Effect of Steel Fiber on The Behavior of Deep Beams With and Without Web Opening

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Abstract

This study investigates experimentally the strengthening of reinforced concrete deep beams using steel fibers. The experimental work could be divided in two parts, the first part consists of casting and testing six deep beams without web opening and the second part consists of casting and testing six deep beams with web openings to show the effect of volume of steel fibers on the behavior of the deep beams with and without web opening on ultimate load, deflection, with various shear span to depth (a/d) ratios [variable of clear shear span].On the other hand, the effects of these parameters on the behavior and capability of deep beams with constant steel fiber – volume fraction are obtained by using three groups of beams having steel fiber– volume fractions of 0.0%, 0.5%, 1.0% and studying the effect of the presence of steel fibers in deep beams with web openings.

The results obtained from the experimental work [solid deep beams and deep beams with web openings], demonstrate that when the steel fiber volume- fraction is increased, the ultimate loads are also increased. The effect of steel fibers increases as the (a/d) ratio is decreased. In addition, the experimental work on deep beams without web opening showed that when the steel fiber volume-fraction is kept constant, the ultimate loads are increased as the (a/d) ratio is decreased. On the other hand, the percentages of increase in ultimate loads become higher as the steel fiber volume-fraction is increased from 0.0% to 0.5% and 1.0%. However, the effect of decreasing the (a/d) ratio on the ultimate and cracking loads of the deep beams with web openings was not significant.

تأثير ألياف الحديد على تصرف العتبات الخرسانية العميقة الصلدة وذات الفتحات في الجذع

الخلاصة

في هذا البحث تم دراسة الجانب العملي من العتبات الخرسانية المعززة بالألياف الحديدية. الجانب العملي من الدراسة يمكن تقسيمه إلى جزئيين . الجزء الأول يتكون من صب وفحص ستة عتبات عميقة بدون فتحات (صلدة) اما الجزء الثاني يتضمن صب وفحص ستة عتبات عميقة تحتوي على فتحات في الجذع (web)من اجل ملاحظة تأثير زيادة النسبة الحجمية للألياف الحديدية على تصرف هذه العتبات و الحمل الأقصى و الهطول مع تغيير نسبة فضاء القص إلى العمق(a/d) . من جهة أخرى ، تم توضيح تأثير هذه المتغيرات عند تثبيت النسبة الحجمية لألياف الحديد عن طريق ثلاث مجاميع للعتبات وهي C, B , A تبعاً للنسبة ال حجمية لألياف الحديد 0.0% ,0.5% و 1.0%على التوالي. كذالك تمت دراسة تأثير وجود الفتحات في العتبات العميقة على تصرف هذة العتبات

النتائج العملية المستحصلة من البحث [للعتبات العميقة الصلدة (بدون فتحات) والعتبات العميقة ذات الفتحات] أظهرت انه عند زيادة النسبة الحجمية لألياف الحديد يزداد الحمل الأقصى . و إن تأثير وجود

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ألياف الحديد يزداد بنقصان نسبة فضاء القص إلى العمق(a/d) .أظهرت التجارب العملية للعتبات العميقة الصلدة (بدون فتحات) انه عند تثبيت النسبة الحجمية لألياف الحديد فان الحمل الأقصى يزداد بنقصان نسبة فضاء القص إلى العمق (a/d) ومن جهة أخرى هذه نسبة الزيادة تزداد بزيادة النسبة الحجمية لألياف الحديد من0.0% الى 0.5% و1.0% .لكن تأثير نقصان نسبة فضاء القص إلى العمق (a/d) على الحمل الأقصى وحمل التشقق للعتبات الخرسانية ذات الفتحات تقريبا تكون معدومة .

1-Introduction

Reinforced concrete deep beams appear as common structural elements in many structures ranging from tall buildings to offshore gravity structures. They are used as panel beams, foundation beams, and as deep grid walls in offshore gravity-type concrete structures [1]. 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 [2]

The term deep beam applies to any beam which has a depth to span ratio great enough to cause non-linearity in the elastic flexural stress distribution over the beam depth and the distribution of shear stress to be non-parabolic[3]. The combination of bending and shear stresses in the shear span results in inclined cracks which transform the beam into a tied-arch [4].

2-Experimental work

2-1 Properties of concrete

2-1-1 Concrete mix

To produce nonfibrous concrete, the mixing proportion [cement: sand: aggregate] was 1:2:2 by weight and the water –cement ratio was 0.4 with superplasticizer of 0.55% by weight of cement [0.55L per 100kg cement] . It was found that the used mixture produces good workability and uniform mixing of concrete without segregation

Steel Fiber Reinforced Concrete was obtained by adding steel fibers [Hooked ends with average length =50mm and nominal diameter= 0.5 mm] with volume fractions of 0.5% and 1.0% to the fresh nonfibrous concrete, and remixed. There are two mixtures of steel fiber reinforced concrete depending on the volume fraction of steel fiber.

This mixing used British practice which has generally relied on high sand content (more than 50% by weight of aggregate) with maximum aggregate size of 10 mm [5]. The workability of the mix and uniform dispersion of the fibers, are important factors that affect the quality of fibrous concrete.

2-1-2 Mixing procedure

The mixing procedure is an important factor for obtaining the required workability and good dispersion of fibers to prevent fiber clumping. All batching was done by weight .The concrete was mixed by hand using a pan. The interior surface of the pan was cleaned and moistened before placing the materials. Initially the fine and coarse aggregates were poured and mixed for several minutes in the mixer and then the cement was added .The materials were mixed until

a uniform color was obtained, afterward the water was added to the mix, one quarter of the water was added to the mix and all components were remixed for a few minutes. Then, the superplasticizer "Glenium 51" was added to the residual water before pouring it into the mixing pan. The fresh concrete was mixed until a homogeneous fresh concrete was obtained. To avoid balling and to distribute the steel fibers uniformly, the required amount of steel fibers was uniformly added to the mix by hand sprinkling. The fresh concrete was then mixed until a good dispersion of the fiber was obtained.

2-2 Reinforced concrete deep beams

3-2-1 Details of tested beams

The experimental program included testing twelve rectangular solid deep beams with and without web opening, which were divided into two series

A-Deep beams without web opening

This series consisted of six beams having the same dimensions [320 mm height, 80 mm width and total length of 770 mm] which led to (h/b) ratio =4

The beams were divided into three groups A, B, and C, according to the volume fraction of steel fibers. Fiber contents in these groups were 0.0%, 0.5% and 1.0% respectively. Each group had two beams, the first one had an (a/d) ratio=0.7[a=196] and the second one had an (a/d) ratio=0.6 [a=168]

B-Deep beams with web opening

This series consisted of simply supported six deep beams having the same dimensions of solid beams [320 mm height, 80 mm width and overall length 770 mm] which led to (h/b)ratio=4 and contained two square openings, [64 mm×64 mm],one in each shear span. They were located symmetrically with respect to the mid-span of the beam.. Location and the size of the web opening was the same for all the beams

The beams were divided into three groups A, B, and C according to the volume fraction of steel fibers. Fiber contents in these groups were 0.0%, 0.5% and 1.0% respectively. Each group had two beams, the first one had an (a/d) ratio=0.7[a=196] and the second one had (a/d) ratio=0.6 [a=168]

Fig (1) shows details of deep beams with and without opening

Each beam was designated by the label XY-Z/W, where

X: the symbol indicating the steel fiber volume fraction, that consist of

N: refers to beams without steel fiber [group A]

0.5F: refers to beams with steel fiber volume fraction of 0.5% [group B]

1.0F: refers to beams with steel fiber volume fraction of 1.0% [group C]

Y: the number indicating the (h/b) ratio

Z: the number indicating the (a/d) ratio

In addition, the symbol (W) refers to beams without web opening [0] or to beams with web opening [1].

2-2-2 Details of the mold

Two wood forms were used in the fabrication of all deep beams. The first one was for deep beams without web opening which had inside dimensions [b=80 mm, L=770 mm and h=320 mm], and the second one for the deep beams with web opening which had the same inside dimensions [b=80 mm, L=770 mm and h=420 mm]

The opening was made by using two wooden cubes with the same size [64 mm×64 mm×90mm] and the cubes were fixed in their correct positions using bolts. The bolts can be easily removed to take off the wooden cubes from the mold after casting

The wooden cubes were covered with a paper and wide tape and oiled before casting, to prevent bonding between the wooden cubes and the concrete

Details of wooden form used for the solid deep beams with and without web opening are shown in Fig. (2)

2-2-3 Details of Steel Reinforcement

All the deep beams were reinforced with plain bars having nominal diameter of 3 mm, which were used as vertical shear reinforcement with spacing of 100 mm center to center. Standard 135^o hooks were provided for these stirrups. Two deformed bars were used as tension longitudinal reinforcement with a nominal diameter of 10 mm. A 90^o standard hook was provided at the ends of the tension bars. At the end of the hooked bars, an 180^o hook was used in order to prevent bond failure, Fig (3)

Both longitudinal and transverse steel bars were arranged and connected together by using (1 mm) steel wire and plain bar with a diameter of (2 mm) was used at the center of the top face of the beams to form the required reinforcement cage.

2-2-4 Details of fabrication and curing

For fabrication of a typical solid beam, the wooden form was cleaned and oiled before casting. The required reinforcement cage was placed horizontally using four bolts, one at each corner. The bolts were fixed at their proper location to avoid any movement during fabrication

Each deep beam was cast in two layers, each layer was mixed according to the mixing procedure presented above. The fresh concrete was placed in the wooden form of the beam and the layer was compacted for about 25 seconds using a table vibrator (over electric generator) and hammered by rubber driver, at the sides and the base of the wooden form which have a suitable vibrator to shake and consolidate the mix into the mold . The process of vibration was continued for the second layer until no further air bubbles appeared on the surface. Fig (4) shows the fabrication details of the deep beams.

2-2-5 Testing procedure

Beam specimens were placed at the testing machine and adjusted so that the centerline, supports, point loads and dial gauges were fixed at their correct and proper locations. Loading was applied in small increments of (4 kN). At each load stage the deflection readings at the center and at the support region were recorded.. After the first crack appeared the cracking depth and cracking width were gradually increased with increasing loads. The position and extent of the first and other consequent cracks were marked on the surface of the beam and magnitude of the load stage at which these cracks occurred was recorded. The loading increments were applied until failure. Fig (5) shows testing details of the solid deep beams and deep beams with web openings respectively.

3-Experimental Results for Deep Beams

3-1 Deep beams without opening

3-1-1 Effect of fiber content on ultimate load

The effect of increasing steel fiber – volume fraction (V_f) on the ultimate load of deep beams of groups A, B, C [having steel fiber –volume fraction of 0.0%, 0.5%, 1.0% respectively] are shown in Fig (6)

The figure illustrates that when the fiber content increases, the ultimate load is significantly increased. The

increase in ultimate load value is higher in beams with (a/d) ratio=0.6 than beams with (a/d) ratio=0.7

The increase in ultimate capacity of deep beams with steel fibers, may be attributed to the role of steel fibers in improving the properties of reinforced concrete in resisting additional shear forces.

The percentage increase in the ultimate loads with increasing fiber content, with reference to beams (A1) and (A2) with (a/d) ratios 0.7 and 0.6 respectively is shown in Table (1). Deep beam C1 gave a high percentage of increase , this may be due to the large differences in compressive strength values between beams C1 and A1. In general, the percentage of increase in ultimate load value when adding steel fibers, became higher when the (a/d) ratio is decreased from 0.7 to 0.6, except the percentage of the beam C2 which was small because this beam had problems during testing. The test machine was turned off in the stage of loading after cracking that reduced its ultimate load.

3-1-2 Effect of (a/d) ratio on ultimate load

The effect (a/d) ratio [constant d] for a given fiber content on ultimate load of the tested deep beams has been studied.

The first part of this study was carried out on deep beams with (h/b) ratio = 4 (h=320).The study included beams A1 and A2 of group A having fiber content 0.0%, beams B1 and B2 of group B with fiber content 0.5% , beams C1 and C2 of group C with fiber content 1.0 %

Fig (7) shows the effect of decreasing (a/d) ratio form 0.7 to 0.6 [constant d] on the ultimate load of deep beams of all groups. The figure shows that when the (a/d) ratio decreases from 0.7 to 0.6, the ultimate load of these deep beams is increased. These results are similar to all beams of groups A, B, and C. The increase in ultimate capacity may be due to the presence of direct compression strut along the line joining the point of load application and the support .The slope of the compression strut is the important parameter of the shear strength capacity of the deep beams] [6]

Table (2) shows the percentages of increase in the ultimate load of the deep beams of groups A, B, and C when the (a/d) ratio is decreased. The Table reveals that, for increasing fiber content, the percentage of increase in the ultimate load becomes higher when the (a/d) ratio, is increased. Such a behavior is expected because the arch action and dowel action become less effective as the (a/d) ratio increases[7]. Beam C2 results in a very small percentage of increase in the ultimate load as compared to beam (C1).

3-1-3 Load – deflection response

Load –deflection curves of the tested beams at midspan and at support region are constructed, as shown in Fig (9). At every stage of loading, the net deflection at midspan of the deep beam is obtained by subtracting the deflection that is measured by dial gauge at support region [reading of dial gauge 2] from the deflection that is measured by dial gauge at midspan [reading of dial gauge 1] as shown in Fig (8) [at every stage of loading]. This method is carried out in this study because the deflection that was measured at support region gives a large value corresponding to the deflection of the deep beams

It can be noticed from the figures that for all (a/d) and (h/b) ratios, the post cracking response becomes stiffer as the volume fraction of fibers is increased

This conclusion is true for all beams of groups A, B, and C that had steel fiber –volume fraction 0.0%, 0.5% and 1.0% respectively. When the (a/d) ratio is decreased the behavior of all deep beams becomes stiffer and gives a large ultimate load. This phenomenon is noticed in all beams of groups A, B, and C. Finally, Fig (10) exhibits the load-deflection curves for all solid deep beams. The figure shows a comprehensive illustration for the behavior of these beams.

3-1-4 Crack pattern

Fig (11) shows the crack patterns after testing the deep beams of groups A, B, and C. The loads, measured in kN, at initiation of each crack and the loads corresponding to crack extension at different post cracking stages are indicated on the beams

In the present work, the sequence of crack initiation and propagation were according to the following steps.

- Fine vertical flexural cracks were formed first, usually the bottom face of the beam close to midspan. The width of these initial cracks was very small. After that these cracks continued to propagate almost vertically toward the neutral axis. This is in contrast to the flexural shear cracks which occurred in beams with higher (a/d) ratios where the cracks propagate towards the point of the load application and become inclined
- On further loading, diagonal cracks suddenly occurred independently in one of the two shear spans. This crack originated at the middle of the shear span and propagated toward the support and point of the load application as the applied load was increased
- New inclined cracks were formed in both shear spans parallel to the load – support direction. These cracks continued to propagate until failure took place

It is worth noting that in the presence of steel fibers, the crack formation was slower, their width was reduced and the spacing between the cracks was decreased.

3-2 Deep beams with opening

3-2-1 Effect of fiber –volume fraction on ultimate load

The effect of using steel fibers with volume fractions of 0.0% ,0.5% and 1.0% on the ultimate load of deep beams with web openings having (a/d) ratios of 0.7 and 0.6 have been studied in this section.

Fig (12) shows the effect of steel fiber content on the ultimate load of deep beams A5, A6, B5, B6 and C5, C6 [of groups A, B and C] which have fiber-volume fraction of 0.0% to 0.5% and 1.0% respectively. The two curves shown in the figure represent the load carrying capacity of the beams with (a/d) ratios of 0.7 and 0.6. The curves demonstrate that when the fiber content is increased, 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 opening in resisting additional shear forces.

The ultimate loads of beams with web openings and the percentage of increase in ultimate load with the addition steel fibers, with respect to beams A5 and A6 in two (a/d) ratios 0.7 and 0.6 respectively are listed in Table (3).The Table, illustrates that the percentage of increase in ultimate load, increases with decreasing (a/d) ratio from 0.7 to 0.6

3-2-2 Effects of (a/d) ratio on ultimate load

For a constant steel fiber content, the effect of decreasing the (a/d) ratio from 0.7 to 0.6, on the ultimate load of the

deep beams with web openings, of groups A, B, and C which have fiber-volume fraction of 0.0% to 0.5% and 1.0% respectively is investigated in the present section.

The effect of decreasing (a/d) ratio from 0.7 to 0.6, on the ultimate load of deep beams A5 A6, B5 B6, and C5 C6 with web openings is shown in Fig(13). This Figure illustrates that as the (a/d) ratio decreases, the ultimate load of these beams is slightly increased.

Table (4) shows the percentage of increases in the ultimate load, when the (a/d) ratio decreases from 0.7 to 0.6. This table illustrates that there is no obvious change in the ultimate load when (a/d) ratio decreases from 0.7 to 0.6. This result may attributed to the fact the ultimate load of deep beams with web openings depends on the extent to which the opening interrupted the natural load path joining the loading process and support reaction points [8,9]. When the (a/d) ratio decreases, the probability of interruption of the load path by the opening increases. However the slight percentage of ultimate load increases with decreasing (a/d) ratio, becomes higher with increasing fiber content

3-2-3 Effect of web opening on ultimate load

In the present experimental investigation, the effects of web openings [using one kind of opening in dimensions and location] on the ultimate load of deep beams [with constant fiber content] have been studied in beams of groups A, B, and C that have steel fiber-volume fraction of 0.0% to 0.5% and 1.0% respectively, with two (a/d) ratios of 0.7 and 0.6.

Fig (14) shows the effect of the presence of web openings in beams A5, B5 and C5 on their ultimate loads. The results are compared with those of solid deep beams A1 B1 and C1 respectively, which have similar dimensions and (a/d) ratio of 0.7. While, Fig(15) shows the effect of the presence web openings in beams A6, B6 and C6 on their ultimate loads. Results of this investigation are compared with those of solid beams

Solid beams A2, B2 and C2 respectively, have the same dimensions and (a/d)ratio equal to 0.6.

The percentages of the decrease in the ultimate load of the selected beams, with respect the corresponding solid beams are listed in Tables (5),(6).These tables show the percentage of decrease in the ultimate loads of groups A, B, C for (a/d) ratios of 0.7 and 0.6. The results of these tables show that the percentage of decrease in the ultimate load, is almost the same, for all the considered steel fiber-volume fractions. And this percentage is increased when the (a/d) ratio decreases from 0.7 to 0.6. Beam C2 gives a smaller ultimate load, the reason for this result may because the beam had a problem during the test. The decrease in this percentage with respect to beam (C6) had been changed.

3-2-4 Load – Deflection Response

Figs (16) shows the load –deflection curves of the tested deep beams with web openings at midspan and support region at all stages of loading and up to failure

The net deflection at midspan of the deep beam is obtained by subtracting the deflection that is measured by the dial gauge at the support region [reading of dial gauge 2] from the deflection that is measured by the dial gauge at midspan [reading of dial gauge 1] as shown in Fig (10) [at every stage of loading]. This method is carried out in this study because the deflection that was measured at

support region gives a large value corresponding to the deflection of the deep beams

Deep beams with web openings behaved in a stiff manner when the steel fibers are added in beams of groups A, B and C. This phenomenon is true for beams with (a/d) ratios of 0.7 and 0.6.

Fig (11) shows that the ultimate load for solid deep beams were higher than deep beams with web opening, on the other hand concerning load –deflection curves, this figure shows that the deflection for solid deep beams were lower than deep beams with web opening,

When the (a/d) ratio decreases, the behavior of these beams, is almost similar. However, the ultimate load is slightly increased, this phenomenon is true for all beams of groups A, B, and C.

3-2-5 Crack pattern and mode of failure

Fig (17) shows the crack patterns after testing the deep beams of groups A, B, and C. The loads, measured in kN at initiation of each crack and the loads corresponding to crack extension at different post cracking stages are indicated on the beams

For all beams with web openings, the cracks were initiated at corners of the opening. These cracks propagated in both ways towards the support and loading points. As the applied load was increased, new diagonal cracks, approximately parallel to the original ones, were developed with simultaneous widening and extension of the existing cracks. Flexural cracks also appeared in all beams, but only at later stages of loading. These cracks however hardly penetrate beyond the mid depth for beams with openings and did not affect the final collapse

The crack pattern and mode of failure are dependent mainly on the extent to which the opening intercepted the load path (joining the load bearing block at the loading point and at the support reaction point) [9]

When steel fibers were added, the cracks were formed more slowly and their widths were reduced.

4-Conclusions

4-1 Deep beams without web openings

1. When the steel fiber volume fraction is increased, the ultimate loads are increased. The percentage of increase becomes higher when the (a/d) ratio decreases.
2. For a constant steel fiber volume fraction, the ultimate loads are increased with decreasing (a/d) ratio. The percentage of increase in ultimate loads is increased as the fiber content is increased 0.0% to 0.5% and 1.0% .
3. The tested deep beams behave in a stiffer response when the (a/d) ratios are decreased. This phenomenon is similar in all beams of groups A, B, and C [having steel fiber –volume fraction of 0.0%, 0.5%, 1.0% respectively].

4-2 Deep beams with web openings

4. The ultimate and the cracking loads increase, with the increase in the steel fiber volume- fraction. This percentage of increase becomes higher with decreasing (a/d) ratios.
5. For a constant steel fiber volume-fraction, the effect of decreasing (a/d) ratio from 0.7 to 0.6 on ultimate and cracking load is negligibly small.
6. The effect of the presence of web openings on ultimate and cracking loads of deep beams depends on the degree of interruption of the natural load path joining the loading and support reaction points.

7. Deep beams with web openings are stiffer when the fiber content increases from 0.0% to 0.5% and 1.0%. This phenomenon is true for all deep beams with (a/d) ratios of 0.7 and 0.6.

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Table (1) Effect of increasing steel fiber –volume fraction (V_f) % on ultimate load of deep beams without web opening

Designation	symbol	f'_c MPa	(a/d) ratio	a mm	V_f %	Pu (kN)	Percentage of increase	
N4-0.7/0	A1	34.2	0.7	196	0.0	288	-------	a/d=0.7
0.5F4-0.7/0	B1	39.2	0.7	196	0.5	340	18.0	
1.0F4-0.7/0	C1	52.9	0.7	196	1.0	486	68.7	
N4-0.6/0	A2	39.2	0.6	168	0.0	386	-------	a/d=0.6
0.5F4-0.6/0	B2	45.6	0.6	168	0.5	486	25.9	
1.0F4-0.6/0	C2	42.2	0.6	168	1.0	512	32.6	

Table (2) Effect of (a/d) ratio on ultimate load of deep beams without web opening

Designation	symbol	f'_c MPa	a mm	(a/d) ratio	Pu (kN)	Percentage of increase	
N4-0.7/0	A1	34.2	196	0.7	288	--------	V_f =0.0%
N4-0.6/0	A2	39.1	168	0.6	386	34	
0.5F4-0.7/0	B1	39.2	196	0.7	340	--------	V_f =0.5%
0.5F4-0.6/0	B2	45.6	168	0.6	486	42.9	
1.0F4-0.7/0	C1	52.9	196	0.7	486	--------	V_f =1.0%
1.0F4-0.6/0	C2	42.2	168	0.6	512	5.3	

Table (3) Effect of increased Steel Fiber –volume fraction (V_f) % on ultimate load of deep beams with web openings

Designation	symbol	fc' MPa	(h/b) ratio	a mm	V_f %	Pu (kN)	Percentage of increase	
N4-0.7/1	A5	36.6	4	196	0.0	192	-------	a/d=0.7
0.5F4-0.7/1	B5	41.3	4	196	0.5	228	18.7	
1.0F4-0.7/1	C5	47.8	4	196	1.0	293	52.6	
N4-0.6/1	A6	36.1	4	168	0.0	196	-------	a/d=0.6
0.5F4-0.6/1	B6	41.8	4	168	0.5	240	22.2	
1.0F4-0.6/1	C6	48.3	4	168	1.0	312	59.1	

Table (4) Effect of decreasing (a/d) ratio on the ultimate load of the deep beams with web openings

Designation	symbol	fc' MPa	a mm	(a/d) ratio	Pu (kN)	Percentage of increase	
N4-0.7/1	A5	36.6	196	0.7	192	--------	V_f =0.0%
N4-0.6/1	A6	36.1	168	0.6	196	2	
0.5F4-0.7/1	B5	413	196	0.7	228	--------	V_f =0.5%
0.5F4-0.6/1	B6	41.8	168	0.6	240	5.2	
1.0F4-0.7/1	C5	47.8	196	0.7	293	--------	V_f =1.0%
1.0F4-0.6/1	C6	48.3	168	0.6	312	6.4	

Table (5) Effect of web openings on ultimate load of deep beams with (a/b)ratio = 0.7

Designation	symbol	fc' MPa	(h/b) ratio	Type of beams	Pu (kN)	Percentage of decrease	
N4-0.7/0	A1	34.2	4	Solid beams	288	---------	V_f =0.0%
N4-0.7/1	A5	36.6	4	with web opening	192	33.3	
0.5F4-0.7/0	B1	39.2	4	Solid beams	340	----------	V_f =0.5%
0.5F4-0.7/1	B5	41.3	4	with web opening	228	32.9	
1.0F4-0.7/0	C1	52.9	4	Solid beams	486	----------	V_f =1.0%
1.0F4-0.7/1	C5	47.8	4	with web opening	293	39.7	

Table (6) Effect of web openings on the ultimate load of deep beams with (a/b)ratio = 0.6

Designation	symbol	fc' MPa	(h/b) ratio	Type of beams	Pu (kN)	Percentage of decrease	
N4-0.6/0	A2	40	4	Solid beams	386	---------	V_f =0.0%
N4-0.6/1	A6	36	4	with web opening	196	50	
0.5F4-0.6/0	B2	46	4	Solid beams	486	---------	V_f =0.5%
0.5F4-0.6/1	B6	41	4	with web opening	240	51	
1.0F4-0.6/0	C2	42	4	Solid beams	512	---------	V_f =1.0%
1.0F4-0.6/1	C6	48	4	with web opening	312	40	

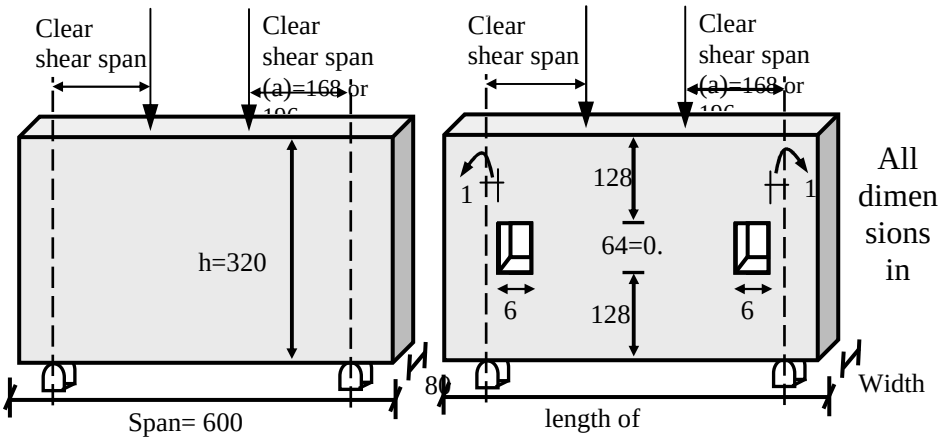


Figure (1) Details of solid deep beams with and without web opening

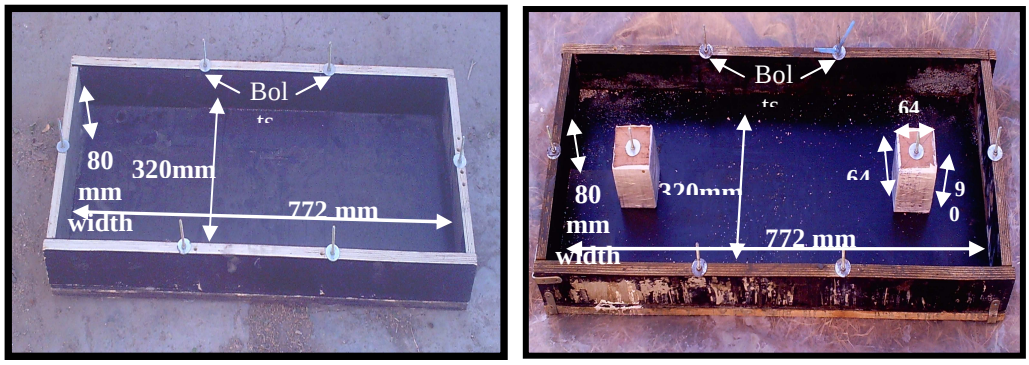


Figure (2) Details of wooden form used for deep beams with and without web openings

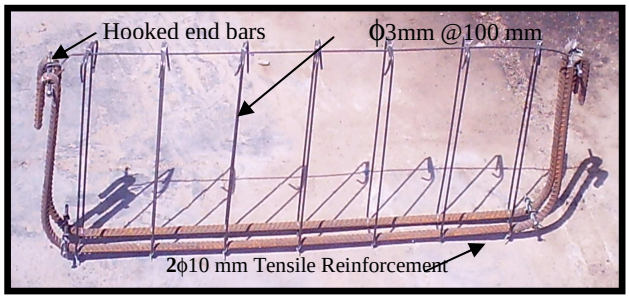


Figure (3) Details of horizontal and web reinforcement

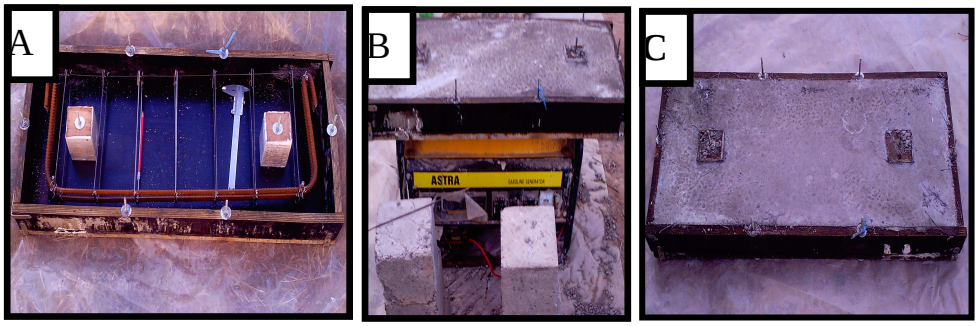
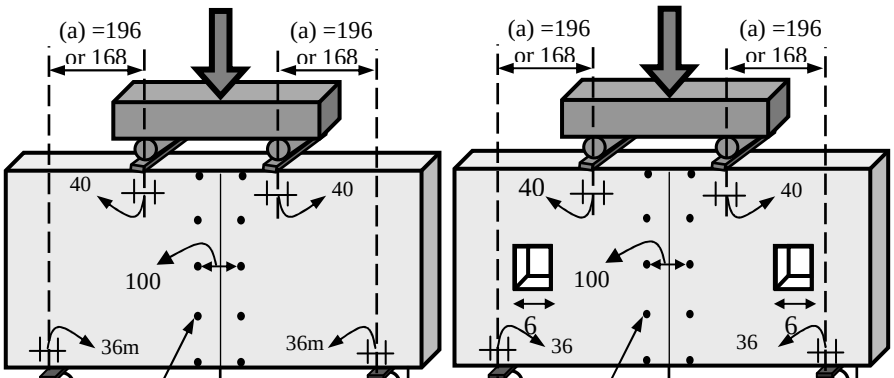


Figure (4) details of the fabrication of deep beams
A-wood form with reinforcement B- table vibrator (generator)
C- Deep beams after casting (in the wood form)



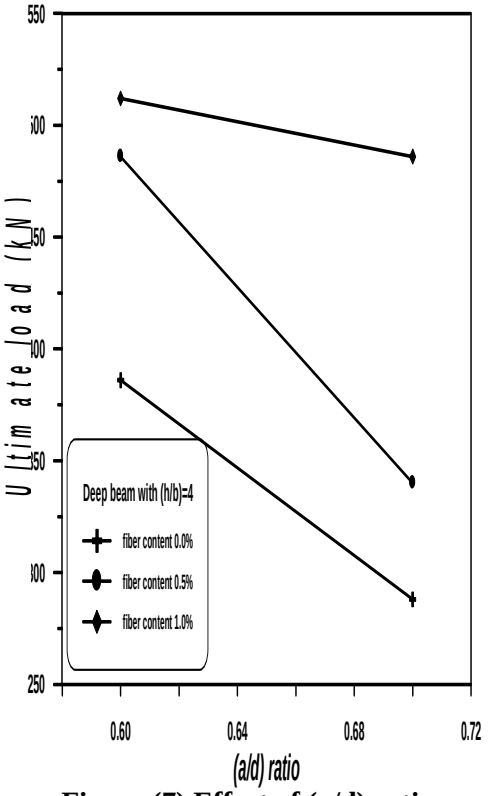


Figure (7) Effect of (a/d) ratio on ultimate load of deep beams without web opening

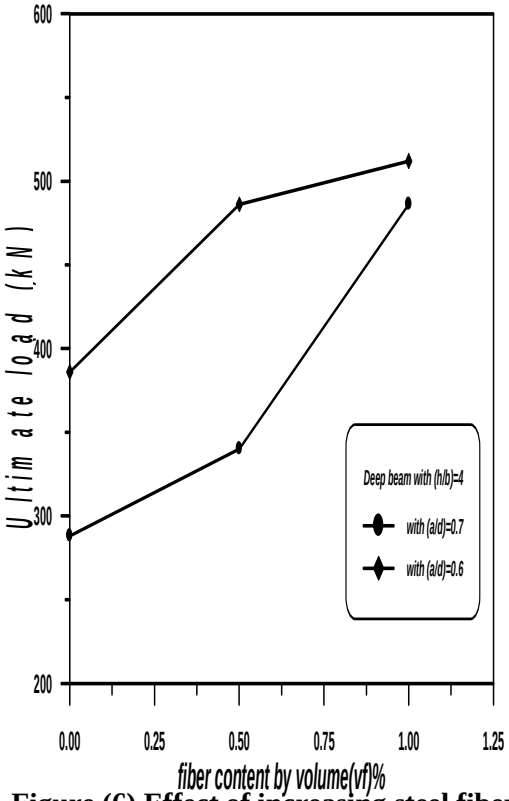


Figure (6) Effect of increasing steel fiber – volume fraction (V_f)% on ultimate load of deep beams without web opening

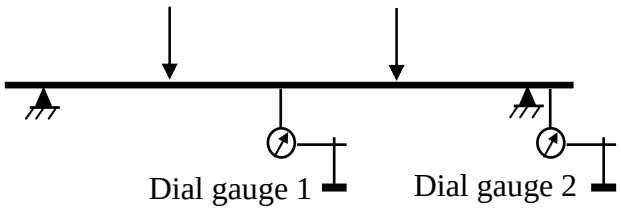


Figure (8) Location of dial gauges

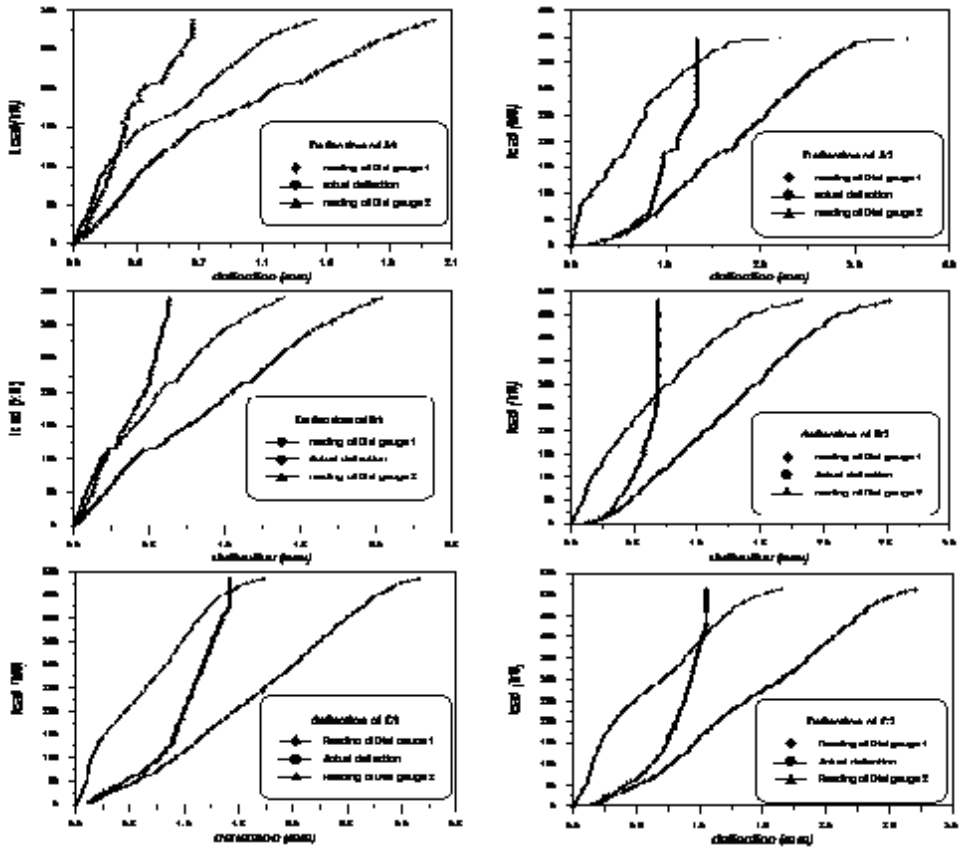


Figure (9) Load-deflection curve for deep beam without web

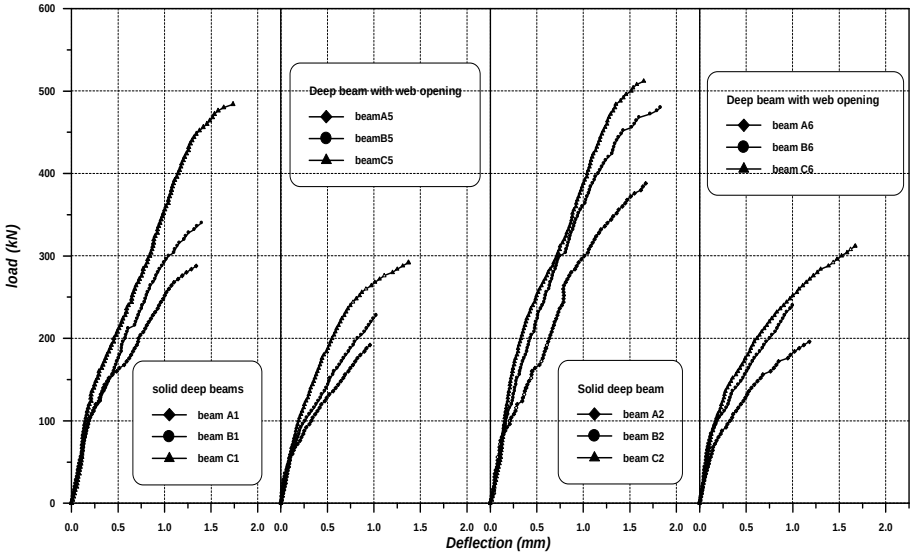


Figure (10) Load-deflection curves for the deep beams without web opening (A1), (B1) (C1) (A2), (B2) and C2 and deep beams with web openings (A5), (B5) (C5)

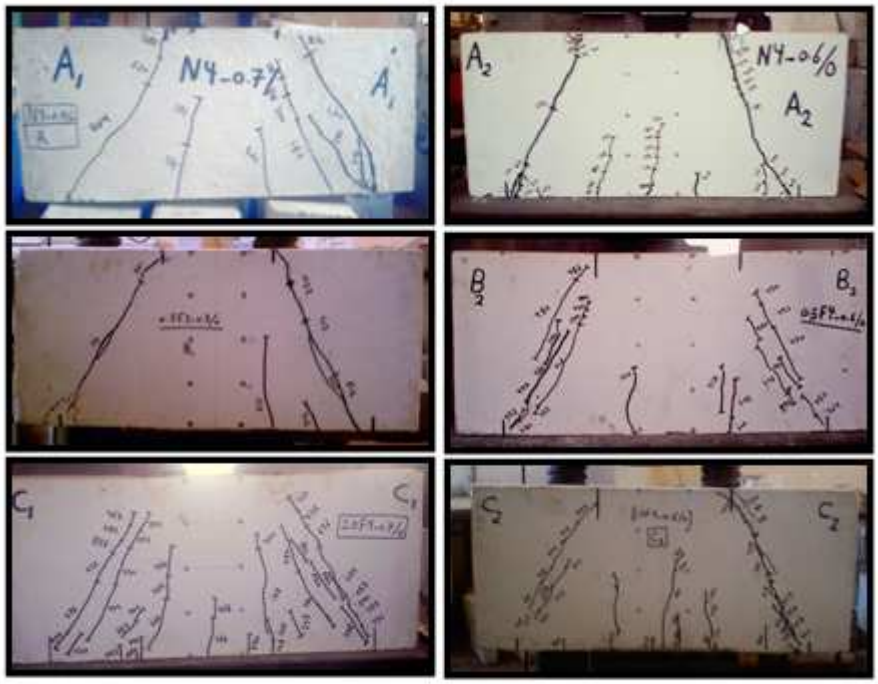
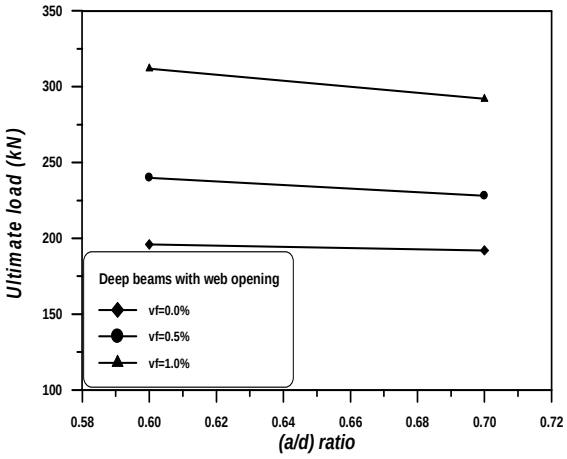


Figure (11) Crack patterns at failure of deep beams without web opening



Figure, (13) Effect of decreasing (a/d) ratio on the ultimate load of deep beams with web openings

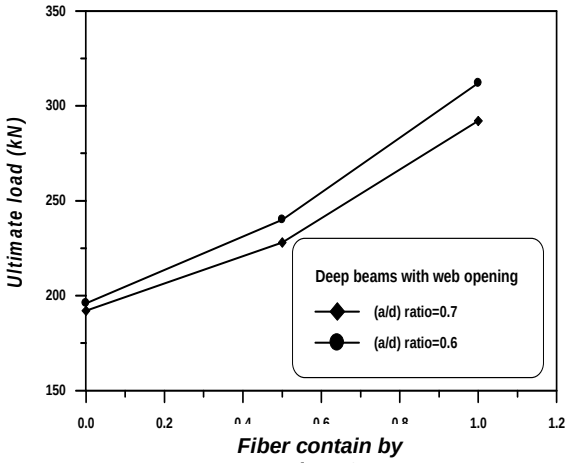


Figure (12) Effect of increased steel fiber–volume fraction (V_f) % on ultimate load of deep beams with web opening

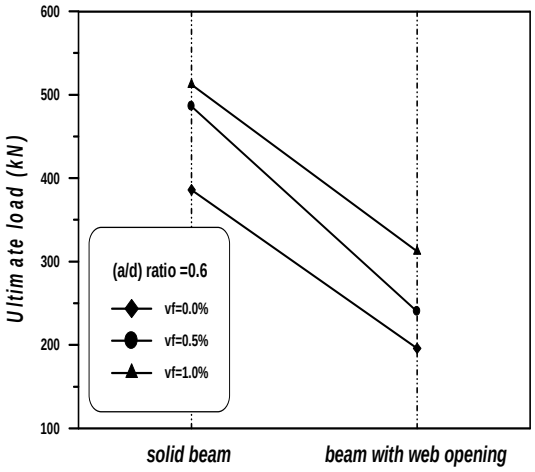
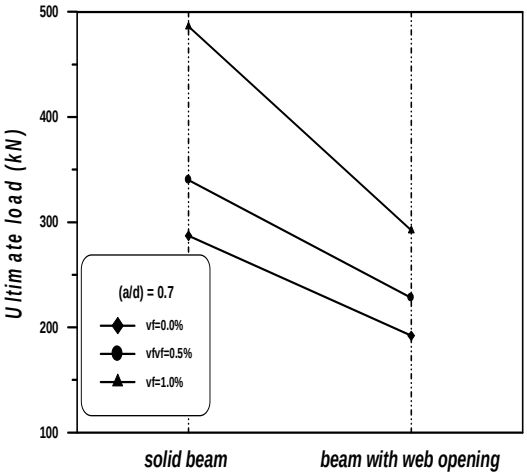


Fig. (15) Effect of web openings on the ultimate load of deep beams with (a/b)ratio = 0.6



Eig (14) Effect of web openings on the ultimate load of deep beams with (a/b) ratio = 0.7

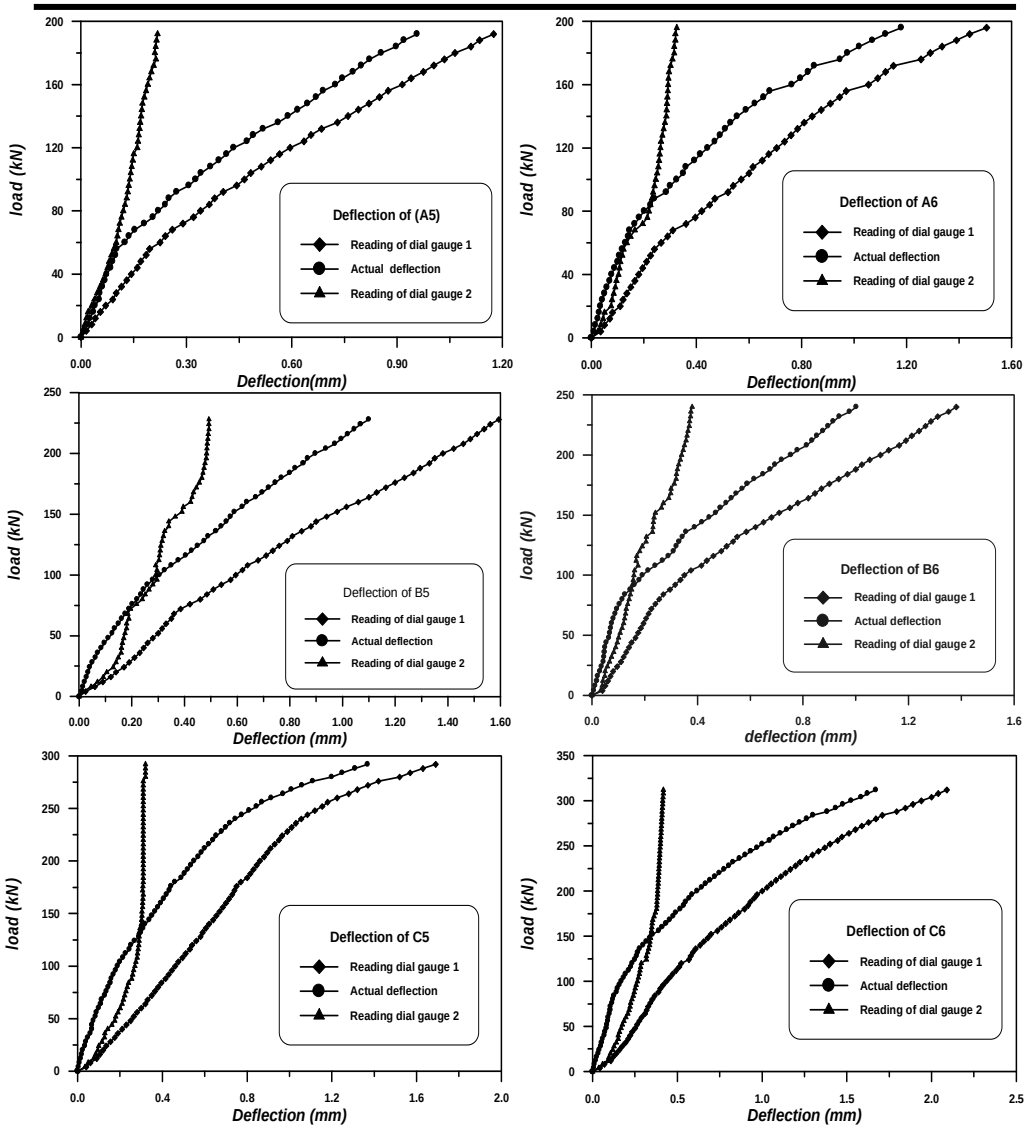


Figure (16) Load – deflection curve for deep beam with web opening

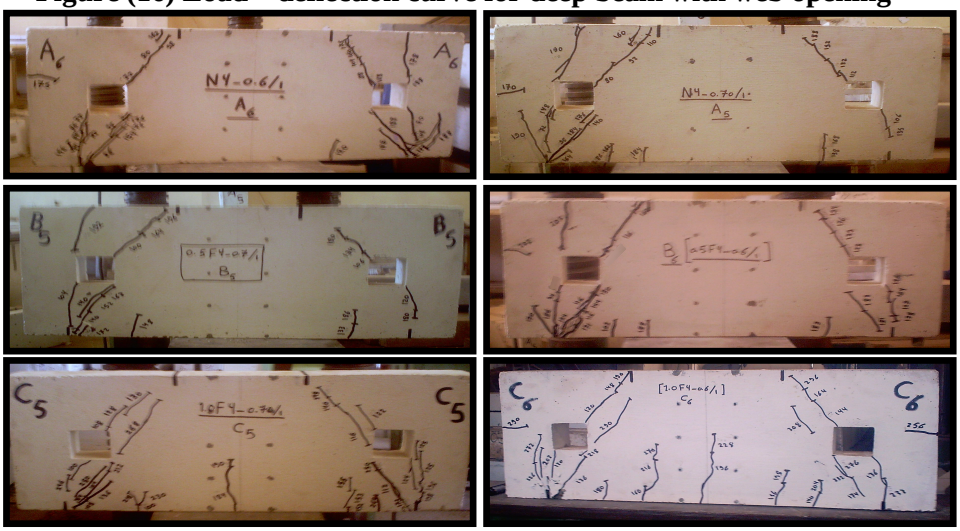


Figure (17) Crack patterns at failure for deep beams with web openings