International Journal of Creative and Open Research in Engineering and Management
ISSN: **3108-1754 (Online)**
Volume 02 Issue 05 May-2026 | Impact Factor: 3.5

Advanced Study on Truss Structures Using Finite Element Analysis

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How to Cite this Article:

Satyam, G., Gautam, G., Mahesh, G., Sarthak, I., Prathmesh, G., Gavhane, S. & Payal, J. (2026). Advanced Study on Truss Structures Using Finite Element Analysis. International Journal of Creative and Open Research in Engineering and Management, 02(05). https://doi.org/10.55041/ijcope.v2i5.655

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Abstract—

Truss structures are widely used in modern engineering applications because of their high strength-to-weight ratio, stability, and economical design. With the development of computational methods, advanced truss analysis now includes nonlinear behavior, finite element modeling, optimization, and dynamic analysis. This paper presents an advanced study of truss structures focusing on space trusses, finite element analysis (FEA), nonlinear behavior, stability, and modern optimization techniques. The study also explains recent developments in computational analysis and practical engineering applications. This paper is useful for engineering students who wish to understand modern approaches used in structural engineering research.

Keywords: Truss Structure, Finite Element Method, Space Truss, Nonlinear Analysis, Structural Stability, Optimization

I. INTRODUCTION

A truss is a framework structure composed of straight members connected at joints. Traditional truss analysis assumes small deformation and linear elastic behavior. However, modern engineering structures such as stadium roofs, transmission towers, aircraft frames, and long-span bridges require advanced analytical techniques because of large loads and complex geometries.

Advanced truss analysis includes:

- Finite Element Analysis (FEA)
- Geometric nonlinearity
- Material nonlinearity
- Dynamic analysis
- Structural optimization
- Stability and buckling analysis

Space trusses are three-dimensional structures capable of carrying loads in multiple directions. These structures are lightweight and suitable for large-span applications.

I. METHODOLOGY

The methodology used in advanced truss analysis involves computational modeling and numerical techniques. The Finite Element Method (FEM) divides the entire truss into smaller elements for accurate analysis.

The equilibrium conditions used are:

$\sum Fx=0, \sum Fy=0, \sum Fz=0$

stiffness equation in finite element analysis is:

$[K][d]=[F]$

Where:

- [K] = Global stiffness matrix
- [d] = Displacement vector
- [F] = Force vector

Finite element analysis helps determine:

- Joint displacement
- Internal member forces
- Stress distribution
- Buckling behavior

Modern software such as ANSYS, SAP2000, and MATLAB are commonly used for truss analysis.

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II. MODELING AND ANALYSIS

3.1 Space Truss Analysis

Space trusses are three-dimensional truss systems used in:

- Airports
- Industrial sheds
- Stadium roofs
- Telecommunication towers

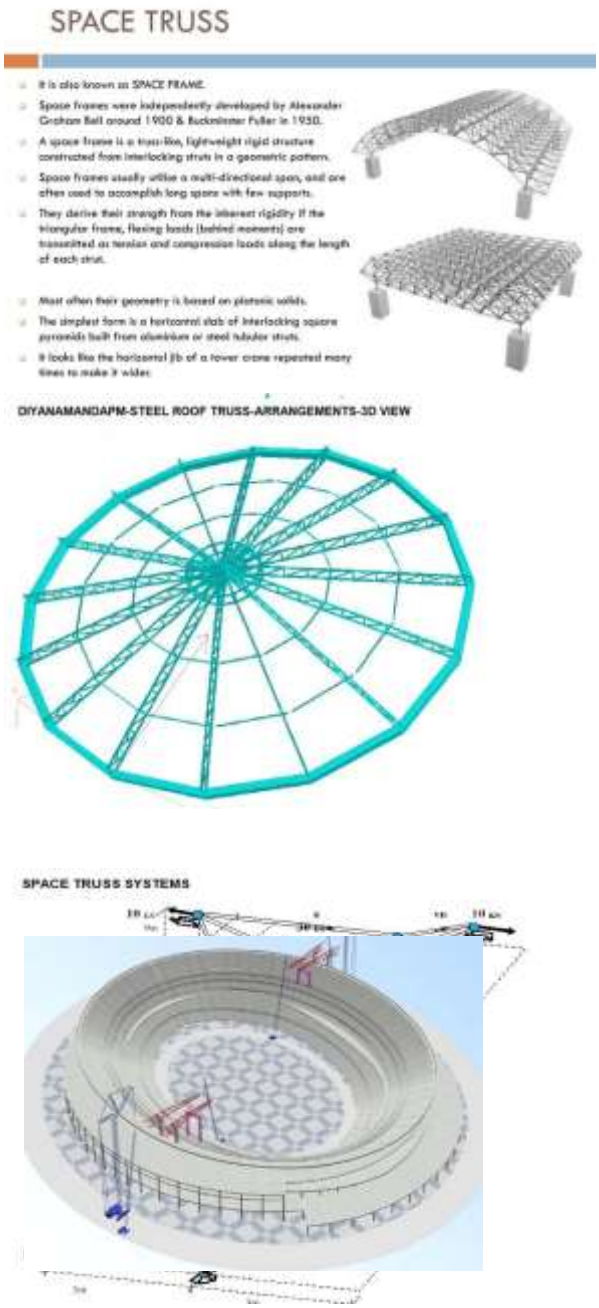

Figure 1: Shape of Different types of Truss.

Unlike plane trusses, space trusses require three-dimensional analysis because each node has multiple degrees of freedom.

Research studies show that finite element methods provide accurate results for large deflection and nonlinear behavior of space trusses.

3.2 Nonlinear Truss Analysis

In practical engineering, truss members may experience:

- Large deformation
- Buckling
- Plastic deformation
- Material yielding

Geometric nonlinearity occurs when deformation changes the structural configuration significantly.

The nonlinear strain relationship is represented as:

$\epsilon = dx/du + 1/2(dx/du)\ 2$

Advanced nonlinear finite element formulations improve the accuracy of truss analysis under heavy loading conditions.

3.3 Buckling and Stability Analysis

Buckling is a major failure mode in compression members. Stability analysis determines the critical load at which a truss becomes unstable.

Euler's buckling formula is:

$Pcr = \pi 2EI/\ (KL)\ 2$

Where:

- Pcr = Critical buckling load
- E = Young's modulus
- I = Moment of inertia
- L = Length of member
- K = Effective length factor

Modern research uses nonlinear finite element analysis to study progressive collapse and instability in space trusses.

III. RESULTS AND DISCUSSION

Advanced computational methods provide more accurate predictions compared to traditional hand calculations. Finite element analysis can simulate:

- Load-deflection behavior
- Member yielding
- Structural collapse
- Dynamic response

Research indicates that nonlinear analysis improves safety and reliability in large-span truss structures. Incremental finite element methods accurately predict elastoplastic behavior and large deformation effects.

Optimization techniques such as Bayesian optimization and homotopy perturbation methods are now being used to improve truss performance while reducing material consumption.

Modern software tools allow engineers to analyze complex trusses efficiently, reducing design time and improving structural safety.

V. APPLICATIONS OF ADVANCED TRUSS STRUCTURES

Advanced truss systems are widely used in:

1. Long-span bridges
2. Stadium roofs
3. Space frames
4. Aircraft structures
5. Offshore platforms
6. Telecommunication towers
7. Industrial buildings

Fig Different Types of Truss Structure

CONCLUSION

Advanced truss analysis has become an important field in structural engineering. Modern computational techniques such as finite element analysis, nonlinear analysis, and optimization methods improve the accuracy and efficiency of truss design. Space trusses are capable of carrying heavy loads while maintaining lightweight construction. The study of nonlinear behavior, buckling, and dynamic response helps engineers design safer and more economical structures. Future developments in artificial intelligence and computational optimization are expected to further improve truss analysis and structural performance.

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