechanical performance by measuring the basalt fiber's effect on the cracking behavior of concrete and investigating how the basalt fiber-concrete interfacial properties influenced that behavior. PL. Meyyappan and M.

Jemimah Carmichael (6) used the basalt fiber in the concrete mix with different volume fractions ranging from 0.5% to 3% for concrete compressive strength of 30 MPa. Cory High et AL (7) study the flexural behavior of concrete members reinforced with basalt fiber bars and they also studied the mechanical properties of the concrete mix when the chopped basalt fibers are additive in it.
Also, Mohamed M. Ahmed et al (8) investigate the behavior of beams reinforced with (BFRP) bars when they are applied to repeated loadings to enhance their stiffness after that Eyþór Rafn Þórhallsson et al (9) presented 2 research; a test of prestressed concrete with basalt bars vice steel and a test of columns strengthened with sheets to increase their capacity. M. M. Kamal et al (10) tested Five series of plates under four loading conditions to study the dynamic responses as mode shape, frequency, and damping factor. Then nonlinear analysis was investigated to study the effect of basalt fiber ratio, steel mesh, and boundary fixations on the dynamic characteristics of concrete structures. Also, the basalt fiber plates were tested in a high-frequency range (up to 140 kHz) using an ultrasonic technique. Surya Sunder S et al (11) made an experimental program to study the influence of strengthening circular openings in R.C beams at the shear zone with one and two openings using the BFRP wrapping system around and inside the openings. Kadhim et al (12) studied the Flexural attitude of RC beams strengthened with one layer of BFRP sheets.
In this paper, 2 layers of BFRP sheets are used to strengthen deep beams with openings, the properties of BFRP sheets (tensile strength, ultimate strain, and elongation at failure have been studied by testing 3 specimens of sheets roughed with sand to simulate the contact of basalt and concrete also, its behavior when using it in strengthening deep beams have been studied where no searches have been used BFRP in strengthening deep beams with openings. Also, in this research, we didn’t only study different types of openings and strengthen them vertically by BFRP but also, studied the behavior of BFRP on strengthening deep beams, not ordinary beams.
In tall buildings, R.C. deep beams are beneficial to resist high loads on structures, such as girders, shear walls, caissons, pile caps, wall footings, diaphragms, and complex foundation systems (13-15).
Although openings are important for accessibility purposes and to execute different services such as ventilation, power supply, and network systems, it causes many problems in the deep beam behavior, such as the beam’s strength reduction, more cracks, and deflection. In addition to that, openings disrupt the normal stresses flow, resulting in a concentration of stress at the openings' sides and early cracking of concrete (16). therefor many researchers studied the parameters that affect the presence of openings in deep beams (location and dimensions of openings) to know the problems caused by this openings (16-20) some of them studied the behavior related to rectangular sections (16-18) where Campione G, and Minafò G.(16) tested 20 small scale deep beams with and without circular openings and low shear span to depth ratios ,then they made analytical study to predict ultimate loads and corresponding deflection and they achieved that the effect of circular opening depend on its positions in the beam also the effect of reinforcement depends on its arrangement, Tseng, C.C. and Hwang, Shyh-Jiann(17)suggested an analytical method to predict the shear strength of deep beams with web openings and different modes of failure, also Hamid Karimizade and Abolfazl Arabzadeh(18) presented an analytical model based on strut and tie method to predict ultimate load for simply supported deep beam with circular or rectangular openings. Other researchers cared with T-shaped sections (19,20) Ata El-Kareim et al(19) studied experimentally the behavior of flanged deep beams with web openings while Ghali MK et al (20) studied numerically the Behavior of T-shaped deep beams with openings using different loading conditions.

At the same time, many researchers have been trying to solve the problems that the opening cause in deep beams by strengthening them with FRP composites, especially by using carbon fibers (21-26). El Maaddawy T and Sherif S (21) investigated the shear strength of 13 deep beams with openings using CFRP composites testing it under four points and they achieved that the existence of CFRP around the opening increases the shear strength in the range from 35-73%. Hawileh RA et al (22) used non-linear analysis to study the effect of CFRP in strengthening openings in deep beams. WY Lu et al (23) tested 18 H.S.C deep beams with web openings strengthened with CFRP, 6 beams were strengthened horizontally and 6 are strengthened vertically with 4 layers of CFRP they reached the horizontal CFRP increasing the shear strength by 6% while the vertical increase the strength by 10%. Rahim NI et al (24) tested 9 deep beams with openings strengthened with carbon fiber and 1 control deep beam without opening under four-point loads, they achieved that the capacity was increased by about 10-40 % and the most effective number of layers is 2 and 3 layers for sizes 150 and 200 mm respectively. Khalaf, M.et al (25) tested 3 externally strengthened continuous deep beams with large openings under 5 points load they achieved that the CFRP enhances the strength by 17 %. Karimizadeh H et al (26) tested 11 deep beams with square openings strengthened with CFRP using two techniques (externally bonded and externally bonded with grooves) and steel protective frames (SPF) applied to 3-point loads, the results showed that the capacity increased by 42%,58%, and 115%when using those techniques respectively. However, some researchers turned to strengthen openings using other fibers, Qudeer Hussain and Amorn Pimanmas (27) tested 29 deep beams with web openings using 3-point loads and strengthen the opening by sprayed GFRP and they concluded that GFRP is more effective in normal strength concrete than that in high strength concrete, IN THIS PAPER the behavior of deep beams with opening strengthened vertically using BFRP sheets has been studied with different types of openings (vertical rectangle, horizontal rectangle, circle, and square) and a prediction of ultimate loads using analytical equations has been investigated. Whereas no searches are attended to use the basalt fibers in strengthening deep beams with or without openings.

2. Material properties

Local materials are used in casting beams, the type of cement was ordinary portland cement, fine and coarse aggregates were composed of siliceous sand and good dolomite with a maximum nominal size of 20mm, and the steel used for stirrups is mild steel with fy =280 MPa with 6 mm diameter bars and high-tensile steel for longitudinal bars with fy =360MPa with 16 mm diameter at the top and have a rough surface to get more bonds between steel bars and concrete. The bottom reinforcement of beams was 2 bars with 25 mm, clean drinking water is used in this work. BFRP sheets with a thickness of 0.36mm are used, three tests were done on the sheets with the used resin (epoxy of type Sikadur – 330) and roughed with sand to simulate the contact of the sheet with concrete as shown in Figure(1) then the mean values of the results are listed in Table (2), Also the properties of the epoxy from the manufacturer are listed in the same table.

Figure (1): Basalt fiber before and after roughing its surface with sand

2.1 Experimental program

The experimental program consists of six deep beams as listed in Table (1). All beams have the same cross-section with dimensions of 150 mm, 500 mm, and length of 1000 mm. the clear spans of the tested beams were fixed at 850 mm, and all strips of basalt fibers have a width of 100mm with two layers Figure (2) shows the concrete cross-section and the span of all the beams. We choose this dimension to sure that the beam act as a deep beam where $l_n/h = 1.7 < 4$ according to ACI 318-8 [28] where l_n is the clear span of the beam and h is the height of the beam

Table (1): The experimental program

Group no.	Beam symbol	Type of opening	Direction of opening	Size of opening	Fiber
G1	B 1	-	-		No
	B3-RO-V	rectangle	vertical	100mm*200mm	No
G2	B4-RO-V-F	rectangle	vertical	100mm*200mm	Yes
	B6-RO-H-F	rectangle	Horizontal	200mm*100mm	Yes
	B8-CO-F	circular	-	D=160mm	Yes
	B10-SO-F	square	-	140mm*140mm	Yes

2.2 Test setup

The beams are tested at the laboratory of the National Center for Housing and Building Research. one loading jack is used at the mid-span of the beam. The load cell is attached to a digital screen to record the applying loads and corresponding deflections. The loading system and test setup are shown in Figure (3) and the locations of LVDT are illustrated in Figure (4)

Table (2): The properties of basalt fiber sheets and epoxy

Material	Basalt fiber sheets	Epoxy
Type	BWUD-400	Sikadur-330
Tensile Strength (MPa)	2148.19	30
Elongation at Failure (%)	2.5	-
Tensile Modulus (GPa)	50.5	3.8
Fabric Density (g/m2)	400	-
Mixing Ratio by Weight	-	A: B, 4: 1

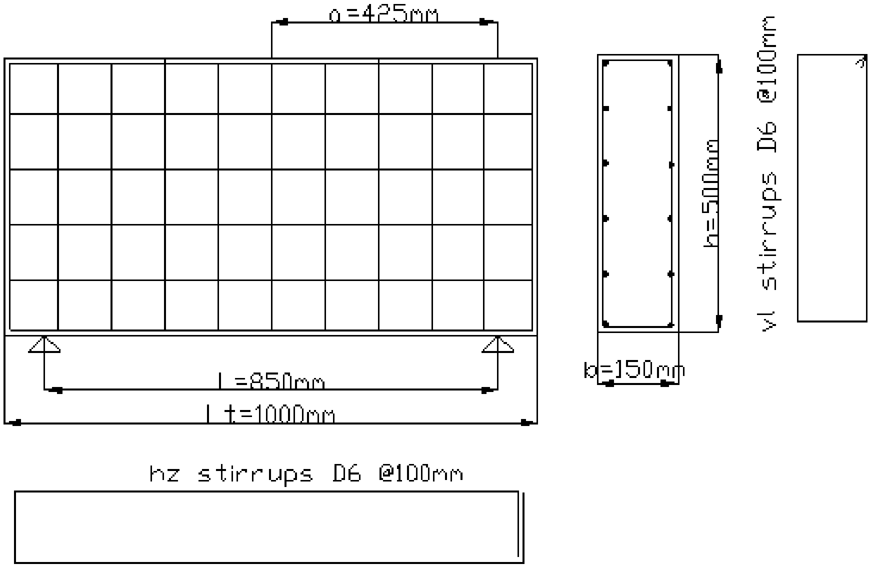


Figure (2): The concrete cross-section and the beams' span.

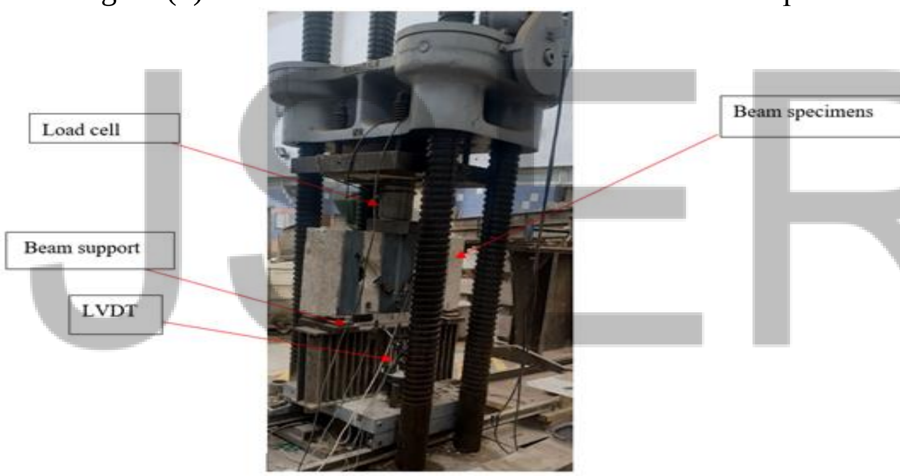


Figure (3): The test setup and loading system

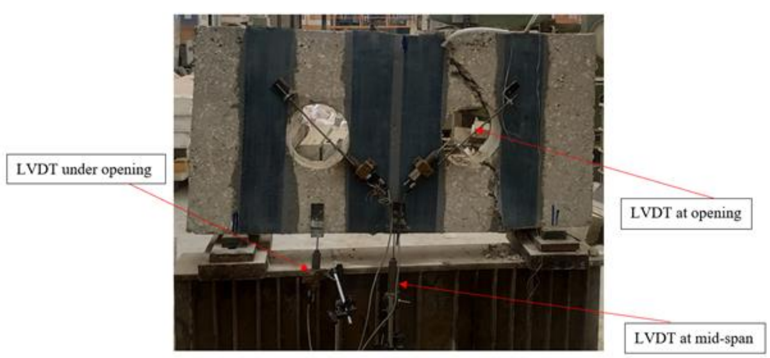


Figure (4): The locations of deflection measurement

3. Test Results

3.1 Crack pattern and modes of failure

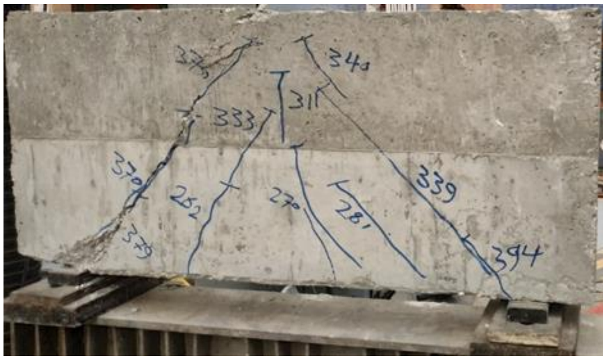
Figure (5) shows the crack pattern of the beams and their mode of failure, at reference beam B1 diagonal cracks were observed at the loading point towards the edge of the beam until the support. but when we look at the crack patterns of beams with openings (B3-RO-V), It was noted that the diagonal cracks first existed surrounding the openings and then spread out to the loading point and supports. also, in beam B4-RO-V-F the cracks were diagonally propagated at the bottom of the opening to the support. the crack pattern of beam B8-CO-F was found almost similar to those obtained in beam B4-RO-V-F. However, the diagonal cracks at the bottom of the openings near the support were graver than that in beam B4-RO-V-F which leads them to crush concrete at the edge of the beam. While in beam B6-RO-H-F the crack pattern shows that there are 2 diagonal cracks spread toward the load point. However, the crack pattern in beam B10-SO-F showed mainly three cracks on the left and right sides of the beam which appeared initially at the loading point and then the crack on the left side propagates towards the support during the test until the failure of the beam and finally the concrete crush and then the cover separated from the top of the beam at left side.

3.2 Load-deflection relationship

The load-deflection curves of all beams are drawn in figure (6) which showed that the deflections of strengthened beams (B4-RO-F, B6-RO-H-F, B8-CO-F, and B10-SO-F) are higher than that in non-strengthened-beams (B1 and B3-RO-V). By comparing B1 and B3-RO-V, it was founded that the behavior of the deep beam with an opening is mainly different from the beam without an opening where in B3-RO-V the initial slope is more than it in B1 and the deflections at the first part of the curve is bigger than it in B1until ultimate load then the deflections decreased slowly than it in the beam without opening.

4.3 Cracked and ultimate loads

By studying the first crack load and ultimate load shown in figure (7).it was observed that the cracking loads in the strengthened beams are created at a higher load compared to the cracking loads in the non-strengthened beams, the cracking load appears at nearly 59% of the ultimate load while in strengthened beams with opening the cracking load appears at nearly 65, 59.3, 51.4, 76.8% of the ultimate load for beams B4-RO-F, B6-RO-H-F, B8-CO-F, and B10-SO-F respectively. By studying Figure (8) and Figure (9), it was found that the vertical opening reduces the ultimate load by 34% while strengthening this opening with basalt fiber sheets the strength is still the same. However, the beam with a horizontal opening strengthen with BFRP (B6-RO-H-F) increases as compared to (B3-RO-V) by about 18.5%. In beams B8-CO-F and B10-SO-F, the strength was increased by 17.8% and 4.6% respectively. From these results, we can achieve that the horizontal rectangular opening reaches 78.3% of the beam's original structural capacity when compared to B1



B1: Shear faliure

B3-RO-V: Diagonal-shear splitting failure

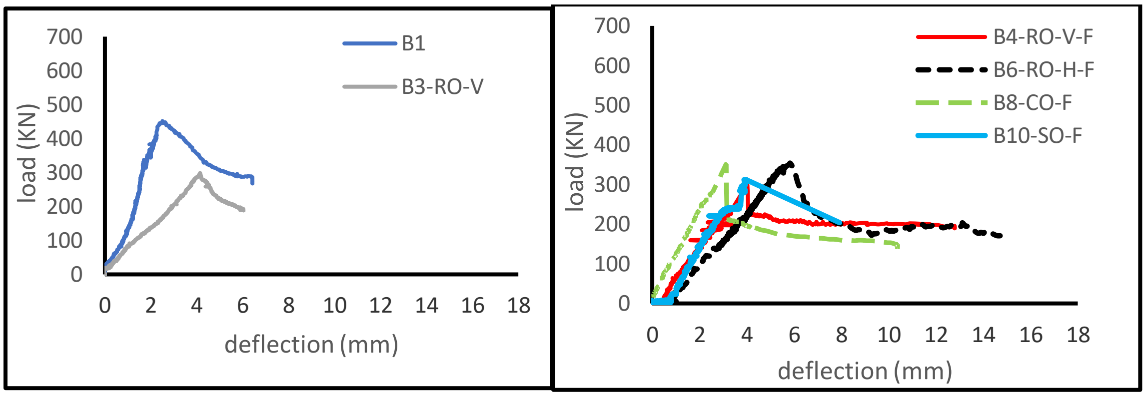
B4- RO-V-F :Diagonal-shear splitting failure

B6-RO-H-F : Diagonal-shear splitting failure

B8-CO-F: Diagonal-shear splitting failure

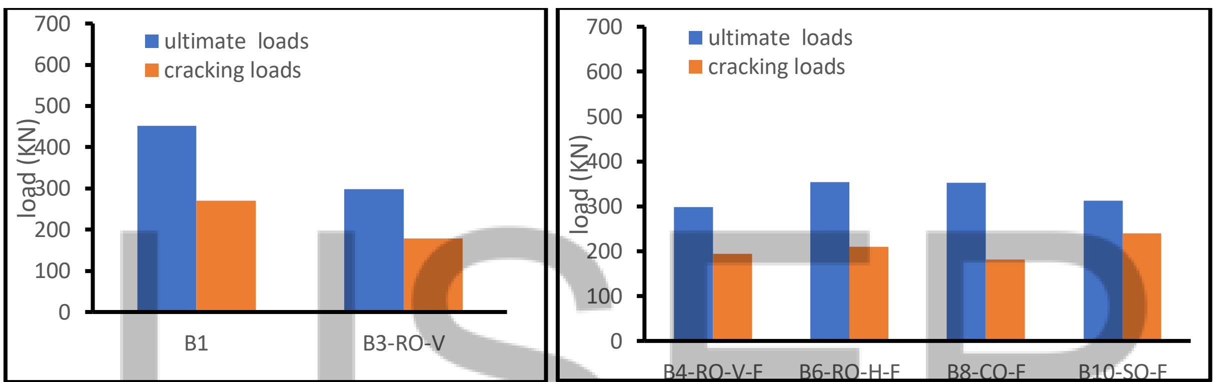
B10-SO-F: Diagonal-shear, concrete cover splitting

Figure (5): crack pattern for all beams



(a) Beams without BFRP sheets (b) Beams strengthen with BFRP sheets

Figure. (6). Load deflection curve of all beams



(a) Beams without BFRP sheets (b) Beams strengthen with BFRP sheets

Figure (7): The first crack load and ultimate load of all beams

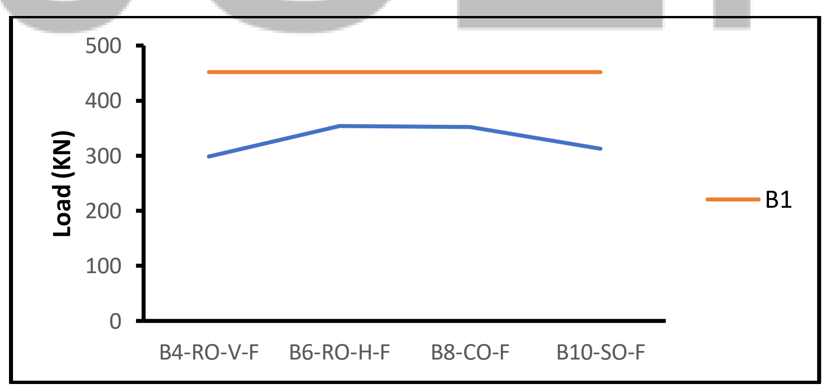


Figure (8): The ultimate load of all beams concerning B1

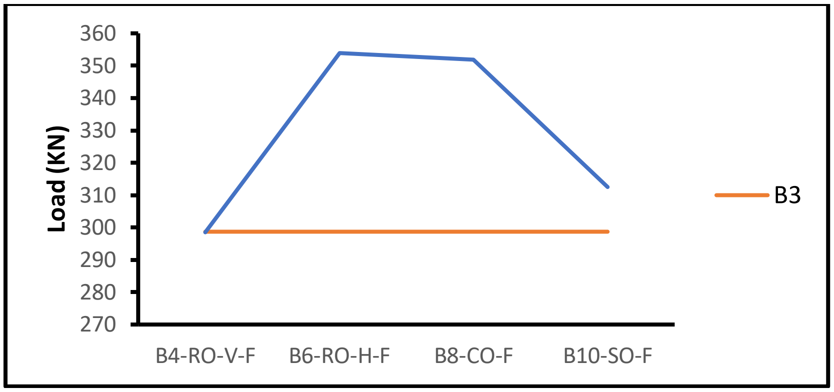
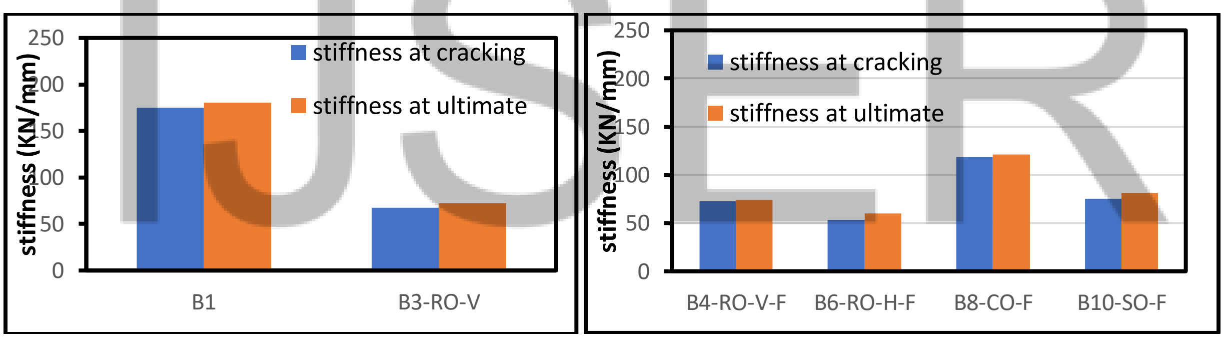


Figure (9): The ultimate load of all beams concerning B3-RO-V

4.4 Stiffness of the beams

The beam stiffness can be calculated as the ratio of the force and displacement (F/Δ). Figure (10): shows the values of stiffness of the beams tested at the stage of cracking load and the stage of ultimate load. By studying these values, it is obvious that the beam without opening has higher stiffness than those in beams with openings, the stiffness increased at the ultimate stage than that in the cracking stage in beams without BFRP sheets of about (3 and 7) % for B1 and B3-RO-V respectively and therefore in beams strengthen with BFRP sheets the stiffness increased at ultimate stage than that in cracking stage.

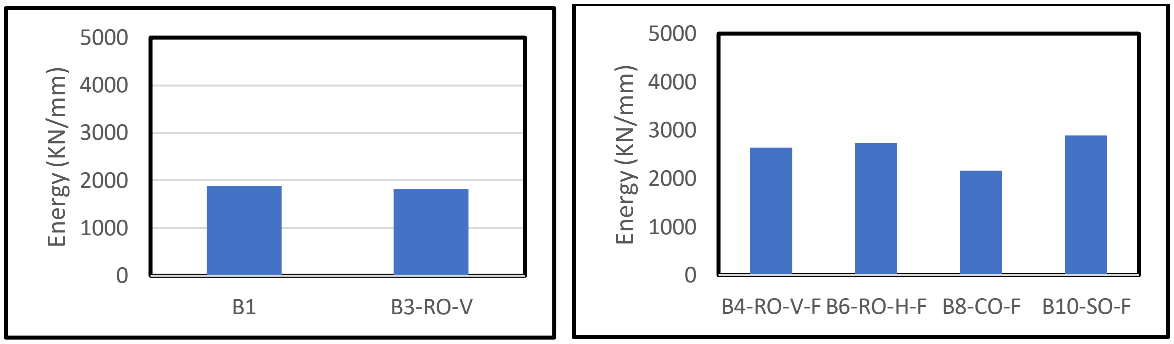


(a) Beams without BFRP sheets (b) Beams strengthen with BFRP sheets

Figure (10): Stiffness at cracking and ultimate loads for all beams

4.5 Energy absorption

The energy absorption capacity of the beam members can be calculated as the area enclosed by the load-deflection curve. Figure (11) shows the different values of the energy absorption capacities for all beams. From Figure (11), it is seen that the energy absorption capacity is increased when the beam is strengthened with basalt fiber sheets of about 144.7,150.3,119.1and 158.6 % for B4-RO-V-F, B6-RO-H- B8-CO-F and B10-SO- F respectively, the deep beam with the opening (B3-RO-V) nearly has the same energy of the solid beam(B1). **Table 3** shows the values of deflection, crack loads, ultimate loads, stiffness, and energy absorption capacities for all beams.



(a) Beams without BFRP sheets (b) Beams with BFRP sheets

Figure (11): Energy absorption for all beams

Table 3: Deflection, crack loads, ultimate loads, stiffness, and energy absorption values of all beams.

beam	Δcr	Δu	P cr	P u	Stiffness at cack	Stiffness at ultimate	Energy absorption
B1	1.54	2.5	270	451.8	175.3	180.72	1885.28
B3-RO-V	2.64	4.14	178	298.69	67.4	72.1	1820.7
B4-RO-V-F	2.67	3.3	194	298.5	72.6	90.45	2633.64
B6-RO-H-F	3.93	5.9	210	353.9	53.4	59.98	2735.8
B8-CO-F	1.53	2.5	181	351.9	118.3	140.76	2169.5
B10-SO-F	3.2	3.82	240	312.5	75	81.8	4039.4

4. Equations used to Determine the ultimate loads expected for strengthened deep beams using ACI code

This paper presents 3 types of equations to determine ultimate loads in deep beams with opening strengthened with BFRP, there are equations to determine additional loads due to FRP (28) it has been applied using the properties of basalt fibers from testing 3 specimens of sheets roughed with sand to simulate the contact of basalt and concrete, other equations for ultimate loads in solid deep beams (29) and finally equations used to expect ultimate loads in deep beams with openings (30). As the results give good agreement for deep beams with openings when using ref.30, we could determine the ultimate loads for more specimens for deep beams with horizontal rectangle openings, circle, and square openings.

The 3 types are added together to determine the ultimate loads and are presented in table (4). From this table, it can be noted that good agreement between the experimental and the theoretical results as the variation ranged from (3-33)

4.1 Equations used to determine additional loads in strengthened beams with opening by ACI-440 Code (28)

The ACI-440 Code (15) provides an expression to calculate the additional shear strength provided by the FRP strips (***Vf***) as given by Eq. (1).

$$\boldsymbol{Vf} = \frac{Avf * ffe * (\sin\alpha + \cos\alpha) * dfv}{sf} \quad (1)$$

Where

A_{vf} is the area of the FRP strip within spacing (s_f) given by Eq. (2)

f_{fe} is the effective stress in the FRP strip given by Eq. (3)

α is the angle of FRP strip orientation about x-axis
d_{fv} is the effective depth of the FRP strip (distance from the center of flexural reinforcement to the extreme of the strip of fiber
s_f is the spacing center to center between strips in the vertical direction

$$A_{vf}=2*n*t_f*w_f \quad (2)$$

t_f is the FRP strip thickness (mm)
w_f is the FRP strip width (mm)

$$f_{fe}=\varepsilon_{fe}*E_f \quad (3)$$

ε_{fe} is the effective strain in the FRP strip given by Eq. (4)
E_f is the modulus of elasticity of the FRP strip (MPa)

$$\varepsilon_{fe}=k_v*\varepsilon_{fu}\leq 0.004 \quad (4)$$

ε_{fu} is the rupture strain of the FRP strip given by Eq. (5)
k_v is the bond-dependent coefficient given by Eq. (6)

$$\varepsilon_{fu}=\frac{ffu}{Ef} \quad (5)$$

f_{fu} is the ultimate tensile strength of FRP strip (MPa)

$$K_v=\frac{k1*k2*le}{11900\varepsilon fu} \quad (6)$$

K_1 is the modified concrete factor given by Eq. (7)
K_2 is the modified FRP scheme factor given by Eq. (8)
L_e is the active bond length of the FRP strip given by Eq. (9)

$$K_1=\left(\frac{f'c}{27}\right)^{2/3} \quad (7)$$

$$K_2=\frac{dfv-2le}{dfv} \text{ for two sides bonded} \quad (8\text{-a})$$

$$K_2=\frac{dfv-le}{dfv} \text{ for U-wrapped bonded} \quad (8\text{-b})$$

$$L_e=\frac{23300}{(nf*tf*Ef)^{0.58}} \quad (9)$$

n_f is the modular ratio of elasticity given by Eq. (10)

$$n_f=\frac{Ef}{EC} \quad (10)$$

E_c is the modulus of elasticity of concrete given by Eq. (11)

$$E_c=4700\sqrt{f'c}\,(MPa) \quad (11)$$

4.2 Equations used to determine the ultimate load of the deep beam without opening (B1) by ACI 318-8(29)

$$v_n=fce*\sin\theta s*b_w*w_s \quad (12)$$

where $fce = 0.85\beta s\, fc'$
$ws = \min[(wt \cos\theta s + wb \sin\theta s), (hc \cos\theta s + wb \sin\theta s)]$
βs for bottle-shaped struts with reinforcement satisfying Section A.3.3 of ACI 318-08
βs for bottle-shaped struts without reinforcement satisfying Section A.3.3 of ACI 318-08

4.3 Equations used to determine the ultimate loads of deep beams with opening by ASCE-ACI practice (30)

the simplified design expression for the strength of the beam with web openings can be written as

$$Qu/bD\ (= Pu/2bD) = 0.1\, f'c(\lambda 1)(\lambda 2)(\lambda 3) + 0.0085\, \psi s\, ps\, fsy + 0.01\psi w\, Kw\, rw\, fwy \quad (13)$$

$and\ Kw = 0.85\ (for\ a\ horizontal\ web\ bar);$
$cot\ ß\ (for\ a\ vertical\ web\ bar);$
$and\ 1.15\ (for\ inclined\ web\ bar)$

The equations of the coefficients $\lambda 1$, $\lambda 2$, $\lambda 3$, ψ_s and ψ_w are as follows

$\lambda1= (1-\frac{1}{3}(\frac{K1XN}{K2D}))$ for $(\frac{K1XN}{K2D}) \le 1$ (14)

$= \frac{2}{3}$ for $(\frac{K1XN}{K2D}) \ge 1$

where K_1X_N and K_2D are illustrated in figure (11)

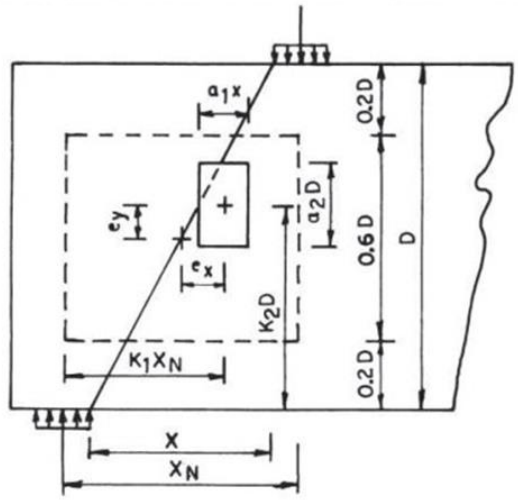


Figure (11): Typical position of an opening intercepting natural load path (17)

$\lambda2 = (1 - m)$ (15)

$\lambda_3= (0.85\pm0.3(\frac{ex}{Xnet}))\ (0.85\pm0.3(\frac{ey}{ynet}))$ (16)

Where m is the ratio of path length intercepted to total path length along the natural load path =0 for non-interception

where $e_x \le X_N/4$, $e_y \le 0.6D/4$

and $X_{net} = (X_N - a_1x)$, $Y_{net} = (0.6D - a_2D)$

$\rho_s = A_S/bD*100\%$ (17)

$r_w = \sum A_W/bD*100\%$ (18)

Table (4): Experimental and analytical increase in ultimate load

Type of opening	Pu expected (KN) Reference (29)and (30)	Vf (kN)(Ref. (28)	Increase in ultimate load*	Combined load due ACI and Ref. (30)	Experimental ultimate load Pu (kN)	Analytical /exp
B1	451.7(Ref.29)	-	-	-	451.8	1
B3-RO-V	300.578(Ref.30)	-	-	-	298	1
B4-RO-V-F	300.578(Ref.30)	48.3	96.6	397.2	298.5	1.33
B6-RO-H-F	299.26[Ref.30]	32.2	64.4	363.66	353.9	1.03
B8-CO-F	301.9[Ref.30]	37.17	74.34	376.24	351.9	1.07
B10-SO-F	305.35[Ref.30]	40.3	80.6	385.95	312.5	1.23

* increase in ultimate load = 2 x Vf

5. Finite element analysis

all beams have been simulated to make a comparison with the experimental results, by using ANSYS 19. The concrete material was simulated using SOLID65 elements, The steel bars for stirrups and reinforcements were simulated using LINK180 elements, solid 185 for the fiber materials, and SOLID 45 for plates. The main reinforcement has a yield stress of 360 N/mm^2 while the web horizontal and vertical reinforcement has a yield stress of 280 N/mm^2. The steel reinforcement had a modulus of elasticity of 200000MPa with a Poisson's ratio of 0.3. The material property of steel was defined as elastic-perfectly plastic material. The used resin is epoxy (Sikadur 330) had a tensile strength of 30 N/mm^2 and an ultimate elongation of 1.5%. the layer of epoxy is assumed to have a thickness of 0.3mm. According to the results of testing the basalt fiber sheets, the sheet has a typical thickness of 0.4mm, an average tensile strength of 894MPa, an elastic modulus of 50.5GPa, and with maximum elongation of 1.33%. The cured BFRP composite sheet was treated as an elastic orthotropic material up to failure to simulate its natural behavior. The elastic orthotropic material properties used are [Ex = 50.5GPa, Ey,z= 3.8 GPa, νxy,xz = 0.4, νyz = 0.3, Gxy,xz= 18GPa, and Gyz = 19.4GPa]. there are three plates representing the loading point and two supports hinged and roller as shown in figure (13), also this figure shows the details of reinforcement of the solid deep beams and others with the opening.

5.1 Results from FE analysis

Figure (14) shows the load-deflection curves of all beams from Ansys and experimental results, it is obvious from that figure that there is a good acceptable result between the experimental and FE load-deflection curves. Where the results differ from (1.2 to 10 %) in ultimate loads and differ from (7 to 36 %) in ultimate deflection. moreover, Table 5 shows the values of the failure load and mid-span deflection for all beams, and figure (15) shows a comparison of crack patterns in experimental and FE analysis

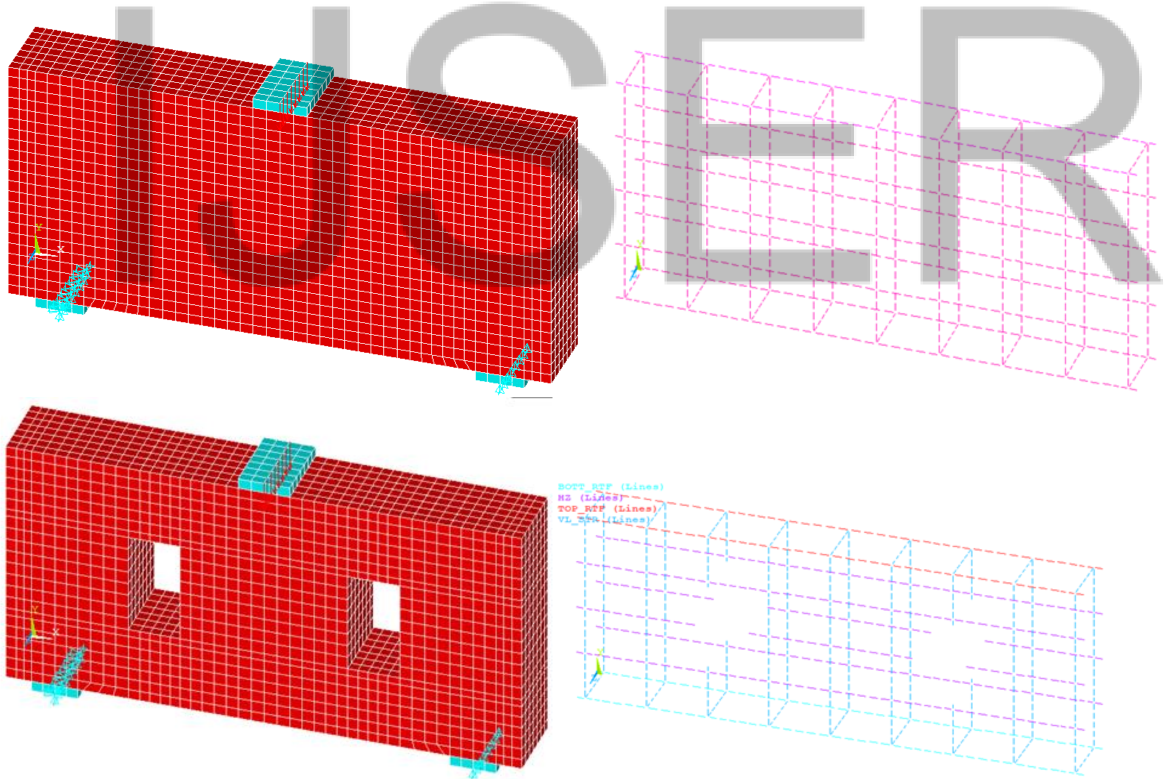


Figure (13): the loading system, meshing, and details of reinforcement for specimens in ANSYS

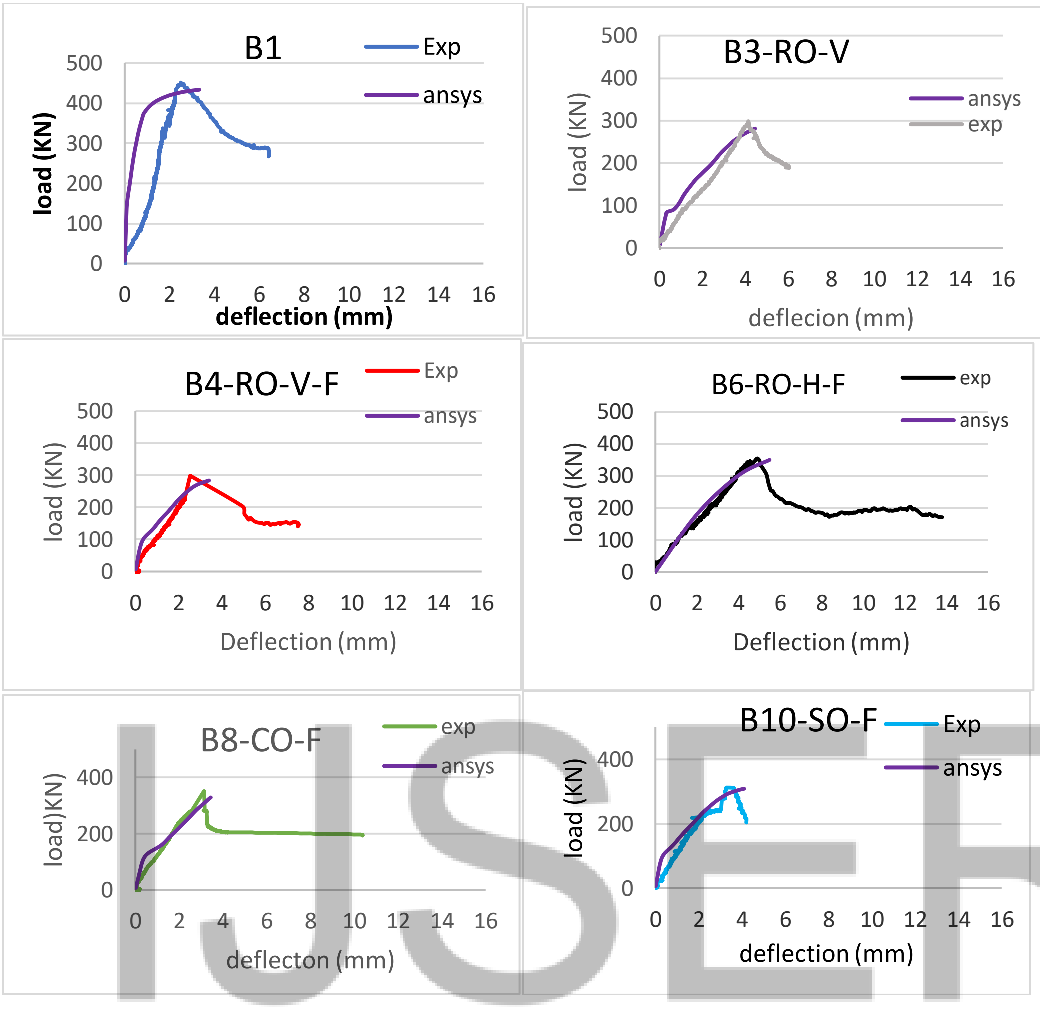


Figure (14): Comparison between ANSYS and experimental load-deflection curves for all beams

Table (5): loads and deflections values for all beams from experimental and nonlinear analysis

Beam no.	Max. load exp.	Max. load F. E	F.E/ exp. %	Max. deflection exp.	Max. deflection F. E	F.E/ exp. %
B1	451.8	433.8	96	2.5	3.33	1.32
B3-RO-V	298.6	281.4	94.2	4.14	4.45	1.07
B4-RO-V-F	298.5	283.9	95.1	3.3	4.54	1.36
B6-RO-H-F	353.9	349.3	98.7	4.9	5.49	1.12
B8-CO-F	351.9	329.12	93.5	3.14	3.44	1.09
B10-SO-F	312.5	308.91	98.8	3.82	3.9	1.02

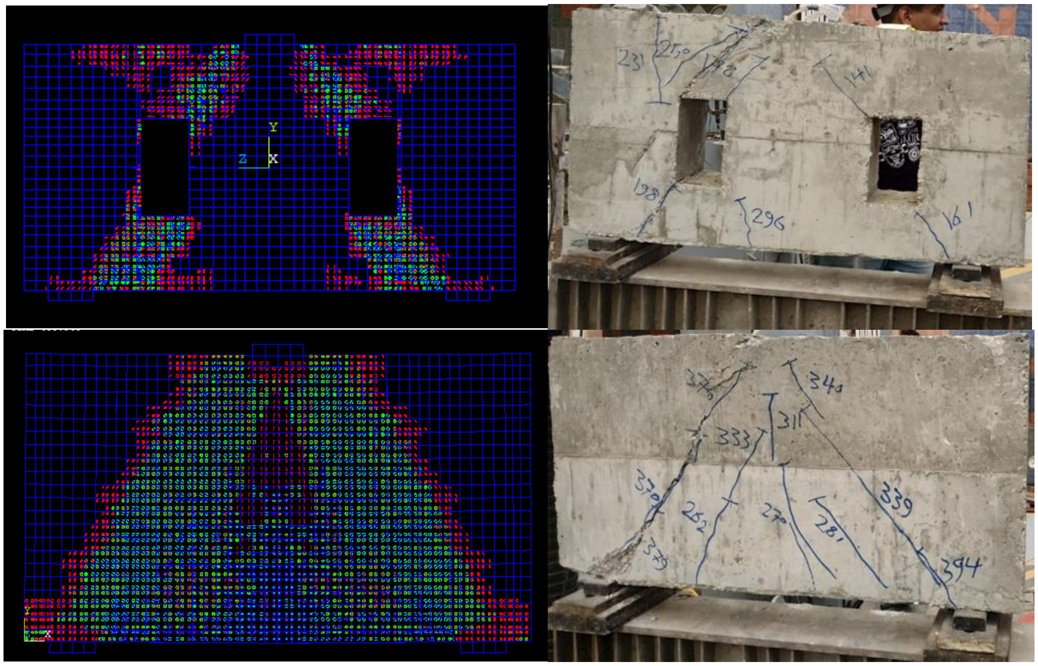


Figure (15): Comparison between nonlinear analysis and experimental crack pattern for some beams

6.1 Conclusion

Based on the experimental and finite element investigation of the strengthening of RC deep beams with openings using externally bonded unidirectional BFRP composites, the following conclusions are drawn:

1. Basalt fiber sheets make the cracking loads appear lately when compared to non-strengthened beams
2. BFRP sheets reduce the number of cracks in the deep beams with openings.
3. Openings in deep beams decrease the strength of the deep beams by (34, 33.7, 33.2, and 32.4) while strengthening these openings by vertical BFRP sheets enhances the strength of the deep beams with opening by (0, 12.1, 11.7 and 3.2) for vertical, horizontal, circular and square openings respectively
4. The horizontal rectangular strengthen openings are the best type of opening which could reach 78.4% of the beam's original structural capacity Contrary to what was usual previously that circular opening is the best type of opening, that may be because of the shear behavior of deep beams in the horizontal direction.
5. using BFRP in the beam with vertical openings did not improve the capacity of the deep beams with openings which may be because it needs more than 2 layers of basalt sheets
6. The analytical investigation used by this paper (ACI-440 code provisions and ASCE-ACI practice) is give good agreement results when compared with experimental results and also, nonlinear analysis using ANSYS gives acceptable results
7. Strengthening the beam with BFRP increase the stiffness of the deep beam in case of a rectangular vertical opening
8. The stiffness increased at the ultimate stage than that in the cracking stage in beams strengthen with BFRP sheets.

9. The energy absorption capacity is increased when the beam is strengthened with basalt fiber sheets of about 19 to 58.6 % for different types of opening

REFERENCES

1- Ramakrishnan V, Panchalan RK. A new construction Material—Non-corrosive basalt bar reinforced concrete. Special Publication. 2005 Sep 1; 229:253-70.
2- Shetty MS, Jain AK. Concrete Technology (Theory and Practice), 8e. S. Chand Publishing; 2019.
3- Ólafsson H, Þórhallsson E. Basalt fibre bar Reinforcement of concrete structures. Reykjavík University. 2009 Jan:5-12.
4- Yuan C, Chen W, Pham TM, Hao H. Effect of aggregate size on bond behavior between basalt fiber reinforced polymer sheets and concrete. Composites Part B: Engineering. 2019 Feb 1;158:459-74.
5- Branston, John-Sebastian. Properties and applications of basalt fiber reinforced concrete. Diss. University of Windsor (Canada), 2015.
6- PL. Meyyappan, M. Jemimah Carmichael, Studies on strength properties of basalt fiber reinforced concrete, Materials Today: Proceedings, Volume 43, Part 2,2021, Pages 2105-2108, ISSN 2214-7853,
7- High C, Seliem HM, El-Safty A, Rizkalla SH. Use of basalt fibers for concrete structures. Construction and Building materials. 2015 Oct 15;96:37-46.
8- Ahmed MM, Abdel Hafez AM, Assaf KA, Mohamed AK. Flexural behavior of basalt FRPRC beams under repeated load. JES. Journal of Engineering Sciences. 2014 Sep 1;42(5):1179-92.
9- Thorhallsson ER, Snaebjornsson JT. Basalt fibers as a new material for reinforcement and confinement of concrete. InSolid State Phenomena 2016 (Vol. 249, pp. 79-84). Trans Tech Publications Ltd.
10- M.M.Kamal, M.A,Safan, M.A.Hamada . Dynamic Analysis of Concrete Structures Reinforced with Basalt Fiber. International Journal of Advanced Engineering and Global Technology (2017) I Vol-05, Issue-02
11- Surya Sunder S, Nisha Babu, Dinu Paulose.Experimental Study on Strengthening of Openings in R.C Beams using BFRP Fabric. International Journal of Innovative Research in Science, Engineering and Technology, 2016 (Vol. 5, Issue 8)
12- Kadhim, Sara, and Mustafa Özakça. "Flexural performance of RC beams externally strengthened with a single-layer of basalt fiber reinforced polymer sheets." Composites and Advanced Materials 31 (2022): 26349833221102471.
13- de Paiva HR, Siess CP. Strength and behavior of deep beams in shear. Journal of the Structural Division. 1965 Oct;91(5):19-41.
14- Ramakrishnan V, Ananthanarayana Y. Ultimate strength of deep beams in shear. InJournal Proceedings 1968 Feb 1 (Vol. 65, No. 2, pp. 87-98).
15- Arabzadeh A. Analysis of some experimental results of simply supported deep beams using truss analogy method. Iranian Journal of Science and Technology. Transaction B, Technology. 2001;25(1):115-28
16- Campione G, Minafò G. Behaviour of concrete deep beams with openings and low shear span-to-depth ratio. Engineering Structures. 2012 Aug 1;41:294-306.
17- Tseng, C.C.,Hwang, Shyh-Jiann, and Wen-Yao Lu. Shear strength prediction of reinforced concrete deep beams with web openings. ACI Structural Journal, Vol. 114, no.6, pp.1569-1580, 2017

18- Karimizadeh H, Arabzadeh A. A STM-based analytical model for predicting load capacity of deep RC beams with openings. In structures 2021 Dec 1 (Vol. 34, pp. 1185-1200). Elsevier.
19- El-Kareim A, Arafa A, Hassanin A, Atef M, Saber A. Behavior and strength of reinforced concrete flanged deep beams with web openings. InStructures 2020 Oct 1 (Vol. 27, pp. 506-524). Elsevier.
20- Ghali MK, Said M, Mustafa TS, El-Sayed AA. The behavior of T-shaped RC deep beams with openings under different loading conditions. InStructures 2021 Jun 1 (Vol. 31, pp. 1106-1129). Elsevier.
21- El Maaddawy T, Sherif S. FRP composites for shear strengthening of reinforced concrete deep beams with openings. Composite Structures. 2009 Jun 1;89(1):60-9.
22- Hawileh RA, El-Maaddawy TA, Naser MZ. Nonlinear finite element modeling of concrete deep beams with openings strengthened with externally-bonded composites. Materials & Design. 2012 Dec 1;42:378-87.
23- WY Lu, HW Yu, CL Chen, SL Liu "High-strength concrete deep beams with web openings strengthened by carbon fiber reinforced plastics." Computers and Concrete (2015) 192.192.83.167.
24- Rahim NI, Mohammed BS, Al-Fakih A, Wahab MM, Liew MS, Anwar A, Amran YM. Strengthening the structural behavior of web openings in RC deep beam using CFRP. Materials. 2020 Jun 22;13(12):2804.
25- Khalaf MR, Al-Ahmed AH, Allawi AA, El-Zohairy A. Strengthening of continuous reinforced concrete deep beams with large openings using CFRP strips. Materials. 2021 Jun 6;14(11):3119..
26- Karimizadeh H, Arabzadeh A, Eftekhar MR, Amani Dashlejeh A. Shear Strengthening of RC Deep Beams with Symmetrically or Asymmetrically Positioned Square Openings Using CFRP Composites and Steel Protective Frames. Advances in Civil Engineering. 2022 Sep 19.
27- Hussain Q, Pimanmas A. Shear strengthening of RC deep beams with openings using sprayed glass fiber reinforced polymer composites (SGFRP): part 1. Experimental study. KSCE Journal of Civil Engineering. 2015 Nov;19(7):2121-33.
28- ACI Committee 440.2R, 2011, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures, American Concrete Institute, Detroit, USA.
29- ACI Committee 318 (2019), Building code requirements for structural concrete (ACI 318-19) and commentary. Detroit
30- Ray SP. Deep beams with web openings. Reinforced concrete deep beams. 1990 Jun 15:288.