International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 3, Issue 5 (September-October, 2015), PP. 59-62

EFFECT OF OPENINGS IN DEEP BEAMS USING STRUT AND TIE MODEL METHOD

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Abstract— **Reinforced concrete deep beams are fairly common in all structures. Deep beam has its application in tall buildings, offshore structures etc. Deep beams are having small values of span to depth ratios. The present study is to determine the effect of openings in deep beams using strut and tie model approach. Experimental investigation is conducted on seven deep beams which are designed as per ACI 318, with various position of opening as per strut and tie formation. The same specimens are analysed in software ANSYS 14 and results compared.**

Index Terms— **Deep beam, Strut and tie model method, Openings in deep beam, Span to depth ratio**

I. INTRODUCTION

Buildings without column are sometimes designed for aesthetical consideration. Under such condition if we are providing ordinary beams then it causes flexural failure. If span of beams exceeds 10 m, it cannot be considered as a normal beam and fails in flexure when it is loaded. Alternative methods for long span beams are post tensioned beams, composite beams, plate girders, deep beams etc. In these methods, deep beams are elements which are loaded as simple beams in which the load is taken to the supports by a compressive force. Due to the geometry of deep beams, the failure in deep beams is totally governed by shear rather than flexural failure. Hence, shear strength is considered as an important factor in the design of concrete deep beams.
Introduction of openings in deep beams further complicates the problem. Web openings are created within the deep beams to pass for utilities such as electronic cables, air-conditioning ducts. Thus we can reduce the area needed for the inclusion of these utilities and increase the useful space within the structure. There are several methods for analysis of deep beams. Among those methods strut and tie model design is considered as most efficient and economical. The Strut-and-Tie model approach is considered useful for shear critical structures. In this method complex elements are replaced with suitable truss model.

II. OBJECTIVE

- Experimental investigation on strut and tie formation in deep beams with and without openings.
- To predict the behaviour of deep beam based on experimental investigation, following parameters are studied
  - (a) Opening in deep beam
  - (b) Shape of opening in deep beam
  - (c) Position of opening
  - (d) Number of opening
- Validation of numerical model created in ANSYS with experimental results.

III. EXPERIMENTAL INVESTIGATION

A. Geometry and reinforcement details

For the experiments, seven reinforced concrete deep beams were cast. The cross section of the beam is 200 × 400 mm and the length is 800 mm. Square and circular openings were provided in the beam to study the effect of openings in deep beam. Basically there are three different opening positions in beam.

(a) Opening without affecting strut and tie model.
(b) Single opening that affects strut and tie model
(c) Two openings that affects strut and tie model

The reinforcement details obtained as per ACI 318 are tabulated as shown below.

Reinforcement details of deep beam

Sl.no	Type of reinforcement	Details of reinforcement
1	Main steel	4-12 mm dia bars (Fe 500)
2	Vertical stirrups	2 legged 8 mm dia at 140 mm c/c

Fig. 1. Reinforcement cage for deep beam

B. Preparation of formwork, casting and curing of specimens

Shuttering's for beams were made using 8 mm thick plywood sheets. pvc pipes were used to create circular opening of dia 100 mm and plywood's were used to create square openings of size 100 × 100 mm. Opening size was fixed as 0.25 times depth of beam. The shuttering for beam specimen is shown in Fig. 2.

M20 concrete mix was used. The longitudinal reinforcement is extended beyond the supports and terminated with 90 degree hooks to provide adequate anchorage. Stirrups were provided at equal intervals. Reinforcement cage was prepared and lowered into the shuttering. Proper cover to the reinforcement was ensured using cover blocks. All the seven specimens were cured using wet sacks and tested after 28 days. The casting of deep beam specimen is shown in Fig. 3.

The details of deep beam specimens casted are tabulated in Table II.

Fig. 2. Shuttering and placing of reinforcement cage for deep beam

Fig. 3. Concreting for deep beam

details of deep beam specimens

Sl no:	Beam id	Representation
1	BWOH	Deep beam without hole
2	BCH1C	Deep beam with circular hole one at centre
3	BRH1C	Deep beam with rectangular hole one at centre
4	BCH1S	Deep beam with circular hole one at side
5	BRH1S	Deep beam with rectangular hole one at side
6	BCH2S	Deep beam with circular hole at two sides
7	BRH2S	Deep beam with rectangular hole at two sides

C. Experimental setup

The specimens had a clear span of 600 mm and subjected to a point load at mid span except for BRH2S which had a clear span of 700 mm. The concentrated load was applied through a steel bearing plate in Universal Testing Machine.

IV. FINITE ELEMENT ANALYSIS

Finite element analysis of beams casted was done using the software ANSYS 14 workbench

A Solid65 element is used to model the concrete. It has eight nodes and at each node there are three degrees of freedom that is translations in the x, y, and z directions. A Link180 element is used to model the steel reinforcement. It is a 3D spar element and it has two nodes and each node has three degrees of freedom that is translations in nodal x, y, and z directions.

The support was modelled as a fixed support at one end and simply supported at the other end. A steel bearing plate was modelled in the top mid span of the beam to give the displacement to the beam. Mesh size of 10 mm was adopted.

Loading was given in displacement controlled manner in the mid span of the beam. Static structural analysis was done.

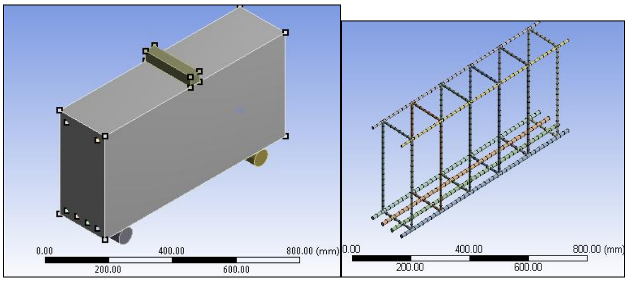


Fig. 4. Modelling of deep beam in ANSYS

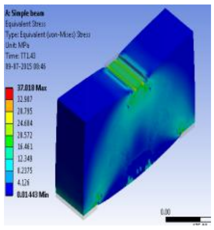
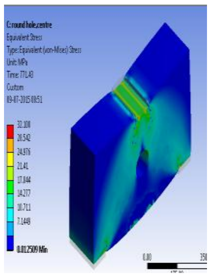
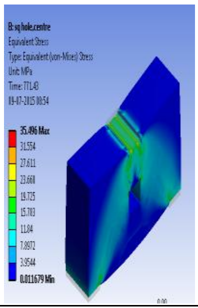
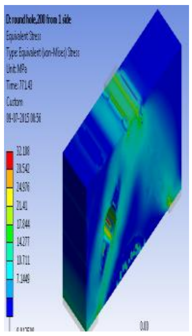
V. RESULTS

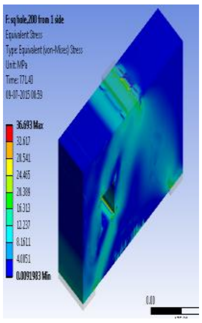
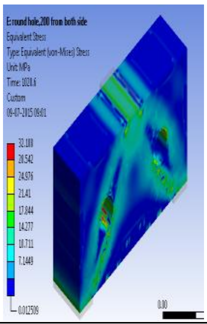
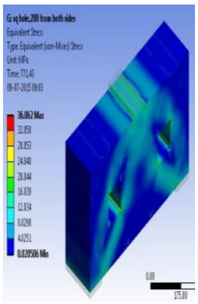
The ultimate load carrying capacity of beams was affected by the position of opening in beam. Maximum load carrying capacity was observed for beam without opening and minimum for beam with rectangular opening at two sides. The effect of openings in deep beam was experimentally studied using the seven beam specimens. Percentage reduction in load was calculated keeping the solid beam as control specimen is tabulated in table III. The results obtained from experiment and finite element analysis are compared in table IV.

EFFECT OF OPENINGS IN DEEP BEAMS

Sl.no	**Beam specimen id**	**Ultimate load (kN)**	**Percentage reduction in load (%)**
1	BWOH	544	Control specimen
2	BCH1C	528	3
3	BRH1C	524	3
4	BCH1S	436	19
5	BRH1S	414	23
6	BCH2S	340	38
7	BRH2S	168	69

Reinforcement details of deep beam

Beam specimen	Specimen after loading IN UTM	Equivalent stress diagram obtained from software
BWOH		
BCH1C		
BRH1C		
BCH1S		

BRH1 S		
BCH2 S		
BRH2 S		

VI. CONCLUSION

Experimental study on deep beams of size 800 mm × 200 mm × 400 mm were conducted using strut and tie method of analysis. The corresponding beams were modelled in ANSYS 14 and ultimate load carrying thus obtained were compared with the experimental result. The ultimate load obtained from the finite element software has only 5% variation compared to experimental results. Parametric study was conducted on deep beams by varying l/d ratio and conclusions were made.

- Deep beams with openings shows a decrease in ultimate load carrying capacity compared to solid beams.
- Deep beams with rectangular openings shows an decrease in ultimate load carrying capacity compared with circular openings.
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- The percentage reduction in load carrying capacity was 3% for BRH1C and BCH1C, 19% for BCH1S, 23% for BRH1S, 38% for BCH2S and 69% for BRH2S compared with BWOH.

Comparing the results obtained from experiment and software, it can be seen that the crack pattern falls within the maximum stress region obtained from finite element results

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