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Effect of openings in deep beams with varying span to depth ratios using strut and tie model method

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Abstract: *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. Parametric study was also conducted to know the effect of increasing l/d ratio keeping length or depth fixed. The results show that deep beams with openings shows a decrease in ultimate load carrying capacity compared to solid beams. Also deep beams with rectangular openings shows an decrease in ultimate load carrying capacity compared with circular openings. As l/d ratio increased, the load carrying capacity of the beam decreased. For a particular l/d ratio the ultimate load carrying capacity of beam for a particular l/d ratio was more for beams with constant length compared to beam with constant depth.*

Keywords - *deep beams, span to depth ratio, strut and tie model, web opening*

I. Introduction

The shear behaviour and capacity of concrete beams depends on various factors and among them overall span to depth ratio of beam plays a crucial role. The behaviour of beams varies depending on the span to overall depth ratio. The beams are broadly classified as deep beams and ordinary beams depending upon their behaviour and failure mode. Before a deep beam could take up its full flexural strength, diagonal cracks are formed which tend to cause shear failure. Hence, shear strength is considered as an important factor in the design of concrete deep beams.

In construction of modern buildings, many pipes and ducts are necessary to accommodate useful services such as water supply, air conditioning ducts, electricity etc. Usually these pipes are placed under the soffit of beam and for aesthetical reason are covered by false ceilings. An alternative arrangement is to pass these ducts through openings in beams. Such an arrangement of services leads to economic and compact design.

In case of shear critical structures strut and tie model method is useful and economical for designing. In strut-and-tie method, the actual structure will be replaced with a system of virtual truss so that the entire system is in equilibrium with the externally applied forces.

II. Experimental Investigation On Deep Beam With Span To Depth Ratio 2

Experimental investigation was done on deep beam with and without hole. The size of beam considered was 800 mm X 200 mm X 400 mm. The typical deep beam specimens considered for the present study is tabulated in table 1.

Table. 1. 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
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

The deep beams were designed as per ACI 318 and the following reinforcement was obtained.

Table. 2. Details of reinforcement in deep beam

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

Seven reinforced concrete deep beams were casted and cured for 28 days. The deep beam specimens were tested in universal testing machine to obtain the ultimate load carrying capacity. The results obtained are tabulated in table 3

Table. 3. Ultimate load carrying capacity of beam specimens

Beam ID	Specimen before loading	Ultimate load obtained (kN)
BWOH		544
BCH1C		528
BRH1C		524
BCH1S		436
BRH1S		414
BCH2S		340

BRH2S		168

III. Parametric Study On Deep Beams

Parametric study was done on deep beams with varying span to depth ratios using finite element software ANSYS 14 workbench. Solid 65 was used to model concrete and link 180 was used to model the steel reinforcement.

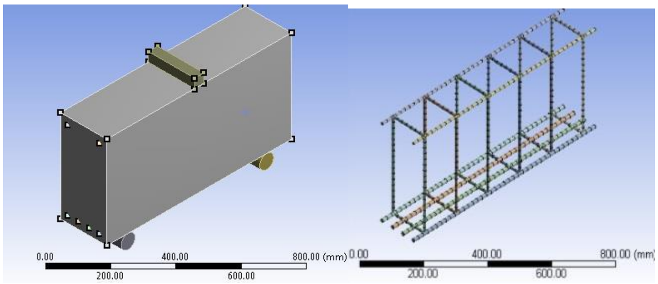

Fig. 1. Modelling of beam in ANSYS 14

Studied beams were categorized in two main categories; the first group is simply supported deep beams with l/d ratio equal to 2.5. The second group includes simply supported deep beams with l/d ratio equal to 3.5. The variables considered for the present parametric study are the effect of openings in deep beams with increasing l/d ratio keeping

1) Length of beam as fixed and reducing the depth
2) Depth of beam as fixed and increasing the length

3.1. Parametric study by increasing the l/d ratio reducing the depth of deep beam

l/d ratio can be increased by decreasing the depth and thus keeping the length as constant. In this study, length has been kept constant ie 800 mm and depth decreased. For the l/d ratios 2.5 and 3.5, the corresponding beam sizes are obtained as below.
1) l/d = 2 (800 mm x200 mmx 400 mm) (Experimental beam size)
2) l/d = 2.5 (800 mm x200 mm x320 mm)
3) l/d = 3.5 (800 mm x200 mmx 230 mm)
Analysis of beams was done in ANSYS 14 and ultimate loads were obtained as follows for beam specimens

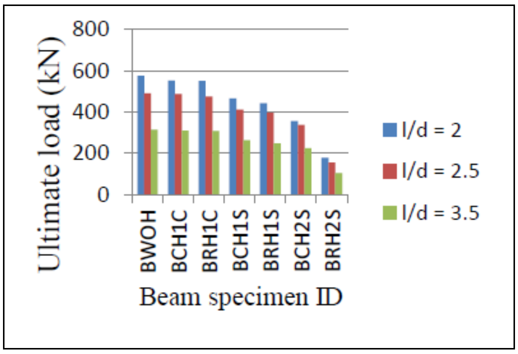

Fig. 2. Ultimate load for beam with reduced depth

3.2. Parametric study by increasing the l/d ratio increasing the length of deep beam

l/d ratio can be increased by increasing the length and thus keeping the depth as constant. In this study, depth has been kept constant ie 400 mm and length increased. For the l/d ratios 2.5 and 3.5, the corresponding beam sizes are obtained as below.

1) l/d = 2 (800 mm x200 mmx 400 mm) (Experimental beam size)
2) l/d = 2.5 (1000 mm x200 mm x400 mm)
3) l/d = 3.5 (1400 mm x200 mmx 400 mm)

Analysis of beams was done in ANSYS 14 and ultimate loads were obtained as follows for beam specimens with constant depth (400 mm).

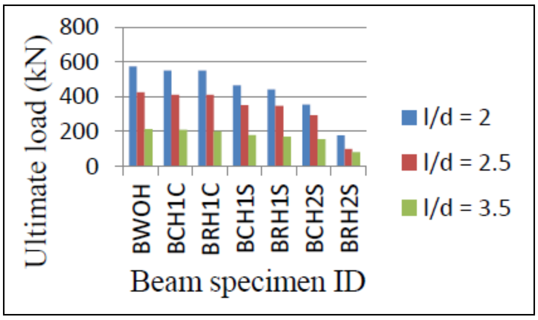

Fig. 3. Ultimate load for beams with increased length

IV. Conclusion

Experimental study on deep beams of size 800 mm 200 mm 400 mm were conducted using strut and tie method of analysis. To study the effect of openings in deep beam to accommodate utilities, openings were provided in beams. The position of openings were provided depending upon the strut and tie formation in deep beam when it is loaded. Parametric study was conducted on deep beams by varying l/d ratio and the following conclusions were made.

1) Deep beams with openings shows a decrease in ultimate load carrying capacity compared to solid beams.
2) 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.
3) As l/d ratio increased, the load carrying capacity of the beam decreased. l/d ratio can be increased by either increasing the length or decreasing the depth of beam.
4) By reducing the depth of beam to increase l/d ratio, the percentage reduction in load was 10-15% for beams with l/d ratio 2.5 and 40-45 % for beams with l/d ratio 3.5 compared with l/d ratio 2.
5) By increasing the length of beam to increase the l/d ratio, the percentage reduction in load was 18-26 % for beams with l/d ratio 2.5 and 58-62 % for beams with l/d ratio 3.5 compared with l/d ratio 2.

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