International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

Effect of Web Openings Size on Steel Fiber Reinforced Concrete Deep Beams

Heba A. Mohamed[a*]

[a]Department. of Structural Engineering, Faculty of Engineering., Zagazig University, Egypt.

Accepted 06 September 2013, Available online 01 October 2013, **Vol.3, No.4 (October 2013)**

Abstract

In this paper, an analytical study is conducted to investigate the effect of web opening size on the behavior of steel fiber deep beams. Large openings often interrupt the load transfer by concrete struts in these beams and cause a sharp decrease in strength and serviceability. The results obtained from the finite element analysis are verified against previous experimental results. The finite element results are compared in term of load deflection curve, showing a good agreement. sixteen reinforced concrete deep beams with or without openings are analyzed under two-point top loading. The main parameters were the width and depth of the opening, steel fiber volume fraction, and shear span to depth ratio. Materials nonlinearities due to cracking or crushing of concrete and yield conditions of the reinforcing steel are considered. Results and conclusions which are useful for structural engineering practice are drawn from the research.

Keywords: *Nonlinear; finite element; Web openings; Steel fiber; Deep beam; Reinforced concrete.*

1. Introduction

Deep beams are often used in engineering structures such as deep girders, bunkers, water tanks where the walls act as vertical beams spanning between column supports. In some cases (e.g. in hotels and theaters), it is often desirable to have the lower floor free of columns therefore the external walls may be designed as deep beams spanning across the column free space (Yousif 1986). Large openings through structural members are frequently required for mechanical and electrical conduits or even for means of passageways, such as openings for doors and hallways in buildings. Large openings often interrupt the load transfer by concrete struts in these beams and cause a sharp decrease in strength and serviceability. Openings are classified as small or big openings and the best position of the opening is decided based on its size. Web openings have been found to take many shapes such as circular, rectangular, diamond, triangular, trapezoidal and even irregular shapes. However, circular and rectangular openings are the most common ones in practice (Prentzas 1968). Mansur (1998), recommended certain criteria with which to classify the size of an opening as either large or small, where the opening is classified as Small opening when $l_0 \leq h_{max}$ and as large opening when $l_0 > h_{max}$, where l_0 is the opening length and h_{max} is the larger of the depth above the opening and the depth below the opening.

Strut-and-tie models (STMs) are extensively used for these structures with D-regions since their implementation in various U.S. design codes. These models idealize a deep member as a series of concrete compressive struts and steel tensile ties connected at joints (called nodes) idealized as frictionless “pins” forming a truss (Dipti et al. 2012). Schlaich *et al*. (1987); Muttoni *et al*. (1997) indicated that The applied force is transferred from the loading point to supports only through the STM, and the remaining concrete between the trusses is neglected for design and strength calculation purposes. STMs satisfy any load system based on a statically admissible stress field that does not exceed the yield criteria and provide safe and lower-bound designs of discontinuous structures.
Studies have been made to understand the behavior of deep beams without web reinforcement (Shioya *et al*. 1989), in which further 25% reduction of shear strength was observed when the beam depth increased from 1200mm to 3000 mm. Steel fiber-reinforced concrete (SFRC) has gained increased popularity in construction industries in recent years. Reinforcing concrete with steel fibers has been used to reduce conventional steel reinforcement in structural members such as slabs (ACI Committee 544 1996). SFRC offers a multidirectional reinforcement, simple detailing without congestion, and higher post-cracking residual stress and ductility. Past studies (Narayanan and Darwish 1988; Mansur and Ong, 1991) have shown that including discrete fibers in concrete enhance the strength and the deformation capacities of deep beams in addition to better cracking

*Corresponding author **Heba A. Mohamed** is working as Lecturer

control. The results of study carried out by Dipti et al. (2010) demonstrated that Steel fibers in the SFRC specimen restrained the widening of crack growth and increased the number of cracks. This helped in better stress redistribution in the specimen even if the steel reinforcement bars were not present and a ductile plastic mechanism was developed after the formation of plastic hinges.

2. Verfication of finite element program

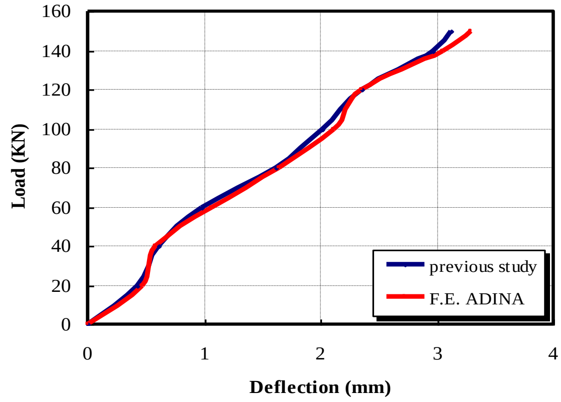
To verify the analytical analysis, the numerical analysis using the finite element program (ADINA program) is conducted on two deep beams which have already tested experimentally by Vengatachalapathy *et al*. to determine the vertical deflection. The analytical results by ADINA program are compared to experimental results, the relation between the mid – span deflection and load are plotted in figure (1– a), and (1 – b) for beam WBOA without fiber content and beam WBOA with 1 % fiber volume fraction respectively. It can be seen from the figure that good agreement has been achieved.

3. Finite element model

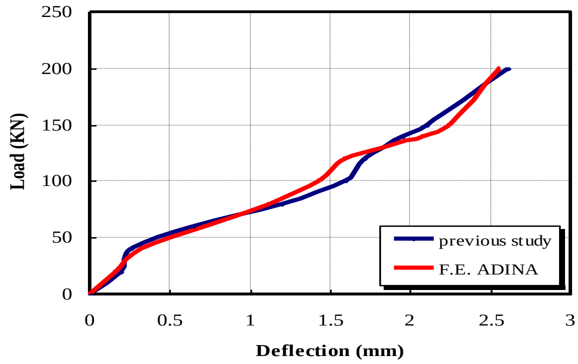
The aim of this study is to investigate the behavior of steel fiber reinforced concrete deep beams without and with web openings with different size by a simple finite element model. The details of the beams are shown in figure (2) and are listed in table (1), all beams were 400 mm in height, 100 mm in width, and overall 1000 mm in length. Each beam is reinforced with two bars of 16 mm diameter as main reinforcement. In this study, two different finite element idealizations are required, concrete idealization and steel reinforcement idealization. Concrete is idealized as 3-D solid elements having three degrees of freedom per node. the concrete requires nonlinear material properties to properly model concrete. Poisson's ratio is assumed to be 0.2 and the stress-strain curve of concrete without steel fiber is shown in figure (3). Reinforcement is idealized by truss element and is represented by two – node axial element embedded anywhere within a concrete element along local coordinates lines, the steel reinforcement is taken as plastic multilinear material. Perfect bond between the concrete and steel is existed. Model of concrete and reinforcement used in ADINA program is shown in figure (4), where mesh geometry used for concrete is illustrated in figure (5).

4. Effect of web openings size

Openings are inevitably installed in deep beams to facilitate conduits, air conditioning, electricity, and computer network cables. Based on the above, the size of the openings varies depending on the purpose of use. In this study, openings are used with three different sizes as 80 x 80 mm, 80 x 120 mm, and 120 x 120 mm.



(a)



(b)

Figure 1. Load – deflection curve of previous study and finite element model of a) beam WBOA without fiber, b) beam WBOA with 1 % fiber content

4.1 Vertical Displacement

The deformed shape for deep beams with different openings size in case of shear span to depth ratio (a/h) = 0.7, and without steel fibers are shown in figure (6). The values of mid – span deflection are plotted verses loads at figures (7) and (8) for deep beams with fiber volume fraction (V_f) = 0 %, and 1 % respectively. One can be seen from the figures that the increase the size of the openings the increase the values of deflection according to the decrease in the stiffness of the beam, where the stiffness is defined as the area under the load deflection curve. Also, one can be notice from figure (7) for (V_f) = 0 % that the presence of web opening causes significantly increase in the values of deflection than that the case of deep beam without web opening. However, in figure (8) for (V_f) = 1 % there is convergence to some extent between the load deflection curves of deep beam without opening and deep beam with 80 x 80 mm web opening till its failure.

4.2 Ultimate Load

The values of ultimate load for all cases of studies are listed in table (2) and (3) for deep beams with shear span to depth ratio (a / h) = 0.7, and 0.5

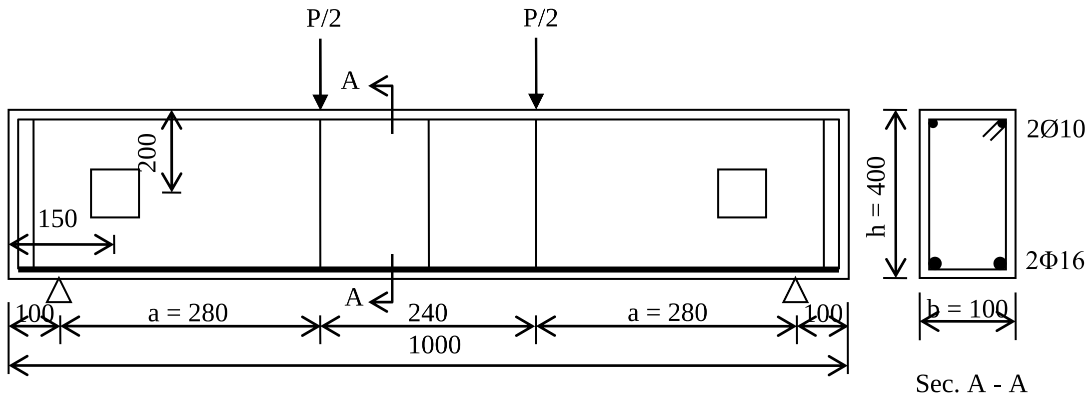


Figure 2. Specimen details (unit : mm)

respectively. The maximum value of ultimate load occurs in case of deep beam S_{10} without web opening and with fiber volume fraction (V_f) = 1 % and (a / h) = 0.5, this is due the absence of opening that clearly affect on beam stiffness and the presence of steel fiber that resisting additional shear forces. While, the small value occurs in case of beam S_7 with 120 x 120 mm web opening and (a / h) = 0.7 and without fiber, the reason for this result was the presence of opening with large size and there is no steel fiber. As can be seen from the table, for all opening size used in this study , the percentage of decrease on ultimate load in case of shear span to depth ratio (a / h) = 0.5 was higher than that of (a / h) = 0.7 for both steel fiber volume fraction.

5 Effect of shear span to depth ratio (A / H)

In this study, two values of shear span to depth ratio (a / h) are used. The first value was (a / h) = 0.7 and the second value was 0.5. To show the effect of shear span to depth ratio on the behavior of steel fiber reinforced concrete deep beams with and without opening, the following parameters are discussed.

5.1 Vertical Displacement

The deformed shape for deep beams for both shear span to depth ratio in case of no opening and steel fiber, are shown in figure (9). Load – deflection curves for all tested beams are shown in figure (10) and (11). The figures illustrated that there was a clear convergence in load – deflection curves for both shear span to depth ratio except for the case of deep beam without opening and steel fiber (V_f) = 1 % as shown in figure (11 – a). In this case, the decrease of (a / h) from 0.7 to 0.5 leads to reduce the values of deflection by a large rate after the formation of first crack and high increase in the ultimate load.

5.2 Ultimate load

The effect of shear span to depth ratio on the ultimate load are listted in table (4). From the table, one can be seen that as shear span to depth ratio (a/ h) is decreased from 0.7 to 0.5 for beams without web opening and with V_f = 1 % the value of the ultimate load is increased by about 27.7 %. However, the increase is estimated by only about 4.5 % for beams with 120 x 120 web opening and without steel fiber. The table also indicated that the decrease in shear span to depth ratio (a / h) from 0.7 to 0.5 is not sufficiently effective in increasing the beams capacity to withstand loads in case of using web opening with size 80 x 120 mm and 120 x 120 mm and without steel fibers. However, the change in shear span to depth ratio is fairly reasonable in increasing the ultimate load when using steel fibers by 1 % with any opening size used in this study.

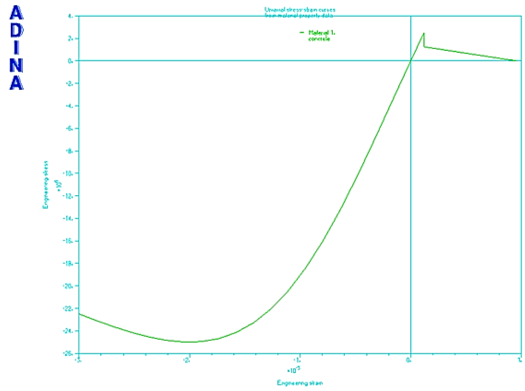


Figure 3. Stress-Strain Curve for Concrete.

6 Effect of steel fiber

Steel fibers are used in eight beams by volume fraction equal to 1 %, where another eight beams were without steel fiber. Steel fibers are represented in ADINA program by making change in the physical properties of concrete represented in cube compressive strength, split tensile strength, modulus of elasticity, and density of concrete. These values have been imposed applied to the values contained in table (5) and similar to those used by Vengatachalapathy *et al.*.

6.1 Vertical Displacement

The effects of steel fiber content on the values of deflection at ultimate load are shown in figure (12).

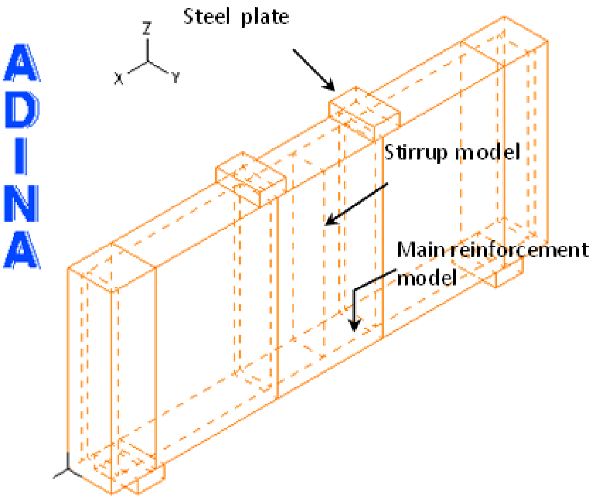


Figure 4. The concrete and reinforcement model.

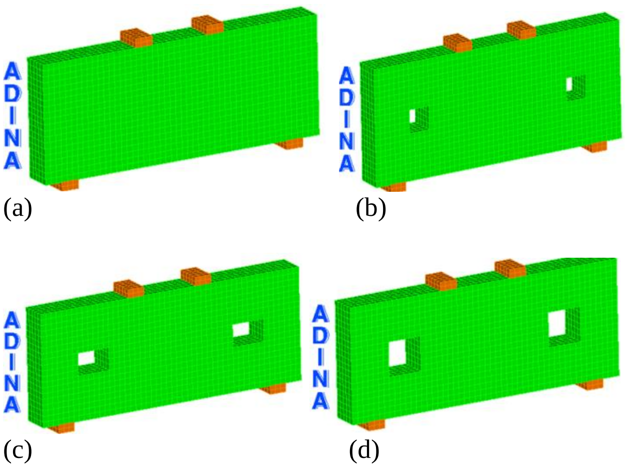


Figure 5. The mesh geometry for the concrete : a) without opening; b) with opening 80 x 80 mm; c) with opening 80 x 120 mm; d) with opening 120 x 120 mm.

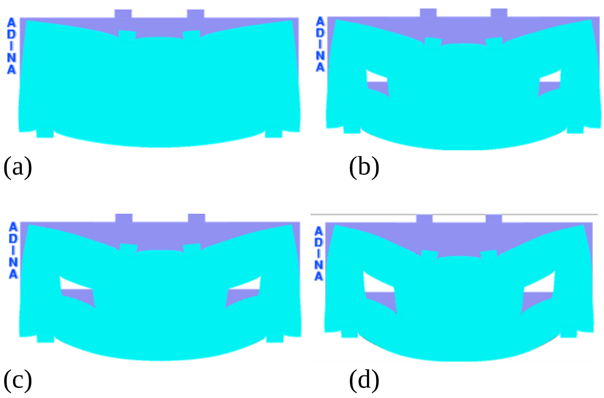


Figure 6. Deformed shapes for deep beams with a/h = 0.7, and V_f = 0 % : a) without opening; b) with opening 80 x 80 mm; c) with opening 80 x 120 mm; d) with opening 120 x 120 mm.

Figure (12 – a) indicated that use steel fibers by 1 % reduces the value of deflection by convergent rates in cases of using opening with different size used in this study than that the case without opening, where the value of deflection is decreased by about 48.8 %, 49.7 %, and 45.8 % for opening with size 80 x 80 mm, 80 x 120 mm, and 120 x 120 mm respectively. This reflects the fact that, the steel fiber increases the stiffness of the deep beam. According to the above, the use of steel fiber with volume fraction (V_f) = 1 % does not cause significant difference between opening with size 80 x 80 mm and 80 x 120 mm, therefore, steel fiber with volume fraction 1 % be appropriate for opening with size 80 x 80 mm and (a / h) = 0.7. Figure (12 – b) for (a / h) = 0.5 demonstrated that use of steel fibers by 1 % decreased the value of deflection by about 23.3 % and 25.1 % for case without opening and 80 x 80 mm opening size, respectively. Based on the above, the use of steel fiber by 1 % not effective enough in case of opening 80 x 80 mm. The percentage of decrease in deflection is estimated by about 43.2 % and 43.8 % for opening size 80 x 120 mm, and 120 x 120 mm respectively. Therefore, steel fiber with volume fraction 1 % be appropriate for opening with size 80 x 120 mm and (a / h) = 0.5.

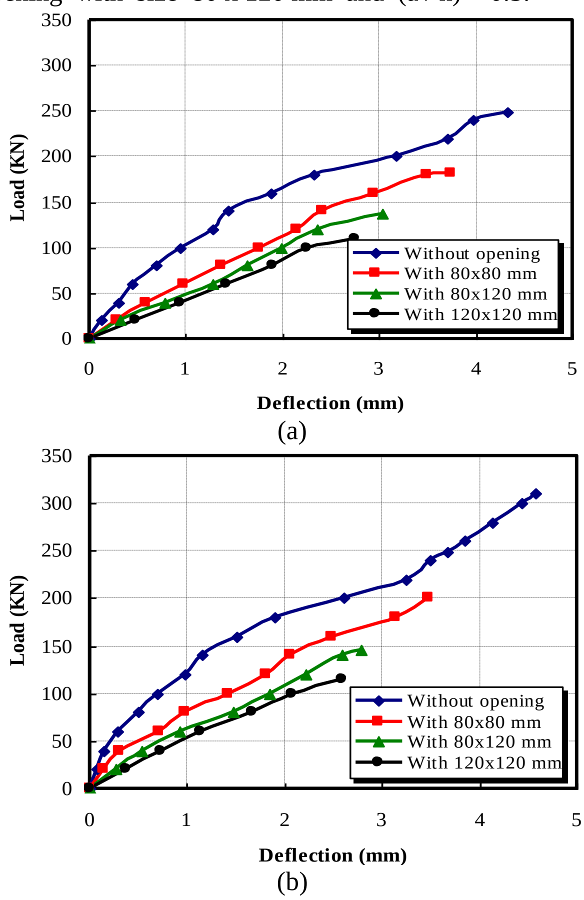


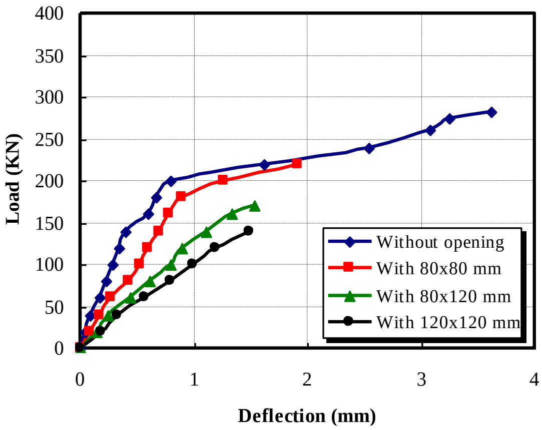
Figure 7. Effect of opening size on load – deflection curve for deep beams with V_f = 0 % : a) a / h = 0.7; b) a / h = 0.5.

6.2 Ultimate load

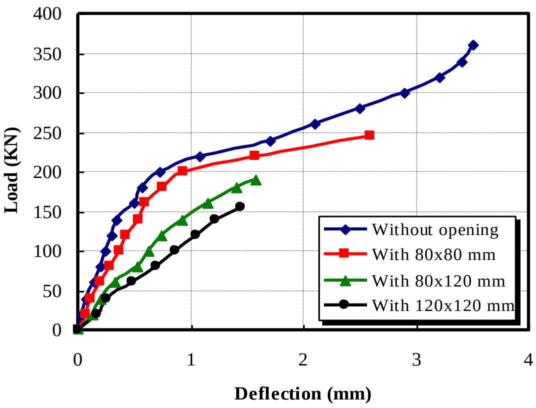
Table (6) shows the increase in the ultimate load according to the increase in steel fiber content for all tested beams. The table indicated that the steel fibers improve the loads by increasing the stiffness of the beam. As can be seen from the table, the percentage of increase in ultimate load was higher for (a / h) = 0.5 than that for (a / h) = 0.7.

Table 1: Details of specimens.

Specimen	a / h	Size of opening (mm)	Location of opening (mm)	Fiber volume fraction (%)
S_1	0.7	Without	-	0.0
S_2	0.5	Without	-	0.0
S_3	0.7	80 x 80	150	0.0
S_4	0.5	80 x 80	150	0.0
S_5	0.7	80 x 120	150	0.0
S_6	0.5	80 x 120	150	0.0
S_7	0.7	120 x 120	150	0.0
S_8	0.5	120 x 120	150	0.0
S_9	0.7	Without	-	1.0
S_{10}	0.5	Without	-	1.0
S_{11}	0.7	80 x 80	150	1.0
S_{12}	0.5	80 x 80	150	1.0
S_{13}	0.7	80 x 120	150	1.0
S_{14}	0.5	80 x 120	150	1.0
S_{15}	0.7	120 x 120	150	1.0
S_{16}	0.5	120 x 120	150	1.0

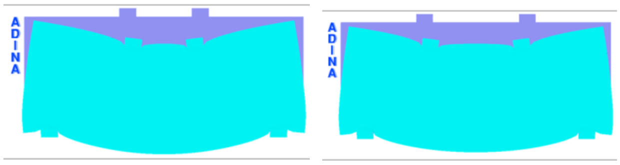


(a)



(b)

Figure 8. Effect of opening size on load – deflection curve for deep beams with V_f = 1 % : a) a / h = 0.7; b) a / h = 0.5.

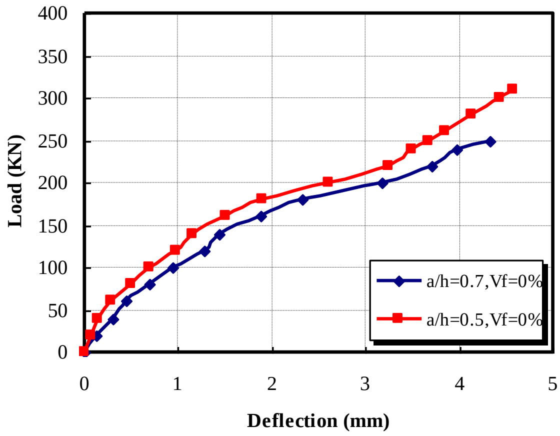


(a) (b)

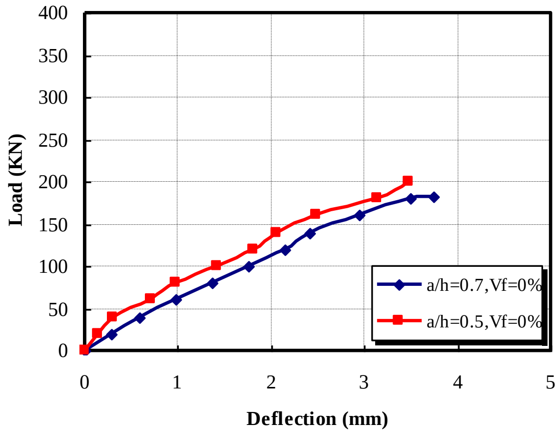
Figure 9. Deformed shapes for deep beams without opening and steel fiber: a) with (a / h) = 0.7; b) with (a / h) = 0.5 .

Table 2 : Effect of web opening size on the ultimate load for deep beams with (a/h) = 0.7.

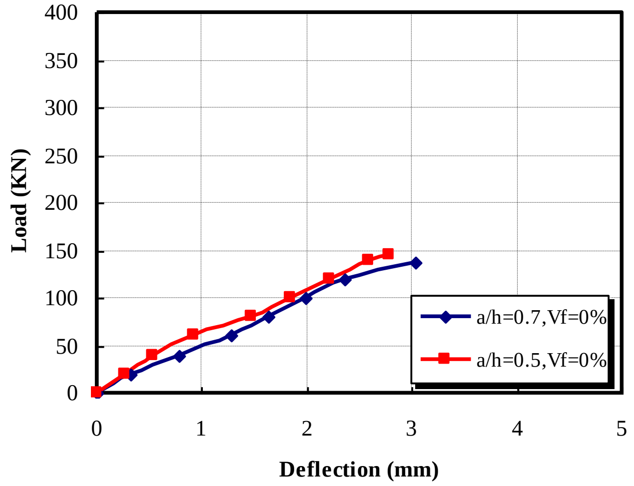
Beam	Web opening (mm)	P_u (KN)	Percentage of decrease	Fiber volume fraction
S_1	without	249	-	V_f = 0%
S_3	80 x 80	182	27	
S_5	80 x 120	138	44.6	
S_7	120 x 120	110	55.8	
S_9	without	282	-	V_f = 1%
S_{11}	80 x 80	220	22	
S_{13}	80 x 120	170	39.7	
S_{15}	120 x 120	140	50.4	



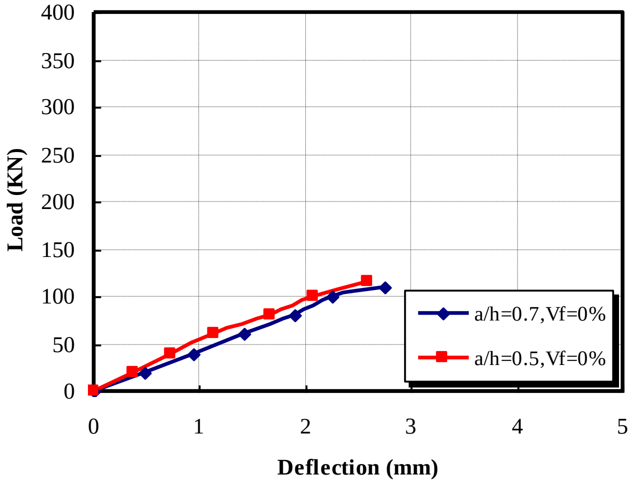
(a) Without opening



(b) With 80 x 80 mm opening



(c) With 80 x 120 mm opening

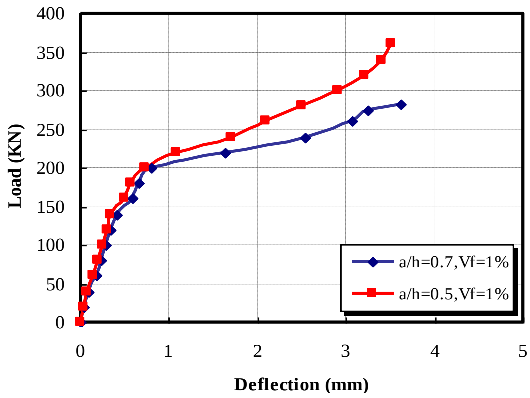


(d) With 120 x 120 mm opening

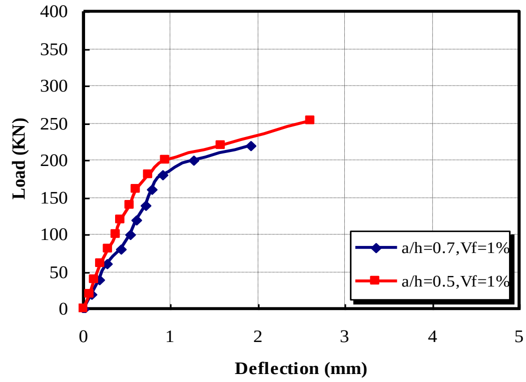
Figure 10. Effect of shear span to depth ratio on load – deflection curve for deep beams without steel fiber.

Table 3 : Effect of web opening size on the ultimate load for deep beams with (a/h) = 0.5.

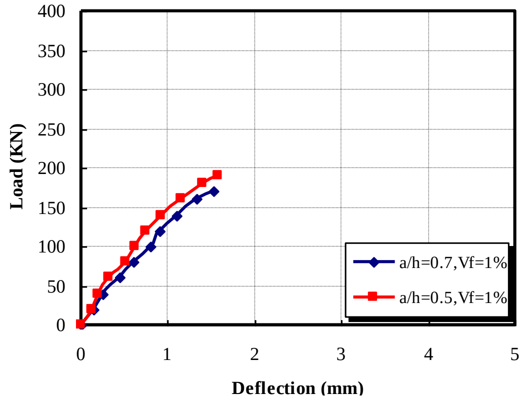
Beam	Web opening (mm)	P_u (KN)	Percentage of decrease	Fiber volume fraction
S_2	without	310	-	V_f = 0%
S_4	80 x 80	200	35.5	
S_6	80 x 120	145	53.2	
S_8	120 x 120	115	63	
S_{10}	without	360	-	V_f = 1%
S_{12}	80 x 80	252	30	
S_{14}	80 x 120	190	47.2	
S_{16}	120 x 120	155	56.9	



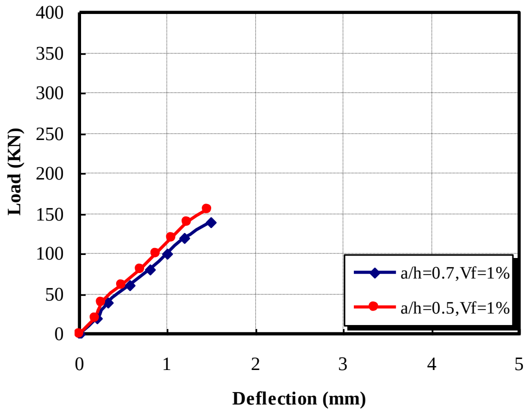
(a)Without opening



(b)With 80 x 80 mm opening

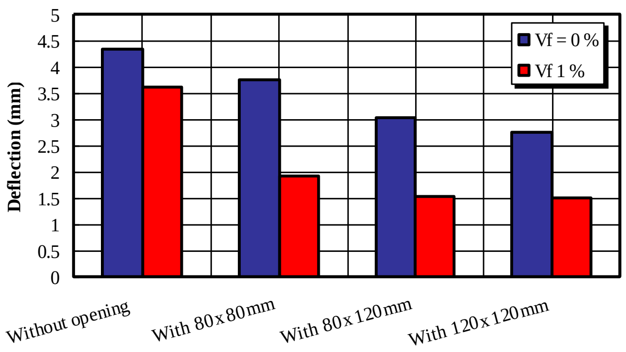


(c)With 80 x 120 mm opening

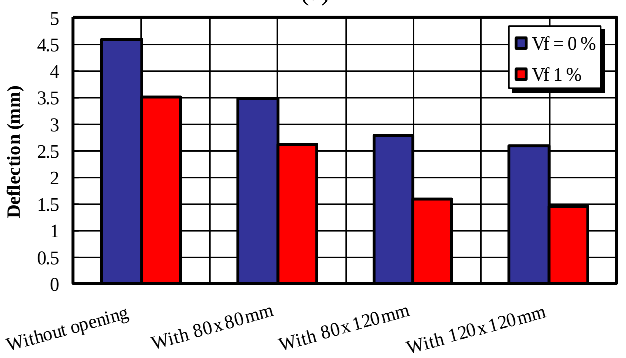


(d)With 120 x 120 mm opening

Figure 11. Effect of shear span to depth ratio on load – deflection curve for deep beams with steel fiber (V_f) = 1.0 %.



(a)



(b)

Figure 12. Effect of steel fiber on the values of deflection: (a) (a / h) = 0.7; (b) (a / h) = 0.5.

Table 4 : Effect of shear span to depth ratio (a/h) on the ultimate load of deep beams.

Beam	(a / h)	P_u(KN)	Percentage of increase	Fiber volume fraction V_f (%)	Web opening (mm)
S_1	0.7	249	-		
S_2	0.5	310	24.5	0	Without
S_3	0.7	282	-		
S_4	0.5	360	27.7	1	80 x 80
S_5	0.7	182	-		
S_6	0.5	200	9.89	0	80 x 120
S_7	0.7	220	-		
S_8	0.5	252	14.5	1	120 x 120
S_9	0.7	138	-		
S_{10}	0.5	145	5.1	0	Without
S_{11}	0.7	170	-		
S_{12}	0.5	190	11.8	1	80 x 80
S_{13}	0.7	110	-		
S_{14}	0.5	115	4.5	0	80 x 120
S_{15}	0.7	140	-		
S_{16}	0.5	155	10.7	1	120 x 120

Table 5 : Physical properties of concrete.

Fiber content	Avg. cube compressive strength (N/mm^2)	Avg. split tensile strength (N/mm^2)	Modulus of elasticity	Avg. density of concrete
0%	27.1	2.57	29715	24.52
1%	30.42	2.96	31113	25.62

Table 6: Effect of fiber volume fraction (Vf) on the ultimate load of deep beams.

Beam	Fiber volume fraction (%)	P_u(KN)	Percentage of increase	(a / h)	Web opening (mm)
S_1	0	249	-		
S_9	1	282	13.3	0.7	Without
S_2	0	310	-		
S_{10}	1	360	16	0.5	Without
S_3	0	182	-		
S_{11}	1	220	20.9	0.7	80 x 80
S_4	0	200	-		
S_{12}	1	252	26	0.5	80 x 80
S_5	0	138	-		
S_{13}	1	170	23.2	0.7	80 x 120
S_6	0	145	-		
S_{14}	1	190	31	0.5	80 x 120
S_7	0	110	-		
S_{15}	1	140	27.3	0.7	120 x 120
S_8	0	115	-		
S_{16}	1	155	34.8	0.5	120 x 120

Conclusions

This paper presents an analytical analysis by using ADINA program to describe the effect of web opening size on the behavior of steel fiber reinforced concrete deep beams with (a / h) = 0.7 and 0.5. The following conclusions can be drawn from the analytical results:

- The presence of web opening causes significantly increase in the values of deflection than that the case of deep beam without web opening.
- For all opening size used in this study , the percentage of decrease on ultimate load in case of shear span to depth ratio (a / h) = 0.5 was higher than that of (a / h) = 0.7 for both steel fiber volume fraction.
- The decrease of (a / h) from 0.7 to 0.5 for case of (V_f) = 1 % and without opening, leads to reduce the values of deflection by a large rate after the formation of first crack and high increase in the ultimate load.
- The decrease in shear span to depth ratio (a / h) from 0.7 to 0.5 is not sufficiently effective in increasing the beams capacity to withstand loads in case of using web opening with size 80 x 120 mm and 120 x 120 mm and without steel fibers.
- Steel fiber with volume fraction 1 % be appropriate for opening with size 80 x 120 mm and (a / h) = 0.5, because of the reduced in deflection by about 43.2 %.

- The steel fibers improve the loads by increasing the stiffness of the beam. The percentage of increase in ultimate load was higher for (a / h) = 0.5 than that for (a / h) = 0.7.

References

Yousif, A.R. (1986), Effect of web reinforcement on the strength and behavior of deep beams, M.Sc, Thesis, *University of Mosul, Iraq.*

Prentzas EG. (1968), Behavior and reinforcement of concrete beams with large Rectangular apertures , PhD Thesis, *University of Sheffield*, UK; p. 230.

Mansur M. A. (1998), Effect of openings on the behavior and strength of RC beams in shear , *Cement Concr Compos* ; 20 (6), 477– 486.

Dipti R. Sahoo, Carlos A. Flores, Shih - Ho Chao (2012), Behavior of steel fiber – reinforced concrete deep beams with large opening , *ACI Structural Journal*, Vol. 109, No.2, 193 – 203.

Schlaich, J.; Schäfer, K.; Jennewein, M. (1987) , Toward consistent design of Structural Concrete , *PCI Journal*, Vol. 32, No. 3.

Muttoni, A.; Schwartz, J.; Thurlimann, B. (1997), Design of concrete structures with stress fields , *Birkhauser Verlag, Basel*, Switzerland, 147.

Shioya T., Iguro M., Nojiri Y., Akiayma H., Okada T. (1989), Shear strength of large reinforced concrete beams, fracturemechanics: Application to concrete, SP-118, (Detroit: American Concrete Institute) 259–279.

ACI Committee 544 (1996), Report on Fiber Reinforced Concrete (ACI 544.1R-96) Reapproved 2009), American Concrete Institute, Farmington Hills, MI, pp. 63

Narayanan, R., and Darwish, I. Y. S. (1988), Fiber concrete deep beams in shear, ACI Structural Journal, 85(2), 141-149

Mansur, M. A., and Ong, K. C. G. (1991), Behavior of reinforced fiber concrete deep beams in shear, *ACI Structural J.*, American Concrete Institute, 88(1), 98-105

Dipti R. Sahoo, S. H. Chao (2010) , Use of steel fiber reinforced concrete for enhanced performance of deep beams with large openings, Structures Congress © 2010 ASCE,1981-1990

Vengatachalapathy, V., Ilangovan, R. (2010), A study on steel fiber reinforced concrete deep beams with and without openings , International Journal of Civil and Structural Engineering, Vol. 1, No. 3, 509 - 517 .