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Analysis and Design of Single Curvature Double Layer Tensegrity Grid

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Abstract

Tensegrity is an emerging and comparatively new system which creates astonishing, lightweight and flexible structures, giving the impression of a constellation of struts floating in the air. They are a special type of light-weight space truss structures, where the tensile elements are made of cables. However, a lot of research has concentrated on the theoretical side such as form finding, only a few practical mechanisms have been done on how to use these structures. This paper provides the base study for design and construction of a single curvature double layer tensegrity grids. This paper also explores the specific form appropriate for such systems if used for large roofs. Also, this study reviews the performance of tensegrity grids for different loads. The comparison is done with a conventional roof system based on the economy and practicality.
Keywords: Cable Stayed Roof Structure, Half-Cuboctahedron, Single Curvature Roof Structure, Tensegrity, Tensegrity grids, Tensile Structure

I. INTRODUCTION

A distinguishing characteristic of the tensegrity structures is the existence of geometric nonlinearities due to the varying geometry as they deflect due to loads. That is the stiffness matrix [k] is a function of the displacement (u). There are four kinds of geometric non-linearity - large strains, large rotations, stress stiffening and spin softening (Cook et al 2003).

In tensegrity structures, stress stiffening is more protruding. In this type of non-linearity both strains and rotations are minor. Stress stiffening outcome usually needs to be measured for thin structures, such as cables, thin beams and shells that have very small bending stiffness as compared to the axial stiffness. The in-plane and the transverse displacements are coupled in such structures. This result also enhances the general non-linear stiffness matrix formed by large strain or large deflection effects. Producing and then applying additional stiffness matrix called as stress stiffness matrix accounts for the outcome of stress stiffening. It may be used for static and transient analysis.

So during the preparation of the tensegrity grid model in ANSYS Workbench 14.5, geometrical non linearity and large deformation effects are considered.

II. ASSUMPTIONS MADE FOR MODELING

1) All structural components are assumed as truss elements i.e. there are no bending moments established. To justify this assumption, the components are modeled as 3-D spar elements (LINK180) which has three degrees of freedom at each node i.e. translations in x, y and z directions and are uniaxial tension-compression elements.
2) Each component is defined by two nodes, the cross-sectional area, an initial strain and material properties. The readings of initial strain are obtained from former experimental data.
3) The materials' behavior is supposed to be elastic, isotropic and linear.
4) The degree of freedom in Z-direction is locked at the bottom nodes except for the central node for which all the degree of freedom is locked and at the top nodes all the degrees of freedom are released.

III. ANSYS MODEL OF TENSEGRITY GRID

The modeling for the structure was done in AutoCAD 2011 and the wireframe is exported to ANSYS Workbench 14.5 after incorporating above assumptions. Figure 1, 2 and 3 shows 3D view, the top view and perspective view of the model.

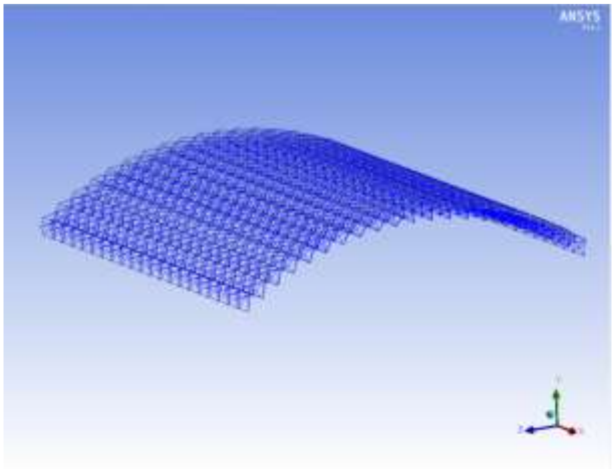

Fig. 1: 3D View of the model

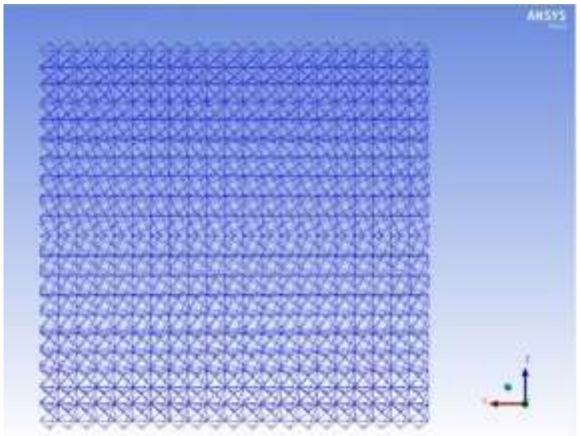

Fig. 2: Top view of the Model

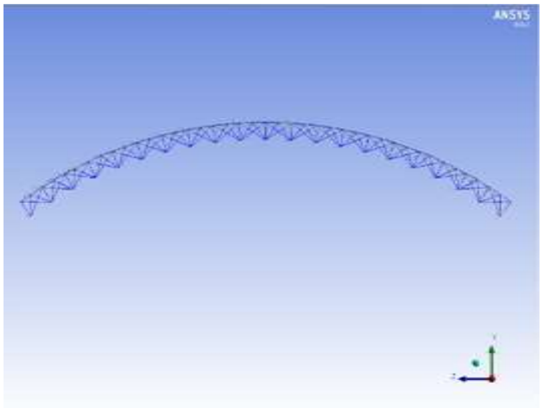

Fig. 3: Side View of the Model

IV. MODEL PARAMETERS AND PRELIMINARY DATA

The table below shows the physical properties, material properties and other preliminary data for the grid

Table - 1
Physical and Material Properties

Sr.no	*PARAMETER*	*VALUE*
1.	*Area*	*40m x 40m = 1600 m^2*
2.	*Central Rise*	*6.5 m*
3.	*Module Unit*	*Half Cuboctahedron*
4.	*Module Dimension*	*2m x 2m*
5.	*Total No. of Units*	*20 x 20 = 400*
6.	*Length of strut*	*2.73m*

7.	Length of Top Cable	1.517m
8.	Length of Bottom Cable	2.0 m
9.	Height of Module	1.5 m
10.	Slenderness ratio of strut	128.65
11.	Cable Construction	6x19(6mm)
12.	Young's Modulus (Cable)	0.954×10^5 N/mm^2.
13.	Yield stress (Cable)	1421.335 N/mm^2
14.	Young's Modulus (Strut)	2.05 x 10^5 N/mm^2
15.	Yield stress	240 N/mm2
16.	Poisson's Ratio	0.25
17.	Initial Strain	0.648 x 10^{-4}
18.	Pre-stress force	2.49 kN

V. LOAD CALCULATION

1) Dead Load: Self Weight + Fabric Cladding = 0.4 kN/m2
2) Live Load

(As per TABLE-2) IS: 875-PART (II) - curved roof more than 10 degree
As per calculation: - 0.75-0.52Y
Y= $(h/l)^2$
= $(4/40)^2$ = 0.01
= 0.75-0.52(0.01)
= 0.7448 kN / m2
Load on cable = 2.13 kN/m

3) Wind Load

For Basic Wind speed = 39.0 m/s

Table - 2
Wind Pressure Calculation

Load Condition	Pressure or Suction	Roof (kN/m2)
Static	Pressure	0.086
	Suction	-1.12
Dynamic	Pressure	
	Suction	-0.83

4) Earthquake load:
   Total Base shear: 817 kN
5) Load Combinations:

Below are the load combinations applied for the analysis:

Table - 3
Load combinations

Load Combination	Load Factor			
	DL	LL	WL	Earthquake
Combi 1	1.0	1.0		
Combi 2	1.0	1.0	1.0 (x)	
Combi 3	1.0	1.0	-1.0 (x)	
Combi 4	1.0	1.0	1.0 (z)	
Combi 5	1.0	1.0	-1.0 (z)	
Combi 6	1.0		1.0 (x)	
Combi 7	1.0		-1.0 (x)	
Combi 8	1.0		1.0 (z)	
Combi 9	1.0		-1.0 (z)	
Combi 10	1.5	1.5		
Combi 11	1.2	1.2	1.2 (x)	
Combi 12	1.2	1.2	-1.2 (x)	
Combi 13	1.2	1.2	1.2 (z)	
Combi 14	1.2	1.2	-1.2 (z)	
Combi 15	1.5		1.5 (x)	
Combi 16	1.5		-1.5 (x)	
Combi 17	1.5		1.5 (z)	
Combi 18	1.5		-1.5 (z)	
Combi 19	0.9		1.5 (x)	
Combi 20	0.9		-1.5 (x)	
Combi 21	0.9		1.5 (z)	

Combi 22	*0.9*		*-1.5 (z)*	
Combi 23	*1.2*	*1.2*		*1.2 (x)*
Combi 24	*1.2*	*1.2*		*-1.2 (x)*
Combi 25	*1.2*	*1.2*		*1.2 (z)*
Combi 26	*1.2*	*1.2*		*-1.2 (z)*
Combi 27	*1.5*			*1.5 (x)*
Combi 28	*1.5*			*-1.5 (x)*
Combi 29	*1.5*			*1.5 (z)*
Combi 30	*1.5*			*-1.5 (z)*
Combi 31	*0.9*			*1.5 (x)*
Combi 32	*0.9*			*-1.5 (x)*
Combi 33	*0.9*			*1.5 (z)*
Combi 34	*0.9*			*-1.5 (z)*

VI. ANALYSIS RESULTS & DISCUSSION

Following are the results obtained from ANSYS analysis:

A. *Maximum Displacement*

Displacement Point	*Value*	*Allowable Deflection*
Maximum vertical deflection at vault crown	*37 mm*	*123 mm*

B. *Roof Design Forces*

Force	
Member	*Fx (kN)*
Strut	*11.3*
Cable	*-16.8*
Stress	
Member	*S Max (N/mm2)*
Strut	*129.3*
Cable	*-1153.7*
Reactions	
Fx (kN)	*-19.16*
Fy (kN)	*-24.5*
Weight (Kg)	
Weight of 1600 Struts	*13104 Kg*

C. *Comparison*

	Double layer Barrel Vault	*Double Layer Tensegirty Grid*
Weight/m^2	*45 Kg*	*8.19 Kg*

VII. CONCLUSION

A 1m×1m tensegrity grid structure has been analyzed by a single half cuboctahedron unit in FEM Software. The comparison of deflection and various member forces obtained experimentally and numerically for the grid structure show reasonable agreement. The load carrying capacity of the structure increases by increasing height and keeping other parameters constant. By providing additional support on periphery, the deflection and strut force decreases and the load carrying capacity increases. Economical Design is achieved by a considerable margin.

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