



## Numerical Study On The Influence Of Web Opening Location On Shear Strength Of Reinforced Concrete (R.C) Deep Beams For Square Opening

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### Abstract

The presence of web openings in reinforced concrete deep beams is often inevitable due to service ducts and utility provisions; however, such discontinuities may significantly alter the internal load transfer mechanism. This study examines the influence of opening location on the ultimate load capacity of deep beams comprising square openings using nonlinear finite element tool ANSYS. A series of beam models with varying normalized opening positions along the span were analyzed to evaluate their structural response. The numerical results indicate that beam strength is strongly dependent on the interaction between the opening and the diagonal compression strut responsible for shear transfer. Openings located near the support region exhibited comparatively higher load capacities, suggesting minimal disturbance to the principal stress trajectory. As the opening moved toward the central shear zone, a continuous reduction in ultimate load was noted, with the lowest strength recorded when the opening intersects the dominant strut path. The findings highlight that the position of the opening significantly influences the structural performance of deep beams and should be carefully considered in design. The study provides numerical insight into optimal opening placement for minimizing strength degradation in practical structural applications.

**Keyword:** Web openings, Deep beams, Finite Element Analysis, Shear span-to-depth ratio and Ultimate strength.

### Introduction

A deep beam is a structural element characterised by relatively small span-to-depth ratio, where shear deformation has dominant role in its behavior. As per Clause 29.1 of IS 456, a beam is classified as deep beam if its effective span-to-overall depth ratio ( $l/D$ ) is below:

- (a) 2.0 beams that are simply supported
- (b) 2.5 for beams that are continuous

Structural behavior of reinforced concrete (RC) deep beams is significantly more complex than that of shallow beams. Load transfer in deep beams mostly takes place via compression struts, with minimal or no flexural action. Consequently, deep beams are not covered by conventional assumptions like linear-elastic flexural theory or the idea that flat portions stay plane after bending.

RC deep beams are commonly utilized in structural applications such as foundation walls supporting strip footings or raft slabs, single-span or continuous transfer girders, pile-supported foundations, shear wall systems, silo and bunker walls, and offshore structures.

Deep beam analysis ought to be treated as 2-dimensional (2-D) plane stress problem. Accordingly, 2-D stress analysis methods must be employed to accurately determine the stress distribution, even when considering linear elastic solution.

### Factors influencing the behaviour of deep beams

Structural behavior as well as deep beams performance with web openings are impacted by many key factors, including:

- a) Shear span-to-depth ratio
- b) Span-to-depth ratio
- c) Cross-sectional properties.
- d) Amount and placement of primary longitudinal reinforcement
- e) Amount, type, as well as positioning of web reinforcement
- f) Material properties of concrete” as well as reinforcement
- g) Type as well as location of applied loads
- h) Shape, size, as well as position of web “openings

### Effect of openings on Reinforced Concrete (RC) deep beams

Incorporating openings in Reinforced Concrete (RC) deep beams” is essential for accommodating services, including electrical wiring and air conditioning ducts. However, these openings create geometric discontinuities within beam, affecting nonlinear stress distribution across its depth. Because of loss of concrete mass and the increased risk of shear crack propagation, web openings lower a deep beam's ultimate strength. When opening is placed along beam's natural load path, this effect is very pronounced.

The extent to which opening disrupts a natural load path, a direct relationship between load and support points, determines how much shear capacity is reduced. If this path is fully interrupted by opening, shear capacity of beam is significantly compromised.

Larger openings tend to alter crack patterns and also influence failure modes. As size of opening increases, crack formation and propagation occur more rapidly, further weakening the beam structure.

The position of opening also has an essential role in beam's load-bearing capacity. Compared to shape of opening, its location has more substantial effect on stress distribution, making it a critical factor in design as well as deep beam performance.

This study aims to numerically investigate the influence of varying web opening locations on the shear behavior of RC deep beams subjected to two-point loading with a shear span-to-depth ratio of 0.8. A nonlinear finite element approach is adopted to capture realistic material behavior, crack development, and failure mechanisms.

### Problem Definition

This study focuses on deep beam analysis utilizing finite element software ANSYS. The beams considered for analysis are simply supported, with an overall length 2000mm, depth 1000mm, and width 200mm. A steel plate having a thickness 25 mm is placed at loading and support points to ensure a more uniform stress distribution in these areas. Beam is subjected to 2-point loading, with single-line support positioned beneath centerline of steel plate to facilitate rotation.

Reinforcement is provided using steel bars of 20 mm and 10 mm diameters. Tension reinforcement comprises two 20mm diameter bars, although two 10mm diameter bars function as hanger bars. Additionally, 10mm diameter bars serve as stirrups and web reinforcement. The beams are examined under varying opening location with an  $a/D$  ratio of 0.8.

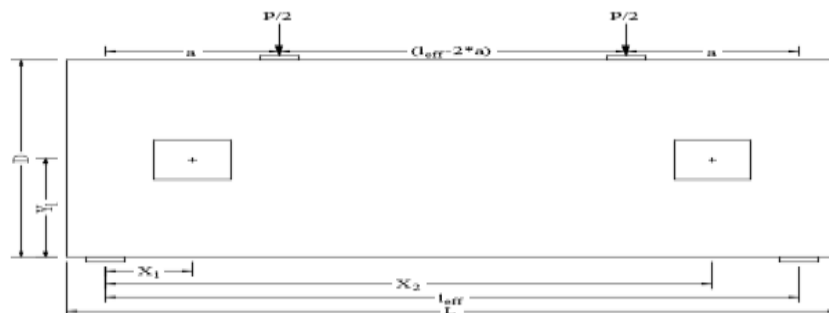


Fig. 1: Deep beam showing location of web opening

Where,

- a = Shear span
- L= Overall length of deep beam
- $l_{eff}$  = Center to center length between supports
- P= Ultimate load
- D= Overall Depth of deep beam
- X1= Distance to center of 1st opening along length from left support
- X2= Distance to center of 2nd opening along length from left support
- Y1= Distance to center of openings across depth from bottom of beam
- b = width of deep beam
- d = effective depth of deep beam

Analyses are carried out considering square openings.

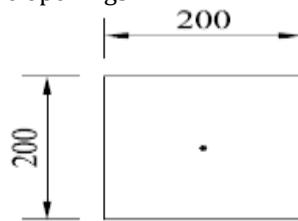


Fig. 2: Square opening (200X200 mm)

### Solution Methodologies

This section aims to describe a procedure for modelling “RC deep beams with web openings utilizing FE (finite element) software. NLFEA(Non-Linear Finite Element Analysis) is performed on RC deep beams with openings of varying  $a/D'$ . ANSYS, a powerful engineering tool for finite element analysis (FEA), is utilized for both modelling and analysis of RC deep beams.

#### Elements Selected from the ANSYS Element Library

##### Solid65 Element:

SOLID65 element is employed for 3-D (three-dimensional) modeling of concrete structures. It is specifically designed to simulate nonlinear behavior of concrete, encompassing cracking under tension as well as crushing under compression.

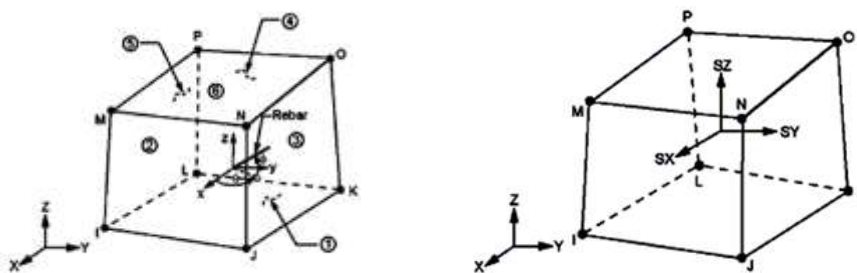
##### Link 180 Element:

LINK180 element is 3-D spar element commonly utilized in various engineering applications, including modeling trusses, links, sagging cables, as well as springs.

##### Solid185 Element:

SOLID185 “element is utilized for 3-D modelling of solid structures. Similar to SOLID65, it is an 8-node element with 3 degrees of freedom per node, representing translations in x, y, z directions”.

Key distinction between SOLID65 and SOLID185 is that while SOLID65 can simulate cracking under tension as well as crushing under compression, SOLID185 lacks these specific fracture modelling capabilities.



(a) SOLID65 element for concrete

(b) SOLID185 element for steel plate

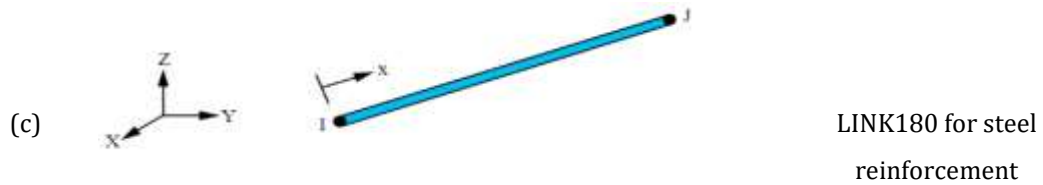


Fig. 3: Elements utilized for modelling RC deep beams using ANSYS

**Idealization of Steel Reinforcement in Concrete Elements**

In finite element modelling of reinforced concrete deep beams, steel reinforcement may be represented either through a discrete approach or a smeared reinforcement approach. In the discrete method, the reinforcing bars are modelled explicitly using spar or beam elements with properties equivalent to the actual steel bars. These elements are embedded within the concrete mesh and typically share nodes with the surrounding concrete elements, enabling strain compatibility and force transfer between the two materials. Consequently, the location of reinforcement governs the local mesh arrangement of the concrete domain.

In contrast, the smeared reinforcement approach assumes that the reinforcement is uniformly distributed within a specified region of the concrete elements. This simplification reduces modelling effort and computational demand and is therefore often adopted for large structural systems where individual bar behaviour does not significantly influence the global response.

For deep beams with clearly defined geometry and reinforcement layout, however, explicit representation of the bars provides a more realistic simulation of stress distribution, crack development, and load transfer mechanisms. Accordingly, the present study employs a discrete reinforcement modelling strategy in order to capture the structural behaviour of the deep beams with greater fidelity.

**C. Material Properties**

For SOLID65 element, concrete is modeled using both linear isotropic as well as multilinear isotropic material properties.

**Table 1: Material Properties**

Material	Element	Material Properties
Concrete	SOLID65	Ultimate Uniaxial Compressive Strength (MPa) - 25
Steel Rebars	LINK180	Yield Stress (MPa) - 500
Steel Plates	SOLID185	Yield Stress (MPa) - 250

**Results and Discussion**

The numerical investigation examined how the longitudinal position of a web opening influences the ultimate load capacity of reinforced concrete deep beams. The opening size was kept constant at 200 × 200 mm, while its location within the shear span was progressively shifted.

Ultimate load capacity for different opening positions is summarized in following table 2.

**Table 2. Ultimate strength of R.C Deep beam with web opening for (a/D) = 0.8**

Beam No.	Size of opening (mm)	Position of opening		Ultimate Load (kN)
		X1/D	X2/D	
B-01	200 x 200	0.175	1.625	467.75
B-02		0.225	1.575	425.55
B-03		0.275	1.525	415.45
B-04		0.325	1.475	403.10
B-05		0.375	1.425	385.16

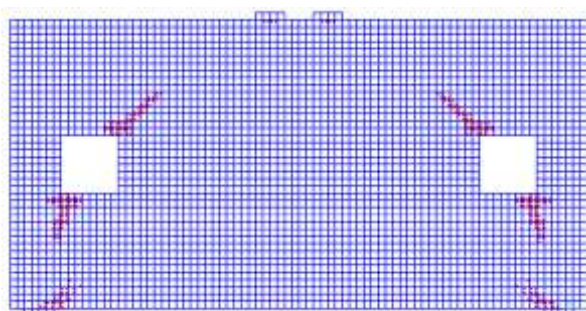
B-06		0.425	1.375	374.73
B-07		0.475	1.325	413.18
B-08		0.525	1.275	386.09
B-09		0.575	1.225	405.87
B-10		0.625	1.175	449.12

### Influence of Opening Position

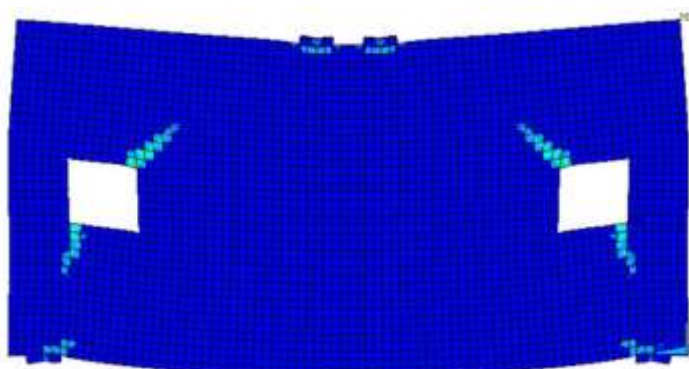
Referring to above table 2, the results show a clear dependence of beam strength on opening location. The highest ultimate load of 467.75 kN was obtained for Beam B-01, where the opening was located closest to the support. As the opening moved further into the shear span, a steady decline in load capacity was observed. This reduction continued up to Beam B-06, which recorded the lowest strength of 374.73 kN. The reduction relative to B-01 is nearly 20%, indicating a substantial sensitivity of deep beams to interruptions within the load transfer region.

The loss of strength observed in the intermediate positions can be explained by the disruption of the internal compression strut that normally forms between the loading point and the support. When the opening lies along this stress path, the flow of compressive forces is forced to deviate around the opening. This results in localized stress concentrations, reduced strut efficiency, and earlier diagonal cracking. Consequently, the beams ability to sustain shear forces is diminished.

These findings emphasize that the location of service openings should be treated as a primary design parameter in deep beams.



**Fig. 4:** FEM-predicted diagonal shear cracking for beam B-01



**Fig. 5:** FEM-predicted equivalent strain distribution for beam B-01

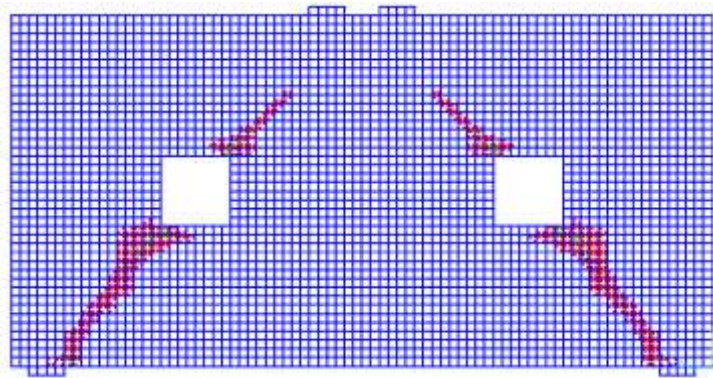


Fig. 6: FEM-predicted diagonal shear cracking for beam B-06

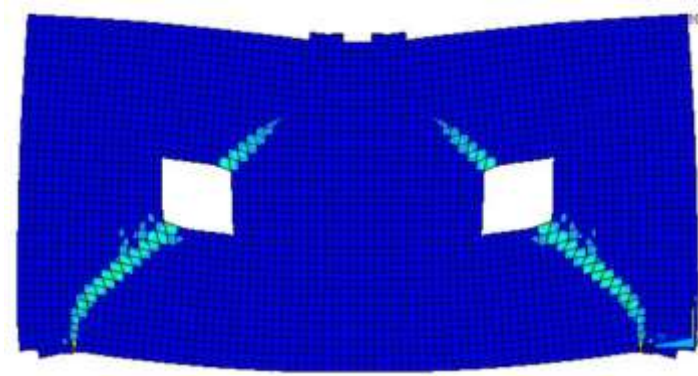


Fig. 7: FEM-predicted equivalent strain distribution for beam B-06

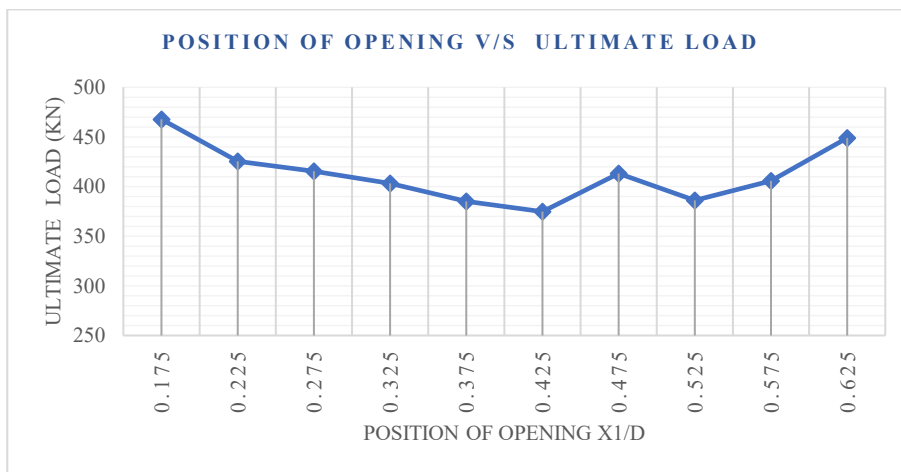


Fig. 8: Influence of web opening position on the ultimate load capacity of the RC deep beam

### Conclusions

The results demonstrate that the location of the opening plays a decisive role in governing load capacity, strain localization, and cracking response.

When openings intersect the principal load transfer path between the load point and support, the internal compression strut is disrupted. This leads to intensified strain near the opening corners, earlier diagonal crack initiation, and a noticeable reduction in ultimate strength. In contrast, openings positioned away from this critical load path allow the beam to maintain a more stable stress flow, resulting in comparatively higher load resistance and delayed failure.

The numerical trends also indicate that ultimate capacity reduces progressively as the opening approaches the shear-dominant zone, while partial recovery in strength is observed when the opening is shifted toward regions of lower stress intensity. Failure of beams with unfavourable opening locations is primarily associated with diagonal shear cracking, whereas beams with better-placed openings exhibit a more gradual redistribution of stresses before collapse.

Overall, the findings highlight that opening location must be treated as a key design consideration in deep beams. Proper positioning can significantly reduce adverse effects on structural performance of beams. When openings cannot be relocated, strengthening measures or modified reinforcement detailing should be considered to restore the disrupted load path.

**Conflict of Interest:**

There was no relevant conflict of interest regarding this paper.

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