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Review on Study of Space Frame Structure System

S. A. Ashtul[1], S. N. Patil[2]

[1]PG Student, Department of Civil Engineering
[2]Assistant Professor, Department of Civil Engineering, Rajarambapu Institute of Technology, Maharashtra, India

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Abstract - *In the last few decades there was continuous development in the construction industry. Mankind is always attempted to utilize the maximum space for the structure. The need for modern structures is to achieve a large clear span with the economy. Now-days it is observed that there is a growing interest in space frame systems. A space frame is a 3D structural system in which well-organized linear axial elements are put together for the uniform distribution of forces. The main purpose to use these systems is to cover a large span area and giving a pleasant appearance to the structure. Also, the space frames are light in weight and can easily be transported to the site. The objective of this paper is to present the detailed concept of space frame systems and applications of these systems. Also, the study of various parameters that affect the structural behavior of the space frame system is carried out through a literature review.*

***Key Words*: Space frame systems, 3D structure, Light-weight, long span structures.**

1. INTRODUCTION

The development of space frame structures has a growing interest in worldwide. In architectural and structural engineering, the main attempt is to make the large unobstructed area with all necessary facilities and safety. Although with the advent of new construction techniques, materials and methods space frame make the right choice for fulfilling all requirements. Many researchers proposed their theories, methods and experimental results for developing space frame structure system. In last few decade space frame system gain importance because of their aesthetic appearance and capacity to cover large area without any mid-support obstruction.

The space frame was independently developed by Alexander Graham Bell around 1900 and Buckminster Fuller. Space frame structures are widely used to construct the transmission line towers, airport hangers, stadiums, exhibition halls, swimming pool [9]. They have the ability to resist and redistribute concentrated and unsymmetrical loading. Services like lightning, air conditioning can easily be accommodated in these structures. Space frames are highly indeterminate structures. The instability of the space structures is mainly due to the critical compression members, which causes sudden and progressive brittle failure. To improve the buckling failure of compression members certain techniques are useful such as providing concrete slab on the top chord members, by introducing mechanical devices, by providing heavier sections. Among these techniques concrete slab over the top chord which enhances the compression capacity and shows better performance of space frame structure [10].

The present paper focuses on the basic concept of a space frame system. And also on the studies carried out by several researchers for understanding the structural behavior of the space frame system by considering various parameters. .

2. SPACE FRAME SYSTEM

2.1 Introduction

In architecture and structural engineering, a space frame or space structure is a rigid, lightweight, truss-like structure constructed from interlocking struts in a geometric pattern. Space truss consists of pin-jointed connected bars with node connectors. According to the connection of member's space frame structures are mainly classified into two categories namely nodular system and modular system. In a nodular system, linear truss members are interconnected through nodes. Mero node connector is widely used for connecting the members. In a modular system, prefabricated modules are assembled to make the geometry of the structure. Various types of modules of different sizes and shapes are available in the market which gives a better aesthetic appearance to the structure.

2.2 Classification of the space frame system

1. Based on the grid layer system

There are three types of grid layers, single, double and triple. The single grid layer system is mostly useful for structures like a braced vault, braced dome or latticed shell which mostly has curved shape geometry. In the double-layer grid system, two layers are parallel to each other and interconnected by vertical and diagonal members. The double-layer grid provides greater rigidity and reduces the deflection of the structure (Fig. 1). The triple-layer grid is used when the span to depth ratio is more and to cover the large span areas.

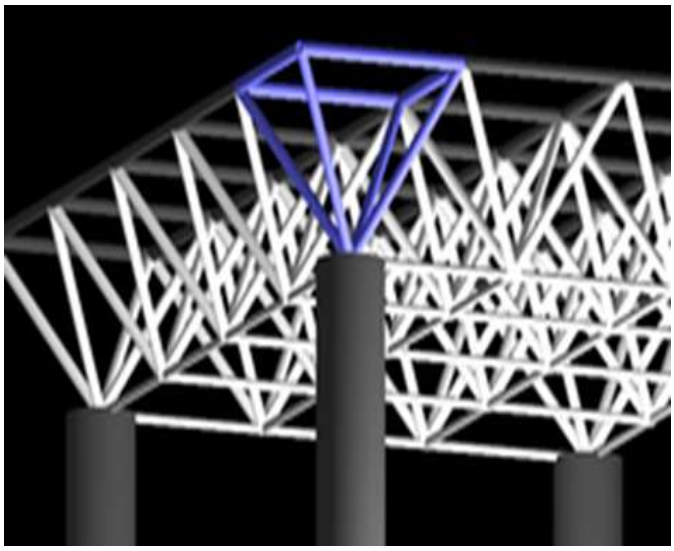
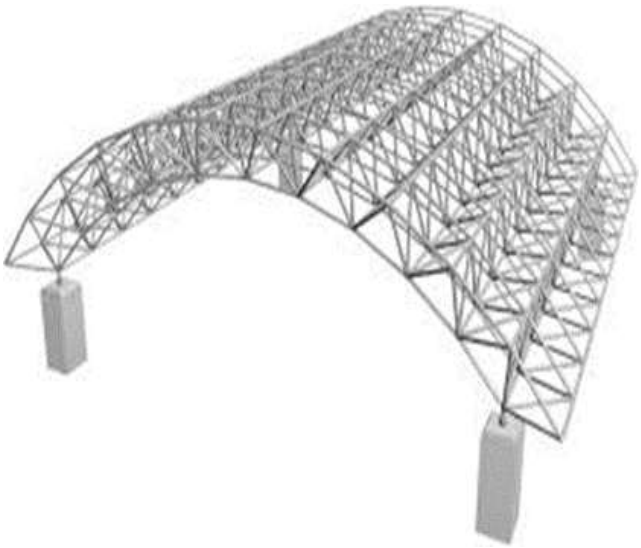


Fig – 1: (a) Space Frame Truss



(b) Barrel Vault Space Structure

2. Based on the grid layout

The double-layer grid system is classified into four types according to the grid layout as (Fig. 2);

1. Square on square geometry
2. Square on diagonal geometry
3. Diagonal on square geometry
4. Diagonal on diagonal geometry

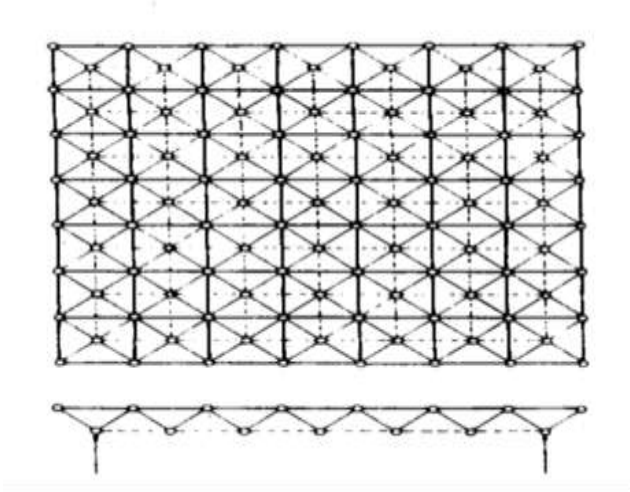
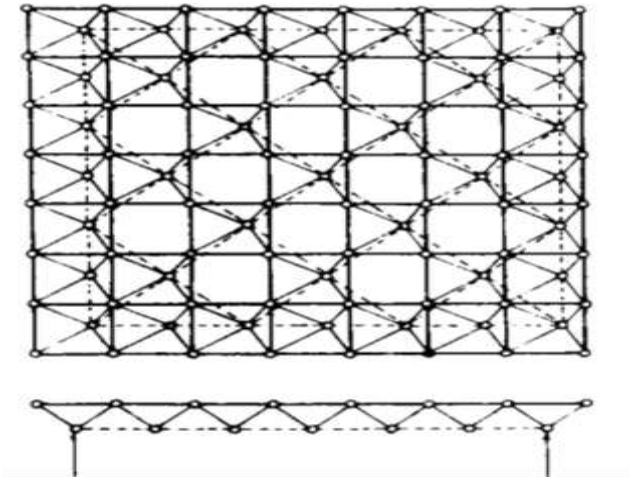
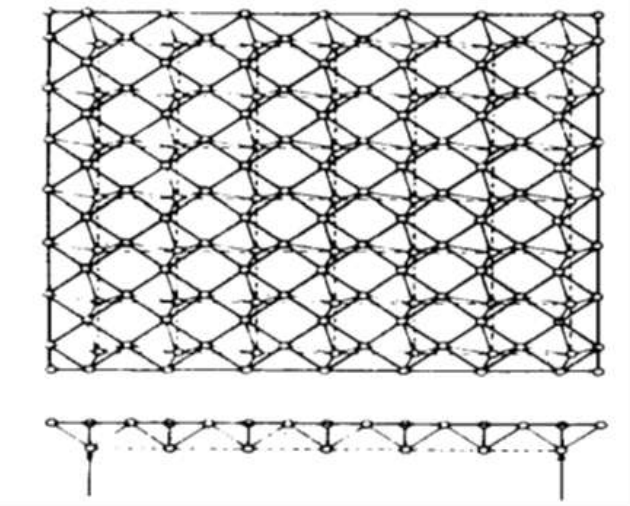


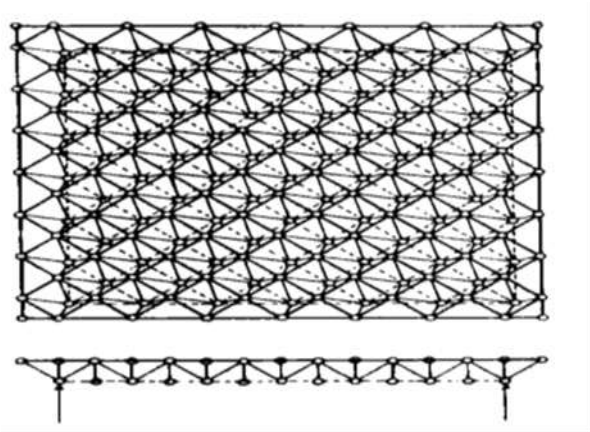
Fig -2: (a) Square on Square



(b) Square on Diagonal



(c) Square on Diagonal



(d) Diagonal on Diagonal

3. Components of Space Frame System

Space frame structures mainly consist of

1. Linear axial members
2. Node Connector

1. Linear Axial Members

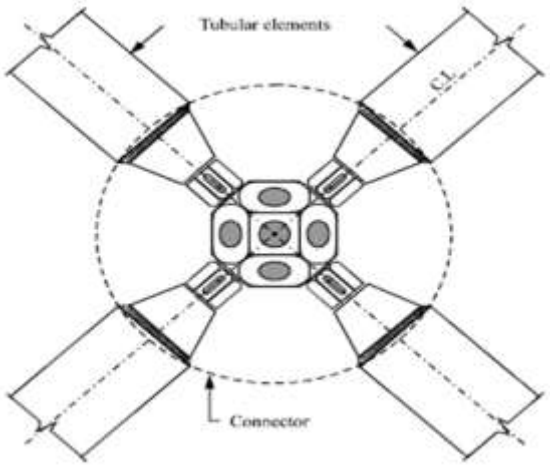
Linear axial members are mainly of circular and rectangular tubular members. Other than this angle section, the channel section, structural T and flat sections can also use as axial members. The main advantage of using tube or pipe sections as they can easily be assembled with the help of a node connector. These members are usually made up of steel and aluminum material.

2. Node Connector

The node connectors are used for connecting the members at the joint (Fig. 3). As the whole structure is axially loaded the total applied structural load is transferred through nodal joints only, hence nodal joints should be very strong. There are a variety of node connectors are available in the market. The node connectors are the most expensive component of the space frame system. MERO connector, Tuball connector, Octatube connector, NS connector, and Plate node connector are the few familiar node connectors.

Fig -3: (a) NS Node Connector

MERO connector is widely used for connecting members at the node (Fig. 3a). It has a solid spherical shaped body with threaded holes. MERO node connector can hold 18 members at one joint and capable of distributing load uniformly in three dimensions. The NS joints are mostly suitable for domes, barrel vaults, and double-layer grid structures.



(b) MERO Node Connector

3. ADVANTAGES OF SPACE FRAME SYSTEMS

1. The space frame structures are light in weight and the distribution of loads is in a 3D uniform manner so that all materials in the given structure is utilized to its full extent.
2. The simple prefabricated units of space frame of standard size and shapes are available in the market. The industry produced such prefabricated units in mass quantity. These units can easily be transported and assembled at the site by skilled workers.
3. The speed construction is rapid and can cover large areas with minimum time duration. The space frames are economical than other structures.
4. Due to its 3D dimensional behavior, space frame structures are usually stiff. These structures can sustain with heavy concentrated or eccentric loading because of their inherent rigidity property.
5. Space frames can be mold into any shape and size such as latticed shell, barrel vault shape. These structures give a better aesthetic appearance to the structure.
6. In a double-layer grid, the space frame has a more free area between the top and bottom layer which is useful for the installation of any type of mechanical or electrical services systems throughout the structure.
7. Space frames are indeterminate structures. If one or a number of the members are failed this will not lead to a collapse of the whole structure.

4. DISADVANTAGES OF SPACE FRAME SYSTEMS

For the erection of space frame structures, skilled workers are necessary.

5. LITERATURE REVIEW

In this section, the present theories and practices related to the space frame structure system are studied by referring published literature in various journals, books and conferences from India and abroad. Researchers have been studying the various parameters and the behavior of long-span space frame structures. Following the review of Literature gives an outlook on the behavior of the space frame structural system.

Vatansever C. (2019) has investigated the buckled truss bar of space truss of major shopping market chain in Adana, Turkey. The structure taken for the study was designed according to the Turkish Seismic Code considering earthquake zone 2. The author observed that without any type of external loading like snow or rain some bar led to flexural buckling. After a survey, the reason for the buckle truss bar is found that the differential settlement of foundation is occurred due to an increase in the consolidation of soil. This paper aims to study the buckling phenomenon occurred in space truss bars due to soil condition. To find the amount of settlement of roof the photogrammetrical survey was carried out by observing vertical co-ordinates. Besides, the author also examined the distribution pattern of space truss bar which is buckle due to differential settlement. The non-linear analysis of space roof truss is carried out by making an analytical model in SAP2000v19. The results show that the tubular truss bars which have higher slenderness ratio according to ANSI/AISC 360-16 are more prone to flexural buckling. The authors concluded that settlement of foundation induced due to increasing consolidation of soil with time. Also, the settlement of foundation tends to structural damage in the form of buckling of space truss bars.

Basil. B. et al (2019) have proposed the procedure for analysis and design of space truss by using STADD. Pro software. STADD-Pro software is useful for all type structures analysis and design, which supports 90 international concrete, steel, aluminum, and timber design codes. The space frames are long-span structures that cover large unobstructed areas. For analysis and design, certain assumptions are made that the structural elements are assumed to be pin jointed and load should be axially applied at joints only. Space truss elements are mainly classified into three categories simple, compound and complex. The elements are connected by triangular pyramidal geometry. The author explains the stability and determinacy aspects of space truss by giving a sample example of a space roof truss. Besides, the author also explains the detail dead, live and wind load calculations for a space roof truss. IS 875 (Part 1, 2, 3, 5):1987-Code of practice for design load (other than earthquake) for buildings and structures is used for loading calculations. After analysis author concludes that the space structure is useful in many ways such as they are light in weight, have higher stiffness and suitable for long spans. STADD Pro software checks the structure for bending moment, shear force and gives the idea about the deflection behavior of the whole structure. This software also suggests the right section for given loading to make the structure safe.

Lorenzo. G. D. et al (2018) have studied the composite space truss structure made by the combination of 3D lattice beam and structural glass for the protection of monumental and archeological sites. The author gives a detailed design methodology for 3D lattice beams. In the present study, Steel lattice beams and structural glass slab are used to cover the large archeological site. The structural glass slab is designed for the brittle collapse mechanism. These 3D lattice beams have prominent properties like anti-corrosive nature, high strength. Also, the beam is easy to fabricate and requires less maintenance. S355J2W steel 3D lattice beams and castellated cold-formed rectangular hollow section (RHS) are used according to EN 10219-1 and EN 10219-2.After proposing design methodology numerical analysis also carried out by using FEM commercial code Pro_ Sap and home-made code. The model of composite space truss was performed on ABAQUS software. Further lattice beam prototype is made for experimental investigation of structural collapse. The author concludes that the proposed design criteria are robust and can withstand the collapse mechanism. Also, it is observed that the lattice beam can be reused for other purposes after dismantling and there is scope for experimental and analytical investigation.

Fu. F. and Parke G. A. R. (2018) have assessed the progressive collapse resistance of double-layer grid space structure using implicit and explicit methods. The main objective of this research is to investigate the structural behavior of the double-layer space structure. The author mentioned two methods for evaluation namely implicit method and explicit method. A 3D finite element model of double-layer grid space structure was made in ABAQUS and designed in SAP2000 using iterative elastic analysis. Firstly the author analyzes the model according to implicit solver available in ABAQUS. The implicit method helps in the analysis of the collapse phenomenon of the structure if certain structural members are removed. The analysis is supported by the alternative path method (APM) given by American design code DOD and GSA. After analysis, it was observed that the support failure is more sensitive than the structural failure of central members. Further work is focused on support failure for analysis of the global failure mechanism of structure. The experimental validation work was performed by the second author. The author also explains the explicit method with the help of a case study. From the comparative analysis of two methods, the author concludes that the implicit method is well defined and straight forward method for examining the collapse mechanism of structural members while explicit method explains the collapse mechanism of the complete structure. Also, it is observed that the failure of one support leads to the progressive collapse of members along the line between failed support and two other opposite supports. Hence it remarks that all supports and members connecting to the supports should be strengthened properly to prevent the progressive collapse of the structure.

P. Sageetha (2017) has studied stiffness and energy absorption capacity of composite space truss. In space truss, the load transfer mechanism is in a 3D manner. The author examined the analytical behavior by considering parameters like slab thickness, concrete strength, and module size of composite space truss. The non-linear analysis was carried out with the help of ABAQUS software. The analytical study was done based on experimental results of EI-sheikh published in 1998 and Mezzina et al. (1975). The author took the slab thickness (50 mm, 80 mm, 100 mm and 125 mm), concrete grade (M 25, M 30 and M 35) and module size of (800 mm * 800 mm, 1000 mm*1000 mm and 1333.3 mm*1333.3 mm) for study. After analysis author concludes that as the thickness of the slab increases, the stiffness of the structure is also increasing which increases energy absorption capacity. Also, it is seen that there will be no effect on the ductility factor. But ductility of the structure is independent of slab thickness and grade of concrete used for it. It is also observed that the stiffness of the non-composite structure is less than the stiffness of the composite structure.

Patel B. and Jamani A. (2017) have carried out research work on the parametric study of the long span industrial steel structures. The industrial steel truss structures require to design accurately with the economy. In long span industrial truss the weight of steel is governing in the planning of the industrial area. In this paper, the long-span steel industrial structure with dimension 125X45 meter is design for lateral loads induced by wind and earthquake. To analyze this structure finite element software STAAD PRO is used. The various parameters like Horizontal forces, Axial Forces, Deflection, Stress, and Lateral Displacement are considered for the comparative study. This paper aims to do a comparative study of cost-analysis and stability-analysis for the various structural system used in long-span roof industrial steel structures. The author considered four structural systems i.e. PEB Structure, I-Section Rafter, Simple truss and Spaceframe. The author concluded that the space frame and truss member have minimum weight compare to other structures. I-section Rafter has minimum deflection than the other steel structure, but the I-section rafter structure is more expensive due to its more weight. Hence Spaceframe and truss members are more economical than the other structures.

Sugavnan. R. and Srinivasan. G. (2016) has studied the analysis and design of space frame shuttle court and validated with the experimental investigation. The author also makes a comparative analysis of PEB and steel space truss. The analytical study of the shuttle court is done by using STADD Pro software. The main aim of the present research work is to reduce the compression chord buckling and increase the efficiency of the space structure. Steel-code of practice IS 800-2007 was used to design steel roof space truss and node connections. The columns and footings are designed by IS: 456-2000 plain and reinforced concrete code of practice. Experimentally space truss is examined under static load increment of 1 KN up-to maximum load of 16 KN. After analysis author observed that at bottom chord edge nodes have symmetrical performance and have identical deflection also there is variation in strain values. The author concludes that in PEB steel quantity is more economical than steel space truss. There is variation in deflection results. Experimental deflection has more values than software analysis. It also concludes that for long-span space truss is more economical than mild steel roof truss.

Dong. S. et al. (2012) have studied the different long-span space structures in China. These space structures are designed with new technologies and consists of lightweight high strength materials. In this research work, space structures are mainly classified into three areas as ancient space structures, pre-modern and modern space structures. This study also includes the practical applications, various shapes, and characteristics of modern space structures in China. The modern space structures are classified into rigid space structure, flexible space structure and rigid-flexible combined space structure. There are five types of modern rigid space structures namely composite space truss, open-web latticed shell, partial double-layer lattice shell, tree type and polyhedron space frame structures. Modern flexible space structures are mainly referred to as membrane structures with supports and air-supported membrane structures. Rigid-flexible combined space structures are classified into ten types as the cable-stayed grid, cable truss structures, composite structures of the dome and single-layer lattice shell, truss string, pre-stressed grid, beam string, pre-stressed segmental steel and tensairity structures. The author concludes that there are three basic elements rigid element consists of beam, plate/shell and bar elements and flexible element includes membrane and cable elements. China Stands first in developing the long span space structures in the world. Also, this country won many awards for developing long-span structures. In addition, the author also mentions that there is a need for future work in the design and construction technology of space structures

Lakshmikandhan K. N. and Senthil R. et al (2010) have analyzed the behavior of steel and composite space structures by considering various parameters. The space structure is of the double-layer grid. The parameters taken for study are i) Concrete slab at top ii) various support arrangements iii) an experimental investigation on a full-scale space grid. The main focus of this study was on the effect of concrete slab at the top side in both composite and non-composite space truss structures. An analytical study was carried with the help of STADD Pro and ANSYS. After experimental investigation, it was observed that the top members of the composite space truss show better performance in transferring compressive forces and have no buckling failure than non-composite space truss. In addition, it was found that due to the mid-edge supporting system there is a 20% saving in steel.

Madi U. R. (1986) has studied the double-layer space frame grids with the help of example structure. The parameters covered for the study are support arrangement, the grid depth, the grid module, and the grid layouts. Four possible grid layouts and seven different support systems are considered for the study. This study investigated that in the case of diagonal on diagonal configuration there is a uniform distribution of member forces for top, bottom and bracing members. In addition, the author observed that, if supports are taken to the inside of the grid there is a substantial decrease in the member forces. This may lead to the

conclusion that it is more economical to increase the depth of the grid as far as possible. Also, this study gives an idea about the effects of the choice of any of these parameters on the grid's behavior and design requirements.

6. SUMMARY OF LITERATURE

1. The researchers concluded that the spatial structures are more suitable for long-span structures and are useful to cover large areas without any mid obstructions. The loads are uniformly transferred so that these structures are stiffer and gain high strength.
2. The space frame structures are light in weight and can be formed into various shapes which give a nice aesthetic appearance to the structure.
3. The various finite element software like STADD Pro, SAP 2000, ANSYS, ABAQUS are useful for detail analysis and design of space frame structure.
4. The various techniques such as composite space frame structures, over-strengthened the top chord members are, use of heavier sections are used for enhancing the efficiency of the structure.
5. The composite space truss shows better performance than non-composite space truss to reduce the compression forces in the top chord members. By reducing the compression forces the buckling failure of top chord members also prevented. The composite space truss system increases the efficiency of the structure.

7. GAPS IN LITERATURE

Based on the literature review investigated regarding the space frame system, there is a certain absence of research work which is not studied earlier, as mentioned below:

1. Looking at the present scenario of the industry, utilization of full area without any obstruction is the main concern for structure. The new possible arrangements of supports should be investigated so that a large area can be accessed without any obstruction. Also, if supports required are less which indirectly benefits the total economy of the structures.
2. Various types of new high strength materials should be used for construction so that the efficiency of the space structure will enhance.
3. In previous work, most of the work is carried out on the behavior of space frame structure by considering mainly static loads, the seismic analysis of space structure with considering different soil interaction and zones has not been done yet.
4. The roof covering material also impacts on the structural behavior of space structure. The effect of various types of roofing material should be investigated which reduces the critical compression buckling of members.

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