International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 06 | Jun 2024 www.irjet.net p-ISSN: 2395-0072

# COMPARATIVE STUDY OF PERFORMANCE OF TRAPEZOIDAL AND RECTANGULAR CORRUGATION IN NON-PRISMATIC STEEL I-BEAMS WITH OPENINGS

**Farhana C A[1], Lakshmy E G[2*],Dr. George K George[3]**

*[1]Post Graduate Student, Dept. of Civil Engineering, KMEA Engineering College, Edathala Ernakulam, Kerala.*
*[2*]Assistant Professor, Dept. of Civil Engineering, KMEA Engineering College, Edathala Ernakulam, Kerala.*
*[3]Assistant Professor, Dept. of Civil Engineering, KMEA Engineering College, Edathala Ernakulam, Kerala.*

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***Abstract*** - *The incorporation of web openings in steel beams reduces weight and enhances design flexibility, but can impact stiffness and strength. This study examines the structural performance of non-prismatic corrugated steel I beams with web openings, focusing on various corrugation profiles (trapezoidal and rectangular) and web heights. Through ANSYS Design Modeler software, a detailed comparative analysis of load-deflection performance identifies the most economical corrugation shape. The findings aim to develop efficient and reliable design guidelines, ensuring the safe and cost-effective use of steel beams with web openings in structural applications, including buildings and industrial facilities*.

***Key Words***: Non-Prismatic Corrugated Steel I-Beams, Trapezoidal Corrugation, Rectangular Corrugation, Web Openings, Finite Element, ANSYS

## 1. INTRODUCTION

In the realm of structural engineering, the utilization of rectangular corrugated steel I beams has garnered significant attention for its potential to balance structural efficiency and economic considerations. The integration of web openings in steel beams has emerged as a key innovation in structural engineering, offering the potential to enhance design flexibility and reduce overall weight by accommodating services and utilities within the structural elements. web openings introduces complexities that can significantly affect the stiffness and strength of steel beams, raising concerns about structural performance.

While web openings offer economic benefits and additional structural support, they also pose a potential threat to the load-carrying capacity of beams. Design engineers often incorporate openings in plate elements to facilitate access for ducts, cables, repairs, and maintenance services. In commercial buildings, circular web openings are introduced to simplify the installation of water pipes. However, the introduction of these openings in the web region alters the stress distribution, thereby reducing the shear resistance of the web plate. Use of corrugated webs to provide enhanced shear stability and eliminate the need for transverse stiffeners.

### 1.1 Corrugated Steel I-Beams with Circular Openings:

Trapezoidal corrugated steel I beams with circular openings represent an innovative and structurally efficient design in the realm of construction and engineering. These beams feature a trapezoidal corrugation pattern, providing enhanced strength and load-bearing capabilities while minimizing material usage. The incorporation of circular openings further adds to the beams' versatility, allowing for weight reduction without compromising structural integrity. This design not only contributes to cost-effectiveness but also facilitates efficient installation processes. The trapezoidal corrugations increase the beams resistance to bending and torsional forces, making them suitable for a variety of applications, from industrial buildings to infrastructure projects.

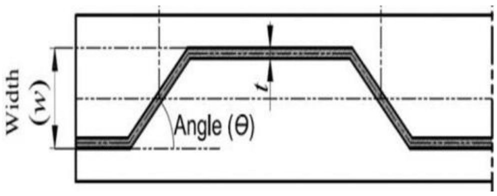



**Fig -1**: Trapezoidal Corrugated Web

Rectangular corrugated webs in steel structures represent a significant advancement in structural engineering, offering a balance between efficiency and economy. The Rectangular configuration imparts unique characteristics to the web, contributing to enhanced structural performance. Rectangular corrugated webs are more efficient than triangular and trapezoidal corrugated webs. A circular web opening enhances beam efficiency and maximizes load-carrying capacity than other shaped openings.

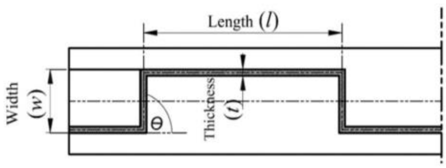



**Fig -2**: Rectangular Corrugated Web

1 Author: farhanaca1998@gmail.com 2*Corresponding Author: leg.ce@kmeacollege.ac.in

### 1.2 Prismatic and Non-Prismatic Beams

Prismatic and non-prismatic beams are fundamental components in structural engineering, each with distinctive characteristics that influence their behaviour and applications. Prismatic beams maintain a consistent cross-sectional shape along their entire length, simplifying analysis and design. These beams are particularly well suited for straightforward loading conditions and are a common choice in simpler structural applications.

On the other hand, non-prismatic beams exhibit varying cross-sectional shapes along their length. This versatility allows more customized designs to meet specific structural requirements, making them invaluable in complex engineering scenarios. Non-prismatic beams often employed in situations where the magnitude or distribution of loads changes, offering adaptability to diverse and challenging conditions.

The choice between prismatic and non-prismatic beams hinges on the complexity of the structural demands. While prismatic beams offer simplicity and ease of analysis, non-prismatic beams provide a tailored solution for intricate loadings and dynamic environments. Understanding the nuances of each type is essential for optimizing structural designs, ensuring efficiency, and meeting the diverse needs of construction projects.

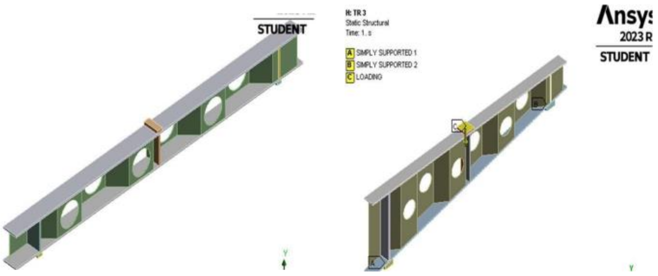



**Fig -3**: Prismatic Rectangular & Trapezoidal Corrugated Webs with Circular Openings

## 2. STUDY THE BEHAVIOUR OF NON-PRISMATIC CORRUGATED STEEL I BEAMS WITH OPENINGS USING TRAPEZOIDAL & RECTANGULAR CORRUGATIONS.

Non- Prismatic corrugated steel I beams are used for behavioral study. Different models are created and analysed in ANSYS. The different aspect ratios are considered. For this, eight models are prepared with trapezoidal and rectangular corrugation with different aspect ratio ranging from 1.25 to 3 and the results obtained are compared.

**Table -1:** Material properties

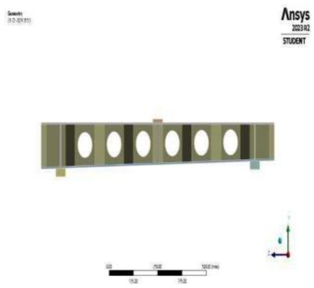
| | |
|---|---|
| Steel | Yield strength – 364 MPa |
| | Tensile ultimate strength – 491 MPa |
| | Youngs modulus E – 204 GPa |
| | Poisson's ratio, μ – 0.3 |

### 2.1 Geometry- Trapezoidal Corrugation

Solid 186 elements were used in the analysis of eight models with trapezoidal and rectangular corrugations. The steel beam specimen measured TRA-150 mm x 50 mm x 2 mm x 45 mm, with a 75 mm opening diameter and a length of 1000 mm, incorporating 25 mm x 5 mm stiffeners.

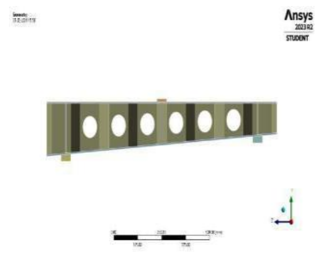
**Table -2:** Aspect Ratio

| ASPECT RATIO | TRAPEZOIDAL | RECTANGULAR |
|---|---|---|
| 1.25 | TRA 1.25 | REC 1.25 |
| 1.5 | TRA 1.5 | REC 1.5 |
| 1.75 | TRA 1.75 | REC 1.75 |
| 2 | TRA 2 | REC 2 |
| 2.25 | TRA 2.25 | REC 2.25 |
| 2.5 | TRA 2.5 | REC 2.5 |
| 2.75 | TRA 2.75 | REC 2.75 |
| 3 | TRA 3 | REC 3 |




(a)


(b)

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(d)

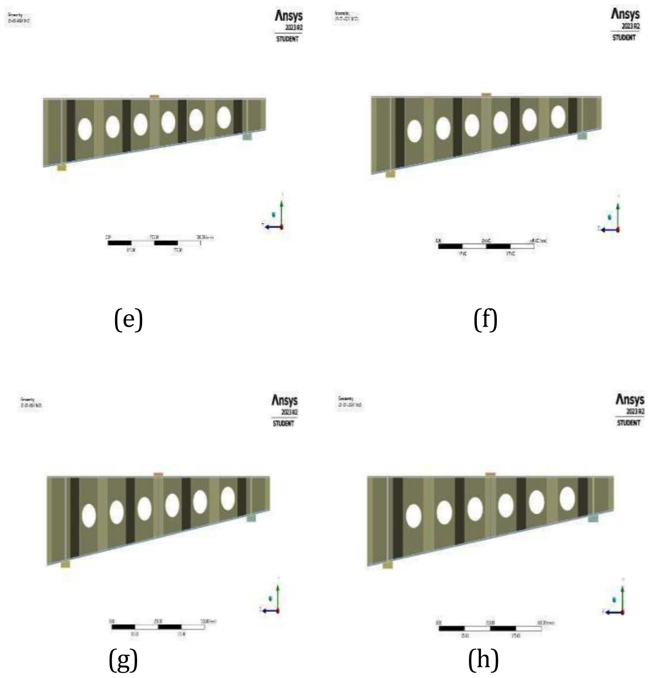


**Fig -4**: Trapezoidal corrugation with aspect ratio (a)1.25, (b)1.5, (c)1.75, (d)2, (e)2.25, (f)2.5, (g)2.75, (h)3.

The boundary conditions are both simply supported. The loading is given from the top meshing typically consumes a significant portion of the time it takes to get simulation results. Meshing is one of the key components to get FEA results. The boundary condition of all the models are same.

- Element type used- SOLID 186
- Element size– MIN 20 mm
- Element shape or meshing- HEXAHERDON

### 2.2 Results- Trapezoidal Corrugation

All the eight different models are analysed. Their resultant deformation diagrams and equivalent stress diagrams are obtained. The deformation and equivalent stress diagrams of the models are shown in Figures 5-8

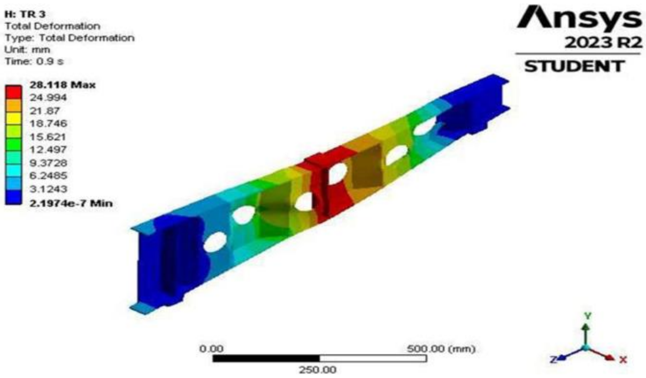


**Fig -5**: Deformation of the Beam with aspect ratio 3

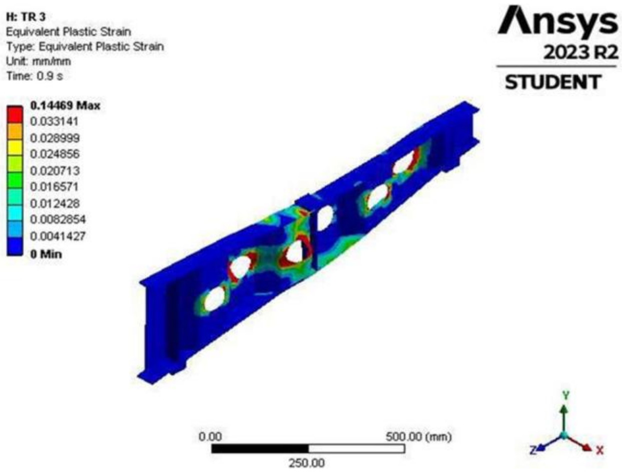


**Fig -6**: Equivalent Plastic Strain with aspect ratio 3

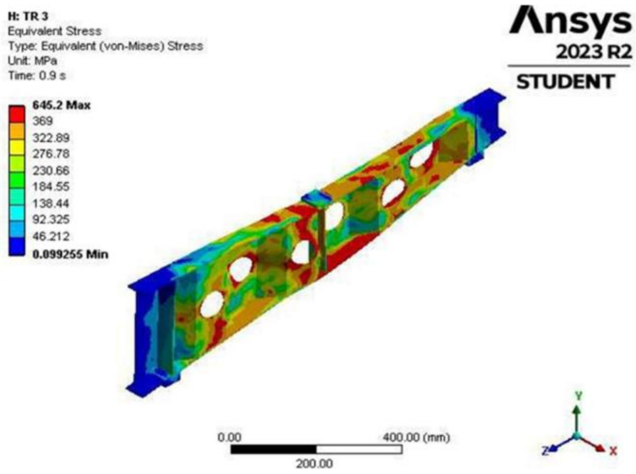


**Fig -7**: Equivalent Von-Misses Stress with aspect ratio 3

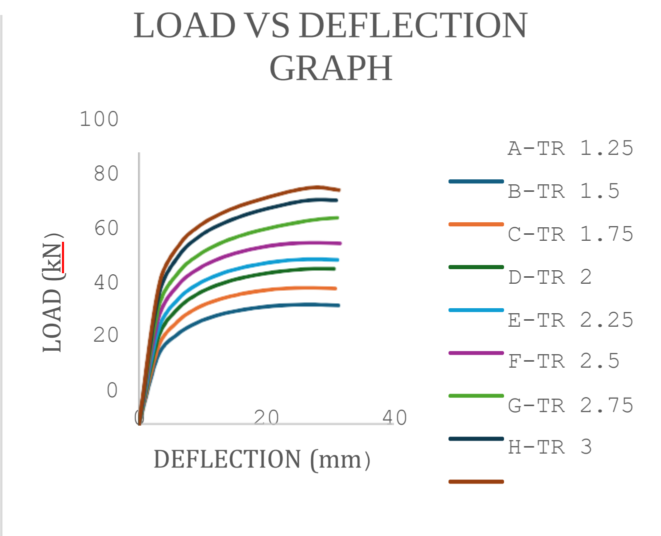


**Fig -8** : Load –Delection diagram of Trapezoidal Corrugated Web

Figure 8 depicts the load-deflection diagrams, illustrating that sections with higher aspect ratios achieve greater load carrying capacities. A symmetric waveform characterizes the load carrying capacity. Trapezoidal sections with an aspect ratio of 3 exhibit greater load carrying capacity compared to those with an aspect ratio of 1.25.

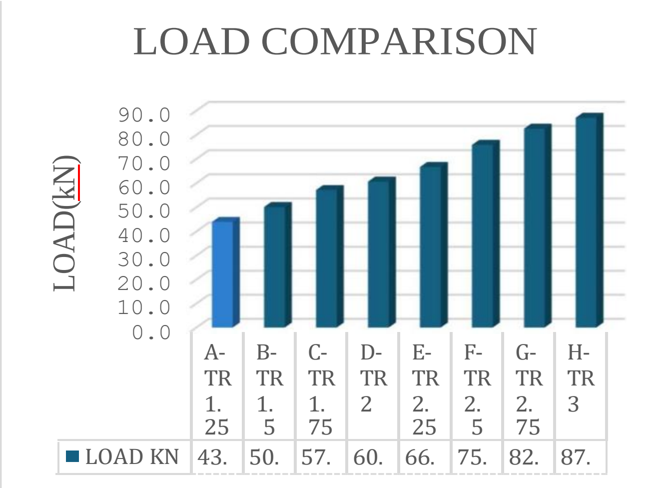


**Fig -9**: Load-comparison of Trapezoidal Corrugated Web

The trapezoidal corrugations enhance the beam's resistance to bending and torsional forces, making them suitable for diverse applications, including industrial buildings and infrastructure projects. The perimeter of trapezium is 341mm.The load carrying capacity increases with increase in aspect ratio.

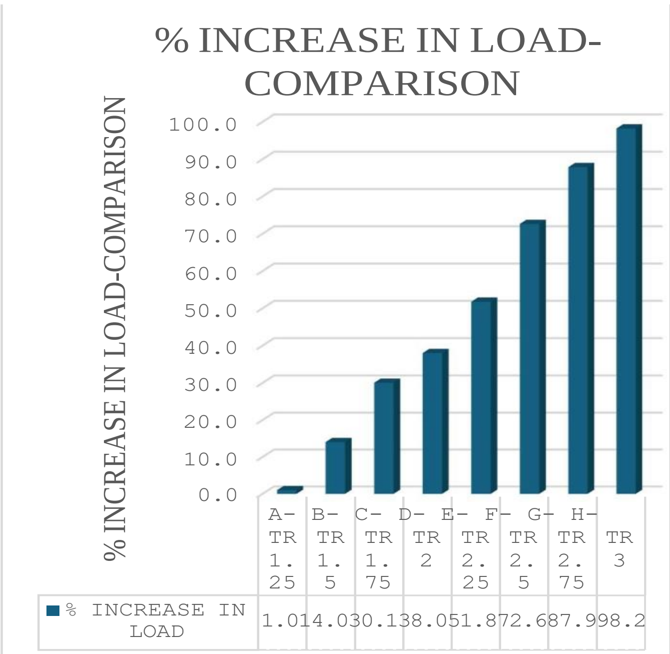


**Fig -10**: % Load-comparison of Trapezoidal corrupted web

Additionally, Figure 10 presents the percentage increase in load for eight models. Notably, the section with an aspect ratio of 3 exhibits the highest load carrying capacity, registering at 87.1kN. This represents a substantial increase of 98.2% compared to the load carrying capacity of aspect ratio 1.25.

## 2.3 Geometry- Rectangular Corrugation

Solid 186 elements is used for ANSYS analysis. The eight rectangular models are shown in figure 5.18. The steel beam specimen measured REC-150 mm x 50 mm x 2 mm x 90mm, with a 75 mm opening diameter and a length of 1000 mm, incorporating 25 mm x 5 mm stiffeners.

The boundary conditions for all models are simply supported, with loading applied from the top. Meshing, a critical component for obtaining accurate FEA results, typically consumes a significant portion of the simulation process. The boundary conditions remain consistent across all models. The analysis utilized SOLID 186 elements with a minimum size of 20 mm, and the element shape was hexahedral.

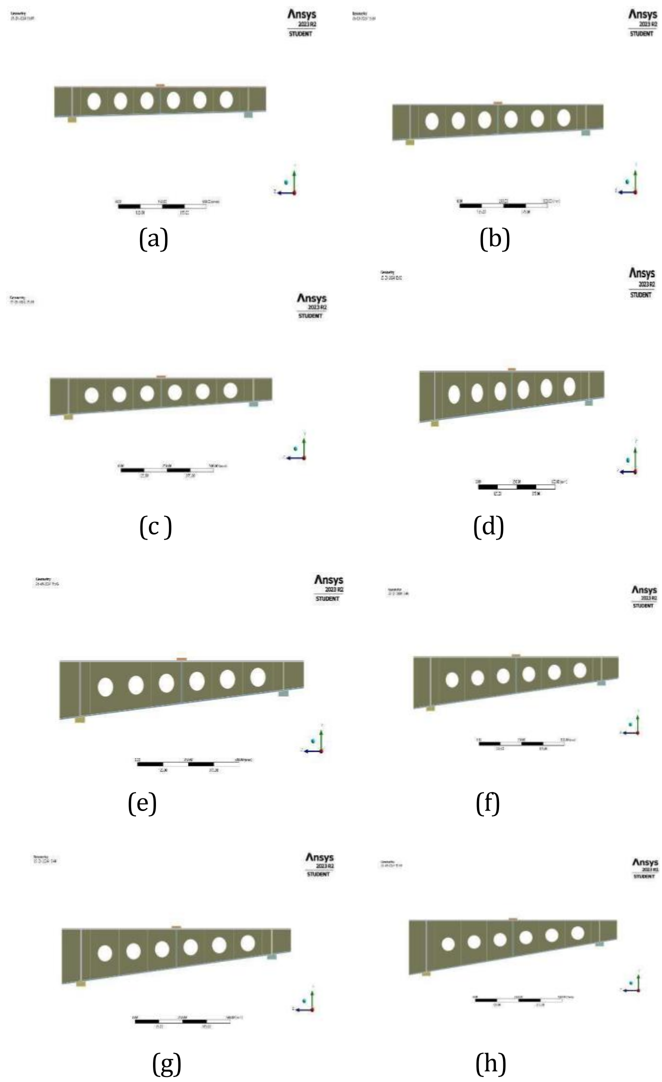


**Fig -11**: Rectangular corrugation with aspect ratio (a)1.25, (b)1.5, (c)1.75, (d)2, (e)2.25, (f)2.5, (g)2.75, (h)3.

### 2.4 Results-Rectangular Corrugation

The deformation and equivalent stress diagrams of the corrugated beams are shown in figures below;

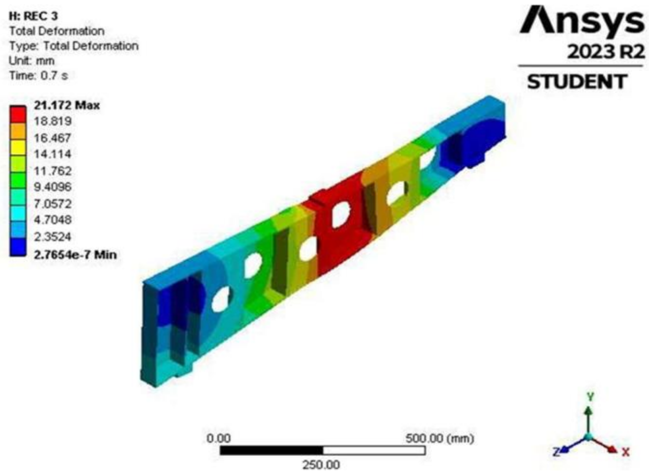


**Fig -12**: Deformation of the Beam with aspect ratio 3

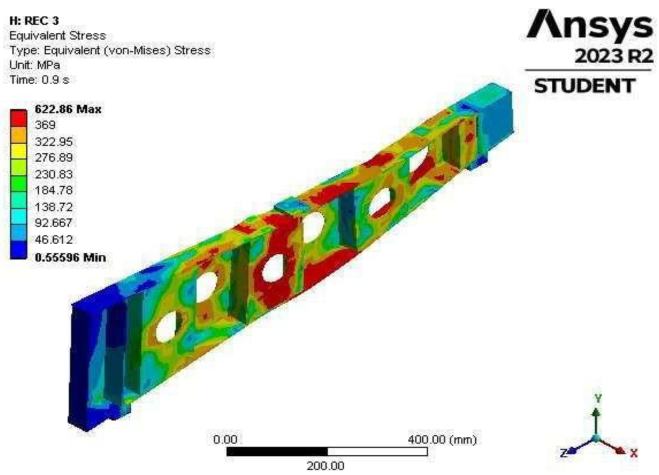


**Fig -13**: Equivalent Plastic Strain with aspect ratio 3

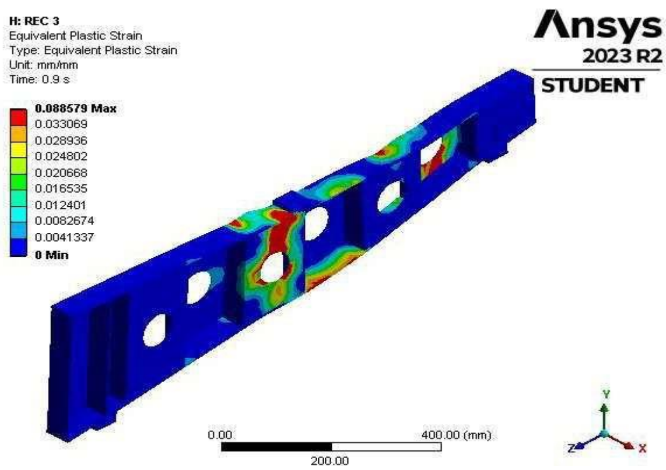


**Fig -14**: Equivalent Von-Misses Stress with aspect ratio 3

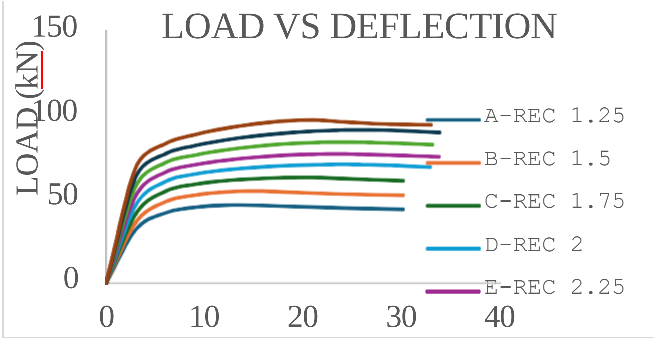


**Fig -15**: Load-Deflection graph of Rectangular Corrugated Web

The load-carrying capacity is depicted by a symmetric waveform. Figure 15 presents the load-deflection diagrams, indicating that sections with larger aspect ratios possess higher load-carrying capacities. Rectangular sections with an aspect ratio of of 3 exhibit greater load carrying capacity compared to those with an aspect ratio of 1.25.

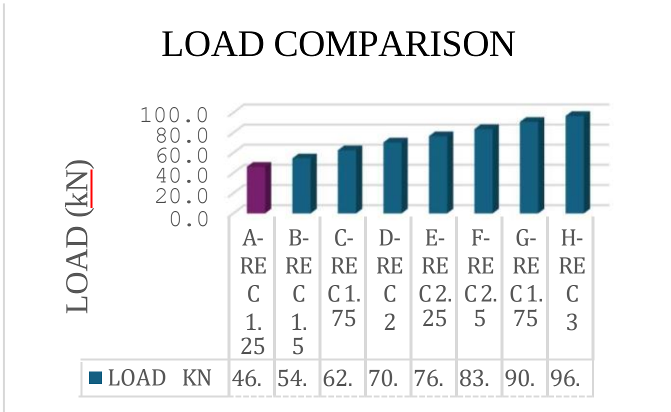


**Fig -16**: Load-comparison of Rectangular Corrugated Web

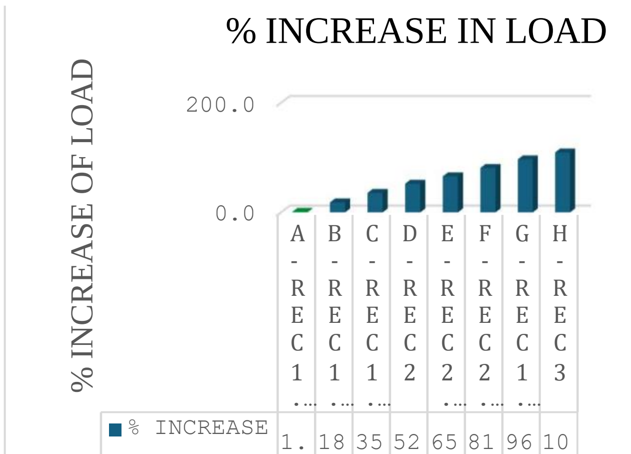


**Fig -17**: % Increase in load of Rectangular Corrugated Web

Figure 5.24 shows the load- deflection diagram. Higher load carrying capacity is obtained for section with higher aspect ratio. A symmetric wave is obtained for load deflection graph. In rectangular corrugation with aspect ratio 3 shows the higher load carrying capacity as 96.7 kN. The perimeter of rectangle is 400mm.The load carrying capacity increases with increase in aspect ratio.

### 2.5 Comparison of Results

The table below shows the comparison of trapezoidal and rectangular corrugations on Non –Prismatic Steel I-Beams with openings with different aspect ratio from the ANSYS analysis.

**Table -3:** Comparison of trapezoidal and rectangular corrugation with different aspect ratio

| MODEL | DEFLECTION (mm) | LOAD (KN) | % INCREASE IN LOAD |
|---|---|---|---|
| A-TR 1.25 | 27.6 | 43.9 | 0 |
| B-TR 1.5 | 27.5 | 50.1 | 14.0 |
| C-TR 1.75 | 27.4 | 57.1 | 30.1 |
| D-TR 2 | 27.9 | 60.6 | 38.0 |
| E-TR 2.25 | 28.3 | 66.7 | 51.8 |
| F-TR 2.5 | 31.0 | 75.8 | 72.6 |
| G-TR 2.75 | 27.7 | 82.5 | 87.9 |
| H-TR 3 | 28.1 | 87.1 | 98.2 |
| | | | |
| A-REC 1.25 | 12.1 | 46.2 | 0 |
| B-REC 1.5 | 15.1 | 54.6 | 18.3 |
| C-REC 1.75 | 21.1 | 62.6 | 35.6 |
| D-REC 2 | 24.1 | 70.4 | 52.5 |
| E-REC 2.25 | 24.4 | 76.6 | 65.8 |
| F-REC 2.5 | 24.1 | 83.7 | 81.2 |
| G-REC 1.75 | 24.7 | 90.9 | 96.8 |
| H-REC 3 | 21.2 | 96.7 | 109.5 |

Table 3 shows the deflection value, maximum load value, % increase in load value of each model of trapezoidal and rectangular corrugation on Non –Prismatic Steel I-Beams with openings with different aspect ratio from the ANSYS analysis.as the aspect ratio increases load carrying capacity also increases

## 3. CONCLUSIONS

In structural engineering, the choice of section shape significantly impacts the overall performance and efficiency of a design. This study examines the load carrying capacity and material usage of rectangular and trapezoidal corrugation in non-prismatic steel I-beam sections to determine the optimal configuration for structural applications. Key metrics, including percentage increases in load capacity and steel volume, are analyzed to draw comparisons between these two section shapes. The findings highlight critical differences in performance and material economy, providing a foundation for informed decision-making in selecting section shapes for further analysis and application.

**Load Carrying Capacity**:

- Rectangular sections exhibit an average of 10% higher load carrying capacity compared to trapezoidal sections.

**Steel Volume Increase**:

- The steel volume in rectangular sections is 17.3% greater than in trapezoidal sections.

**Material Economy**:

- Trapezoidal sections demonstrate superior performance due to more efficient material use.

**Recommendation for Analysis**:

- For further analysis, focus should be on trapezoidal sections with an aspect ratio of 3, given their advantageous material economy.

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