STUDY ON STRESS RELATIONSHIPS OF CURVED SPACE TRUSS

SUDEEP.P.M, SANKARANARAYANAN .K.M

Abstract: Space truss is a most commonly using type of truss for roofing in the structures like auditoriums, stadiums and such big structures nowadays. Curved Space truss is the most commonly using type. Main reason for this is that, it can be used for long span trusses by reducing the intermediate supports. Use of this type of trusses in different structures have different structural properties and structural behavior. One of them is the depth and span relation. For different structures, this will be different. Also due to that, the stress- strain relationship is a factor that is having considerable importance. By knowing this, we can improve different properties of the truss system and that will give economy to the work, strength to the structure etc. Many models of Space Truss were made with different geometry and dimensions that having different Span-Depth ratio. Material properties, Support conditions, loading conditions etc. were assigned properly and uniformly. Modelling and Analysis were done using STAAD Pro. Software. Larger value of Stress from Stress report after analysis were collected from each models. Optimum value of stress were noted corresponding to Span – Depth ratio of different models. Studied these results and relations. It will help us to get an idea to fix the curvature of this type of truss for different span with particular geometry

Index Terms— CURVED SPACE TRUSS, MODELLING AND ANALYSIS, SIMPLE MODEL, JOINED MODEL, COMBINED MODEL, STRESS REPORT, MAXIMUM SPAN-CURVATURE RATIO, MAXIMUM CURVATURE.

1 INTRODUCTION

In architecture and structural engineering, a space frame or space structure is a truss-like, lightweight rigid structure constructed from interlocking struts in a geometric pattern. It can be used to span large areas with few interior supports. Like the truss, a space frame is strong because of the inherent rigidity of the triangle; flexing loads (bending moments) are transmitted as tension and compression loads along the length of each strut. Space trusses are an effective way of spanning large open areas with few or no intermediate supports. The past four decades saw an expanding interest in this form of construction because space trusses can combine light weight and easy assembly with a pleasing appearance. There have been quite a large number of spectacular space truss successes as large-span roofs of stadiums, public halls, aeroplanehangars, and many other buildings. However, in overall, theexistence of space trusses in the markets of large-span structures is by no means strong, and the number of their applications is relatively small and does not reflect their important constructional merits and pleasing appearance. It is a well-known fact that for a space truss system to compete favorably, it should succeed in satisfying the needs of all those involved in potential applications.

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Main advantages of space truss are:
* System has lighter solutions according to other systems. This characteristic of the system affects membersin a good way that faster andcheaper constructions exist.
* Becomes economical than truss system as the opening becomes larger.
* Air condition and electricity systems can easily pass from system openings.
* Using similar type of materials brings faster and easier fabrication.
* Being prefabricated, system can be used in other structures again and again.
* Lighter system brings less earthquake load and the system is more elastic and ductile than reinforced concrete systems.
* System uses pipes and spheres that comes up with low volume of transportation.
* Using lighter and similar elements brings easier Erection (erection can be completed on the ground and mounted to the structure even without scaffoldings).
* The elastic property of the system brings advantages in heat difference conditions.

Curved space truss is one most commonly using type of space truss. Curvature or depth of the curved space truss isthe main property of this truss to get more strength and other properties to truss.

This study deals with different studies conducted on this type of trusses. Due to different properties of the space truss, it is using widely nowadays. So, any advancing inventions will be helpful to increase its uses. Reduction in the intermediate support, use of less weight components etc. are new construction ideas used in this type of truss.

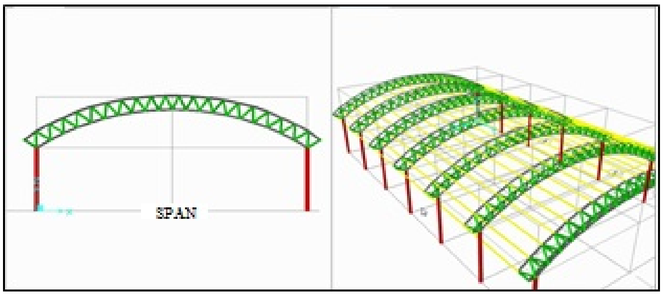

Figure.1 - Curved space truss

These are some reasons for having good scope for the study on Curved Space Truss. Study on steel is on progress. So, this study is also becomes important as a steel structure.

2 Literature Review

In this study, it deals with how the stress or strain is varying with dimensions and geometry in uniform conditions of Supports, Material properties, loading etc. Also to know the changes happens to stress values with different Span-Depth ratio. It will help to get an idea to fix the curvature for different value of span for a particular geometry. In current study, modelling and analysis of different structures with different dimensions were done by using STAAD Pro. and optimum stress values were noted. There are some literature which studies different areas and different behaviour of the space trusses.

Raja R. A. Issa and R. Richard Avent present an analytical methods for a class of longitudinally oriented space trusses [1] which avoids the two-fold disadvantages of high computation costs or the introduction of approximations. Specifically, three types of space truss systems are addressed: (i) X-braced; (ii) Warren (with verticals); and (iii)Vierendeel. These configurations are formed by having the respective truss types on three faces forming a triangular cross section with common chords.

Henning Agerskov made a literature study covering what has, until recently, been obtained as regards optimization of double-layer space grids [2] has been carried out as part of the investigation. Furthermore, actual cases, including both square and rectangular double-layer space grids, simply supported along the entire edge or column-supported at the corners, have been analyzed to determine the optimum design. The members in a single-layer grid are primarily loaded in bending.

Erling Murtha and Smith presented new method of analysis for static geometrically linear space trusses [3]. The method allows load increments and decrements, non-proportional loading and the simultaneous failure of several members, while retaining the computational efficiency of the "initial stress" method. In addition, the new formulation has the capability of including the computationally difficult internal instabilities caused by rupture of tension members and "chordal displacement snap through" of compression members in their post buckling regime. The method can be used with both plane and space trusses in addition to geometrically linear fiber element structures.

Larissa Driemeier et al. present in detail theoretical and numerical aspects of the behavior of spatial trusses undergoing large displacements and strains [4]. Nonlinear material behavior is taken into account, allowing for the development of finite plastic strains and damage. Both theoretical and algorithmic tangent moduli are derived and a finite element approach is used to solve the nonlinear boundary value problem. Restrictions are assumed such as: the material obeys Hooke's Law; small strains; equilibrium is enforced at the initial configuration by neglecting geometrical changes; boundary conditions are kept constant. However, in many applications the material can be loaded well beyond its linear limit, requiring for a more sophisticated analysis to address features like yielding, strain hardening and/or softening, localization and failure. Theoretical aspects, algorithmic issues and numerical applications of space trusses undergoing large strains are presented by them. The iterative procedure used to solve the nonlinear problem is detailed, which is stable and accurate, due to the explicit expression used for the algorithmic tangent modulus.

Attila Fulop and MiklosIvanyi deals with the detailed investigation of this roof system [5]5during the "elastic" range and the collapse. A space-truss roof-system, was experimentally analysed to determine the behavior of this system until collapse. The main aim of the investigation to find what is the stability and ductility behavior of this system under eccentric and concentric force. Tests conducted are:
1. The full-scale tests:
2. Individual experiments on the bars
Both the tests give same results.

Huu-Tai Thai and Seung-Eock Kim presents the large deflection inelastic analysis of space truss structures including both geometric and material nonlinearities [6]. The geometric nonlinearity is considered, based on an updated Lagrangian formulation, while the material nonlinearity is accounted for by tracing a complete stress-strain relationship in the elastoplastic range.

Galawezh Saber et al.[7] presents a method for analysis and optimum design of 2D and 3D curved roof trusses subjected to static loading and specified set of constraints. Here the optimization refers to minimization of total weight of curved roof structures such that they can resist applied forces (stress constraint) and don't exceed certain deformations (displacement constraints). Finite element formulations is developed and implemented to determine the stresses and displacements.

C.V. Camp and M. Farshchin [8] presents a modified teaching–learning-based optimization (TLBO) algorithm is applied to fixed geometry space trusses with discrete and continuous design variables. Designs generated by the modified TLBO algorithm are compared with other popular evolutionary optimization methods.

3 Methodology

Doing analysis in various number of structures is the way to get a desired result. For that, many truss models were made and analysed by the following steps. Auto CAD and STAAD Pro are the softwares mainly used here for the process. Different steps involved in this are as follows:
i) Modelling of Curved Space Truss using CAD drawing and STAAD Pro:
Model of the truss will be drawn in the AutoCAD first with a particular value of span andcurvature. Then, this cad drawing will be imported to the STAAD Pro.

ii) Modelling and Analysis of Truss using STAAD Pro, Finding stress - strain relationship on loading:
This AutoCAD drawing will be imported to the STAAD Pro. Then it will be modeled by assigning member property, Support conditions and loading conditions to the structure properly. Then, desired result will be taken from the analysis report. Here, for this, maximum axial stress value corresponding to maximum stress is taken from the analysis result.

iii) Changes in dimensions:
Dimensions of the truss will be changed in this stage. Following dimensions will be changed

- Span
- Curvature

Then procedure will be repeated.

iv)Checking relation between Span-Depth ratio and stress:
From the stress reports of different models, take optimum value for corresponding Span-Depth ratio of each models. Also check the stress-strain relationship of different models to know whether there is any chance to improve the properties and strength of space truss structure.

4 Modelling And Analysis

i) Preliminary steps in Modelling
Before doing modelling and analysis, some preliminary steps have to be done. Study of software is the first one. Auto CAD and STAAD Pro. are the softwares using here. Different tools and methods to do operations in softwres studied thoroughly first.
Next is to fix Support conditions, Material property, loading condition etc. Here, the support condition is selected as Fixed conditions. So, all supports made as fixed supports. Then load applying on the structure is fixed as concentrated loads. Here, it selected and applied 10KN load as concentrated load on the nodes at the top of the truss frame. Material property to be assign to the structure have to be selected before modelling. Properties of the structure selected from the collected details of space truss. Normally theses are constructing as tubular structures. By using small pieces of pipes of different cross sections, they were connected together to make the structure. I used pipe of 48 mm outer diameter and 2.9 mm thickness.
Properties assigning to the structure is as follows:

- Name of Pipe: PIP483.0L
- Outer diameter = 48.3 mm
- Thickness = 2.9 mm
- Ax = 4.14 cm2
- I = 10.7 cm4 ; Z = 4.43 cm3

ii) Modelling and Analysis
For this, structures with three type geometry are modelling and analyzing. They are:

a) Simple model

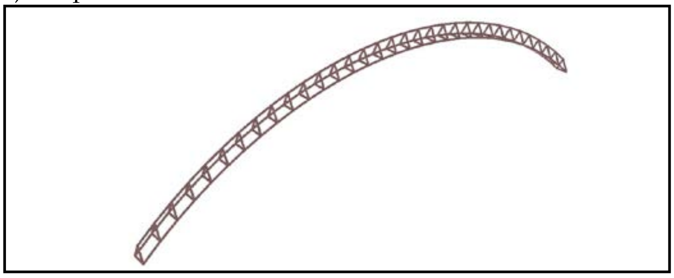

Figure.2 - Simple model

b) Joined model

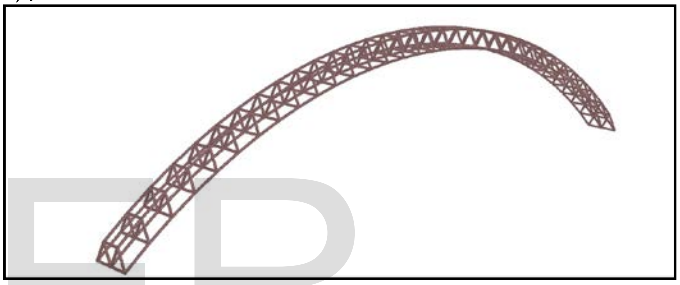

Figure.3 - Joined model

c) Combined model

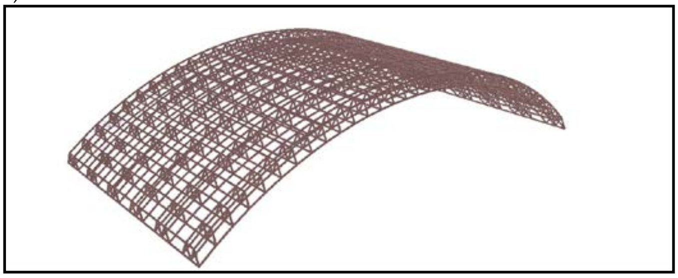

Figure.4 - Combined model

First one is the simple geometry that is using in the space trusses. Joined model is the advanced one of the simple model. Its having much more complex geometry than the first one. Third type geometry is the combined type of the second type geometry. These three type of geometry were used in the study to know the changes that happened to the structure with change in the geometry of the space truss.
CAD drawings were made as the first step of modelling. 3 dimensional drawing is made using Auto CAD. Then this will be imported to STAAD Pro for modelling and analysis processes. After importing to STAAD Pro, Member property, Support condition, Loading etc. were assigned properly. These were assigned to all the models undergoing analysis uniformly. This uniformity is keep to

evaluate the result of analysis of all the models properly. That means, member property, support condition and loading were assigned with same value to all models so that output result will be under same condition for all structures.

Modelling and analysis done for all the members with dimensions which were already fixed. Span of the structure is selected in between 10m and 25m with 4m interval. i.e., 10m, 14m, 18m, 22m, and 25m. At first, curvature value is selected from 0m (Plane truss) and varied with 0.5m. About 5 values of curvature is fixed. Afteranalysis done upto these values, a steady decrease in the stress value is obtained. Further analysis with more structure with higher value of curvature, there found a change in the stress value. This stress value is increasing gradually after a particular value of curvature. So, for all models with each span value, the curvature value is selected upto where this change in the stress value occurs. This is how the dimensions of the models to be analysed is fixed.

5 Results And Discussions

After analysis, so many results can be obtained from the software like moment, shear, deflection, strain etc. Here, the stress values is taken as the result. The results obtained for different spans and dimensions are tabulated as follows:

Table 1- stress report of 10m span

10m			
CURVATURE(m)	STRESS (N/mm2)		
	SIMPLE	JOINED	COMBINED
0	400.946	762.338	755.159
0.5	440.169	624.535	622.58
1	257.428	348.16	347.753
1.5	196.764	268.288	267.873
2	175.389	242.939	242.636
3	153.486	208.811	208.759
3.5	154.564	211.855	211.69

Table 2- stress report of 14m span

14m			
CURVATURE(m)	STRESS (N/mm2)		
	SIMPLE	JOINED	COMBINED
0	826.528	1483.211	1470.68
0.5	814.532	1159.537	1155.235
1	510.676	722.073	720.108
1.5	357.717	488.161	487.354
2	305.045	402.492	401.781
3	239.866	320.886	320.919
4	218.581	276.043	277.957
4.5	217.908	269.015	272.065
5	223.341	274.37	278.171

Table 3- stress report of 18m span

18m			
CURVATURE(m)	STRESS (N/mm2)		
	SIMPLE	JOINED	COMBINED
0	1400.214	2403.47	2385.456
0.5	1309.67	1853.732	1846.896
1	823.55	1159.692	1156.379
1.5	573.308	781.949	780.523
2	461.128	627.593	627.387
3	356.792	481.504	479.685
4	302.821	385.8	387.451
4.5	287.94	352.259	355.36
5	278.543	325.359	330.597
5.5	266.327	384.436	293.018
6	273.865	395.48	392.941

Table 4- stress report of 22m span

22m			
CURVATURE(m)	STRESS (N/mm2)		
	SIMPLE	JOINED	COMBINED
0	2120.019	3516.921	3493.531
0.5	1929.747	2708.668	2699.277
1	1215.684	1700.926	1696.209
1.5	878.208	1150.173	1148.023
2	670.756	910.744	909.251
3	503.594	683.484	681.348
4	412.186	531.763	536.347
5	361.562	500.517	509.998
5.5	344.707	477.823	475.978
6	331.737	471.455	468.77
6.5	321.99	469.752	465.391
7	315.239	471.86	465.608
7.5	311.763	477.305	472.456
8	312.467		

Table 5- stress report of 25m span

25m			
CURVATURE(m)	STRESS (N/mm2)		
	SIMPLE	JOINED	COMBINED
0	FAILED	FAILED	FAILED
0.5	2477.722	3456.141	3444.843
1	1562.364	2175.142	2169.372
1.5	1125.11	1475.296	1472.584
2	856.638	1160.963	1159.08
3	633.161	860.939	855.645
4	509.431	669.449	667.803
5	465.298	587.233	594.209
6	391.792	545.658	542.543
7	539.232	526.956	521.202
8	334.913	520.506	516.634
8.5	325.736	520.216	516.265
9	319.514	521.956	518.016
9.5	317.98		
10	323.833		

The above tables shows the result different span structure with different curvature. Following tables shows results

structures with more span values.
We get the full report of the stress value of different members of the structure. From the stress values of stress report, selected the maximum axial stress value of the maximum combined stress value for each models. That value is taken. In all these models, it's seems that this maximum value is getting at the supports of the truss.

In the results, it show that there are some variations happens to the stress values with respect to the change in dimension. This happens differently for different Span-Curvature ratios. These are the results obtained from the analysis of the structures used in this study. Here, we can see the change happening to the stress values according to the change in the dimension.Once we look at a glance, we can see that the stress value is decreasing regularly with the increase in the curvature value. This is repeating in all structures with different span values. But, looking into detail, we can see some changes. In the 10m span, when curvature changes to 0.5m from 0m, stress is increasing. Then, all the other values were decreasing. In all other cases, regular decreasing is occurs apart from this case only. In the case of 25m span structure, we can see that the structure is failed under loading in the 0m curvature. That is, plane truss is failed under loading. But all other structures don't failed since they are becoming curved. Then, going to other values of curvature, this stress value is decreased regularly and at a point, this is start increasing. This is a specialty of this type of trusses. All the structures with varying span shows the same property as shown in the result values. This experiment is continued upto when this happens. For all structures with different span, this change in the nature of stress value is happens at a particular curvature or at a particular ratio of span and curvature of the space truss. The analysis is continued up to getting into that particular ratio in all the used span of truss. In these results, we have the values of stress that will be help to get into a conclusion about these ratio. This will help us to get an idea about providing curvature to these curved space trusses with a particular span and geometry.

6 Summary AndConclusions

From this study, many inferences were made. First of all, its shows that the Curved type of trusses are better compared to the plane trusses. The stress value of Plane trusses is higher than the curved trusses in all the cases studied here. So, the stress value is smaller for curved truss and so they are better for making truss. This is why they are well used in large span trusses. Then, from the results, it shows that stress value is increasing with respect to increase in span. Also, stress value is decreasing with respect to increase in curvature up to a limited value of curvature. From this, we can say that due to different reasons, stress will increase with increase in span. Also, the stress value is decreasing with increasing curvature up to a limit. That means, this type of curved space trusses are becoming safer when curvature increasing upto a limit. These are the primary conclusion.

Next one is the most important one. From the results, it shows that for a particular value of curvature, stress becomes increasing where up to that, the stress value is decreasing. That is, we get a optimum value of stress in these structures. So, from there we get a Span-Curvature ratio at that point. This ratio can be used for designing of this type of curved space trusses with maximum efficiency. The following shows that ratio obtained from the study.

Table 6- Maximum Span-Curvature ratio

SPAN (m)	SPAN-CURVATURE RATIO		
	COMBINED	JOINED	SIMPLE
10	2.857	2.857	2.857
14	2.8	2.8	2.8
18	3	3.273	3
22	3.143	3.143	3.143
25	2.778	2.778	2.5

This is the showing the Span – Curvature ration for different span of the structure. We can use this ratio for making Curved space truss. For example, a curved space truss with 25m span, curvature with getting a maximum Span-Curvature ratio of 2.778. Here, combined type of truss is considered because that is having structure which is using for most of the trusses.

It can be represent in other way. That is, the maximum amount of curvature value. For each span of truss, maximum curvature value that can be provided to the structure with maximum economy and efficiency.

Table 7- Maximum curvature

SPAN (m)	MAXIMUM CURVATURE		
	COMBINED	JOINED	SIMPLE
10	3.5	3.5	3.5
14	5	5	5
18	6	5.5	6
22	7	7	7
25	9	9	10

For example, a truss with curvature 10m, the structure with combined model, the curvature can be provided with 3.5m which will be having the maximum efficiency and economical.

7. Future Scope Of The Study

This study is very much useful in the area of Space truss, especially in case of curved space truss. As said earlier, the use of this type of trusses are becomes more common in the construction industry due to different properties. Since the use of concrete is becomes difficulty in the current situation, use of this type of truss will increase. So, some findings onthis type of truss will give some easiness and some more efficiency in this type of trusses.

Journals dealing with this type of studies conducted on curved space truss is rare. So, this study will be helpful for different studies in future. Here, I just used single steel pipe for all the models analysed. More structures with different material property, with different geometry and dimensions, with different connection methods etc. can be used to do more studies and experiments. In such a way, this study is just a starting. Let it be a good start to do more findings and studies about this in different areas and properties of such a fantastic creation of civil engineers- Curved Space Truss

ACKNOWLEDGEMENT

Using this opportunity to express sincere gratitude towards all the people who helped directly and indirectly throughout this study.

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