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International Science Index, Structural and Construction Engineering Vol:11, No:7, 2017 waset.org/Publication/10007518

***Abstract*—**This paper aims to investigate the structural behaviour of RC beams with circular openings of different sizes and locations modelled using ABAQUS FEM software. Seven RC beams with the dimensions of 1200 mm×150 mm×150 mm were tested under three-point loading. Group A consists of three RC beams incorporating circular openings with diameters of 40 mm, 55 mm and 65 mm in the shear zone. However, Group B consists of three RC beams incorporating circular openings with diameters of 40 mm, 55 mm and 65 mm in the flexural zone. The final RC beam did not have any openings, to provide a control beam for comparison. The results show that increasing the diameter of the openings increases the maximum deflection and the ultimate failure load decreases relative to the control beam. In the shear zone, the presence of the openings caused an increase in the maximum deflection ranging between 4% and 22% and a decrease in the ultimate failure load of between 26% and 36% compared to the control beam. However, the presence of the openings in the flexural zone caused an increase in the maximum deflection of between 1.5% and 19.7% and a decrease in the ultimate failure load of between 6% and 13% relative to the control beam. In this study, the optimum location for placing circular openings was found to be in the flexural zone of the beam with a diameter of less than 30% of the depth of the beam.

***Keywords*—**Ultimate failure load, maximum deflection, shear zone, flexural zone.

I. INTRODUCTION

IN the construction of new buildings, utility ducts and pipes are necessary to accommodate necessary services such as electricity, water supply, gas pipes, computer networks, etc. [1]. Normally, these ducts and pipes are placed under the beams; however, if these ducts and pipes can pass through the web of the beam by creating circular openings within the beam during the design stage, it will help in reducing the dead space and make the ceiling look tidier, without the need to cover it with a suspended ceiling. This, in turn, will reduce the time and cost needed for bending the pipes under the beams [2]. If the beam web is drilled to accommodate pipes or ducts for different mechanical and electrical services, this may lead to undesirable issues such as the reduction in beam stiffness as the beam was not designed to have these openings. However, if the beam is pre-designed to have an opening of known size and location, this will be sufficient to ensure the safety and serviceability of the structure [3]. Commonly, there are three different shapes of openings; circle, rectangular and square. The issue associated with the utilisation of rectangular and square is the great concentration of stresses at the sharp corners of openings that may cause some cracks which might be aesthetically unacceptable [4].

The openings can be classified into two kinds, small and large openings. The opening can be classified as a small opening when it does not affect the stiffness, deflection and strength of the beam. However, large openings are those that have a considerable effect on the stiffness, deflection and strength of the beam [5]. Experimentally, square and rectangular openings are categorized as small openings when their height is 25% or less than the depth of the beam's web. In addition, circular openings with diameter of less than 40% of the depth of the beam are considered as small openings [6].

Many studies have been carried out to investigate the effect of using openings of different shapes, sizes and locations on the behaviour of RC beams. Al-Sulayfani and Al-Hamdani have conducted an experimental study to investigate the effect of the opening size on ultimate failure load and maximum deflection of RC beams [7]. They found that the use of circular openings with diameters of 100 mm, 125 mm & 150 mm at the shear zone caused a reduction in the ultimate failure load between 16% and 51%. The research found an increase in the maximum deflection of between 25% and 39% compared to the solid control beam depending on the diameter of the openings. Alsaeq [8] used FE software in addition to the experimental work to simulate the behaviour of RC beams with openings. The results showed that the location of the opening has more effect on the ultimate failure load than the shape of the opening. In addition, this study found that the results of the software analysis were 20% less that the results obtained from the experimental work.

Hafiz et al. [9] have studied the effect of using circular openings with different sizes located at the shear zone on the load-deflection curves using FE software. In addition, the effect of the shape of opening on the ultimate failure load has been studied by using rectangular openings with equivalent area to the circular openings. They concluded that there was only small effect on the ultimate failure load and maximum deflection when RC beams incorporated circular opening with

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diameter of less than 44% of the depth of the beam in comparison to the solid control beam. However, a reduction of minimum 34% have been recorded when the diameter of the openings was more than 44% of the depth of the beam. In addition, the results demonstrated that the utilisation of rectangular opening with equivalent area to the circular opening caused a decrease in the ultimate failure load by about 10% relative to the circular opening.

This paper presents the results of an investigation into the influence of using circular openings of different sizes and locations on the maximum deflection and ultimate failure load of the beam.

II. Material Properties

A. Concrete

The dimensions of the rectangular RC beams were 1200 mm x150 mm x 150 mm. The modulus of elasticity Ec was 30 MPa and the Poisson's ratio was 0.2 as illustrated in Fig. 1.

B. Main Reinforcement Bars

Fig. 1 shows the bar of reinforcements. In this study, four main steel reinforcement bars were used in each beam, two at the top and two at the bottom each with a length of 1140 mm, to provide 30 mm cover at each end. The steel bar diameter was 8 mm, the modulus of elasticity Es was 200 MPa and the Poisson's ratio was 0.3.

C. Link Bars

The link was a square steel bar with dimensions of 90 mm x 90 mm, to provide a 30 mm cover to the sides around the links. The number of links in each one of the of the beams' cage was 9. The steel bar diameter was 6 mm, the modulus of elasticity Es was 200 MPa and the Poisson's ratio was 0.3 as shown in Fig. 1.

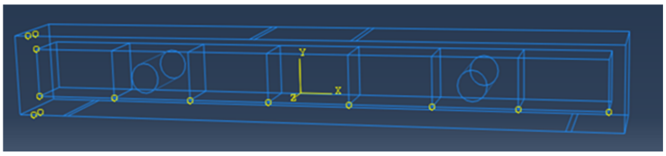

Fig. 1 Reinforced concrete beam with circular openings

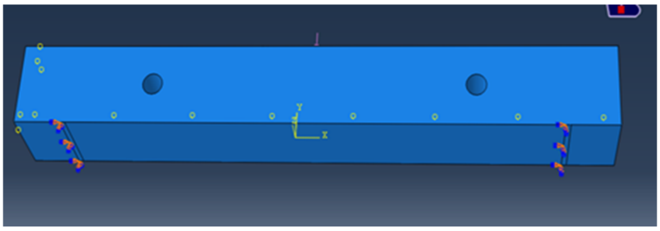

Fig. 2 The fixed supports under the beam

D. Loading and Boundary Conditions

Two fixed supports at the bottom of the RC beams were used at a distance of 100 mm from each of the ends as displayed in Fig 2. Rectangular slices of 10 mm × 150 mm simulated the two supports. The loaded area at the middle of the top face of the beam was simulated by a rectangular slice and the type of loading was a pressure load uniformly distributed along the slice as shown in Fig. 3.

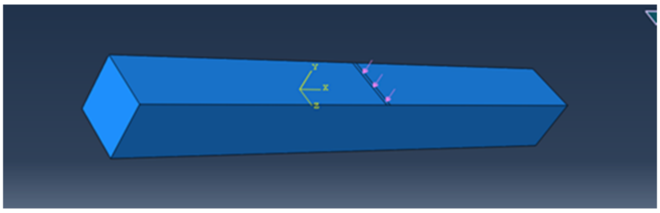

Fig. 3 The load distribution on the beam

E. Meshing

In this research, the mesh density used for the rectangular concrete beams and the main reinforcement were 50 mm and for the link bars was 10 mm as shown in Fig. 4.

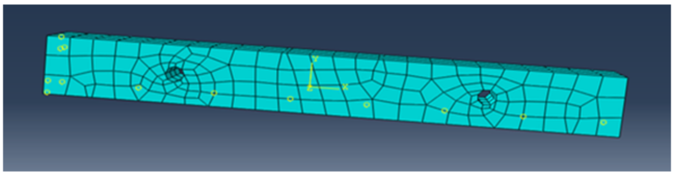

Fig. 4 RC beam mesh

F. Verification Study

In order to ensure the validity of the results, experimental work was carried out by casting a solid beam with no openings to compare the results with the results obtained using ABAQUS modelling for a solid beam of the same dimensions. The results are shown in Figs. 5 and 6, which demonstrate that the ultimate failure load in the FE software was 18% less than the experimental and the for the maximum deflection was 13%. This in turn shows that ABAQUS software can provide a valid simulation for the physical work.

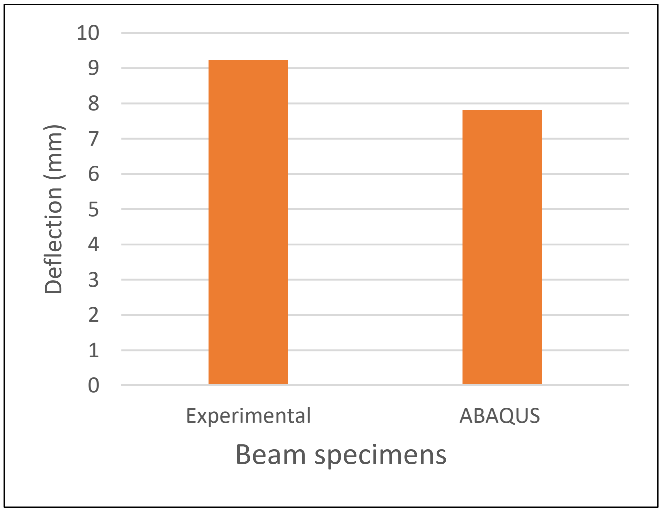

Fig. 5 Comparison between the deflection results from the experimental work and ABAQUS modelling

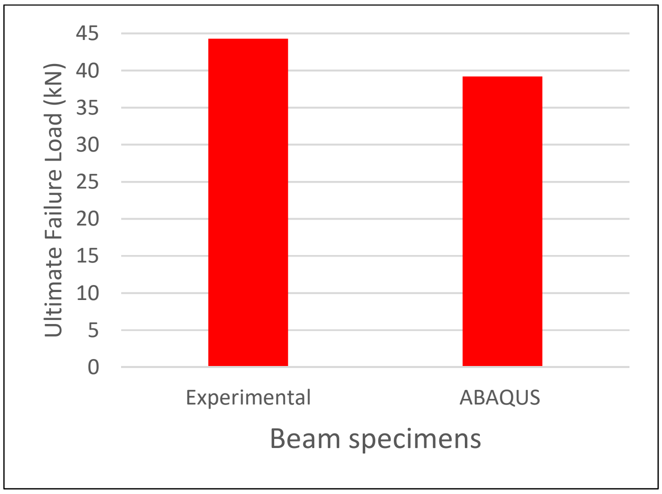

Fig. 6 Comparison between the ultimate failure load results from the experimental work and ABAQUS modelling

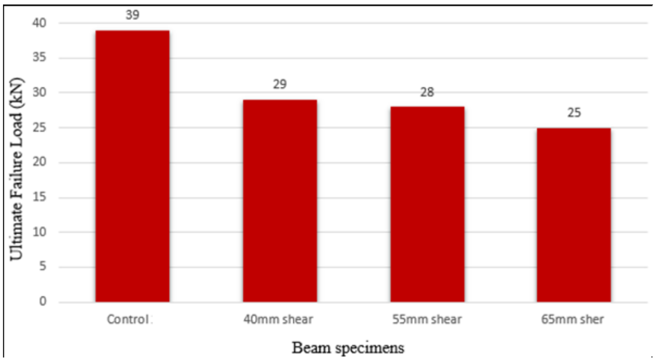

Fig. 7 The effect of circular opening size in the shear zone on the ultimate failure load

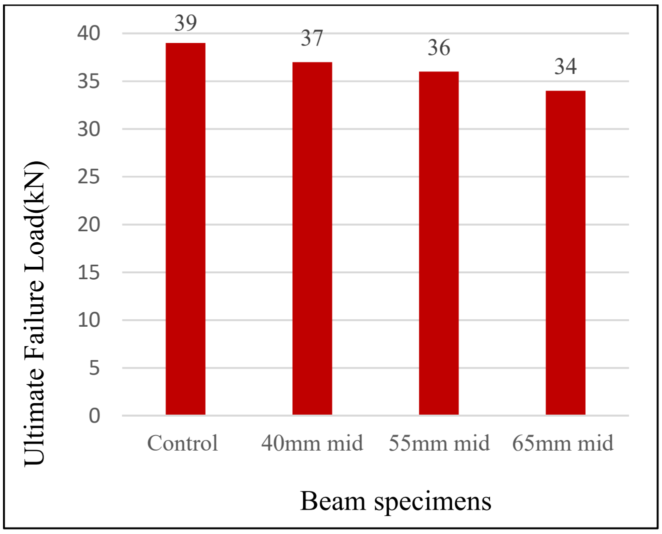

Fig. 8 The effect of circular opening size in the flexural zone on the ultimate failure load

III. Results and Discussion

A. The Ultimate Failure Load

The effect of size of the circular openings in the shear and flexural zones on the ultimate failure loads are shown in Figs. 7 and 8 respectively. It can be seen from the two bar charts that the presence of openings in the shear zone caused a considerable decrease in the ultimate failure loads in comparison to the control beam. However, the reduction in the ultimate failure load was very small when the openings where located at the flexural zone. In addition, Figs. 7 and 8 reveal that changing the size of openings does not affect the results of the ultimate failure load very much. When the openings were located at the shear zone the reduction in the ultimate failure load was between 26% and 36% and between 6% and 13% when the openings were in flexural zone.

B. The Maximum Deflection

The effect of size of the circular openings in the shear and flexural zones on the maximum deflection is shown in Figs. 9 and 10 respectively. Comparing the two bar charts reveals that the presence of the openings in the flexural zone caused less deflection than openings in the shear zone for each of the three sizes of openings. In addition, it can be seen from the two bar charts that the 40 mm circular opening, which is less than 30% of the depth of the beam, caused a very small increase in deflection relative to the control beam for both locations.

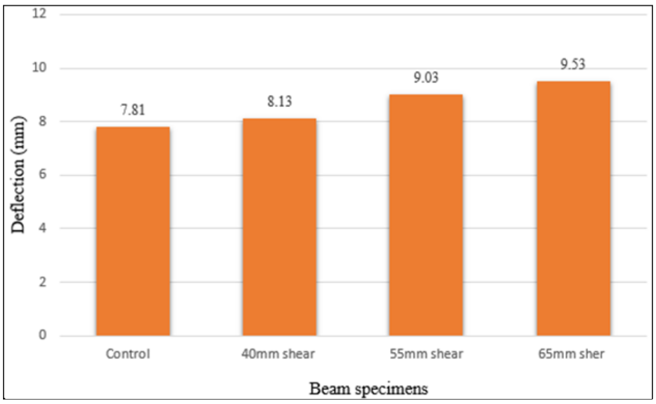

Fig. 9 The effect of circular opening size on maximum deflection at shear zone

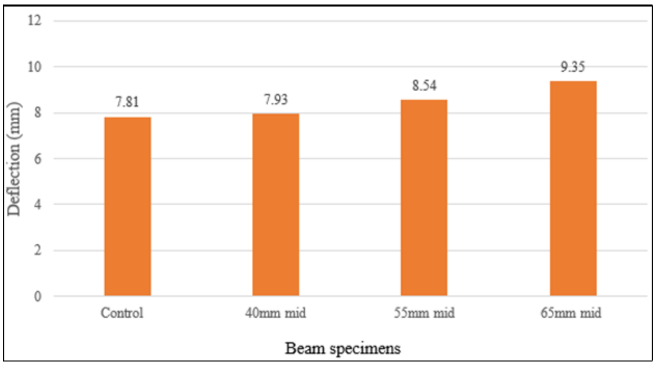

Fig. 10 The effect of circular opening size on maximum deflection at flexural zone

IV. Conclusion

The aim of this study was to investigate the structural behaviour of RC beams with circular openings of different sizes and locations using ABAQUS software modelling. It may be concluded that:

- The position of the openings has a great influence on the maximum deflection and ultimate failure load of RC beams. The effect is increased when the openings are towards the ends of the beam.
- In the flexural zone, when the diameter of the opening was 40 mm, the maximum increase in the deflection was 1.5% and the decrease in the ultimate failure load was 6% compared to the control beam.
- In the shear zone, when the diameter of the opening was 40 mm, the maximum increase in the deflection was 4% and the decrease in the ultimate failure load was 26% compared to the control beam.
- By increasing the diameter of the circular openings, the maximum deflection was increased and the ultimate failure load was decreased regardless the location of the openings.
- The best place for locating circular opening was found to be the middle of the beam with a diameter of less than 30% of the depth of the beam

Acknowledgment

The first author would like to express his acknowledgment to the Iraqi ministry of high education and scientific research for funding.

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