Experimental study of reinforced concrete beams with elliptical opening under flexural loading

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Abstract. The existing of openings in the structural elements of concrete may be useful in some cases and necessary at other cases. Experimental study on Reinforced Concrete (RC) beams was address in this research to examine the conduct of the opening in RC beams. The target of this study is to evaluate the impact of web elliptical openings in reinforced concrete beams experimentally. Under two-point top loading, four reinforced beams were tested, three of them with openings and one without opening. Test variable included the number of elliptical openings. Test results indicated that in case of the number of opening increased the ultimate load decreased. The ultimate load of CBEH1, CBEH2 and CBEH3 beams are decreased by 12%, 24% and 28% respectively compared with the ultimate load of CB beam.

1. Introduction
In practical applications, openings may need to be made in some parts of the building such as ceilings or beams. These openings provide a facilitator service, where they allow being the outlet for utility lines to pass through the building by of a system of ducts and canals. However, it caused an unexpected alteration of the cross-section dimensions which leading to a decrease in stiffness due to the generation of concentrated stresses because of the cracks that formed at the edges of the openings. This decreasing in stiffness allows high deflection to occur. Figure 1 shows conventional category of opening that used in beam while this study specializes in studying behaviour of elliptical opening in RC beams. Some researchers reported the use of opening in concrete structures [1–11], and others used elliptical shapes of opening in structures [12–15].

Eskandarinadaf and Esfahani [1] tested six samples of a full-scale two-way RC strengthened slab have an opening at its center, as well one slab has no opening as a reference to explore the strengthening of two-way RC slabs with an opening. One of these two strengthening methods was utilized for the slabs, the first one is outwardly fastened glass fiber reinforced polymer and the second one is embedded additional steel bars at the tension side of the slabs. It was found that embedding additional steel bars around the opening probably not boost the load-carrying capacity of the slab to the value of the continuous slab. While utilizing glass fiber reinforced polymer as a method for strengthening remarkably increased the ultimate strength and flexural stiffness of the slabs.

Yang et al. [3] performed reinforced high-strength concrete deep beams of thirty-two in number. These beams were consists of two groups; the first contains openings and the other without openings they were examined by two-point upper loading. The tests variables in this study are; the width and depth of the opening, concrete strength and shear span-to-depth proportion. The study shows that the angle of the inclined plane combining the support and the corner of the web opening was firmly related to the strengths at diagonal crack and at peak
The cross-sectional axial behavior of elliptical hollow sections packed with concrete was inspected by Yang et al. [4]. A laboratory experimental program was utilized to investigate the impact of these variables; steel tube thickness, concrete strength and restricting factor on elastic stiffness, ductility and ultimate strength. It was carried out by a test samples of twenty one in number, three values of nominal tube thicknesses (4 mm, 5 mm and 6.3 mm) of (C30, C60 and C100) concrete grades. It was found that the greater value of tube thickness lead to a greater value of load carrying capacity and boost ductility, also the greater value of concrete grades enhancing load-carrying capacity, however decreasing ductility. Al-Bayati et al. [7] investigate the impact of the transverse circular openings on the performance of simple span reinforced self-compacting concrete deep beams. It was carried out by utilizing eleven samples were investigated by applying symmetrically two point's top load. The shear span to effective ratio a/d, opening sizes and positions and the quantity of inclined reinforcement encircling the openings are the variables that were explored. The tests outcomes indicated that in any case of investigated a/d ratio and size, the opening located at the mid of the shear span essentially influences the behavior of the investigated beams.

Jabbar et al. [10] utilizing the finite element technique and analyzed under torsional, flexural, and cyclic loading of high-strength concrete and ultra-high performance concrete materials to modeling hollow beam with an opening to explore the behavior of a reinforced concrete hollow beam has an opening then make a comparison to a hollow beam behavior has no opening. It was found that the beam capacity reduced when openings are made at the web of hollow beams. It also found that the capacity of ultra-high performance concrete beams for torsion is double of those high-strength concrete beams. The main aim of targeted tests is to evaluate the structural behavior, also the impact of number elliptical opening upon the deflection, strain at compression zone and crack patterns in concrete beams with openings. Under two-point top loading, four reinforced beams were tested, three of them with openings and one without opening.

![Conventional category of opening](image)

**Figure 1.** Conventional category of opening

### 2. Experimental program

The concrete mix that used in this study is illustrated in table 1. The below table also explains the mechanical properties of reinforcements. All beams have been reinforced with four $\phi 16$ bars in longitudinal direction and $\phi 10$ bars as stirrups. The reinforcement has an average rate of yield stress of 400,000 kPa and young’s modulus of 206,000 MPa. The dimensions of beams were a 2000*300*200 mm as explained in figure 2. The reinforcement details are shown in figure 3.
Four concrete beams were casting in the laboratory to study the impact of the elliptical-shaped openings upon the flexural behavior. The first beam (CB) is the model that was adopted as a basic reference for the other models as it is a typical concrete model without any opening with dimensions $2000 \times 200 \times 300$. 

### Table 1. Proportions Concrete Mix design and Reinforcement

| Mix designation | Cement kg/m$^3$ | Aggregate kg/m$^3$ | Water kg/m$^3$ | w/c for Slump 120±10 mm |
|-----------------|----------------|--------------------|----------------|--------------------------|
| C40             | 445            | 700                | 750            | 0.50                     |

### Reinforcement Details

| Reinforcement Dia. (mm) | Yield strength (kPa) | Ultimate tensile strength (kPa) | Type |
|-------------------------|----------------------|---------------------------------|------|
| 16 and 10               | 400000               | 605000                          | Deformed |

**Figure 2. Beam dimensions and loading**

**Figure 3. Reinforcement details of specimens**

Four concrete beams were casting in the laboratory to study the impact of the elliptical-shaped openings upon the flexural behavior. The first beam (CB) is the model that was adopted as a basic reference for the other models as it is a typical concrete model without any opening with dimensions $2000 \times 200 \times 300$. 

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mm. The remaining three beams are CBEH1 with one elliptical opening 50×100 mm in center, CBEH2 with two elliptical opening 50×100 mm along the line of shear effect and CBEH3 with three elliptical opening 50×100 mm one in centre and the other along the line of shear effect. The properties of tested beams are illustrated table 2.

Table 2. Properties of specimens

| Beam   | Cross section dimension | Dim. of opening | $f'_c$ (MPa) | Number of openings |
|--------|-------------------------|-----------------|--------------|--------------------|
| CB     | 200×300                 | ---             | 38.5         | ---                |
| CBEH1  | 200×300                 | 50×100          | 38.5         | 1                  |
| CBEH2  | 200×300                 | 50×100          | 38.5         | 2                  |
| CBEH3  | 200×300                 | 50×100          | 38.5         | 3                  |

All beams were tested using a flexural device at the University of Diyala College of Engineering under a static load. All tested beams are identical in dimensions and reinforcement arrangements. figures 4-6 show the tested beams.
3. Test Results and Discussions

3.1 Behaviour of load-deflection

Nonlinear behavior of flexural of all the specimens was calculated due to subjected four points load and their deflection was plotted. The load magnitude was gradually increased until failure occurred in the beams. Table 3 illustrated ultimate load values for each tested beam. Figures 7-10 explain the load-deflection curves in the middle of the span for all beams. It's noted that when the number of opening increased the ultimate load decreased. The ultimate load of CBEH1, CBEH2 and CBEH3 are decreased by 12%, 24% and 28% respectively compared with the ultimate load of CB. From the figures, it can be noted that the most critical location of opening to get the ultimate strength in beams is close to the support and furthermore the best spot of opening in these beams is in center of a separation between the place of applied load and support (in middle of the shear span).

| Beam     | Ultimate load, $P_u$ (kN) | $\% \ \frac{P_u}{P_u \text{ of } CB}$ | $\%$ decreasing in $P_u$ | Type of Failure |
|----------|---------------------------|--------------------------------------|---------------------------|----------------|
| CB       | 265                       | 100                                  | 0                         | Flexural       |
| CBEH1    | 231.6                     | 87.39                                | 12.61                     | Flexural       |
| CBEH2    | 201                       | 75.58                                | 24.42                     | Flexural       |
| CBEH3    | 189                       | 71.31                                | 28.69                     | Flexural       |

3.2 Concrete strain at compression zone

As illustrated in figures 11-14, strain gauges along the length of beam at center line were installed to recording the concrete strains at the top layer (compression zone) of the tested beams. From figures, it can be noted that the strain at compression zone of beams CBEH1, CBEH2 and CBEH3 is decreased
comparing with the beam CB due to effect of openings. Table 4 illustrate concrete strain at compression zone.

| Beam  | Ultimate strain $\varepsilon_u$ (mm/mm) | $\% \frac{\varepsilon_u}{\varepsilon_u \text{CB}}$ | $\%$ Decrease in $\varepsilon_u$ |
|-------|----------------------------------------|-------------------------------------------------|----------------------------------|
| CB    | 0.002723                               | 1                                               | 0                                |
| CBEH1 | 0.00122                                 | 44.8                                            | 53.2                             |
| CBEH2 | 0.00138                                 | 51.11                                           | 48.99                            |
| CBEH3 | 0.00101                                 | 37.09                                           | 62.01                            |

**Figure 7.** Load - deflection curve in the middle of the span for CB Beam

**Figure 8.** Load - deflection curve in the middle of the span for CBEH1 Beam

**Figure 9.** Load - deflection curve in the middle of the span for CBEH2 Beam

**Figure 10.** Load - deflection curve in the middle of the span for CBEH3 Beam
3.3. Crack Patterns of beams

In the case of the beam CB, the first crack was manifested longitudinally at the center of the beam at the side of tension zone; and by increasing the applied load, the width and number of these cracks increased and extend to top face of beam in compression zone. When the load reaches its ultimate value, all beams showed flexural failure mode with flexural cracks. figures 15- 18 illustrate the tested beams crack patterns. From the figures it can be noticed that the load that motivated the first flexural crack does not rely on the existence or the absence of opening and its status, however shear cracks encircling the opening will motivated earlier than shear cracks encircling the similar area in solid beam.
Figure 15. Crack patterns of CB beam.

Figure 16. Crack patterns of CBEH1 beam.

Figure 17. Crack patterns of CBEH2 beam.
Figure 18. Crack patterns of CBEH3 beam.

4. Conclusions

The aim of this study is to clarify the impact of openings through the experiment by using number of elliptical openings as test variable. The study result can be briefly outlined as following.

1- The number of opening increased the ultimate load decreased. The ultimate load of CBEH1, CBEH2 and CBEH3 are decreased by 12%, 24% and 28% respectively compared with the ultimate load of CB.

2- The strain at compression zone of beams CBEH1, CBEH2 and CBEH3 is decreased comparing with the beam CB due to effect of openings.

3- The first crack was manifested longitudinally at the center of the beam on the tension side; and by increasing the applied load; the width and number of these cracks increased and extend to top face of beam in compression zone.

4- The load that motivated the first flexural crack does not rely on the existence or the absence of opening and its status; however shear cracks encircling the opening will motivated earlier than shear cracks encircling the similar area in solid beam.

5. References

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