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REVIEW ON UNDERSTANDING SPACE FRAME THROUGH DOUBLE GRID SYSTEM

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Abstract - A spatial frame structure is a strong, lightweight lattice structure consisting of interconnected struts in a geometric design used in architecture and construction engineering. With the introduction of new building techniques and new building materials, space structures generally offer the right solution and meet the requirements of lightness, economy, and speed of construction. The development of the spatial grid has made great progress. A large number of theoretical and experimental research programs have been carried out by many universities and research institutes in different countries. This review article provides a fundamental understanding of space frame structures and further studying in detail about double grid space frame and the analysis of several research publications for better understand of the topic, space frame.

***Key Words*:** space frames, long span, composite, space truss, double grid system.

1.INTRODUCTION

Over the last half-century, there has been a worldwide increase in interest in space frame structures. It takes shape to accommodate a wide-open space while still meeting the requirements for lightness, economy, and quick construction. Sport arenas, exhibition pavilions, assembly halls, transit hubs, airplane hangars, workshops, and warehouses are just a few of the building types where space frame is being used in new and inventive ways.

A space frame, also known as a space structure, is a lightweight rigid structure that resembles a truss and is made up of interconnecting struts in a geometric design. With minimal internal supports, a space frame may span enormous regions. Rigid jointed frames, such as building frames, are often three-dimensional space structures in practice.

Fig -1: image showing space frame roof structure.

However, for ease of design, the space structure is modelled as a series of separate plane frames interacting with one another, causing internal pressures to redistribute and torsional moments to form in the space frame members. Although ignoring the torsional moments results in significant simplification, it is neither cost-effective nor safe in all cases. Another example of when ignoring the twisting moment is neither safe nor cost-effective is a grid construction. Despite the fact that the members of a grid construction are typically in one plane, twisting moments exist because the external loads are normal to the grid's plane. The definition of a space frame is a three-dimensional structure in the broadest meaning.

2. LITERATURE REVIEW

The researchers mentioned below concluded that spatial structures are better suited for long-span constructions and are effective for covering huge regions with no mid obstacles. Because the stresses are distributed equally, these structures become stiffer and stronger. The space frame constructions are light in weight and may be moulded into a variety of shapes, giving the building a good aesthetic appeal. For detail study and design of space frame structures, finite element tools such as STADD Pro and ABAQUS are useful. For increasing efficiency, different approaches such as composite space frame constructions, over-strengthened top chord members, and the employment of heavier sections are utilised. To minimise compression pressures in the upper chord elements, the composite space truss outperforms the non-composite space truss. Buckling failure of upper chord elements is also prevented by decreasing compression forces. The composite space truss system improves the structure's efficiency.

(S. A. Ashtul, 2020)This study focuses on the fundamental idea of a space frame system. In addition, numerous scholars have conducted studies to better understand the structural behaviour of the space frame system by considering various factors

(Basil Baby, 2019)This study provided a method for analysing and designing space trusses using STADD Pro software. Because of its minimal weight, mass manufacturing, rigidity, and flexibility, space truss offers numerous benefits over other kinds. Furthermore, as compared to others, it is far superior in terms of extended durations. The arch form is preferred because of its simplicity and visual appeal. With the introduction of the STAAD Pro, analysing civil engineering constructions has become considerably easier. The author illustrates the stability and determinacy features of space truss by using a space roof truss as an example. Aside from that, the author goes over the dead, live, and wind load calculations for a space roof truss in depth.(Parke, 2018)

The authors developed a 3D finite element model of a double-layer space structure grid to explore the structural behaviour of a space frame structure, and different collapse scenarios were investigated using an implicit technique that follows the alternative path method specified in GSA. Furthermore, case studies have been created utilising the explicit approach, which simulates the entire structural collapse process. Various member failures or support collapses were investigated in the analysis. The structure's response was studied, and the possibility for gradual collapse was thoroughly explored.

(Sangeetha, 2017)This article compares the analytical behaviour of a composite space truss to previously reported experimental data. The variables in the study include slab thickness, concrete strength, and space truss module size. The stiffness, energy absorption capacity, and ductility factor of a composite space truss were determined and compared. ABAQUS software was used to do the non-linear analysis. The analytical analysis was based on experimental results published in 1998 by EI-sheikh and Mezzina et al (1975).

(Madi, 1986)The paper presents a parametric analysis of the different aspects influencing the design of double layer space frame grids. This parametric research was carried out using example structures and addressed the support arrangement as well as the grid depth, grid layouts with the grid module. The goal is to provide the designer a sense of how changing any of these factors would affect the grid's behaviour and design needs. This knowledge should be used to build effective early designs, reducing the requirement for several experiments before the design is finalised. This study explored whether there is a uniform distribution of member forces for top, bottom, and bracing members in the situation of diagonal-on-diagonal arrangement. Furthermore, the author discovered that moving the supports to the interior of the grid reduces the member forces significantly. This research provides insight into the implications of changing any of these characteristics on the grid's behaviour and design needs

3. TYPE OF SPACE FRAME – BASED ON GEOMETRY

Space Plane Covers

These spatial structures are made up of flat substructures. Their behaviour is similar to that of a plate in which the arrows in plane are guided by the horizontal bars and the transverse forces are supported by the diagonals.

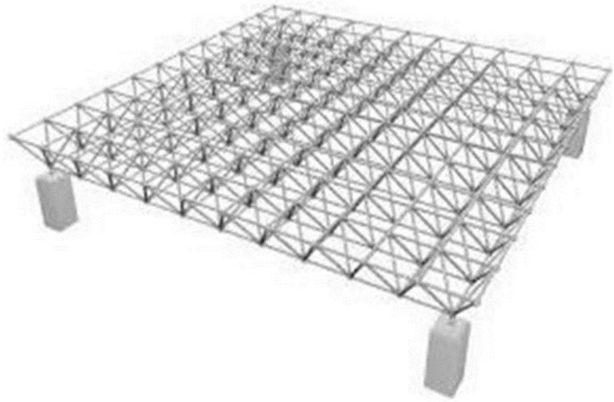

Fig -2: Space plane covers.

Barrel Vaults

This type of arc has a cross section of a simple arc. The structure of the barrel vault space allows for a structural design to integrate the vault theory and the use of steel provides a high mixing force, allowing long clear spans and low-height skylight vaults for entrance canopies and curved glass walls. It is considered the simplest form of bow; basically, a series of juxtaposed arcs, that is, one after the other.

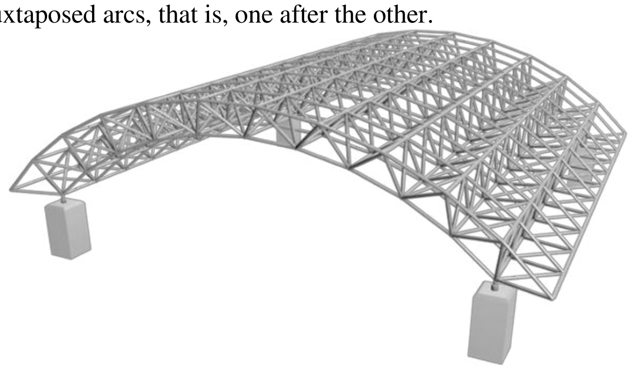

Fig -3: Barrel vaults

Spherical Domes

Spherical domes and other compound curves generally require the use of tetrahedral modules or pyramids and additional skin support.

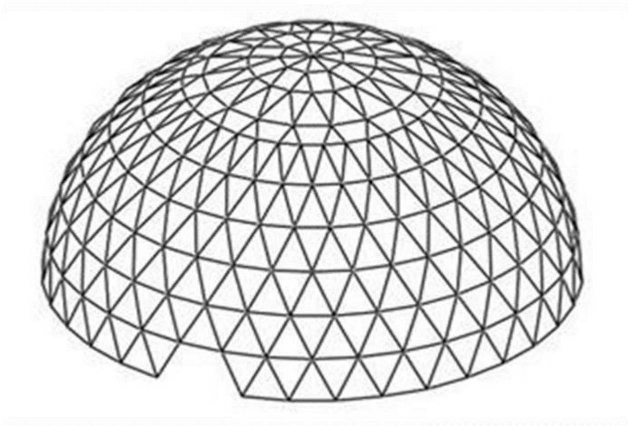

Fig -4: Spherical domes

4. TYPE OF SPACE FRAME – BASED ON GRID

Single-layer grid

All elements are located on the surface to be approximated.

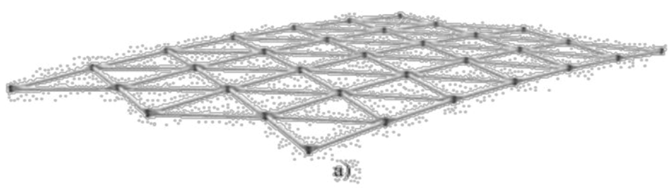

Fig -5: Single layer grid

Double-layer grid

The elements are organized in two layers parallel to each other at a distance of each of the layers forms a network of triangles, squares or hexagons in which the projection of the nodes of a layer can overlap or displace each other. Diagonal bars connect the nodes of the two layers in different directions in space.

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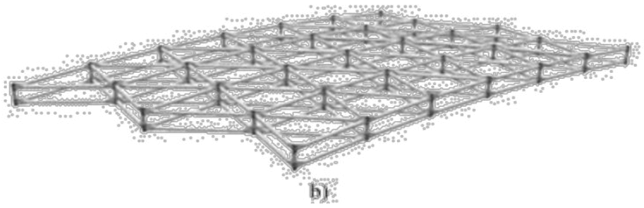


Fig -6: Double layer grid

Triple-layer grid

The elements are placed in three parallel layers, connected by diagonals. They are almost always flat.

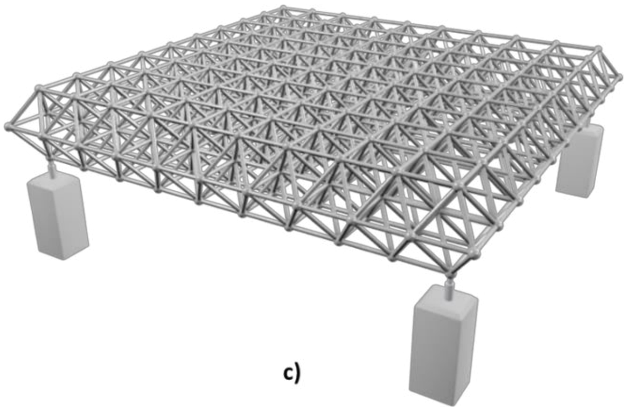


Fig -7: Triple-layer grid.

5. COMPONENTS OF SPACE FRAME

Members

Axial members are generally circular or rectangular hollow sections(tubes) welded with props on either side.

Fig -8: Rectangular hollow section

Connectors

- Solid nodes:

Spherical in shape and can be made as required by the design ranging from 50mm to 300mm diameter

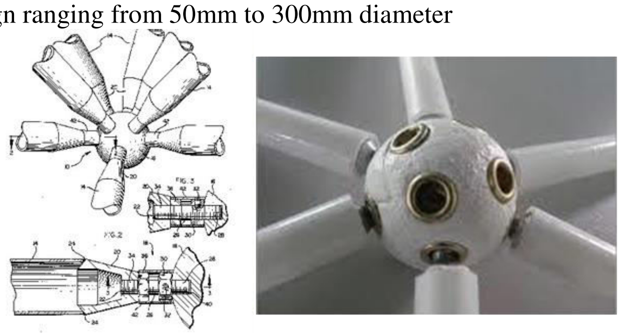


Fig -9: Solid nodes.

- Hollow nodes:

Spherical sections casted at required size and end of tube section members are by welding. Connection from inside the cup is by use of bolt and nut

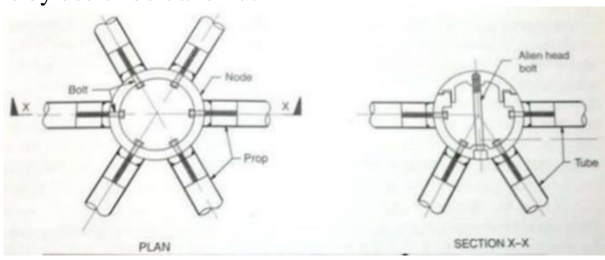


Fig -10: Hollow nodes.

- Nodus connector:

It can accept both rectangular and round hollow profiles and the cladding can be attached directly to the frames. Rope connectors must be soldered on site to the ends of hollow sections

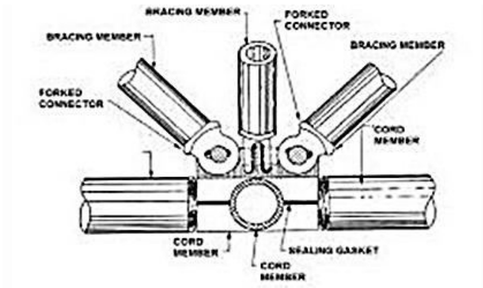


Fig -11: Triodetic connector.

It comprises of a hub, generally an aluminium extrusion, with slots or keyways into which the ends of members are pushed or coined.

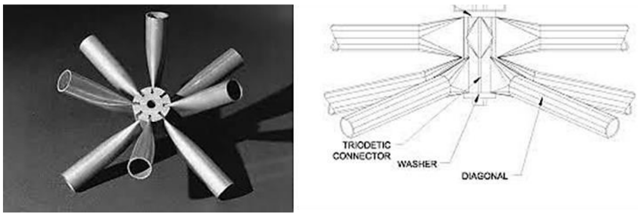


Fig -12: Triodetic connector.

Support type

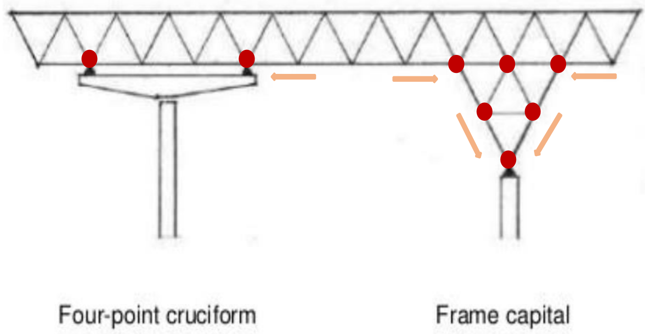
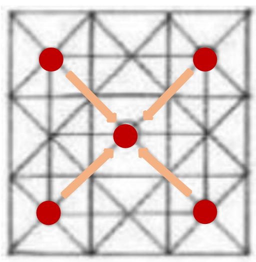


Fig -13: Support type.



Better The arrow in orange indicates the direction and movement in which the load transfers and the red dots represent point load at joineries transferring downwards to the column.

Fig -14: Load transfer diagram.

6. THUMB RULES

When designing a space frame system, it is essential for the architect to collaborate with the engineer. While the engineer typically measures structural components after the architect has built the building, his or her involvement must be more participatory to ensure that each design decision maximises the benefits of a space frame system while staying under budget. Changing the modular sizes of space frame components alone, can have an impact of the costing of materials.

Typically, space frames are not as economical for spanning systems under 7-10 metre in length. For determining depth of space frame:

1. Use ratio of 1:12 depth to span for a 1-way space frame.
2. Use ratio of 1:15 depth to span for a 2-way space frame.
3. Use ratio of 1:18 depth to span for a 3-way space frame.

7.METHODOLOGY

The review paper is based on basic space frame structure understanding the joiners the type of structural grids and shapes. And the double grid system is studied in detail. The geometry allows the researcher to zoom in on the many parts of the structure. Space frame structures are made up of length members, such as bars or tensioned cables, and their connectors, which are also known as nodes or joints. The structure will have many sorts of these components. Some bars, for example, will need to be adjustable in length, whilst others would have fixed lengths. These differences will also exist in the nodes, some of which will need to be able to link parts of varying lengths, and some connections will need to be fixed while others will need to be dynamic

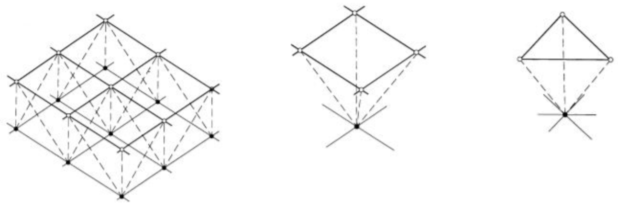
8. DOUBLE GRID SYSTEM

Double layer grids, also known as flat surface spaceframes, are made up of two planar networks of members that comprise the top and bottom layers and are connected by vertical and inclined web members.

Double layer grids are distinguished by hinged joints that lack moment and torsional resistance; hence, all components can only resist tension or compression. Even when connecting by relatively stiff joints, the impact of bending or torsional moment is negligible.

Double layer grids are often made up of the following fundamental elements:

a) a planar latticed truss
b) a pyramid with a square base that is effectively an octahedron
c) a triangle pyramid with a triangular foundation (tetrah)



a) b) c)

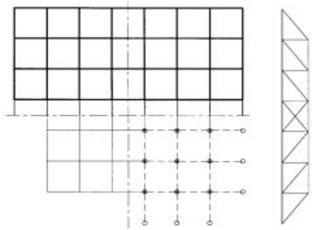
Fig -15: Basic elements.

Types and Support

Group 1 – Composed of latticed trusses

1. Two-way orthogonal latticed grids (square on square).

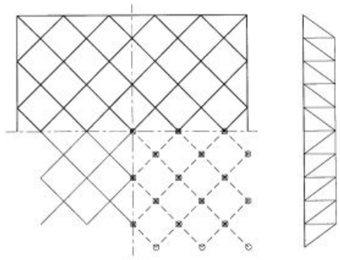
This sort of latticed grid has the benefit of being easy to configure and with little joint detail. All chord members are the same length and are located in two planes that cross at 90 degrees. Because of its low torsional strength, horizontal bracing is often installed along the perimeters.



(a)

2. Two-way diagonal latticed grids.

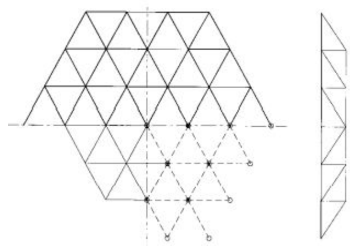
The arrangement of the latticed grids is identical to Type 1, except that it is offset by 45 degrees from the edges. At each intersecting joint, the latticed trusses have distinct spans along two directions. Because the depth is constant, the stiffness of each latticed truss changes with its span. Shorter span latticed trusses can be thought of as a type of support for longer span latticed trusses, resulting in greater spatial activity.



(b)

3. Three-way latticed grids.

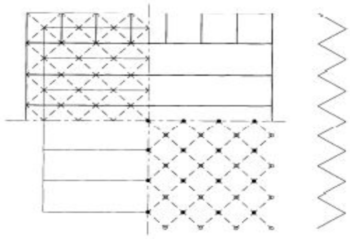
All chord members meet at 60 degrees to one another, forming equilateral triangular grids. It is a strong and efficient system that can be adapted to odd forms like circular and hexagonal layouts. The joint detail is complicated by several members intersecting at one location, with as many as 13 members in the extreme instance.



(c)

4. One-way latticed grids.

It is made up of a set of mutually inclined latticed trusses that combine to produce a folded shape. Because there are only chord members along the spanning direction, one-way movement predominates. To enhance the integral stiffness, horizontal bracings are required around the perimeters, much like in Type 1.

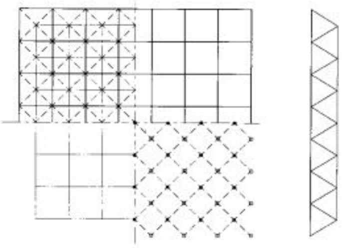


(d)

Group 2A. – Composed of square pyramids.

1. Orthogonal square pyramid space grids (square on square offset).

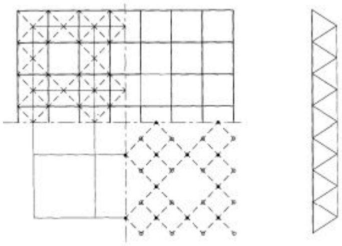
This is a popular framing design with top layer square grids offset above bottom layer grids. In addition to the same length of top and bottom chord members, if the angle between the diagonal and chord members is 45, all members in the space grids will have the same length. The fundamental element is a square pyramid, which is utilised as a prefabricated unit in certain proprietary systems to construct this sort of space grid.



(e)

2. Orthogonal square pyramid space grids with openings (square on square offset with internal openings, square on larger square).

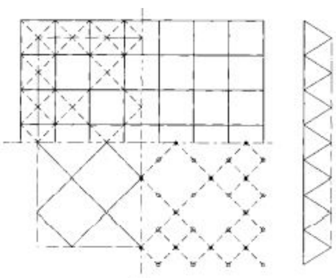
The frame pattern is identical to Type 5, except that the inner square pyramids are alternately removed to produce bigger grids in the bottom layer. This change reduces the overall number of members and, as a result, the weight. It is also visually appealing because to the increased openness of the space grids network, which creates an outstanding architectural impact. This system is compatible with skylights.



(f)

3. Differential square pyramid space grids (square on diagonal).

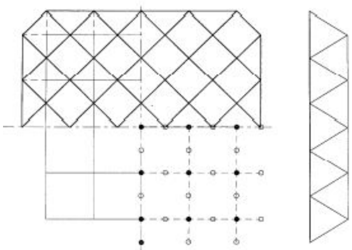
This is a common example of a differential grid. The two planes of the space grids are at 45 degrees to one other, which effectively increases the torsional rigidity. The grids are orthogonally organised in the top layer and diagonally in the lower layer. It is one of the most efficient framing systems, with shorter top chord members resisting compression and longer bottom chord members resisting tension. Even with a significant number of members removed, the system remains structurally robust and visually attractive.



(g)

4. Diagonal square pyramid space grids (diagonal square on square with internal openings, diagonal on square).

This type of space grid likewise has a differential arrangement; however, the pattern is reversed from Type 7. It is made up of square pyramids that are linked at their apexes, with fewer members crossing at the node. Because there are just six members joining at the top chord joint and eight members connecting at the lower chord joint, the joint detail is very basic.

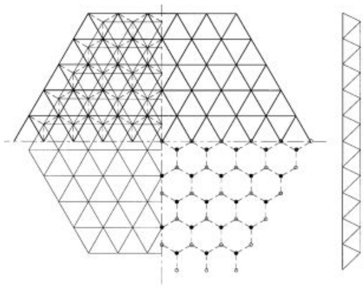


(h)

Group 2B. – Composed of triangular pyramids

1. Triangular pyramid space grids (triangle on triangle offset).

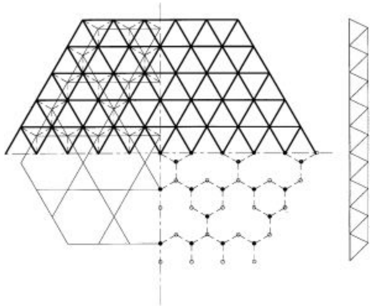
As fundamental elements, triangular pyramids are linked at their apexes to produce a pattern of top layer triangular grids offset over bottom layer grids. If the depth of the space grids is equal to two-thirds of the chord length, then all members will be the same length.



(i)

2. Triangular pyramid space grids with openings (triangle on triangle offset with internal openings).

The inner triangular pyramids, like Type 6, can be removed in a different way. As indicated in the picture, triangular grids are created in the top layer, while triangular and hexagonal grids are formed in the bottom layer. The pattern on the bottom layer might change based on how it is removed. Such space grids have a very open sense to them, and the pattern contrast is excellent.



(j)

Method of Support

Square, circular, or other polygonal forms with overhanging and continuous supports along the perimeters would make ideal double layer grids. This will be more of a plate-like design that minimises the maximum bending moment. The building's configuration, on the other hand, has a wide range of possibilities, and the support of the double layer grids can be found in the following places:

1. Support along perimeters

The supports of two-layer grids might be directly supported by the columns or by ring beams linking the columns or the outside walls. Grid module sizes should be chosen with care to fit column spacing.

2. Multi-column supports

Double layer grids can be supported on four intermediate columns in single-span constructions such as a sports hall. Multi-span columns in the shape of grids are commonly employed in structures such as workshops. Column grids are sometimes used in conjunction with perimeter supports. Overhangs should be used whenever practical to offer some stress reversal and therefore minimise internal chord forces and deflections. Overhangs of 1/4 to 1/3 of the midspan are recommended for those double layer grids supported by intermediate columns. Corner supports should be avoided if feasible since they generate significant pressures in the edge chords. If just four supports are to be supplied, they should be placed in the centre of the sides rather than at the corners of the structure.

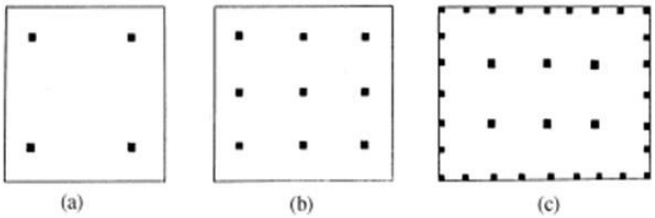


Fig -16: Multi-column support

3. Support along perimeters on three sides and free on the other side–

One side of a rectangular structure must be open, such as in the case of an aviation hangar or for future expansion. Triple layer grids can be constructed by simply adding another layer of multiple module widths instead of creating the supporting girder or truss on the free side. It may also be addressed for shorter spans by increasing the depth of the double layer grids. As a result, the sectional area of the members along the free side will grow.

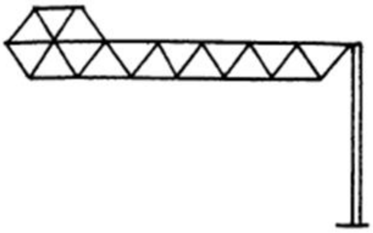


Fig -17: Triple layer grid on the free side.

Columns for two-layer grids must be able to withstand gravity loads as well as any lateral forces. Support kinds that are commonly used on multi-column layouts. Typically, the member forces surrounding the support will be too enormous, necessitating some method of transmitting the loads to columns. It may use an inverted pyramid to transport the space grids down to the column top, or it may use triple layer grids to convey skylights. If necessary, the inverted pyramids can be extended all the way to the ground.

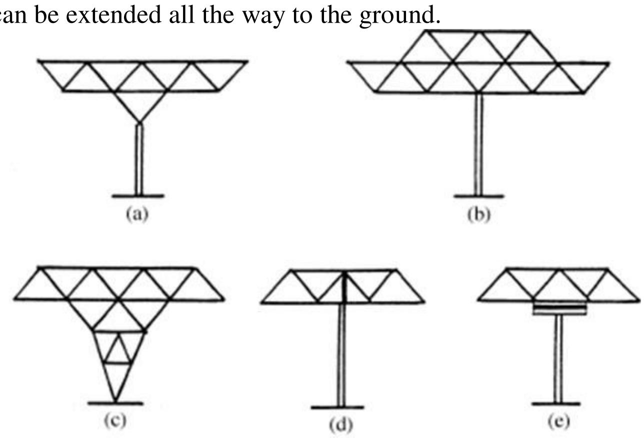


Fig -18: Supporting columns.

The spread out of the concentrated column reaction on the space grids decreases the maximum chord and web member pressures near to the column supports, as well as the effective spans. The installation of a vertical strut on column tops allows space grids to be supported on top chords, but the vertical strut and connecting connection must be extremely robust. The use of crosshead beams on column tops achieves the same appearance as the inverted pyramid, but at a higher expense in terms of material and specific manufacturing.

Method of Erection

1. Assembly of space frame elements in the air

Members and joints, as well as prefabricated subassembly parts, are assembled in place. For these sorts of erections, full scaffolding is generally necessary. If cantilever building of a space frame is possible, just partial scaffoldings are sometimes employed. No heavy lifting equipment is required because the pieces are manufactured in the shop and delivered to the building site. It may be used with any sort of space frame that has bolted connectors.

2. Erection of space frames by strips or blocks

On its plane, the space frame is split into separate strips or blocks. These pieces are built on the ground, then lifted into place and put together on temporary supports. The quantity of assembly work at high elevation is reduced when more work is done on the ground. This method is suitable for those double layer grids where the stiffness and load-resisting behaviour will not change considerably after dividing into strips or blocks, such as two-way orthogonal latticed grids, orthogonal square pyramid space grids, and the those with openings. The size of each unit will be determined by the available lifting capability.

3. Assembly of space frames by sliding element in the air

On the roof level, separate strips of space frame are constructed by sliding along rails provided on either side of the structure. The sliding units can either move one after the other to the ultimate position and then be assembled, or they can be built sequentially while sliding. As a result, the installation of a space frame may be done concurrently with the construction activity beneath it, reducing construction time and scaffolding costs. The sliding technique is straightforward and does not necessitate the use of any special lifting equipment. It is appropriate for orthogonal grid systems in which each sliding unit is geometrically non-deferrable.

4. Hoisting of whole space frames by derrick masts or cranes

The whole space frame is constructed on the ground level, allowing the majority of the work to be completed prior to lifting. As a consequence, efficiency will improve and quality will improve. The space frame may be lifted up by numerous cranes for short and medium spans. Derrick masts provide support for long-span space frames, while electric winches provide lifting force. In the air, the entire space frame can be moved or rotated before being seated in its ultimate position. All sorts of double layer grids can be used using this approach.

9.CONCLUSION

The researchers concluded that spatial structures are better suited for long-span structures and are useful for covering large areas with no mid obstructions. Because the loads are distributed uniformly, these structures become stiffer and stronger. The space frame structures are light in weight and can be formed into a variety of shapes, giving the structure a nice aesthetic appearance. Space Frames are one of the most weight-efficient types of light steel structures. To form frames, elements and nodes are separated and bolted together. Geometrical shapes can be curved or flat, and grid types vary greatly. These fundamental elements may be used to create a wide variety of double layer grids. They are created by changing the orientation of the top and bottom layers in relation to one another, as well as the placement of the top layer nodal points in relation to the bottom layer nodal points. Change the size of the top layer grid in relation to the bottom layer grid to introduce more variations. Internal holes can thus be made by removing every second piece from a typical arrangement.

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