RESEARCH ARTICLE

RSP Science Hub

International Research Journal on Advanced Science Hub
2582-4376
www.rspsciencehub.com
Vol. 08, Issue 01 January

Check for updates

http://dx.doi.org/10.47392/IRJASH.2026.004

Dynamic Analysis of Space Structure

Raghu M[1], Hussain Imran K M[2]
[1]PG, Structural Engineering, SJM Institute of Technology, Chitradurga, Karnataka.
[2]Assistant professor, Structural Engineering, SJM Institute of Technology, Chitradurga, Karnataka.
Emails: *05raghumarappa@gmail.com[1], hussainmd.km1@gmail.com[2]*

Article history
Received: 24 November 2025
Accepted: 21 December 2025
Published: 22 January 2026

Keywords:
Grid space structure, dynamic analysis, Time history analysis.

Abstract
Space structures are a common element in modern architecture because of their expressive form and intrinsic geometric complexity, which allow architects to produce designs that are both aesthetically pleasing and structurally sound. The majority of studies and research on space structures have traditionally concentrated on their structural behaviour, highlighting elements like geometric stability, load distribution, and material efficiency. However, it is becoming more and more crucial to look at space structures from both an engineering and an architectural design standpoint as they continue to acquire traction in architectural practice. In the present study. Researches on dynamic analysis of space structures were widely carried out across the world. The study on structural behavior of grid, domes, vaults which are subjected to earthquake were carried out through many analytical and experimental works. The present work focuses on the study of orientation of stiffness of the supporting roof, and the effect of peripheral cross-bracings on overall lateral response. Further, dynamic analysis has been carried out for grid space structure with different horizontal bracings. Finally, criticality and its locations in various configurations of the space structures are identified. Based on the results and discussions, it is concluded that, the presence of horizontal and vertical bracings will resist the lateral load efficiently and particularly in model 5 where cross bracings are provided. From linear time history analysis, it can be concluded that, the presence of fixed base, vertical bracings and horizontal bracings has significant effect on the vibration characteristics. Presence of horizontal and vertical bracings will contribute significantly in resisting the lateral load of grid space structures.

1. Introduction

A kind of load-bearing systems known as space structures is distinguished by its effective structural behavior and three-dimensional arrangement. In architectural applications, these structures greatly enhance the built environment's spatial and aesthetic qualities in addition to meeting utilitarian needs. Space structures are a common element in modern architecture because of their expressive form and intrinsic geometric complexity, which allow architects to produce designs that are both aesthetically on their structural behavior, highlighting elements like geometric stability, load distribution, and material efficiency. pleasing and structurally sound. The majority of studies and research on space structures have traditionally concentrated

However, it is becoming more and more crucial to look at space structures from both an engineering and an architectural design standpoint as they continue to acquire traction in architectural practice. A more comprehensive perspective is required, one that takes into account these systems' topological, functional, psychological, and aesthetic aspects in addition to their structure. [Lan, T.T., 1999] Based on their physical design, space frames, also known as space structures, can be generically categorized into systems with flat or curved surfaces. The single-layer grid, which is made up of linear components arranged in a planar pattern, is the earliest and most basic type of space frame. In order to create a continuous structural network, this system is usually built by joining intermediate grids and creating strong connections between joists and girders

1.1. Components - Space Frame Structures

The strength of a space frame comes from two key elements:

- **Members** – the linear components of the frame, typically circular or rectangular in cross-section, designed to resist both tension and compression forces.
- **Joints** – the connecting elements that unite the members, playing a crucial role in ensuring the overall stability and safety of the structure

1.2. Types of space structures

Depending on their design and the arrangement of its components, space frames can be classified into several types. Let's examine some of them:

1.2.1. Classification Based on Curvature

- **Space Plane Covers:** These have flat sections that function similarly to a plate. Horizontal bars and diagonal sections provide support for them.
- **Barrel Vaults:** These resemble a barrel's top. They don't necessarily require additional pieces of support.
- **Spherical Domes:** A ball is about half of them. They frequently require a covering and other support element.

1.2.2. Classification Based on Arrangements

- **Single Layer Grid:** All components of space structures are at the same level.
- **Double Layer Grid:** These have parts on two layers, one on top of the other. They're often used for larger spaces.
- **Triple Layer Grid:** These have parts on three layers, connected by diagonal pieces. They're also used for larger spaces.

1.3. Literature Survey

Ramesh B, et al,. (1996) conducted a thorough review of static, dynamic, and thermal analysis methodologies, dynamic analysis methods and related specific subjects that are essential to the behaviour and design of Double-Layer Grids (DLG) structures. In-depth discussions of linear and nonlinear dynamics, stability analysis, progressive collapse, dynamic loadings, vibration control, optimisation strategies, and damage detection of DLG done by dynamic analysis

Fu and Parke (2018) conducted a study on the structural behaviour of double-layer grid space structures under abnormal loading conditions, with a particular focus on the potential for progressive collapse. While such structures are generally considered highly redundant and indeterminate, previous failures suggest that progressive collapse may occur if critical components fail, especially under extreme loads such as heavy snow. Using both implicit and explicit methods, the authors developed a three-dimensional finite element model to investigate collapse scenarios. The study evaluated various failure mechanisms, including the loss of individual members and support failures, and concluded by recommending mitigation strategies to prevent such occurrences.

Tarek et.al (2024) considered, the mechanical behaviour of double-layered tension grids (DLTGs) is analysed numerically. The behaviour of tensegrity grids is compared by the authors using two methods: Combined Nonlinear Analysis (CNLA), which takes into account both geometric and material nonlinearity, and Geometric Nonlinear Analysis (GNA). The influence of cable relaxation, namely the elasto-plastic behaviour of the cable elements, on the structure's displacement is examined in this work. To simulate the behaviour of these grids, the authors adapt the Newton-Raphson iterative technique with incremental loading and apply the updated Lagrangian formulation. The results of applying the created computational model to a grid, based on demi-cuboctahedral tensegrity cells, are shown, along with validation of the model Shown in Table 1.

1.4. Methodology

- Modelling of the grid space structure in ETABS software by varying the stiffness, support condition and structure with lateral bracings of the structure for 1m depth of the space truss and the other parameters like total span, Height, storeys, grid spacing are kept constant.
- Various parameters like maximum displacements, member stresses, member forces are found.
- Modifications are done by providing horizontal top cross bracing and centre bracing.
- Dynamic analysis of structure by Equivalent static for zone V and Time History method using El Centro earthquake data.
- The analysis is done for 6 different configurations of space structure like stiffness in one direction, stiffness in two directions, vertical bracings in both direction, vertical bracings with hinge base, vertical bracings with fixed base, fixed base with top cross bracing, fixed base with top centre bracings.
- Evaluation of analytical results for displacement, acceleration and story displacements Shown in Figure 1 - 4

1.4.1. Structure details

Table 1 General Building Geometry and Structural Parameters

Components	Details
Plan dimension	33 m × 33 m
Number of grid layers	2
Grid spacing	3m
Grid depth	1m
Storey height	4m
No. of Storey	3 storeys
Total building height	13m
Column spacing	12m
Foundation depth	1.5m

1.4.2. Modelling

Modelling has been done in ETABS Ultimate C 19.0.0 Six models of space structure has been done for different cases as follows:

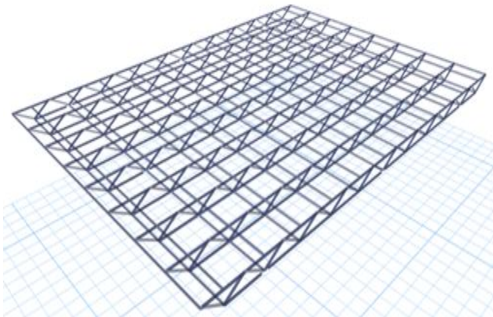

Figure1 Space Structure with Single Axis Stiffness

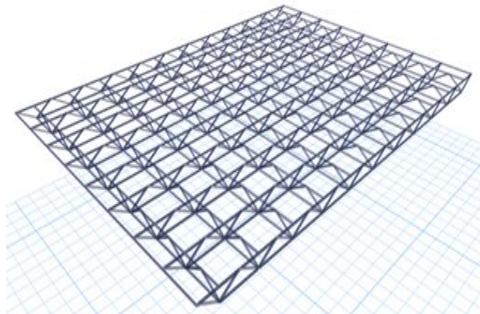

Figure 2 Space Structure with Double Axis Stiffness

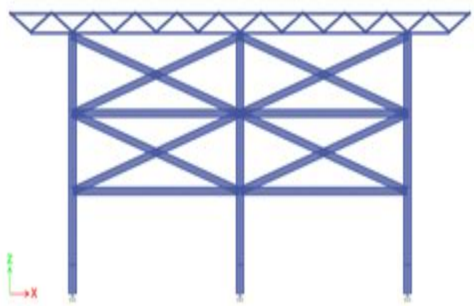

Figure 3 Space Structure with double axis stiffness and bracings with hinge support

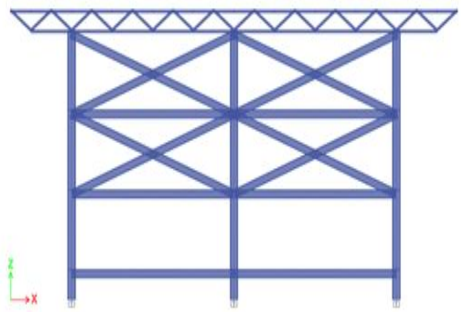

Figure 4 Space Structure with double axis stiffness and bracings with fix support

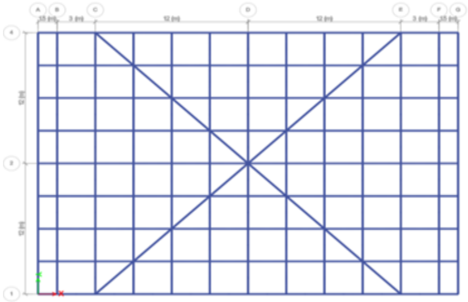

Figure 5 Space structure with double axis stiffness with vertical and horizontal cross bracings bracing roof and fixed support

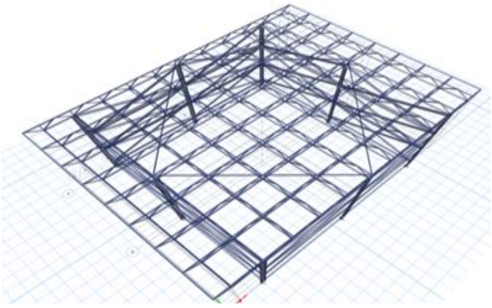

Figure 6 Space structure with double axis stiffness with vertical and horizontal centre-centre bracing roof and fixed support

1.5. Results and Discussion

In this chapter, the results extracted from the modal analysis and lateral load analysis (Earthquake analysis) of all models are presented in the form of tables and graphs. The results are interpreted, and technical discussions are made.

Gravity Load Analysis

1.5.1. Axial Load on Columns

The axial load on columns varies across different structural models. Model M3 has the lowest axial load. Model M2 shows the highest axial load, with a 9.14% increase over M3. Models M1, M4, and M5 exhibit moderate increases ranging from 6.17% to 8.89% Shown in Table 2 and 3.

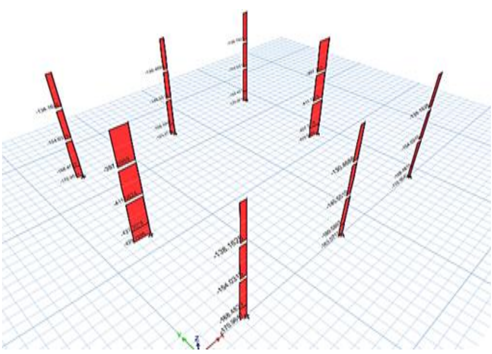

Figure 7 Maximum Axial load location on column

Table 2 Maximum Axial force on Columns

Maximum Axial Load on Column (1.5DL+1.5LL)	
Model Type	**Max. Axial Load (kN)**
M1	430
M2	440
M3	400
M4	430
M5	440

1.5.2. Bending Moment in Columns

The results indicate that Model M1 experiences the highest bending moment, at 65 kN-m, whereas the remaining models (M2–M5) show significantly lower values, ranging from 30 to 35 kN-m. The percentage variation of bending moments with respect to M1 model is 43.3 %, 48.6%, 42.3% and 47.1% for Model M2, Model 3, Model 4 and Model 5, respectively.

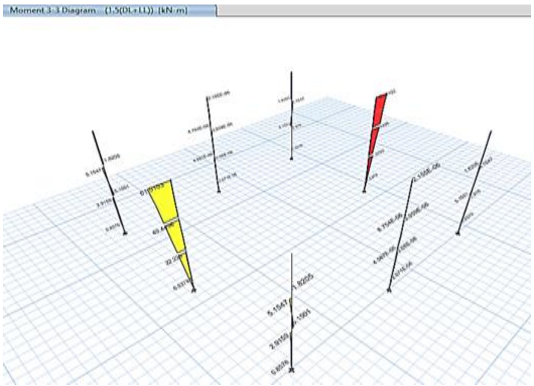

Figure 8 Maximum Bending Moment location on column

Table 3 Maximum Bending Moment on Columns

Maximum Bending Moment on Column (1.5DL+1.5LL)	
Model Type	**Max. Bending Moment (kN-m)**
M1	65
M2	35
M3	30
M4	35
M5	30

1.5.3. Axial Load on Space Structure

The variation of maximum axial load in the space structure for different models (M1–M5) under the load combination 1.5DL+1.5LL is presented in Figure 5-10. The marked position in Figure 5-5 to Figure 5-9 is the maximum axial load position in the space structure Shown in Table 4.

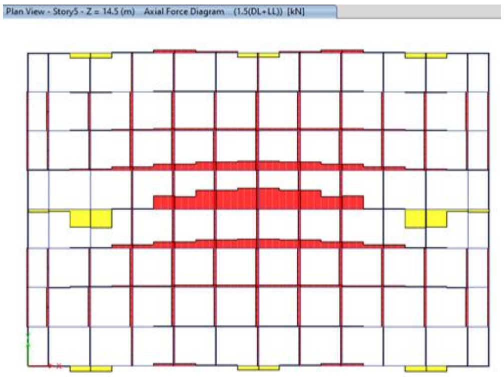

Figure 9 **Axial load on space structure -Model M1**

Table 4 **Maximum Axial load on Space Structure**

Maximum Axial Load on Space Structure (1.5DL+1.5LL)	
Model Type	**Max. Axial Load (kN)**
M1	550
M2	260
M3	260
M4	265
M5	300

It is observed that Model M1 carries the highest axial load of 540 kN, while the remaining models (M2–M5) experience comparatively lower axial forces. The variation of reduction in Model M2, Model 3, Model 4, and Model 5 is 50%, 50.9 %, 49.1% and 44.4% respectively, compared to M1

1.5.4. Bending Moment on Space Structure

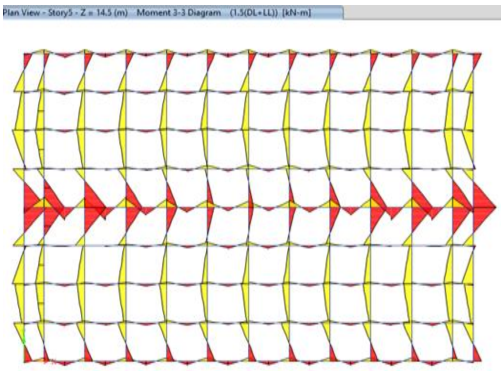

Figure 10 **Bending Moment diagram of space Structure- Model M1**

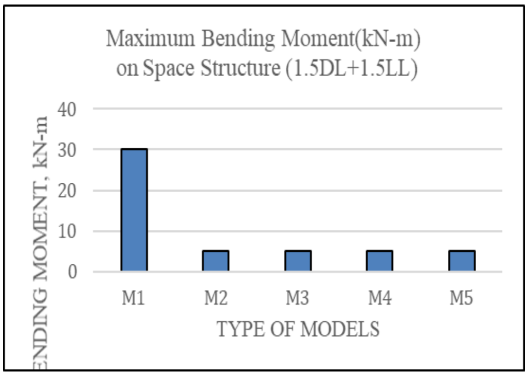

Figure 11 **Variation of Bending Moment for different type of models**

The variation of maximum bending moment in the space structure for different models (M1–M5) under the load combination 1.5DL+1.5LL is presented in Figure 5-16. The marked position in Figure 5-11 to Figure 5-15 is the maximum bending moment position in the space structure. It is observed that Model M1 carries the highest bending moment of 30 kN-m, while the remaining models (M2–M5) experience comparatively lower bending moment

1.5.5. Deflection of Space Structure

The variation of maximum deflection in the space structure for different models (M1–M5) under the load combination 1.0DL+1.0LL is presented in Figure 5-17. It is observed that Model M1 carries the highest deflection of 105.85 kN, while the remaining models (M2–M5) experience comparatively lower deflection. The variation of reduction in Model M2, Model 3, Model 4 and Model 5 is 65.54%, 65 %, 65.5% and 67.83% respectively compared to M1 Shown in Table 5.

Table 5 **Maximum Deflection of Space Structures**

Maximum Deflection (DL+LL)	
Model Type	**Max. Deflection(mm)**
M1	105.85
M2	36.566
M3	36.482
M4	36.386
M5	34.049

1.6. Equivalent Static Analysis

Figure 12 **EQ X**

The variation of maximum storey displacement in the space structure for different models (M1–M5) under the load combination EQX is presented in Tabel 5-5. It is observed that Model M2 carries the highest storey displacement of 17.457 kN, while the remaining models (M1, M3, M4 andM5) experience comparatively storey displacement. The variation of reduction in Model M1, Model 3, Model 4 and Model 5 is 0.04%, 40 %, 55.75% and 89.96% respectively compared to M2 Shown in Table 6 and 7.

Table 6 Storey Displacement of Model M1 along EQ X

Story	**Elevation m**	**Location**	**X-Dir mm**	**Y-Dir mm**
Story 5	14.5	Top	17.45	0.039
Story 4	13.5	Top	17.425	0.002
Story 3	9.5	Top	12.773	3.475E.04
Story 2	5.5	Top	7.617	2.595E.04
Story 1	1.5	Top	2.106	2.782E.04
Base	0	Top	0	0

Table 7 The Maximum Storey Displacement of Various Model Type

Maximum Displacement (EQ X)	
Model Type	**Max. Displacement (mm)**
M1	17.45
M2	17.457
M3	10.455
M4	7.723
M5	1.752

1.7. EQ Y

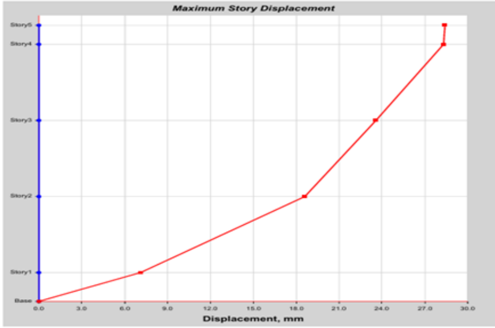

Figure 13 **EQ Y**

The variation of maximum storey displacement in the space structure for different models (M1–M5) under the load combination EQY is presented in Tabel 5-6. It is observed that Model M2 carries the highest storey displacement of 43.71 kN, while the remaining models (M1, M3, M4 andM5) experience comparatively lower storey displacement. The variation of reduction in Model M1, Model 3, Model 4 and Model 5 is 34.98%, 85.57 %, 78.06% and 95.76% respectively compared to M2 Shown in Table 8 and 9.

Table 8 Storey Displacement of Model M1 along EQ Y

Story	**Elevation m**	**Location**	**X-Dir mm**	**Y-Dir mm**
Story 5	14.5	Top	0.015	28.418
Story 4	13.5	Top	0.007	28.299
Story 3	9.5	Top	0.001	23.595
Story 2	5.5	Top	0.001	18.615
Story 1	1.5	Top	1.504 E.04	7.134
Base	0	Top	0	0

Table 9 The Maximum Storey Displacement of various model type

Maximum Displacement (EQY)	
Model Type	**Max. Displacement (mm)**
M1	28.418
M2	43.71
M3	6.303
M4	9.587
M5	1.853

Conclusions

- The inclusion of horizontal and vertical bracings has minimal influence on axial loads and bending moments in columns under gravity analysis.
- Axial load variation in the space truss is most pronounced at the mid-span. Horizontal bracings play a vital role by reducing axial forces in the main grid members.
- Roof truss members generally experience no bending moment. In Model 1, however, bending moments were observed, which became negligible when horizontal and vertical bracings were introduced.
- Structural deflection is nearly uniform across all models, except in Model 1, where the truss system is unidirectional.
- Horizontal and vertical bracings significantly enhance lateral load resistance, with Model 5 (cross-braced) demonstrating the highest efficiency.
- Time history analysis shows that fixed supports, together with horizontal and vertical bracings, strongly influence the vibration characteristics of the structure.
- Overall, horizontal and vertical bracings markedly improve the lateral load-carrying capacity of grid space structures.

References

[1]. F. Fu and G. A. R. Parke, "Assessment of the progressive collapse resistance of double-layer grid space structures using implicit and explicit methods,"

[2]. L. M. Tian, J. P. Wei, and J. P. Hao, "Optimisation of long-span single-layer spatial grid structures to resist progressive collapse,"

[3]. R. B. Malla and R. L. Serrette, "Double-layer grids: review of dynamic analysis methods and special topics,"

[4]. L. J. Li, Z. H. Xie, Y. C. Guo, and F. Liu, "Structural optimization and dynamic analysis for double-layer spherical reticulated shell structures,

[5]. [Y. Zhang, G. Nie, J. Dai, and X. Zhi, "Experimental studies of the seismic behavior of double-layer lattice space structures

Journal reference style:

[6]. T. Zhang, Z. D. Xu, X. H. Huang, Y. R. Dong, and Q. X. Shi, "Seismic performance analysis of the two-dimensional isolation device for double-layer grid structure," Int. J. Struct. Stab. Dyn., vol. 24, no. 05, p. 2450051, 2024.

[7]. C. Zhang, M. Nie, J. Dai, and X. Zhi, "Experimental studies of the seismic behavior of double-layer lattice space structures I: Experimental verification," Eng. Fail. Anal., vol. 64, pp. 85–96, 2016.

[8]. Y. He, P. Shepherd, and J. Wang, "Topology optimisation of double-layer grid structures with stability constraints," J. Constr. Steel Res., vol. 227, p. 109323, 2025.

[9]. Y. Luo and Y. Xue, "Recent development and engineering practices of space grid structures in China," Int. J. Space Struct., vol. 39, no. 1, pp. 36–49, 2024.

[10]. T. Metrouni, N. Khellaf, and K. Kebiche, "Non-Linear Behavior of Double-Layered Grids," Slovak J. Civ. Eng., vol. 32, no. 1, pp. 10–17, 2024.