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Available online at: www.jrrset.com

ISSN (Print) : 2347-6729
ISSN (Online) : 2348-3105
JIR IF : 2.54
SJIF IF : 4.334
Cosmos: 5.395

Volume 10 Issue 9 - September 2022 - Pages 42-48

# Behaviour of Reinforced Concrete Beams with Circular Opening Strengthened by Steel Plates in the Flexural Zone

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## Abstract

The objective of this paper is to study the behaviour of R.C beam with circular opening in the flexure zone strengthened with steel plate. In this experiment, four beams using M20 concrete and Fe415 steel were tested. Beam 1 casted as solid control beam and the beam 2 with unstrengthened circular opening of 150mm diameter in the flexure zone. The other two beams were casted with circular opening strengthened by circular steel plates stiffened by 4 and 8 shear connectors. The beams were tested as simple beam with two concentrated load. The test results revealed that the strength of the beams with circular opening strengthened by steel plates was reduced up to 15% compared to the regular beam and the strength is increased up to 70% compared to the unstrengthened beams. Thus, from the tests, it was found that strengthening of beams with circular opening in the flexure zone using steel plates are effective.

Keywords—flexural zone; circular openig; steel plates

### 1. ntroduction

In modern buildings, web openings in the beams occur quite often in practice to provide convenient passage for environmental services. As a result, story heights in buildings can be reduced and slight reduction in concrete beams weight would improve the demand on the supporting frame both under gravity loading and seismic excitation which resulting in major cost savings. These openings may be of different shapes and sizes [4]. Although numerous shapes are possible, circular and rectangular openings are the most common ones. The presence of an opening in the web of a reinforced concrete beam leads to many problems in the beam behaviour such as reduction in the beam stiffness, excessive cracking, excessive deflection and reduction in the beam strength. [7 and 5]

Strengthening of beams provided with openings depends mainly on whether those openings are pre-planned or post-planned. In the case of pre-planned openings, both the upper and lower chords are designed and reinforced to resist the internal forces that they are subjected to two

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point loads. Both the reinforcement provided for the upper and lower chords and the steel reinforcement provided around the opening are considered as internal strengthening [4].

Hamid and Mohammed(1992) [3] investigated the behaviour of reinforced concrete beams strengthened with GFRP plates. Abdulla (2003) [2] proposed a design against cracking at openings in beams strengthened with fiber reinforced polymer and Balamuralikrishna (2009) [1] investigated the behaviour of R.C beams with openings strengthened with steel fiber, the test results concluded that the GFRP plates improves the flexural strength, defection is decreased using CFRP and increase in load carrying capacity using steel fiber.

**Objectives:**

- To Study the load carrying capacity of the beam with unstrengthened opening in the flexure zone of the beam compared to the control beam.
- To determine the percentage increase in the load carrying capacity of the beam strengthened with steel plate compared to the unstrengthened beam.
- To investigate the effect of strengthening of the beams with circular opening in the flexure zone compared to the load carrying capacity of the control beam.

## 2. Materials Used

The mix design for the concrete is carried for M20 grade using OPC 53 grade, local sand and coarse aggregate. The reinforcement in the beam consists of 3 numbers of 12 mm diameter bars at the bottom, 2 numbers of 10 mm diameter bars at the top and 8 mm stirrups at 150 mm c/c. The beams were cast and cured for 28 days. The steel plates were used for the external strengthening of the beam with circular opening and it is bound to the beam with shear connectors.

## 3.Test Specimen

The experimental program includes testing of beams with circular opening having different strengthening techniques. All tested beams had a rectangular cross section of 150mm width and 300mm depth and a effective length of 2000mm. The dimension and location of the opening as shown in figure 1.

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Fig 1.Reinforcement of beam with circular opening

The test set up is shown in figure 2. The beams were tested in a loading frame of 40 kN capacity under two point loading. The load was applied incrementally by means of hydraulic jack until beam fails. The deflection at mid span and opening centers were recorded.

Table 1 shows the details of the test specimens, 'BS' refers to the solid control beam without opening, 'BN' refers to beam with unstrengthened circular opening, 'BNF' and 'BNE' refer to the beams with circular openings strengthened by steel plates with 4 and 8 numbers of shear connectors respectively.

**Table 1. Details of beam specimen**

| S.No. | Beam Designation | Diameter of opening (mm) | No. of shear connectors |
|---|---|---|---|
| 1. | BS | - | - |
| 2. | BN | 150 | - |
| 3. | BNF | 150 | 4 |
| 4. | BNE | 150 | 8 |

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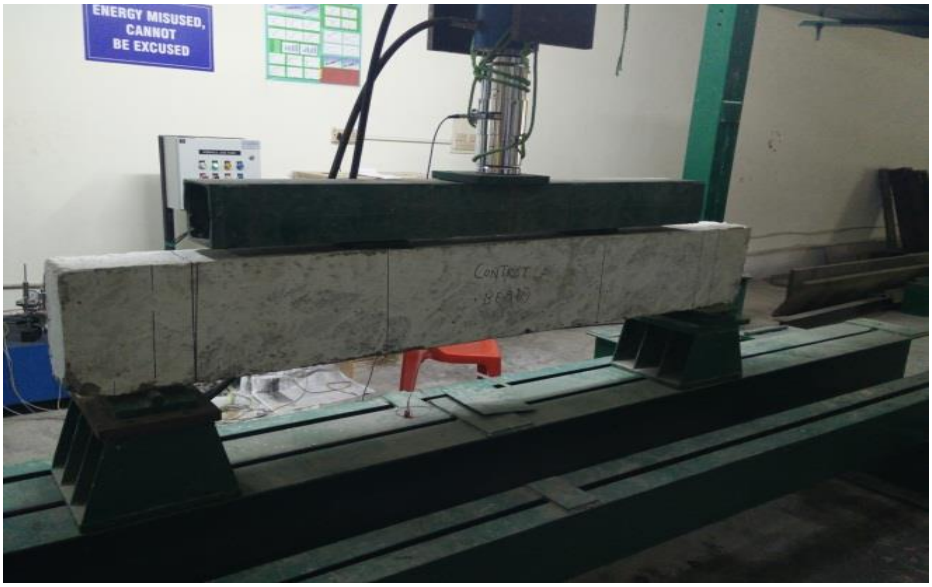


**(a)**

**Control Beam**

**(b)**

**Beam with duct opening**

**Fig 2. Test setup**

## 5. Results and Discussions

The ultimate load, deflection, failure mode and load-deflection behaviour of control beam without opening, reinforced concrete beams with openings strengthened using steel plates are observed.

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### 5.1 Test Results

Table 2 shows the ultimate load and deflection of the various beams tested. The details of the results are given in Table 2.

**Table 2. Test Results**

| Designation of beam | Types of strengthening (No. of studs) | Initial crack load (kN) | Ultimate failure load (kN) | Maximum deflection (mm) |
|---|---|---|---|---|
| BS | - | 34.9 | 147 | 10.1 |
| BN | - | 32.8 | 74.6 | 6 |
| BNF | 4 | 39.3 | 127.4 | 9.6 |
| BNE | 8 | 29.7 | 126 | 8 |

### 5.2 Load versus Deflection Behaviour

In order to investigate the load carrying capacity and deflections of beams with opening, Load – deflection curves of the beams were studied. Figure 3 shows the load- deflection curves of beam specimens.

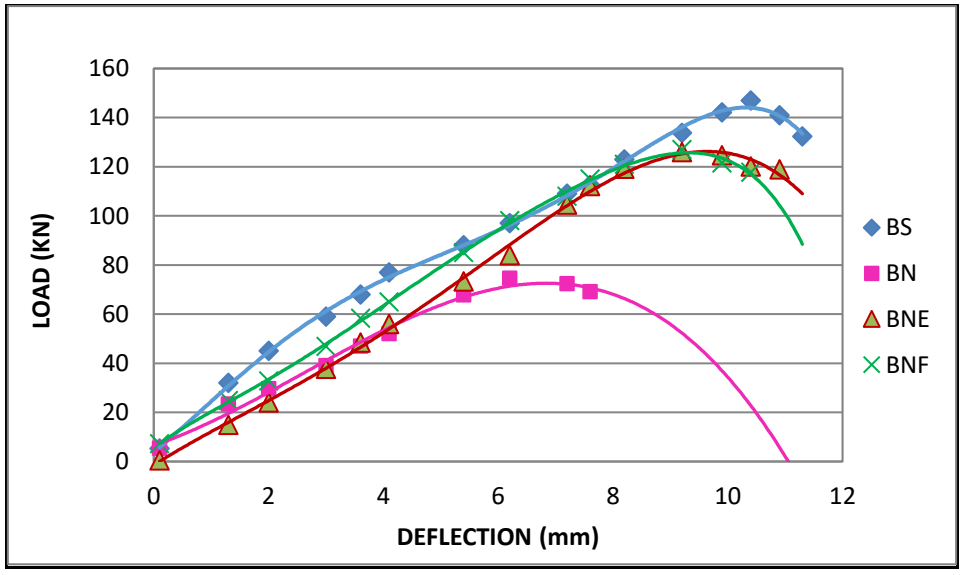


**Fig. 3 Load vs Deflection**

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### 5.3 Investigation of Ultimate Strength of Beams with Opening

The result of this research has shown that the load carrying capacity of the beam increases about 70 %, for the beams strengthened with steel plates, compared to the unstrengthened beam. Fig 4 shows the load carrying capacity of the specimens.

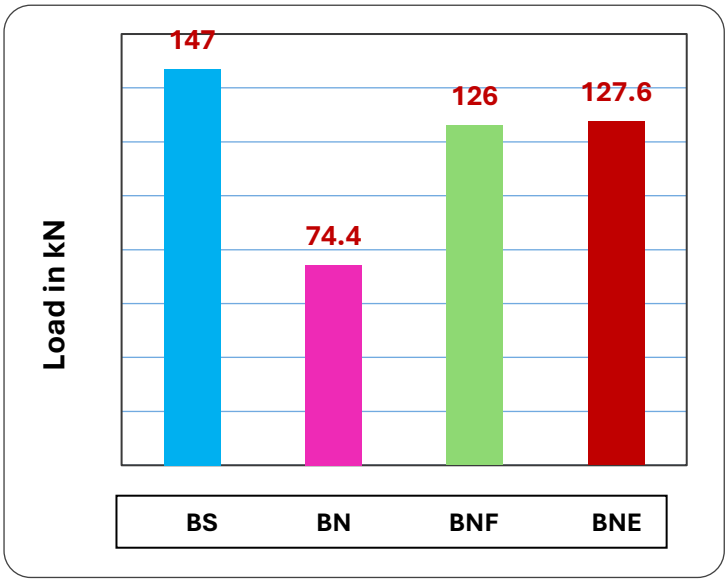


**Fig. 4. Ultimate load carrying capacity**

The load under which the first flexural crack induced was not due to the presence or the lack of opening. The inclusion of circular opening in the flexural zone the load carrying capacity of the beam decreases by 50% as compared to solid control beam and the diagonal cracks were developed due to stress concentration around the opening edges. Strengthening of the beam opening with steel plates connected by 4 shear connectors around the opening is more efficient than strengthening of the beam opening with steel plates connected by 8 shear connectors.

### Conclusion

From the test results the following conclusions were draw

- The unstrengthened opening in the flexure zone of the beam tends to reduce the load carrying capacity of the beam by 50% compared to the control beam.The load carrying capacity of the beam strengthened with steel plate was reduced by 15% and it is increased by 70% compared to the unstrengthened beam.

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- Strengthening of the beams with circular opening in the flexure zone was found to achieve 85% of the load carrying capacity of the control beam.

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