**International Journal of Scientific Research in Engineering & Technology**
Special Issue, Volume 4, Issue 3 (May-June 2024), PP: 01-08.
Recent Advances in Civil Engineering and Technology (REACT)-2024
www.ijsreat.com ISSN No: 2583-1240

# Tube Wall Plasticity Behaviour and Strengthening of Hollow Sectional Tubes

**M. S. Anagha[1], Anjal Santhosh[2]**
*[1]P. G. Student, Universal Engineering College, Vallivattom, Thrissur Kerala, India.*
*[2]Assistant Professor, Universal Engineering College, Vallivattom, Thrissur, Kerala, India.*

***To Cite this Article:*** *M. S. Anagha[1], Anjal Santhosh[2], "Tube Wall Plasticity Behaviour and Strengthening of Hollow Sectional Tubes", International Journal of Scientific Research in Engineering & Technology Volume 04, Issue 03, May-June 2024, PP: 01-08.*

**Abstract:** *Polygonal hollow section tubes such as dodecagonal, oval, square, and hexagonal tubes offer a number of advantages over conventional circular and rectangular tubes. They can be used for a variety of engineering and architectural applications due to its distinctive geometry, which offers various structural qualities and aesthetic appeal. Hollow sectional tubes are widely employed in a wide range of structural applications due to their high strength-to-weight ratio and structural efficiency. This study investigates the strengthening of hollow sectional tubes under tensile loading that are square, dodecagonal (twelve-sided), oval, and hexagonal (six-sided) using finite element analysis (FEA). The purpose of the study is to determine how strengthening methods impact the plastic deformation and failure processes of these tubes. Applying a load that exceeds the elastic limit of the tube wall causes plastic deformation, which permanently alters the material. Analytical analysis was done on the failure processes, load-displacement curves, and load-carrying capacities of hollow section tubes under strengthening strategy. In addition, it studies the behaviour and performance of hexagonal, oval, dodecagonal, and square-shaped hollow sectional tubes with ring and vertical stiffeners. By changing the depth of the stiffener, for instance, the effectiveness of these tubes was investigated in more detail. In order to create and improve hollow sectional tubes for a variety of structural purposes, the study's findings provide significant new knowledge that will lead to safer and more efficient building techniques.*

**Key Word:** *Tube deformation, Finite element analysis (FEA) modelling, Cold-formed section, Hollow section tubes, Tube wall plasticity, Tensile loading.*

## I.INTRODUCTION

Steel or aluminum tubes with a hollow cross-section are referred to as hollow section tubes, hollow structural sections (HSS), or structural hollow sections (SHS). Because of their advantageous strength-to-weight ratio and other mechanical qualities, they are frequently utilized in infrastructure, mechanical engineering, and construction for a range of purposes [10]. Square, rectangular, hexagonal, octagonal, and dodecagonal (12-sided) tubes are examples of common polygonal shapes. Because these tubes are hollow, they can cut weight without sacrificing structural integrity because they have an empty center void. Several strengthening methods can be used to improve the characteristics of polygonal hollow sectional tubes. The use of ring and vertical stiffeners improves the structural strength and stability of polygonal hollow section tubes, particularly under tensile loading. Regarding tubes with polygonal hollow sections such as those with dodecagonal, oval, square, or hexagonal geometries vertical stiffeners are typically positioned perpendicular to the faces or sides of the tube, and ring stiffeners are positioned around the entire tube. The main purpose of ring stiffeners is to keep the tube walls from buckling, collapsing, or deforming when they are bent or put under pressure from outside sources. By displaying ring and vertical stiffeners, this study also looks at the behaviour and performance of hollow sectional tubes that are square, dodecagonal, oval, and hexagonal under strengthening techniques. Moreover, investigate the efficacy of hollow sectional tubes by modifying stiffener properties such stiffener depth. ANSYS is a finite element analysis software package widely used for engineering simulations.

A number of investigators carried out several experimental studies and analyses on various hollow section tubes in order to ascertain the behaviour of the tube wall flexibility. Comprehensive numerical analyses of the stub column behaviour of octagonal hollow section tubes were studied by Chen et al. [1]. The Plate Slenderness Ratio was examined by Godat et al. [2] and found to be the main factor influencing the local buckling capacity of thin-walled tubular polygon columns. For local buckling capacity, columns with smaller plate slenderness ratios showed advantages. In their study, Lee et al. [3] investigated the behaviour and stiffness of t-stub connections in relation to welded connections for columns with empty hollow sections. In a study conducted by Lee et al. [4], the stiffness and behaviour of blind bolted connections for hollow section columns were evaluated. The accuracy of the finite element model was also validated by contrasting its predictions with experimental data. Under various conditions, Li et al. [5] investigated the effects of square hollow section connections and their constituent parts on failure modes, load-displacement characteristics, and load-carrying capacities. In order to compare the energy absorption capacity of simple sections to multi-cell sections, Nia et al. [6] investigated the behaviour of thin-walled constructions with various geometric sections (triangular, square, hexagonal, and octagonal) under quasi-static compression loading. The behaviour of blind bolted moment-resisting connections between SHS columns and open section beams was investigated by Tahir et al. [7]. Examined the effects of changes in end plate thickness and beam size on the stiffness and strength of the connection. The behaviour, strength, stiffness, and deformation capabilities of the blind bolted moment connections for square CFST columns were studied by Wang et al. [8]. Hang and others [9] To evaluate the performance and failure modes of Standard High-strength Bolts bolted Connections (SHBCs) and T-head Square-neck One-side Bolts bolted Connections (TSOBCs), tensile tests were conducted. Xu and associates [10] investigated the structural behaviour of octagonal hollow section tubes with blind-bolted t-stub connectors under lateral tensile loads. examined the effects of connection types, boundary conditions, and tube geometry on the strength and deformation of blind-bolted connections.

## II.ANALYTICAL STUDY

### 2.1 Modelling of hollow section tube

ANSYS software was used to study the behaviour and structural performance of several hollow sectional tubes under tensile loading. The ANSYS software's engineering data sections were utilised to assign the material attributes of the models. A 25-mm plate was selected to be the bottom plate of the stiff T-stubs. This work involved the modelling of hollow sectional tubes with 150 mm of width (B) and 1600 mm of length (L). The tube's thickness (t) is 6 mm, and the bolt diameter is 12 mm. The column's top and bottom were constrained by boundary constraints, and a 25 mm mesh size was used to finish the meshing process. The element types used in the investigation were solid 185 and beam 188 (for the bolt), and the meshing element shape was a hexahedron. By using the displacement control mode, axial tensile loading was provided.

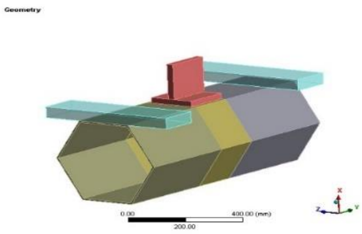

*Fig. 1. Geometry of HEX-T6-D12.*

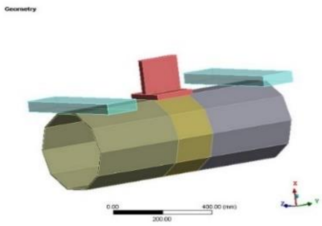

*Fig.2. Geometry of DODE-T6-D12.*

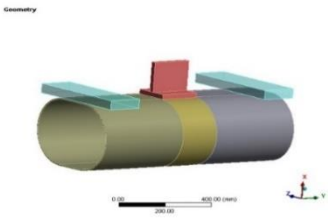

*Fig. 3. Geometry of SQ-T6-D12.*

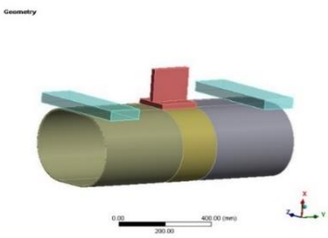

*Fig. 4. Geometry of OVAL-T6- D12.*

**Table 1**. Material Properties [10].

| Material | Yield strength(MPa) | Poisson ratio | Young's modulus (GPa) |
|---|---|---|---|
| Hollow section tube | 441.2 | 0.3 | 199.0 |
| T-stub | 387.8 | 0.3 | 214.5 |

| | | | |
|---|---|---|---|
| Bolt | 1117.4 | 0.3 | 196.6 |

### 2.2 Modelling of hollow section tube with Vertical stiffeners

In a polygonal hollow section tube, such as those with dodecagonal, oval, square, or hexagonal shapes, vertical stiffeners are typically positioned perpendicular to the faces or sides of the tube. Vertical stiffener with depth 50 mm and thickness 5 mm is provided for dodecagonal, oval, square, and hexagonal hollow section tubes. Models were analyzed to find an optimum model with higher load bearing capacity and deformation capacity. The labels of HEX-VST5DE50, DODE-VST5DE50, SQ-VST5DE50, OVAL-VST5DE50 defined a hexagonal (HEX), dodecagonal (DODE), square (SQ) and oval (OVAL) hollow section tubes with vertical stiffener of depth 50 mm (DE50) and thickness 5 mm (T5), VS represent vertical stiffener.

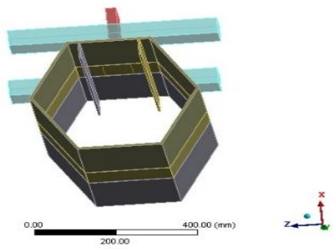

*Fig. 5. Geometry of HEX-VST5DE50.*

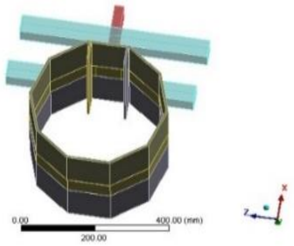

*Fig. 6. Geometry of DODE-VST5DE50.*

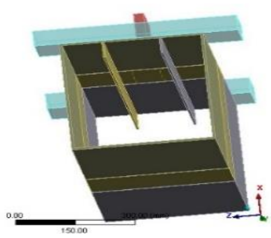

*Fig. 7. Geometry of SQ-VST5DE50.*

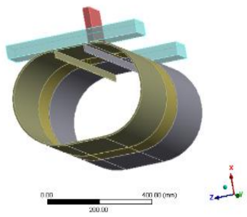

*Fig. 8. Geometry of OVAL-VST5DE50.*

### 2.3 Modelling of hollow section tube with ring stiffeners

Ring stiffeners in hollow section tubes are structural elements that are placed around the perimeter of the tube to enhance its resistance to local buckling and improve its overall stability. Ring stiffener with depth 50 mm and thickness 5 mm is provided for dodecagonal, oval, square, and hexagonal hollow section tubes. Models were analyzed to find an optimum model with higher load bearing capacity and deformation capacity. The labels of HEX-RST5DE50, DODE-RST5DE50, SQ-RST5DE50, OVAL-RST5DE50 defined a hexagonal (HEX), dodecagonal (DODE), square (SQ) and oval (OVAL) hollow section tubes connection with ring stiffener (RS), depth of stiffener 50 mm (DE50) and 5 mm thickness (T5).

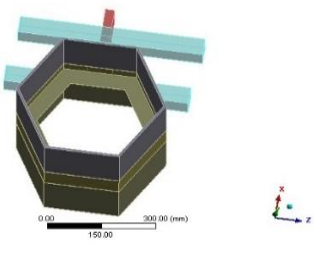

*Fig. 9. Geometry of HEX-RST5DE50.*

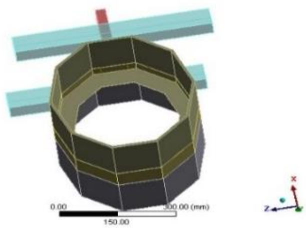

*Fig. 10. Geometry of DODE-RST5DE50.*

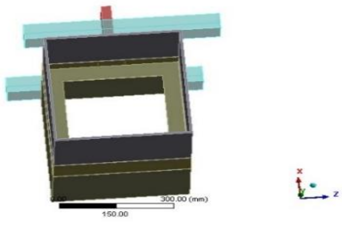

*Fig. 11. Geometry of SQ-RST5DE50.*

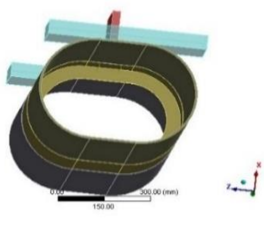

*Fig. 12. Geometry of OVAL-RST5DE50.*

### 2.4 Modelling of hollow section tube with stiffener by changing the depth

To determine which hollow section tube was better, analysis was done on square, hexagonal, dodecagonal, and oval hollow section tubes. In this phase of the project, the depth of the ring and vertical stiffener was changed into 50 mm to 25 mm. So, ring and vertical stiffener with depth 25 mm and thickness 5 mm is provided for dodecagonal, oval, square, and hexagonal hollow section tubes. The ring and vertical stiffener provided inner steel tubes. Models were analyzed to find an optimum model with higher load bearing capacity and deformation capacity. The labels of HEX-RST5DE25, DODE-RST5DE25, SQ-RST5DE25, OVAL-RST5DE25, HEX-VST5DE25, DODE-VST5DE25, SQ-VST5DE25, OVAL-VST5DE25 defined a hexagonal (HEX), dodecagonal (DODE), square (SQ) and oval (OVAL) hollow section tubes connection with ring stiffener (RS), depth of stiffener 25 mm (DE25) and 5 mm thickness (T5). The effect of variations in parameter and the better model was selected.

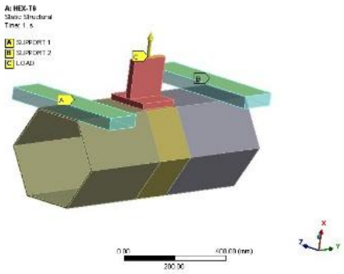

*Fig. 13. Boundary condition in specimen.*

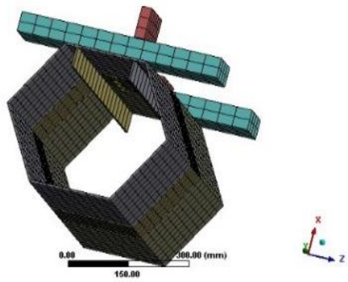

*Fig. 14. Meshing of HEX-VST5DE50.*

## III. RESULTS AND DISCUSSION

### 3.1 Effect of tensile load on the tube wall plasticity behavior of different hollow section tubes

If the tensile load applied to the hollow section tube is greater than its capacity, deformation occurs. According to these models analysed, oval hollow section tubes have greater load carrying and deformation capacities. In comparison to other hollow section tubes, this one exhibits a higher load bearing capacity, and its deformation capacity has also greatly increased. The highest load carrying capacity of a hexagonal hollow section tube is 415 kN, but in comparison to other, its deformation capacity is quite low. Dodecagonal hollow section is very weak, has low load carrying capacity and deformation capacity that is 216.7 kN and 10.9 mm.

**Table 2.** Ultimate load and deformation of different hollow section tubes.

| Models | Ultimate deflection (mm) | Ultimate load(kN) |
|---|---|---|
| HEX-T6-D12 | 25.7 | 415.0 |
| DODE-T6-D12 | 10.9 | 216.7 |
| SQ-T6-D12 | 108.9 | 305.0 |
| OVAL-T6-D12 | 148.1 | 348.7 |

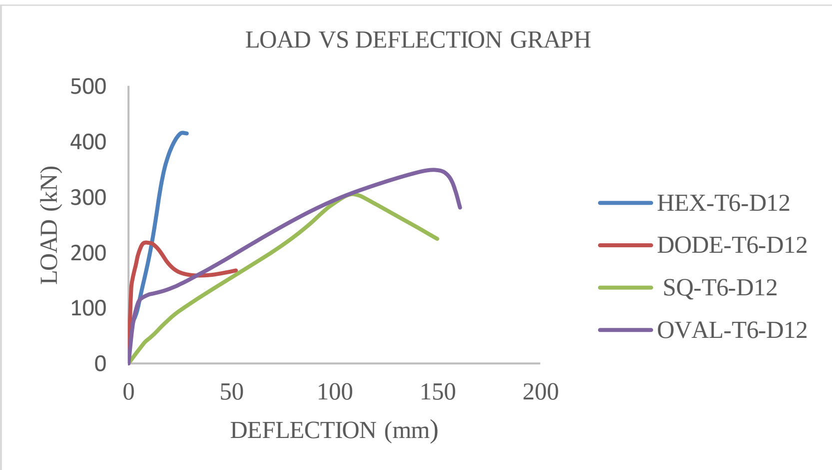


*Fig. 15. Load deformation curve of different hollow section tubes.*

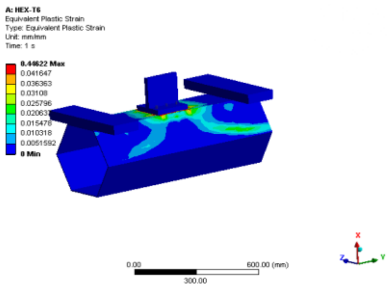

Fig. 16. Plastic strain of HEX-T6-D12.

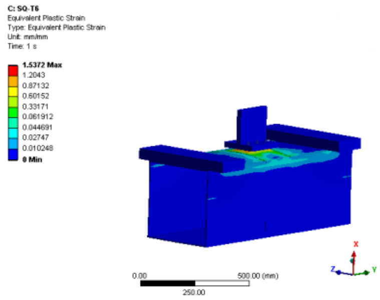

Fig. 17. Plastic strain of SQ-T6-D12.

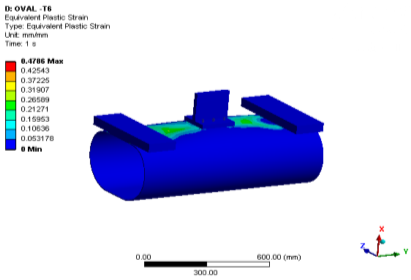

Fig. 18. Plastic strain of OVAL-T6-D12.

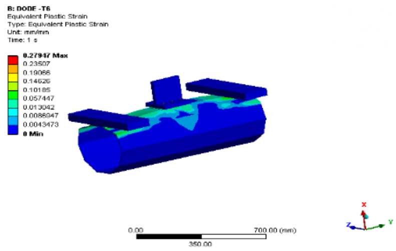

Fig. 19. Plastic strain of DODE-T6-D12.

### 3.2 Behavior of Hollow Sectional Tubes Under Strengthening Strategy by Providing Vertical Stiffener

From these models analyzed under strengthening strategy by proving vertical stiffener, there is increase in the load carrying capacity for dodecagonal, oval and hexagonal hollow section but square hollow section not much improved after addition of stiffener, because of its flat surface. The oval hollow section with vertical stiffener can take up to a load of 432.93 kN. Whereas the oval hollow section without vertical stiffener can only take load up to 348.7 kN, which makes the oval hollow section with vertical stiffener is better. Also, the dodecagonal hollow section with vertical stiffener can take up to a load of 284.47kN, which makes increase in load carrying capacity.

**Table 3.** Ultimate load and deformation by providing vertical stiffener.

| Models | Ultimate deflection (mm) | Ultimate load(kN) |
|---|---|---|
| HEX-VST5DE50 | 26.7 | 437.1 |
| DODE-VST5DE50 | 12.3 | 284.4 |
| SQ-VST5DE50 | 96.2 | 297.8 |
| OVAL-VST5DE50 | 182.3 | 432.9 |

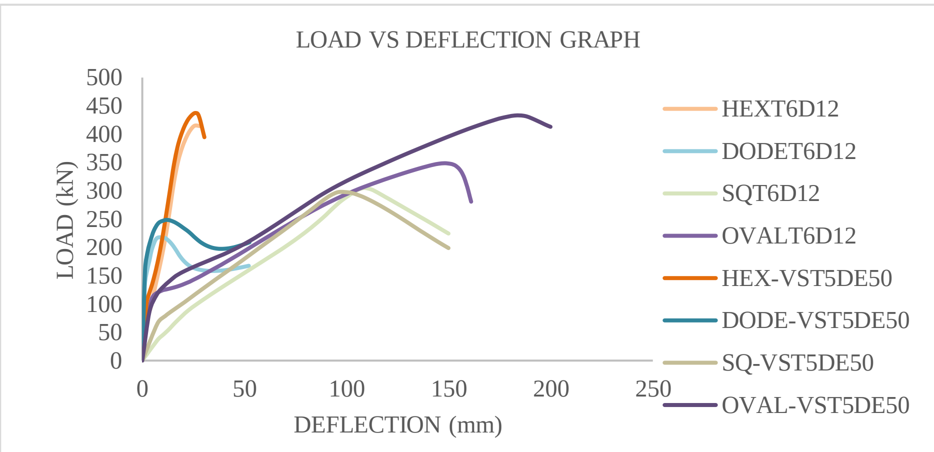


Fig. 21. Load deformation curve of vertical stiffener.

### 3.3 Behavior of hollow Sectional Tubes Under Strengthening Strategy by Proving Ring Stiffener

From these models analyzed under strengthening strategy by proving ring stiffener, there is increase in the load carrying capacity for square, oval and hexagonal hollow section. But dodecagonal hollow section not much improved after addition of stiffener. The hexagonal hollow section with ring stiffener can take up to a load of 469.2 kN. Whereas the hexagonal hollow section without ring stiffener can only take load up to 415.02 kN, which makes using ring stiffener on hexagonal and square hollow section tube is effective, increase in load carrying capacity.

**Table 4.** Ultimate Load and Deformation by Providing Ring Stiffener.

| Models | Ultimate deflection (mm) | Ultimate load(kN) |
|---|---|---|
| HEX-RST5DE50 | 21.627 | 469.2 |
| DODE-RST5DE50 | 7.3223 | 219.16 |
| SQ-RST5DE50 | 109.42 | 328.63 |
| OVAL-RST5DE50 | 211.9 | 366.13 |

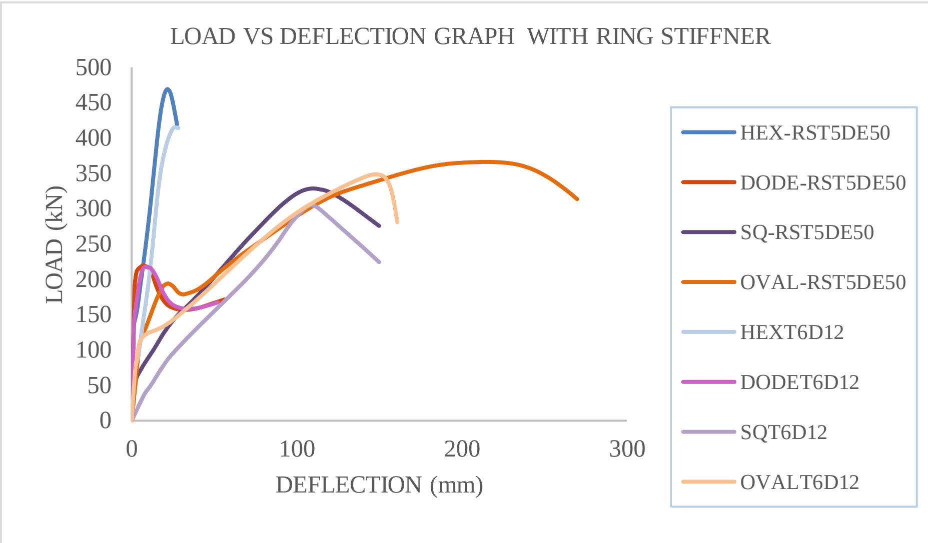


*Fig. 22. Load deformation curve of ring stiffener.*

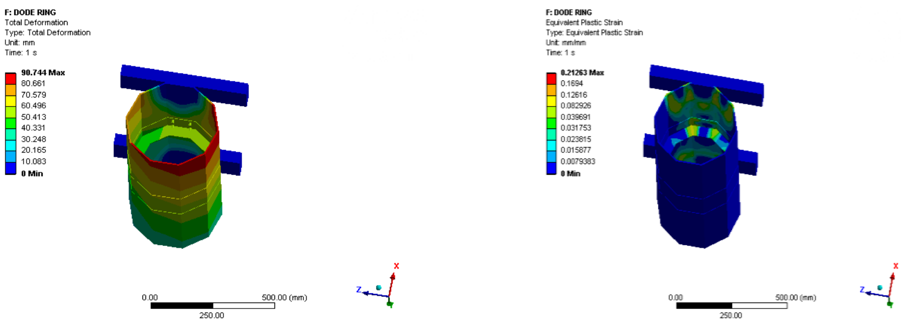


*Fig. 23. Total deformation and plastic strain DODE-RST5DE50.*

### 3.4 Behavior of Hollow Sectional Tubes by Varying Parameters Like Depth of Ring Stiffener

From the models analyzed under strengthening strategy by proving ring stiffener and vertical stiffener depth 25 mm. In case of vertical stiffer when compare without stiffener, there is increase in the load carrying capacity for dodecagonal and oval hollow section. But square and hexagonal hollow section not much improved after addition of stiffener. In case of ring stiffener when compare without stiffener, there is increase in the load carrying capacity for square and hexagonal hollow section. In ring and vertical stiffener of depth 25mm, when compare with depth 50 mm, there is not much improvement for load caring capacity. So this can conclude that increase the depth of the vertical and ring stiffener, gives not much effect on increase in load bearing capacity of hollow section tubes.

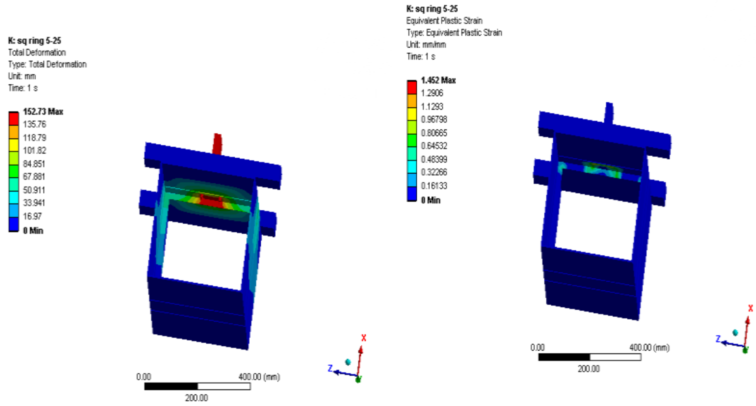


*Fig. 24. Total deformation and plastic strain of SQ-RST5DE25.*

**Table 5.** Ultimate load and deformation of the specimens by varying depth of stiffener.

| Models | Ultimate deflection (mm) | Ultimate load(kN) |
|---|---|---|
| HEX-RST5DE25 | 25.8 | 437.9 |
| DODE-RST5DE25 | 9.3 | 220.2 |
| SQ-RST5DE25 | 115.4 | 336.9 |
| OVAL-RST5DE25 | 183.9 | 350.5 |
| HEX-VST5DE25 | 24.7 | 421.4 |
| DODE-VST5DE25 | 11.2 | 229.4 |
| SQ-VST5DE25 | 100.2 | 302.1 |
| OVAL-VST5DE25 | 191.9 | 394.5 |

## IV. CONCLUSIONS

The structural behavior of blind-bolted connections in hollow section tubes by providing strengthening strategy under tensile loading was investigated analytically. In order to compare the output parameters such as ultimate load and ultimate deflection with hollow section tubes that are dodecagonal, oval, square, and hexagonal, models were created. The oval hollow section is more effective than the dodecagonal, square, and hexagonal hollow section tubes, according to a comparison of these four hollow sections. Only oval hollow section tubes have seen a simultaneous rise in both load bearing capacity and deflection capacity when compared to other variants.

The influence of ring and vertical stiffener in tube wall plasticity behavior of hollow section tubes was determined. Structural components called ring and vertical stiffeners, are increase the strength and stability of polygonal hollow section tubes, especially while bending or applying external pressure. In tubes having polygonal hollow sections, including dodecagonal, oval, square, or hexagonal geometries, ring and vertical stiffeners are usually placed inside the tube. Ring and vertical stiffeners are primarily used to prevent the tube walls from buckling, collapsing, or deforming when they are bent or subjected to external pressure. For square and hexagonal hollow section, ring stiffener is more effective than vertical stiffener. For oval and dodecagonal hollow section, vertical stiffener is more effective than ring stiffener. Based on the models examined under the strengthening technique, ring stiffeners and vertical stiffeners with a depth of 25 mm the load-carrying ability does not significantly improve when these models (depth 25 mm) compared to a depth of 50 mm. In conclusion using 50mm depth is more effective in case of both vertical and horizontal stiffeners.

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