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Parametric Study on Tensegrity Grid Structures

R. Panigrahi[1], A. Gupta[2] and S. Bhalla[3]

Summary

This paper presents the development of a tensegrity grid structure, 2mx2m in size, by integrating four single tensegrity modules based on half-cuboctahedron configuration, using galvanised iron (GI) pipes as struts and high tensile stranded cables as tensile elements. A comprehensive monitoring is carried out on the grid structure using strain gauges to obtain the prestress levels, deflection pattern, forces in the struts and the overall load carrying capacity. The monitored structure is also analyzed using finite element method (FEM), considering the prestress level in struts as reference. The experimental and numerical results are compared and reasonable agreement is found. The influence of height of structure, rigidity ratio and support conditions on maximum deflection is also investigated in detail.

Introduction

'Tensegrity' is a relatively new and revolutionary concept in structural engineering. A tensegrity structure typically consists of a set of discontinuous compression members tied together by tensile members, generally cables, in a continuous manner. The term 'tensegrity' was formally coined and patented as a contraction of the two words, 'tension' and 'integrity' [1]. The most recent definition of tensegrity structures has been given as, "A system in a stable self-equilibrated state comprising a discontinuous set of compressed components inside a continuum of tensioned components" [2]. A lot of literature can be found on tensegrity structures related to form finding, static and dynamic analysis, fabrication and applications [3, 4].

The present study includes the fabrication of a 2m×2m size grid as a cohesive unit by joining four individual units of 1mx1m size along the bottom cables and experimental investigations on deflections, member forces and numerical modeling. The tensegrity grid of 8mx8m is analysed numerically for different parameters like rigidity ratio, height of the structure and the support conditions. The effect of these parameters on the maximum deflection and the member forces is studied.

Experimental investigations

In this study, compression members made of galvanized iron (GI) pipes of medium type and tension members in the form of cables, made from 0.25 mm diameter galvanized high carbon steel wires, conforming Indian standard code of practice are used. Each cable consists of six strands with nineteen wires in each strand. Both the struts and the cables are tested in the laboratory for Young's modulus and

[1]Lecturer, College of Engineering and Technology, Bhubaneswar, Orissa, India 754032
[2]Professor, Civil Engineering Department, IIT Delhi, New Delhi, India 110016
[3]Assistant Professor, Civil Engineering Department, IIT Delhi, New Delhi, India 110016

the ultimate strength [5]. For the strut, the Young's modulus has been determined as 2.05×10^5 N/mm^2 and the ultimate stress as 410 N/mm^2. Similarly, for the stranded wire, these values are 0.954×10^5 N/mm^2 and 1119.6 N/mm^{2}respectively. It is observed that the cables possess much higher strength, several times in magnitude, as compared to the struts.

A dismountable tensegrity grid of size 2m×2m is fabricated using the GI pipes and the 6×19 stranded wires by joining four half-cuboctohedral units. The erected grid is shown in Fig. 1. The bottom cables measure 1m in length, the top and the side cables 0.707m and the struts 1.224m in length, centre to centre of joints. Cable mode of erection is adopted i.e. assembling and dismantling is facilitated through a cable by means of a turnbuckle. The length of the top cable is adjusted by means of the turnbuckle after positioning the struts. The structure attained self stressed equilibrium as soon as all the four units acquired configuration of half-cuboctahedron. The grid structure is achieved by joining along the inner bottom cables. As a result, the numbers of cables is less by four as compared to conventional approach.

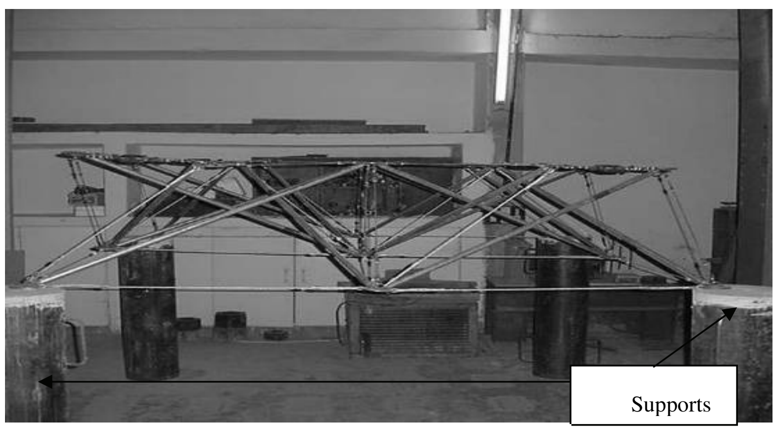

Figure 1: Fabrication of tensegrity grid

All members of one unit (quarter) of the grid are instrumented with electrical strain gauges (ESGs), four on each pipe (5mm gauge length) and two on each cable (2mm gauge length). Two linear variable displacement transducers (LVDT) are positioned, one under the central bottom node and the other is under a side bottom node, for measuring displacements. The average prestress force in the struts is computed as 2.58 kN from the measured strain data. The structure is loaded in quasi-static mode by gradually increasing the vertical loads in the form of iron weights and concrete cubes. The final failure occurred due to the failure of a cable connection. In addition, several cables are found to be slack. More details of the test are covered [5].

Finite element analysis

The tensegrity grid structure is modelled using finite element method (FEM) using the preprocessor of ANSYS 9.0 [6]. The detailed procedure for geometric nonlinear analysis of prestressed cable networks using matrix displacement approach is described in [7]. All the cable and the strut elements have been considered as 3D spar elements with three degrees of freedom in translation at each node. The material has been assumed to be linearly elastic and isotropic. All the bottom nodes are restrained against translation along each coordinate axis. The prestress force measured in the struts in the self stressed equilibrium configuration upon erection is used to determine the initial strain in the cables. The axial force in top cable, F_a, bottom cable, F_b and leg tie, F_t can be expressed in terms of strut force F_s, based on [4] and [5] as

$$F_t = F_a = 0.578F_s \tag{1}$$

$$F_b = 0.41F_s \tag{2}$$

From these equations, the average prestress force in the top, the bottom and the tie cables is computed as 1.50 kN, 1.06 kN and 1.49 kN respectively considering the strut force F_a=2.58 kN as the reference. The model is simulated with external loads as applied during the experiment, distributed equally among all top nodes as concentrated loads. Fig. 2 compares the results obtained using FEM with those obtained experimentally. It is observed that key displacements and key member forces obtained in the strut through FEM match well with the experimental results. This provides a validation to the finite element model of the structure, which will be used for parametric study as described in the next sections.

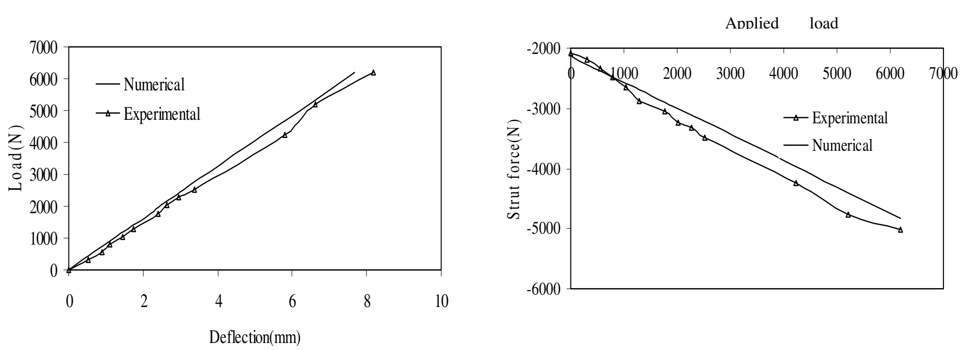

Figure 2: Comparison of experimental and numerical results for 2m grid structure

Parametric study of tensegrity structures

After validating the finite element model of 2m×2m grid, it is extended to 8m×8m grid to study the effect of rigidity ratio (ratio of the axial stiffness of the strut to that of the cable), height and support conditions. The prestress force in the self stressed equilibrium configuration is considered as 1.5kN for the top cable as the reference. In general, due to high flexibility associated with the tensegrity structures, deflection is expected to govern the design. The analysis is first carried out on 8m×8m grid. The maximum deflection of the structure is determined for a uniformly distributed load of 0.4 kN/m^2, at a load step of 0.005 kN/m^2, for four different heights of 0.5m, 0.6m, 0.7m and 0.8m. The cross sectional area of the struts is fixed as 160.28 mm^2 and the necessary cross sectional area of cables is varied so as to achieve rigidity ratios of 10, 20, 30, 40 and 50. The support conditions have considerable influence on the deflection. In the first case, the structure is supported on four corners with all three degrees of freedom locked. In the second case, additional supports at intermediate nodes on the periphery are locked in the vertical direction. In general, deflection is the governing criteria for design of tensegrity structures.

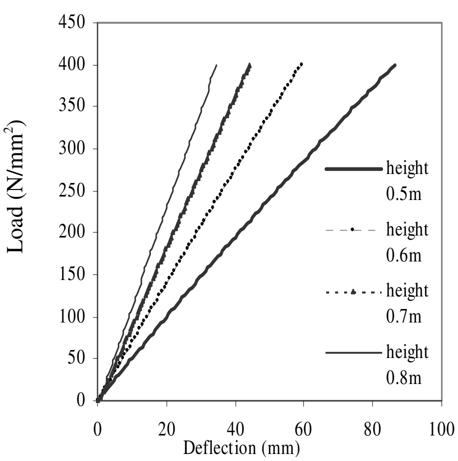

Figure 3: Maximum deflections for 8m×8m grid structure for different heights for a rigidity ratio of 10.

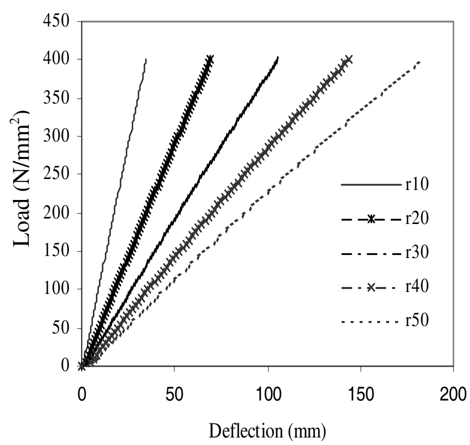

Figure 4: Maximum deflections for 8×8m grid structure for different rigidity ratios for a height of 0.8m

Typical variation of the maximum deflection for different heights corresponding to a rigidity ratio 10 is shown in Fig. 3 for the structure supported on four corners only. It is observed that with increase in height, the maximum deflection decreases appreciably. Comparing the results for a height of 0.8m with 0.5m, a reduction of 33% to 60% is observed. Fig. 4 similarly shows maximum deflection for the 8×8m grid structure for different rigidity ratios corresponding a height of 0.8m. The increase in deflection is substantial with increase in the rigidity ratio, since increase in rigidity ratio implies reduction in the area of cable elements. Fig.

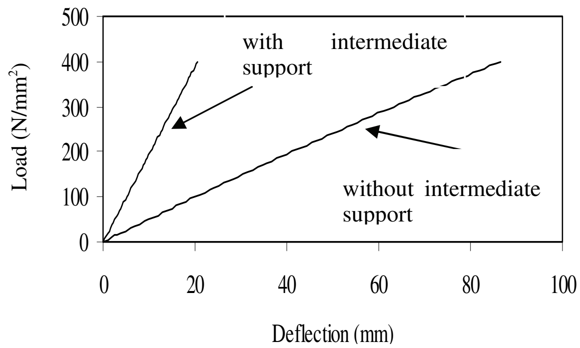

Figure 5: Comparison of maximum deflections in 8×8m grid structure for different support conditions

5 shows a comparison of the maximum deflection for the grid structure with and without intermediate supports at the centre periphery nodes. The maximum deflection is observed at the central bottom node in both the cases. It is observed that the deflection reduces considerably for the case with intermediate supports. For example, the deflection reduces from 86.5 mm to 20.6 mm for a load of 400 N/m^2.

Conclusions

The present study has presented the fabrication and the structural behavior of the tensegrity grid structure. The structure was modeled using FEM and validated experimentally. The effect of rigidity ratio, height and support conditions on maximum deflection is studied in detail. Tensegrity structures have great potential in modern structures such as bridges, communication towers and masts.

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