Design and Construction of Bamboo Spatial Structure Using Bended Bamboo Arch and Handmade Joint

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Summary

In this article, design and construction process of a building made of bamboo is reported. The design and construction were required to be conducted so that it can be made by manual labor of students due to the limited budget and materials right after the disaster of the East Japan Great Earthquake on 2011. To satisfy those requirements, bamboo which is supplied easily at near the site, was adopted as structural material, and handmade joint with sufficient strength was developed. And the structural performance of this building was verified by experiments and structural analysis.

Keywords: structural design; bamboo structure; manual labor; handmade joint; pre-bending.

1. Introduction

In this article, the design and the construction process of this building are presented from the following points of view. (i) Outline of bamboo structural design and numerical analysis, (ii) Estimation of allowable strength of bamboo, (iii) Development of handmade joint and estimation of its allowable strength, (iv) Construction planning and its application.

Fig. 1: "Bamboo Ark", (left) exterior view, (right) interior view at dawn

2. Design of "Bamboo Ark"

"Bamboo Ark" is defined as temporary building under the Japan building standard law so that the specification code about fireproof is not subjected. Bamboos used in this building are exposed to outside and the bamboo frames are dressed in membrane which also plays a role of structural element. The plan has round form and the structure is composed of arch-shaped frames in a radial

pattern. The building has an opening on east side from where we can see the Pacific Ocean.

Main frames are structures connected by joint using rope, in each of which the arch and the post are connected to the foundation truss beam as upward cantilever. A flow of constructing them is as follows. At first arch and post elements are connected, next, bamboo of arch is bended so that its top position coincides with anticipated intersection point, and finally connected with others at that point by the rope joint. Finished frame is a self-balancing in-plane frame.

The peripheral membrane resists against a rotating deformation mode caused by seismic load or gust wind load. The cutting pattern of this membrane was designed 10 % smaller than the bamboo frame so that the membrane works as tensioned membrane. Both ends of the membrane are supported by bearing walls made of split bamboo woven in mesh pattern as shown.

3. About materials

At near the site of this building, *Ma-dake* and *Mou-sou-chiku* are available. We used *Mou-sou-chiku*, which is fleshy thick and has large stiffness and strength, for arch constituting main frames and upper and lower beam of foundation truss, and also for post in B-type frame. *Ma-dake* that has light flesh and less curving body, was applied to parts of post, truss suffering only axial force. As generally known, bamboo has various diameter, length and mechanical coefficients within the same species. Therefore we sampled some test pieces in the bamboo forest near the building site, and conducted experiments to verify the strength and other properties. The peripheral membrane for the purpose of sunshade has a role of brace to transfer in-plane stress to the foundation when excited by winds and earthquake.

4. Development of handmade joint

In this building, it was required that almost all the constructions could be done by manual labor while keeping the demanded structural strength and stiffness. To solve such a problem, we utilized the joint method using special gaffer tape and rope.

In joint between bamboos, sufficient capacity to transfer shear force is required to prevent the slide between bamboo members at the intersection point. And it is important to keep up large friction strength. Therefore we developed a joint by putting gaffer tape on both bamboos and binding up them strongly using rope. The gaffer tape used in the joint has heat-resistant property and water-resistant property, and the rope is polyester rope of 3 mm diameter.

5. Construction planning

This project was subjected to the precondition that all the construction works could be carried out by students, volunteers and inhabitants in the town near the building site. We had to plan the construction strategies so that we could do it without special techniques and heavy machines as possible. In this building, almost 1,000 of bamboos including *Ma-dake* and *Mou-sou-chiku* are used. And the length of used rope reaches 24 km. Human works (number of workers multiplied by days) are about 400 in the construction period 28 days.

6. Conclusion

The paper has given an actual example of building made of bamboo structure in the disaster area hit by the East Japan Great Earthquake. In the project, the design and construction method were required so that it could be completed by only manual labor in almost constructing under limited budget and equipment right after the great disaster.

By the completion of an actual bamboo building, we also might be able to give valuable information and experience to help grows of bamboo structures and usage of bamboo in the future.