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EFFECT OF SMALL CIRCULAR OPENING ON THE SHEAR AND FLEXTURAL BEHAVIOR AND ULTIMATE STRENGTH OF REINFORCED CONCRETE BEAMS USING NORMAL AND HIGH STRENGTH CONCRETE

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SUMMARY

In this investigation the effect of small circular opening on the shear and flexural and ultimate strength of beams made by normal and high strength concrete have been studied. The main factors of this test are the changes of diameter, the position of opening and the type and location of reinforcement around the opening and changes in the strength of concrete. In this investigation 9 beams by using normal concrete and 5 beams by using high strength concrete were made and tested. One beam was solid and filled with normal concrete and was used as reference for comparison with other beams with an opening. The testing beams have been loaded as simple beam with two concentrated and symmetrical load. In the beams made of ordinary concrete, when the diameter of opening exceeded the 1.3 of depth of the beam, the reduction of ultimate strength increased and patterned of cracking as well as mode of failure of the beam changed. The effect of concrete strength depended on parameters such as diameter and the position of opening. In order to control the cracks and restrain their width, it is better to use diagonal shear reinforcement. For increasing the ultimate shear strength of the beam usage of diagonal reinforcement and stirrups in top and bottom of opening is recommended. At the end the results of tests were compared with equation of some codes.
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Key word: Experimental test, Shear and Flexural Behavior, Circular opening, Reinforced concrete beams

Introduction

In practice, transverse opening in Reinforced concrete beams is a facility, which allows the utility line to pass through the structure. This type of design encourages the designer to reduce the height of the structure, which leads to an economical design. Because of sudden changes in the dimension of cross section of the beam; the corners of opening would be subjected to stress concentration and it is possible to induce transverse cracks in the beam. Also it can reduce the stiffness, which led to deformation and excessive deflection under the service load and

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considerable distribution of forces and internal moments in a continuous beam. So, the design of these beams needs special consideration, however current code of practice for design of concrete building structures do not provide provision for design of beams with opening.

Research for the beams with an opening started from 1960 and the most of the results are about the reinforced concrete beams with large rectangular opening [2, 3, 4]. For the small circular opening the behavior of the beam is different from the state where the opening is large and rectangular. Also limited experimental work has been carried out for the shear and flexural behavior of the beam that mainly belongs to T shape beams subjected to particular loading with limited parameters [5]. Design codes such as ACI code, the architectural of institute of Japan [AIJ], and plastic truss method, presented the theory equation for especial case of reinforced concrete beam by opening [7,8]. The aim of this research is to investigate the amount of the effect of the presence of small circular opening in the web of reinforced concrete beams and the evaluation of these effects which includes the effect on the ultimate strength, the type of cracking, ductility and in general the shear and flexural behavior of these beams. The main factors in these research is the diameter of opening, the distance of opening from support and the location of applied load, web reinforcing bars and the type of position of reinforcing bars around the opening and also variation in the concrete strength which will be explained.

EXPERIMENTAL PROCEDURE

Specimens Description

In this research 14 specimens were made and tested, 9 of them were made of normal concrete and 5 of them were made of high strength concrete. In the group of beams made of normal concrete one solid beam was used as a reference to be compared with beams with an opening.

It should be mentioned, in order to study the effect of parameters related to opening in the beam, the amount of shear and flexural reinforcement, their strength and the stirrups spacing, along all beams were considered constant. The length of beams were 160 cm which were loaded over support with span length of 140 cm. Cross section of these beams: the width of section 12.5 cm, the height of section 25 cm, the effective depth 21.7 cm and the distance of compression fiber to compression reinforcement 3.3 cm. For tensile bars, two bars with 14 mm diameter and for compression reinforcement two bars with 6mm diameter were used.

Stirrups also have a diameter of 6mm and apart from the location of opening, are placed in the shear span, with 10 cm distance from each other. For loading also symmetrical and concentrated load, which were placed with a 40 cm distance from each other, were used. The value of shear span is equal to 50 cm and the shear span- to – depth Ratio is 2.3. The structural design and the choice of value and the pattern of shear and flexural reinforcement of these beams are selected in a way that the test beam reaches the shear and flexural failure simultaneously. Table 1 will show the properties of steel bars used in the beam and table 2 will show all the details of beams used in these researches, which includes the concrete strength, diameter and the distance of opening from nearest support. In order to make it easy to recognize the properties of each beam, abbreviation of words have been used. So "N" will indicate the beams made of normal concrete and "H" will indicate the beams with high strength concrete, and the number after "D" will show the diameter of opening in centimeter and the number after "X" will show the distance of center circular opening from nearest support which is also in cm, and also "S" will show small stirrup on top and bottom

TABLE 1 : MECHANICAL PROPERTIESOF REINFORCEING BARS USED IN THE R.C .BEAMS

Bars	Modulus of elasticity 10^5(MPa)	Ultim ate stress (Mpa)	Yield stress (Mpa)	Diameter of bar (Mpa)
Tension reinforcement	2	600	450	14
Compression reinforcement	2	435	250	6
Large Stirrups	2	435	250	6
Small Stirrups	2	435	250	4
Bar in top and bottom of opening	2	435	250	6
Diagonal reinforcement	2	435	250	6

TABLE 2: DETAIL OF BEAMS THAT USED IN THIS RESEARCH

Beams	Diameter of opening D (cm)	Opening distance from Support X (cm)	Concrete Strength $f_c^{\times}$ (Kg/cm^2)
S	--------	-----------	310
ND8X35	8	35	295
ND8X15-S	8	15	292
ND8X25-S	8	25	302
ND8X35-S	8	35	299
ND8X35-D	8	35	307
ND8X35-Sd	8	35	301
ND6X35-S	6	35	296
ND10X35-S	10	35	304
HD8X15-S	8	15	712
HD8X25-S	8	25	701
HD8X35-S	8	35	687
HD6X35-S	6	35	699
HD10X35-S	10	35	703

opening and "d" will show the presence of diagonal reinforcement around the opening for example the abbreviation of ND8x35-Sd will introduce a concrete beam made of normal concrete which the diameter of its opening is 8 and the distance of center of opening from nearest support is 35 cm and in bottom and top of opening small stirrup and around the opening diagonal reinforcement have been used. Figure 1 for example shows the properties of ND8X35-SD beam.

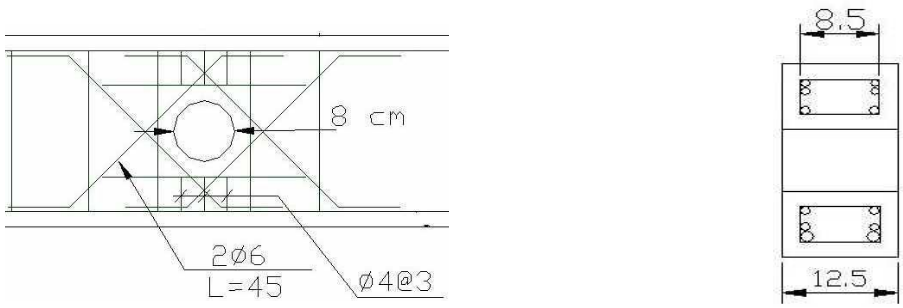


FIGURE 1 – PROPERTIES OF BEAM ND8X35-sd AND THE TYPE OF LOCATION OF BARS

METHOD OF TESTING BEAMS

The test of all beams was carried out 28 days, after the casting of concrete. In order to evaluate the strain, we determined two points, then on these points, the device were installed to evaluate the strain. After placing the beam on the supports we must be sure about the right position of the supports and the place which the load would be applied. The total load would be applied to the beam from load cell by a solid steel beam as a two concentrated symmetrical load, and the load cell is being calibrated between jack and steel beam. The load from the start of loading until 9 ton should be applied gradually with growth of 1 ton and after that until the time of failure with

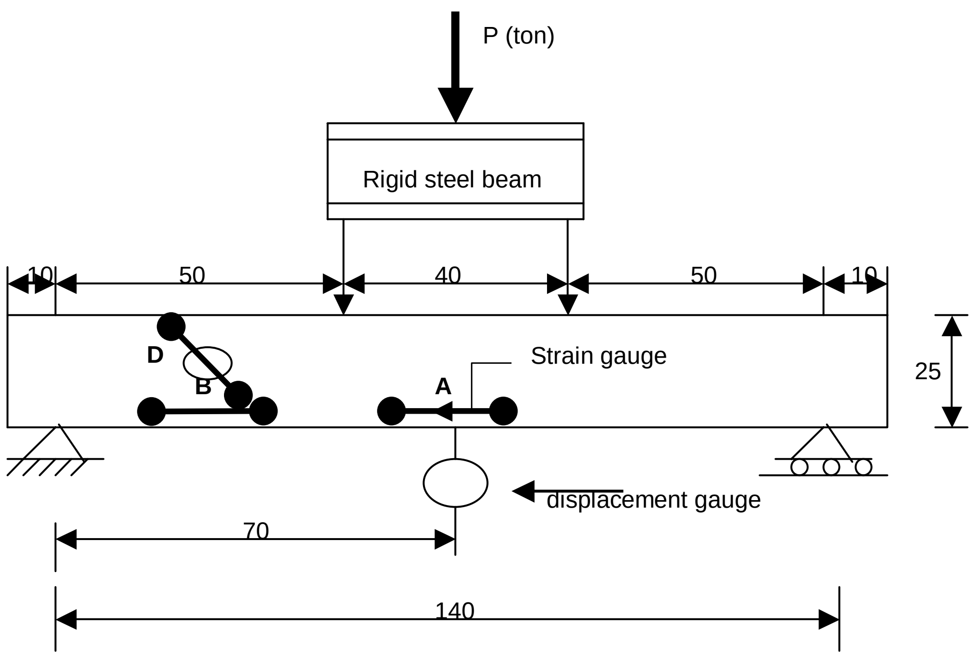


FIGURE 2 – POSITION OF APPLIED LOAD, LOCATION OF STRAIN AND DISPLACEMENT

growth of 0.5 ton, and in each step the duration of load should be 30 second, until the ultimate load is applied. In each stage in addition to recording the values, strains, deflection of center of the beam and induced cracks with the amount of applied load were recorded.

Figure 2 shows the model of testing beam with the position of applied load, the location of displacement gauge and the buttons, which evaluate the strain. Strain- gauge A has been placed in the middle of the span of the beam, and strain- gauge B has been placed under the opening (in every location that a opening is located), and strain-gauge D has been placed with a 45 angle to the horizontal direction and its alignment was passed through the opening. The other strain-gauge was located symmetrically with those strain gauge in the beam.

EVALUATION OF RESULTS

STIFFNESS AND DEFLECTION

In order to investigate the stiffness and deflections of beams with opening, Load – deflection curves of the beams were studied. Figures (3-a) to (3-c) will show the effects of changes in diameter and location of opening and reinforcement around the opening in normal strength reinforced concrete beams respectively. Figures (3-c), (3-d), (3-e) shows the effects of changes in the diameter and the position of opening in the beam with high strength concrete. As it has been shown in figure (3-a), the deflection curve belonging to ND6X35-S which has the smallest size of opening, from the beginning to reach the ultimate strength, was almost similar to the S solid beam. Beam ND8X35-S that has opening diameter 8 cm, in linear domain is as S solid beam, but after that, with increasing the applied load, it will show larger deflections relative to reference beam, which is due to increased width of cracks in the beam. Beam ND10X35-S which has an opening diameter of 10 cm, from the beginning, with increasing the applied load, shows larger deflections relative to other beams and the slope of its curve is considerably less than other beams. It will show the increase in the diameter of opening in addition to its effect on the ultimate strength of the beam, it has negative effect on the stiffness and serviceability of the beam. When the diameter of the opening exceed from one third of depth of the beam, it causes greater reduction in the serviceability of the beam. The concept of serviceability is that under service load the induced deflections in the beam as well as maximum width of the crack do not exceed from allowable limit. Figure (3-b) shows the effect of the location of opening on the load deflection curve. The linear part of three curves belongs to beams with opening that is almost parallel and similar to the reference beam. As we can see after the linear part, these curves are broken and separated from each other. What we understand from linear part of curves is that the changes in the position of opening have not considerable effect on the serviceability of the beam. But the most critical position of opening to reach the ultimate strength, is the nearest position relative to support. Figure (3-c) shows the effect of the type of shear reinforcement around the opening on the load-deflection curve. With regard to the figure we will understand that the absence of reinforcement around the opening in addition to the reduction of ultimate strength will induce greater deflections in the beam. The presence of diagonal reinforcement is due to controls of cracks which increases the stiffness in the beam, in a way that the stiffness in the Beams ND8X35-Sd, ND8X35-d is more than the other two beams with opening and even the reference beam or the solid beam.

Also we can observe that in the beam ND8X35-Sd, were 2 kinds of reinforcement have been used around its opening, has equal strength to reference beam which shows the importance usage of this kind of reinforcement on the ultimate strength. Figure (3-d) also shows the effect of the changes in the diameter of opening on the load-deflection curve in the beams with opening, made of high strength concrete. As we can see in the figure the increase in the strength of concrete has a large effect on the stiffness of beams with an opening under service load. Almost similar to the results which were obtain from beams made of normal concrete, in this case we can say that the increase in the diameter of the opening will lead to the reduction

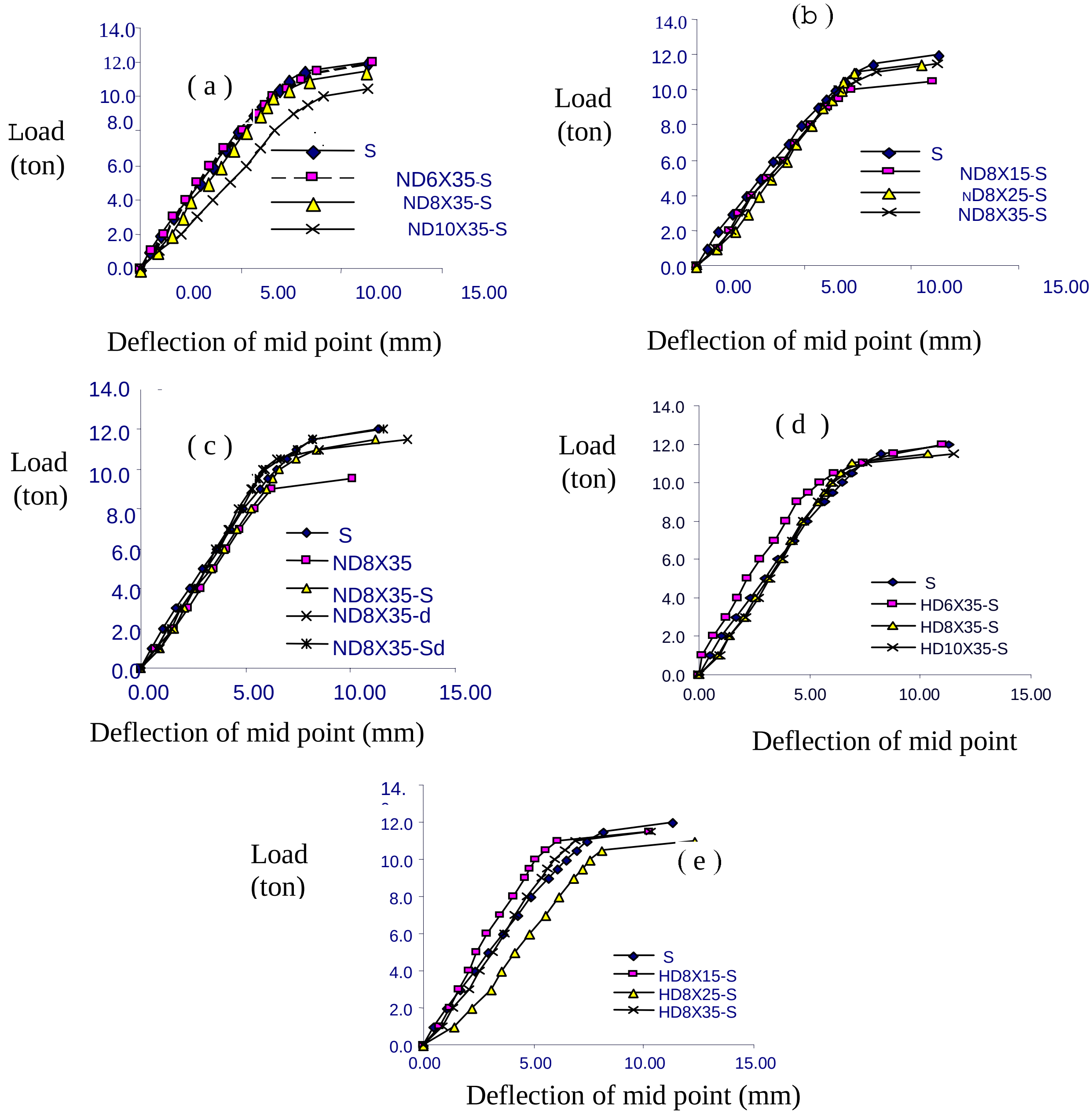


FIGURE3: LOAD – DEFLECTION OF BEAMS

of stiffness in the beam, but, however, the increase in the strength of concrete will improve the serviceability of the beam. Figure (3-e) will show the effect of position of opening in the beams made of high strength concrete. Contrary to the beams made of normal concrete were the most critical position of opening is near the support, the most critical position of opening in the beams with high strength concrete is almost in the middle of the distance between support, and the place of applied load and the beam which its opening is near the support, has a better serviceability relative to the other beams. By comparing the beams with opening made of normal and high strength concrete, we can understand that the increase in the strength of concrete will increase the slope of linear part of the curve, which means the increase in the stiffness and the reduction of deflection in the beams with opening made of high strength concrete. The increase in the strength of concrete is more effective to improve the serviceability of the beams with larger opening.

INVESTIGATION OF SHEAR BEHAVIOR

LOAD-STRAIN CURVE IN STRAINGAUGE D

In order to investigate the shear behavior of beams with opening, particularly investigating the cracks and the width of cracks which passes through the opening, we will use the result obtained from strain gauge D. Figure (4-a) to (4-c) will show the effect of diameter of opening, position of opening and the type of reinforcement around the opening on the diagonal strain in the normal concrete and figure (4-d) to (4-e) the effect of diameter and position of opening in the high strength concrete, respectively.

As seen from these figures, the curve belongs to reference beam which has no opening, as can be predicted before the yielding of longitudinal reinforcement and widening of cracks it continued in a linear state (linear part of the curve), then with increasing the load a gradual curving of the load-deflection curve will induced. Beams with opening before the creation of the first cracks are similar and act in a linear state. But after the appearance of first cracks, during the propagation of crack, a gradual curving of the load-deflection curve induced. The increase of diameter will show larger deflections. particularly beam ND10X35-S which has an opening with 10 cm diameter, after the first shear crack in the area of opening will show very large strains. Very large strain observed in the state of failure of the beam is due to large cracks induced in the time of failure so called (frame type failure)[6]. By investigating the curves of this figure and other curves, this assumption would be more certain that if the diameter of opening exceeds 1/3 depth of the beams it will induce considerable changes in the shear and flexural behavior as well as ultimate strength of the beam. By comparing different positions we can understand that most strain and the width of cracks in the beams made of normal concrete belong to the situation, were the opening is near the support. In a position where the opening is near the location of applied load or in the distance between the place of applied load and the support of the beams will show similar behavior. As we were expecting by installing diagonal reinforcement, we can see it has a very important effect on the control of cracks and the reduction of diagonal strain before and after creation of cracks. This issue is quiet clear for the beam ND8X35-Sd which has diagonal reinforcement and small stirrups in the top and bottom of opening. The most important effect of installing the diagonal reinforcement together with small stirrups around the opening is that, it will prevent the early cracking of web of the beam (which will induced due to presence of opening) and control and prevent the development of shear cracks. Although the presence of diagonal reinforcement can only control the cracks, but for the increase of shear strength of the segment with opening is not sufficient. The curve belonging to ND8X35 beam will also show which, by installing an opening in the concrete beam without using shear reinforcement it will cause an early shear cracking in the beam and after inducing first crack, we will observe the rapid propagation of cracks around the opening which has undesirable effect on the serviceability of the beam with opening. Similar to beams made of normal concrete in the beams made of high strength concrete by increasing the diameter of opening, the stiffness of the beam will reduce and at the same time strains and changes in length in the diagonal direction will increase.

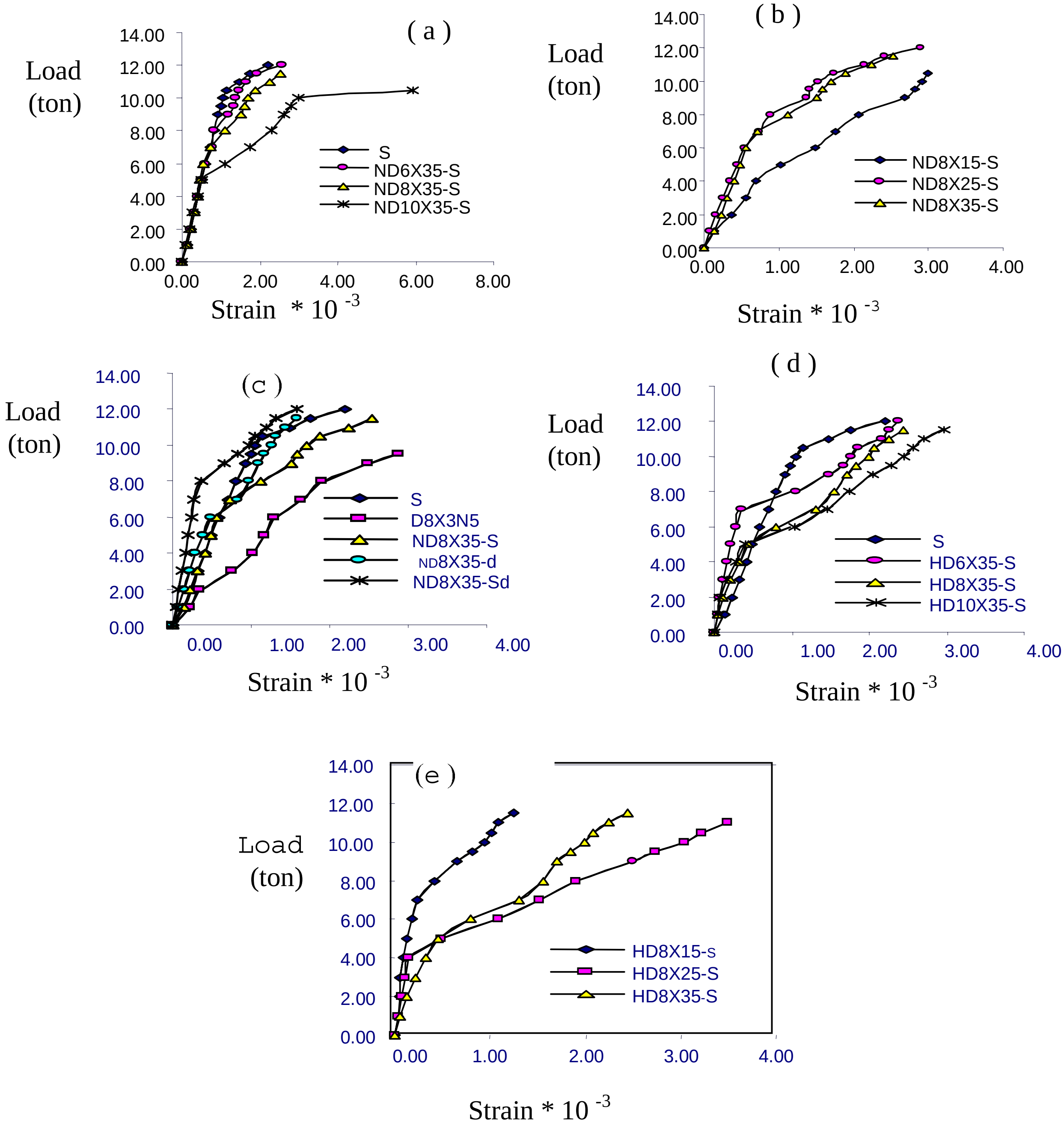


FIGURE 4- LOAD-DEFLECTION CURVE IN THE STRAIN GAUGE D

But unlike beams made of normal concrete were the greatest change of lengths in diagonal direction belongs to opening near the support in the beam made of high strength concrete, the greatest diagonal strain belongs to a beam with an opening in a distance between the place of applied load and support, namely, in middle of shear span of the beam. Beams with high strength concrete, will show more stiffness and less strain, before the creation of the first crack, relative to beams with low strength, but after the creation of cracks and by increase of their width, it will show greater variation in the length in diagonal direction relative to beams made of normal concrete, but in the beams which their diameter is 10 cm the increase in the strength of concrete before and after the creation and development of cracks will cause the reduction of strain and change of lengths in diagonal direction.

INVESTIGATION OF ULTIMATE STRENGTH OF BEAM WITH OPENING

The results of this research will show, the increase in the diameter of opening will cause the reduction of ultimate strength in the beam, where the strength of a beam with an opening with 10 cm diameter is %12.5 less than a solid beam and this beam under a 10.5 Ton load due to a shear which pass through the opening failed in frame type made. Although the ND6X35-S beam will reach the ultimate strength under the 12 Ton load, but regarding the results its level of serviceability is lower than the reference beam. The most critical place for the opening in beams with normal concrete is near the support which in this situation will induce a reduction of %12.5 in the ultimate strength. The lack of shear reinforcement around the opening will also cause a reduction of %20 in the ultimate strength relative to solid beam and if such a opening located near the support the ultimate strength will show a larger reduction.

INVESTIGATION OF CRACKS AND THEIR PATTERN

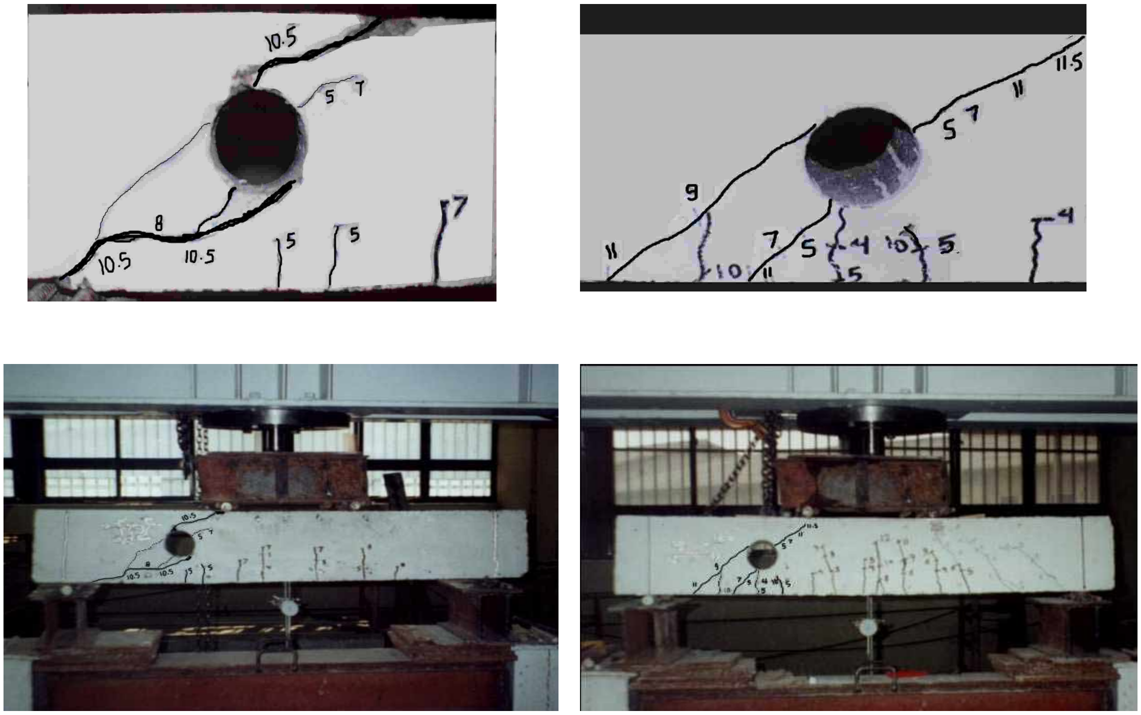
The results of tests about the type of shear and flexural cracking in the beams with opening will show, the load were the first cracks will induce, does not depend on the presence or the lack of opening and the amount of this load in all beams with normal or high strength concrete is about 3 or 4 Tons. But the shear cracks around the opening in beams with opening will induce sooner than in the reference beam (in similar location). Table 1 will show the amount of first shear crack induced in the beam. According to the results, although with increase of diameter in opening, the amount of load related to shear cracking around the opening in beams made of normal concrete reduced, but the type and pattern of cracking in these beams are different. Beam ND6X35-S which has an opening with 6 cm diameter from cracking point of view and general behavior will act mostly like a solid beam. In contrast to beam ND8X35-S the direction of shear cracks passed through the center of opening and rapidly will grow through top and bottom of section of beam which with increasing the width of these cracks, the beam under the load of 11.5 Ton and subjected to shear failure where its direction passes through the center of opening will collapse which according to Mansoor research [6], this kind of failure is known as beam failure type.

In beam ND10X35-S also first shear crack induced under 5 Ton. The direction of this preliminary cracks, which has an angle of approximately 45 degree relative to horizontal direction, passed through the center of opening, but with increase of load, its direction will change nearly in the horizontal direction. As the amount of load increased, additional cracks on top and bottom of opening will form. These cracks will join the horizontal cracks and when the total amount of applied load reaches 10.5 Ton the beam suddenly failed in frame type mode.

TABLE 3- THE AMOUNT OF LOAD BELONGS TO FIRST SHEAR CRACK AROUND THE OPENING

BEAM	*LOAD(TON)*
ND8X35	2
ND8X15-S	3
ND8X25-S	6
ND8X35-S	7
ND8X35-d	5
ND8X35-Sd	8
ND6X35-S	8
ND10X35-S	5
HD8X15-S	7
HD8X25-S	4
HD8X35-S	5
HD6X35-S	7
HD10X35-S	5

The type of failure of ND10X35-S beam and the obtained results from strain- gauges and the behavior of beam will show if the diameter of opening exceed 1/3 depth of section, behavior and the type of failure of beam with opening made of normal concrete relative to previous states will change completely. The increase of concrete strength in beam with opening, in case of the diameter of opening is less than 1/3 depth of beam, it has not much influence in the controls of cracks and the amount of load failure, but in the beams which the diameter of opening is 10 cm (HD10X35-S beam) the increase of concrete strength in addition to increase of load failure, will cause the changes in the mode of failure of the beam from the frame type mode to the beam type failure and this beam will collapse because of the shear cracks which pass through the center of opening. The changes in the position of opening in beams with opening made of normal concrete will influence the type of cracking around the opening, as we come closer from the place of applied load to the support, the amount of load which will induce the first shear crack around the opening, will reduce. The beam which has an opening near the support (ND8X15-S) under the shear which pass through the center of opening and under the 10.5 Ton load and ND8X35-S beam which has an opening near the place of applied load, in the same way, and under the 11.5 Ton load will fail, but the beam ND8X25-S which its opening is in a distance between support and the place of applied load, although it will not show a better control of cracks in comparison with previous beams, under the 12 Ton load and due to flexural failure at mid span and the shear force which passes through the center of opening which will induce simultaneously will collapse. On the contrary the beams made of normal concrete in the beams with high strength concrete, the longest and widest shear crack belongs to HD8X25-S beam which has an opening in the middle of shear span. Although this beam has been made of high strength concrete, but relative to similar beam made of normal concrete will fail under less load and will show larger cracks. Type of reinforcement around opening has a very clear effect on the first shear crack around the opening and also on the control of cracks.



ND10X35-S HD10X35-S

FIGURE 5- THE PATTERN OF CRACKS IN ND10X35-S AND HD10X35-S BEAMS

In beam ND8X35 which has an opening with no particular reinforcement, the first crack under the 2 Ton load (relative to other beams is very little) will induce. Small stirrups which were used on top and bottom of ND8X35-S beam could not control the crack, and around the opening of this beam lots of cracks were observed. Also first shear crack around the opening of this beam induced under the 7 Ton load, but ND8X35-d beam which has diagonal bar, had a good control of crack. Although the first crack around the opening in this beam will induce under the 5 Ton load, but its growth is very slow and the number of cracks around the opening are little. Among the beams ND8X35-Sd beam which has a small stirrup on top and bottom of opening and also has diagonal bar, will act better than the other beams in controlling the cracks and the load with first shear crack around the opening.

The first shear crack around the opening of this beam induced under the 8 Ton load and until the beam reached to the ultimate strength of 12 Ton, (Like solid reference beam), the rapid growth of cracks and also their width was very little. In fact, in addition to influencing the ultimate strength, it will help the beam with opening to have a better serviceability. Figure 5 also shows the types of cracks of beams with opening.

EVALUATION OF SOME EQUATION PRESENTED IN SOME CODES

The most important analytical equations in determining the ultimate strength beams with opening belongs to ACI and AIJ codes and method of plastic truss.

According to ACI code, shear strength of section with opening were obtained from the following:

$$V_c = \frac{1}{6}\sqrt{f'_c}.b_w.(d - d_0) \tag{1}$$

$$V_s = V_{sv} + V_{sd} = \frac{A_v . f_{yv}}{S}(d_v - d_0) + A_d . f_{yv}.Sin\alpha \tag{2}$$

In equation mentioned above d and d_0 are effective depth of section and diameter of opening respectively, d_v the distance between longitudinal bars on top and bottom, b_w the width of section and s the distance between stirrups in mm, A_v and A_d cross section of vertical and diagonal reinforcement respectively in mm sq. f'_c is ultimate compressive strength of concrete and F_{yv} is yielding stress of shear reinforcement in Mpa , α is also slope angle of diagonal reinforcement.

The Japanese code (AIJ) will use a formula known as (Hirosawa) in order to show the estimation of shear strength of beam with opening.

$$V_n = \left[\frac{0.092\ k_u.k_p.\left(f'_c + 17.7\right)}{\frac{M}{V.d} + 0.12}\left(1 - \frac{1.61.d_0}{h}\right) + 0.846\sqrt{\rho_w f_{yv}} \right] bd_v \tag{3}$$

In this equation ρ_w is ratio of shear reinforcement around the opening and k_u and k_p, are factors which are dependent to the height of section and the ratio of longitudinal reinforcement respectively.

The method of plastic truss will obtain the shear strength of segment with opening from the following equations:

$$V_n = b.d_{tw}.\rho_v.f_{yv}.\cot\phi_s \tag{4}$$

$$d_{tw} = d_v - \frac{d_0}{\cos\phi_s} - S_v \tan\phi_s \tag{5}$$

In equations mentioned above Sv is the distance between stirrups in both side of opening in mm and d_{tw} is the effective depth and Φ_s is angel of diagonal compression struts of concrete element regarding plastic truss model.

Table 4 shows shear strength of beams with opening which obtained from different codes with results obtained from tests. In this table Ve is shear strength obtained from experimental investigation carried out in this research, ACI code determined shear strength of segment with opening without considering the effect of small stirrup on top and bottom of opening.

This code has nearly accurate prediction for a beam which its opening has no special reinforcement, and also beams which use a combination of diagonal reinforcement and small stirrup. It has a conservative prediction about larger openings with the diameter of 10 cm and as we can see in ND8X35-d beam which has diagonal reinforcement without any small stirrups will present a dangerous and unrealistic prediction.

TABLE 4- SHEAR STRENGTH OF BEAMS WITH OPENING

Beam	V_e(ton)	V_{PT}(ton)	V_{AIJ}(ton)	V_{ACI}(ton)
ND8X35	4.75	3.22	2.61	4.27
ND8X15-S	5.25	3.22	3.28	4.27
ND8X25-S	6	3.22	2.82	4.27
ND8X35-S	5.75	3.22	2.61	4.27
ND8X35-d	5.75	5.25	3.71	5.97
ND8X35-Sd	6	5.25	3.71	5.97
ND6X35-S	5.75	4.13	4.28	5.14
ND10X35-S	5.5	4.13	3.43	5.14
HD8X15-S	5.75	4.13	3.05	5.14
HD8X25-S	5.25	2.48	-------	3.6
HD8X35-S	5.75	3.27	-------	4.37

We should mention that, the results obtained from ACI equations have been multiplied by strength reduction factor which is equal to % 85.

In equation belonging to AIJ code we can not use the results obtained from 10 cm opening because the diameter of this opening is more than 1/3 depth of beam which is one of disadvantage of this code. As we can see, this code will present a conservative prediction about all the beams with opening. Of course the difference between this code with ACI code is that Japanese code will predict the shear strength according to loading condition and applied moment in the position of opening. V_{pt} will show the shear strength by using plastic truss method. This method has a satisfactory prediction about beams which their opening has diagonal reinforcement and conservative prediction about the rest of the beams particularly those beams made of normal concrete. One of draw backs of this approaches is that, they will not consider the role of small stirrup on top and bottom of opening on the strength of beam with opening against the applied shear. It is necessary to point out that the prediction of codes and methods mentioned above is only about the ultimate strength of the beams, while using the special shear reinforcement is for increase of ultimate shear strength and also for the improvement of level of serviceability of the beams with opening.
All the issues mentioned above is presented for a comparison between results obtained from this research (according to laboratory conditions situations and explained loading) with results obtained from analytical equation written in codes.

CONCLUSIONS

1- The load under which the first flexural crack induced does not depend on the presence or the lack of opening and its situation, but shear cracks around the opening will induce sooner than shear cracks around the similar area in solid beam.

2- The increase of the diameter of opening in beams with opening made of normal concrete will cause the change in the pattern of cracks and the type of failure from flexural failure to frame type or beam type shear failure.
3- The increase of strength in concrete does not have much influence on the ultimate strength, but it will increase the stiffness and will improve serviceability of the beams.

4- The most critical position of opening to reach the ultimate strength in beams made of normal concrete is near the support and also the best place for the location of opening in these beams is in middle of a distance between the place of applied load and support (in middle of the shear span).

5- If the diameter of opening is less than 1/3 depth of beam, high strength concrete beams with opening before the creation of first crack will show more stiffness and less diagonal strain relative to beams with normal strength concrete, but after the creation of cracks and the increase of their width, greater changes in diagonal length were observed with high strength concrete beams, relative to normal strength concrete beams with opening. But if the diameter of opening is more than 1/3 depth of beam, the increase of strength of the beam before and after the creation and development of cracks reduces the strains and changes in length of diagonal direction.

6- The presence of longitudinal bars on top and bottom of opening is necessary to control the cracks and flexural strains around the opening.

7- The installation of diagonal bars and small stirrup on top and bottom of opening will increase the ultimate strength of the beams with opening.

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