



Technical Sciences  
Academy of Romania  
www.jesi.astr.ro

## **Journal of Engineering Sciences and Innovation**

Volume 11, Issue 3 / 2026, pp. 373-390

<http://doi.org/10.56958/jesi.2026.11.3.373>

### **A. Mechanical Engineering**

Received 04 December 2025

Accepted 11 September 2026

Received in revised form 22 May 2026

## **Theoretical and Numerical Studies of Stresses in Trusses Using Analytical Calculation and Finite Element Analysis**

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**Abstract.** This paper presents a comprehensive study of a truss beam, focusing on the design, analytical calculation, and computational validation of two configurations: one with welded joints and another with bolted joints. Analytical methods such as the method of joints were used to calculate internal forces in the beam members, followed by validation through the structural analysis software MDSolids. Additionally, a detailed Finite Element Analysis (FEA) was conducted using Ansys, examining key parameters like displacements and Von Mises stress. The results from both the analytical and FEA methods were compared to evaluate the performance of the welded and bolted truss beams.

**Keywords:** structural mechanics, truss, analytical calculation, random vibration, structural deformation.

### **1. Introduction**

Truss beams are essential in structural engineering, frequently used in the construction of bridges, industrial halls and other structures that require effective structural support. These beams are valued for their ability to distribute loads evenly and for their efficiency in the use of materials. The choice of method of joining the beam components can significantly influence the structural performance and its durability [1-5].

In general, trusses can be joined by two main methods: welding and bolting. Each method has specific advantages and disadvantages, and the choice between them depends on the project requirements, costs, availability of materials and installation conditions [3][10]. Welding provides a permanent and continuous joint, but can be more expensive and requires special equipment and skills.

Bolting allows for easier construction and dismantling but can lead to local stress concentrations and the need for periodic joint maintenance.

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**Welded beams**

Welding creates permanent joints between structural components, providing continuity in load transfer. This method is often used for structures that require high strength and durability. However, welding requires specialized equipment and skills and may involve additional costs. Also, the welding process can affect the material properties in the joint area.

**Beams with bolts**

Bolts allow for relatively easy construction and dismantling and are frequently used in prefabricated structures or temporary construction. This method can lead to the concentration of efforts in the joint areas and requires regular maintenance.

**1.1. The objectives of the work**

This study focuses on the design, analytical evaluation, and computational validation of two truss beam variants: one with welded joints and the other with bolted joints. The chapter highlights the primary objectives of the research, detailing the methods used to achieve each goal and explaining how these contribute to the broader understanding of truss beam behavior. The analytical calculations, validation through software, and finite element analysis (FEA) form the main components of the study, ultimately leading to a comparison of the two variants.

This chapter outlines five main objectives of the research:

1. Design and modeling of truss beams: develop CAD models of both welded and bolted truss beams to be used for analysis and comparison.
2. Analytical calculation of internal forces: calculate the forces acting on each member of the truss beam using the method of joints.
3. Validation using MDSolids: validate the analytical results with the structural analysis software MDSolids to ensure the accuracy of the theoretical calculations.
4. Finite element analysis: perform an in-depth FEA of the two beam variants to evaluate displacement, stress distribution, and reaction forces under load.
5. Comparative analysis and conclusions: compare the theoretical and computational results to draw conclusions about the relative performance of welded versus bolted joints.

The objectives focus on integrating both theoretical and practical approaches, ensuring that the research delivers a robust analysis of truss beam performance under different connection types. Through this structured approach, the chapter provides a clear approach for achieving the research goals and understanding the structural dynamics of truss beams.

**2. Theoretical model of the truss beam**

In structural engineering, truss beams are vital components due to their ability to efficiently transfer loads while minimizing material usage. The theoretical modeling of a truss beam forms the foundation of understanding its behavior under various loading conditions [2][8]. This chapter aims into the development of an analytical

model for a simple truss beam, designed to determine the internal forces within its members and to predict how the structure responds to external loads.

This chapter will also introduce the key formulas and equilibrium equations that govern the internal forces within the truss, providing a detailed mathematical foundation for further analysis.

### **2.1. Assumptions and simplifications for the analytical model**

The behavior of a truss beam can be simplified to allow for an easier mathematical approach while still maintaining sufficient accuracy for most engineering applications. The assumptions and simplifications used in this study are based on classical truss theory and mechanics, which enable us to compute the internal forces and analyses the stability of the truss beam [5][17].

Trusses are pin-jointed structures, each connection (joint) between two or more members is modelled as a frictionless hinge (pin-joint), allowing free rotation but no translation [4]. This assumption means that members only experience axial forces (tension or compression) and not bending moments.

Implication, with only axial forces are considered, meaning members either stretch (tension) or shorten (compression) [9][11].

Members are straight and deform only axially, the members of the truss beam are assumed to be straight, with uniform cross-sectional areas. They are idealized as deforming only along their length, meaning lateral deformations or out-of-plane buckling are neglected.

Forces perpendicular to the axis of the member are not considered. The deformation of the members does not affect the geometric shape of the structure.

Loads are applied only at the joints and all external forces and reactions are applied directly at the joints. No loads are applied along the length of the members and forces are transferred through the members purely as axial loads. This is a crucial assumption for using methods like the method of joints.

In this model, the self-weight of the truss members is assumed to be negligible compared to the applied external loads. While real truss members do have weight, the influence is small in comparison to other loads (such as  $F_1$  and  $F_2$ ).

Material properties are homogeneous and isotropic, the material of the truss members is assumed to be homogeneous (same properties throughout) and isotropic (same properties in all directions) [7][14][8].

### **2.2. Simplifications for the analytical model**

To simplify the analysis and ensure tractability, the following simplifications are introduced for the research:

- Plane truss assumption, in which the truss beam is considered as a two-dimensional (2D) plane truss. All forces and reactions occur in the same plane, and out-of-plane forces are neglected [3].
- Because each member is assumed to carry only axial forces, shear forces and bending moments are neglected. This is a direct consequence of the pin-joint

assumption.

- The truss is statically determinate, meaning the number of unknowns (forces in the members and reactions at the supports) equals the number of independent equilibrium equations [2][12].

By making these assumptions and simplifications, the analysis of the truss beam becomes more straightforward, allowing for the determination of forces in each member, ensuring that the results are mathematically tractable.

### 2.3. Force application, nodes and bars

In the theoretical analysis of a truss beam, understanding the distribution of forces and how they are applied to the structure is essential for accurately calculating internal forces within the bars and nodes. This chapter describes the forces applied to the truss beam, focusing on the configuration of nodes, the types of supports, and how these factors influence the theoretical calculations.

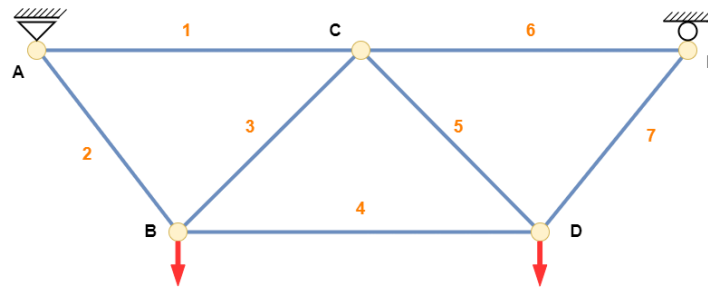


Fig. 1. Theoretical model for truss beam.

The truss beam in this study consists of five nodes (labeled A, B, C, D, and E) and seven bars (labeled 1 through 7). Two external forces,  $F_1$  and  $F_2$ , each with a magnitude of 20 N, are applied at nodes B and D, respectively. These forces are vertical loads, representing typical loading conditions a truss might experience in practical applications, such as in bridges or roof structures [3]. The forces are assumed to act only in the vertical direction, simplifying the analysis while providing insights into the behavior of the beam under such loading conditions.

The truss beam's configuration, with external forces applied at nodes B and D, and supports at nodes A (cylindrical joint) and E (simple rest), creates a stable structure. The internal forces within the bars are calculated using the method of joints, ensuring that all forces within the truss are in equilibrium.

### 3. Analytical calculations and validation

This chapter focuses on the analytical calculations used to determine the internal forces within the truss beam and the subsequent validation of these results. The analysis begins with the application of classical structural mechanics principles, particularly the method of joints, to solve for the forces in the members of the truss beam.

### 3.1 Analytical calculation results

The node isolation method, also known as the node method, is a method used in the analysis of trusses to determine the internal forces in the beams. This method involves isolating an individual node and analyzing the forces acting on it using equilibrium conditions [5].

It assumes the balance of horizontal and vertical forces. At each node, the sum of the horizontal forces and the sum of the vertical forces must be zero, according to the principle of static equilibrium.

Sum of horizontal forces:  $\sum F_x = 0$

Sum of vertical forces:  $\sum F_y = 0$

To determine the stresses in the truss members, the node isolation method was used. The analyzed beam has five nodes (A, B, C, D, E) and seven bars (1-7). Nodes B and D are subjected to concentrated forces  $F_1$  and  $F_2$  of 20 N each.

Following the calculation of the equations from for each node, using equilibrium equations, the following values of the stresses in each bar resulted, which are presented in Table 1 below.

Table 1. Tension values for nodes and bars

| Node | Bar | Force value [N] |
|------|-----|-----------------|
| A    | AB  | 30              |
|      | AC  | 36.5            |
|      | AD  | 1.1             |
| B    | BD  | -1.3            |
|      | BE  | 35.6            |
| C    | CD  | -30.9           |
| D    | DE  | -28.9           |

It can be seen from the presented values, that for the bars of the truss beam system, both tensile and compression forces were obtained.

Bar AB is subjected to a tensile force of 30 N, which means that this bar is stretched. Bar AC, with a tensile force of 36.5 N, is subjected to the highest tensile force of all the bars. This high value shows that node C is significantly pulled towards nodes A and B.

Bar AD is subjected to a relatively small tensile force of only 1.1 N. This small value suggests that bar AD contributes minimally to the absorption of forces in the structure, being mostly a connecting element between nodes A and D.

Bar BD is subjected to a compressive force of -1.3 N, indicating that it is pushed and bar BE is subjected to a tensile force of 35.6 N, very close to the value obtained for bar AC. This bar helps transfer the force from node B to node E, which is fixed by a simple support.

Bar CD is subjected to a high compressive force of -30.9 N, indicating that it is strongly pushed, especially under the influence of the force  $F_2$  applied at node D.

Bar DE is subjected to a compressive force of -28.9 N, almost as large as bar CD.

### 3.2 Validation with MDSolids

Validation of analytical calculations is essential to ensure the accuracy and reliability of the results obtained. In this subchapter, the MDSolids is used to verify the theoretical results of the stresses in the truss beam bars. The MDSolids program provides effective tools for analyzing the structure and determining the stress state in each bar.

Using this software, one can check the distribution of forces in the bars of a truss beam and confirm whether they are subjected to tensile or compressive. The results obtained contribute to a better understanding of structural behavior and allow the design to be optimized for safety and structural efficiency.

To validate the results obtained by analytical calculation, the beam was modeled and analyzed in the MDSolids program.

In Fig.2 presented below, the values for each bar of the beam were obtained, from which it can be seen whether it is subjected to traction (blue) or compression (yellow).

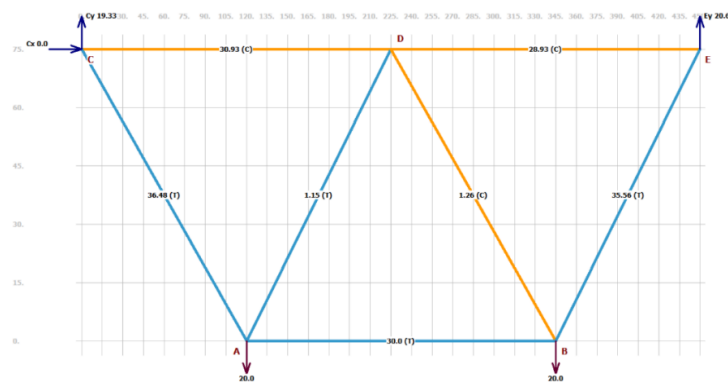


Fig. 2. MDSolids results for truss.

MDSolids generated the axial forces in the bars, along with indications of whether they are in tension or compression. The results are compared directly with those obtained by analytical calculation, which are presented in Fig.3.

| Normal Stresses in Truss Members |              |                            |                 |
|----------------------------------|--------------|----------------------------|-----------------|
| Member                           | Force<br>(N) | Area<br>(mm <sup>2</sup> ) | Stress<br>(MPa) |
| AB                               | 30.0         | 6,000.00                   | 0.005000        |
| AC                               | 36.5         | 4,000.00                   | 0.009125        |
| AD                               | 1.1          | 3,000.00                   | 0.000           |
| BD                               | -1.3         | 3,000.00                   | 0.000           |
| BE                               | 35.6         | 4,000.00                   | 0.008900        |
| CD                               | -30.9        | 6,000.00                   | -0.005150       |
| DE                               | -28.9        | 6,000.00                   | -0.004817       |

Fig. 3. Table with resulted values from software.

**AB** bar: 30 N (*tension*) – confirmed by MDSolids.

**AC** Bar: 36.5 N (*tension*) – confirmed by MDSolids.

**AD** bar: 1.1 N (*tension*) – confirmed by MDSolids.

**BD** bar: -1.3 N (*compression*) – confirmed by MDSolids.

**BE** bar: 35.6 N (*tension*) – confirmed by MDSolids.

**CD** bar: -30.9 N (*compression*) – confirmed by MDSolids.

**DE** bar: -28.9 N (*compression*) – confirmed by MDSolids.

Comparing the results obtained from MDSolids with the analytical ones showed a very good agreement between them, thus validating the value of the theoretical calculations.

The analytical calculation of the stresses in the truss beam bars was successfully carried out, and the validation of these calculations in MDSolids confirmed this. These results will be used later for comparison with analyzes performed in the ANSYS program, in the finite element analysis chapter.

#### 4. Finite element analysis (FEA)

Finite element analysis (FEA) is a method used to investigate the structural behavior of truss beams under given loads. This chapter will detail the performance of the FEA analysis in the Ansys program for two variants of truss beams: one welded and one bolted. Both models will be subjected to the same forces and the displacements in the bars, the equivalent von Mises stress, the value of the reactions and other important parameters will be tracked.

##### 4.1 CAD model development

CAD models are an important step in the structural analysis process, providing a detailed geometric representation of components. In this work, the CAD models of the bars and fasteners for the truss beam were made in the CATIA V5 program. These models will be used in the structural analysis stage to evaluate the behavior of the beam under load. The bars for the welded truss beam have been designed with the following dimensions: width: 25 mm, thickness 2 mm, lengths 135 mm, 155 mm and 225 mm for welded beam bars, and bolted truss beam bars are 200 mm long. These dimensions have been chosen to ensure a balance between strength and weight, being suitable for the targeted structural applications.

###### 4.1.1 Welded and bolted truss beam models

Welded beam and bolted beam have similar configurations, but differ in how the bars are connected to the nodes. In the case of welded beam, the ends of the bars are fixed with the help of fixed supports, ensuring a permanent and rigid connection. In contrast, the bolted beam uses screws to clamp the bars, allowing for a removable and flexible connection [7][13]. These structural differences are essential to understand the behavior of the beam under applied loads and to evaluate the performance of each variant.

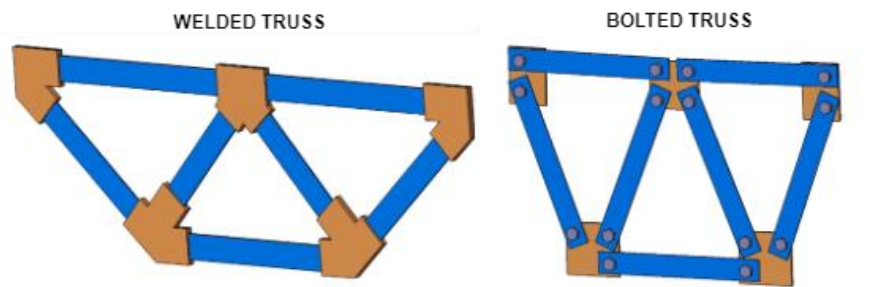


Fig. 4. CAD models for trusses.

The welded truss is characterized by its rigid joints, where the bars are permanently connected to the supports, presented in Fig.4 [14][16]. This method results in a structure that behaves as a single unit under external forces, offering high stiffness and resistance to deformation.

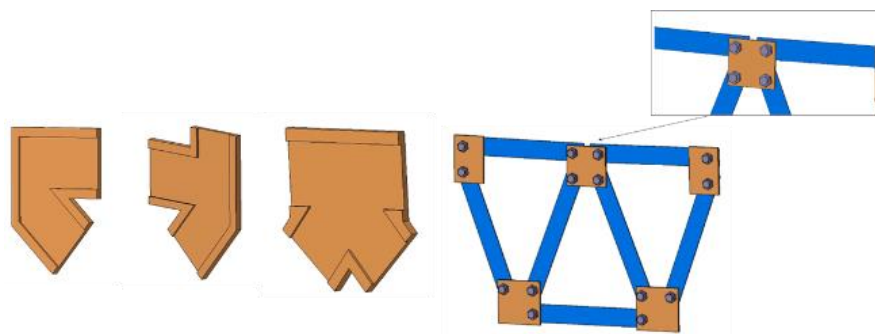


Fig. 5. Fixing methods used.

The bolted connections consist of bolts, nuts, and plates, where the bolts pass through the plates and the ends of the bars, holding the entire structure together, as in Fig.5. These bolts allow the truss to experience slight movement at the joints, depending on the level of tightening and the friction between the bars and the plates.

## 4.2 Simulation setup in ANSYS

In this chapter, the process of preparing the welded and bolted truss beams for simulation within the ANSYS software environment will be outlined. This simulation involves two main stages: a static structural analysis to assess the mechanical response under static loading, and a vibration analysis to evaluate the dynamic behavior of the truss beams under vibrational forces.

The CAD models created in CATIA V5 for both the welded and bolted truss variants will be imported into ANSYS for further analysis.

*Key steps in simulation setup*

**Importing CAD Models-** the detailed 3D CAD models for the truss beams, including all structural elements, are imported into ANSYS to maintain the geometric accuracy of the beam configurations.

**Material assignment-** for both variants, aluminum is assigned as the material, with appropriate material properties such as Young's modulus, Poisson's ratio, and density.

#### *Analysis Types*

**Static structural analysis,** this will evaluate how each truss variant responds to static forces, focusing on parameters such as total deformation, von Mises stress, and strain energy.

**Vibration analysis,** a random vibration analysis will be conducted to study how the truss beams behave under dynamic loading conditions, evaluating their ability to handle vibrational forces across different frequencies.

#### *4.2.1 Boundary conditions and load application*

In the finite element analysis simulation performed in ANSYS, accurately defining the boundary conditions and load application is essential to achieving reliable results. These aspects are important for simulating how both the welded and bolted truss variants behave under the applied forces, as the correct modeling of support and contact conditions directly influences the deformation and stress results.

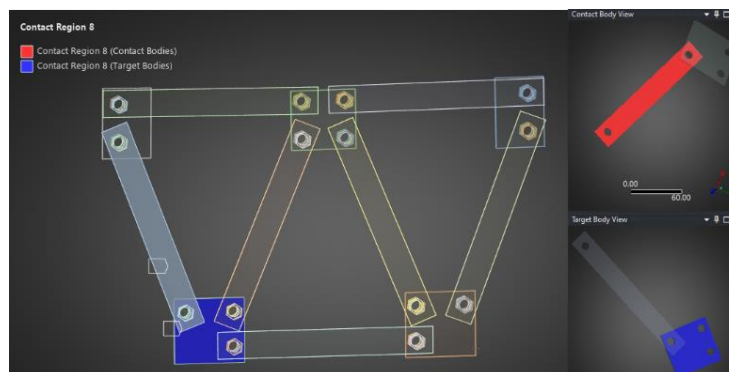


Fig. 6. Contact between element components in bolted truss.

The contact between the bolts and the bars was modeled as a frictional contact, as presented in Fig. 6 and Fig. 7. This allows for some level of movement or slippage between the components, depending on the applied forces.

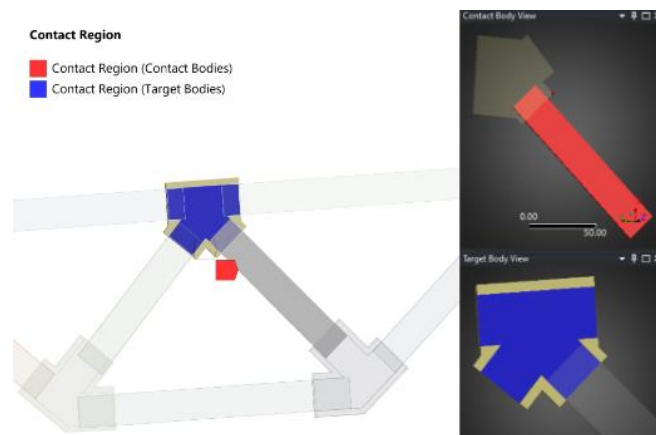


Fig. 7. Contact between element components in welded truss.

A load of 20 N was applied to both the welded and bolted trusses, aspect presented in Fig. 8 below. This load was distributed across specific nodes of the trusses to simulate external forces. In this case, the load was applied at bottom of the truss, which is a critical point in the truss structure.

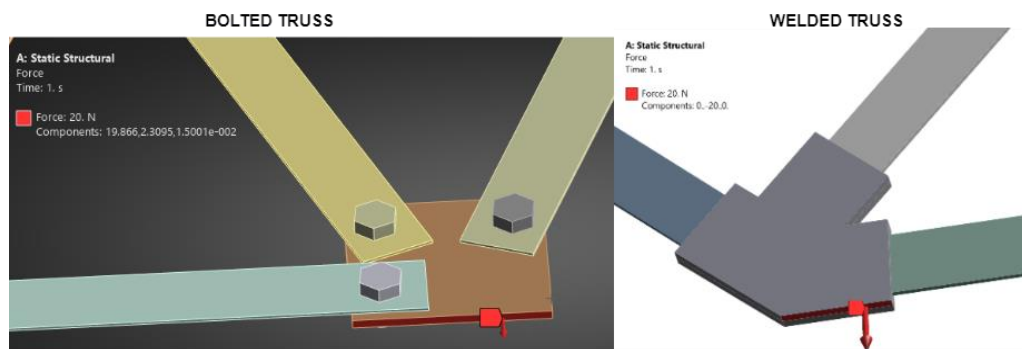


Fig. 8. Force applies zones for trusses.

By defining fixed supports, contact conditions, and applying a 20 N load, the structural behavior of both the welded and bolted trusses was successfully simulated in ANSYS.

#### 4.2.2 Material properties

Both the welded and bolted truss beams are made from aluminum, a lightweight yet strong material often used in structural applications due to its high strength-to-weight ratio, corrosion resistance, and good machinability.

The properties used for aluminum include its elastic modulus, Poisson's ratio, density, and yield strength, among other parameters are presented in Table 2.

Table 2. Material properties for aluminum

| Property                                                                | Value  |
|-------------------------------------------------------------------------|--------|
| Density ( $\text{kg/m}^3$ )                                             | 2700   |
| Young's Modulus (E)(MPa)                                                | 70,000 |
| Poisson's Ratio ( $\nu$ )                                               | 0.33   |
| Yield Strength (MPa)                                                    | 250    |
| Ultimate Tensile Strength (MPa)                                         | 310    |
| Shear Modulus (MPa)                                                     | 26,000 |
| Thermal Conductivity ( $\text{W/m}\cdot\text{K}$ )                      | 237    |
| Specific Heat ( $\text{J/kg}\cdot\text{K}$ )                            | 900    |
| Coefficient of Thermal Expansion ( $\mu\text{m/m}\cdot^\circ\text{C}$ ) | 23.1   |

Each property influences how the truss beams respond to applied forces and external conditions. For example, the Young's modulus directly impacts the beam's stiffness, while the density is important for assessing its mass and inertia during vibrational analysis.

## 5. Static structural analysis results

In this chapter, the results of the static structural analysis performed using finite element analysis are presented and analyzed. The primary objective of this analysis is to assess the behavior of two different truss beam configurations—one with welded joints and the other with bolted joints—under the same loading conditions. The parameters analyzed include total deformation, Von Mises stress, and strain energy, which provide critical insights into the structural performance of each variant.

### 5.1. Deformation

In this chapter, the results obtained from the finite element method simulations are presented and analyzed for the two types of truss beams: the welded beam and the bolted beam. The main parameters monitored in this analysis are the total strains and the equivalent von Mises stress.

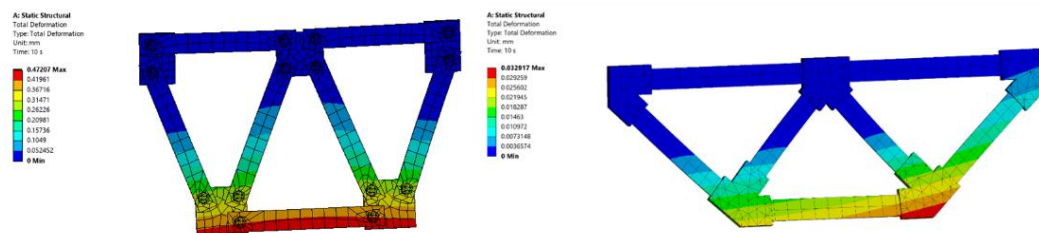


Fig. 9. Deformation values for trusses.

The total deformations represent the amount by which the structure moves under the action of the applied loads. This parameter is essential for evaluating the rigidity of the structure and its ability to withstand external forces without suffering excessive deformations.

The results presented in Fig.9 show that the welded beam shows significantly less total deformation compared to the bolted beam. This indicates that the welded beam is much stiffer and more resistant to deformation under the action of the same forces. The order of magnitude difference between strain values (0.032 mm vs. 0.47 mm) suggests that welding provides a much stronger and more stable structural connection compared to bolting.

## 5.2. von Mises stress

The equivalent von Mises stress is a criterion used to assess the potential for material failure under various stress conditions. This combines the normal and tangential stresses into a single parameter, which can be compared to the material strength to determine whether the structure is safe or at risk of failure.

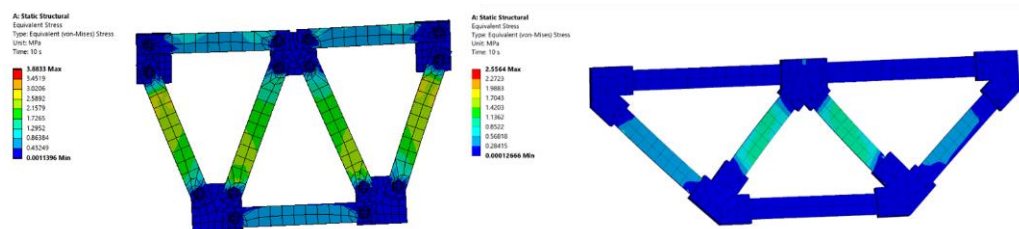


Fig. 10. von Mises stress values for trusses.

The equivalent von Mises stress is higher for the bolted beam (3.88 MPa) compared to the welded beam (2.55 MPa). This indicates that the bolted beam is more demanding in terms of material strength, with a greater risk of failure under applied loads.

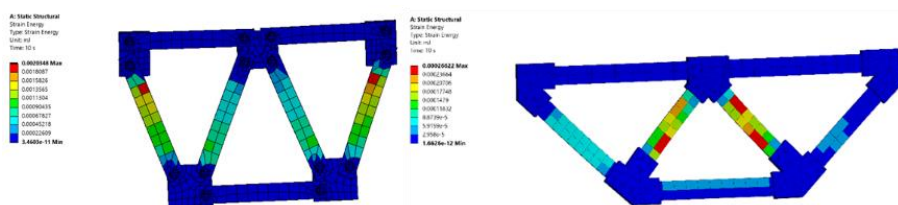


Fig. 11. Strain energy values for trusses.

## 5.3. Comparison between welded and bolted truss

The static structural analysis of the welded and bolted truss beams has provided insightful data regarding the differences in their behavior under identical loading conditions. By comparing key parameters such as total deformation and von Mises stress, we can better understand the structural performance and the advantages or disadvantages of each connection type.

Table 3. Comparison of parameters for welder and bolter trusses

| Parameter              | Welded truss beam | Bolter truss beam |
|------------------------|-------------------|-------------------|
| Total Deformation (mm) | 0.032             | 0.47              |
| Von Mises Stress (MPa) | 2.55              | 3.88              |
| Strain Energy (mJ)     | 0.00026           | 0.002             |

This significant difference highlights that the welded truss is far more rigid and resistant to deformation than the bolted truss. The rigidity of the welded beam is due to the continuous, strong connections at the joints, which prevent the bars from experiencing rotational or translational movement. In contrast, the bolted joints allow for slight movement, resulting in a larger overall displacement. This suggests that the welded truss beam is better suited for applications where minimal deflection and higher rigidity are essential.

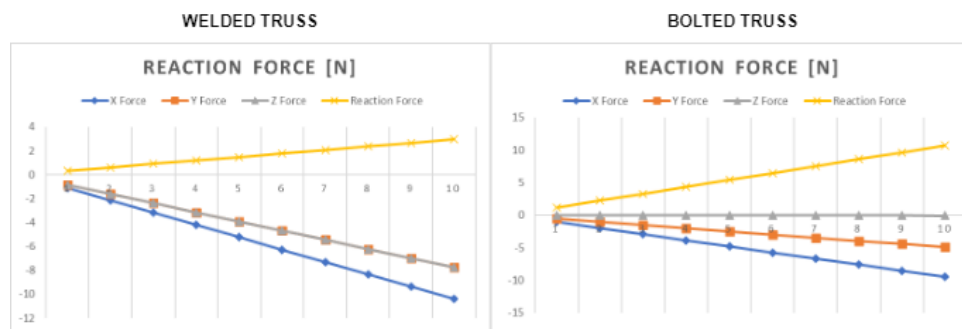


Fig. 12. Reaction force diagram.

From the results of the static structural analysis, the welded truss beam shows superior performance in terms of rigidity and stress distribution. It experiences significantly less total deformation and lower von Mises stress, making it more reliable and stable under static loading conditions. The bolted truss beam, while easier to assemble and more flexible, is subjected to higher stress levels and greater deformation, indicating that it may not be as suitable for applications where stiffness and minimal displacement are required.

#### 5.4 Random vibration analysis

In addition to the previously performed static analysis, we also performed a Random vibration analysis to evaluate the dynamic behavior of truss beam. This analysis is essential to understand how structures react to random vibrations, which can occur under various operating conditions, such as dynamic loading or vibration environments.

The purpose of this analysis is to evaluate the displacement responses of both truss beams under varying random vibration frequencies. In this study, 10 different frequencies were selected, and the displacement per unit frequency (mm/Hz) was calculated for each case.

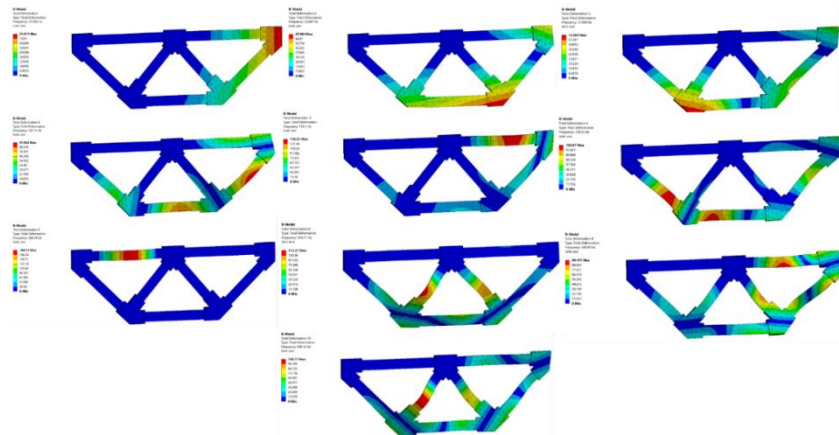


Fig. 13. Random vibration results for welded truss

The bolted truss beam shows significantly higher displacement at lower frequencies, peaking at 69.8 Hz with a displacement of 572.88 ( $mm^2/Hz$ ).

The largest displacement of 8014.5 ( $mm^2/Hz$ ) occurs at 1036 Hz, indicating a potential resonance point, where the beam is more likely to experience dynamic instability, presented in Fig. 13.

The results give an insight into how each truss variant behaves under dynamic conditions and helps to identify potential weaknesses in the design.

The displacement data collected for each frequency is a critical indicator of how well the structure can withstand random vibrations without experiencing significant deformation.

The purpose of this analysis was to determine the dynamic response of the beams under the action of vibrations applied at different frequencies.

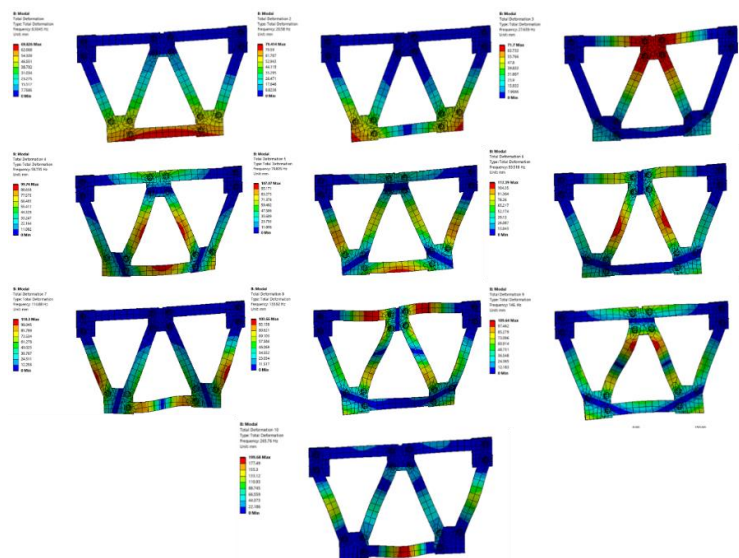


Fig. 14. Random vibration results for bolted truss.

The welded truss beam exhibits much lower displacements overall, with a maximum displacement of 378.49 ( $\text{mm}^2/\text{Hz}$ ) at 81.01 Hz, suggesting greater stability and rigidity under vibrational loads.

Deformation for the welded truss remain consistently lower across all frequencies, as visible in Fig. 14, indicating superior performance in resisting vibrations compared to the bolted truss.

Table 4. Frequency and displacement results for each truss

| Bolted truss   |                                            | Welded truss   |                                            |
|----------------|--------------------------------------------|----------------|--------------------------------------------|
| Frequency [Hz] | Displacement [ $(\text{mm}^2)/\text{Hz}$ ] | Frequency [Hz] | Displacement [ $(\text{mm}^2)/\text{Hz}$ ] |
| 69.8           | 572.88                                     | 67.8           | 136.42                                     |
| 71.7           | 186.                                       | 75.6           | 98.559                                     |
| 79.4           | 306.33                                     | 81.01          | 378.49                                     |
| 99.74          | 166.54                                     | 97.8           | 67.292                                     |
| 107.07         | 143.65                                     | 99.4           | 28.274                                     |
| 109.6          | 82.275                                     | 103.9          | 45.164                                     |
| 110.3          | 105.9                                      | 108.1          | 31.744                                     |
| 117.39         | 147.36                                     | 112.5          | 39.962                                     |
| 199.68         | 150.12                                     | 136.6          | 120.31                                     |
| 103.6          | 8014.5                                     | 184.7          | 119.79                                     |

The results from the random vibration analysis presented in Table 4 above, show that the welded truss beam is more robust and experiences significantly less deformation across most frequencies compared to the bolted truss beam. The bolted truss, on the other hand, demonstrates higher vulnerability to vibrational forces, particularly at higher frequencies, where it approaches resonant conditions.

#### 5.4.1 Vibrational behavior

The random vibration analysis provides insights into how each structure deforms and the stresses it endures under various vibrational conditions.

The key parameters analyzed include directional deformation and von Mises stress, which are critical for assessing how each truss variant responds to dynamic forces and vibrations over time.

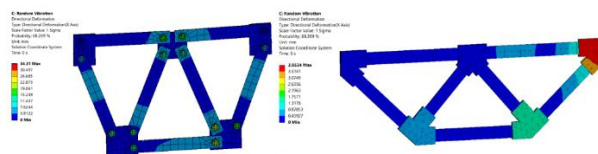


Fig. 15. Directional deformation in vibration analysis for trusses.

The maximum von Mises stress for the bolted truss reached 99,770 MPa, as in Fig.15, which indicates a high likelihood of material failure under extreme vibrational forces. This high value suggests that the structure may experience significant stress concentrations in certain regions, respectively for average von Mises stress was 4,623.8 MPa, which is concerning, as it indicates a relatively high stress level across the structure, even under average vibrational conditions.

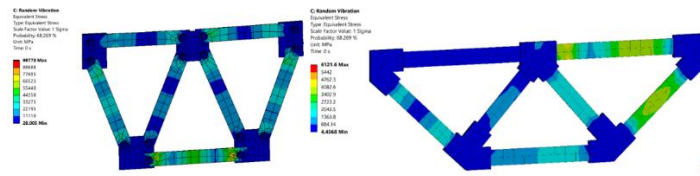


Fig. 16. Equivalent stress in vibration analysis for trusses.

The maximum von Mises stress for the welded truss was 6,121.6 MPa, significantly lower than the bolted truss but still a substantial stress level.

The average von Mises stress was 4,623.8 MPa, which is similar to the bolted truss.

Table 5. Displacement and von Mises in PSD analysis

| Parameter | Bolted truss |            | Welded truss |           |
|-----------|--------------|------------|--------------|-----------|
|           | Displacement | Von Mises  | Displacement | Von Mises |
| Minimum   | 0. mm        | 28.005 MPa | 0            | 4.4568    |
| Maximum   | 34.31 mm     | 99770 MPa  | 3.9534       | 6121.6    |
| Average   | 6.5477 mm    | 4623.8 MPa | 6.5477       | 4623.8    |

The results presented in Table 5 reveal how each truss beam responds to vibrational forces and help identify areas of potential structural concern.

The bolted truss shows a higher susceptibility to deformation and stress under vibrational loads compared to the welded truss. The maximum displacement and von Mises stress are significantly higher for the bolted truss, indicating that the bolted connections introduce flexibility and stress concentrations that can compromise the structural integrity under dynamic conditions.

#### 5.4.2 Frequency response analysis

The Frequency Response Analysis is an essential step in understanding how a structure behaves under random vibrations. It involves analyzing the Power Spectral Density (PSD) Response, which is a function that describes how the power (energy) of a signal is distributed across different frequencies.

The PSD response is particularly important when dealing with structures subject to dynamic loading or vibrations. By analyzing the frequency response, we can identify the resonant frequencies where the structure might experience amplified vibrations, which can lead to excessive deformations or material fatigue.

In the context of the truss beam structures, the frequency response helps evaluate how the bolted and welded trusses respond differently to vibrational forces across multiple frequency ranges.

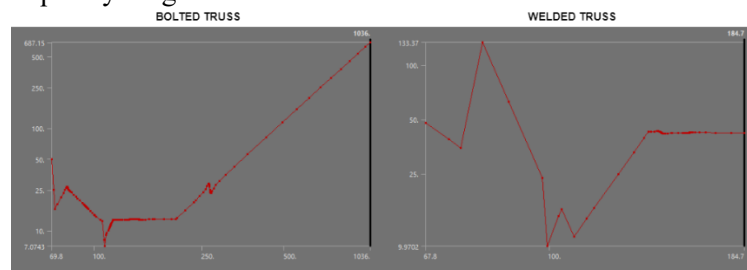


Fig. 17. PSD tool for both truss variants.

The Fig. 18 above illustrates the relationship between frequency (Hz) and power spectral density response [ $mm^2/Hz$ ] for both the bolted and welded truss variants. The bolted truss shows a relatively linear increase in PSD Response as the frequency increases. This linearity suggests that the bolted truss is more susceptible to accumulating vibrational energy as the frequency rises, leading to a consistent amplification of displacement across the frequency range.

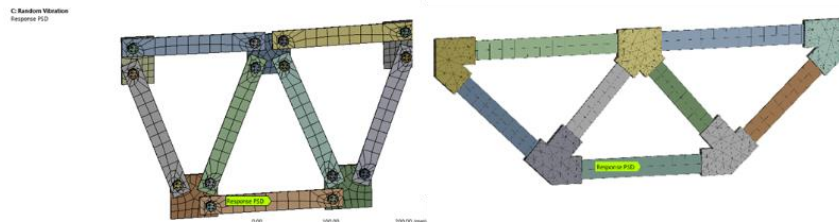


Fig. 18. PSD Response.

Overall, the welded truss consistently outperforms the bolted truss in terms of vibrational stability across all axes, particularly in the X and Y directions, according to Fig. 18 above and coordinated for axes given in Table 6 below. This indicates that the welded truss has a stronger ability to resist vibrations, making it more suitable for dynamic loading conditions where minimizing displacement is critical for structural integrity and performance.

Table 6. PSD Response coordinates for truss

| Coordinates | Bolted truss | Welded truss |
|-------------|--------------|--------------|
| X           | 273.05       | -143.51      |
| Y           | -252.8       | -47.406      |
| Z           | -3.6171      | 8.2162       |

The frequency response analysis indicates that the bolted truss is more susceptible to vibrational forces in the X and Y directions, with significantly higher PSD values compared to the welded truss. This higher sensitivity to vibrations makes the bolted truss more prone to deformation and potential failure under dynamic loading conditions.

## 6. Conclusion

In this work, two variants of truss beams were designed and analyzed: one welded and one fastened with bolts. A theoretical analysis of the stresses in the bars was carried out using the method of node isolation. These analytical calculations were validated using the MDSolids program, and then a finite element analysis (FEA) was performed using ANSYS software to study the structural behavior under the applied loads.

This study demonstrated that the combined use of theoretical analyses, validation with specialized programs such as MDSolids, and finite element analysis in Ansys provides a comprehensive and robust approach to the design and evaluation of truss structures. The main final conclusions are:

- Theoretical models are essential for the initial understanding of structural behavior and provide a solid basis for subsequent validations.
- Validation with MDSolids is an important step in confirming the correctness of analytical calculations and provides additional confidence in the methods used.
- FEA analysis is crucial for creating the detailed behavior of the structure under real loads, providing valuable information for project improvement and optimization.
- Through these integrated approaches, a safer and more efficient design and evaluation of structures is ensured, contributing to the realization of reliable and sustainable technical solutions.

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