

Ultimate Shear Strength of Fibrous Reinforced Concrete Deep Beam With Various Sizes of Square Web Openings Under Shear-Control Loading

Dhyaa A. Al-Sattar^{1*}Jasim A. Abdulla¹¹Department of Civil Engineering, College of Engineering, University of Mosul, Mosul, Iraq*Corresponding author E-mail: dhyaa.23enp47@student.uomosul.edu.iq

Received:	10/2/2026	Accepted:	22/6/2026	Published:	28/6/2026
-----------	-----------	-----------	-----------	------------	-----------

Abstract

In practice, in high-rise buildings, especially in reinforced concrete deep beams bearing high axial loads, openings may be located in the zone of maximum shear force and zero bending moment (shear control), and this may be a serious problem if the shear strength of these beams is not predicted. Therefore, this study aimed to investigate the ultimate shear strength in this case (shear control) experimentally and compare the results with analytical equations to make it easier for those working in this field to use these equations when needed. In this research, the experimental deep beam specimens were divided into two groups. The first group consists of three reinforced concrete deep beams as normal concrete beams; the first is solid, and the second and third have square openings of 200 mm and 300 mm, respectively. The second group has the same arrangement as the first group, with the addition of 0.75% steel fibers to the concrete mix as fibrous concrete deep beams. The experimental results indicated that the presence of square openings with sharp corners leads to a reduction in the ultimate shear strength of the beams due to the interruption of the load transfer path. Steel fibers improved the performance of the beams, increased the cracking load, and delayed the failure load. The Kong and Sharp equation was used for reinforced concrete deep beams (solid and with opening), the ratio of experimental to analytical ultimate shear strength for the fibrous reinforced concrete deep beams was 0.998 for the solid beam, 1.162 and 1.585 for beams with 200 mm and 300 mm square openings, respectively. For the normal reinforced concrete deep beams, the ratios were 0.871 for the solid beam, 1.167 and 1.245 for beams with 200 mm and 300 mm square openings, respectively. In general, the analytical results were close agreement with the experimental results. Therefore, these equations can be reliably used to predict the ultimate shear strength of normal and fibrous reinforced concrete deep beams with openings located in the region of maximum shear forces and zero bending moments (shear control).

Keywords : Deep beam , Web opening , Shear control , Fibrous concrete.

1. Introduction

Reinforced concrete deep beams are of great importance in structural engineering. They are used in bridges, tanks, pile caps, and high-rise buildings. Their importance is especially

significant in high-rise buildings because they transfer high axial loads from the upper floors to the foundations and soil [1,2]. According to ACI Code 318-19, deep beams are "members loaded on one face and supported on the opposite face such that strut-like compression elements can be developed between the loads and supports" and the clear-span-to-total-depth ratio is less than four, and concentrated loads are located at a distance of $2h$ from the support face [3].

In practice, openings in reinforced concrete deep beams are used for the passage of some services such as electrical, mechanical, internet networks, etc. The problem with these openings is that they lead to significant weakness in these beams and a decrease in stiffness and strength, especially if the location of these openings intersects with the natural load transfer path [4,5]. Therefore, in recent years, researchers have developed various technologies to enhance the efficiency and performance of structural members, such as carbon fibers, glass fibers, steel fibers, etc. Steel fibers play an effective role in enhancing mechanical properties, such as compressive and tensile strength. They also play an effective role in delaying the appearance of cracks, increasing stiffness and maximum load, etc. [6,7].

Many previous studies have investigated the effect of adding steel fibers in reinforced concrete deep beams with openings, as well as the effect of the shape, size, and location of the openings and the effect of the shear span-to-the depth ratio (a/d) on the behavior and performance of reinforced concrete deep beams.

Waleed A. Jasim et al. (2019) [8] conducted an experimental and numerical investigation of five simply supported reinforced concrete deep beams with square openings in shear span. The result showed that moving the openings from the mid-span of the shear region to the inner boundaries results in stiffer behavior and reduced deflection. Zeinab Reda et al. (2021) [9] conducted a numerical study on the performance of reinforced concrete continuous deep beams with openings using different sizes of square openings (250 x 250) mm and (350 x 350) mm. Moreover, three types of steel fibers were used (end-hooked fibers, end corrugated rounded fibers, and end corrugated segmented fibers). The researchers concluded that the end-hooked steel fibers gave better results compared to the other types. In addition, it is preferable that the openings be located along the center line of the beam.

Mohammed R. Khalaf et al. (2021) [10], Al-Mahbashi et al. (2023) [11] conducted an experimental investigation on reinforced concrete continuous deep beams with openings located in (external shear span, internal shear span, and mid-span under load). The experimental results indicated that creating large openings in the external or internal shear span leads to a significant decrease in the ultimate load and stiffness. Therefore, it is preferable for these openings to be located in the mid-span region.

Mona Saleh et al. (2023) [12] conducted a numerical study using the Abaqus program. Several parameters were tested, including the shear span to the depth ratio (a/d), the opening size

and location, concrete compressive strength, the main and web reinforcement ratio, researches concluded the ultimate load increased with a decreasing shear span to the depth ratio (a/d), and that an opening located in the shear zone significantly reduces ultimate load due to high concentration of shear cracks at the corners of the opening.

Mazura et al. (2025) [13] conducted an experimental study on fibrous reinforced concrete deep beams with mid-span opening, the results indicate that steel fiber reinforced concrete exhibits superior compressive and flexural strength compared to normal concrete, incorporating just 1% steel fiber by volume can increase the load at which first crack appears in a deep beam with web opening by at least 50%.

However, there are many studies on the behavior and performance of reinforced concrete deep beams with openings and the effect of many parameters such as the presence of steel fibers, shear span to the depth ratio (a/d), the shape, size, and location of the openings, and the concrete compressive strength. Researchers have not studied the reinforced concrete deep beams when the openings are located in a region with maximum shear force and zero bending moment (shear control), this condition may be in reinforced concrete continuous deep beams, where in a region with maximum shear force and zero bending moment, as shown in Fig.(1).

This research paper aims:

- Conduct an investigation of the ultimate shear strength of fibrous reinforced concrete deep beams with various sizes of square openings located in the region of maximum shear force and zero bending moment (shear control), as shown in Fig (2).
- To estimate the ultimate shear strength of fibrous reinforced concrete deep beams with various sizes of square openings located in the region of maximum shear strength and zero bending moment (shear control) using the equations developed by previous researchers and comparing the analytical with experimental results.

2. Research Methodology

The plan of this research paper, as shown in Fig (3), is:

- Experimental testing of fiber-reinforced concrete deep beams with different sizes of square openings located in the region of maximum shear force and zero bending moment (shear control), finding the ultimate load for these beams, and then determining the ultimate shear strength.
- Testing the mechanical properties of fibrous concrete and normal concrete (compressive strength and splitting tensile strength).
- Estimating the ultimate shear strength of fibrous reinforced concrete deep beams tested experimentally using some equations from previous researchers, and compare the experimental with analytical results.

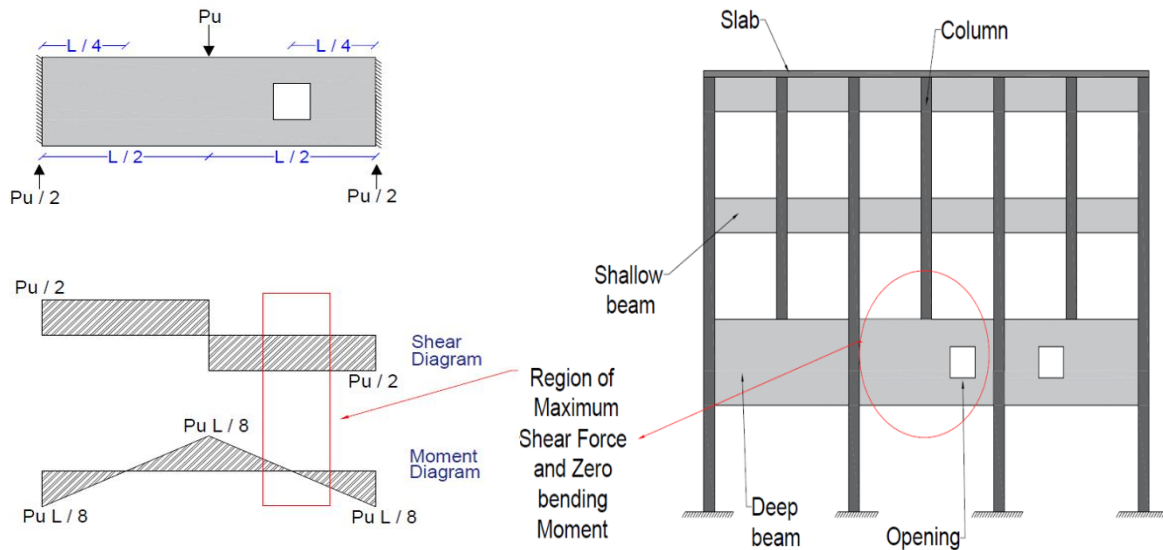


Fig. 1 Continuous deep beam with an opening located in the zone of maximum shear force and zero bending moment

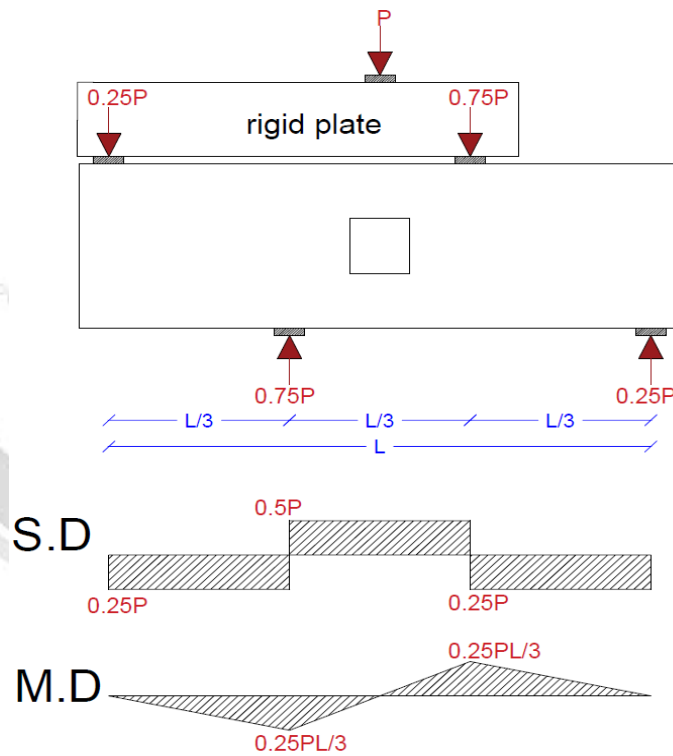


Fig. 2 Load application under shear-control loading

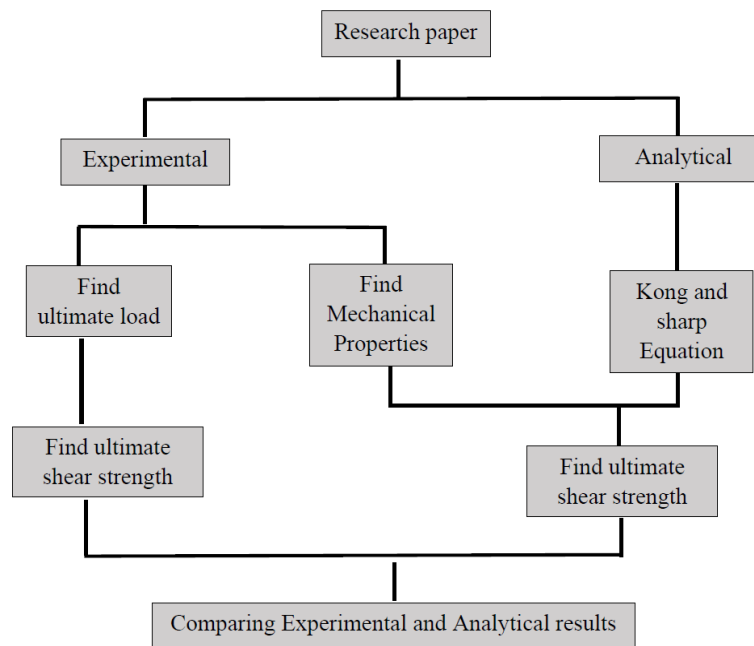


Fig. 3 Summary of the work in this paper

3. Specimen Details

In this study, six reinforced concrete deep beams with and without square web openings were prepared and tested. The beams were divided into two groups: the first group contained three beams of normal concrete, and the other group had three beams containing steel fibers with 0.75% of the mix volume.

In each group, there was a solid deep beam as a reference, and the other beams had a square opening 200 x 200 mm and 300 x 300 mm, respectively. The dimensions of each beam are (2000 mm) in length, (600 mm) in depth, (150 mm) in width. Table (1) shows the details of the beams in this study. The beams are named as follows: (FC) for fibrous concrete and (NC) for normal concrete, (WO) for solid beam (without opening), (W200) and (W300) for the beams with openings (200 x 200 mm) and (300 x 300 mm), respectively

Table .1 Specimens details

Group	Opening Size (mm)	Specimens Designations
Normal Concrete	-----	NC-WO
	200 x 200	NC-W200
	300 x 300	NC-W300
Fibrous Concrete	-----	FC-WO
	200 x 200	FC-W200
	300 x 300	FC-W300

All beams were designed based on ACI-Code 318-19 [3]. Deformed steel bars with diameters $\text{Ø}12$ mm and $\text{Ø}10$ mm were used, the yield stress and ultimate strength for $\text{Ø}10$ mm are 522 MPa and 760 MPa, and for $\text{Ø}12$ mm are 610 MPa and 803 MPa respectively, 3 $\text{Ø}12$ mm are used for flexural reinforcement, and 2 $\text{Ø}10$ are used for top reinforcement; the horizontal and vertical shear reinforcement are $\text{Ø}10@275$ mm and $\text{Ø}10@300$ mm, respectively. Vertical shear reinforcement was intensified at a distance of 50 mm at load application point and supports to avoid crushing of the deep beam during testing. In addition, 2 $\text{Ø}10$ mm with ($L=70$ cm) is added at top and bottom of openings as additional reinforcement. Fig. (4) shows the reinforcement details of specimens.

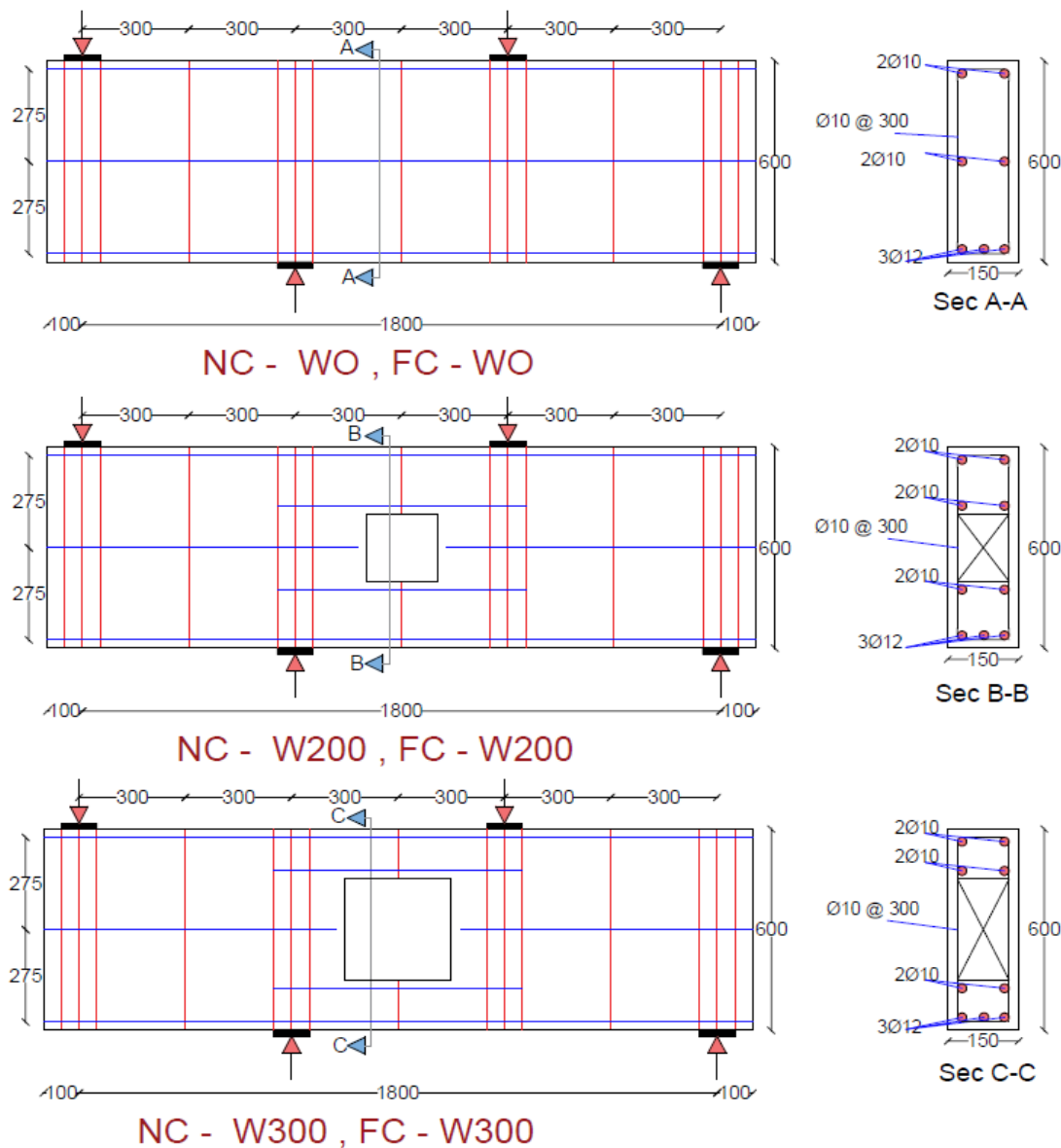


Fig. 4 Reinforcement layout for tested beams

4. Material Properties

Crimped steel fibers with properties shown in Fig. (5) were used in this study. The fiber tensile strength is up to 1100 MPa, ordinary Portland cement was used in this study. The physical and chemical properties were tested according to Iraqi specification (IQS NO.45/1984) [14], fine aggregate and coarse aggregate with a maximum size of 12.5 mm were used and tested according to Iraqi specification (IQS.NO.45/1984) [15].

The concrete mix was designed according to ACI 211 [16] with a compressive strength of up to 30 MPa, and the mix proportion is (1 : 2.1 : 2.76) for cement, sand and gravel and the water/cement ratio is (0.48). Table (2) shows the weights of materials used in the casting process.

The wooden formworks for casting reinforced concrete deep beams were made of plywood with dimensions of (2000 x 600 x 150 mm). Six cubes (150 x 150 x 150 mm) and six cylinders (150 x 300) of fibrous concrete and normal concrete were cast. The compressive strength and splitting tensile strength were tested at the age of 28 days and also during the testing of reinforced concrete deep beams.

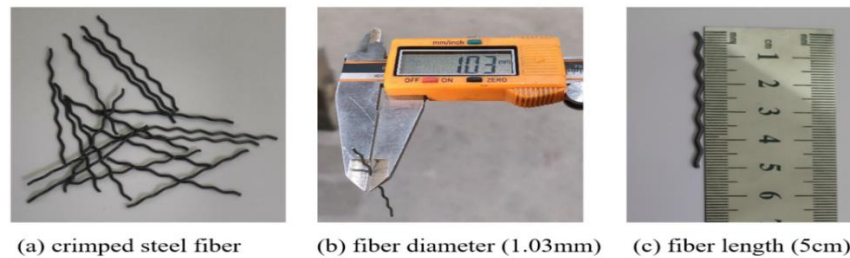


Fig. 5 Properties of crimped steel fibers

5. Casting and Testing Deep Beam

A central mixer was used for casting the reinforced concrete deep beams. A vibrator was used for the compacting process. The specimens were also leveled using a leveling tool, as shown in Fig. (6-a). After one day of casting, the wooden formwork was opened, and the specimens were covered with burlap to maintain moisture in the specimens as shown in Fig. (6-b). After that, the beams were painted and prepared for testing in the Construction Materials Testing Laboratory at the University of Mosul at the age of 28 days as shown in Fig. (6-c). The beams were tested with a device that can withstand 1000 kN as shown in Fig. (6-d).

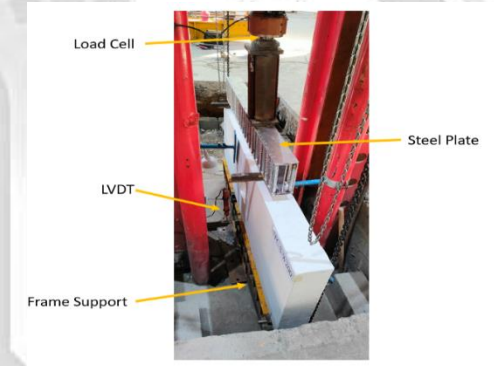


(a) Casting

(b) Curing



(c) Painting



(d) Testing

Fig. 6 Casting, Curing, painting and Testing

6. Results and Discussions

6.1 Mechanical Properties

6.1.1 Compressive Strength

Compressive strength cubes were tested according to BS-1881-116 [17]. Six cubes of fibrous concrete (FC) and other six of normal concrete (NC) were tested. For each normal and fibrous concrete, three cubes were tested at 28 days, and other three testing during the testing of reinforced concrete deep beams. Table (2) shows the results of the compression cubes test. The average compressive strength of normal and fibrous concrete at 28 days was 31.75 MPa and 33.35, respectively. The results indicate that the inclusion of fibers led to an approximate 5% increase in compressive strength. This improvement can be attributed to the role of fibers in restricting the propagation of micro-cracks within the concrete under compressive loading, improving stress distribution capacity, and delaying failure. The results further demonstrate that, at advanced ages, the steel fiber enhances the ductility and load-carrying capacity of concrete, even after prolonged curing periods.

Table .2 Result of Compressive Strength Test

Group No	Cube No	testing time	f_{cu} (MPa)	average	Group No	Cube No	testing time	f_{cu} (MPa)	average
Normal concrete (NC)	1	At 28 days	31.92	31.75	Fibrous concrete (NC)	1	At 28 days	33.51	33.35
	2		30.47			2		34.02	
	3		32.87			3		32.53	
	4	At testing beam	33.11	33.61		4	At testing beam	35.00	35.29
	5		34.66			5		35.29	
	6		33.06			6		35.58	

f_{cu} : Cube compressive strength

6.1.2 Splitting Tensile Strength

Splitting tensile strength of six cylinders of fibrous concrete (FC) and another six of normal concrete (Nc) was tested according to ASTM C496-17 [18]. Table (3) shows the results of the splitting tensile strength test of the cylinders. The average results at 28 days and during deep beam testing were 1.86 MPa and 2.26 MPa for normal concrete, 2.41 MPa and 3.13 MPa for fibrous concrete. The average increase in splitting tensile strength was 29.5% at 28 days and 38.4% during the testing of reinforced concrete deep beams. These results confirm the role of steel fibers in improving the tensile strength and controlling diagonal cracks of these cylinders.

Table. 3 Result of Splitting strength test

Group No	Cylinder No	testing time	F_t (MPa)	average	Group No	cylinder No	testing time	F_t (MPa)	average
Normal concrete (NC)	1	At 28 days	2.19	1.86	Fibrous concrete (NC)	1	At 28 days	2.53	2.41
	2		1.76			2		2.37	
	3		1.62			3		2.34	
	4	At testing beam	2.31	2.26		4	At testing beam	3.10	3.13
	5		2.26			5		2.98	
	6		2.21			6		3.32	

F_t : Splitting tensile strength

6.2 Ultimate Shear Strength of Deep Beam

The results of the ultimate load values for all tested beams are summarized in Table (4). The ultimate load values for the normal reinforced concrete deep beams NC-WO, NC-W200, and NC-W300 were 462.7 kN, 287.0 kN, and 210.0 kN, respectively. As for the fibrous reinforced concrete deep beams, the ultimate loads for beams FC-WO, FC-W200, and FC-W300 were 657.1 kN, 313.0 kN, and 272.0 kN, respectively. The steel fibers increased the ultimate load by 42%, 9%, and 29%. This demonstrates the role of steel fibers in improving the mechanical properties of deep beams, delaying the appearance of initial shear and flexural cracks, and increasing the ultimate load.

The ultimate shear strength (V_u) for all the beams tested experimentally was calculated from the shear force diagram as shown in Figure (2), where the value of the ultimate shear strength is ($V_u = 0.5 P_u$). Table (4) shows the ultimate shear strength for all beams tested.

Creating openings in reinforced concrete beams leads to a significant decrease in the ultimate load of these beams, especially if openings are located in the natural load transmission path. For normal reinforced concrete deep beams, the presence of openings (200 x 200 mm) and (300 x 300 mm) led to a decrease in the ultimate load by 38% and 55%, respectively, compared to the solid beam. As for the fibrous reinforced concrete deep beams, the presence of openings (200 x 200 mm) and (300 x 300 mm) led to a decrease in the ultimate load by 53% and 59% respectively. Table (5) shows the percentage of decrease in the ultimate load of the deep beam with openings compared to the solid beam.

Table. 4 ultimate shear strength of reinforced concrete deep

Beam (Normal)	P_u	$V_{u (exp)} = 0.5 P_u$	Beam (Fibrous)	P_u	$V_{u (exp)} = 0.5 P_u$	P_F / P_N
NC-WO	462.7	231.35	FC-WO	657.1	328.55	1.42
NC-W200	287.0	143.50	FC-W200	313.0	156.50	1.09
NC-W300	210.0	105.00	FC-W300	272.0	136.00	1.29

P_u : ultimate load (kN)

P_F : ultimate load fibrous concrete deep beam (kN)

P_N : ultimate load Normal concrete deep beam (kN)

$V_{u (exp)}$: ultimate shear strength (kN)

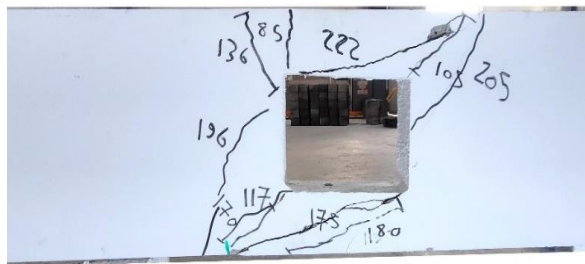
Table. 5 Percentage decrease in ultimate load due to opening

Beam (Normal)	P_u	P_o / P_s	Beam (Fibrous)	P_u	P_o / P_s
NC-WO	462.7	1.00	FC-WO	657.1	1.00
NC-W200	287.0	0.62	FC-W200	313.0	0.47
NC-W300	210.0	0.45	FC-W300	272.0	0.41

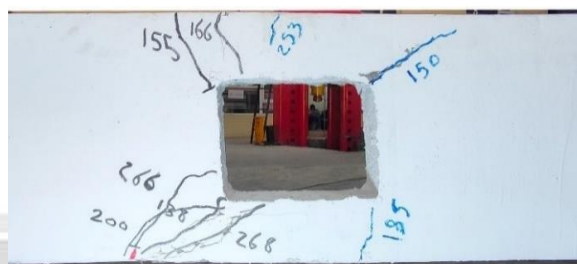
P_u : ultimate load (kN)

P_o : ultimate load of beam with opening (kN)

P_s : ultimate load of solid beam (kN)



(d) NC-W300



(d) FC-W300

Figure (7) Crack Pattern of Deep beams**Table (6) Cracking load and Mode of Failure**

Beam Code	F_{cr}	S_{cr}	P_u	$\frac{F_{cr}}{P_u}$	$\frac{S_{cr}}{P_u}$	Failure Mode
NC-WO	180	302	462.7	0.38	0.65	Shear
NC-W200	103	135	287.0	0.35	0.47	Shear
NC-W300	85	105	210.0	0.40	0.50	Shear
FC-WO	200	287	657.1	0.30	0.43	Shear
FC-W200	185	120	313.0	0.59	0.38	Shear
FC-W300	138	166	272.0	0.50	0.61	Shear

F_{cr} = First flexural cracking load (kN)

S_{cr} = First Shear cracking load (kN)

P_u = Ultimate load (kN)

6.3 Analytical equations

Kong and Sharp (1977) [19] conducted an experimental investigation on reinforced concrete deep beams with web openings. They cast thirty-two reinforced concrete deep beam specimens. Based on the experimental results, the researchers proposed an empirical equation to estimate the ultimate shear strength of reinforced concrete deep beams. The researchers assumed that the load is transmitted in deep beams with openings from the point of load application to the support point through paths ABC and AEC, as shown in Fig (8). As for solid beams, the load is transmitted radially without any interruption. The shear strength of solid and deep beams with openings was calculated using some definitions related to the size and location of the opening and the shear-span-to-depth ratio.

diagonal crack represented by the paths **CB** and **EB**, as shown in Figure (8)

C_1 : Emperical Cofficent (1.4 for Normal strength concrete
and 1.35 for light weight concrete)

C_2 : Emperical Cofficent (300 N/mm^2 for deformed steel bar
and 130 N/mm^2 for plain steel bars)

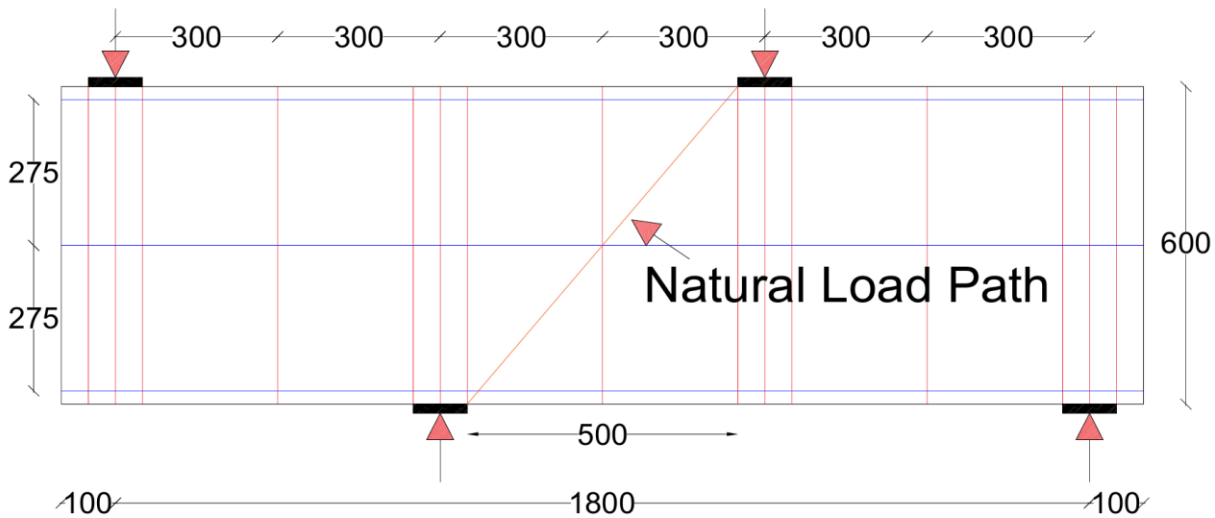
λ : Emperical Cofficent (1.5 for web bars
and 1 for main bars)

k_1x & k_2D : Coefficients to define the coordinates of the opening location
in the beam as shown in the Figure (8)

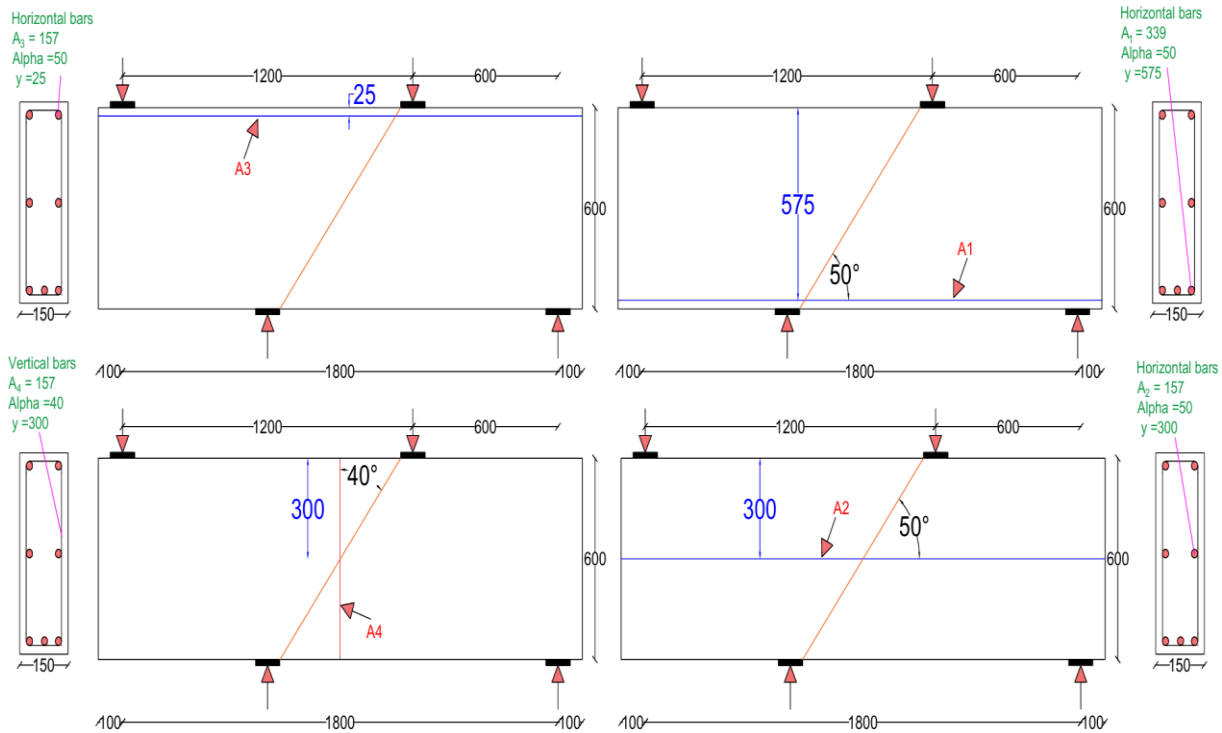
A : Area of reinforcement bars (mm^2)

α_1 : angle between the intersection of the reinforcing steel and the diagonal crack. as shown in the Figure (8)

This equation will be applied to all experimental deep beam specimens as shown in Figures (9), (10), and (11) and compare the analytical with the experimental results. Table (7) shows the ratio between experimental and analytical results.

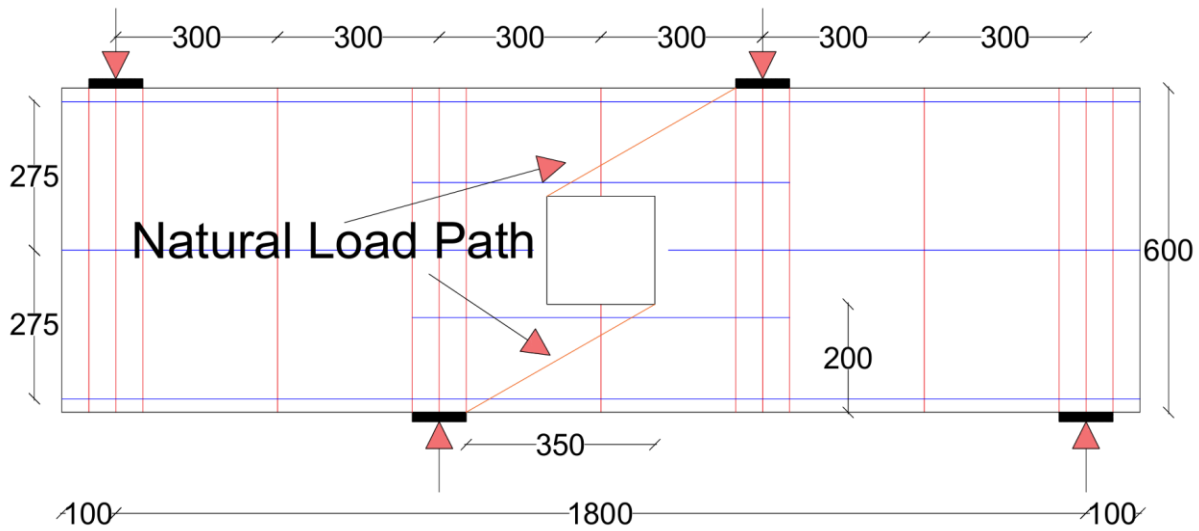


(a) Natural load path of beams (NC-WO, FC-WO)

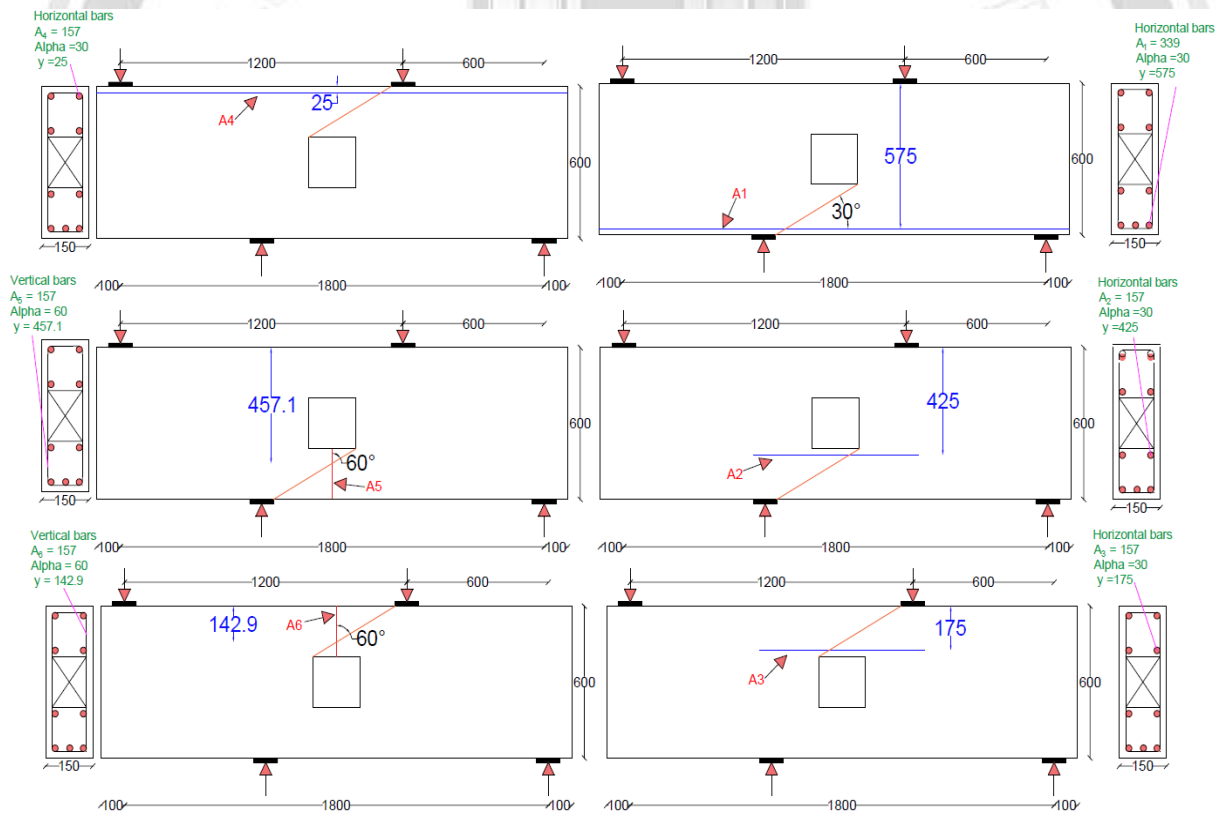


(b) Distance of each bar to the top of beams (NC-WO,FC-WO)

Fig. 9 Structural idealization of deep beams (NC-WO, FC-WO) according to Kong and Sharp

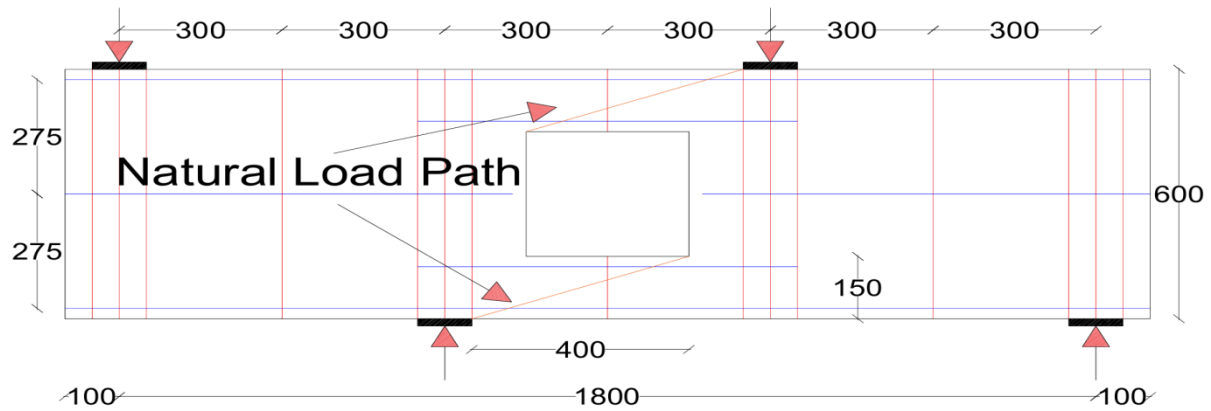


(a) Natural load path of beams (NC-W200, FC-W200)

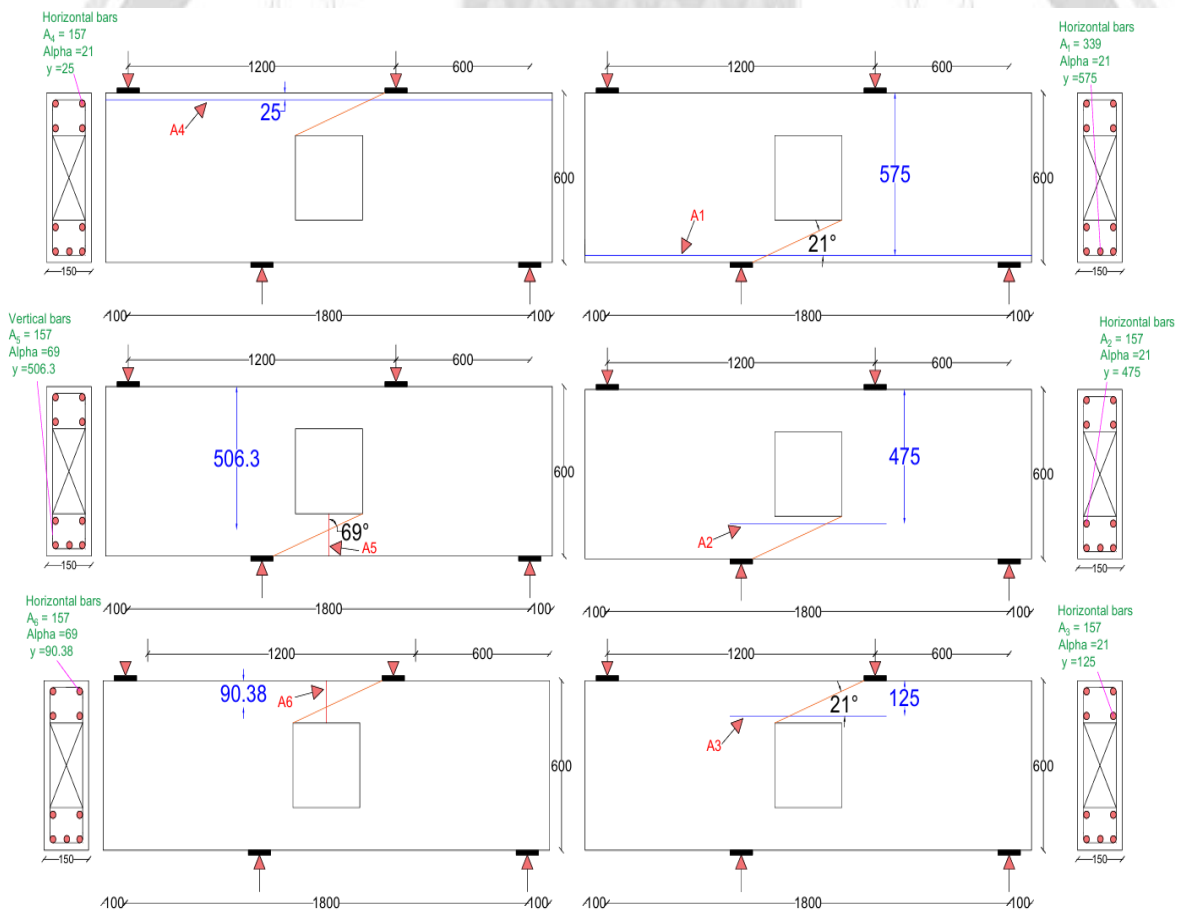


(b) Distance of each bar to the top of beams (NC-W200,FC-W200)

Fig. 10 Structural idealization of deep beams (NC-W200,FC-W200) according to Kong and Sharp



(a) Natural load path of beams (NC-W300, FC-W300)



(b) Distance of each bar to the top of beams (NC-W300, FC-W300)

Fig. 11 Structural idealization of deep beams (NC-W300, FC-W300) according to Kong and Sharp

Table. 7 Comparing between experimental and analytical results

Beam NO	Bar Direction	A	A (mm ²)		Y (mm)		α	$\sum \sigma_c A_i Y_i^2 \times 10^6$	f _t (MPa)	Y/D	k ₁ X (mm)	k ₂ D (mm)	C ₁ 1 - 0.35 (Y ₁ /D) f _c b ₁ D	C ₁ 1 - 0.35 (Y ₂ /D) f _c b ₂ D	V _u (anal) (kN)	V _u (exp) (kN)	V _u (exp)/V _u (anal)	
			A ₁	A ₂	Y ₁	Y ₂												a ₁
NC-W0	Horiz bars	-	A ₁	339	Y ₁	575	a ₁	50	81.9	2.06	500/600	-	-	183.6	-	265.5	231.35	0.871
		-	A ₂	157	Y ₂	300	a ₁	50										
		-	A ₃	157	Y ₃	25	a ₁	50										
FC-W0	Horiz bars	-	A ₁	339	Y ₁	575	a ₁	50	81.9	2.77	500/600	-	-	247.3	-	329.2	328.55	0.998
		-	A ₂	157	Y ₂	300	a ₁	50										
		-	A ₃	157	Y ₃	25	a ₁	50										
NC-W200	Horiz bars	1	A ₁	339	Y ₁	575	a ₁	30	89.6	2.06	-	350	200	-	33.5	123	143.5	1.167
		1	A ₂	157	Y ₂	425	a ₁	30										
		1	A ₃	157	Y ₃	175	a ₁	30										
FC-W200	Horiz bars	1	A ₁	339	Y ₁	575	a ₁	30	89.6	2.77	-	350	200	-	45	134.6	156.5	1.162
		1	A ₂	157	Y ₂	425	a ₁	30										
		1	A ₃	157	Y ₃	175	a ₁	30										
NC-W300	Horiz bars	1	A ₁	339	Y ₁	575	a ₁	21	80	2.06	-	400	150	-	4.3	84.3	105	1.245
		1	A ₂	157	Y ₂	475	a ₁	21										
		1	A ₃	157	Y ₃	125	a ₁	21										
FC-W300	Horiz bars	1	A ₁	339	Y ₁	575	a ₁	21	80	2.77	-	400	150	-	5.81	85.8	136	1.585
		1	A ₂	157	Y ₂	475	a ₁	21										
		1	A ₃	157	Y ₃	125	a ₁	21										
FC-W300	Vert bars	1.5	A ₄	157	Y ₄	506	a ₁	69	80	2.77	-	400	150	-	5.81	85.8	136	1.585
		1.5	A ₅	157	Y ₅	506	a ₁	69										
		1.5	A ₆	157	Y ₆	90.4	a ₁	69										

C₁ = 1.4

C₂ = 300

f_t = average value of six tested cylinders: (2.06 MPa) for normal concrete and (2.77 MPa) for fibrous concrete.

7. Conclusion

Based on the experimental and analytical results, the following can be concluded:

- The addition of steel fibers improved the mechanical properties of the concrete (compressive strength, splitting tensile strength). The steel fibers enhanced and increased the results and delayed the failure of cubes and cylinders even after long curing periods.
- The average increase in splitting tensile strength due to steel fibers was 29.5% at 28 days and 38.4% during the deep reinforced concrete beam testing; these results confirm the role of steel fibers in improving the tensile strength and reducing diagonal cracking of these cylinders.
- Creating square openings within the shear span of reinforced concrete deep beams, intended for the passage of electrical, mechanical, and other services, led to the weakening of the load-carrying capacity of these beams and interrupted the natural load transfer path from the top of the beam to its supports.
- When it is necessary to create openings within reinforced concrete deep beams, circular openings are preferable to square or rectangular ones, as the latter have sharp edges and corners that significantly weaken the shear strength of the beams.
- The addition of steel fibers resulted in a 42% increase in shear strength in the solid beam compared to beams with square openings (200 mm and 300 mm), where the increase in shear strength was 9% and 29%, respectively. The significant increase (42%) in the solid beam is due to the absence of the influence of square openings, which allows for normal load transfer and optimal performance of the steel fibers.
- An increase in the size of square openings led to a reduction in the shear and flexural cracking load for all beams compared to solid beams. On the other hand, the geometric characteristics of square openings lead to a high concentration of stresses at sharp edges and corners, thus creating a large weak area around the openings. Steel fibers play a role in reducing the width of cracks through crack bridging, thus improving the performance of reinforced concrete deep beams. Steel fibers also reduce crack propagation, thus reducing the concentration of stresses around openings.
- The ratio between the experimental and analytical results for beams (NC-WO, FC-WO) was 0.871 and 0.998 respectively. As for beams with the square opening (NC-W200, FC-W200), the ratio was 1.167 and 1.162. The analytical results show a good agreement with the experimental results. Therefore, these equations can be reliably used to predict the ultimate shear strength of normal and fibrous reinforced concrete deep beams with openings located in the region of maximum shear forces and zero bending moments (shear control).
- The ratios of experimental to analytical results for beams NC-W300 and FC-W300 were 1.245 and 1.585, respectively. Due to the presence of the large square opening (300 mm), the analytical equation underestimates the beam's actual load-bearing capacity. This conservative prediction is a highly desirable attribute for ensuring safe structural design.

References

- [1]Sahoo, D. R., Flores, C. A., & Chao, S. H. (2012). Behavior of Steel Fiber-Reinforced Concrete Deep Beams with Large Opening. *ACI Structural Journal*, 109(2).
<https://www.researchgate.net/publication/257763431>
- [2]Nayak, C. B. (2022). Experimental and numerical study on reinforced concrete deep beam in shear with crimped steel fiber. *Innovative Infrastructure Solutions*, 7(1), 41.
<https://doi.org/10.1007/s41062-021-00638-2>
- [3]American Concrete Institute (2019) *Building Code Requirements for Structural Concrete (ACI 318-19)*, USA, ch9. Sec.9 pp 152.
- [4]El-Kareim, A., Arafa, A., Hassanin, A., Atef, M., & Saber, A. (2020, October). Behavior and strength of reinforced concrete flanged deep beams with web openings. In *Structures* (Vol. 27, pp. 506-524). Elsevier.
<https://doi.org/10.1016/j.istruc.2020.06.003>
- [5]Liu, J., & Mihaylov, B. (2020). Shear strength of RC deep beams with web openings based on two-parameter kinematic theory. *Structural Concrete*, 21(1), 349-361.
<https://doi.org/10.1002/suco.201800356>
- [6]Laranjeira de Oliveira, F. (2010). Design-oriented constitutive model for steel fiber reinforced concrete. *Universitat Politècnica de Catalunya*.
- <http://dx.doi.org/10.5821/dissertation-2117-93486>
- [7]Löfgren, I. (2005). *Fibre-reinforced concrete for industrial construction*. Department of civil and environment engineering. Chalmers university of technology, Göteborg, Sweden.
<https://www.researchgate.net/publication/257944272>
- [8]Jasim, W. A., Allawi, A. A., & Oukaili, N. K. (2019). Effect of size and location of square web openings on the entire behavior of reinforced concrete deep beams. *Civil. Eng. J*, 5(1), 209-226
<http://dx.doi.org/10.28991/cej-2019-03091239>
- [9]Zeinab Reda Moubarek, Ibrahim Hassan EL-Kersh. 2020. "Numerical Study of Steel Fiber Reinforced Concrete Continuous Deep Beams With Openings." *life science journal* 17(11): 11-17.
- [10]Khalaf, M. R., & Al-Ahmed, A. H. A. (2021). Effect of large openings on the behavior of reinforced concrete continuous deep beams under static and repeated load. In *E3S Web of Conferences* (Vol. 318, p. 03012). EDP Sciences.
<https://doi.org/10.1051/e3sconf/202131803012>
- [11]Al-Mahbashi, M., Elsanadedy, H., Abbas, H., Abadel, A., & Al-Salloum, Y. (2023). Experimental and numerical study of high strength reinforced concrete continuous deep beams with circular and rectangular openings. *Journal of Building Engineering*, 79, 107868.

<https://doi.org/10.1016/j.jobe.2023.107868>

- [12]Saleh, M., AlHamaydeh, M., & Zakaria, M. (2023). Finite element analysis of reinforced concrete deep beams with square web openings using damage plasticity model. *Engineering Structures*, 278, 115496.<https://doi.org/10.1016/j.engstruct.2022.115496>
- [13]Syed Mohsin, S. M., Hammoud, R. A ., Ariffin, N. F., Muthusamy, K. , & Ahmad, S. W. (2025). Steel Fiber Performance in Reinforced Concrete Deep Beams with Mid-Span Web Opening. *Journal of Advanced Research in Applied Mechanics*, 133(1), 52–62.
<https://doi.org/10.37934/aram.133.1.5262>
- [14]Central Organization for Standardization and Quality Control. (2019). “Iraqi Standard Specification No.5/1984”
- [15]Central Organization for Standardization and Quality Control. (2019). “Iraqi standard Specification No.45 /1984”
- [16]Standard practice for selecting proportions for Normal, Heavyweight, and Mass concrete (ACI 211.1.91)
- [17]Methods of testing concrete. Method for determination of compressive strength of concrete cubes (BS 1881-116:1983)
- [18]Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496/C496M-17)
- [19]Kong, F. K., & Sharp, G. R. (1977). Structural idealization for deep beams with web openings. *Magazine of Concrete Research*, 29(99), 81-91.
<https://doi.org/10.1680/mac.1977.29.99.81>

مقاومة القص للعتبات الخرسانية المسلحة الليفية العميقة ذات الفتحات المربعة بمقاسات مختلفة تحت تأثير حمل الفشل بالقص

ضياء عبد الستارفاضل جاسم علي عبد الله

قسم الهندسة المدنية، كلية الهندسة، جامعة الموصل، العراق، الموصل

dhyaa.23enp47@student.uomosul.edu.iq

الخلاصة :

في الجانب العملي، في المباني العالية، ولا سيما في العتبات الخرسانية المسلحة العميقة والتي تتعرض لأحمال محورية عالية، قد تقع الفتحات في منطقة ذات قوة قص بأعلى ما يمكن وعزم انحناء مقارب للصفر (التحكم بالقص)، ويمكن أن تسبب مشكلة خطيرة إذا لم يتم التنبؤ بمقاومة القص لهذه العتبات. لذلك، هدفت هذه الدراسة إلى التحري عن مقاومة القص القصوى في هذه الحالة (التحكم بالقص)، (مختبرياً) ومقارنة النتائج بالمعادلات التحليلية لتسهيل استخدام هذه المعادلات من قبل العاملين في هذا المجال. في هذا البحث، تم تقسيم نماذج من العتبات الخرسانية المسلحة العميقة إلى مجموعتين؛ تتكون المجموعة الأولى من ثلاثة عتبات من الخرسانة الإعتيادية (بدون ألياف)؛ العتبة الأولى صلبة، والثانية والثالثة تحتويان على فتحات مربعة بأبعاد 200 ملم و300 ملم على التوالي. أما المجموعة الثانية فلها نفس ترتيب المجموعة الأولى، مع إضافة ألياف فولاذية بنسبة 0.75% إلى الخلطة الخرسانية. أظهرت النتائج المختبرية إلى أن وجود فتحات مربعة ذات زوايا حادة يؤدي إلى انخفاض مقاومة القص القصوى للعتبات بسبب انقطاع مسارات انتقال الحمل. وقد حسنت الألياف الفولاذية من أداء تلك العتبات، وزادت من حمل التشقق، وأخرت حمل الفشل. تم تطبيق معادلات الباحثين (كونغ وشارب) على العتبات الخرسانية المسلحة العميقة، وكانت نسبة مقاومة القص القصوى المختبرية إلى التحليلية للعتبات الخرسانية المسلحة العميقة الليفية هي 0.998 للعتبة المصمتة، و1.162 و1.585 للعتبات ذات الفتحات المربعة 200 ملم و300 ملم على التوالي، وللعتبات الخرسانية المسلحة العميقة الاعتيادية، كانت النسب 0.871 للعتبة المصمتة، و1.167 و1.245 للعتبات ذات الفتحات المربعة 200 ملم و300 ملم على التوالي. بشكل عام، جاءت النتائج التحليلية متوافقة مع النتائج المختبرية. ويمكن الاعتماد على هذه المعادلات للتنبؤ بمقاومة القص للعتبات الخرسانية المسلحة العميقة الاعتيادية والليفية ذات الفتحات الواقعة في منطقة ذات قوة قص بأعلى ما يمكن وعزم انحناء مقارب للصفر (التحكم بالقص)

الكلمات الدالة : عتبة عميقة، فتحة الويب، التحكم بالقص، الخرسانة الليفية.