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ORIGINAL ARTICLE

Shear Resistance of Fibrous Reinforced Concrete Deep Beams with Opening – A Critical Review

L.D. Ahmed[1] and F.R. Karim[2*]

[1]MSc. Student, Civil Engineering Department, College of Engineering, University of Sulaimani. Iraq.
[2]Lecture, Civil Engineering Department, College of Engineering, University of Sulaimani, Iraq.

ABSTRACT – Reinforced concrete deep beams are more prone to shear failure. Thus, it is important to study the shear behavior for structural reinforcements. The presence of web openings in reinforced concrete deep beams is frequently required to provide accessibility such as doors and windows or to accommodate essential services such as ventilating and air conditioning ducts that affect the shear resistance. This research highlights the limited research on the shear resistance of fibrous reinforced concrete deep beams containing openings worldwide and illustrates their influence on shear behavior. This review has shown that the ultimate and the first cracking loads increase, increasing steel fiber content to a certain limit. End hooked steel fiber with 1.5% gave the highest shear resistance and ultimate load capacity compared with other types of steel fiber. Moreover, the stiffness of reinforced concrete deep beams increased with increasing fiber content from 0 to 1.5%. In addition, the effect of web openings on the shear strength of deep beams at the ultimate and cracking loads depends on the degree of interruption of the natural load path joining the loading.

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INTRODUCTION

Reinforced concrete (RC) structures are widely used in civil engineering construction [1]. Nowadays, reinforced concrete (RC) deep beams are common structural elements in modern constructions ranging from tall buildings to marine gravity structures [2-5]. They are also used as foundation beams, panel girders, and deep mesh walls in marine-type gravity concrete structures [3-6]. Deep beams are often used as load distribution elements in engineering structures such as deep girders, shear walls, bent caps (in the bridges), pile caps (in foundation), warehouses (bunker), and water tanks where the walls act as vertical beams that span between column supports [3-7]. Reinforced concrete (RC) deep beams transfer a load as a supported beam to the support through a compression mechanism [4].

There are many definitions of deep beams. The term deep beam applies to any beam with a sufficiently large depth-span ratio to cause a non-linearity in the distribution of elastic flexural stress over the depth of the beam and distribution of shear stress to be non-parabolic. In simple words, RC deep beams are structural members with a depth much greater than their span length, while the thickness of the vertical direction is much smaller than the depth or span [3-6, 8]. According to the American Concrete Institute (ACI), 318-14 [9] definition, deep beams are structural members supported on the face and oppositely loaded on the other face so that compressive struts can develop between the support and the loads. That satisfies two aspects. Firstly, single forces lie within twice the depth of the member from the support face. Secondly, beams have a clear span beyond four times beam depth.

RC deep beams are considered a complex phenomenon, many experimental types of research have been performed previously, but the structural behavior of RC deep beams is still unreliable [4, 6, 7, 10]. Most researchers have concluded that failure is significantly affected by its shear resistance (capacity) than flexural resistance [4-8, 10-14]. Thus, shear behavior is the key point of this critical review.

The behavior of RC deep beam is influenced by many factors such as shear to depth ratio, span to depth ratio, type of loading, load placement, percentage of compression and tension reinforcement, anchorage of main reinforcement, the width of the support, amount and location of web reinforcement, strength of concrete, and yield strength of the steel bars. However, inserting an opening into the web region of the RC deep beams also leads to a more complex behavior [5, 8]. Separated short fibers are also added to concrete to improve some special abilities of concrete, such as crack resistance, tensile strength, stiffens, and improved energy absorption of concrete. Adding these fibers will add additional factors affecting the behavior of deep beams [5, 8, 13].

The many parameters affecting RC deep beams strength have limited understanding of shear failure. There have been extensive experimental investigations of simply supported deep beams with web openings [4-18], but very few tests of continuous reinforced concrete deep beams have been published. The inclusion of web openings in RC beams is frequently required to accommodate essential services such as air conditioning conduits, water supply, electricity, and heating ducts that are usually placed below the beam soffit and covered by a suspended ceiling due to aesthetic purposes, which will create a dead space [4, 5, 7, 8, 12, 17, 18]. However, passing the pipes and openings through the transverse

*CORRESPONDING AUTHOR | F.R. Karim | ✉ ferhad.karim@univsul.edu.iq

openings in the deep beams reduces the dead space, resulting in a more compact and economical design [4, 7, 8, 17, 18]. The presence of openings in deep beams leads to many problems in the behavior of the beam, such as reduction in the beam strength and causes excessive cracking and deflection. Openings may be of different shapes and sizes depending on the requirement of the architect and mechanical engineer [4, 8, 12, 17, 18]. The existence of web openings causes geometric discontinuity within the beam and non-linear stress distribution over the depth of the beam [4, 8, 12, 17, 18]. In addition, the current code (ACI-318) of practices does not cover the design of deep beams with web openings [4, 8, 17]. The shape, size, and location of the opening greatly affect the behavior of RC deep beams [4, 12, 17, 18]. Therefore, a detailed literature survey has been carried out to identify the gaps in the current study.

Shear failure is catastrophic and usually occurs without warning; thus, the beam should fail in flexure rather than in shear. The shear behavior is the main cause that could generate disturbances in internal stresses of the deep beam structure [4-7, 19, 20]. Because of the geometric proportions of deep beams, their strength is usually controlled by shear rather than flexure if normal amounts of reinforcements are provided [4, 5, 7]. In shear behavior, compression grows in one orientation, whereas tension grows in vertical orientation [4, 7, 19, 20]. As the depth of the beam increases, the shear behavior results in sudden failure [4, 19, 20]. Due to the brittle nature, crack propagation in larger size deep beams is much higher than in smaller size deep beams [4, 10]. Failure of deep beams occurs due to the crushing of concrete in the compression region of nearby supports or directly along with the shear crack formation [4, 5, 7]. In order to enhance shear resistance and regain the strength of the RC deep beams, steel fibers are added to concrete [4-7, 11-16, 18].

A proliferation of new developments in steel fiber reinforced concrete technology has greatly extended the range of applications to improve the mechanical properties of concrete, reduce main steel reinforcements, time-consuming the projects and labor [7, 11-16]. The application currently depends on the ingenuity of the designer and builder, taking advantage of the improved static and dynamic tensile strength, ductility, energy-absorbing characteristics, abrasion resistance, and fatigue strength of this construction material [7, 12, 18]. The addition of steel fibers to RC causes a significant increase in the ultimate strength of deep beams [5, 7, 12, 18]. Also, from past studies, it was observed that the failure of fiber RC beams was more ductile and gradual compared with the failure of plain RC beams due to the uniform dispersion of steel fiber throughout the concrete that provides isotropic strength properties which are not exhibited by conventionally RC [5, 7, 11-16, 18].

A limited amount of research has been conducted to investigate the shape, size, and location of openings on the shear behavior and resistance of RC deep beams containing steel fibers.

The primary objective of this study is to review the shear behavior of fibrous reinforced concrete deep beams with opening and finding gabs from the conducted researches by researchers because of the limited amount of research and design guidelines on the shear resistance of the RC deep beams containing opening with the addition of fibers.

LITERATURE REVIEW

EFFECT OF PROPERTIES OF FIBER ON THE SHEAR RESISTANCE OF FIBROUS REINFORCED CONCRETE DEEP BEAMS

A study by Al-Sarraf et al. [3] investigated the effect of the volume of steel fibers on the behavior of the deep beams with and without web opening on ultimate load and deflection, with various shear span to depth (av/d) ratios (variable of clear shear span). The experimental program included testing twelve rectangular solid deep beams with and without web opening. Hooked-end fibers with an average length of 50 mm and a nominal diameter of 0.5 mm were used with volume fractions of 0, 0.5, and 1.0%. A series consisted of simply supported six RC deep beams having the same height, width, and overall length of 320, 80, and 770 mm, respectively, which led to (h/b) ratio of 4 and contained two square openings with a dimension of 64 × 64 mm, one in each shear span (at outer region). The web opening's location and size were the same for all the beams. They were located symmetrically concerning the mid-span of the beam.

Moreover, these beams were divided into three groups based on fiber volume fraction. Each group had two beams, the first one had an av/d ratio of 0.7 (av=196), and the second one had an av/d ratio of 0.6 (a=168). Figure 1 shows details of the tested deep beams with and without opening.

Figure 2 represents the load-carrying capacity of the beams with av/d ratios of 0.7 and 0.6. The curves demonstrate that when the fiber content increases, the ultimate load also increases. This effect may be attributed to the role of steel fibers in improving the properties of reinforced concrete beams with web openings in resisting additional shear forces. The ultimate loads of beams with web openings increased compared with the control beam by 18.7 and 52.6%, containing fiber content of 0.5 and 1%, respectively, in the av/d ratios of 0.7 group beams. With the addition of fiber content, the ultimate load increases with decreasing av/d ratio from 0.7 to 0.6, which was increased by 22.2 and 59.1% for 0.5 and 1% of fiber content, respectively.

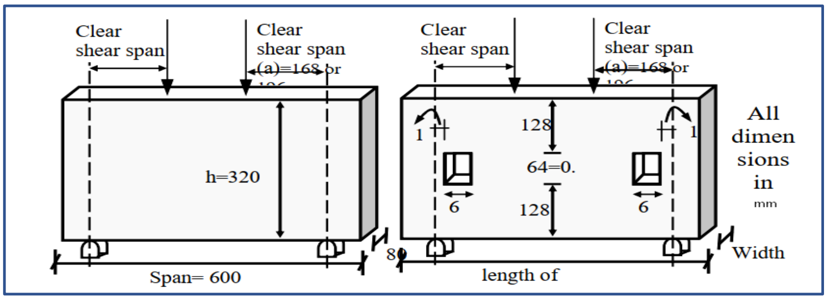

Figure 1. Geometric and cross-section of the control and tested deep beams [3].

Figure 3 shows the effect of web openings using one kind of opening in dimensions and location on the ultimate load of deep beams with continuous fiber, and the results are compared with solid beams. The test result showed a decrease in the beams' ultimate load with av/d ratios of 0.7 by 33.3, 32.9, and 39.7%, containing fibers content of 0, 0.5, and 1%, respectively, for the corresponding solid beams. As for beams with av/d ratios of 0.6, the ultimate load decreased by 50, 51, and 40%, containing fibers content of 0, 0.5, and 1%, respectively, to the solid beams.

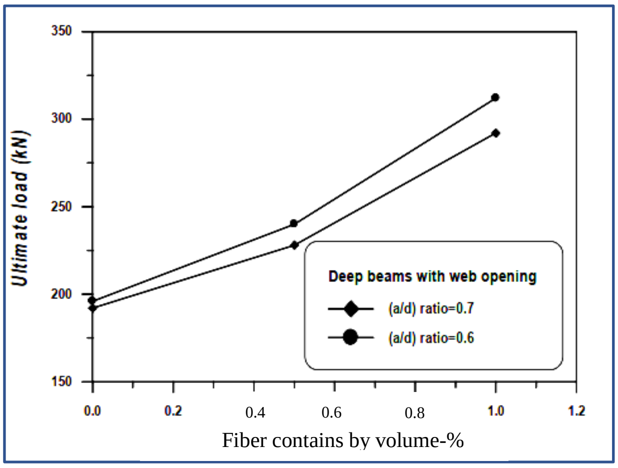

Figure 2. The effect of fiber contents on the ultimate load of RC deep beams with the opening [3].

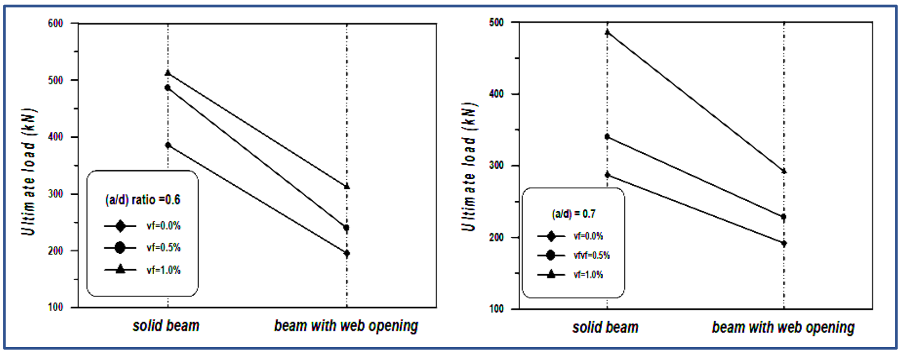

Figure 3. The effect of web opening on the ultimate load of RC deep beams with av/d ratio of (a) 0.6 and (b) 0.7[3].

In a study by Ewida et al. [12], eight RC deep beams having the dimension of 1800 x 1100 mm with a thickness of 100 mm and an opening size of 350 x 350 mm were cast and tested under 3 points loading setup after 28 days of curing. In addition, Two conventionally reinforced concrete deep beams were cast, tested, and used as control specimens. The concert was grade 35 MP, and three types of steel fibers (hooked end, round, and corrugated) with a diameter of 10 and 12 mm, and three percentages of steel fibers (1, 1.5, and 2%), and two aspect ratios (L/d) (40 and 50) were used aiming to show the effect of these parameters on the behavior of deep concrete beams. They also used the strut and tie method to predict the behavior of their experimental works.

The test results showed that installing openings in transfer deep beams decreases first crack load. It decreased from 260 KN to 160 KN which decreases about 62.5% of that obtained in case of the beam without opening. The behavior of a deep beam with an opening in failure was not predicted as good behavior for the beam with opening due to plastic hinge around the opening with increased beam capacity in failure load and a slight decrease in load due to installing opening from 370 KN to 340 KN which decrease about 8 % from the beam containing opening as shown in Figure 4.

Figure 5 shows test results for strengthening deep beams with 1.5% steel fiber increase both; first crack and failure load. Rounded fibers as end hooked and crimped rounded have good behavior in concrete as they are more workable than segment fiber. End hooked fiber gave the highest value in ultimate load, which reached 500 KN and is more ductile than the other beams it other words, hooked end steel fiber improved ultimate load by capacity by 32%, and cracking load by 60% compared to control beam. As for corrugated steel fibers, the best percentage for traditional concrete is 1.5 %, giving the highest results compared to other percentages in the first crack and failure load. Using a steel fiber percentage of 1.5% improved the first crack load by about 40%, and the failure load capacity improved by about 60%. While a decrease in loads for the beam with 2% of fiber happens due to the formation of a Honeycomb in concrete, as shown in Figure 6. The aspect ratios shown in Figure 7 showed that the best aspect ratio for traditional concrete was L/d of 50, giving the highest values, and improved first crack load by 40% and failure load by 30%. Steel fibers with an aspect ratio L/d of 40 increased first crack load by about 25% and ultimate load by about 5%.

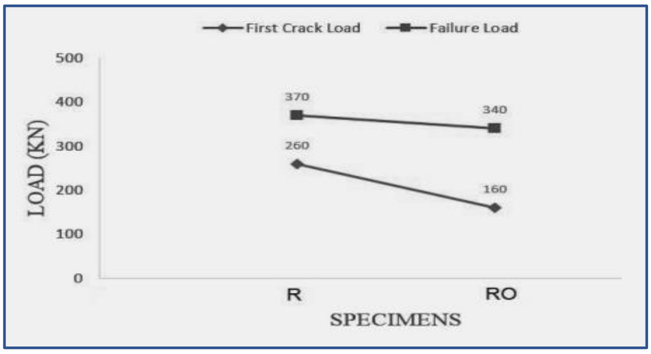

Figure 4. Test results of RC deep beams with and without opening [12].

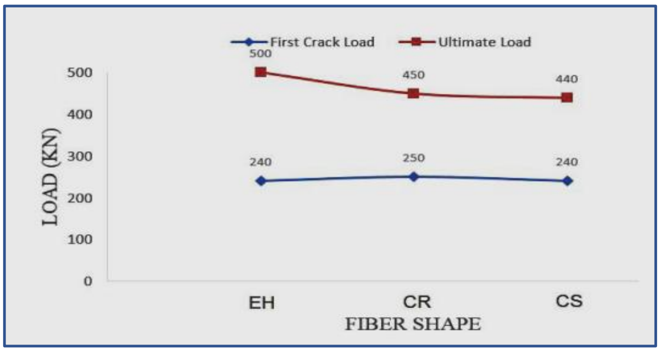

Figure 5. Test results of effect fiber shape on RC deep beams with the opening [12].

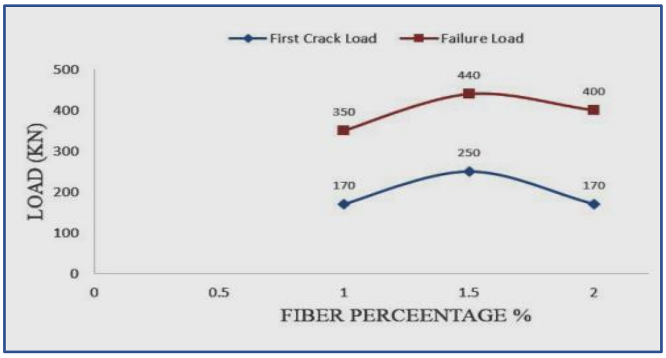

Figure 6. Test results of corrugated fiber percentage in deep beams with the opening [12].

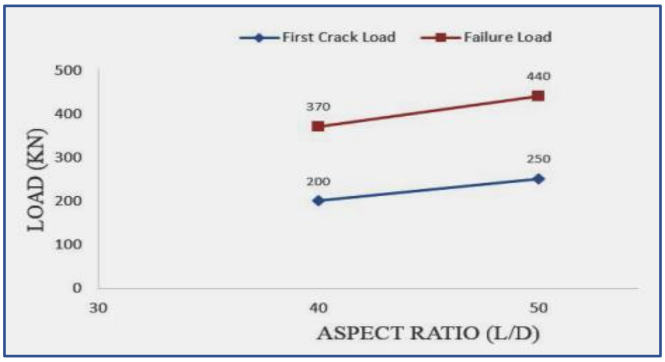

Figure 7. Steel fiber aspect ratio effect on load in deep beams with the opening [12].

Mansur and Alwis [14] investigated parameters including volume fraction of fibers, opening location, shear span to effective depth ratio, and the amount of web reinforcement on the behavior and strength of RC deep beams with an opening. Twelve reinforced concrete deep beams were tested under two concentrated loads. Each beam was 1550 mm long with an overall cross-section of 80 x 650 mm and supported on a span with a length of 1300 mm, giving an L/d ratio of 2. The opening had a size of 125 mm in width and 175 mm in length, as shown in Figure 8. Fiber volume fraction varied in 0 to 1.5% by 0.5% increments, and hooked end fiber type was used, having a length and diameter of 30 and 0.4 mm, respectively. Grade 40 MP concrete was used in this study.

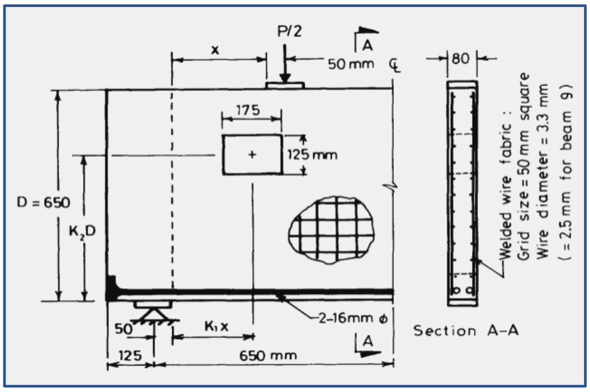

Figure 8. Geometrical and cross-sectional details of the tested RC deep beams [14].

It was concluded that the volume fraction of fibers and locations of openings are the two principal parameters that affect the cracking load. An increase in the volume fraction of fibers, in other words, increases the amount of web steel and increases the first crack load. It also increases with less interruption of the natural load path by the opening. They concluded that, similar to cracking load, the ultimate shear strength of deep beams with openings is primarily influenced by the amount of web reinforcement, either discrete or continuous, and the relative position of openings. Figure 9 shows the effect of fiber content on ultimate strength. It increases almost linearly with an increase in the volume fraction of fibers; the maximum was about 58% for specimen NO.5, which contained a 1.5% volume of fibers. It can be seen that the fibers contributed significantly to the ultimate shear strength of the beams.

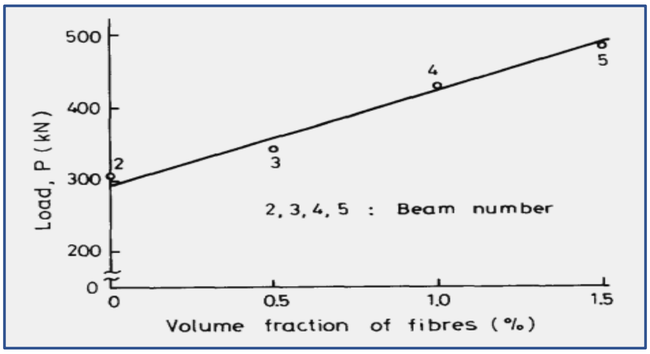

Figure 9. Effect of fiber content on the ultimate shear strength of RC deep beams with an opening [14].

The function of using fiber for enhancing shear resistance of deep beams at the crack and ultimate loads could be more effective if the twisted type of micro-steel fiber is adopted in the next research due to the high bond strength between the matrix of the concrete and fibers which helps the fiber to rupture instead of pull-out from the matrix of the concrete.

EFFECT OF CHARACTERISTICS OF WEB OPENING ON THE SHEAR RESISTANCE OF FIBROUS REINFORCED CONCRETE DEEP BEAMS

Saeed and Yousif [5] studied twenty-four two-span reinforced concrete deep beams tested with or without web openings and steel fibers. All test specimens had the same cross-section, main longitudinal top and bottom reinforcement, and web reinforcement. The main parameters considered were the shear span-to-total beam depth ratio (av/d), the position of the web openings, and the number of steel fibers. Only one type of steel fiber (Duoform) with a diameter of 0.25 mm and length of 25 mm (aspect ratio of 100) was used. The beams had a rectangular cross-section with a width of 100 mm and a total depth of 350 mm. The beam length was varied to obtain the desired span-to-depth ratio. One size of the opening (140 x 90 mm) and three locations of web openings were investigated, while the fiber volume fraction was either 0% or 0.8%. Two web openings were selected to interrupt the load path to the central or end supports, while the other location was within the maximum positive moment region; the beams' details are shown in Figure 10.

The test results showed that the effect of fiber content on the crack patterns was almost insignificant; however, it affected the failure mode in some cases. All fibrous beams failed at loads higher than the companion ordinary beams.

Beams with fibers showed high ductility, less damage at failure and smaller observed crack widths than beams without fibers. It was observed that openings within the mid-span region of deep beams without fibers had negligible influence. In contrast, for beams containing 0.8% of fiber content, the ultimate shear strength of these beams increased since the ultimate load capacity increased by 12.6, 5, and 13% for the beams with av/d ratios of 0.6, 1.2, and 1.65, respectively, and it was clear that the ultimate loads decreased with increasing av/d ratio. The existence of web openings within exterior or interior shear spans caused a high reduction in the shear capacity of the beams. It was observed that openings within the outer region of deep beams containing 0.8% of fiber content improved load capacity by 143, 75, and 40% for the beams with av/d ratios of 0.6, 1.2, and 1.65, respectively, but the shear capacity decreased by 43, 15, and 36% respectively compared with solid beams.

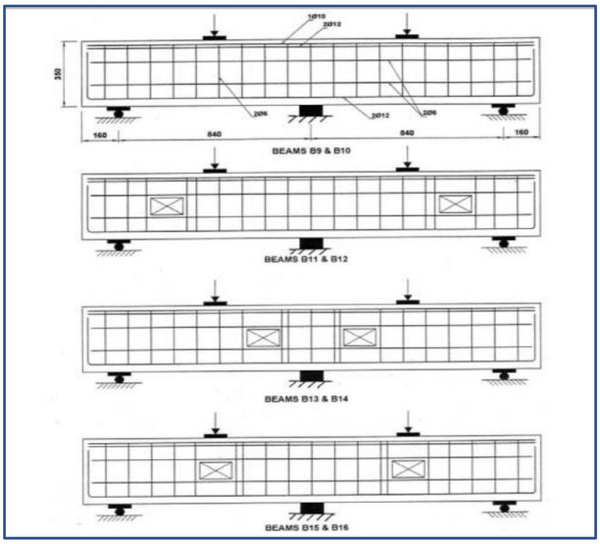

Figure 10. Geometric and reinforcement of the fibrous RC deep beams with the opening [5].

Sahoo and Chao [10] studied RC deep beams with large openings. The reinforcement detailing of deep beams based on strut-and-tie models can be complex, and, very often, these models may not predict the failure mechanism of deep beams due to localized damages. This study investigates the performance of two RC and two steel fiber-reinforced concrete (SFRC) deep beams with large openings under monotonically increased concentrated loads. The RC specimen with strengthened boundaries exhibited a ductile failure mode and had significantly greater ultimate strength than predicted by STMs. The SFRC specimens with a 1.5% volume fraction of fibers reached much higher ultimate strength than the design load and exhibited significant post-peak residual strength and a ductile failure mode.

Abd and Abd [11] studied the mechanical properties; of compressive, tensile, flexural, and shear strength of RC deep beams, and the second aspect was the study of the behavior of silica fume (SF-CON) on RC deep beams with and without openings. The study was divided into two groups. The first group was prepared to cover the following cases: variation in SF-CON ratio, the effect of shear span to depth ratio, removing vertical steel, and removal of mesh reinforcement. While the second group was prepared to study the following cases: variation in SF-CON ratio, openings reinforcement effect, and effect of opening shape. Type I of cement and SF grade 920 D were used and two types of hooked-end steel wire fibers were used, having a length of 30 and 60 mm, respectively.

The test result concluded that the increase in SF-CON ratio by 6, 7.5, and 9% gave a significant improvement in the behavior of the RC beams subjected to two-point load, and the increase in the cracking and ultimate loads were about 60% and 223.8%, and 140% and 242.85%, and 236% and 309.52% for each SF-CON ratios respectively, when compared with conventional concrete beams. The SF-CON deep beam with circular openings gave high cracking and ultimate loads than square and triangular openings. The reduction in the ultimate loads for square and triangular openings was about 22.44% and 13.9%, respectively.

Shanmugam and Swaddiwudhipong [15] proposed an experimental formula to predict the ultimate shear strength of fiber RC deep beams containing openings. Nine beams were tested under two points load to failure. All the beams had the same dimensions, a length of 1550mm, a width of 80 mm, and an overall depth of 650 mm, and supported on a simply supported span with an exact length of 1300 mm. The steel fiber content in all the beams was kept the same, equal to 1% by volume. Two rectangular openings, one in each shear span, were placed symmetrically about the vertical axis in each beam. Figure 11 shows the reinforcement detailing of the tested beams in this study.

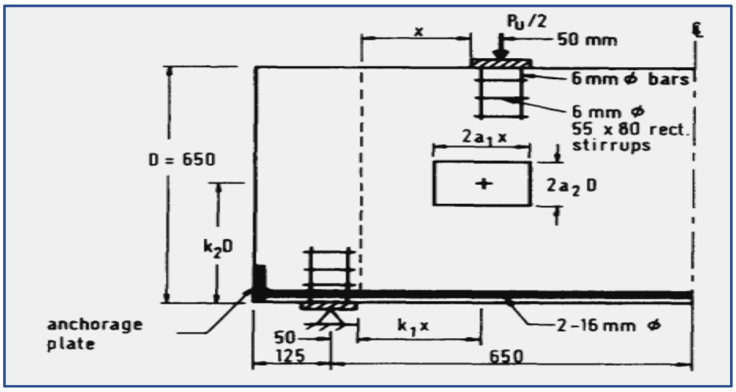

Figure 11. Geometrical dimensions and reinforcement details of the deep beams [15].

The failure load of the experimental tests varied between 170 to 250 kN depending on the opening location and if the opening interrupts the load path. It was concluded that the ultimate strength is reduced significantly in those beams where the openings interrupt the natural load path, depending on the degree of interruption. A lower strength was observed for the beams where the opening partially interrupted the natural load path than the beam where the opening partially interrupted the natural load path. It was also observed that the openings in the tension zone affect the behavior and strength of deep beams more than those in the compression zone. The shear resistance decreases with increasing the opening size and volume fraction of fiber while the shear resistance might enhance if the shape of the web opening is circular and located at the mid-span of the deep beam.

CONCLUSIONS

Based on the previous studies on the shear behavior of the fibrous RC deep beams with an opening from the literature, the following conclusions could be drawn:

a) The ultimate and the cracking loads increase with the steel fiber volume fraction. This enhancement may increase with decreasing shear span to depth av/d ratios.

b) For a constant percentage of steel fiber, the effect of decreasing av/d ratio on the ultimate and cracking load was negligibly small.

c) End hooked steel fibers with an aspect ratio of 50 and a percentage of 1.5% gave higher shear resistance than other steel fibers.

d) The effect of web openings on shear strength at the ultimate and crack loads of deep beams depends on the degree of interruption of the natural load path joining the loading and support reaction points.

e) Deep beams with web openings are stiffer when the fiber content increases from 0 to 1.5%; however, increasing fiber contents (2%) reduces the shear strength.

f) Circular opening beams offered higher shear resistance than beams with square openings.

g) Shear resistance decreases with increasing the opening size.

h) Web openings within exterior or interior shear spans caused a high reduction in the shear capacity of the deep beams compared with web openings located on the mid-span.

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