STUDY ON FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE BEAM WITH EFFECTIVE OPENINGS

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ABSTRACT: Reinforced Concrete (RC) beams are essential structural elements that transfer loads from the slabs to the columns through flexure and shear. Openings in Reinforced Concrete (RC) beams are required for a variety of architectural and mechanical reasons. The purpose of this article is to investigate the flexural behaviour of an RC beam with circular openings running the length of it. The three-dimensional nonlinear finite element method was used to investigate a supported RC beam with circular web openings of varying diameters using ANSYS, a finite element software package. The study's primary characteristic is the variation in diameter and location of reinforcement around the openings. Five RC beams with simple supports were constructed, and tested were conducted under two-point loads. Beams were constructed with one conventional specimen without any openings in beams and two beams with unstrengthen circular openings located in the flexure zone with varying diameters such as 80mm and 100mm considered as a control beam. In contrast, the remaining two beams provided effective diagonal reinforcement around the openings. The load-bearing capacity and load-deflection behaviour of such openings in beams were studied and analysed in detail. To increase the ultimate strength of the beam, effective diagonal reinforcement and short stirrups at the top and bottom of openings are used to prevent the beam from collapsing prematurely.

Keywords: Reinforced concrete (RC) Beam, Circular opening, Diagonal Reinforcement, ANSYS.

1. INTRODUCTION

In today's scenario, we all have a multi-story building, which requires many pipes and pipes, to provide services such as air conditioning, telephones, electricity, fire exhaust pipes, and networks. Usually, the pipes and conduits are placed on the underside of the beam and inside the soffit. It creates an unnecessary dead space from just a few cm to half a meter. The dead space increases on each floor and increases the general height of the building with the size and depth of the pipelines. The alternative arrangements for the provision of cross-web opening in RC Beam to provide utilities shall therefore be made.
This type of web opening means that dead space is reduced and the design is compact. This makes it more complex to include openings in RC beams by sudden changes to the beam cross-section. The most specific beam behaviour. The provision of such openings in RC beams causes an interruption of everyday stress flux, thus reducing beam rigidity, excessive cracking, disruption, torsional strength, and beam capacity.

The web openings are randomly available in certain circumstances. If these openings are planned before building, precautions can be taken by adding further reinforcements and stirrups to the openings. However, these beams’ strength and rigidity must be monitored, and necessary precautions if these web openings are boiled without any planning. The critical issue is that when these hole/openings are boiled in the supporting region, the shear capacity of the beam can be reduced considerably, and the deflection of the beam can also increase when loaded. In addition to the ductile behaviour, these opening/holes may lead to broken beams.

From the Year 1960, Research on RC beams with an opening started; most of the research results are about RC beam with Rectangular and square openings. The most adaptable openings are circular as compared with rectangular and square. Many scientists use the terms small and large without defining it or a clear-cut limit, depending on the size of the openings. Mansur and Tan [8] recommended that small openings in circular, square, or almost square shapes are, whereas the circular diameter of the opening in Somes and Corley [11] is more than 0.25 times the depth of the beam considered significant.

In the RC beam analysis with geometric discontinuities as a transversal circular opening on the Web, Mansur et al. [9] examined the model strut-and-tie. The truss model clearly explains the role of diagonal strengthening in alleviating the substantial distress at the throat area by transmitting a large amount of applied shear across the discontinuity. The effect of small circular opening on shears and the bending and ultimate strength of beams produced from standard and high strength concrete has been examined by Javad Vaseghi Amiri et al. [7]. For standard concrete, if the opening diameter exceeds 1/3 the beam depth, the ultimate capacity reduction and cracking design have changed, as has the failure mode. High concrete strength is not very strong for the ultimate strength, but the rigidity and serviceability of the beams are increased. In the course of an RC beam on his flexural behaviour, Bengi Aykac et al.[1] examined the experimental investigation into the influence of various web openings. The Vierendel action protected the web from buckling before failure, which contributed to a premature fracture of the beams around the openings. The rebars and stirrups extending down each side of the beam shaft prevented shear failures.

This study aims to investigate the amount of the effect of the presence of a circular opening in the flexure zone of the reinforced concrete beams using finite element analysis and with the consideration of the following main factors are Diameter of opening, Location of applied load, Web reinforcing bars and the type of position of reinforcing bars around the opening. Providing Proper Reinforcement Detailing around the prescribed openings can minimize Stress Concentration & Prevent Premature failures.

2. EXPERIMENTAL STUDY

Four rectangular RC beams have been designed and tested for this experimental program with openings and a single beam without openings. In the following sections, the experimental program is detailed.

2.1 MATERIALS

The properties of the materials used were experimentally obtained. The test beams were all prepared simultaneously and cured to ensure the compressive strength was virtually equal under the same conditions. At 28 days, the average testing strength was 37 MPa. Testing nine cube
sizes 150 to 150 or 150 to 150 mm using a Compressive Testing Machine achieved the compressive strength (CTM). The reinforcement concrete beam, which consists of 2mm to 12 mm at bottom, 2mm to 10 mm at the top, and 8 mm stirrups, was placed at 150 mm c/c. 8mm dia reinforcement steel is used in the top and bottom of openings by providing small stirrups and around the openings, diagonal reinforcement has been used.

2.2 TEST SPECIMEN

This experimental program has included several five rectangular RC beams of the same length and the exact cross-sectional dimensions. The beams have been tested under four points bending. All of them have a length of 1200 mm, a width of 150 mm, and a height of 280 mm. The Circular opening of 80mm and 100mm opening was formed by using PVC pipes. The dimension, Reinforcement details, and location of the opening are shown in Figs 1 & 2.

Table 1. DETAILS OF BEAM SPECIMEN

| S.No | Beam Details            | Diameter of Opening(mm) |
|------|-------------------------|--------------------------|
| 1    | Conventional Beam       | -                        |
| 2    | Unstrengthen Beam (UB1) | 80                       |
| 3    | Unstrengthen Beam (UB2) | 100                      |
| 4    | Strengthened Beam (SB1) | 80                       |
| 5    | Strengthened Beam (SB2) | 100                      |
2.3 TEST SETUP
The test of all beams was carried after 28 days. The specimen position to be adjusted on the supports with a clear span of 1000mm, and when subjected to a weight of 400kN/m bearing, the beams were found to be strong enough to bear a total load of 500kN. By hydraulics, the load was distributed until it was out of tolerance. The load setup is shown in fig.3. The deflection in the mid-span was recorded using LVDT and the crack pattern of the beams. Testing arrangement of the beam with the opening as shown in fig.4.

3. TESTS RESULTS AND DISCUSSIONS
Test specimens were loaded up to their ultimate capacity. The load-deformation and failure mode of the conventional beam without openings, beams with unstrengthen circular openings, and beam with openings strengthened using diagonal reinforcement around openings were observed.
3.1 CRACK PATTERN AND MODES OF FAILURE

In Figure 5, the crack patterns and failure modes of the test specimen are demonstrated. The experimental investigation concluded that most cracks in the brittle regions continued into the pressurized regions. The original flexibility zone and increased load are correlated; both are observed in the early deformation stages. Beam UB1, which has an opening of 80mm diameter because of the cracking pattern and behavior, is similar to a solid beam. Initially, flexural cracks developed, and cracks in the opening region also lead to shear failure while increasing load. Hence it shows similar to beam type failure according to Mansur research [3]. In beam UB2 circular opening with 100 mm diameter, preliminary cracks are initiated as the amount of load increased additional cracks are developed in top and bottom of the opening region, and the beam failed suddenly in frame type failure.

![Fig 5. The Crack pattern of Tested Specimen.](image)

Beam with 100mm diameter Opening (SB2), although it initiates shear crack but its growth prolonged. Among the other beams, an 80mm diameter opening beam (SB1), which has a small stirrup on top and bottom of the opening and diagonal reinforcement, will act better than the other beams controlling the cracks attains shear failure. At loads equal to or above their carrying capacity, the beams with circular openings failed. The presence of diagonal reinforcement and short strands prevented premature failure and contributed to the bending capacity of beams.

3.2 LOAD-DEFLECTION CHARACTERISTICS

As a result of experimental studies, unreinforced beams with openings were observed in certain test specimens that conducted ductile and fragile damage. Table 2 shows the results of the test.

| S.NO | Beam Designation | Initial Crack Load (kN) | Deflection in mm ($\delta_y$) | Ultimate Load (kN) | Deflection in mm ($\delta_u$) |
|------|------------------|-------------------------|----------------------------|--------------------|----------------------------|
| 1    | CB               | 95                      | 1.02                       | 310                | 5.35                       |
| 2    | UB1              | 90                      | 1.35                       | 294                | 5.27                       |
| 3    | UB2              | 82                      | 1.47                       | 285                | 5.75                       |
| 4    | SB1              | 105                     | 0.77                       | 337                | 5.05                       |
| 5    | SB2              | 98                      | 0.85                       | 328                | 5.25                       |

The experimental test results show the Conventional Beam (CB) Ultimate load is 310kN and maximum deflection is 5.35 mm. The beam with a circular opening show that it reduces the load-carrying capacity compared with other beams. While comparing 80mm (UB1) and 100mm (UB2) beams, UB1 is observed similar to that of the conventional beam. Besides, UB2 behave more brittle, and sudden failure occurs because of increased opening diameter. RC beam (SB1 & SB2) strengthened with diagonal reinforcement around opening increases the load-carrying capacity by 8.7%, and the maximum deflection is 5.25 mm. Diagonal strengthening around
openings increases the beam's flexural capacity. The characteristic of load-deflection is shown in Figure 6. The load-deflection characteristics, ductility factor, bending stiffness, and energy absorption capacity are used to evaluate the test results. The ductility ratio was defined as the ratio of the displacement value ($\delta_u$) corresponding to 85 percent of the beam's maximum loading capacity to the yielding displacement value ($\delta_y$). According to the literature, this ratio should be around 4–5 for a ductile beam [4].

![Fig 6. LOAD DEFLECTION CHARACTERISTICS](image)

The bending stiffness of the beams was determined using their initial stiffness (rigidity). The area beneath the load-deflection curve was used to calculate the energy absorption capacity. The absolute values of ductility and stiffness and their relative values are summarised in Table 3.

| Test Specimen | Ductility factor Absolute | Ductility factor Relative | Energy Absorption (kN.mm) Absolute | Energy Absorption (kN.mm) Relative | Initial Stiffness (kN/mm) Absolute | Initial Stiffness (kN/mm) Relative | Failure Mode |
|---------------|---------------------------|---------------------------|-----------------------------------|-----------------------------------|----------------------------------|----------------------------------|--------------|
| CB            | 5.25                      | 1                         | 2975                              | 1                                 | 93.14                            | 1                                | Shear & Flexural Failure         |
| UB1           | 3.90                      | 0.58                      | 2718                              | 0.91                              | 66.67                            | 0.91                             | Flexural-Opening Region          |
| UB2           | 3.91                      | 0.75                      | 2638                              | 0.88                              | 55.78                            | 0.88                             | Flexural-Opening Region          |
| SB1           | 6.56                      | 1.24                      | 3170                              | 1.06                              | 136.36                           | 1.06                             | Shear Failure                     |
| SB2           | 6.18                      | 1.18                      | 3250                              | 1.09                              | 115.29                           | 1.09                             | Shear failure                     |

The energy absorption decreases by including an opening in the beam, whereas using diagonal reinforcement around the opening is similar to that of a conventional beam. Besides, the stiffness also decreased when compared to the solid beam. The short strands at the top and bottom of the beam chords improved the ductility of RC beams using factor ductility.

4. **FINITE ELEMENT MODELLING**

ANSYS, a finite element software, is solving complex structural engineering problems faster and more efficiently. Finite element modeling is a powerful technique for calculating the displacements, stresses, and strains in a structure as a function of a given set of loads. ANSYS workbench environment is highly automated and users friendly to customize the geometric modeling according to the type of analysis or application. The central concept in finite element modeling is to generate the mesh. Meshes are used to divide a model into numerous small areas, which makes the analysis accurate.
4.1 Modelling & Deformation

The specimen models were created for conventional beam and beam with the circular opening as per the geometric required using ANSYS Software as shown in Figures 7 & 8.

![Fig 7. Conventional Beam](image1)

![Fig 8. Beam with Openings](image2)

All the Specimen models are subjected to two-point loading in which load is applied at L/3 distance from both the ends and support conditions are given at 100 mm from the ends of the beam. After the load applications, the model is solved for the required results, and the failure mode of the model is obtained shown in Table 4. The deformation of the conventional beam and beam with an opening is shown in Fig 9 & 10.

![Fig 9. Deformation of Conventional Beam](image3)

![Fig 10. Deformation of Beam with Openings](image4)

From table 4, it is observed that a strengthened beam with diagonal reinforcement increases the load-carrying capacity, and correspondingly deformation is decreased compared with other beams.

| S.No | Beam Designation | Ultimate Load(kN) | Deflection in mm |
|------|------------------|-------------------|------------------|
|      |                  |                   | Experimental    | Analytical     |
| 1    | CB               | 310               | 5.35             | 5.11           |
| 2    | UB1              | 294               | 5.27             | 5.02           |
| 3    | UB2              | 285               | 5.75             | 5.19           |
| 4    | SB1              | 337               | 5.05             | 4.99           |
| 5    | SB2              | 328               | 5.25             | 4.83           |

When compared with Analytical and Experimental results, the deformation of beams varies 5-10% only. It clearly shows that the good correlation between experimental and analytical work.
5. CONCLUSION

From the above results, it is concluded that

- In this experiment, the initial flexural crack induced is independent of the presence or absence of an opening, but a large number of shear cracks will initiate sooner, corresponding to a conventional beam. As a result, when an opening is included, the beam's load capacity decreases.
- If the opening diameter is less than 0.3, the depth of the beam will behave normally; however, the location of the opening and the minimum depth of the compression chord should be considered. While the diameter of the opening exceeds the depth of the beam by more than 0.3, increasing the load causes shear cracks to develop on both the top and bottom of the opening, reducing the beam's load-carrying capacity.
- As the opening diameter in the beams increases, crack pattern and failure type change from bending to shear failure type frame or strap.
- By installing diagonal reinforced bars and the stirrups on the top and bottom of openings, the beams' ultimate strength will be increased by 8.7 percent. To increase the ultimate strength of the beam, an effective diagonal reinforcement bar and short stirrups at the top and bottom of openings are used to prevent the beam from collapsing prematurely.
- When analytical and experimental results are compared, the deflection value varies by approximately 5%-10% from the experimental deflection at their ultimate load. FE modeling with ANSYS Software can be used to predict reinforced concrete beams with openings numerically.

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