

Analysis and test for shaping formation of space truss by means of cable-tensioning

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Abstract

For developing innovative construction techniques, extensive research has been carried out on the behavior characteristics for shaping formation of space structures by means of cable-tensioning method. This paper discusses the shaping formation of space structures by means of post-tensioning of the cable in bottom chords. It is a fast and economical construction method used in many types of space structures. Test models presented herein consist of uniform pyramids with multi-directional ball type joint, the space structure is shaped and erected into its final shape by cable-tensioning in the bottom chords. The feasibility of the proposed post-tensioning technique and the reliability of the established geometric model were confirmed by finite element analysis and tests on a small-scale test model. Once the proposed post-tensioning technique had been applied for shaping formation of space structure with multi-directional ball type joint, characteristics were determined from shaping test for practical design purposes. It proved to be an economic and reasonable method compared to conventional construction method including the heavy crane and scaffold.

Introduction

Space structure is relatively lightweight, easy to fabricate and transport, flexible in workability, and requires short period for construction. In general, though the major use of pre-stressing method is in concrete structure, recently various types of space trusses such a barrel vault, dome, hyper, arch shaped structures are being studied with model test and theoretical analysis for shape formation by post-tensioning (Clarke and Hancock 1995, Dehdashti, and Schmidt 1996, Kim 2000, 2001, Kim and Hao, 2002, Kim et al. 2001, Kim and Schmidt 2000, Kim et al. 2002, Kim, et al. 2004, Kim et al. 2006, Kim et al. 2005, Schmidt and Selby 1999, Schmidt and Selby 2001). Some engineers consider existing construction methods for space structures will remain the same as existing practice without recognizing the changes taking place in this practice. But it can be altered beneficially taking advantage of new approaches. For developing the innovative construction techniques, extensive research has been carried out on the behavior characteristic of shaping formation for space truss by means of post-tensioning method. Therefore, by means of post-tensioning, to improve the construction method and propose an alternative solution, shape formation test and theoretical analysis for the space structure was conducted with the test model that was consisted of ball type joint and steel pipe. When space structure is formed with post-tensioning, its behavior is known a nonlinear manner. Through model test and nonlinear finite element analysis, the behavior characteristic and the feasibility of formation for space structure with ball type joints were verified, and as a result, it can be used in the prediction of final shape for the space structure.

Nonlinear analysis and experiments for shape formation

The basic structural type for post-tensioned and shaped space structure is a kind of single-chorded space truss (SCST). In the initial planar configuration for post-tensioning, it is the SCST condition, so it has the mechanisms or near mechanisms, for these reasons SCST can be shaped easily with relatively small post-tensioning forces. Because the SCST can resist with only its weight, the friction of its joints, and flexural stiffness of the top chords, it is very weak structure. But after post-tensioning and the self-locking process, the SCST can be a stable structure. Though the post-tensioning process may reduce the load capacity, due to the existence of compressive pre-stress forces in some critical members after shape formation, the reduction in ultimate load capacity of post-tensioned and shaped structures could be improved by stiffening only a few critical members. In general, numerical analysis technique using computer has been applied to form a shape of space structure, and general study has been performed to predict the structural shape under a certain geometric and material conditions such as length, height of structure, applied load, and required stress. Generally shape formation of space structure by post-tensioning shows a difference according to the type of plan layout and gap size of the chord. These researches applied negative temperature load on bottom chords of test model for shape formation of space structure, and nonlinear finite element analysis has been conducted to analyze the behavior of test model.

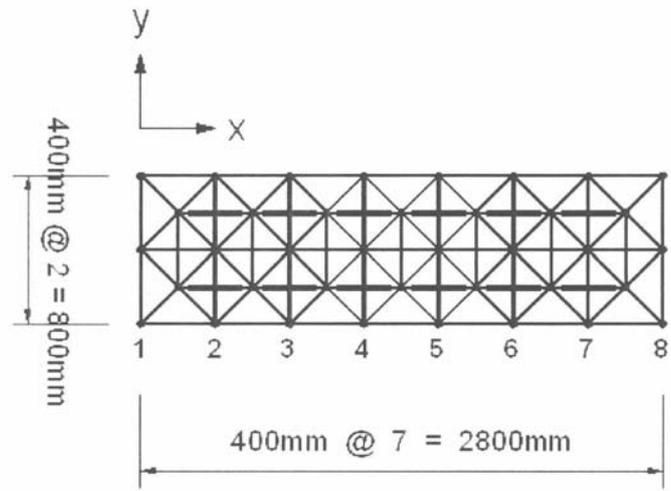
Layouts of experimental model

As shown in Figure 1, it is three dimensional type, the space structure for experimental model of this research consists of pyramidal shaped unit, and an each pyramidal unit consists of Circular Hollow Section (CHS). The Young's modulus is taken as 136 GPa, Poisson's ratio and yield strength is 0.3 and 334 MPa, respectively. The details of bottom chord are described in Figure 1 (c). This test model satisfies with the mechanism condition and geometric compatibility condition, which were required in shape formation by post-tensioning. A mechanism condition means that a mechanism or near mechanism condition (flexure only the top chords) must exist in its initial configuration, and that no mechanisms are allowed to exist in its final configuration. The geometric compatibility condition between the initial and final configuration of a post-tensioned and shaped space structure is that all the non-gap members remain the same length (only deflection without large strain) during the shape formation process. (Calladine, C. R. 1978)

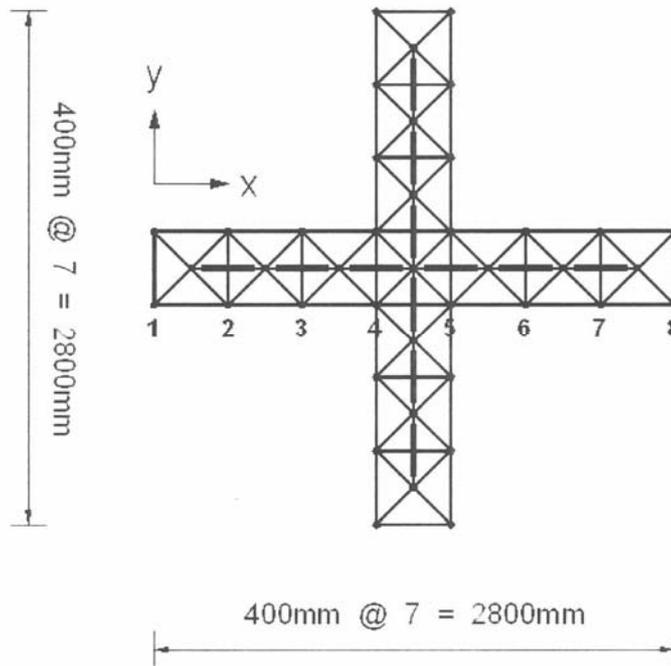
Nonlinear analysis

A finite element simulation for the shape formation must exactly represent the practical procedure. In such an analysis, the important point is how to model the closing of the bottom chord gaps. In reality, the bottom chords are composed of separate bottom chords and a continuous strand for post-tensioning. The strand is located inside the bottom chord tubes and passed through the joints. In the finite-element analysis herein, the closing of the bottom chord gaps were simulated by the element shortening caused by a negative temperature change. To consider the nonlinear characteristic of the structural behavior, the commercial program MIDAS is used in this analysis modeling with rod element. The finite element method can be used to predict the final shape formation and post-tensioning forces of space structure. The shape formation process induces large deformations, so the analysis should be performed with geometric nonlinear analysis. So the space structure can be modeled with nonlinear finite analysis, in this numerical analysis, the negative temperature loads were applied to the bottom chords in Figure 2 (a). As a result, the deformed shape is shown in Figure 2 (b). Based on the results of the finite element analysis, when the final space shape is determined, the post-tensioning forces and induced stresses can be found from the current results of the finite element analysis. These results can be used to form the desired space shape with the predicted post-tensioning forces.

Cutting the bottom chords shorter according to the values of the gaps, and assembling them in the planar layout, the structure can be formed to the desired space shape with the predicted post-tensioning forces.



(a)



(b)

Figure 1. Layouts of experimental model and detail of bottom chord (continue)

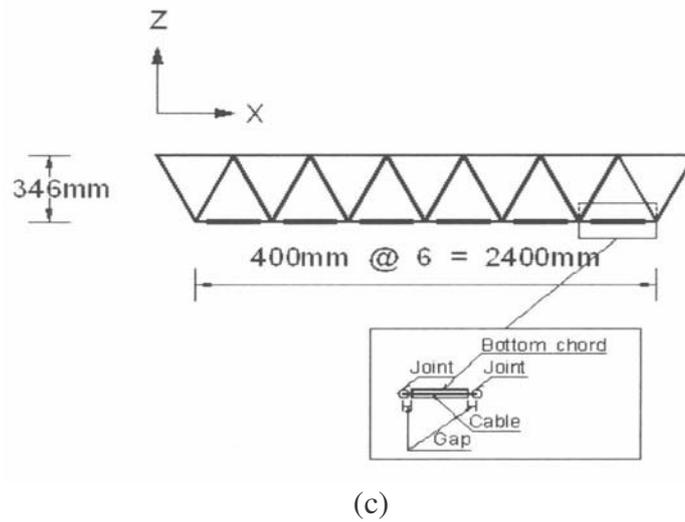


Figure 1. Layouts of experimental model and detail of bottom chord (continued)

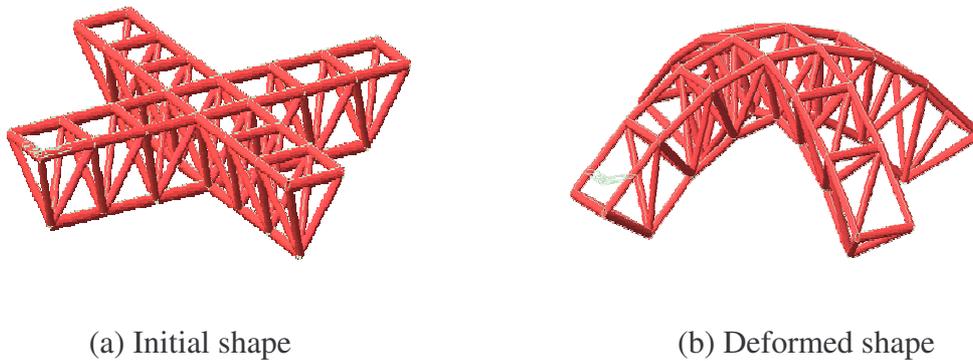


Figure 2. Shaping of space structure by nonlinear finite element analysis

Experiments for shape formation

The planar layouts were assembled on the floor by connecting the prefabricated pyramidal units. The bottom chords connected with multi-directional joints consist of Circular Hollow Section (CHS), and the size of gap in bottom chord is closely related to desired shape of space structure. By post-tensioning of the test model, when the gaps of bottom chords were closed, space structure was formed into its required shape. Consequently when the gap was completely closed between the each joint of the bottom chord, i.e. there were no gaps in bottom chords, the post-tensioning process was completed. The final space structure is shown in Figure 3 (a) and (b) with the post-tensioning process. Before the main experiment for shaping formation, to find the behavior characteristic of pyramidal unit with ball type joint shown in Figure 4, the load test was performed using load-displacement test with applied load along the diagonal direction in a parallel to the ground. The pyramidal unit used in this test is the basic structure unit of this test model. From the result of this test as shown in Figure 5 (a), the behavior characteristic of pyramidal unit is found to be a nonlinear relationship between load and displacement. Moreover as shown in Figure 5 (b), the shaping formation of space structure, values with nonlinear finite element analysis are showing closer to experimental value than the values by linear analysis. Therefore, nonlinear analysis should be performed when estimating the final shape of space structure and post-tensioning load required to form a ball type jointed

space structure. The behavior characteristic of ball type joint in this research is similar to the result of author's previous research that was performed on the full size scale of pyramidal structure unit. Thus, the behavior characteristic of joint in space structure is more significant than that of any other member element. Generally in shape formation, some discrepancies between theory and test exist due to the geometric imperfections of the members and assembly, the rotations and slippage of joints in the test model. But nevertheless these imperfections affect the structural behavior of the shaping formation; most of these factors are not considered in detail for the finite-element modeling. Consequently for improvement of the efficiency of the finite-element method for simulating the structural behavior of shape formation of space structure, further research is necessary.



(a)

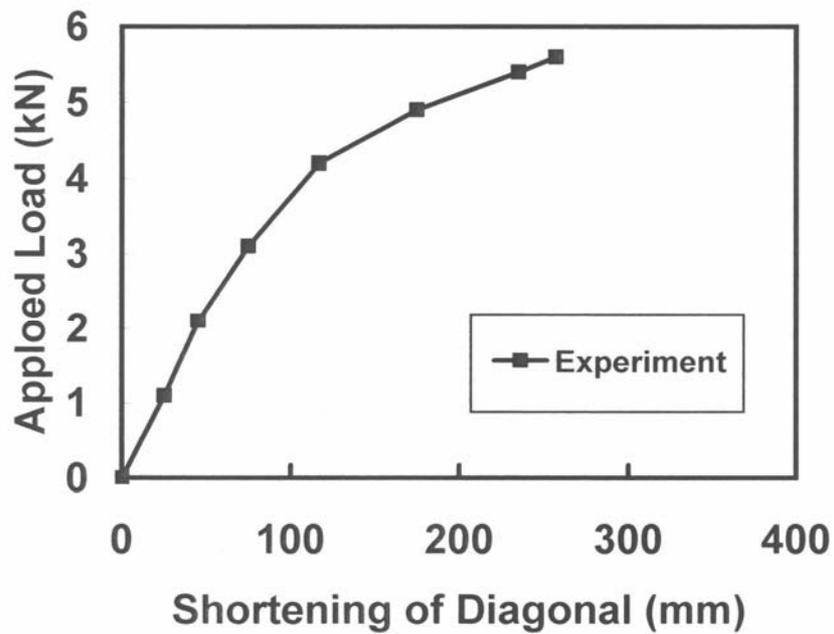


(b)

Figure 3. Deformed shape of space structure by means of post-tensioning



Figure 4. Pyramidal unit test of space structure



(a)

Figure 5. Behavior characteristic of space structure (continue)

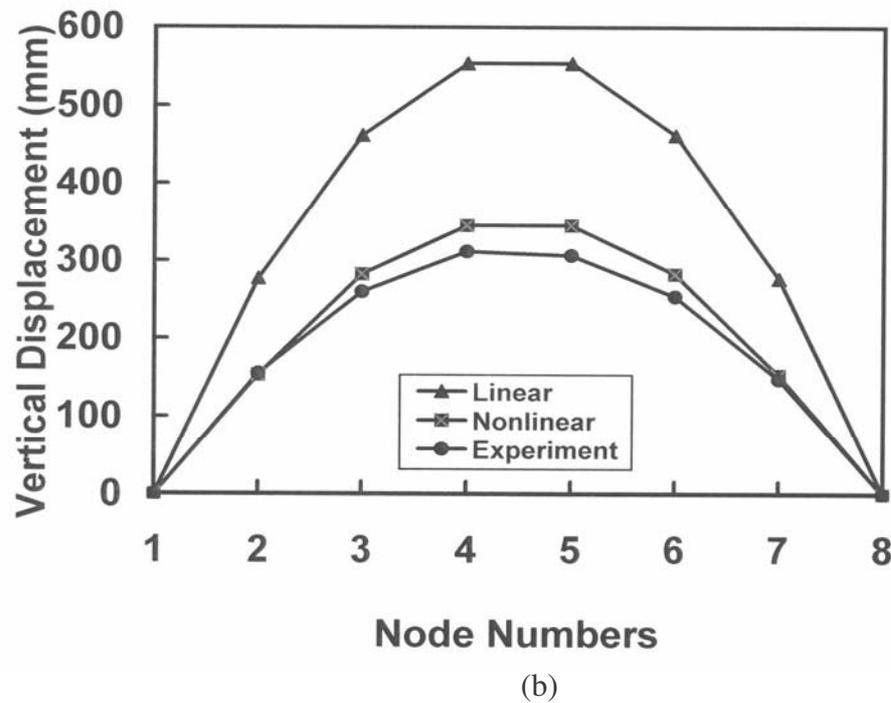


Figure 5. Behavior characteristic of space structure (continued)

Conclusions

Through the shape formation experiment and nonlinear finite element analysis for ball type jointed space structure, the following conclusions can be drawn:

- 1) The shaping formation of space structure with ball type joint is possible by post-tensioning, and the shape formation of space structure by post-tensioning can be considered as economic and time saved construction technique compare with the conventional techniques using a big crane or scaffold for erection.
- 2) A nonlinear finite element analysis method can be used for predicting the space shape and the post-tensioning forces in a shaping formation of ball type jointed space structure.
- 3) However, there is a large discrepancy due to differences between the test model and theoretical model, so the shape formation behavior needs further study.

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