Pearl Kachhawah, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 10, Issue 6, (Series-I) June 2020, pp. 29-33

RESEARCH ARTICLE OPEN ACCESS

To Review, the Optimization of Space Frame Structures

Pearl Kachhawah*, Prof. Rupali Goud**
**(M.Tech Structure Engg., Department of Civil Engineering, SVITS, SVVV, INDORE, INDIA*
*** (Assistant Professor, Department of Civil Engineering, SVITS, SVVV, INDORE, INDIA*

ABSTRACT
Since 1950s, space frames have been in continuous development because of its economical means of covering large column free space. The space frames are comprised of three- dimensional plane or curved meshes, these are interconnected by structural element called as bars and joints. The structural members in space frame are connected at a single node at different angles posing problem of resolution of loads and subsequent effects. Therefore, they are light in weight, structurally efficient and uses material optimally. Space frames save construction time, because they use factory produced components that can be manufactured by fast production techniques, transported to the site and erected easily. In recent years for covering large area, use of space frame increases, especially in the form of double layer space grids. Usually, space frames are formed by two meshes: One is in the bottom of the structure named as bottom chords and another is in the top, comprised by upper chords, they are generally interconnected in their nodes by diagonals and resulting in space mesh in form of tetrahedral or pyramids etc.

Keywords: Connections, Double layer grid, Geometry optimization, Steel space frame, Strut design.

Date of Submission: 18-05-2020 Date of Acceptance: 03-06-2020

I. INTRODUCTION

Space trusses/frames are 3-D structures assembled of linear elements. These elements are arranged in a way to ensure 3-D force transfer from load application point to supports. In past years, there is rapid increase in number of steel structure because of its structural potential and visual beauty. These have factors such as large indoor space, sports tournament, cultural program held under one roof. The steel structures are usually constructed to the building type such as assembly halls, auditoriums, exhibition pavilions, warehouses, workshops etc. They are not only used over large span roofs, but also mid span, short span encloses as roofs, floors, canopies etc. The material used for the space frame is timber and steel. Timber therefore used in 19th century, causes high maintenance cost therefore uneconomical. Steel now-a-days most commonly used material in spaced frame sustains more load and can carry tones of weight also providing proper maintenance and economical to use over large span. The members are the axial elements with circular or rectangular sections. All members can only resist tension and compression. A space frame is built of long tension members and short compression members. These structures are statically indeterminate and their structural manual calculation is very tedious. Thus, using computer program as tool to analyze the complex space structure with great accuracy and less time. The space frames are strong because of inherent rigidity of triangles, as bending moments are transferred along the length of each strut.

In a space frame, connecting members at a node plays an important role in both as a structural element and esthetical view. Since, nodes have a decisive effect on the strength and stiffness of the structure. The nodes compose around 20 to 30 percent of the total weight. Connection design is critical in space frame with respect to safety and economy.

The structural members in space frame are connected at a single node at different angles posing problem of resolution of loads and subsequent effects. The connection of struts in space structure is preferred as bolted connection, but not welded due to easy transportation, fast assemblage, reduced cost, uncomplicated dismantling and expansion.

II. LITERATURE REVIEW

1) Vital da Silva et. al. (2018) This paper deals to correct the eccentricity of connection and avoid the stamp bar's end of space trusses. They studied spatial structure at manus convention centre (1995) at Brazil; this spatial structure had collapsed and gave the limitation of the use of space structures. The limitations are mainly related to the fragility (not strong) of the nodes, specifically those classified typical nodes, due to eccentricity generated by the coupling.

The models of space truss were executed with correction of typical node by glass fiber reinforced polymer spacer. The strength of the structure by using spacers is increased up to 22.5%, avoiding nodes to collapse. In the prototype with spacer the collapse occurred by buckling of bars. The effectiveness of the spacers, with resistance capacity gain of 22.5% according to the experiments performed for different types of spacers. The overall displacement of the structure with modified connection was 45.6% lower as compared to the structure.

2) Antiopi KORONAKI et. al. (2018) This paper deals with geometry optimization of space frame structure of joint uniformity. This paper proposed computational work for their geometrical optimization which includes three steps: the comparison and identification of varying joint configuration within a structure, their clustering into a minimum number of groups that are satisfying given tolerance, joint uniformity by their geometrical optimisation. It aims to study the relationship between change in curvature of a design surface and the respective construction complexity of space frame structure as a factor of joint customization.

This paper focuses on changing curvature, including surfaces that can be analytically described, freeform NURBS surfaces and surfaces generated with non-geometric methods, after application of forces. Fabrication processes were so studied which are described in relation to their degree of automation and the angle tolerance allowed for between their connecting members. 1- Continuous fabrication 2 – Discrete fabrication process 3 – Fabrication in groups Nevertheless, the flexibility of “FABRICATION IN GROUPS” process allows them some level of standardization and of customization.

3) Amr M. Ibrahim et. al. (2018) The structural performance of space truss under static and dynamic loads up to failure was discussed in previously published researches. Thus, this paper works on the behavior of space truss under fire.To study the behavior of space truss under fire, they worked on two trusses. These trusses were tested under several testing stages as concentrated load applied at middle of truss, applying constant static load in addition to increase in temperature to two lower joints, uniform increase in temperature at four lower joints of truss. This paper concludes the following result as – Due to high stiffness the trusses collapse locally in corner joint. From the experimental test of fire, the failure occurred is due to increase in tension force. There is loss of tension in members that are directly attached to the heated joints. Half of the truss was heated in another model, the deflection of the heated joints increased than that joints which are far away from the heat source, this increase in deflection reached about 77%. In results they found that, the members which were in direct contact with the heat source, then the axial force induce in that members are nearly (171kN) whereas the member which were far away from the heat source, in that members axial forces induced were very less nearly (30kN). In another model the failure was occurred in the truss due to buckling of a top member that is attached directly to the joint on which load was applied.

4) Eric C. Clough et. al. (2016) this paper conducted a systematic finite element study to determine optimal geometric parameters of hollow tetrahedral truss cores with given height and density constraints. It introduced the nodal height truncation for their architecture as an additional parameter, and explained that nodal truncation yields further improvements in the compression and shear strength of cores of truss. From the results of finite element, they proceeded to fabricate specimens by additively manufacturing polymer templates, coating the templates with nano-crystalline nickel, and subsequently removing the templates resulting in free- standing, hollow truss cores. This study had demonstrated that hollow truss cores offer an attractive alternative to state of the art of sandwich core materials.

5) Cleirton André Silva de Freitas et. al. (2011) This paper worked on computer simulations and experimental lab tests on prototypes, small changes on the staking end flattened connections such as reinforcement and eccentricity correction are evaluated. Numerical models, using finite elements, of this prototype truss are assembled and tested.

They used SAP2000 to discretize the 3-D standard truss with its different node/ connection configuration. Two types of finite elements from the SAP element library are used for the numerical modeling: the FRAME element and the SHELL element. The test result shows that the use of spacers increased in 53% the local collapse strength of the prototypes. The increase in strength can achieve 68%, if spacers are used together with reinforcement plates at the connections. For global collapse, when only spacers are used the increase in strength was 7%, and the increase in strength reaches 17% when spacers and reinforcement plates are used.

6) A. I. El-Sheikh et. al. (1996) The paper presented a space truss system newly developed with the main objective of achieving a larger reduction in the overall cost of space trusses without compromise in the structural reliability or ease of construction. This paper introduces a space truss system newly developed as an attempt to reduce the cost of space trusses without a compromise in their behavior or ease of construction. It shows an experimental program involving three full-scale models of the new truss system to assess its structural performance in various situations. The results obtained indicated a significant ability to distribute forces away from affected areas and a good joint stability. These characteristics were reflected in overall ductile performances that continued while several top chord members were showing large lateral deformations. Ample warning to failure in the form of noticeable sagging and top chord deformations was clearly seen in all tests. Overall, the experimental result illustrates that jointing system of the new truss is quite simple, its use does not result any structural deficiencies. On the contrary, it is able to improve the overall truss behavior by introducing ductility and enhancing the ability to redistribute forces. They showed that zero loss of strength and a moderate loss of stiffness were with the use of chord splices in all panels. The splices had been reduced in number which could be expected in practice, the loss of properties associated with the use of splices could have been less. Furthermore, the use of the two-plate splice (instead of the lap splice) could have also reduced the loss in stiffness further. But it is expected that the increase in cost associated with this type of splice would outweigh its structural benefit and might prohibit its use.

7) A. I. El-Sheikh et. al. (1993) This paper indicates that a composite concrete top chord is more effective than over strengthened upper chord members in reducing the brittle failure modes developing in space trusses. To improve the behavior of space trusses with the possibility of using over strengthened upper chord members or concrete slab acting compositely with the upper chord. The concrete slab was there for reducing buckling of upper chord members and increase the stiffness of the structure also to induce a ductile type of failure by making the overall behavior of space frame mainly dependent on the tension characteristics of the bottom chord members. An analytical study based on the finite-element method was carried out using a developed computer program and verified.

8) Christopher D. Hill et. al. (1989) this paper developed methodology to perform nonlinear post-buckling analysis of steel space truss systems. At element level the structural behavior was modeled through stress strain relationship. Using a tangent modulus in the evaluation of the element elastic stiffness matrix, member buckling due to nonlinearities are modeled.

The result of this research is that an accurate finite element analysis procedure to access the behavior of truss systems in their failure modes is available. Substantial reduction is shown in truss limit loads when they considered material and geometric nonlinearities.

The ability exists to focus on the members found to be as critical concern for an individual truss. Modification in design such as change in geometry, cross section types, and member dimensions can be investigated thoroughly within the same analysis scheme to evaluate alternative designs.

The results have shown the value of incorporating redundancy in space truss systems. Even though individual member fails by weakened, a truss system may well be able to carry additional loading. Consideration of this reserve strength can be important in quantifying the safety of truss systems when subjected to overload conditions. Although redundancy may not represent usable strength from the standpoint of design, it can provide additional insight into the mechanisms by which truss strength and safety can most effectively be increased. Though the reported analysis capability is fairly complete, additional features are required for complete space truss analysis/design. The occurrence of the sudden progressive type of failure experienced in the non-composite truss models was significantly reduced by the development of composite action. In the composite model, the overall behavior was dependent on the ductile properties of the bottom chord members under tension. In the composite case, plastic deformation was observed which provides adequate warning of impending failure. The economic viability of composite trusses could be enhanced because of this behavior and the factor of safety adopted for design might perhaps be reduced.

9) Ariel Hanaor et. al. (1989) By imperfections in the presence of brittle-type compression member buckling coupled with high degree of static indeterminacy space truss response is adversely affected. This paper gives a critical review of enhancement techniques evolved in recent years that aim at improving space truss response in terms of ductility and load bearing capacity. In design the overdesign of critical compression members coupled with tension members, diagonal member removal or eccentric diagonals, and pre-stress by imposed lack of fit in members are effective techniques that are relatively simple to implement. General recommendation of conservative approach to the design as the studies carried out over the past decade indicate that conventional approaches to space truss design may result in unsafe designs. These findings should be taken into account when designing space trusses and frames of the double-layer grid configuration. Reduction in allowable stresses in compression members of the order of 15%-25% compared to conventional column design is suggested by the data, particularly when elastic design is governed by buckling of compression members.

10) Henning Agerskov (1986) In recent years, extensive and increasing use has been made of space trusses, especially in the form of double-layer space grids. The optimum design of double-layer space trusses has been investigated in this paper. The member density must be small. The system was so chosen of long tension member and short compression member of the space grid. For rectangular, relatively long space grids, optimum design is obtained with systems where the load is mainly carried across the short span. Systems where the members in both top and bottom layer grids are parallel to the edges will generally result in the least material consumption. If both the material consumption and the number of nodes and number of members are considered, the space grid type results in good overall economy. This could be concluded from investigations on both square and rectangular double-layer space grids, simply supported along the entire edge and column supported at the corners. The type proved to be advantageous for both square and rectangular grids. In the case of a corner-supported grid, a relatively low material consumption was found for both square and rectangular grids.

11) Erling A. Smith (1984), This paper describes and models the non-linear behavior of space truss members, detailing of interaction between space truss member and its adjoining structure. They described CHORDAL SNAP THROUGH phenomenon, a non-linear stepwise linearization analysis method was developed which does not require the double updating of structural stiffness matrix.

Stepwise linearization used : Virgin linear elastic, prebuckling plateau, prebuckling linear elastic, yield or buckling plateau, reversing linear elastic, post-buckling "Step Down" and "Chordal Snap Through", post-buckling plateaus; and post-buckling reversing linear elastic. Computationally, only four types of regime are needed to model the full response: (i) Virgin linear elastic; (ii) constant force plateaus; (iii) reversing linear elastic; and (iv) Step Down.

The nonlinear behavior of space truss members has been described and modeled. The space truss member and its adjoining structure was interacted and detailed also the Chordal Snap Through phenomenon described. A nonlinear stepwise linearization analysis method has been developed which does not require multiple updating of the structural stiffness matrix.

12) Manolis Papadrakakis (1983) This paper considers the geometric and physical nonlinearities in the investigation of the post-critical ultimate load conditions of space trusses. Tracing the complete stress-strain relationships in the elastoplastic range to account the inelastic behavior of strut. Unloading characteristics of struts is determined in the post critical elastic perfectly plastic stage and the irreversibility of plastic strains are considered through an incremental procedure. For the solution of the nonlinear algebraic equilibrium equations they used dynamic relaxation method. Use of the relatively simple force-displacement relations of the individual discrete elements is needed, hence the method does not require the evaluation of any stiffness matrix.

Results shows that the exact post-buckling response of struts has been considered using the elastoplastic and elastic-perfectly plastic approaches for the loading path. Unloading path laws have been developed based on the elastic-perfectly plastic stress strain distribution. The nonholonomic nature of plastic strains was fully allowed for by means of a displacement incremental analysis.

III. CONCLUSION

From the study, we noticed that space frames are optimized, analysed in different ways such as practical experiments were performed or using software as a tool for optimization via different codes such as Euro-code3, BS code 5950 (Part 1): 1989 etc.

These codes give the design procedure of space frame and the property of material to be used. Therefore, for analysing the steel space frame we are using the same design procedure of space frame and optimizing it with software (STAAD Pro.) as a tool by providing property to the strut as per Indian Standards.

REFERENCES

Journal Papers:

[1] Vital da Silva, W., Bezerra, L. M., Silva de Freitas, C., & Rubim Costa Silva, Experimental analysis of steel space trusses with correction of the stamped connection with glass fiber reinforced polymer spacer, *International Journal Of Engineering*

Sciences & Research Technology, 7(6),2018, 117-127

[2] Antiopi KORONAKI, Paul SHEPHERDa, Mark EVERNDENa, Geometry optimization of space frame structures for joint modularity, *International Association for Shell and Spatial Structures (IASS), Symposium 2018, Creativity in structure design*,2018

[3] Amr M. Ibrahim, Ahmed A. Elshafey, Boshra A. El- taly & Kamel S. Kandil, Structural performance of space trusses under fire, *Malaysian Journal of Civil Engineering 30(1),* 2018, 37-56.

[4] Eric C. Clough, Jie Ensberg, Zak C. Eckel, Christopher J. Ro, Tobias A. Schaedler, Mechanical performance of hollow tetrahedral truss core, *International Journal of Solids and Structures 91*, 2016, 115- 126.

[5] Cleirton André Silva de Freitas, Luciano Mendes Bezerra and Ramon Saleno Yure Costa Silva, Numerical and experimental study of steel space truss with stamped connection, *Journal of Civil Engineering and Architecture, 5(6)* 2011,*1934-7359*

[6] A. I. EI-Sheikh, Member, ASCE and H. EI-Bakrf , Experimental study of behavior of new space truss system, *Journal of Structure Engineering, 122(8),* 1996, 845-853.

[7] A. I. El-Sheikh, Associate Member, ASCE, and R. E. McConneF, Experimental study of behavior of composite space trusses, *Journal of Structure Engineering, 119(3),* 1993, 747-766.

[8] Christopher D. Hill, Associate Member, ASCE, George E. Blandford, and Shien T. Wang, Members, ASCE, Post-buckling analysis of steel space trusses, *Journal of Structure Engineering, 115(4),* 1989, 900-919.

[9] Ariel Hanaor, Cedric Marsh, Members, ASCE, and Gerard A. R. Parke, Modification of behavior of double layer grid: overview, *Journal of Structure Engineering, 115(5),* 1989, 1021-1037.

[10] Henning Agerskov, Optimum geometry design of double-layer space trusses, *Journal of Structure Engineering, 112(6),* 1986, 1454-1463.

[11] Erling A. Smith, M. ASCE, Space truss nonlinear analysis, *Journal of Structure Engineering, 110(4),* 1984, 688-705.

[12] Manolis Papadrakakis, Inelastic post-buckling analysis of trusses, *Journal of Structure Engineering, 109(9),* 1983, 2129-2147.