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Analysis of Castellated Beams With and Without Stiffeners Using ANSYS Software

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Abstract: The growing popularity of castellated beams in various construction projects stems from their ability to offer increased depth without extra weight, a greater ratio of strength to weight, and reduced maintenance costs. Castellated beams are I-sections that have been cut and rejoined in a zigzag pattern to augment their depth. This increase in depth enhances vertical bending stiffness, facilitates service installations, and enhances aesthetic appeal.

Fabricating castellated beams involves cutting and rejoining I-sections to create a modified profile that boosts structural performance. However, this modification can introduce new challenges such as web post buckling and lateral torsional buckling under loading conditions. Additional failure modes, including flexure mechanism formation, lateral torsional buckling, vierendeel mechanism formation, welded joint rupture in web posts, and shear buckling of web posts, also need consideration.

Research suggests that incorporating stiffeners in the web portion of perforated web can mitigate these failure modes. Therefore, detailed investigations into the optimal number, size, and placement of stiffeners are crucial for optimizing the performance of castellated beams. Current literature underscores that using stiffeners in castellated beam webs not only enhances strength but also minimizes deflection, enhancing overall structural performance.

***Keywords* - Castellated beams, Structural modification, Lateral torsional buckling etc.**

1. INTRODUCTION

1.1 Background Information

A beam is a structural component crafted to withstand sideways forces perpendicular to its length, chiefly through bending. When these forces act upon a beam, they prompt reaction forces at its supports, causing internal stresses, strains, and deformations. Beams come in diverse configurations, including different support arrangements, cross-sectional shapes, lengths, and materials.
While beams are frequently linked with construction and civil engineering projects, they play vital roles in numerous other systems, including automotive chassis, aircraft parts, machine frameworks, and various mechanical or structural setups. These beam systems are engineered to endure sideways pressures and are assessed using analogous principles across various applications.

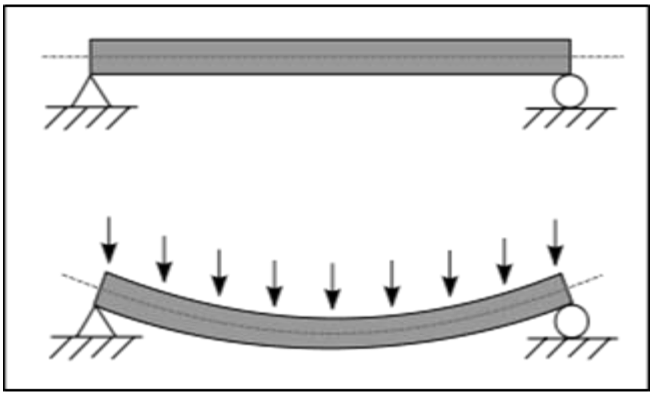

Fig.1.1 simply supported beam, bending under a uniformly distributed load

1.2 Classification of Beams Based on Support

Simply Supported Beam: A beam whose both ends are supported, which have no moment resistance and rotate freely.
Fixed Beam: A beam with both ends fixed and which is restricted for rotation.
Overhanging Beam: A simple beam sticking out further than its support on one side.

Double Overhanging: A straightforward beam that sticks out on both sides past its supports.
Continuous Beam: A type of beam that stretches across two or large number of supports.
Cantilever Beam: A type of beam sticking out and attached only on one side.
Truss Beam: A type of beam made stronger with attachment in a truss with a cable.

2. CASTELLATED BEAMS

A beam with perforations is a specialized beam type which is created through longitudinally slicing an I-beam along its web in a specific pattern. The objective is to increase the depth of the beam by rearranging its sections without significantly increasing its weight. These beams are sorted into categories according to the shapes of the holes in the web section, like hexagonal, circular (cellular openings), octagonal, or diamond shapes.

2.1 HISTORY OF CASTELLATED BEAMS

The name "castellated" is derived from the Latin word "castellatus," meaning "built like a castle with regular openings in walls." Castellated beams were initially designed as a structural solution to improve beam depth and strength without adding excessive material or weight. Engineers, facing steel shortages after World War II, discovered that castellated beams were cost-effective and offered an excellent strength-to-weight ratio. Consequently, castellated beams became a preferred construction solution from the 1950s onwards, particularly in Europe, where labor costs were relatively low compared to material costs.

2.2 PROPERTIES OF CASTELLATED BEAMS

Highly Efficient Steel: Castellated beams allow for increased beam depth without a significant increase in weight, resulting in enhanced load-bearing capacity. They can achieve 40% more moment-carrying capacity without additional steel.
Extended Beam Length: Castellated beams can be manufactured in lengths up to 28 meters, making them ideal for wide-span and open-bay designs.
Asymmetric Design: The unique split fabrication of castellated beams reduces the weight of the top half of the beam, enhancing load-carrying capacity while minimizing overall weight.

2.3 APPLICATIONS OF CASTELLATED BEAMS

Originally used extensively in parking garages due to their long-span capabilities, castellated beams are now employed in a wide range of floor and roof structures across various construction projects.
These specialized beams continue to offer significant advantages in terms of structural efficiency, load-bearing capacity, and cost-effectiveness in modern construction applications.

3. REVIEW OF LITERATURE

M. Kowsalya (2020), "Study on Castellated Web Beam with Optimized Web Opening"

Author found that castellated beams hold up better than regular I-beams when it comes to bending and being strong enough. But, when the holes in them get too deep, they start to weaken because the stress gets concentrated around those holes. In industries, people usually like to use hexagonal or circular holes in these beams because they're easier to make. For the best strength, they suggest using diamond-shaped beams with holes that are about two-thirds the total depth of the beam.

Wakchaure and Sagade (2017), "Parametric study of castellated beam with varying depth of web opening"

This research looks into how I-shaped beams, which have been changed with hexagonal holes, bend under pressure. They tried out various sizes and distances between these holes. They used a computer program called ANSYS14 to analyze how the beams reacted when they were pushed down from two points, with support at both ends. They measured how much the beam bent in the middle and looked at different ways it might fail. What they found was that these modified steel beams work fine for regular use, especially when the holes in the web are not more than 60% of the total depth of the beam.

Erdal and Saka (2015), "Ultimate load carrying capacity of optimally designed steel cellular beams"

Author examined how the load-carrying capacity of an optimally constructed castellated beam is affected by varying the number of holes and their spacing. Using Finite Element Analysis with a central point load, we analyzed the beam using ANSYS to identify potential failure patterns. Despite the shorter lengths of the members, the testing with lateral supports of beam were obtained. The findings revealed that the beam fails in a vierendeel mode when the load is applied on the upper part of openings, but the post web remains unaffected when loads are applied between the opening spaces.

Mr. Dhanraj K. Shendge (2015), "Castellated Beam Optimization By Using Finite Element Analysis: A Review"

The author shares a detailed report about a method and computer program designed to improve the structure and dimensions of castellated beams through computer analysis. They're particularly interested in how well these beams hold up under pressure, especially when they're simply supported and at risk of the web posts buckling. They use a technique called finite element analysis (FEA) to check this, tweaking different factors to see how they affect the beams' ability to bear loads. They find that beams with curved corner openings can carry more weight than those with hexagonal or rectangular ones of the same height, though they're still not as strong as beams with circular openings.

Miss. Pooja P. Rugge (2017), "Review on Study of Castellated Beam with & without Stiffeners"

The study talks about looking into how strong castellated beams are against shear buckling, how they resist lateral-torsional buckling, how their vierendeel mechanisms work, and how they flex under weak axial pressure. They also compare different kinds of openings like circular versus hexagonal or diamond versus circular. However, after reviewing everything, they found that there aren't enough studies on castellated beams, especially ones with and without stiffeners, using both experiments and analysis.

Peijun Wang, Kangrui Guo, et.al.(2016), "Shear buckling strength of web-posts in a castellated steel beam with hexagonal web openings"

The author used a computer simulation method called the finite element method to look into how the web-posts in castellated steel beams react when they're pushed down from the top, especially when they have hexagonal holes in them. This paper explains how they used this method to analyze castellated beams with hexagonal holes in their webs. It also talks about comparing how these beams bend and deform under pressure, comparing circular and hexagonal openings to make it easier to understand.

3.1 SUMMARY OF LITERATURE REVIEW

Title	Authors	Year	Conclusion
Study on Castellated Web Beam with Optimized Web Opening	M. Kowsalya	2020	Investigated the performance of castellated beams, highlighting their advantages over I-beams and optimal web opening sizes for strength.
Parametric study of castellated beam with varying depth of web opening	Wakchaure and Sagade	2017	Analysed the flexural response of castellated beams featuring hexagonal apertures using finite element software, indicating good performance up to certain web opening depths.
Ultimate load carrying capacity of optimally designed steel cellular beams	Erdal and Saka	2015	Examined the weight-bearing ability of well-planned castellated beams with different whole arrangements, revealing failure modes and performance under loads.
Castellated Beam Optimization By Using Finite Element Analysis: A Review	Mr. Dhanraj K. Shendge	2015	Presented a methodology for optimizing castellated beam design using finite element analysis, focusing on load-carrying capacity and web post buckling.
Review on Study of Castellated Beam with & without Stiffeners	Miss. Pooja P. Rugge	2017	Conducted a review of castellated beam studies, identifying gaps in research on stiffeners and various opening types, such as circular versus hexagonal and diamond versus circular.
Shear buckling strength of web-posts in a castellated steel beam with hexagonal web openings	Peijun Wang, Kangrui Guo, et.al.	2016	Investigated the resistance to shear buckling in castellated beams with hexagonal web apertures, comparing load-deflection curves and buckling deformations.

4. METHODOLOGY

Selection of shape

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Selection of I section Member

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Design consideration

↓

Material creation in ANSYS

↓

Create Testing assembly in ANSYS

↓

Analysis of Deformation in ANSYS for Portal Frame

↓

Result

1. Selection of Perforation Shapes

Castellated beams are being fabricated using various perforation shapes, such as Hexagonal and Circular, chosen for their ease of fabrication. This project focuses specifically on creating castellated beams with and without stiffeners using these selected shapes.

2. Selection of I-Section Member

Initially, an Indian Standard Medium Weight Beam (150) was utilized and modified by cutting it in a zig-zag pattern for Hexagonal perforations and a semi-circular pattern for Circular perforations. The beam was then split into two parts and rejoined to form the desired Hexagonal and Circular castellated beam shapes. Subsequently, the project transitioned to using an Indian Standard Medium Weight Beam (200) for fabricating these beams and transforming them into a Portal Frame Structure.

3. Design Considerations

Portal Frame design was adopted for the Hexagonal and Circular Castellated Beams to minimize bending moments resulting from external loading. Converting the castellated beams into Portal Frame Structures enhances load-carrying capacity and structural efficiency without the need for additional material or weight.

4. Material Creation in ANSYS

For structural testing in ANSYS, the material created and utilized is Structural Steel (S275), characterized by its low carbon content, ductility, ease of shaping, and good weldability. The S275 grade of structural steel offers specific mechanical properties suitable for welding and construction purposes.

5. Testing Assembly Creation in ANSYS

An assembly for testing purposes is created in ANSYS, ensuring geometry cleanliness and correction of any model imperfections. This testing assembly is prepared to undergo analysis under various loading conditions.

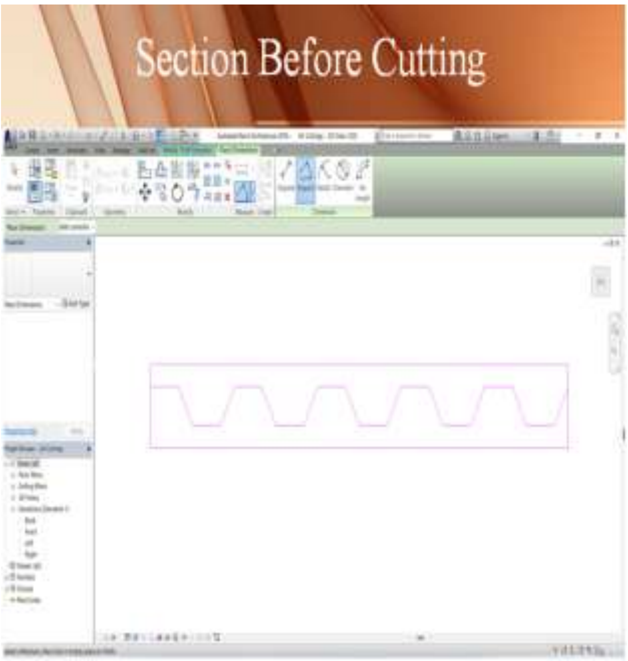
6. Deformation Analysis in ANSYS for Portal Frame

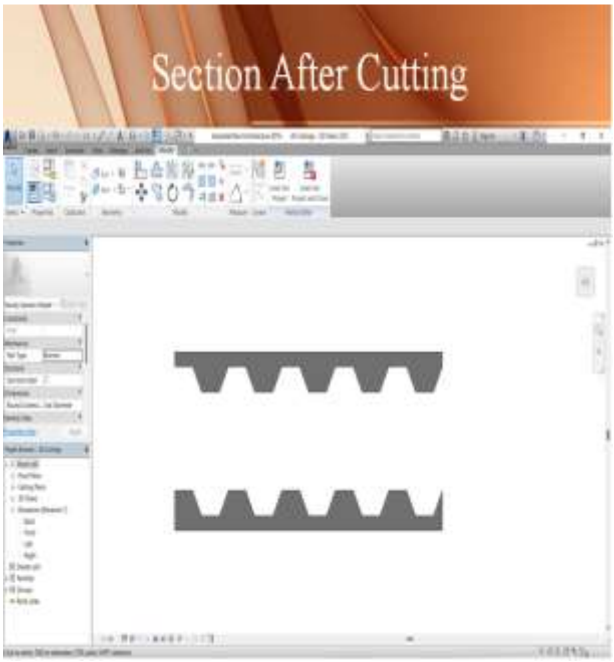
After importing the Portal Frame Structure from REVIT to ANSYS, fixed supports are added at both ends of the beam. The structure is subjected to different loading conditions to analyze deformation characteristics, including loading in X, Y, and Z directions, evaluation of equivalent stress, maximum principal stress, and total deformation, all with respect to the specified Structural Steel (S275) material properties.

This project aims to demonstrate the performance and behavior of Hexagonal and Circular Castellated Beams when converted into Portal Frame Structures under distributed loading scenarios using ANSYS software for comprehensive analysis and validation.

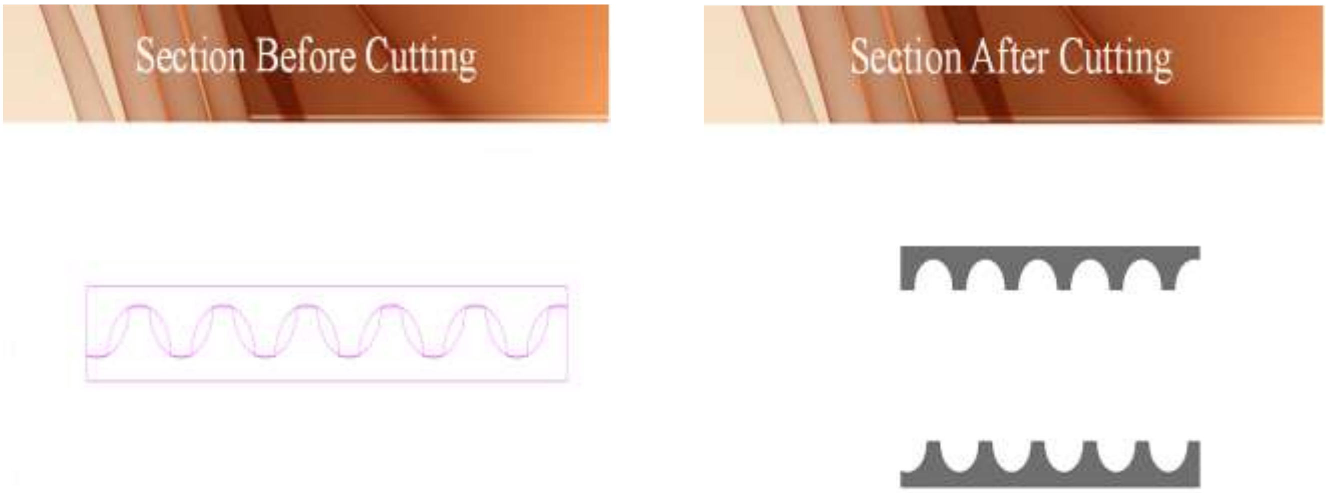
5. CASTELLATED BEAM SECTIONS

HEXAGONAL CASTELLATED BEAM



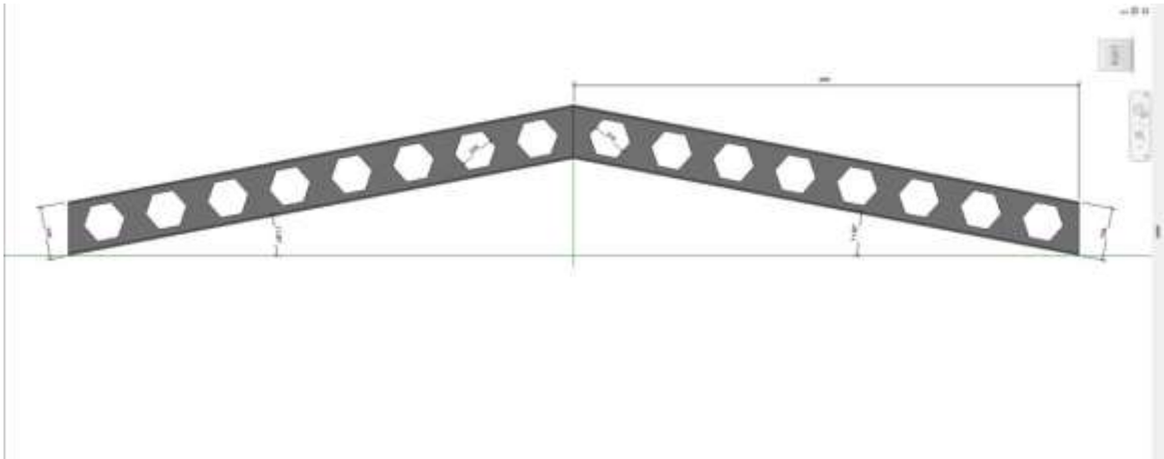


CIRCULAR CASTELLATED BEAM



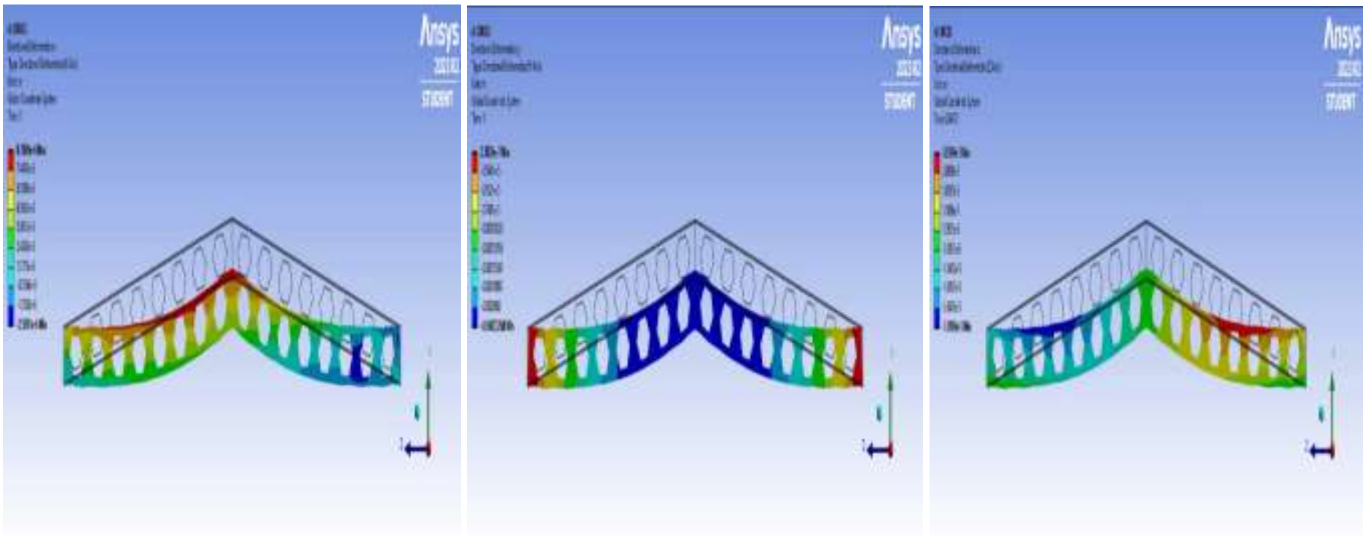
6. RESULTS AND CONCLUSION

6.1 HEXAGONAL CASTELLATED BEAM AS PORTAL FRAME WITHOUT STIFFNER

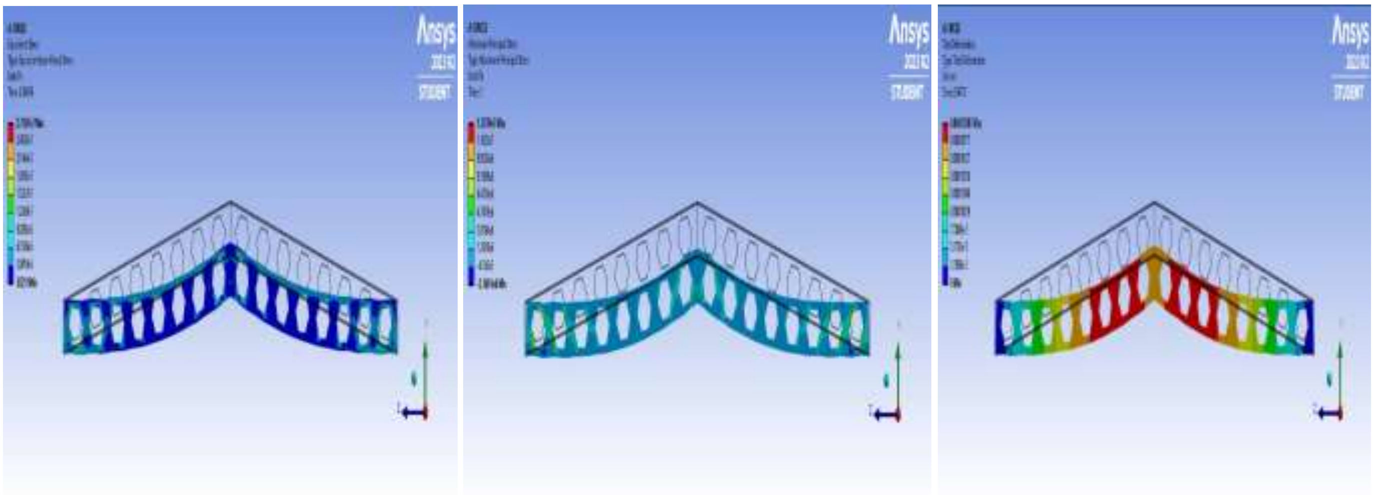


Original Beam Length = 6000 MM
New Beam Length = 5774 MM
Original Beam Depth = 200 MM
New Beam Depth = 304 MM
As we can observe, the beam depth has raised by 1.52 times its original depth without needing any additional material.

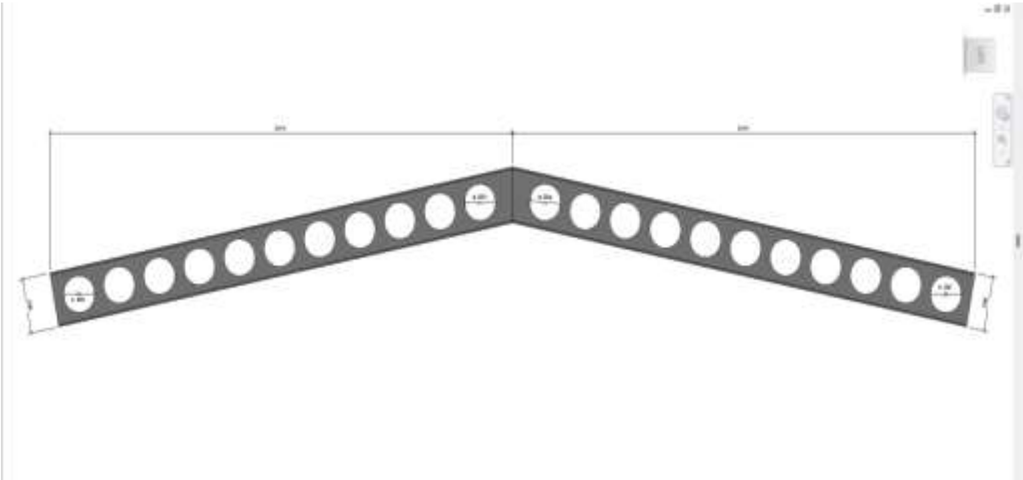
DEFORMATION IN X, Y & Z DIRECTION



EQUIVALENT STRESS, MAX. PRINCIPAL STRESS & TOTAL DEFORMATION

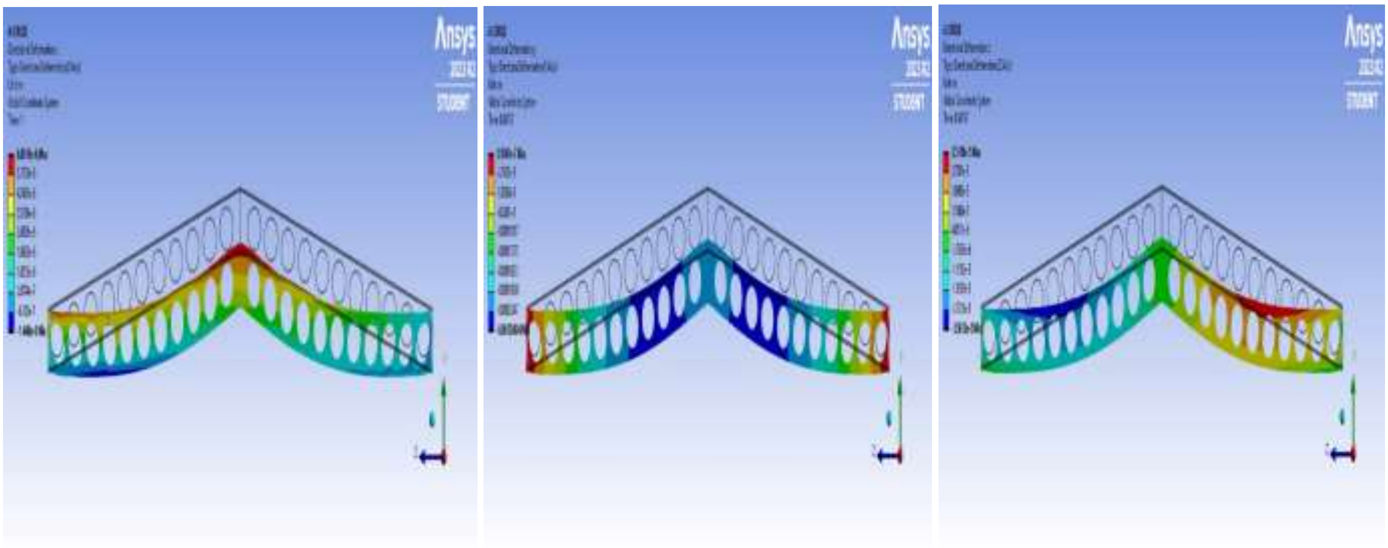


6.2 CIRCULAR CASTELLATED BEAM AS PORTAL FRAME WITHOUT STIFFNER

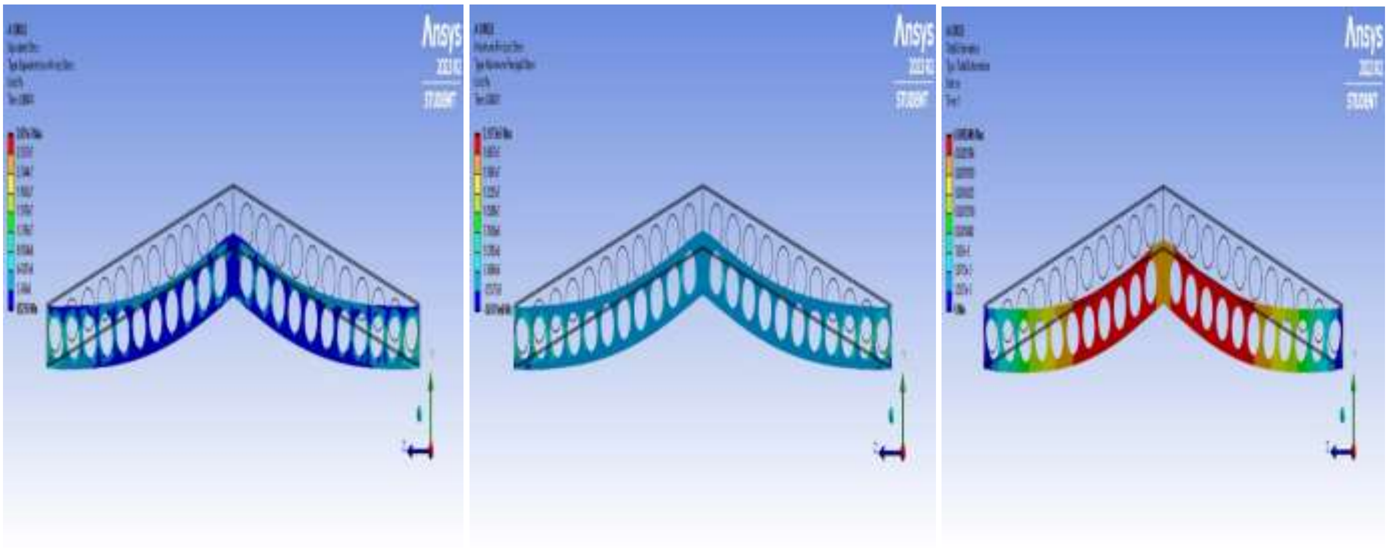


Original Beam Length = 6000 MM
New Beam Length = 5890 MM
Original Beam Depth = 200 MM
New Beam Depth = 296 MM
As we can observe, the beam depth has raised by 1.48 times its original depth without needing any additional material.

DEFORMATION IN X, Y & Z DIRECTION



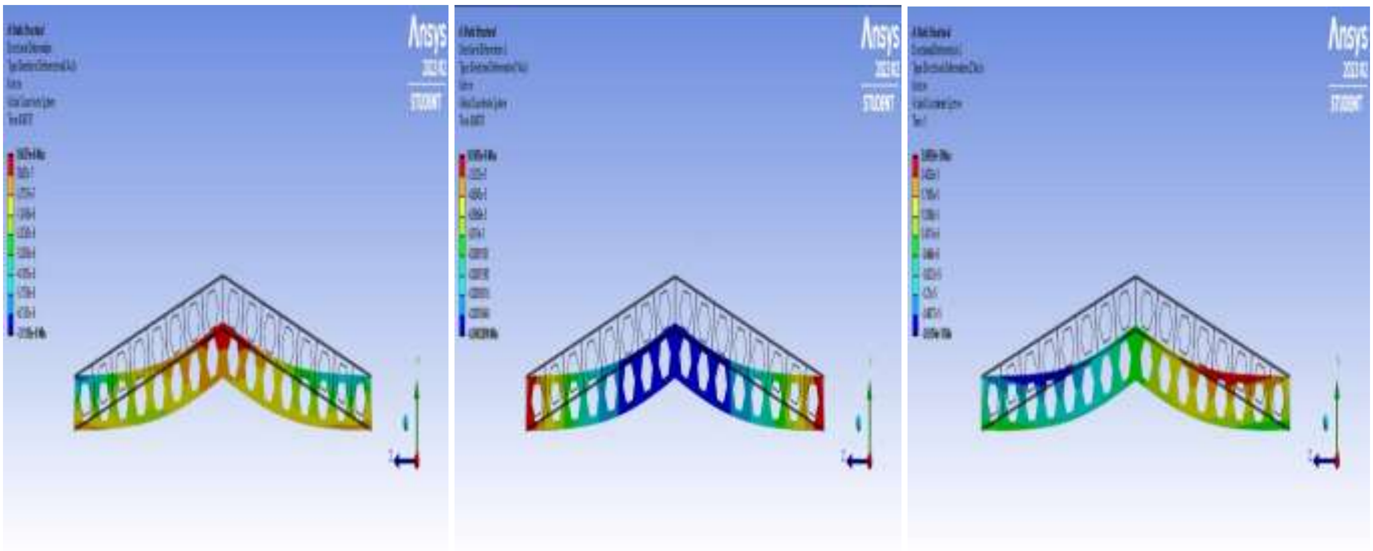
EQUIVALENT STRESS, MAX. PRINCIPAL STRESS & TOTAL DEFORMATION



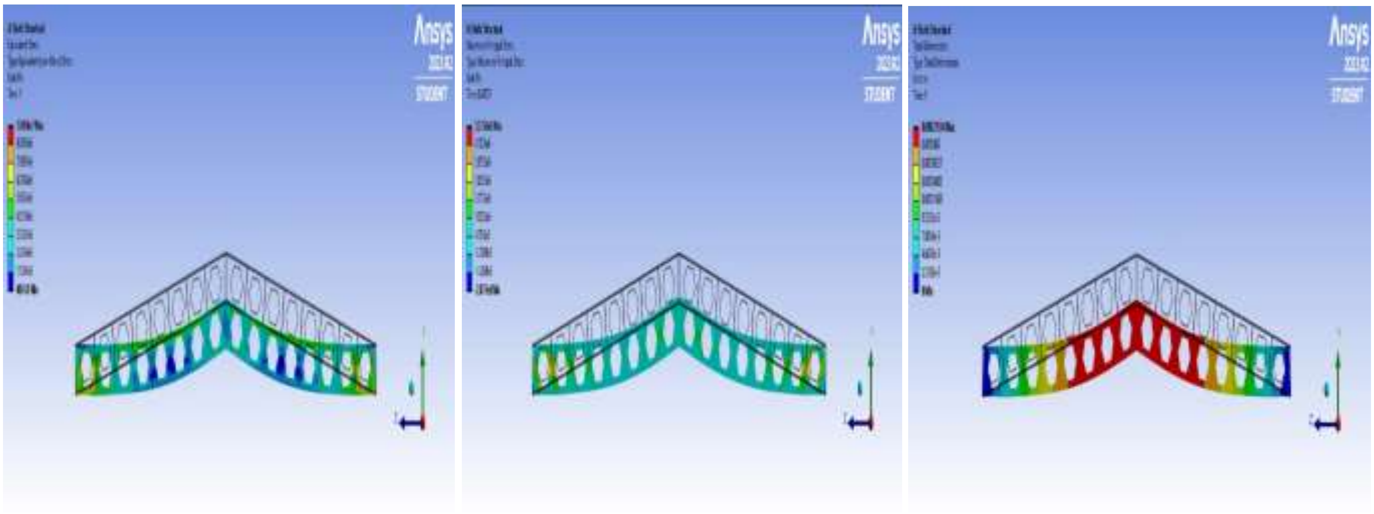
6.3 HEXAGONAL CASTELLATED BEAM WITH STIFFENERS AS PORTAL FRAME

Type of Stiffener: - Transverse Stiffener
Stiffener Specifications: Width - 100 MM
Thickness - 5 MM
Depth– 282 MM

DEFORMATION IN X, Y & Z DIRECTION



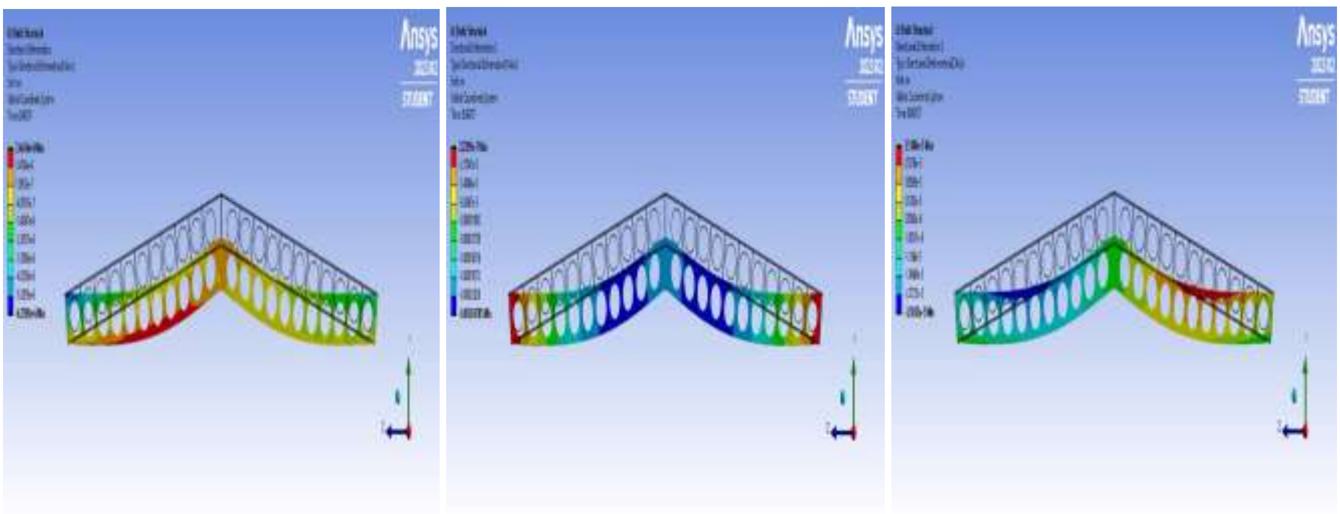
EQUIVALENT STRESS, MAX. PRINCIPAL STRESS & TOTAL DEFORMATION



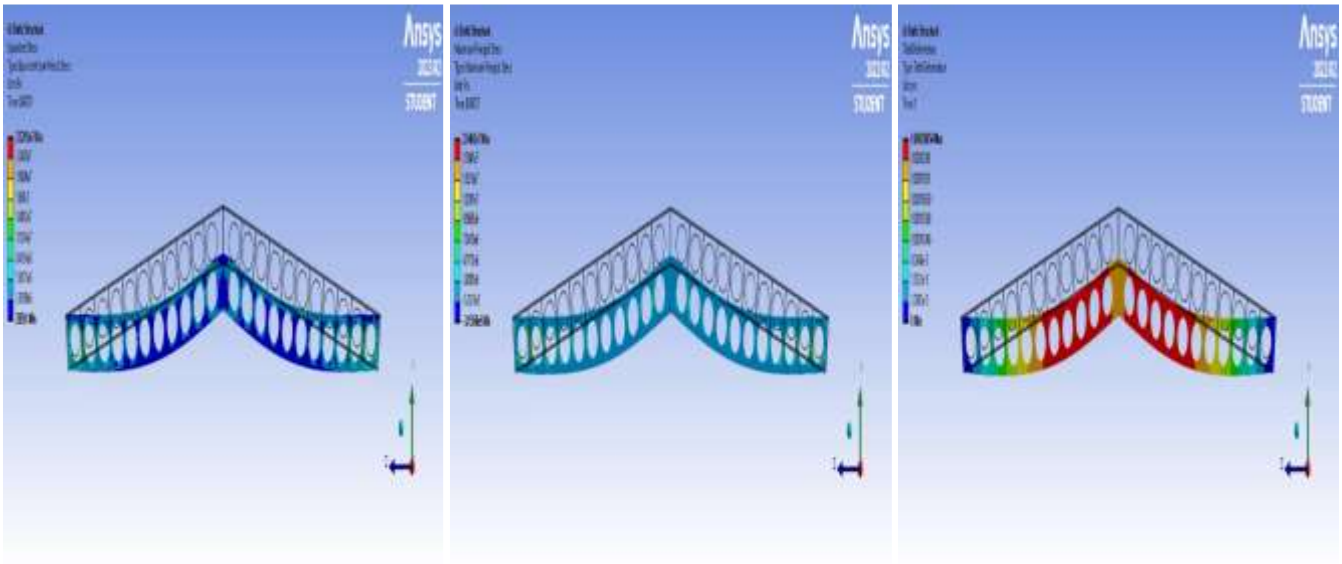
6.4 CIRCULAR CASTELLATED BEAM WITH STIFFENERS AS PORTAL FRAME

Type of Stiffener: - Transverse Stiffener
Stiffener Specifications: Width - 100 MM
Thickness - 5 MM
Depth– 282 MM

DEFORMATION IN X, Y & Z DIRECTION



EQUIVALENT STRESS, MAX. PRINCIPAL STRESS & TOTAL DEFORMATION



HEXAGONAL CASTELLATED BEAM AS A PORTAL FRAME

AVERAGE DIFFERENCE OF DEFORMATION IN X, Y & Z DIRECTION

LOAD	AVERAGE DEFORMATION					
	WITHOUT STIFFENER			WITH STIFFENER		
	X	Y	Z	X	Y	Z
7KN/M	3.3486e-006	-1.6227e-004	-3.1235e-007	-1.0183e-006	-1.5435e-004	-1.5684e-007

% REDUCTION IN DEFORMATION		
WITH STIFFENER		
X (%)	Y (%)	Z (%)
130.40	5.00	49.78

DISCUSSION:

X Direction: There is an overall decrease in average deformation with stiffeners compared to without stiffeners. The percentage reduction in average deformation is 130.40 %. This indicates that the presence of stiffeners tends to reduce the deformation in the X direction.

Y Direction: There is also an overall decrease in average deformation with stiffeners compared to without stiffeners. The percentage reduction in average deformation is 5.00 %. This suggests that the presence of stiffeners tends to reduce the deformation in the Y direction.

Z Direction: There is also an overall decrease in average deformation with stiffeners compared to without stiffeners. The percentage reduction in average deformation is 49.78 %. This suggests that the presence of stiffeners tends to reduce the deformation in the Z direction.

Overall discussion states that the presence of stiffeners has a notable effect on reducing deformation in the X, Y and Z direction.

AVERAGE EQUIVALENT STRESS, MAXIMUM PRINCIPAL STRESS & TOTAL DEFORMATION

LOAD	AVERAGE STRESSES AND DEFORMATION					
	WITHOUT STIFFENER			WITH STIFFENER		
	Avg. Equivalent Stress	Max. Principal Stress	Total Deformation	Avg. Equivalent Stress	Max. Principal Stress	Total Deformation
7KN/M	3.7961e+006	6.8309e+005	1.6371e-004	1.9451e+006	3.1892e+005	1.5544e-004

% REDUCTION IN STRESS & DEFORMATION		
WITH STIFFENER		
Avg. Equivalent Stress (%)	Max. Principal Stress (%)	Total Deformation (%)
48.76	53.31	5.05

CONCLUSION:

Based on the calculations of percentage reduction in stress and deformation across the parameters (Average Equivalent Stress, Max. Principal Stress and Total Deformation) for Hexagonal Castellated Beam, we can draw the following conclusions:

- **Average Equivalent Stress:**
  The average equivalent stress is lower with the stiffener compared to without the stiffener. The percentage reduction in average equivalent stress is 48.76 %. This indicates that the presence of the stiffener helps in reducing the average equivalent stress experienced in the structure.
- **Max. Principal Stress:**
  Similar to the average equivalent stress, the maximum principal stress is also lower with the stiffener than without the stiffener. The percentage reduction in maximum principal stress is 53.31 %. This suggests that the stiffener effectively decreases the maximum stress levels experienced in the structure.
- **Total Deformation:**
  The total deformation after using the stiffener is lower compared to castellated beam without stiffener. The percentage reduction in total deformation is 5.05 %. This implies that the stiffener contributes to reducing the overall deformation, indicating enhanced structural stability.

CIRCULAR CASTELLATED BEAM AS A PORTAL FRAME

AVERAGE DIFFERENCE OF DEFORMATION IN X, Y & Z DIRECTION

LOAD	AVERAGE DEFORMATION					
	WITHOUT STIFFENER			WITH STIFFENER		
	X	Y	Z	X	Y	Z
7KN/M	2.1642e-006	-1.7953e-004	-3.4436e-007	-2.6813e-007	-1.7692e-004	1.7321e-007

% REDUCTION IN DEFORMATION		
WITH STIFFENER		
X (%)	Y (%)	Z (%)
112.38	2.00	150.30

DISCUSSION:

X Direction: There is an overall decrease in average deformation with stiffeners compared to without stiffeners. The percentage reduction in average deformation is 112.38 %. This indicates that the presence of stiffeners tends to reduce the deformation in the X direction.

Y Direction: There is also an overall decrease in average deformation with stiffeners compared to without stiffeners. The percentage reduction in average deformation is 2.00 %. This suggests that the presence of stiffeners tends to reduce the deformation in the Y direction.

Z Direction: There is also an overall decrease in average deformation with stiffeners compared to without stiffeners. The percentage reduction in average deformation is 150.30 %. This suggests that the presence of stiffeners tends to reduce the deformation in the Z direction.

Overall discussion states that the presence of stiffeners has a notable effect on reducing deformation in the X, Y and Z direction.

AVERAGE EQUIVALENT STRESS, MAXIMUM PRINCIPAL STRESS & TOTAL DEFORMATION

LOAD	AVERAGE STRESSES AND DEFORMATION					
	WITHOUT STIFFENER			WITH STIFFENER		
	Avg. Equivalent Stress	Max. Principal Stress	Total Deformation	Avg. Equivalent Stress	Max. Principal Stress	Total Deformation
7KN/M	4.8294e+006	1.3277e+006	1.8078e-004	4.2564e+006	1.139e+006	1.7817e-004

% REDUCTION IN DEFORMATION WITH STIFFENER		
Avg. Equivalent Stress (%)	**Max. Principal Stress (%)**	**Total Deformation (%)**
11.86	14.21	2.00

CONCLUSION:

Based on the calculations of percentage reduction in stress and deformation across the parameters (Average Equivalent Stress, Max. Principal Stress and Total Deformation) for Circular Castellated Beam, we can draw the following conclusions:

•**Average Equivalent Stress:**

The average equivalent stress is lower with the stiffener compared to without the stiffener. The percentage reduction in average equivalent stress is 11.86 %. This indicates that the presence of the stiffener helps in reducing the average equivalent stress experienced in the structure.

• **Max. Principal Stress:**

Similar to the average equivalent stress, the maximum principal stress is also lower with the stiffener than without the stiffener. The percentage reduction in maximum principal stress is 14.21 %. This suggests that the stiffener effectively decreases the maximum stress levels experienced in the structure.

•**Total Deformation:**

The total deformation after using the stiffener is lower compared to castellated beam without stiffener. The percentage reduction in total deformation is 2.00 %. This implies that the stiffener contributes to reducing the overall deformation, indicating enhanced structural stability.

7. OVERALL CONCLUSION:

- After analyzing the calculations, it is determined that a Hexagonal Castellated Beam with stiffeners outperforms one without stiffeners in terms of effectiveness.
- Similarly, the calculations indicate that a Circular Castellated Beam with stiffeners demonstrates greater effectiveness than a Circular Castellated Beam without stiffeners.
- Using transverse stiffeners has proven to improve the load-bearing capacity and stability of Hexagonal Castellated Beams when compared to Circular Castellated Beams with stiffeners.
- In terms of stress and deformation characteristics, the Hexagonal Castellated Beam with stiffeners exhibits lower equivalent stress, maximum principal stress, and total deformation compared to the Circular Castellated Beam with stiffeners.
- Consequently, employing Castellated Beams with Hexagonal perforations in structures is deemed more efficient based on the findings of this study.

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