MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 1669-1673

Numerical Study on the Influence of Web Opening Location on Shear Strength of Reinforced Concrete (R.C) Deep Beams for Square Opening

***Chethan. H. G*[1]*, Narendra. B. K*[2]**
[1]*Research Scholar, Civil Engineering Department, BGS Institute of Technology, Adichunchanagiri University, B G Nagara, Nagamangala, Mandya, India.*
chethanhg526@gmail.com
[2]*Research Supervisor, Civil Engineering Department, BGS Institute of Technology, Adichunchanagiri University, B G Nagara, Nagamangala, Mandya, India.*
Corresponding Author: Chethan H G
Email: [1]chethanhg526@gmail.com,

Abstract:
The presence of web openings in reinforced concrete deep beams is often unavoidable due to service ducts and utility provisions; however, such discontinuities may significantly alter the internal load transfer mechanism. This study investigates the influence of opening location on the ultimate load capacity of reinforced concrete deep beams containing 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 progressive reduction in ultimate load was observed, with the lowest strength recorded when the opening intersected 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.
Keywords: *Web openings, Deep beams, Finite Element Analysis, Shearspan-to-depth ratio and Ultimate strength*

1. Introduction

A deep beam is a structural component distinguished by a relatively low span-to-depth ratio, wherein shear deformation predominates its behavior. According to Clause 29.1 of IS 456, a beam is a deep beam if its effective span-to-overall depth ratio (l/D) is less than
(a) 2.0 for beams that are simply supported
(b) 2.5 for beams that are continuous

The structural behavior of reinforced concrete (RC) deep beams is considerably more intricate than that of shallow beams. Load transfer in deep beams mostly occurs through compression struts, exhibiting negligible or absent flexural action. As a result, deep beams are not encompassed by traditional assumptions such as linear-elastic flexural theory or the principle that plane sections remain planar post-bending.

Reinforced concrete deep beams are frequently employed in structural applications, including foundation walls that support strip footings or raft slabs, single-span or continuous transfer girders, pile-supported foundations, shear wall systems, silo and bunker walls, and offshore buildings. Structural behavior of reinforced concrete (RC) deep beams is considerably more intricate than that of shallow beams. Load transfer in deep beams mostly occurs through compression struts, exhibiting negligible or absent flexural action. As a result, deep beams are not encompassed by traditional assumptions such as linear-elastic flexural theory or the principle that plane sections remain planar post-bending.

Deep beam analysis should be seen as a two-dimensional (2-D) planar stress problem. Consequently, two-dimensional stress analysis techniques must be utilized to precisely ascertain the stress distribution, even while accounting for linear elastic solutions.

1.1 Factors that affect the behavior of deep beams

There are numerous critical factors that influence the performance of deep beams with web openings and structural behavior,

a) Shear span-to-depth ratio
b) The ratio of span to depth
c) The cross-sectional properties.
d) The amount and location of primary longitudinal reinforcement
e) The quantity, type, and location of web reinforcement
f) Reinforcement grade and concrete grade
g) The location and type of the applied load
h) The position, size, and shape of the web openings

1.1.1 The impact of web openings on Reinforced Concrete (RC) deep beams

It is necessary to incorporate openings in Reinforced Concrete (RC) deep beams to accommodate services, such as electrical wiring and air conditioning conduits. Nevertheless, the geometric discontinuities that these openings generate within the beam have an impact on the nonlinear stress distribution throughout its depth. Because of the increased risk of shear fracture propagation and the loss of concrete mass, web openings reduce the ultimate strength of a deep beam. This effect is particularly noticeable when the opening is situated along the natural load path of the beam. The degree to which an opening disrupts a natural load path, which is a direct relationship between load and support, is the determining factor in the reduction of shear capacity. The shear capacity of the beam is substantially compromised if this path is completely interrupted by the opening.Crack patterns and failure mechanisms are typically altered by larger openings. The beam structure is further weakened as fracture formation and propagation occur more rapidly as the size of the opening increases.

The load-bearing capacity of a beam is also significantly influenced by the position of the opening. It is a critical factor in the design of deep beams and their performance, as its location has a more substantive impact on stress distribution than the shape of the opening.

This work intends to quantitatively examine the impact of different web opening positions on the shear behavior of reinforced concrete deep beams subjected to two-point stress, with a shear span to depth ratio of 0.8. A nonlinear finite element method is employed to accurately represent material behavior, crack propagation, and failure mechanisms.

2. 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.

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 1669-1673

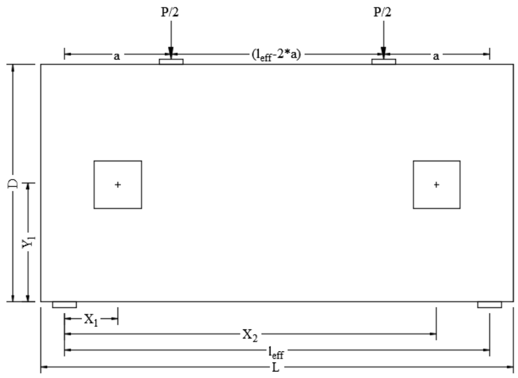


Fig 1. Deep beam showing location of web opening

Nomenclature

a =Shear span
L=Overall length of deep beam
leff =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.

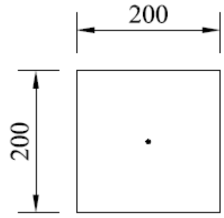


Fig 2. Square opening (200X200 mm)

3. Solution Methodologies:

This section outlines a process for modeling web openings in R C deep beams using finite element tool. Non Linear Finite Element Investigation is conducted on R C deep beams featuring openings at variable locations along length. ANSYS, a powerful engineering tool for finite element analysis (FEA), is utilized for both modelling and analysis of RC deep beams.

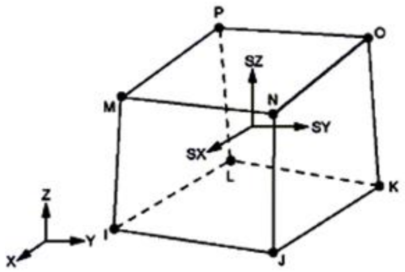
3.1 Elements Selected from the ANSYS Element Library

3.1.1 Solid 65 Element: SOLID65 element is utilised 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.

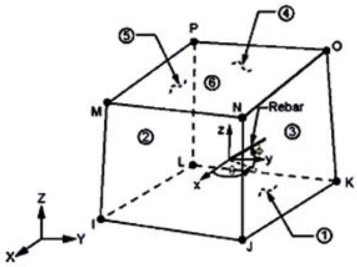
3.1.2 Link180 Element: LINK180 element is 3-D spar element commonly utilized in various engineering applications, including modeling trusses, links, sagging cables, as well as springs.

3.1.3 Solid185 Element: The SOLID185 element has been used for modeling of solid structures. Like SOLID65, it is an 8-noded element with 3 degrees of freedom at each node, representing translations in all 3 directions.

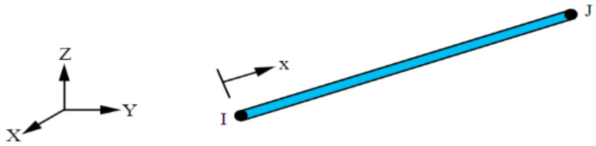
Key distinction between SOLID65 and SOLID185 is that while SOLID65 can simulate cracking under tension as well as crushing under compression, SOLID185 lacks these specific fracture modelling capabilities.



(a) SOLID65 element for concrete



(b) SOLID185 element for steel plate



(c) LINK180 for steel reinforcement

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

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 1669-1673

3.2 Idealization of Steel Reinforcement in Concrete Elements: In ANSYS, steel reinforcement can be represented using either a discrete technique or a smeared reinforcement model. In the discrete technique, the reinforcing bars are explicitly modeled using spar elements with attributes that correspond to the actual steel bars. These elements are integrated within the concrete mesh and generally share nodes with the adjacent concrete elements, facilitating strain compatibility and force transmission between the two materials. Thus, the placement of reinforcement governs the local mesh configuration of the concrete area. 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. In deep beams with well-defined geometry and reinforcement configuration, detailed depiction of the bars yields a more accurate simulation of stress distribution, fracture formation, and load transfer processes. This study utilizes a discrete reinforcement modeling technique to accurately represent the structural behavior of deep beams.

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

Table 1. Material Parameters

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

4. Results and Discussion:

The numerical investigation examined how the longitudinal position of a web opening influences the maximum load capacity of R C 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 are summarised in following table 2.

Table 2. Ultimate strength 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

4.1 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 Beam 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.

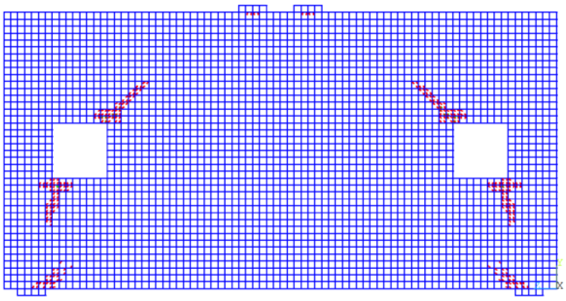


Fig 4. FEM-predicted diagonal shear cracking for Beam B-01

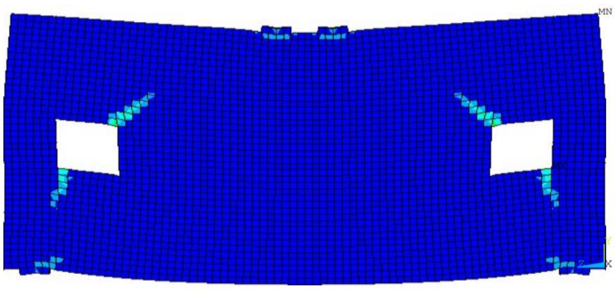


Fig 5. FEM-predicted equivalent strain distribution for Beam B-01

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 1669-1673

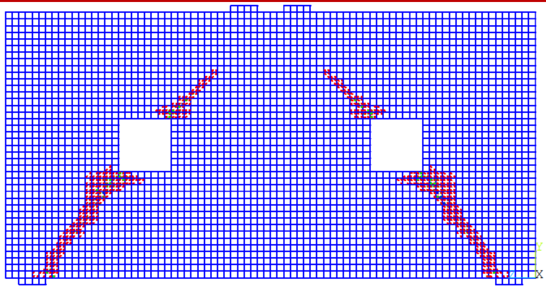


Fig 6. FEM-predicted diagonal shear cracking for Beam B-06

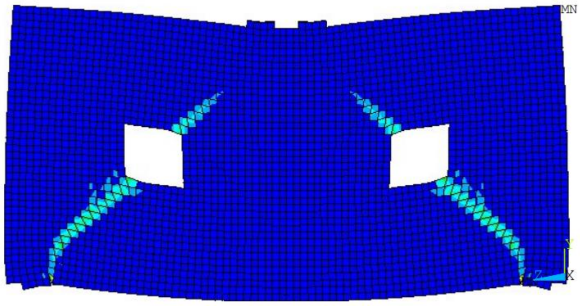


Fig 7. FEM-predicted equivalent strain distribution for Beam B-06

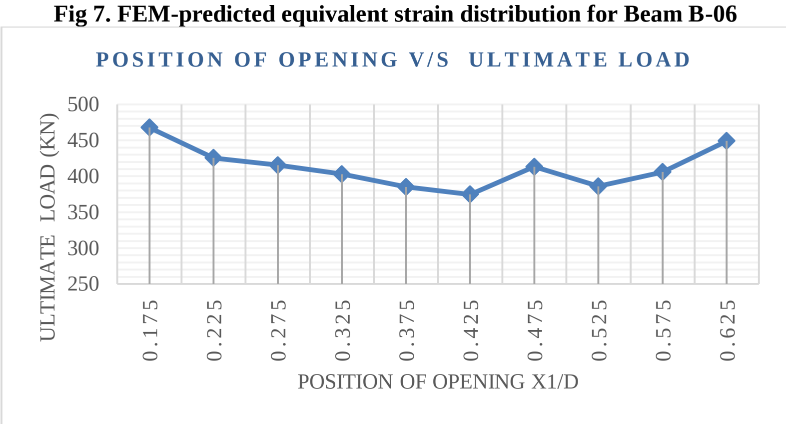


Fig 8. Influence of web opening position on the ultimate load capacity of the RC deep beam

5. Conclusion:

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

When openingsintersect the principalload 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 unfavorable 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.

References

1. Kong F.K, and Sharp G.R, "Structural idealization for deep beams with web openings," *Magazine of Concrete Research*, vol. 29, no. 99, pp. 81-91, 1977. [CrossRef]
2. Swaddiwudhipong S, and Shanmugam N.E, "Fiber-reinforced concrete deep beams with openings," *Journal of Structural Engineering, American Society of Civil Engineers*, vol. 111, no. 8, pp. 1679-1690, 1985. [Crossref]
3. Mansur M.A, "Effect of openings on the behaviour and strength of RC beams in shear," Cement and Concrete composites, vol. 20, pp. 477-486, 1998. [Crossref]
4. Keun-Hyeok Yang, Hee-Chang Eun, and Heon-Soo Chung, "The influence of web openings on the structural behavior of reinforced high-strength concrete deep beams," *Engineering Structures*, vol. 28, no. 13, pp. 1825-1834, 2006. [Crossref]
5. Dipti R.Sahoo, Carlos A. Flores and Shih-Ho Chao, "Behaviour of Steel Fibre-Reinforced Concrete Deep Beams with Large Opening," *ACI Structural Journal*, pp. 193-204. 2012. [Crossref] [Google Scholar] [Publisher Link]
6. Ashraf Ragab Mohamed, Mohie. S. Shoukry and Janet M. Saeed, "Prediction of the behaviour of reinforced concrete deep beams with web openings using the finite element method," *Alexandria Engineering Journal*, vol. 53, no. 2, pp. 329-339, 2014. [CrossRef]
7. M.A. Javed, M. Irfan, S. Khalid, Y. Chen, and S. Ahmed, "An experimental study on the shear strengthening of reinforced concrete deep beams with carbon fiber reinforced polymers," *KSCE Journal of Civil Engineering*, vol. 20, no. 7, pp. 2802-2810, 2016. [CrossRef]

8. A. Kumari, S.S. Patel, and A.N. Nayak, "Shear Strengthening of RC Deep Beam Using Externally Bonded GFRP Fabrics," *Journal of The Institution of Engineers (India): Series A*, vol. 99, no. 2, pp. 341-350, 2018. [CrossRef]
9. Nurul Izzati Rahim, Bashar S. Mohammed, Amin Al-Fakih, M. M. A. Wahab, M. S. Liew, Abdullah Anwar, and Y. H. Mugahed Amran, "Strengthening the structural behavior of web openings in RC deep beam using CFRP," *Materials*, vol. 13, no. 12, pp. 1-21, 2020. [CrossRef] [Google Scholar] [Publisher Link]
10. Jasim W. A, Y. B. A. Tahnat, and A. M. Halahla, "Behavior of reinforced concrete deep beam with web openings strengthened with (CFRP) sheet," *Structures*, vol. 26, pp. 785-800, 2020. [CrossRef] [Google Scholar]
11. A. Kumari, and A.N. Nayak, "Strengthening of shear deficient RC deep beams using GFRP sheets and mechanical anchors," *Canadian Journal of Civil Engineering*, vol. 48, no. 1, pp. 1-15, 2021. [CrossRef] [Google Scholar]
12. M. Mansour, and T. El-Maaddawy, "Testing and modeling of deep beams strengthened with NSM-CFRP reinforcement around cutouts," *Case Studies in Construction Materials*, vol. 15, pp. e00670, 2021. [CrossRef]
13. Mohammed Riyadh Khalaf, Ali Hussein Ali Al-Ahmed, Abbas AbdulMajeed Allawi, and Ayman El-Zohairy, "Strengthening of Continuous Reinforced Concrete Deep Beams with Large Openings Using CFRP Strips," *Materials*, vol. 14, no. 11, pp. 3119, 2021. [CrossRef]
14. T D. Dang, D T. Tran, L. Nguyen-Minh, and A. Y. Nassif, "Shear resistant capacity of steel fibers reinforced concrete deep beams: An experimental investigation and a new prediction model," *Structures*, vol. 33, pp. 2284-2300, 2021. [CrossRef]
15. S. Li, Z. Wu, J. Zhang, and W. Xie, "Experimental Study and Calculation Methods of Shear Capacity for High-Strength Reinforced Concrete Full-Scale Deep Beams," *Materials*, vol. 15, no. 17, pp. 6017, 2022. [CrossRef]
16. A. Sheikh Sobeh, N. Kachouh, and T. El-Maaddawy, "Numerical Analysis of Concrete Deep Beams Reinforced with Glass Fiber-Reinforced Polymer Bars," *Buildings*, vol. 13, no. 11, pp. 2767, 2023. [CrossRef]
17. E. K. Sayhood, N. S. Mohammed, S. J. Hilo, and S. S. Salih, "Comprehensive Empirical Modeling of Shear Strength Prediction in Reinforced Concrete Deep Beams," *Infrastructures*, vol. 9, no. 4, pp. 67, 2024. [CrossRef]
18. Mohammed M.Y, Ali A. Y, Kadhim M. M. A, and Jawdhari A, "RC Deep Beams with Vertical Openings: Behavior and Proposed Mitigation Techniques," *Practice Periodical on Structural Design and Construction*, vol. 29, no. 1, pp. 4023060, 2024. [CrossRef]
19. Hee-changeun, Young-ho lee, Heon-soochung, and Keun-hyeok yang, "On the shear strength of reinforced concrete deep beam with web opening," *The structural design of tall and special buildings, Wiley Online Library*, vol. 15, no. 4, pp. 445-466, 2006. [CrossRef]
20. Ali Hussein Ali Al-Ahmed, and Mohammed Riyadh Khalaf, "Openings effect on the performance of reinforced concrete deep beams," *The First MoHESR and HCED Iraqi Scholars Conference in Australasia, ISCA*, pp. 181-187, 2017.
21. F. K. Kong, *Reinforced Concrete Deep Beams*: Van Nostrand Reinhold Inc, New York, United States of America, 1990.
22. M. A. Mansur, Kiang-Hwee Tan, *Concrete beams with openings, Analysis and design*: CRC press, London, United Kingdom, 1999.
23. IS 456: Plain and Reinforced Concrete - Code of Practice, 2000.