New Bolted Spaceframe System

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Summary

Spaceframes were first developed by Alexander Graham Bell around 1900 and later Buckminster Fuller independently developed it in the 1950s. Bell's interest was primarily in using them to make rigid frames for nautical and aeronautical engineering although few were realized. Buckminster Fuller's focus was architectural structures (1) and has had more lasting influence. After Buckminster Fuller's development and use of spaceframes for large roofs, space frames became a common structural system for large roof spans in commercial and industrial buildings. Even though spaceframe has been a popular 1950s building technology it's potential to generate unique form, and it's potential as a materially efficient sustainable structure type has remained largely unexplored in India and hence presents significant future opportunity. To take advantage of these opportunities, a new bolted spaceframe system for India is proposed.

The intent of this paper is to document the New bolted spaceframe system for India, which can be employed for large span flooring systems. This system may be used for large span floors 50feet by 50feet and go up to 100feet by 100feet column free, in either pre-existing or new office and commercial buildings in India. This paper will also discuss the engineering design methodology and structural analysis for the new bolted system, which includes a) Initial geometry formulation that provides a detailed geometric description of the spaceframe structure b) Engineering analysis and c) Member sizing, Node design and Part type identification. Finally a proposed real project in Bangalore, India, utilizing the new system is discussed in the paper.

Keywords

Spaceframe, Prefabrication, Composite structures, Large span floors.

Theme

Buildings – Design and Construction – Steel and Composite materials

1. Introduction

The space frame (space truss) is a lightweight rigid structure constructed from interlocking strut elements triangulated in three dimensions and assembled to form a large rigid planar surface structure. Spaceframes derive their strength from the inherent rigidity of the triangulation and truss action i.e. bending moments loads are transmitted as tension and compression loads along the length of each strut. Typically spaceframe geometry is based on platonic solids (Tetrahedron, Cube, Octahedron, Dodecahedron and Icosahedron)

In this proposed new spaceframe system the top chords will have double angle struts to receive the metal deck for composite concrete floor decking. The web and the bottom chord members will be either pipe strut or double angle strut. The nodes for the new system is made of steel casting, the cast nodes have fin plates to receive struts for bolted connection.

2. Design of the New Bolted Spacefram System

The design of the new Bolted Space frame system involved three steps:

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2.1 Initial geometry formulation

Initial geometry formulation provides a detailed geometric description of the space frame structure, for the proposed system a half-octahedron geometry with a 1.5m double layer offset square grid with a depth of approximately 1m was chosen as a module (see figure 1) and the offset point was located at the center of the square.

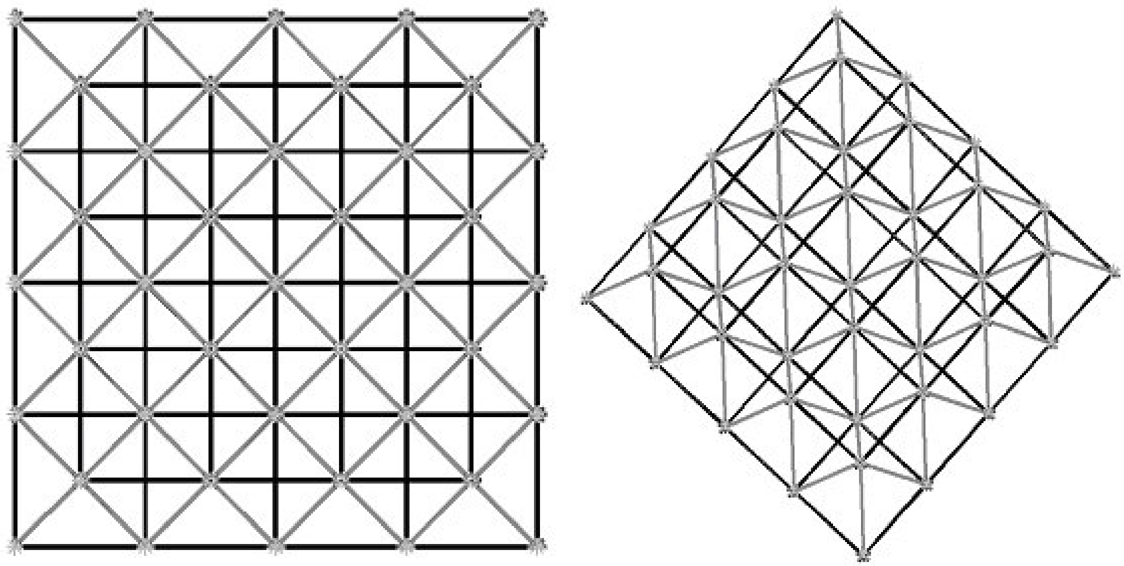

Figure 1. Spaceframe system module in plan and 3d view

2.2 Engineering analysis.

The space frame and the supporting columns are analyzed by SPACE-GASS and SAP 2000 finite element computer programs, for the three dimensional analysis and design of space frames with geometric nonlinear cable elements. The space frame computer model is constructed by definition of nodal coordinates, and connecting truss, beam and cable elements with the appropriate cross-sectional properties between these nodes. The supports are modeled as fixed connections at footing

Truss elements are capable of resisting only axial forces. The beam elements transfer moments and shear forces at connection joints. The cable elements only carry tension loads. The program uses an iterative non-linear approach to analyze the structure and remove stiffness contribution of cable elements when they become slack. The design loads are computed based on IS 875, IS 1893 (Criteria for Earthquake Resistant Design of Structure), and the wind load, were based on IS 875 part 3. The computed design loads are applied at the nodes for the various load cases based on the tributary.

2.3 Member sizing, Component design and Part type identification.

Member sizing of space frame is a two-part procedure, first members are selected from the strut section library and second members are selected from connection part section library to meet the force demand from the analysis output.

The initial analysis resultant forces are compared with the allowable loads in the section library list and the member design is rationalized by the appropriate selection from the list (allowable load in section library list is determined from AISC, ASD1989 manual). The accuracy of any steel member design is dependent on the accuracy of the analysis on which it was based. A truly accurate design can only be obtained when the design member sizes agree with those used in the preceding analysis. The member analysis-design process is iteratively carried out automatically by SPACEGASS and SAP 2000. Figure 2 depicts the typical New Bolted Spaceframe System.

Figure 2. Typical New Bolted Spaceframe System module prototype

3. Considerations for Strut Section Library Creation:

Considerations for Strut are based on availability of the pipe sections in the market and Strut section library should have minimum number of section types to cover all the force range for optimization. This will reduce the number of part types, which considerably helps in fabrication and installation. Maximum pipe size is limited to 168mm outer diameter pipe size since a higher outer diameter is found to be un-economical for fabrication and installation. Further connection parts i.e. nodes cones and bolts get bigger. Based on the analysis output and availability, minimum member sizing was achieved. Table 1 is a summary of list of struts.

STRUT	DESCRIPTION
ST1	60.3MM O.D x 4.5MM Wall IS 1161 (IS 1161Fy=240Mpa&Fu=400Mpa)
ST2	76MM O.D x 4.5MM Wall IS 1161 (IS 1161Fy=240Mpa&Fu=400Mpa)
ST3	88.9MM O.D x 4.8MM Wall IS 1161 (IS 1161Fy=240Mpa&Fu=400Mpa)
ST4	114.3MM O.D x 5.4MM Wall IS 1161 (IS 1161Fy=240Mpa&Fu=400Mpa)
ST5	139.7MM O.Dx5.4MM Wall IS 1161 (IS 1161Fy=240Mpa&Fu=400Mpa)
ST6	168MM O.Dx6.3MM Wall IS 1161 (IS 1161Fy=240Mpa&Fu=400Mpa)
ST6	168MM O.Dx10MM Wall IS 1161 (IS 1161Fy=240Mpa&Fu=400Mpa)

Table 1. Summary of list of struts

After initial strut sizing is complete the connections are verified. Typical connection assembly for a pipe strut as shown in figure 2 consists of nodes, bolt and machined cone welded to the strut. Allowable tension and compression loads on the connection assembly (Machined cone and bolt) for all the strut types in the section library are determined using AISC, ASD1989 manual and controlling capacities are used to check against resultant member forces. If required, components are updated and iterated until connection capacities satisfy the force demand of the analysis results.

3.1 Considerations for Connection Part Section Library Creation

Machined cone library is determined from the diameter of the strut. The bolt library is determined from shear capacity of the bolt in double shear and the block shear consideration. The node library is based on 5 Node types; these nodes have fin plates with drilled holes to receive struts for bolted connection

4. Node and Node design

The nodes for the new system are High Strength Steel Casting per Indian standards IS 2644 grade –2 CS700. The mechanical property after heat treatment is per table 3 and the suggested Chemical composition for the casting is shown to achieve mechanical properties as per table –2. The castings are sand casting and figure 3 shows node pattern and final cast piece. The proposed high strength casting nodes are an invention of the author and are used for the first time in a space frame assembly system.

Table 2 CS 700 Grade 2 Mechanical Properties		
#	Property	Requirement
1	Tensile Strength, Mpa, Mn	700
2	Yield stress (.5% proof stress)	580
3	Elongation, Percent, Mn	14
4	Brinell Hardness, HB, Mn	207

Table 2. CS 700 Grade 2 Mechanical Properties

Table 3 CS 700 Grade 2 Chemical Composition			
		Requirment Percent	
#	Constituents	Min	Max
1	Carbon (C)	0.3	0.35
2	Manganese (Mn)	1.2	1.7
3	Silicon (Si)	-	0.6
4	Sulphur	-	0.035
5	Phosphorus	-	0.035
6	Alluminum(Al)	0.1	0.15

Table 3. CS 700 Grade 2 Chemical Composition

Figure 3. Cast wooden pattern and steel cast sample

The process of casting is prone to cracks unless carefully managed, therefore the following inspection and testing procedure is recommended to assure quality cast:
Non-destructive test (NDT) of 25% of all nodes, by either one of the listed methods a) magnetic particle, b) liquid penetrant c) ultrasonic d) radiographic testing: in accordance with relevant standards.
Areas specified for NDT test are at the bolt holes. Additionally all nodes should be visually inspected. NDT test nodes for which visual examination indicates an unusual condition and/or poor quality, it is also recommended to maintain a log of all certified copies of the cast melt, heat treatment process, mechanical and chemical properties from test bars.

Figure 4. Finished steel cast sample with boltholes

5. Sorting/Part Number Designation

The last part of the space frame design is the sorting/part number designation and bringing the information into a drawing format. The node selection is based on the diameter of the sleeve at the end of strut and the angle between the struts coming to the node. After all the members and connections parts are selected, the fabrication lengths for the struts are determined and all the holes and diameters for the nodes are determined. The entire component design process including bill of materials and erection drawings is generated by MATHSPACE, a computer program developed solely for sorting/part number designation of space frames parts.

6. Double Angle Spaceframe

Double angle strut is an alternate to the pipe strut. Double angle strut, though inefficient compared to pipe for axial compression, will simplify end joint detailing, as it will not have end machined parts to connect to nodes. This will also bring down cost of fabrication of the space frame. The author's understanding is that this is the first time that double angle struts are being used effectively in a space frame assembly.

6.1 Composite Action

In the proposed double layer grids spaceframe system, the top chords will have double angle struts to receive the metal deck for composite concrete floor decking. The web and the bottom chord members will be either pipe strut or double angle strut. By providing shear studs that are welded on to the double angle top chord there is an interaction between the concrete deck slab and the double angle chord to make an effective composite section that utilizes the compression strength of concrete and tension strength of steel. The composite action interaction between the concrete deck slab and the double angle chord will reduce the buckling problems of the compression top chord members and will increase the stiffness of the structure. This would reduce the steel used in space frame and reduce deflection.

Further in the event of overloading the composite action of the top chord would induce a ductile type of failure instead of a buckling failure. This is because the overall behavior with composite action would depend mainly on the tension characteristics of the bottom chord members.

6.2 Advantages of using the new composite spaceframe system (5)

1) More efficient and stiffer composite spaceframe system makes it possible to support a given load with a shallow spaceframe depth and the ability to take extra load without failure.
2) Floor-to-floor height is reduced by not having to run the mechanical lines under the beam due to the ability to route the new mechanical heating, ventilating, plumbing, and electrical lines through the spaceframe open webs. It is easy to relocate and/or move future HVAC during the life of the building.
3) Weight savings resulting from the efficient composite design and member design of floor system will reduce overall building costs.
4) Kit-of-parts construction of spaceframe with standardization of members and connections with simplified erection provides for fastest and quality construction.
5) Large column free areas give the architects the maximum flexibility when selecting a floor layout plan. Customized composite spaceframe design can be employed for any given load and serviceability requirements.

7. Project Application

We have proposed the above briefed new bolted system for a project for a Mechanical block at DSCE. The building proposed is a rectangle in plan with approximate dimension of 60 m length and 30 m wide. It is a ground and 3 floors, plus roof structure with an approximate area of 7200 sqm. (refer to figure 5). The structural system is composed of regularly spaced RCC column and steel beam grid 15Mx15M, as primary framing to resist both gravity and lateral loads, and new bolted system with composite deck as secondary framing to transfer gravity loads (refer to figure 6).

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Figure 5. Building typical floor plan

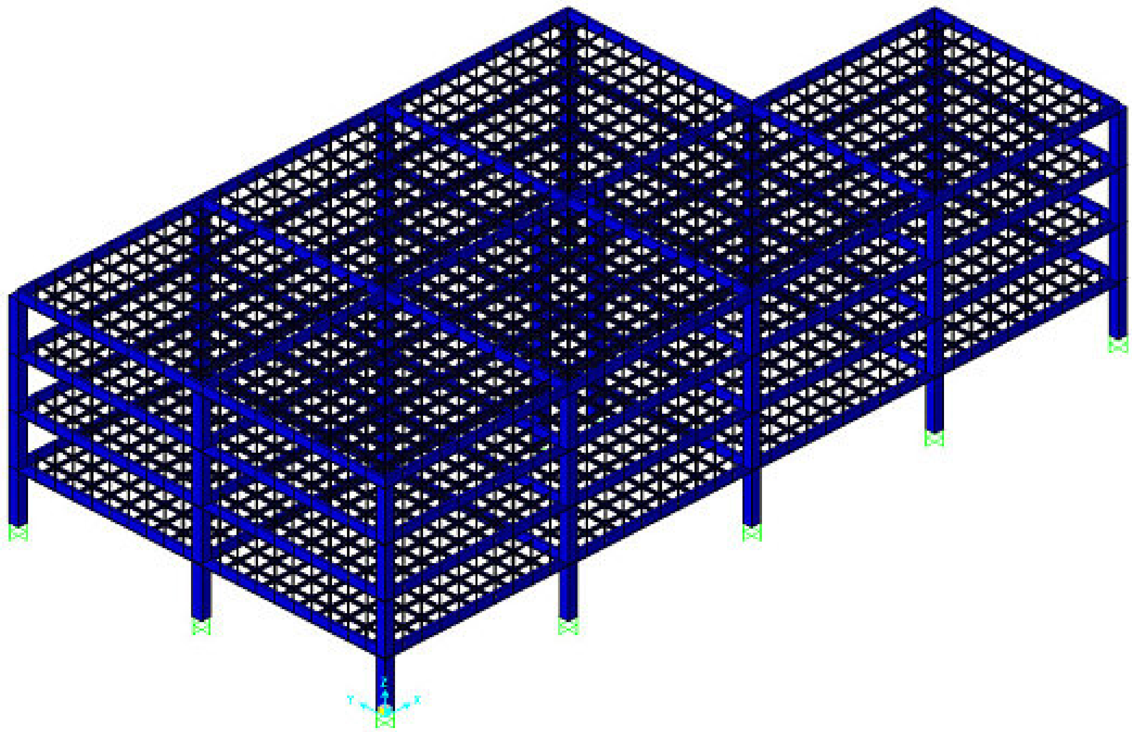

Figure 6. Building structural system

7.1Design Codes and Standards Used for the Building

a) IS 800: 2007 and AISC –ASD or LRFD
b) National Building Code of India 2005 (NBC 2005)

7.2 Design Loading for Proposed Building

7.2.1 Dead Load

a) Self weight of steel roof framing + concrete decking.
b) Floor finishes about 100kg/ sqm
c) False ceiling + Miscellaneous 50 Kg/sqm
d) Interior partition + other dead loads at 200Kg/sqm
e) External peripheral beams to carry additional 500kg/m external wall load

7.2.2Live Load

a) Live load 400kg/sqm

7.2.3 Wind & Seismic Loads

a) IS 875 part 3, code of practice for design loads (other than earthquake) for buildings and structures.
b) IS 1893 (Part 1): 2002, criteria for earthquake resistant design of structure.

STRUT	DESCRIPTION	QTY.
DL1	DL 50x50x5(12mm spacing) (IS 1161Fy=240Mpa&Fu=400Mpa)	12822
DL2	DL 60x60x5(12mm spacing) (IS 1161Fy=240Mpa&Fu=400Mpa)	6522
DL3	DL 65x65x5(12mm spacing) (IS 1161Fy=240Mpa&Fu=400Mpa)	746
DL4	DL 75x75x6(16mm spacing) (IS 1161Fy=240Mpa&Fu=400Mpa)	656
DL5	DL 75x75x10(20mm spacing) (IS 1161Fy=240Mpa&Fu=400Mpa)	437
		21183

Table 4. Summary of list of double angle struts proposed in the project.

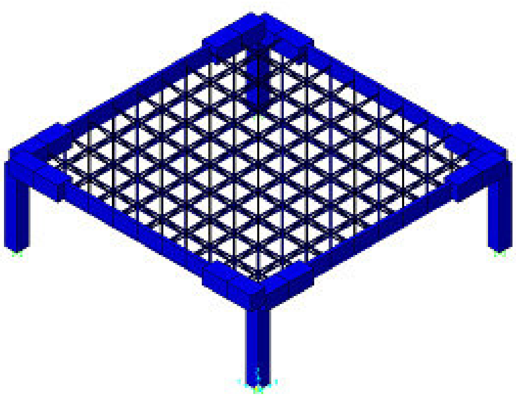

Figure 7. Typical bay framing

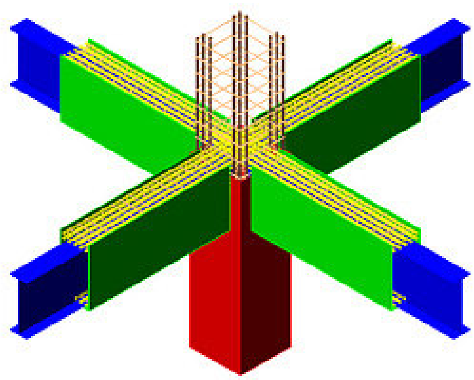

Figure 8. RCC Column& Steel beam detailing

Final Remarks

Even though spaceframe have been a popular 1950s building technology, it's potential to generate unique form, and it's potential as a materially efficient sustainable structure type has remained largely unexplored in India and hence presents significant future opportunity. To take advantage of these opportunities, a new bolted spaceframe system for India is proposed. The proposed new system has few parts compared to the typical ball node system and has higher tolerance during assembly compared to ball socket system, which is a key advantage in building space frame structures in India. Replacement of pipe struts by double angles and making it into a composite construction would further reduce cost of construction in India.

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