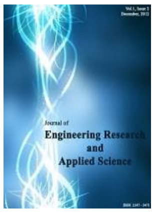
Journal of Engineering Research and Applied Science
Available at [www.journaleras.com](http://www.journaleras.com)
Volume 14 (1), June 2025, pp 113-132
ISSN 2147-3471 © 2025



# Sustainability Study of Telecommunication Towers: Comparing Lattice 4-Legged with 3-Legged Structures under Increased Equipment Load Tenancy Ratios

Fred Balikabya[a], Shokri Teshnizi[b]

Mechanical Engineering, Engineering Institute of Technology (EIT), Australia

Accepted 30 May 2025

## Abstract

The Rapid expansion of telecommunication infrastructure necessitates the optimization of tower designs for sustainability and structural integrity. This study evaluates the mechanical performance of lattice 4-legged and 3-legged self-supported telecommuication towers under increasing equipment load tenancy ratios. Using finite element analysis (FEA) in ANSYS 2025 R1 work bench software design modeler to develop the 2D models tower structures, modal analysis is performed to assess the natural frequencies, mode shapes, and critical stress points. Static structural analysis is performed to assess the tower equipment tenancy load ratios impact on Total deformation, directional deformation along the X-axis and direct stress. The study results indicated that 4-legged lattice steel tower structure design model exhibited higher natural frequencies 12% greater than 3-legged lattice steel tower structure design model which showed enhanced stiffness and sustainability. The study also indicated 3-legged lattice steel tower structure design model exhibited increased stress concentration at XBX bracing joints with 16% greater total defromation than 4-legged lattice steel tower structure design model. The 4-legged tower design offered better and superior mechanical stability with lower potential failure risks.This study research findings will provide important engineering knowlegde to policy makers in the telecommunication industry for infrastructure sustainability and safety.

**Keywords:** Telecommunication, *4-legged lattice self-supported tower, 3-legged lattice self-supported tower, Mode shapes, Natural Frequencies, static to dynamic response, Equipment tenant load ratio, Total deformation, Direct stress*

## 1. Introduction

Telecommunication infrastructure serves as the backbone for socio-economic development, connecting communities and enabling rapid dissemination of information and services essential for education, healthcare, business, governance, and disaster management. The significance of robust telecom infrastructure has grown substantially with advancements in digital technology, mobile internet penetration, and increased reliance on digital communications for daily activities, particularly in emerging markets like Uganda. The number of telecom towers has grown significantly at 66% in the past 5 years, from 3,044 in 2019 to 5,064 in 2023[1], [2].

This expansion is primarily driven by the rising demand for enhanced mobile network coverage and quality improvements, spurred by population growth, urbanization, and increased mobile device affordability[3]. However, this rapid deployment has also introduced substantial technical challenges, particularly regarding tower structural integrity due to higher equipment loads driven by higher tenancy ratios. In Uganda, the average equipment tenancy ratio on towers has reached 1.6 tenants per tower, necessitating structures capable of reliably managing increased mechanical loads[3].

In Uganda Lattice 4-legged and 3-legged self-supported towers are widely used, yet their mechanical performance under increasing equipment loads remains under explored. Several research carried out on steel tower designs investigated structural integrity performance to be the most important design criterion[4]. Also the stability and reliability of modular steel structures and be used to reduce design redundancy[5]. A study compared analysis on the design of three and four Legged Steel Transmission tower indicated 77.81% axial load increased in the three-legged tower support components compared to four-legged tower components. 60% bending moments increased in the three-legged as compared to four-legged tower [6]. On

[a]Corresponding author: [26432@student.eit.edu.au](mailto:26432@student.eit.edu.au), [balikabya2007@yahoo.com](mailto:balikabya2007@yahoo.com), Phone contact: +25675990899
[b]Corresponding author: [shokri.teshnizi@eit.edu.au](mailto:shokri.teshnizi@eit.edu.au), [sharifi.te@gmail.com](mailto:sharifi.te@gmail.com),

tower cost optimization a four fuzzy subtractive clustering model was developed for predicting the weight of telecommunication towers to estimate respective costs [7]. To evaluate both seismic and wind performance Telecommunication tower stability on 4-legged self-supported using viscous dampers indicated that dampers have more effects on dynamic analysis compared to equivalent static analysis[8], Also enhanced seismic resilience of telecommunication tower by linear static approach for without viscous damper indicated tower movement reduction and tension of the internal parts [9]. Seismic performance of 4-legged telecommunication towers with heights ranging from 18 to 67meters indicated satisfied design base and maximum earthquake hazard levels [10]. Seismic effects analyzed on structural performance for three four-leg lattice self-supporting towers with different heights of 30m, 50m and 80m [11]. Comparative analysis of steel towers under seismic and wind loading investigated tower displacement increase with wind speed, stress on tower increase with wind speed and stress increase with tower height [12]. Both static and dynamic analysis of telecommunication towers when subjected to wind loads in comparison of two standard methods used Brazilian NBR 6123:1988 and European IEC 60826:2017, the European standards gave consistent results [13]. Also dynamic analysis of telecommunication tower for optimum modal combination and elemental discretization investigated compatibility of static equivalent load and time history method which provided better accuracy but at a higher computational cost [14]. Steel materials plays a vital role to the telecommunication industry particularly galvanaised metals used to construct lattice towers [15]. Galvanisation of steel tower materals is very important to prevent tower structure surfaces from rusting due to harsh weather and environmental conditions [16].

Tower structural analysis and equipment loads evaluation is very key for the sustainability of telecommunication lattice steel towers.

## 2. Purpose

This study aimed to assess both Lattice steel 4-legged and 3-legged self-supported towers sustainability as mechanical structure integrity under increasing equipment loads tenancy ratios, performed modal analysis compared mode shapes and their natural frequencies, performed static structural analysis compared the static to dynamic load response which contributes to informed engineering knowledge and policy decisions in providing critical insights for sustainable telecommunication infrastructure development.

## 3. Scope

The study was conducted using different lattice steel self-supported towers of same height 50 meters surveyed in Uganda for data collection on equipment loads from tenancy ratio from 1 to 4. The tower design code considered ANSI/TIA/EIA-222-G1with bracing type-XBX. The equipment loading height section of the tower part considered was from 40 to 45 meters being the area of stress concentration. ANSYS 2025 R1 work bench design modeler software was used for the Tower design 2D Line body modelling of the experimental results.

## 4. Tower Equipment loads, key design parameters and methods.

### 4.1. Equipment Tenant loads

Data collected from the field survey for the equipment weights materials installed on both different tower designs of 4 -legged and 3-legged used in the study scope are given in Tables 1,2,3 & 4 below.

### 4.2. Key Tower design parameter and materials used.

This study used various key towers design parameters and materials for the modelling process as given in table 5 below.

Table 1: One-Tenant Equipment weights on the towers

| No | Item | Quantity | Size (m) | Weight of Equipment (kg) | Location From Base tower (m) | TOTALS (kg) |
|---|---|---|---|---|---|---|
| 1 | CDMA (panel) | 5 | 2.69x0.4x1.2 | 35 | 45 | 175 |
| 2 | Microwave (Dish) | 2 | 0.6x0.6x0.2 | 14 | 41 | 28 |
| 3 | RRU5512t | 3 | 0.48x0.37x0.1 | 25 | 44 | 75 |
| 4 | RRU5304w | 3 | 0.4x0.3x0.2 | 22 | 45 | 66 |
| **TOTAL** | | | | | | **344** |

Table 2: Two-Tenant Equipment weights on the towers

| No | Item | Quantity | Size (m) | Weight of Equipment (kg) | Location From Base tower(m) | TOTALS (kg) |
|---|---|---|---|---|---|---|
| 1 | CDMA (panel) | 5 | 2.69x0.4x1.2 | 35 | 45 | 175 |
| 2 | Microwave (Dish) | 2 | 0.6x0.6x0.2 | 14 | 41 | 28 |
| 3 | RRU5512t | 3 | 0.48x0.37x0.1 | 25 | 44 | 75 |
| 4 | RRU5304w | 3 | 0.4x0.3x0.2 | 22 | 45 | 66 |
| 5 | CDMA (panel) | 13 | 2.69x0.4x1.2 | 35 | 45 | 455 |
| 6 | Microwave (Dish) | 2 | 0.6x0.6x0.2 | 14 | 41 | 28 |
| 7 | RRU5512t | 9 | 0.48x0.37x0.1 | 25 | 44 | 225 |
| 8 | RRU5304w | 10 | 0.4x0.3x0.2 | 22 | 45 | 220 |
| **TOTAL** | | | | | | **1272** |

Table 3: Three-Tenant Equipment weights on the towers

| No | Item | Quantity | Size (m) | Weight of Equipment (kg) | Location From Base tower(m) | TOTALS (kg) |
|---|---|---|---|---|---|---|
| 1 | CDMA (panel) | 5 | 2.69x0.4x1.2 | 35 | 45 | 175 |
| 2 | Microwave (Dish) | 2 | 0.6x0.6x0.2 | 14 | 41 | 28 |
| 3 | RRU5512t | 3 | 0.48x0.37x0.1 | 25 | 44 | 75 |
| 4 | RRU5304w | 3 | 0.4x0.3x0.2 | 22 | 45 | 66 |
| 5 | CDMA (panel) | 13 | 2.69x0.4x1.2 | 35 | 45 | 455 |
| 6 | Microwave (Dish) | 2 | 0.6x0.6x0.2 | 14 | 41 | 28 |
| 7 | RRU5512t | 9 | 0.48x0.37x0.1 | 25 | 44 | 225 |
| 8 | RRU5304w | 10 | 0.4x0.3x0.2 | 22 | 45 | 220 |
| 10 | APE4516R1v06(Panel) | 3 | 2.0x0.3x0.2 | 40 | 45.1 | 120 |
| 11 | SA49-90-16 (Panel) | 1 | 0.5x0.2x0.1 | 22 | 42.7 | 22 |
| 12 | PMP 450 (Panel) | 1 | 0.5x0.1x0.1 | 16.6 | 22.5 | 16.6 |
| 13 | RRU 5301 | 3 | 0.4X0.3X0.1 | 15 | 45.9 | 45 |
| 14 | RRU 5309 | 3 | 0.4X0.3X0.2 | 15 | 44.7 | 45 |
| 15 | RRU5513 | 1 | 0.5X0.4X0.1 | 25 | 45.4 | 25 |
| 16 | RRU5513w | 1 | 0.5X0.4X0.2 | 25 | 44.9 | 25 |
| 17 | Microwave (Dish) | 1 | 0.5x0.5x0.3 | 10.8 | 40 | 10.8 |
| | | | | | **TOTAL** | **1461.4** |

Table 4: Four-Tenant Equipment weights on the towers

| **No** | **Item** | **Quantity** | **Size (m)** | **Weight of Equipment (kg)** | **Location From Base tower (m)** | **TOTALS (kg)** |
|---|---|---|---|---|---|---|
| 1 | CDMA (panel) | 5 | 2.69x0.4x1.2 | 35 | 45 | 175 |
| 2 | Microwave (Dish) | 2 | 0.6x0.6x0.2 | 14 | 41 | 28 |
| 3 | RRU5512t | 3 | 0.48x0.37x0.1 | 25 | 44 | 75 |
| 4 | RRU5304w | 3 | 0.4x0.3x0.2 | 22 | 45 | 66 |
| 5 | CDMA (panel) | 13 | 2.69x0.4x1.2 | 35 | 45 | 455 |
| 6 | Microwave (Dish) | 2 | 0.6x0.6x0.2 | 14 | 41 | 28 |
| 7 | RRU5512t | 9 | 0.48x0.37x0.1 | 25 | 44 | 225 |
| 8 | RRU5304w | 10 | 0.4x0.3x0.2 | 22 | 45 | 220 |
| 10 | APE4516R1v06(Panel) | 3 | 2.0x0.3x0.2 | 40 | 45.1 | 120 |
| 11 | SA49-90-16 (Panel) | 1 | 0.5x0.2x0.1 | 22 | 42.7 | 22 |
| 12 | PMP 450 (Panel) | 1 | 0.5x0.1x0.1 | 16.6 | 22.5 | 16.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | RRU 5301 | 3 | 0.4X0.3X0.1 | 15 | 45.9 | 45 |
| 14 | RRU 5309 | 3 | 0.4X0.3X0.2 | 15 | 44.7 | 45 |
| 15 | RRU5513 | 1 | 0.5X0.4X0.1 | 25 | 45.4 | 25 |
| 16 | RRU5513w | 1 | 0.5X0.4X0.2 | 25 | 44.9 | 25 |
| 17 | Microwave (Dish) | 1 | 0.5x0.5x0.3 | 10.8 | 40 | 10.8 |
| 18 | CDMA (panel) | 3 | 2.69x0.4x1.2 | 35 | 45 | 105 |
| 19 | Microwave (Dish) | 1 | 0.6x0.6x0.2 | 14 | 41 | 14 |
| 20 | RRU5512t | 3 | 0.48x0.37x0.1 | 25 | 44 | 75 |
| 21 | RRU5304w | 7 | 0.4x0.3x0.2 | 22 | 45 | 154 |
| | | | | | **TOTAL** | **1809.4** |

Table 5: Key Towers design parameters and materials used

| **Key Tower design Parameter (s)** | **4-Legged lattice Tower** | **3-Legged lattice Tower** |
|---|---|---|
| Tower Height (m) | 50 | 50 |
| Tower Base lay out | Square | Triangular |
| Tower base width (m) | 5.75 | 5.709 |
| Number of Tower sections | 10 | 10 |
| Section height (m) | 5 | 5 |
| Tower design code | ANSI/TIA/EIA-222-G1 | ANSI/TIA/EIA-222-G1 |
| Tower materials | Structural steel | Structural steel |
| Steel Cross-section L-shape Size (mm) | 125X125X10 | 100X100X10 |
| Tower Bracing connection Type | XBX | XBX |
| Load equipment Tenancy ratio | 1 to 4 | 1 to 4 |
| Young's modulus (Pa) | 200G | 200G |
| Density of steel (Kg/m³) | 7850 | 7850 |
| Ultimate Tensile strength (Pa) | 420M | 420M |
| Tower model sketching | 2D Line body | 2D Line body |

### 4.3. Tower model development and modelling.

The Two models of telecommunication lattice steel self-supported towers of 50 meters height were designed using ANSYS 2025 R1work bench design modeler software student version considered 2D model Line body beam structure approach instead of 3D model design due to student verison sofware limitation to find good quality element mesh sizing and failed mathematical solution processing when element nodes excceds limit above 135,000 nodes. There fore the 2D model line sketching was the best approach used for tower models development and modelling as seen below in figures 1 and 2.

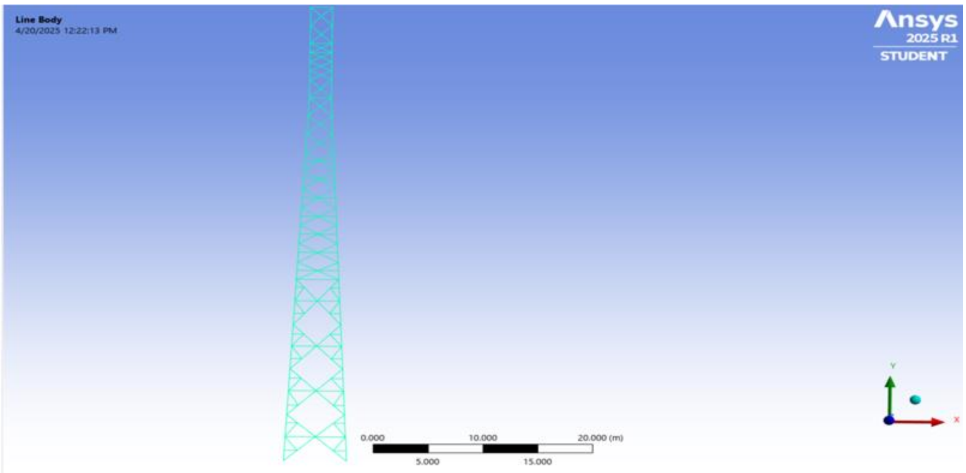



Figure 1 Shows 2D-Solid line body beam structure modal for 4-Legged lattice Tower structure 50-meter height

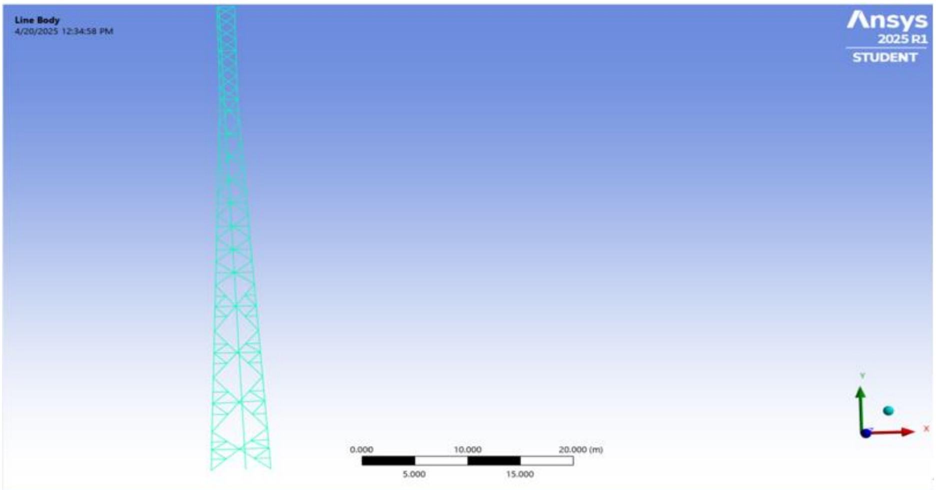



Figure 2 Shows 2D-Solid line body beam structure modal for 3-Legged lattice Tower structure 50-meter height

**4.3.1. Meshing and Element sizing.**

The study used physics type mechanical and automatic mesh method quad dominant with element sizing settings to obtain the good mesh quality of the two tower models as shown in figures 3 and 4 below.

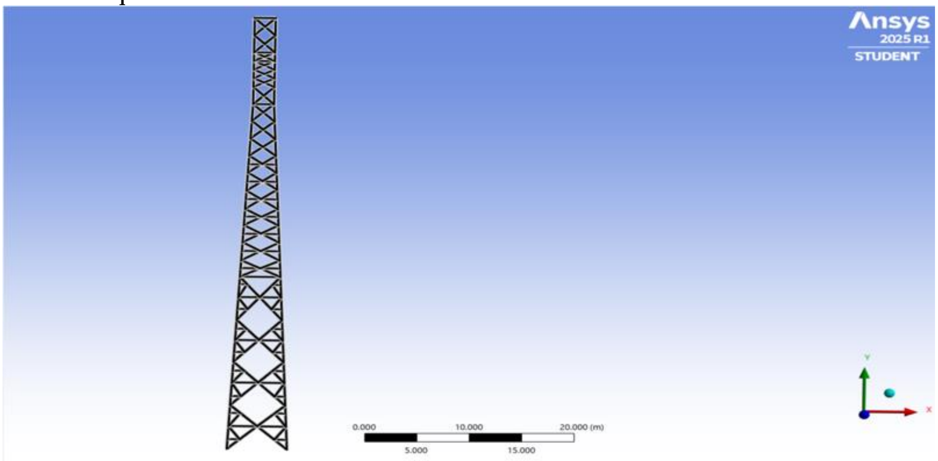



Figure 3 shows 4-Legged tower mesh profile model generated with element size 1.0m, number of nodes 14,507 and elements 7,320 achieved.

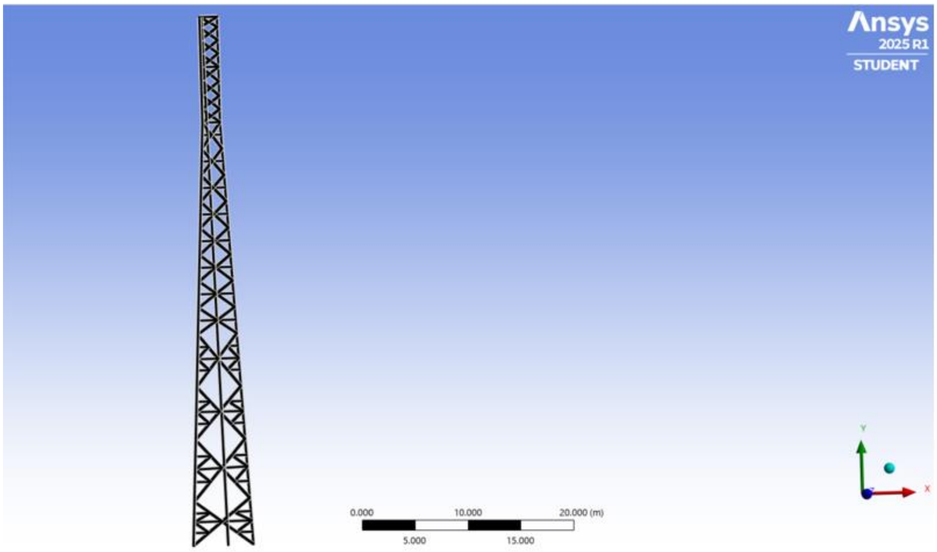



Figure 4 shows 3-Legged tower mesh profile model generated with element size 0.01m, number of nodes 78,578 and elements 39,382 achieved.

## 5. Findings and Discussion

### 5.1. Mode shapes and Natural frequencies

The two tower models were subjected to simulation using ANSYS 2025 R1 work bench and performed modal analysis to obtain the mode shapes and Natural Frequencies results to compare the two towers model stability. Boundary conditions such as fixed base supports were applied at tower base to create realistic simulation environment and obtained good results as seen in Table 6 and 7.

Table 6 shows modal analysis results for 4 -Legged Tower structure model design

| Mode shapes | Frequency (Hz) | Total deformation (M) | Critical solution work sheet Analysis on 4 -Legged Tower structure model design |
|---|---|---|---|
| 1 | 0.028917 | 0.02426 | 92.39% Tower mass deflects in Z direction under mode shape 1 |
| 2 | 0.15652 | 0.02369 | |
| 3 | 0.45722 | 0.02374 | |
| 4 | 0.66393 | 0.01974 | |
| 5 | 0.87644 | 0.02454 | |
| 6 | 1.4404 | 0.02716 | |
| 7 | 1.485 | 0.02587 | 51.9% Tower mass deflects in X direction under mode shape 7 |
| 8 | 1.6411 | 0.02234 | |
| 9 | 2.1672 | 0.02446 | |
| 10 | 2.6551 | 0.02211 | 69.67% Tower mass deflects in Y direction under mode shape 10 |

Table 7 shows modal analysis results for 3 -Legged Tower structure model design

| Mode shapes | Frequency (Hz) | Total deformation (M) | Critical solution work sheet Analysis on 3 -Legged Tower structure model design |
|---|---|---|---|
| 1 | 0.024073 | 0.027811 | 92.03% Tower mass deflects in Z direction under mode shape 1 |
| 2 | 0.14114 | 0.027012 | |
| 3 | 0.39989 | 0.027178 | |
| 4 | 0.58874 | 0.025254 | |
| 5 | 0.77896 | 0.027686 | |
| 6 | 1.2968 | 0.02714 | 49.96% Tower mass deflects in X direction under mode shape 6 0.57x10-3 % Tower mass deflects in Y direction under mode shape 6 |
| 7 | 1.3575 | 0.030628 | |
| 8 | 1.4066 | 0.028499 | |
| 9 | 1.9431 | 0.025421 | |
| 10 | 2.2945 | 0.028203 | |

Potential failure modes for the 10 first natural frequencies are captured from ANSYS 2025 R1 work bench software with Total deformation of the 4 -Legged Tower structure model design shown as figures 5,6,7,8,9,10,11,12,13 and14 below shows.

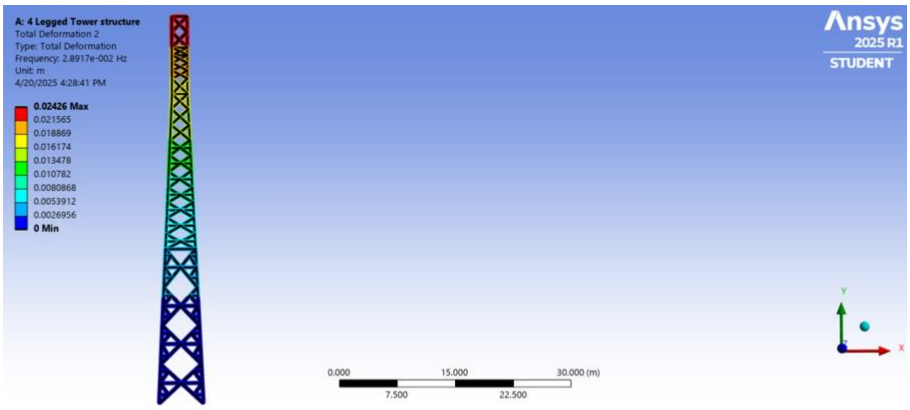



Figure 5 shows Potential failure mode shape 1 for 4 -Legged Tower structure model design.

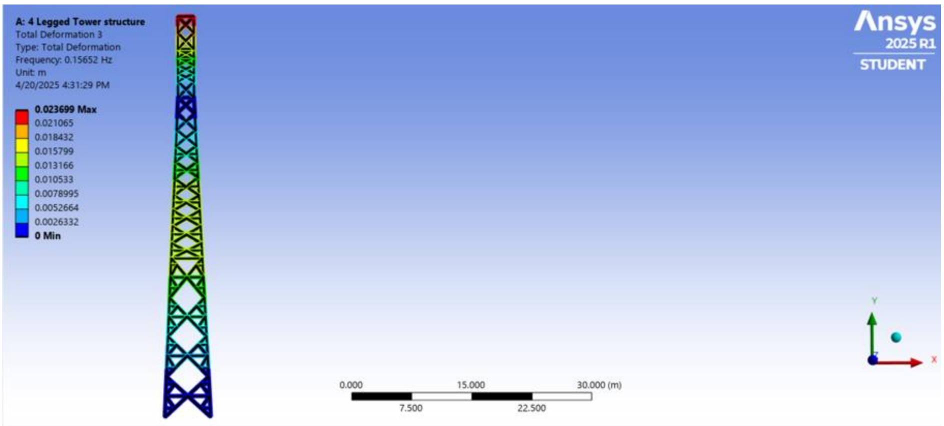



Figure 6 shows Potential failure mode shape 2 for 4 -Legged Tower structure model design

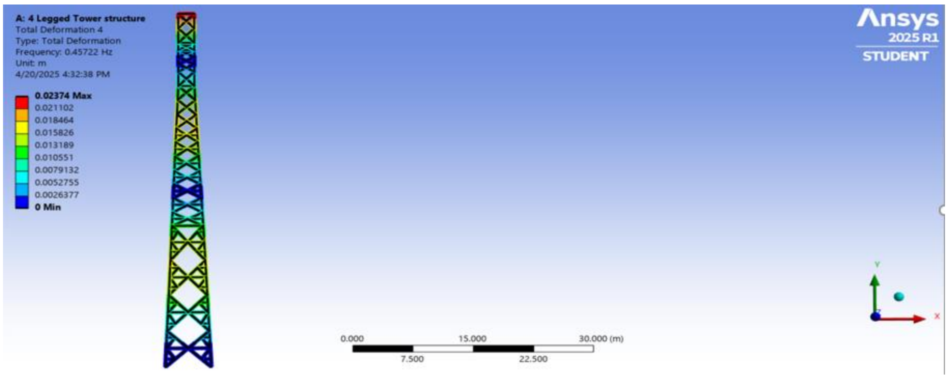



Figure 7 shows Potential failure mode shape 3 for 4 -Legged Tower structure model design.

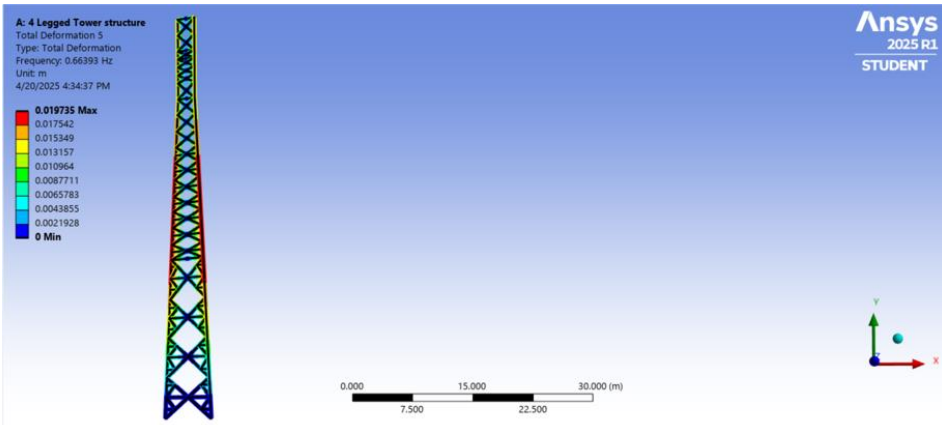



Figure 8 shows Potential failure mode shape 4 for 4 -Legged Tower structure model design.

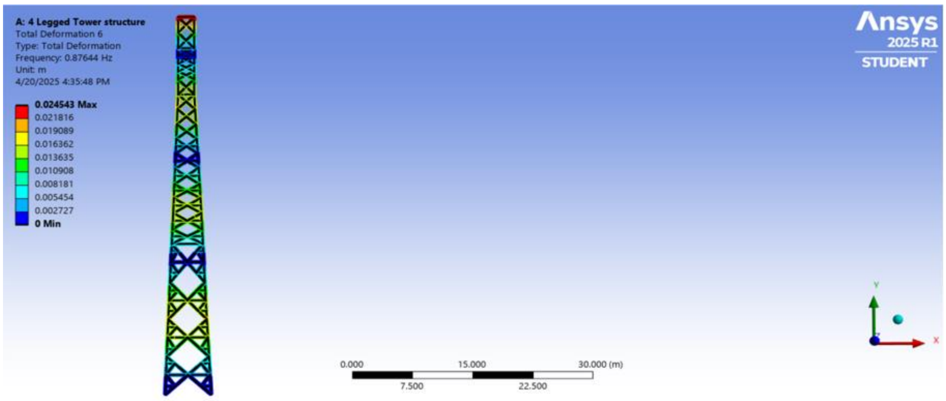



Figure 9 shows Potential failure mode shape 5 for 4 -Legged Tower structure model design.

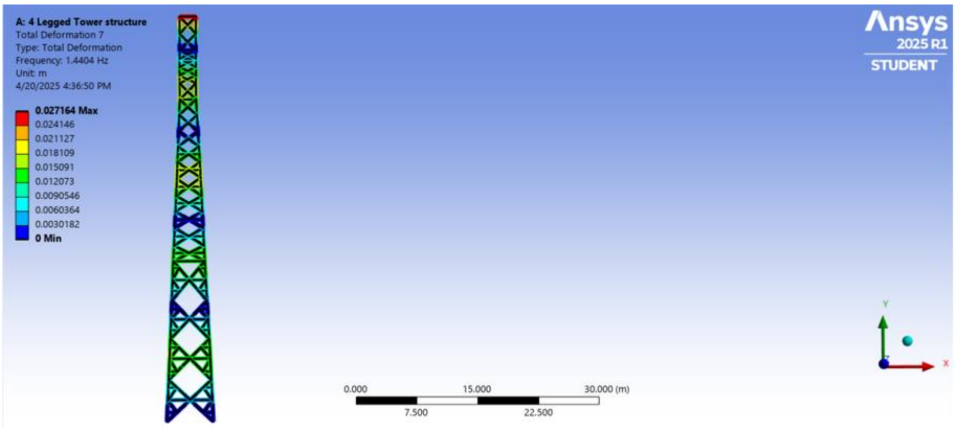



Figure 10 shows Potential failure mode shape 6 for 4 -Legged Tower structure model design.

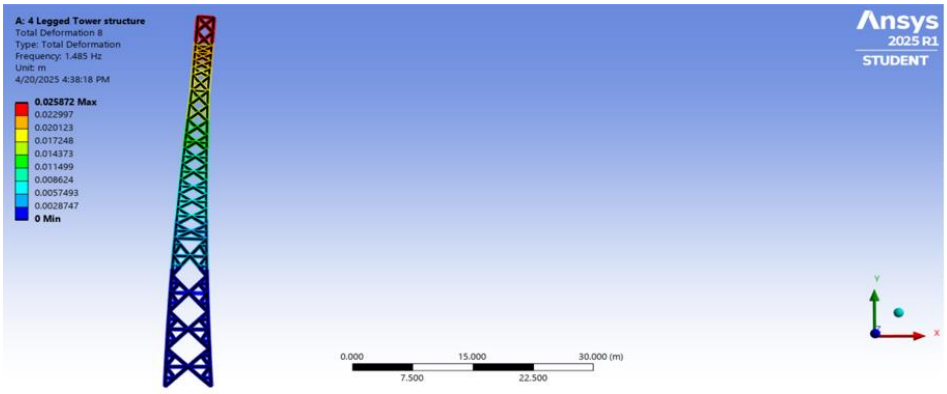



Figure 11 shows Potential failure mode shape 7 for 4 -Legged Tower structure model design.

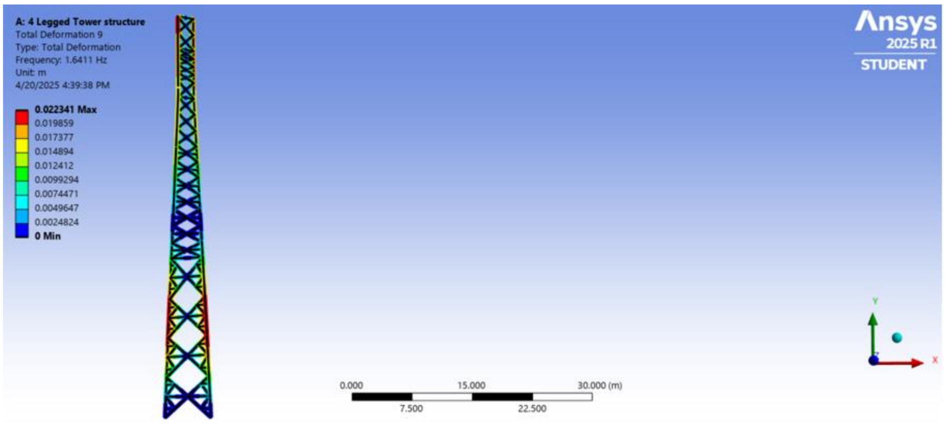



Figure 12 shows Potential failure mode shape 8 for 4 -Legged Tower structure model design.

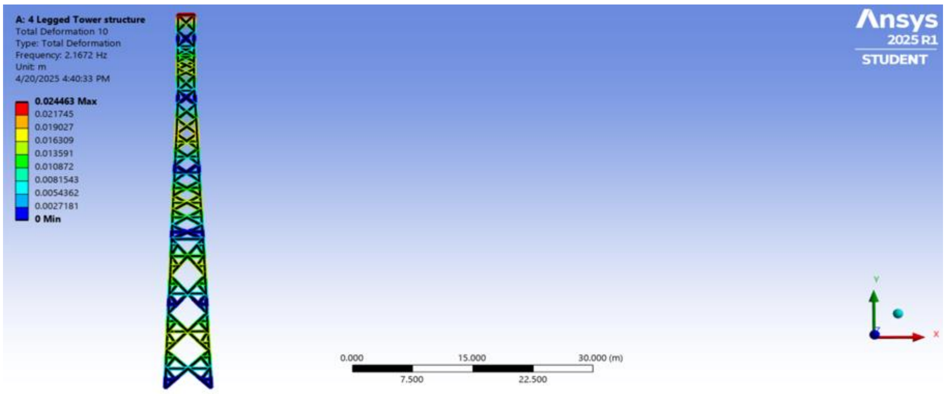



Figure 13 shows Potential failure mode shape 9 for 4 -Legged Tower structure model design.

Potential failure modes for the 10 first natural frequencies are captured from ANSYS 2025 R1 work bench software with Total deformation of the 3 -Legged Tower structure model design shown as figures 15,16,17,18,19,20,21,22,23 and 24 below shows.

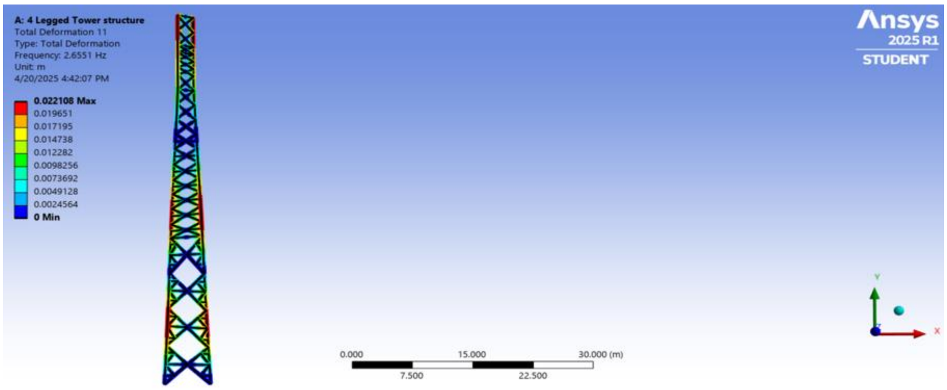



Figure 14 shows Potential failure mode shape 9 for 4 -Legged Tower structure model design.

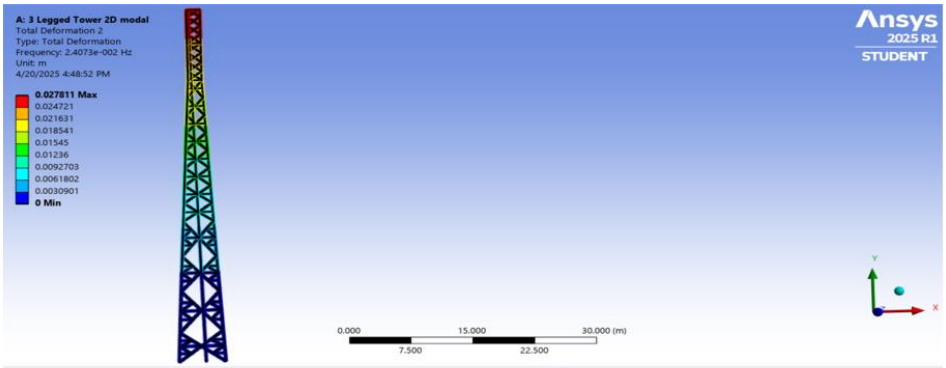



Figure 15 shows Potential failure mode shape 1 for 3 -Legged Tower structure model design.

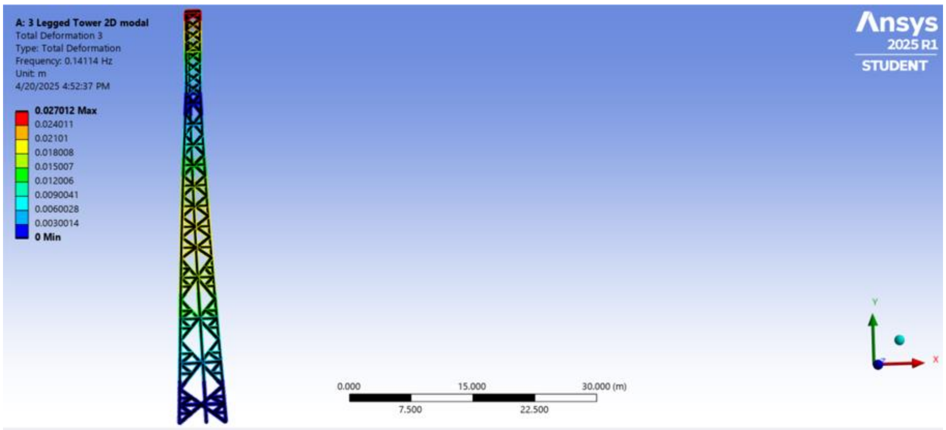



Figure 16 shows Potential failure mode shape 2 for 3 -Legged Tower structure model design.

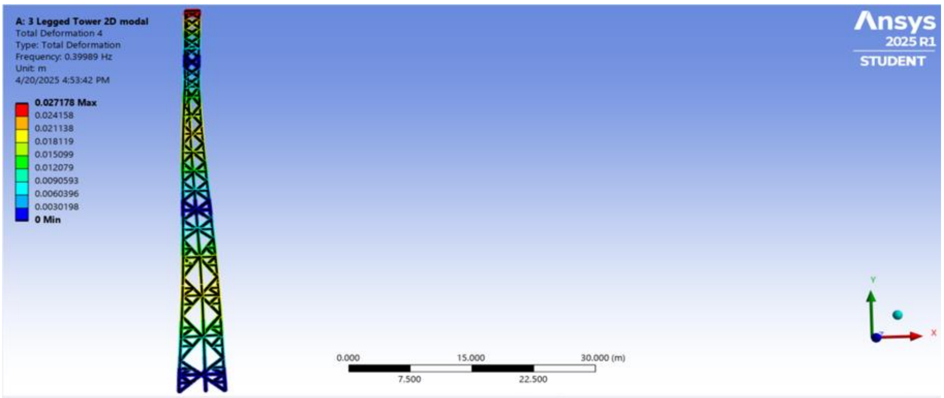



Figure 17 shows Potential failure mode shape 3 for 3 -Legged Tower structure model design.

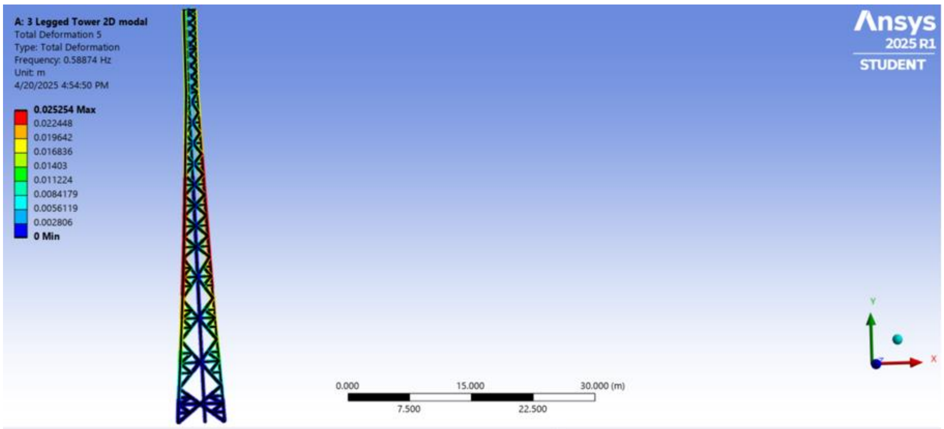



Figure 18 shows Potential failure mode shape 4 for 3 -Legged Tower structure model design.

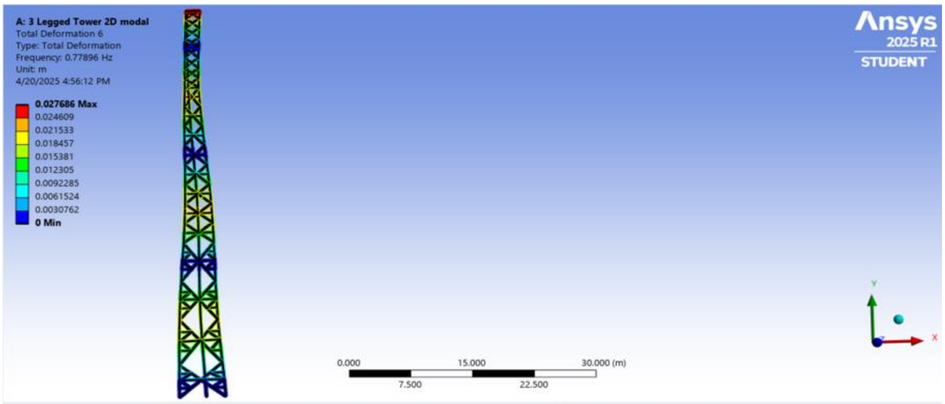



Figure 19 shows Potential failure mode shape 5 for 3 -Legged Tower structure model design.

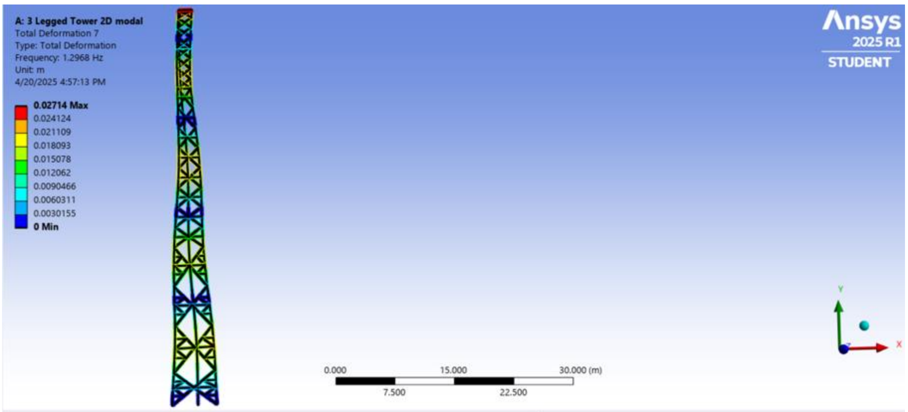



Figure 20 shows Potential failure mode shape 6 for 3 -Legged Tower structure model design.

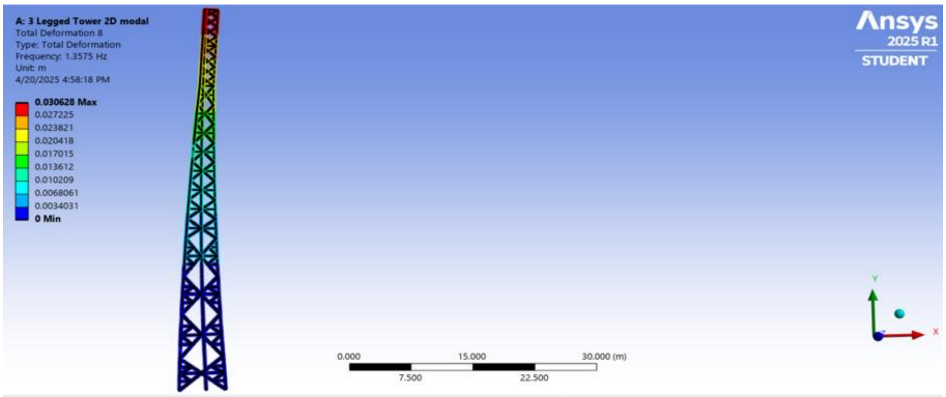



Figure 21 shows Potential failure mode shape 7 for 3 -Legged Tower structure model design.

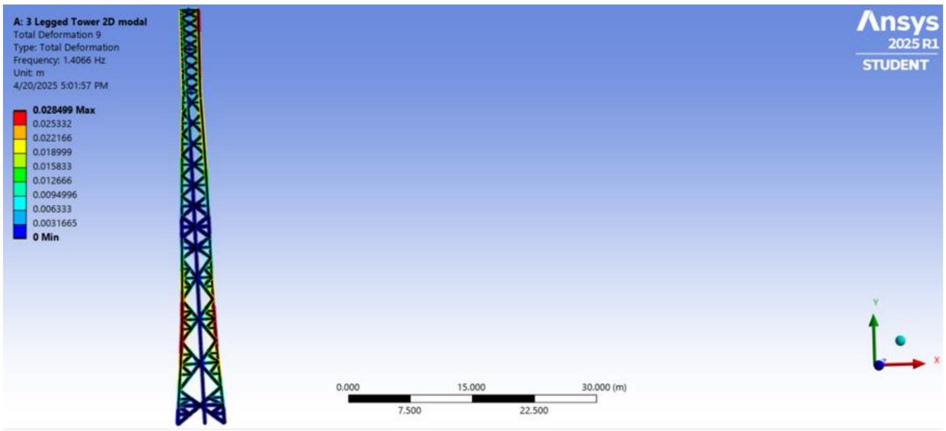



Figure 22 shows Potential failure mode shape 8 for 3 -Legged Tower structure model design.

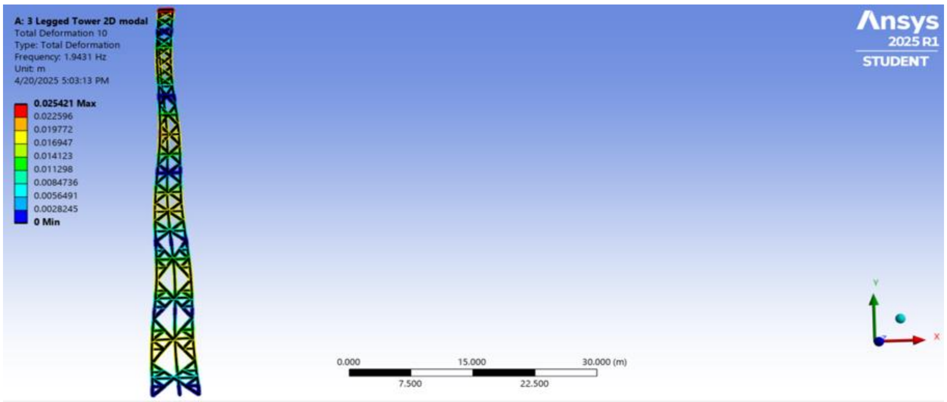



Figure 23 shows Potential failure mode shape 9 for 3 -Legged Tower structure model design.

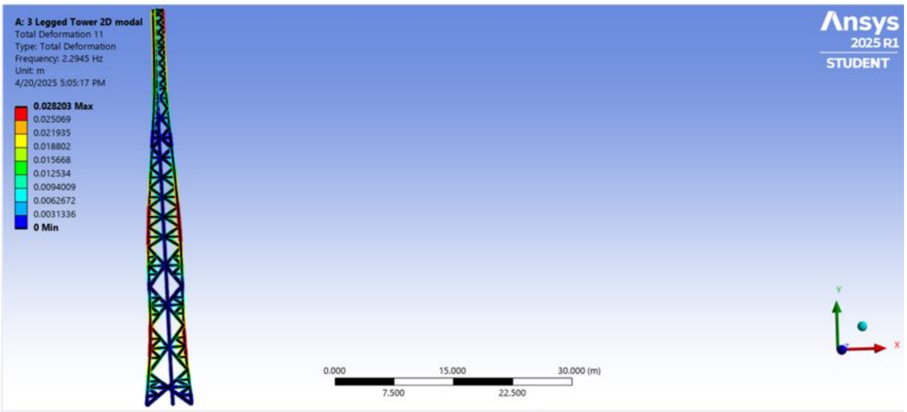



Figure 24 shows Potential failure mode shape 10 for 3 -Legged Tower structure model design.

Comparison graphs are plotted for modal analysis results to study the tower models sustainability structure design as shown in figure 25 and 26 below.

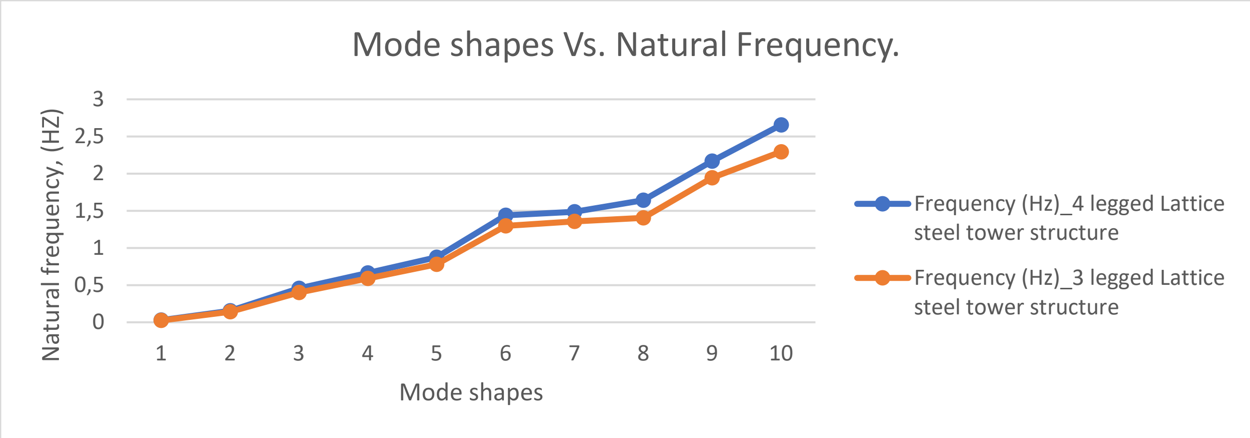



Figure 25 shows comparison graph of mode shapes Vs. Natural frequencies.

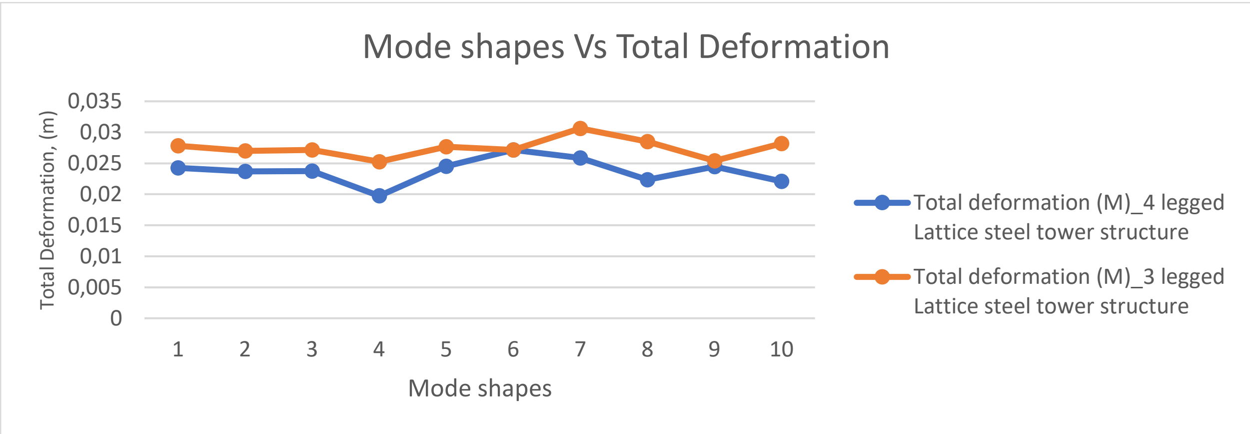



Figure 26 shows comparison graph of mode shapes Vs. Total Deformation.

Comparison Tables for modal analysis results to study the tower models sustainability structure design as shown in Table 8 and 9 below.

Table 8 shows comparison for mode shapes Vs. Natural frequencies of the Tower designs.

| Mode shapes | Frequency (Hz)_4-legged steel tower design | Frequency (Hz)_3-legged steel tower design | % increase |
|---|---|---|---|
| 1 | 0.028917 | 0.024073 | 17% |
| 2 | 0.15652 | 0.14114 | 10% |
| 3 | 0.45722 | 0.39989 | 13% |
| 4 | 0.66393 | 0.58874 | 11% |
| 5 | 0.87644 | 0.77896 | 11% |
| 6 | 1.4404 | 1.2968 | 10% |
| 7 | 1.485 | 1.3575 | 9% |
| 8 | 1.6411 | 1.4066 | 14% |
| 9 | 2.1672 | 1.9431 | 10% |
| 10 | 2.6551 | 2.2945 | 14% |
| | **Average increase in Natural Frequency for 4-Legged compared with 3-Legged steel Tower design** | | **12%** |

From the above comparison Figure 26 and Table 9 for the mode shapes aganist natural frequencies , The study findings shows that the 4-legged lattice steel tower structure design model exhibited higher natural frequencies (~12% greater than 3-legged lattic steel tower structure design model) which indicates enhanced stiffness and sustainability.

Table 9 shows comparison for mode shapes Vs. Total deformation or Stiffness of the Tower designs.

| Mode shapes | Total deformation (M)_4-legged steel tower design | Total deformation (M)_3-legged steel tower design | % increase |
|---|---|---|---|
| 1 | 0.02426 | 0.027811 | 15% |
| 2 | 0.02369 | 0.027012 | 14% |
| 3 | 0.02374 | 0.027178 | 14% |
| 4 | 0.01974 | 0.025254 | 28% |
| 5 | 0.02454 | 0.027686 | 13% |
| 6 | 0.02716 | 0.02714 | 0% |
| 7 | 0.02587 | 0.030628 | 18% |
| 8 | 0.02234 | 0.028499 | 28% |
| 9 | 0.02446 | 0.025421 | 4% |
| 10 | 0.02211 | 0.028203 | 28% |
| | **Average increase in Total Deformation or stiffness for 3-Legged compared with 4-Legged Lattice steel Tower** | | **16%** |

From the above comparison Figure 25 and Table 8 for the mode shapes aganist total deformation , The study findings shows that the 3-legged lattice steel tower structure design model exhibited increased stress concentration at XBX bracing joints (~16% greater total defromation than 4-legged lattice steel tower structure design model).

**5.2. Tower Stability and Equipment tenancy loads.**

The two tower models were subjected to the increasing equipment tenancy loads anchored at tower part section height from 40 to 45 meters and studied the static to dynamic response of the mechanical tower structure using ANSYS 2025 R1 work bench simulations. Performed Static structural analysis to obtain the Tower total deformation, directional deformation in x-direction and direct stress impacted on the two tower models then compared the results. Boundary conditions such as fixed base supports were applied at tower base and equipment loads as Force acting on the tower down wards in the Y-direction due to acceleration of gravity to create realistic simulation environment and obtained good results as seen in Table 10 and 11.

Table 10 shows Static to dynamic analysis results for 4 -Legged Tower structure model design

| No | 4 -Legged Tower Equipment Tenancy Loads | Weights (kgs) | Force on Tower, (N) | Total deformation, (M) | Directional deformation in X-direction, (M) | Direct stress on Tower, (Pa) |
|---|---|---|---|---|---|---|
| 1 | One-Tenant Loads | 344 | 3373.47 | 0.00041834 | 0.00001493 | 68209 |
| 2 | Two-Tenants Loads | 1272 | 12474.00 | 0.0015469 | 0.000055207 | 252210 |
| 3 | Three-Tenants Loads | 1461.4 | 14331.37 | 0.0017772 | 0.000063427 | 289770 |
| 4 | Four-Tenants Loads | 1809.4 | 17744.06 | 0.0022004 | 0.00007853 | 358770 |
| 5 | (Nth)-Tenants Loads (Assume to double) | 3618.8 | 35466.41 | 0.0043981 | 0.00015696 | 717100 |

Table 11 shows Static to dynamic analysis results for 3 -Legged Tower structure model design

| No | 3 -Legged Tower Equipment Tenancy Loads | Weights (kgs) | Force on Tower, (N) | Total deformation, (M) | Directional deformation in X-direction, (M) | Direct stress on Tower, (Pa) |
|---|---|---|---|---|---|---|
| 1 | One-Tenant Loads | 344 | 3373.47 | 0.00065827 | 0.000049109 | 89808 |
| 2 | Two-Tenants Loads | 1272 | 12474 | 0.0024341 | 0.00018159 | 332080 |
| 3 | Three-Tenants Loads | 1461.4 | 14331.37 | 0.0027965 | 0.00020863 | 381530 |
| 4 | Four-Tenants Loads | 1809.4 | 17744.06 | 0.0034624 | 0.00025831 | 472380 |
| 5 | (Nth)-Tenants Loads (Assume doubled) | 3618.8 | 35466.41 | 0.0069206 | 0.0005163 | 944180 |

Equipment loading Static to dynamic response on the tower design models are captured from ANSYS 2025 R1 work bench software results for Total deformation of the 4 -Legged Tower structure design shown as figures 27,28,29, 30 and 31 below.

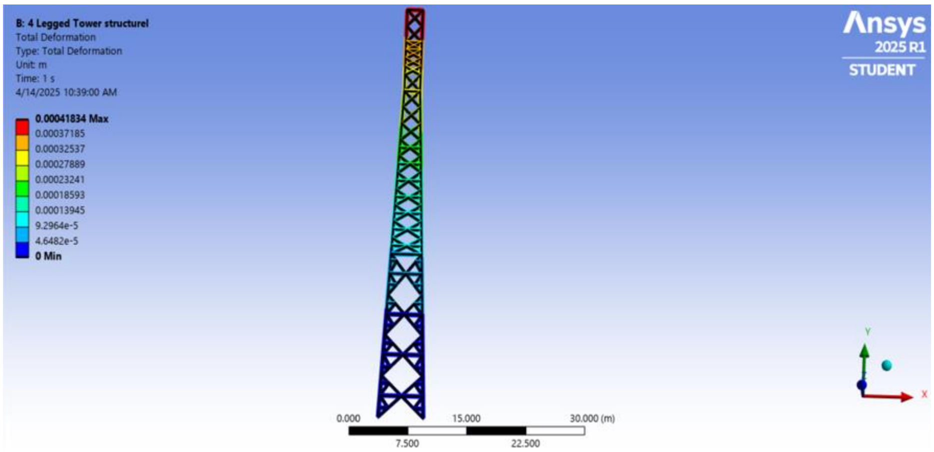



Figure 27 shows Total deformation for one-tenant equipment loading 4 -Legged Tower structure model design.

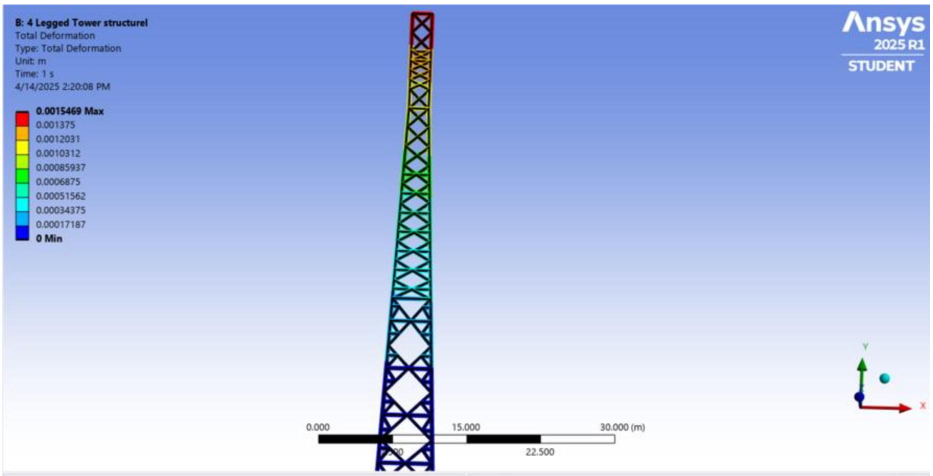



Figure 28 shows Total deformation for two-tenant equipment loading 4 -Legged Tower structure model design

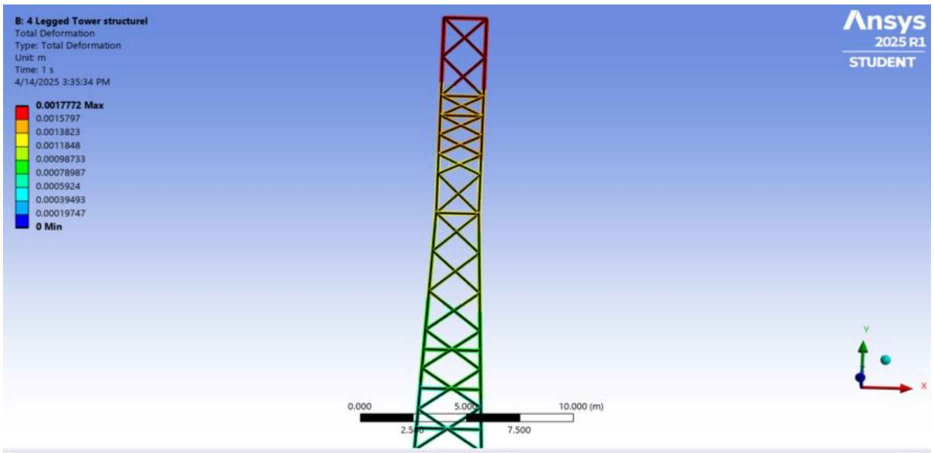



Figure 29 shows Total deformation for Three-tenant equipment loading 4 -Legged Tower structure model design

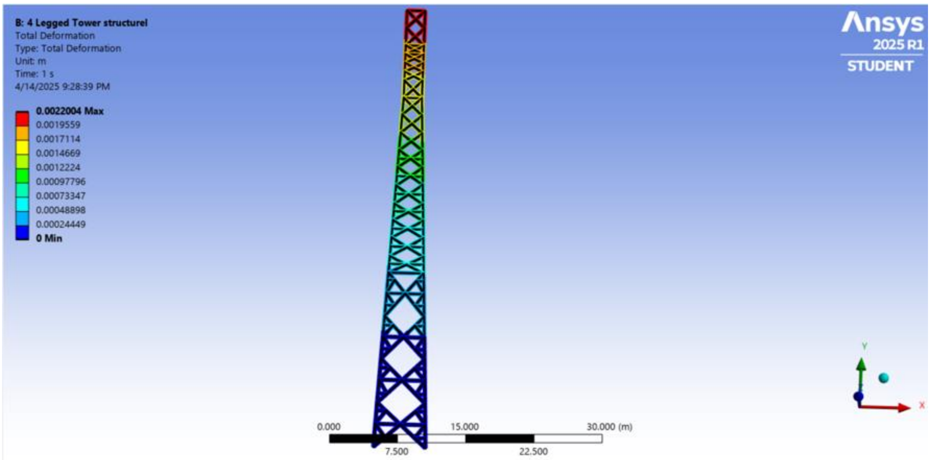



Figure 30 shows Total deformation for Four-tenant equipment loading 4 -Legged Tower structure model design

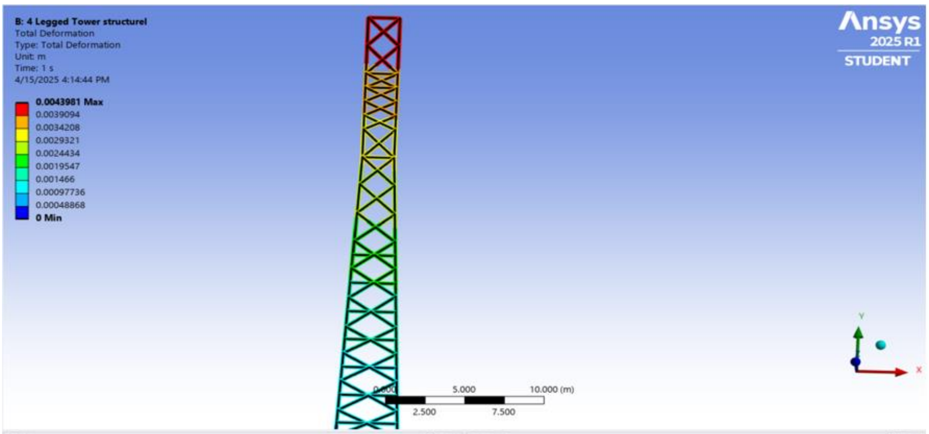



Figure 31 shows Total deformation for $N^{th}$ -tenant equipment loading 4 -Legged Tower structure model design

Equipment loading Static structural dynamic response on the tower design models are captured from ANSYS 2025 R1 work bench software results for Total deformation of the 3 -Legged Tower structure design shown as figures 32,33,34, 35 and 36 below.

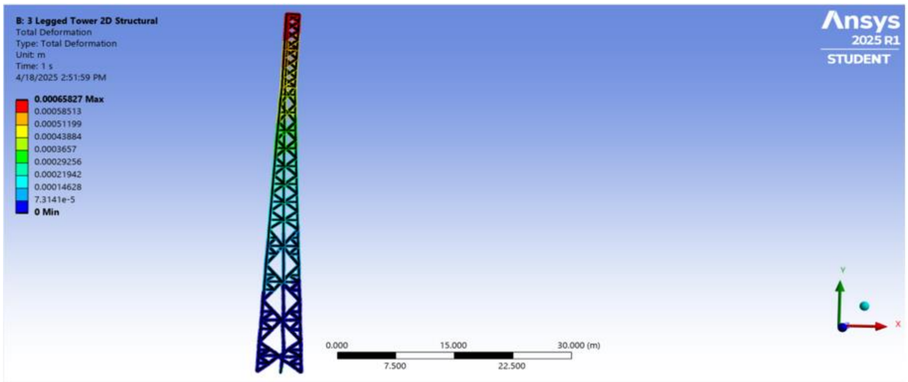



Figure 32 shows Total deformation for one-tenant equipment loading 3 -Legged Tower structure model design.

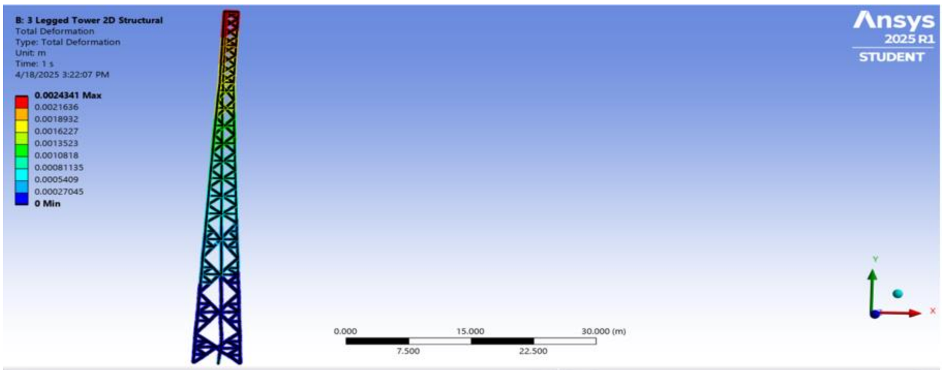



Figure 33 shows Total deformation for Two-tenant equipment loading 3 -Legged Tower structure model design.

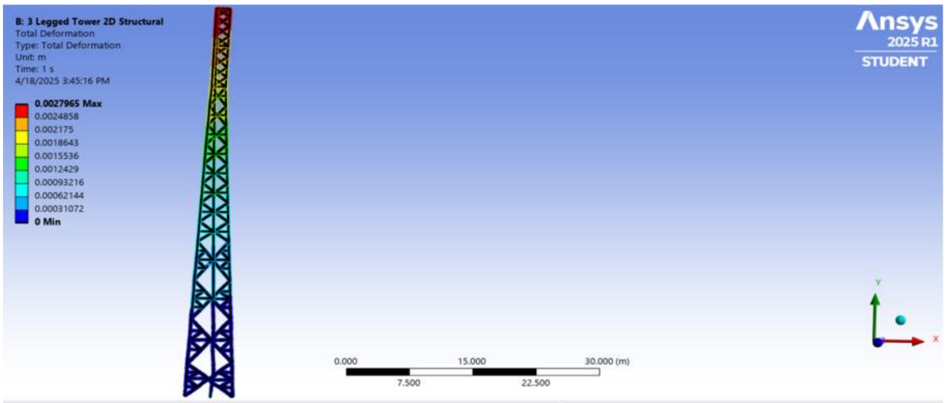



Figure 34 shows Total deformation for Three-tenant equipment loading 4 -Legged Tower structure model design

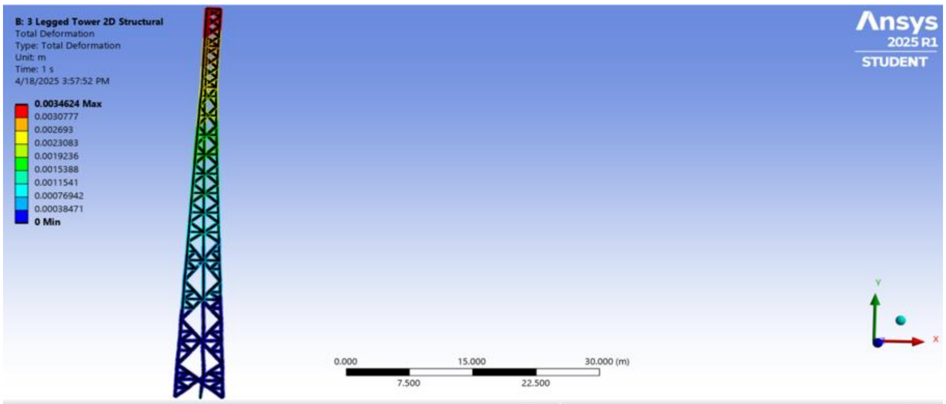



Figure 35 shows Total deformation for Four-tenant equipment loading 4 -Legged Tower structure model design

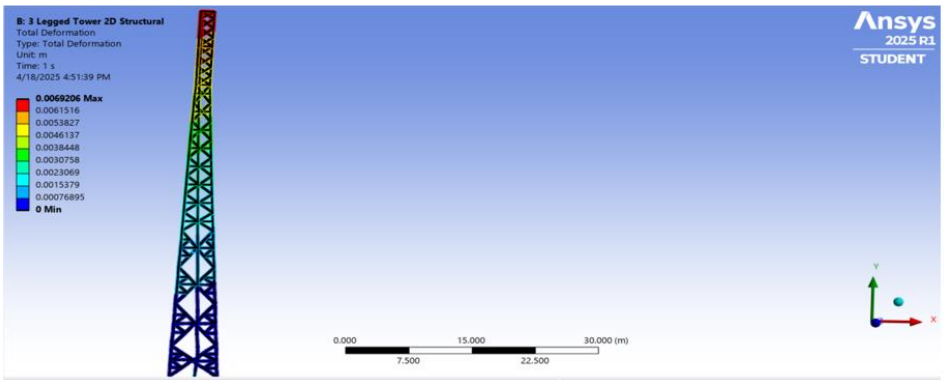



Figure 36 shows Total deformation for N$^{th}$ -tenant equipment loading 3 -Legged Tower structure model design

Comparison graphs are plotted for Static to dynamic response results and studied the tower models sustainability structure design due to increasing equipment tenant loads as shown in figure 37, 38 and 39 below.

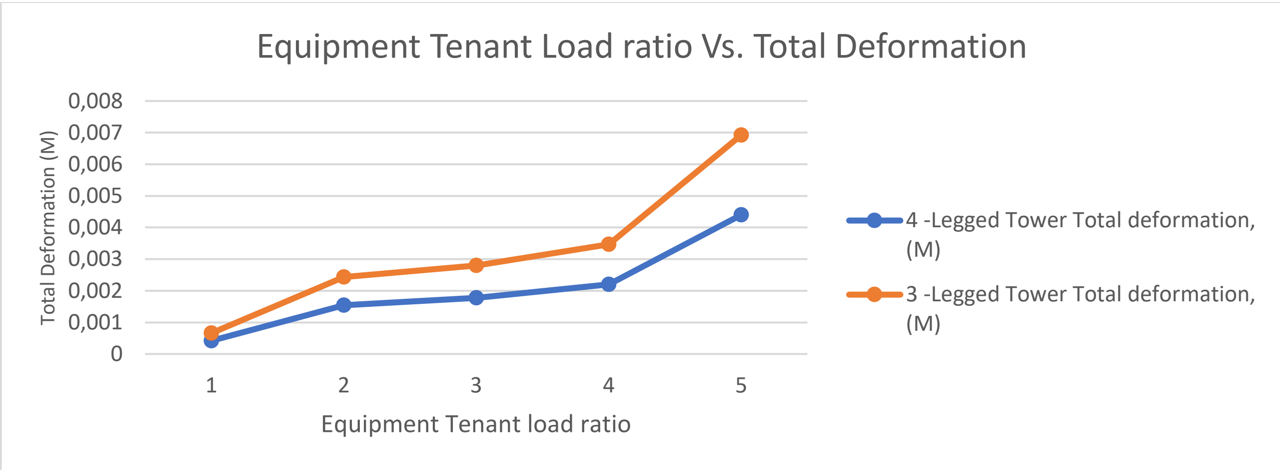



Figure 37 shows comparison graph of Equimpment Tenant Loads Vs. Total Deformation.

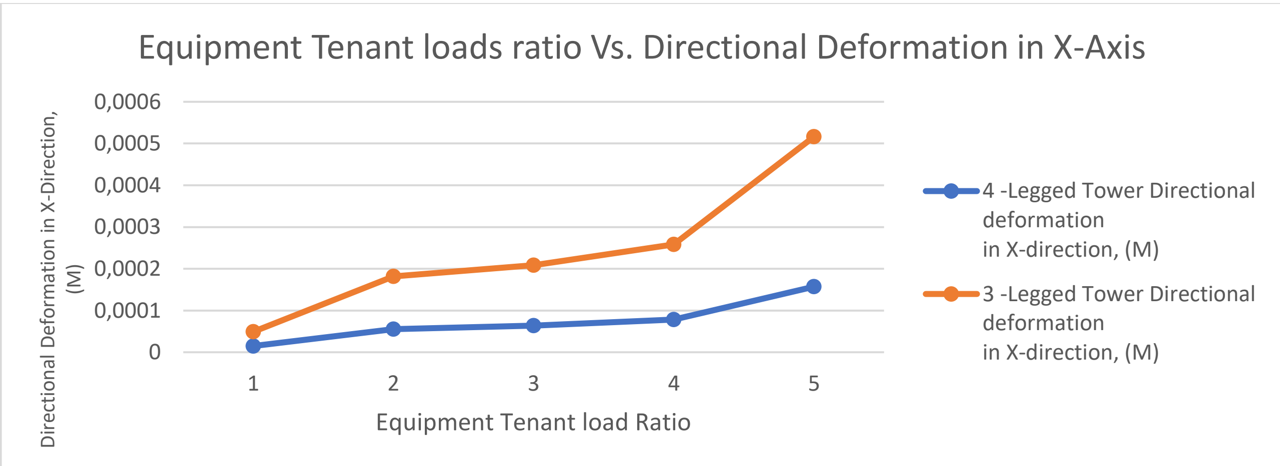



Figure 38 shows comparison graph of Equimpment Tenant Loads Vs. Directional Deformation in X-axis.

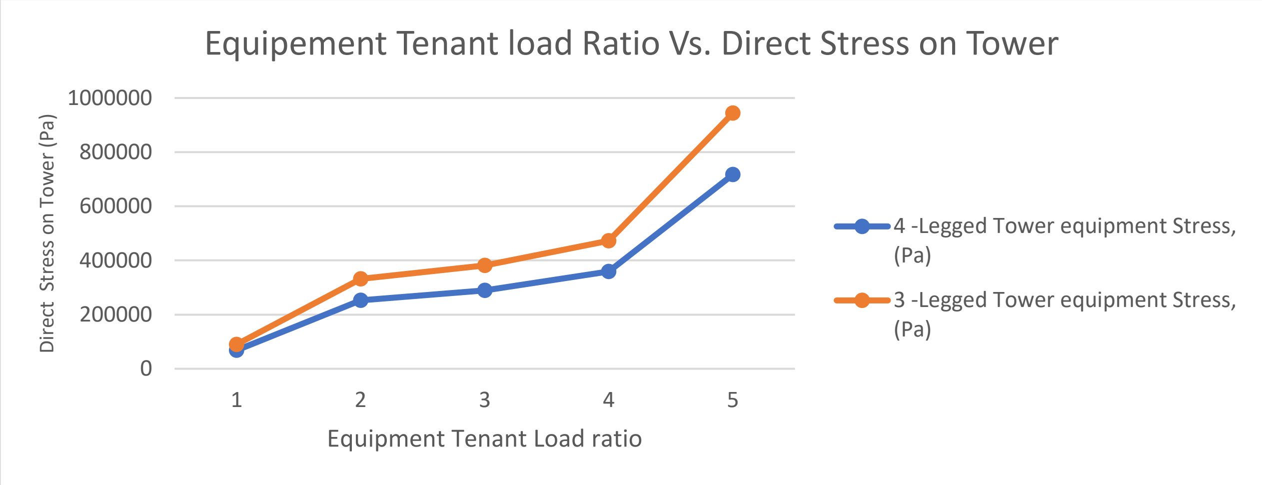



Figure 39 shows comparison graph of Equimpment Tenant Loads Vs. Direct stress on the Towers.

Comparison Tables for static to dynamic response analysis results and studied the tower models sustainability structure design as shown in Table 12, 13 and 14 below.

Table 12 shows comparison for Equimpment Tenant Loads Vs. Total Deformation of the Tower designs.

| Equipment Tenant Loads | Weights (kgs) | 4 -Legged Tower Total deformation, (M) | 3 -Legged Tower Total deformation, (M) | % Increase |
|---|---|---|---|---|
| One-Tenant Loads | 344 | 0.00041834 | 0.00065827 | 36% |
| Two-Tenants Loads | 1272 | 0.0015469 | 0.0024341 | 36% |
| Three-Tenants Loads | 1461.4 | 0.0017772 | 0.0027965 | 36% |
| Four-Tenants Loads | 1809.4 | 0.0022004 | 0.0034624 | 36% |
| ($N^{th}$)-Tenants Loads (Assume to double) | 3618.8 | 0.0043981 | 0.0069206 | 36% |
| **Average increase in Total Deformation for 3-Legged compared with 4-Legged Lattice steel Tower** | | | | **36%** |

From the above comparison Figure 37 and Table 12 for the equipment tenant loads against total deformation, The study findings shows that under higher tenancy loads (ratio >1), the 4-legged tower exhibits better resilience with lower total deformation wheras the 3-legged tower demonstrated increased total derformation at 36% greater which indicated limitations under extreme loading conditions to potential failure risks.

Table 13 shows comparison for Equimpment Tenant Loads Vs. Directional Deformation in X-axis of the Tower designs.

| Equipment Tenant Loads | 4 -Legged Tower Directional deformation in X-direction, (M) | 3 -Legged Tower Directional deformation in X-axis, (M) | % increase |
|---|---|---|---|
| One-Tenant Loads | 0.00001493 | 0.000049109 | 70% |
| Two-Tenants Loads | 0.000055207 | 0.00018159 | 70% |
| Three-Tenants Loads | 0.000063427 | 0.00020863 | 70% |
| Four-Tenants Loads | 0.00007853 | 0.00025831 | 70% |
| ($N^{th}$)-Tenants Loads (Assume to double) | 0.00015696 | 0.0005163 | 70% |
| **Average increase in Directional Deformation in X-axis for 3-Legged compared with 4-Legged Lattice steel Tower** | | | **70%** |

From the above comparison Figure 38 and Table 13 for the equipment tenant loads against directional deformation in the X-axis, The study findings shows that under higher tenancy loads (ratio >1), the 4-legged tower exhibits better resilience with lower deflection along the X-axis wheras the 3-legged tower demonstrated increased deflection along the X-axis at 70% greater which indicated limitations under extreme loading conditions to potential failure risks.

Table 14 shows comparison for Equimpment Tenant Loads Vs. Direct stress on the Tower designs.

| Equipment Tenant Loads | Force on Tower, (N) | 4 -Legged Tower equipment Stress, (Pa) | 3 -Legged Tower equipment Stress, (Pa) | % increase |
|---|---|---|---|---|
| One-Tenant Loads | 3373.47 | 68209 | 89808 | 24% |
| Two-Tenants Loads | 12474 | 252210 | 332080 | 24% |
| Three-Tenants Loads | 14331.37 | 289770 | 381530 | 24% |
| Four-Tenants Loads | 17744.06 | 358770 | 472380 | 24% |
| ($N^{th}$)-Tenants Loads (Assume to double) | 35466.41 | 717100 | 944180 | 24% |
| **Average increase in Direct stress for 3-Legged compared with 4-Legged Lattice steel Tower** | | | | **24%** |

From the above comparison Figure 39 and Table 14 for the equipment tenant loads against direct stress on the tower designs. The study findings shows that under higher tenancy loads (ratio >1), the 4-legged tower exhibits better resilience with lower stress concentration at XBX bracing joints wheras the 3-legged tower demonstrated increased stress concentration at XBX bracing joints at 24% greater which indicated limitations under extreme loading conditions to potential failure risks.

**6. Conclusion.**

This study has provided a comparative sustainability evalaution of the lattice steel 4-legged and 3-Legged telecommuncation tower structure design under increasing equipment load tenancy ratios. The results indicated that the 4-legged tower structural design offers better and superior mechanical stability with lower potential failure risks with comparison to 3-legged tower structural design as follows;

The study indicated that 4-legged lattice steel tower structure design model exhibited higher natural frequencies (~12% greater than 3-legged lattic steel tower structure design model) which indicated enhanced stiffness and sustainability.

The study indicated that 3-legged lattice steel tower structure design model exhibited increased stress concentration at XBX bracing joints (~16% greater total defromation than 4-legged lattice steel tower structure design model).

The study indicated that under higher tenancy loads (ratio >1), the 4-legged tower exhibits better resilience with lower total deformation wheras the 3-legged tower demonstrated increased total derformation at 36% greater.

The study indicated that under higher tenancy loads (ratio >1), the 4-legged tower exhibits better resilience with lower deflection along the X-axis wheras the 3-legged tower demonstrated increased deflection along the X-axis at 70% greater.

The study also indicated that under higher tenancy loads (ratio >1), the 4-legged tower exhibits better resilience with lower direct stress concentration at XBX bracing joints wheras the 3-legged tower demonstrated increased direct stress concentration at XBX bracing joints at 24% greater.

Future work should explore hybrid designs that balance cost-efficiency and structural resilience. These findings serve as a valuable reference for telecommunication infrastructure sustainability engineering knowledge to ensure long-term solutions and safety.

**References**


[1] U. communications commission UCC, "Annual Communications Sector Report 2023 Towards an Inclusive Digital Economy Annual Communications Sector Report 2023 Towards an Inclusive Digital Economy Legal Disclaimer," 2023. Accessed: Feb. 04, 2025. [Online]. Available: https://www.ucc.co.ug/industry-reports/

[2] U. communication commission UCC, "Telecommunications, Broadcasting & Postal markets Industry Report Q3," 2019. Accessed: Feb. 05, 2025. [Online]. Available: https://www.ucc.co.ug/market-performance-reports/

[3] U. communications commission UCC, "UCC-Market-Report-for-Q3-2024-September-2024," *UCC - Telecommunications , Broadcasting & postal markets industry report Q3*, 2024, Accessed: Feb. 05, 2025. [Online]. Available: https://www.ucc.co.ug/market-performance-reports/

[4] K. abdalla, E. Efthymiou, and cc baniotopoulos, "On the design of steel lattice telecommunication towers," 2014.

[5] R. Li and K. Qi, "Modal analysis and optimization design of modular steel structures used in construction," in *Vibroengineering Procedia*, EXTRICA, Dec. 2024, pp. 119–125. doi: 10.21595/vp.2024.24584.

[6] Y. M. Ghugal, Y. M. Ghugal, and U. S. Salunkhe, "Analysis and Design of Three and Four Legged 400KV Steel Transmission Line Towers: Comparative Study," 2011. [Online]. Available: https://www.researchgate.net/publication/265362517

[7] M. Marzouk and M. Alaraby, "Predicting telecommunication tower costs using fuzzy subtractive clustering," *Journal of Civil Engineering and Management*, vol. 21, no. 1, pp. 67–74, Jan. 2015, doi: 10.3846/13923730.2013.802736.

[8] A. Meti and V. Vijapur, "Seismic Analysis of Telecommunication Tower Using Viscous Damper," *International Research Journal of Engineering and Technology*, 2017, [Online]. Available: www.irjet.net

[9] A. Meti and S. Malipatil, "Enhancing seismic resilience of telecommunication tower using response spectrum analysis: A study with and without viscous dampers," in *Deep Science Publishing*, Deep Science Publishing, 2024, pp. 50–61. doi: 10.70593/978-81-981367-9-4_4.

[10] G. Soltanzadeh, H. Shad, M. Vafaei, and A. Adnan, "Seismic performance of 4-legged Self-supporting Telecommunication Towers," *Journal of Applied Sciences and Engineering Research*, vol. 3, 2014, doi: 10.6088/ijaser.030200002.

[11] N. Gunathilaka, C. Sujeewa Lewangamage, and M. Jayasinghe, "ANALYSIS OF FOUR LEG TELECOMMUNICATION TOWERS FOR SEISMIC LOADING USING RESPONSE SPECTRUM METHOD," 2013. [Online]. Available: https://www.researchgate.net/publication/304280670

[12] K. Kr.Sharma, D. S.K, D. Kumar Singh, and S. A.K, "Comparative Analysis of Steel Telecommunication Tower Subjected to Seismic & Wind Loading," *Civil Engineering and Urban Planning: An International Journal (CiVEJ)*, vol. 2, no. 3, pp. 15–33, Sep. 2015, doi: 10.5121/civej.2015.2303.

[13] U. K. de Paula, L. F. R. de Carvalho, E. D. Reis, and D. A. B. Damasceno, "Static and dynamic analysis of telecommunication towers subjected to wind," *Research, Society and Development*, vol. 11, no. 4, p. e18611427279, Mar. 2022, doi: 10.33448/rsd-v11i4.27279.

[14] T. Chandra and S. Sengupta, "Dynamic analysis of telecommunication tower for optimum modal combination and elemental discretization," *Int J Eng Adv Technol*, vol. 9, no. 1, pp. 2229–2237, Oct. 2019, doi: 10.35940/ijeat.A9720.109119.

[15] A. Şeker, M. Hatipoğlu, İ. Arı, and Y. Çetin, "Structural and Morphological Analysis of Electrogalvanized Coating on Sheet Metal," 2024. [Online]. Available: www.journaleras.com

[16] E. Toklu, M. Gur, and M. Celtik, "Investigation on effects of steel surface properties on galvanization behavior," 2018. [Online]. Available: www.journaleras.com.