SHAPE FORMATION OF SPACE STRUCTURE WITH BALL TYPE JOINT

Kim, Jin-Woo[1], Kim, Taek-Soo[2], and Lee, Yong-Hee[3]

ABSTRACT

This paper is concerned with the shaping formation of a ball type jointed space structure by post-tensioning. It is a fast and economical construction method for a space structure by post-tensioning of the cable in the bottom chords. In this paper, test model consists of uniform pyramids with ball type joint, the structure is shaped and erected into its final curved space structures. The feasibility of the proposed post-tensioning technique and the reliability of the established geometric model were confirmed with finite element analysis and experiment for a small-scale test model. As a results, proposed post-tensioning technique could be applied the shaping formation of space structure with ball type joint, so we can know the characteristic of the behavior in shaping test for practical design purposes, it should be an economic and reasonable method compare to conventional construction method including the heavy crane and scaffold.

KEY WORDS

nonlinear finite element analysis, post-tensioning, shaping formation, space structure

INTRODUCTION

Since the beginning of the commercial use of space truss in the fields, the space truss is an efficient and light structure type compare to conventional beam-column typed structure, where there is a need to avoid columns in long span structure system. Though space structure has been used in large span structure in limited cases, recently by aesthetic architectural emphasis many new large span facilities are on construction with space structure system. And space structure is relatively lightweight, easy fabrication, easy transportation, flexible workability, and time save for construction. In general, though the major use of pre-stress method is in concrete structure, however recently various types of space trusses such a barrel vault, dome, hypar, arch are being studied with model test and theoretical analysis for shape formation by post-tensioning (Clarke, M. J. and Hancock, G. J. 1995, Dehdashti, G., and Schmidt, L. C. 1996, Kim J. W. 2000, Kim J. W. 2001, Kim, J. W. and Hao, J. 2002, Kim et al. 2001, Kim, J. W. and Schmidt, L. C. 2000, Kim et al. 2002, Kim, et al. 2004, Kim et al. 2006, Kim et al. 2005, Schmidt, L. C. and Selby, S. 1999,

[1] Professor, Department of Civil and Environmental Engineering, Gyeongsang National University, Gyeongnam, 650 – 160, Korea, Phone: 055/640 3155, FAX: 055/640 3150, kim@gsnu.ac.kr
[2] Postgraduate Student, Department of Civil and Environmental Engineering, Gyeongsang National University, Gyeongnam, 650 – 160, Korea, Phone: 055/263 0575, kts6048@yahoo.co.kr
[3] Special Researcher, Research Institute of Industrial Technology, Pusan National University, Busan 609-735, Korea, Phone: 051/510 1875, FAX: 051/512 1835, yhlee0515@korea.com

Schmidt, L. C. and Steven Selby 2001). Some engineers consider existing construction methods for space structures will remain the same as existing practice without recognizing the changes even in this practice. But it can be altered beneficially due to new approaches. Throughout the world, there are novel approaches being used-compared with the traditional procedure of using erection towers so that modules prepared at ground level are lifted by cranes to land on these towers, where further connections are made in mid-air. For developing the innovative construction techniques, extensive research has been performed about 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 performed with the test model that is consisted of ball type joint and steel pipe. These economic advantages have been verified by laboratory structures and similar practical structures. When space structure is formed with a certain shape by post-tensioning, its behavior is known a nonlinear one. 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.

SHAPE FORMATION AND ANALYSIS

The basic structural type of the 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 view of a topological point, most space structures are of a regular shape, largely belonging to a few categories that can be analytically defined. The fact that almost all space structures have a regular shape can probably be accounted for by a prescribed regular plan: domes on circular or polygonal plans, and barrel vaults on rectangular plans. By means of post-tensioning, general shape formation concept is shown in Figure 1. In general, numerical analysis technique using computer has been applying to form a shape of space structure, and general study has been performed to predict the structural shape under a certain condition of 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. Preceding researchers including author of this paper have studied on various types of space trusses for shape formation with dome, barrel vault, hypar, and arch shaped space structure, these researches applied negative temperature load on bottom chords of test model for shape formation of space structure, and nonlinear finite element analysis was performed to analyze the behavior of test model. In these researches, for the space structure, the shaping formation

was performed by post-tensioning method, and behavior of the test model was numerically predicted by the nonlinear finite element analysis.

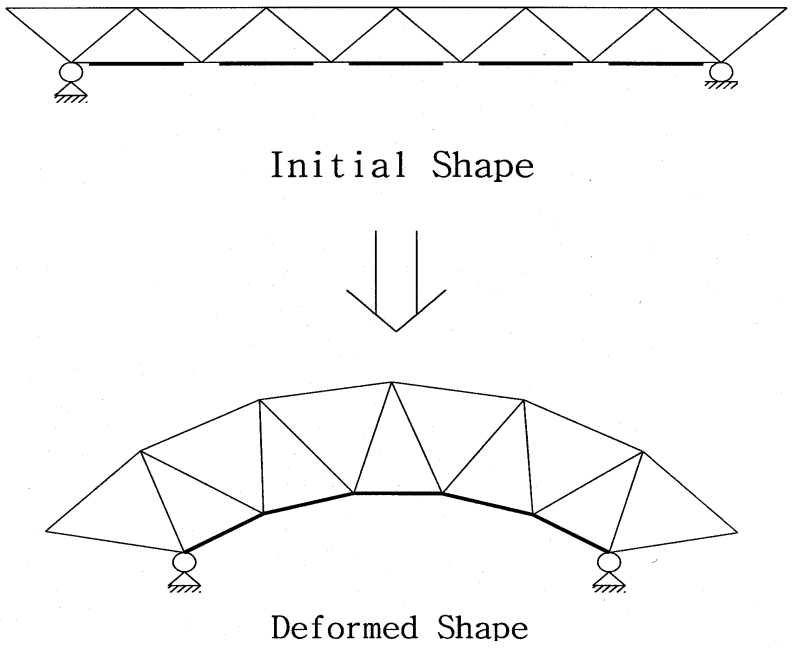
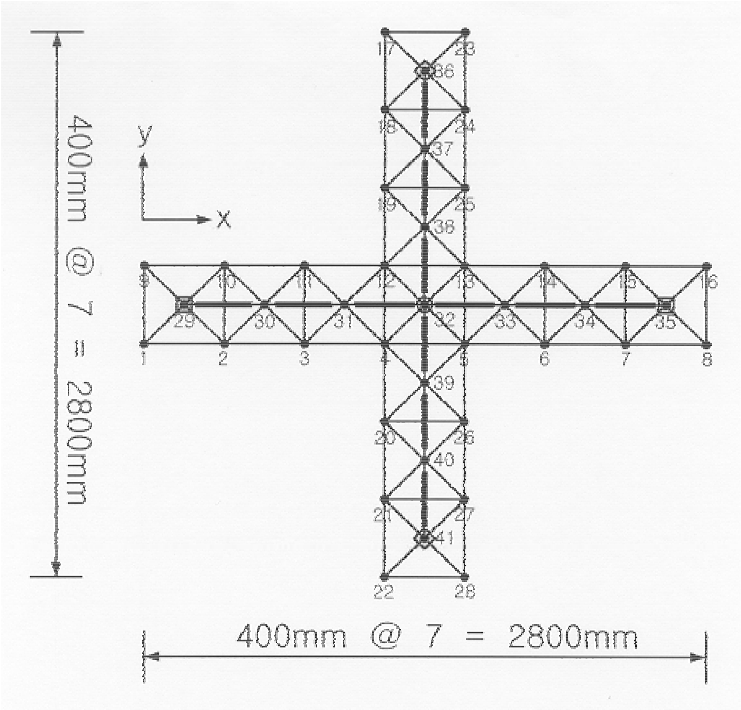


Figure 1: General Shape Formation Idea by means of Post-tensioning

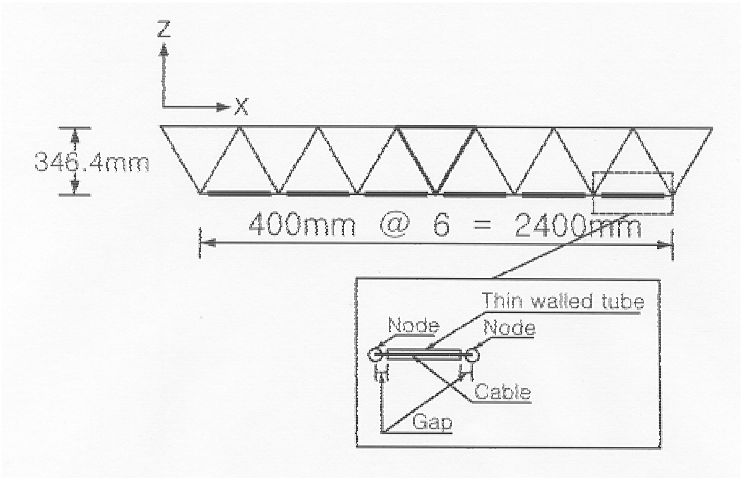
Layouts of Experimental Test Model

As shown in Figure 1, 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 mechanical properties of members are that the Young's modulus is 136GPa, Poisson's ratio is 0.3, and yield strength is 334MPa. The details of bottom chord are described in Figure 2 (b). This test model satisfies with the mechanism condition and geometric compatibility condition, which were required in shape formation by post-tensioning as same as in many types of experimental models studied in previous researches. 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. In three-dimensional space, the mechanism condition of a post-tensioned and shaped space structure can be expressed by a general Maxwell's criterion. 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)



(a) Plan View

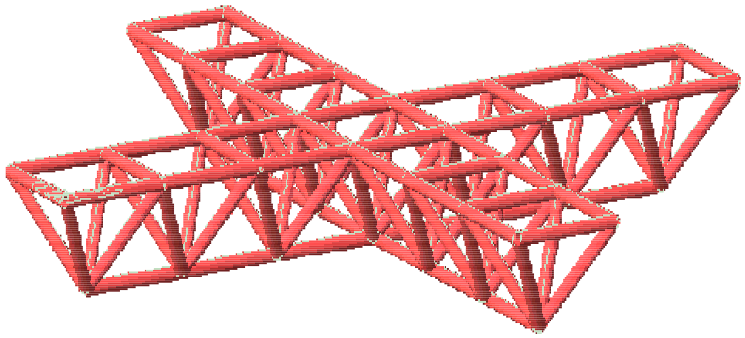


(b) Detail of Bottom Chords

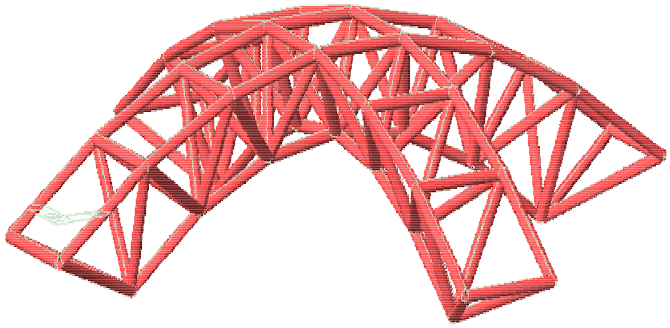
Figure 2: Layouts of Test Model and Detail of Bottom Chord

Nonlinear Analysis for Shaping Formation

A finite-element simulation of the shape formation process must show the practical procedure exactly. In such an analysis, the main point is how to simulate 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. It 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. The finite element method can be used to predict the final shape formation and post-tensioning forces of space structure and to investigate the feasibility of the proposed post-tensioning method. The shape formation process induces large deformations, and then the analysis should be performed with geometric nonlinear analysis. As shown in the Figure 3, ball type jointed space structure can be shaped by nonlinear finite analysis. In nonlinear finite element analysis, the negative temperature loads were applied to the bottom chords, as a result, the deformed shape is shown in Figure 3 (b). In this process, the negative temperature change is divided into many load steps. 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. Based on the results of the finite-element analysis, the coordinates of every joint in the space shape of the structure can be obtained. 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) Initial Shape of Space Structure



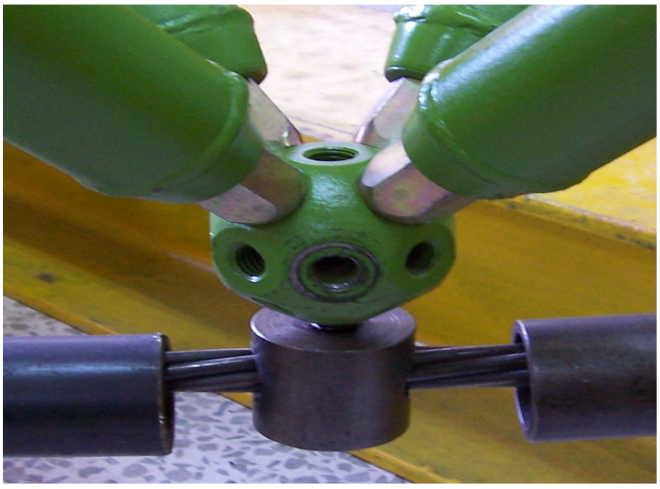
(b) Deformed Shape of Space Structure

Figure 3: Shaping of Space Structure by Nonlinear Finite Element Analysis

Experiments for Shaping 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 the post-tensioning for a test model, when the gaps of bottom chords were closed, space structure was formed into purposed shape. Consequently when the gap was completely closed to the joint of the bottom chord, i.e. there were no gaps in bottom chords as shown in Photo 1 (b), the post-tensioning process was completed. With the post-tensioning process, the final space structure is shown in Photo 2. Before the main experiment for shaping formation, to find the behavior characteristic of ball type joint, the beam test was performed with load-displacement test like as Figure 4. With the result of this beam test as shown in Figure 5, the behavior characteristic of multi-directional joint is showing a nonlinear relationship between load and displacement. And as shown in Figure 6, the shaping formation for space structure, values with nonlinear finite element analysis are showing closer to experimental value than the values by linear analysis. Therefore, it should be considered that 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. And it is found out that behavior characteristic of ball type joint in this research is similar to the result of author's preceded research that was performed with the full size scale of pyramidal structure unit. Therefore the behavior characteristic of joint in space structure is more significant than any other member elements. Generally in shape formation, some discrepancies between the theory and test are owing 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 in the finite-element method for simulating the structural behavior of shape formation for space structure, the further research is necessary.



(a) Before Post-tensioning

(b) After Post-tensioning

Photo 1: Gap Shape of Bottom Chord in Post-tensioning

Photo 2: Deformed shape of Space Structure by means of Post-tensioning

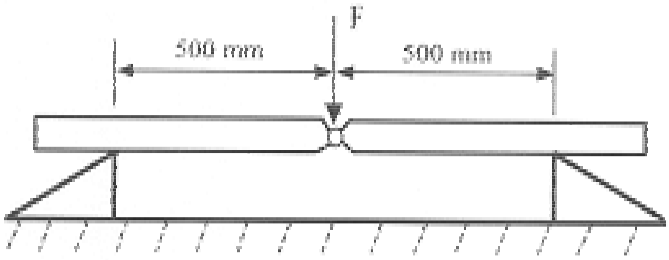


Figure 4: Joint Test of space structure

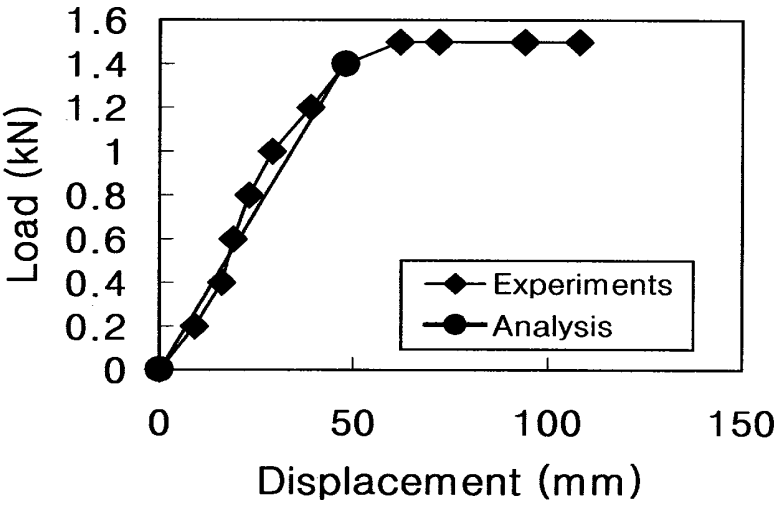


Figure 5: Behavior Characteristic of Ball Type Joint in Beam Test

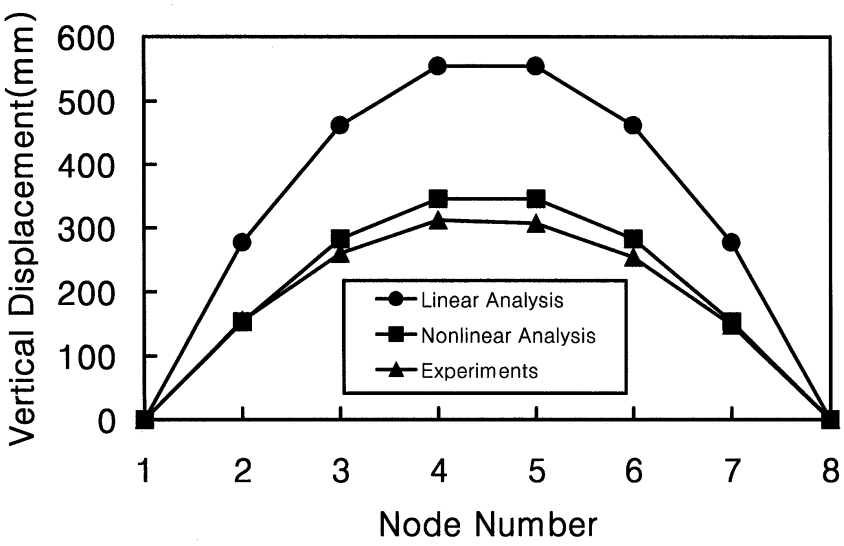


Figure 6: Final Shape Formation of Space Structure by Post-tensioning

CONCLUSIONS

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

Firstly it is presented that shaping formation of space structure with ball type joint is possible by post-tensioning, secondly 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, and finally 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 of space structure. However, there is a large discrepancy due to differences between the test model and theoretical model. So the shape formation behavior needs further study.

REFERENCES

Calladine, C. R. (1978). "Buckminster Fuller's Tensegrity Structures and Clerk Maxwell's Rule for the Construction of Stiff Frames." *Int. J. Solids Struct.,* 14 (3) 161-172.

Clarke, M. J. and Hancock, G. J. (1995)."Test and Nonlinear Analysis of Small-scale Stressed-arch Frames." *J. Struct. Engrg.,* ASCE, 121 (2) 187-200.

Dehdashti, G., and Schmidt, L. C. (1996). "Dome-shaped Space Trusses Formed by means of Post-tensioning." *Journal of Structural Engineering*, ASCE, 122 (10) 1240-1245.

Kim J. W. (2000). "Analysis and Test of Dome-shaped Space Truss." *Journal of the Korea Society of Civil Engineers,* 20 (1-A) 39-46.

Kim J. W. (2001). "Shape Creation and Ultimate Load Test of Space Truss by Means of Posttensioning." *Journal of the Architectural Institute of Korea*, 17 (5) 51-57.

Kim, J. W., and Hao, J. (2002). "Behaviour Characteristic of a Full-size Scale Pyramidal Space Truss Unit." *KSCE Journal of Civil Engineering*, 6 (1) 33-38.

Kim J.W., Hao and Lee (2001). "New Attachment Device for Post-tensioning of Full Size Scale Space Truss." The Eighth East Asia-Pacific Conference on Structural Engineering & Construction (EASEC-8), Singapore. Paper No.1034.

Kim, J. W. and Schmidt, L. C. (2000). "Test of Deployable Dome-Shaped Space Truss." International Conference on Computing in Civil and Building Engineering (ICCCBE-□), ASCE, California(USA), (1) 66-73.

Kim, J. W., Kim, J. J., and Lee, J. W. (2002). "Form Finding and Experiments for Three Types of Space Trusses." Space Structures 5, London(UK), (1) 711-720.

Kim, J. W., Kim, J. J., and Rhew, H. J. (2004). "Analysis and Experiment for Self-erected Hypar Space Truss." Proceedings of the Second International Conference on Structural Engineering, Mechanics and Computation, Cape Town (South Africa), 365-369.

Kim, J. W., Kim, J. J., and Rhew, H. J. (2006). "Analysis and Experiment for the Formation and Ultimate Load Testing of a Hypar Space Truss." *Journal of Constructional Steel Research,* (62) 189-193.

Kim J. W., Kwon M. H., and Rhew, H. J. (2005). "Shaping Formation and Nonlinear Analysis of Mero Jointed Space Structure with Multi-directional Joint." *Journal of the Architectural Institute of Korea,* (l21) 11-18.

Schmidt, L. C. & Selby, S. (1999). "Domical Space Trusses and Braced Domes: Shaping, Ultimate Strength and Stiffness." *Int. J. of Space Structures,* 14 (1) 17-23.

Schmidt, L. C. and Steven Selby (2001). "Shape Formation of some Dome-like Space Trusses." *Int. J. of Space Structures,* 16 (2) 137-147.