

Nonlinear Finite Element Analysis of Beam Structures with and without Openings Using ANSYS: A Comparative Study

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Abstract

Beams play a crucial role in numerous structures like buildings, bridges, and aircraft. This research utilizes ANSYS software for nonlinear FEA to investigate the impact of rectangular openings on beam structural behavior under vertical loads. In the research, two beam models are analyzed, one being solid while the other has rectangular openings. Studying the impact of openings on stress concentrations and failure modes is a key objective, as well as evaluating load-carrying capacity, deformation, and stress distribution. The results indicate that solid beams display consistent linear stress distributions, while beams without openings exhibit significant alterations due to localized stress concentrations, leading to more deformation and reduced load-carrying capacity. The findings stress the importance of considering openings in beam design to ensure structural strength and safety. By conducting this study, our goal is to enhance engineering techniques and facilitate the development of robust structural plans that meet safety standards and address practical requirements by exploring the impacts of incorporating openings. Ultimately, this study enhances understanding of beam performance under real-life loading conditions, allowing informed decisions in structural engineering designs.

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Introduction

Beams play an important role in the field of structural engineering. They are used in the construction of bridges and buildings. In industries like aerospace and automotives, they are used to construct frameworks. Typically, beams are assumed to be solid and regular. However, modifications like induction of openings and cuts may be needed to solve various modern-day problems. Openings are induced in structural elements like beams and columns for the purpose of ventilation, utilities, and aesthetics. These modifications may have a significant impact on structural response and performance of beams.

Analyzing beam structures with openings is more difficult because of variations in load-carrying capacity, failure modes, and stress distribution. Advanced analytical techniques are used by engineers to precisely analyze these impacts. Among these techniques, nonlinear FEA is proved to be vital in understanding the complex behaviour of structures under actual loading conditions. ANSYS, a renowned software for finite element analysis, offers a reliable platform for simulating and

assessing the performance of beam structures. Engineers can use ANSYS to simulate how beams respond nonlinearly to different loads and geometry changes. This function is very useful for studying how openings affect beam performance, as it enables a thorough examination of stress concentrations, deformation patterns, and possible failure mechanisms.

The primary goal of this study is to compare the nonlinear analysis of two beam structures, one with an opening and the other without, using ANSYS. The primary objective is to comprehend how an opening impacts the structural behavior of a beam in different loading conditions. By thoroughly studying and comparing the results of these analyses, this study aims to explore the effects of including openings in beam design and offer suggestions for enhancing structural performance within practical design limitations. Understanding the impacts is essential for making informed decisions in design and ensuring that beams with openings meet safety and performance standards. The results of this research will help create sturdier structural designs and make more accurate predictions about structural behavior.

Objectives

- To use ANSYS for nonlinear finite element analysis of beams with and without openings.
- To assess and compare stress distribution, deformation, and load-carrying capacity between the two beam models.
- To examine how openings affect stress concentrations and failure modes.
- To determine the impact of openings on the beam's load-carrying capacity.

Methodology

- Creating models using Auto-desk Revit.
- Importing the models in ANSYS 2019.
- Analyzing the models in ANSYS 2019.
- Results and discussions.

Detail Of Models

Table 1. Details of model

Parameters	Beam without opening (B-1)	Beam with opening (B-2)
Length	2000 mm	2000mm
Width	300 mm	300 mm
Depth	120 mm	120 mm
Main Rebar	4-16mm dia	4-16mm dia
Top Bar	2-10mm dia	2-10mm dia
Stirrups	6mm dia @150mm c/c	6mm dia@150mm c/c
Corner Rebar	-	1-10mm dia
Concrete Ultimate Strength	71 Mpa	71 Mpa
Opening Length	-	360mm(each)
Opening Width	-	120mm(each)

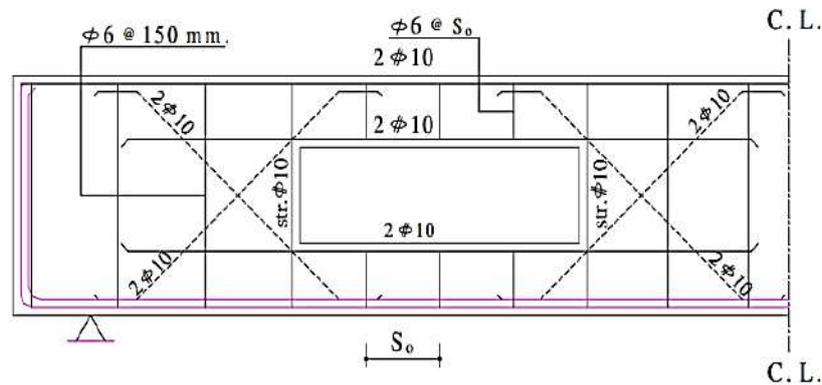


Fig. 3.1 Details of B-2

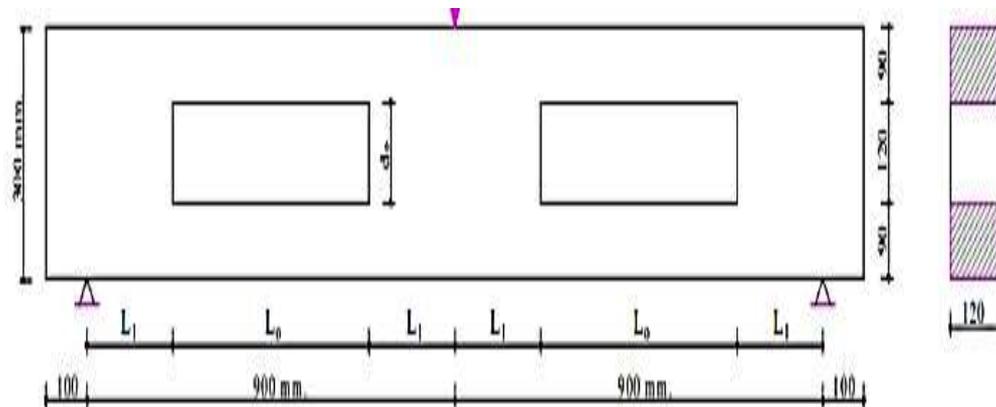


Fig. 3.2 Dimension of B-2

Method of Finite Elements

The Finite Element Method (FEM) breaks down a large domain into smaller elements that are easier to handle and are linked at nodes. This method involves solving complex structural, thermal, and fluid problems. Physical principles are utilized to form equations, with each element possessing specific material characteristics. The global system is formed from these elemental equations and represents the entire structure or domain. This system is exposed to boundary conditions that imitate the loads and constraints observed in the real world. Subsequently, the numerical solution of the global set of equations is carried out to identify any variables that are not known, including temperatures and displacements. The aim of post-processing is to comprehend the structure's behavior by analyzing and visualizing the results. FEM enables thorough analysis of intricate problems, providing valuable data for decision-making and design.

Results and Discussions

Deformation

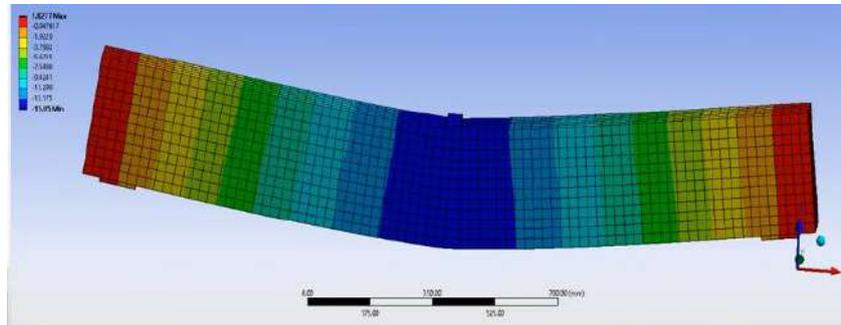


Fig 4.1. Deformation in B-1

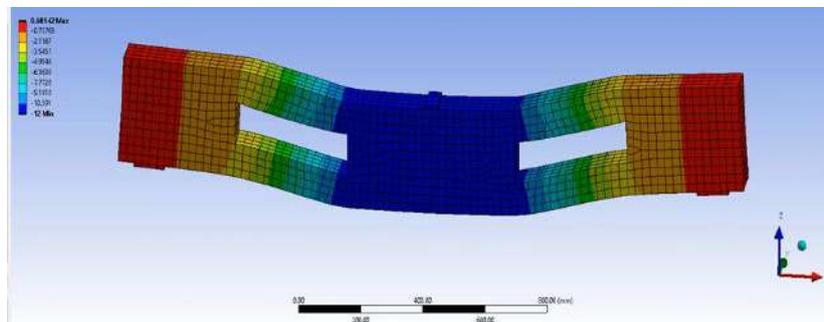


Fig 4.2. Deformation in B-2

In above pictures, it is demonstrated that , beam without opening(B-1) shows predictable deformation under loading. The deflection is shown with respect to positive Z-axis. Hence blue colour shows deflection along negative Z-axis(Positive deflection). The bending stresses are concentrated primarily in top and bottom fibers, while shear stresses are distributed parabolically across the width of beam. The neutral axis remains stable, leading to a consistent deformation pattern along the length of beam

In contrast, beam with opening (B-2) shows altered deformation pattern due to disruption of material continuity. The presence of openings can lead to stress concentrations around edges of the openings, which may result is increased deformation and reduced load-carrying capacity. Openings can significantly affect both the bending and shear capacities of beam, leading to a more complex deformation shape compared to solid beams.

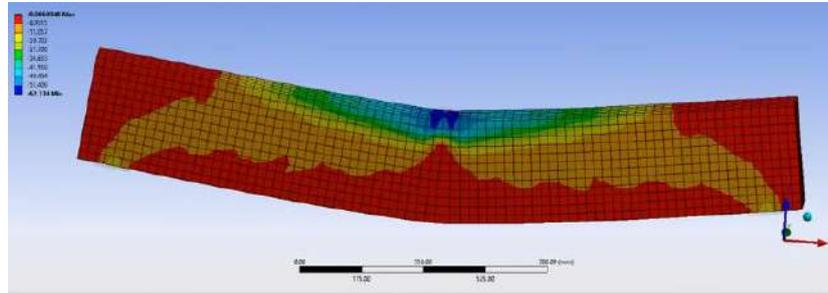
Minor Principal Stress

Fig 4.3 Minor Principal Stress in B-1

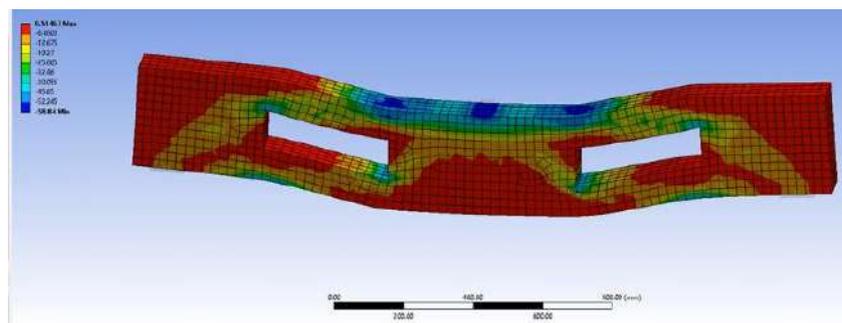


Fig 4.3 Minor Principal Stress in B-1

Analysis results show that the minor stress distribution varies between two beams. In the case of a beam with no openings (B-1), the distribution of the minor principal stress is uniform throughout the cross-section. The top fiber of the beam exhibits maximum compressive stress, which is represented by the blue colour in the picture, and it follows a linear distribution pattern. The lesser secondary stress is commonly due to shear stresses that are present within the beam. Compressive stress occurs above the neutral axis due to shear stresses, while tensile stress occurs below the neutral axis also due to shear stresses. There is a gradual increase in minor stress below the neutral axis until reaching the axis of tensile reinforcement, after which it either stays constant or decreases to zero, depending on the presence of shear reinforcement. In this instance, the lesser primary stress stays consistent under the tensile reinforcement because of the existence of shear reinforcement.

In beam with openings (B-2), the minor principal stress distribution becomes increasingly intricate. Rectangular openings' edges have high levels of stress concentrations. The corners of these openings are especially prone to increased pressures because of sudden shifts in shape. This could result in small increases in localized minor principal stress in these regions. This is clearly shown in Figure 4.4. Openings in beams may result in distinct failure modes in comparison to beams without openings. For example, shear failures frequently start at the edges of the openings because of the intense shear stresses gathered there. This becomes especially important as the opening size gets closer to critical dimensions in relation to the beam depth. In short, solid rectangular beams show consistent minor

principal stress distributions under vertical loading, whereas beams with rectangular openings undergo notable changes due to concentrated stress and possible failure modes.

Minimum Principal Elastic Strain

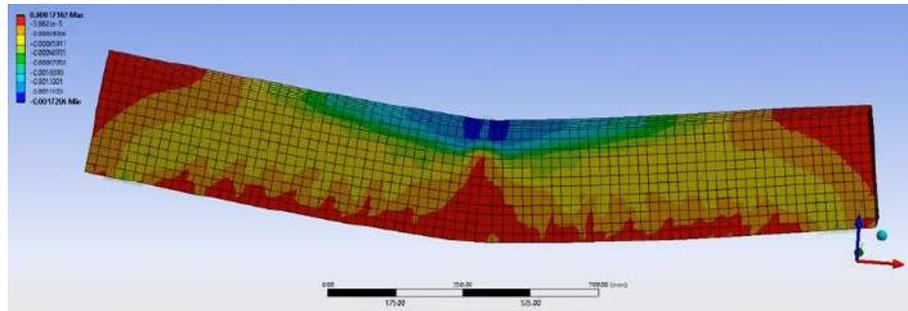


Fig 4.5 Minor Principal Elastic Strain in B-1

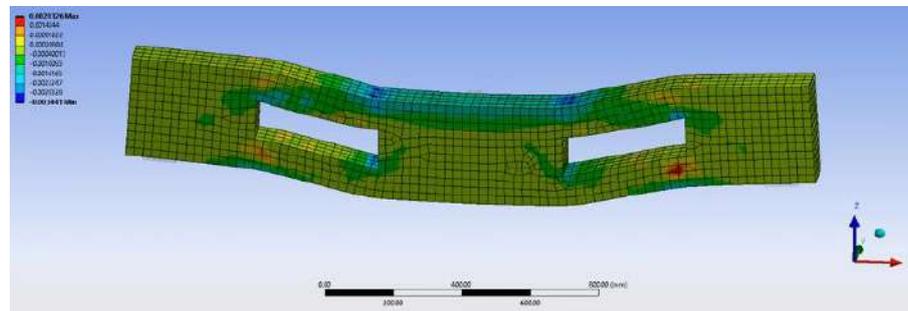


Fig 4.6 Minor Principal Elastic Strain in B-2

In rectangular beams without opening subjected to vertical loading, the minor principal elastic strain is typically uniform across the cross-section. The minor principal strain, which corresponds to the minimum normal strain experienced in the material, varies linearly from the top to the bottom of the beam. The strain is generally compressive at the top and tensile at the bottom as shown in Fig 4.5.

When rectangular openings are introduced into a beam, the distribution of minor principal elastic strain becomes more complex. The edges and corners of rectangular openings experience significant increases in minor principal strain due to stress concentrations. This can lead to higher localized strains compared to areas further away from the openings. The presence of an opening disrupts the uniform distribution of strains. Instead of a linear gradient, there may be abrupt changes in strain values around the opening. This can result in higher tensile or compressive strains near the edges of the opening. The altered strain distribution increases the likelihood of localized failures, such as cracking or yielding at the corners of the openings, particularly under high loading conditions. This is critical for assessing structural integrity and safety. In our model, we provided corner reinforcements around the openings. Hence we can see the minimization of minor elastic strain around the edges of openings in Fig. 4.6.

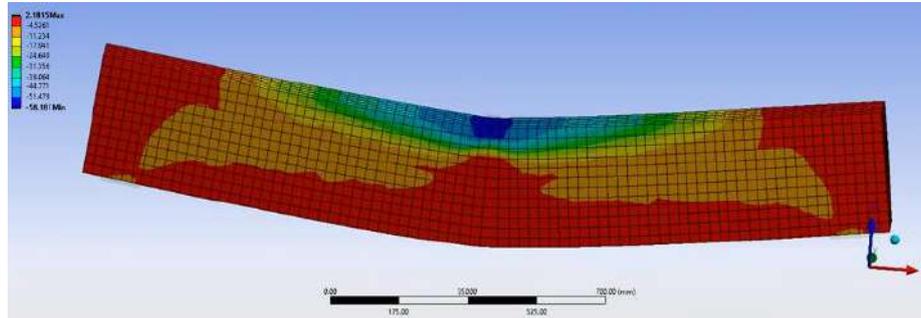
Normal Stress

Fig 4.7 Normal Stress in B-1

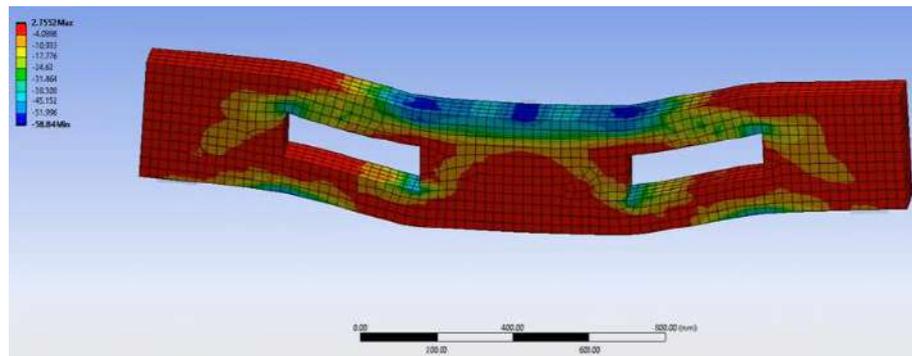


Fig 4.8 Normal Stress in B-2

The beam's geometry and the presence of openings affect how normal stress is distributed. In the beam with no opening. The average stress changes proportionally along the vertical extent of the beam. The top fibers (above the neutral axis) experience the greatest compressive stress, while the bottom fibers (below the neutral axis) experience the greatest tensile stress. Fig. 4.7 illustrates this distribution. At the neutral axis, where there is no bending, the normal stress is zero. Stresses are compressive above the axis and tensile below it. The highest compressive and tensile stresses are found at the outer edges of the beam's cross-section. This straight distribution enables anticipated structural response when subjected to loads.

Adding openings to a beam greatly changes the distribution of normal stress. Openings cause areas of increased stress to form around their edges, especially at the corners. This results in increased normal stresses in these regions in contrast to the solid parts of the beam as shown in Fig. 4.8. The consistent linear pattern observed in solid beams is disturbed. Rather, abrupt changes occur in typical stress values near and surrounding the openings. This could lead to higher tensile or compressive stresses in certain areas, especially near the corners of the openings.

Overall, solid rectangular beams have a predictable distribution of normal stress under vertical loading, while beams with rectangular openings undergo notable changes in structural behavior due to localized stress concentrations. Understanding these variations is essential for successful planning and strengthening tactics in engineering uses to guarantee safety and dependability.

Load-Deflection Graph

Deflections corresponding to their respective loading conditions were obtained from ANSYS simulations. They are plotted to analyse the curve.

Table 2. Load vs deflection

B-1		B-2	
Def(mm)	Load (kN)	Def(mm)	Load (kN)
0	0	0	0
7.5	220.1	1.2	30.132
9.375	226.2	1.74	42.543
9.8438	226.5	2.28	54.561
10.313	226.8	2.82	64.786
11.016	227.4	2.9415	67.392
11.544	227.7	3.0015	68.697
12.08	228	3.0615	69.478
12.483	228.2	3.1215	70.796
12.884	228.3	3.1815	72.02
13.485	228.5	3.2415	72.588
13.893	228.7	3.3015	73.817
14.297	228.6	3.3915	75.639
14.674	228.8	3.4515	76.6
15.05	228.9	3.5115	77.864
		3.6015	79.576
		3.6615	80.063
		3.7215	81.304
		3.8115	83.101
		3.9015	84.841
		3.9915	86.679
		4.0515	87.793
		4.1115	88.76
		4.1715	90.072
		4.2615	91.684
		4.3515	93.173
		4.4415	95.002
		4.5015	95.505
		4.5615	96.138
		4.6215	97.427
		4.7115	98.913
		4.8015	100.58
		4.8615	101.3
		4.9215	101.86
		4.9815	103.04
		5.0715	104.67
		5.2065	107
		5.3415	109.15
		5.4765	111.54
		5.679	114.92

5.8815	118.28
6.1852	123.04
6.489	127.87
6.9446	135.03
7.6281	144.62
8.3115	153.61
8.9949	160.92
9.6784	167.6
10.362	173.47
11.045	178.52
12	183.16

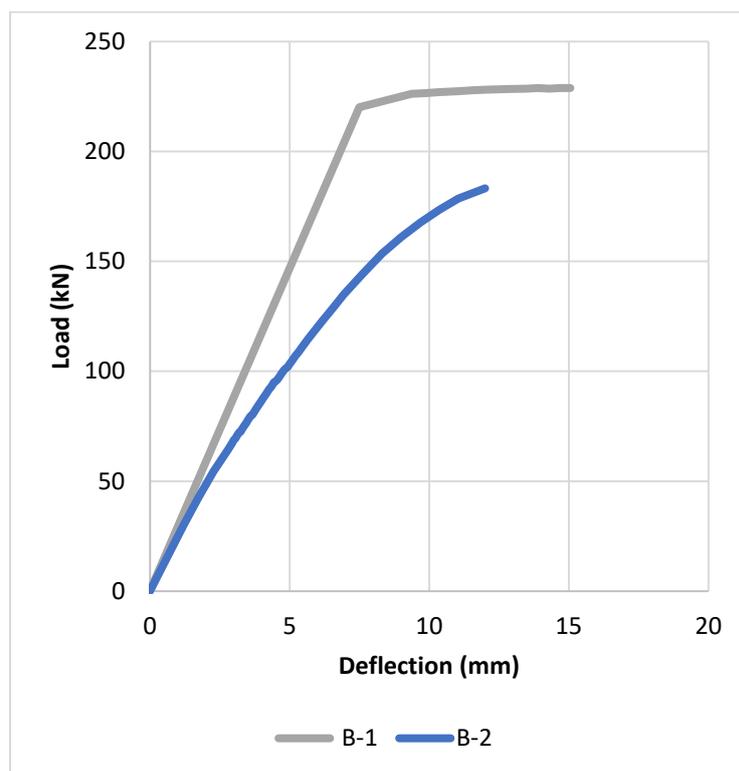


Fig 4.9 . Load vs Deflection Curve

Conclusion

This study conducts a thorough evaluation of beam structural performance under vertical loading, using ANSYS for nonlinear finite element analysis (FEA) in cases with and without openings. The results show that solid rectangular beams have predictable stress and strain patterns, but inducing rectangular openings changes it, causing concentrated stress areas and intricate deformations. More precisely, having openings leads to a decrease in load-carrying ability and a higher risk of failure, especially at the openings' corners. This study highlights the significance of taking into account these changes in

beam design to guarantee structural strength and safety. This study aims to provide information on how openings impact stress distribution, deformation, and performance, in order to help improve engineering practices and create stronger structural designs that meet safety guidelines and practical needs.

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