Vibration Experiments of Tension Truss Dome used as an Annex on the Former Institute Building at Roppongi

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Abstract

The main objective of this research is to investigate the dynamic properties of a full scale model of tension truss dome. Vibration experiments and Wave propagation experiments of the tension truss dome used as an annex on the former institute building of I.I.S., the University of Tokyo, were performed in nine phases and three phases, respectively. In this paper, outline of the vibration experiments and the experimental results of models as a whole with membrane and without membrane are shown. The results show the influence of the existence of membrane for the dynamic properties of a lightweight frame structure.

1. Introduction

Investigation about the dynamic properties of a full size structure is difficult unless experiment is planned at the beginning of its designing, so only a few investigations are reported. Since the Institute of Industrial Science, University of Tokyo, moved from Roppongi to Komaba on the end of March 2001 and withdrawal of the Tension Truss Dome used as an annex on the former institute building became certain, loading experiments and vibration and wave propagation experiments of this dome were planned and performed. This dome is a structural system that consists of tension truss unit (Fig. 1), and is the membrane structure using the membrane as a roof. Vibration and wave propagation experiments were performed in various phases for the purpose of investigation of the influence on dynamic properties of a full scale structure by the existence of membrane, the differences of initial displacement, etc. (Fig. 2). In this paper, outline and the results of vibration experiments of models as a whole with membrane and without membrane. In the first half, experimental models, experimental method, measuring method are described. In the second half, the time history of acceleration response obtained for each model as a whole and its Fourier spectrum are shown.

2. Outline of vibration experiments

2.1 Experimental models

Vibration experiments were performed in the following nine phases, as shown in Fig. 2.

Model as a whole with membrane and without membrane
Model A_{0-0}/Model A_{0-2}/Model A_{0-2} (deviated initial displacement)
Model A_{2-2}/Model A_{2-2} (deviated initial displacement)
Model B (=Model A_{0-0}) (after loading) / model A_{2-2} (after loading)

Here, the number of subscript of Model A means that the experimental model is changed with removal or addition of a unit. Those are half size of a model as a whole. The plan and section of the model are shown in Figs. 3 and 4, respectively. These models are cylindrical shape and consists of tension stabilized truss units which consists of one post, four truss members as a compression member and eight cable members as a tension member which connects them. The material is steel and pipes are used for truss and post members and rods are used for cable members.

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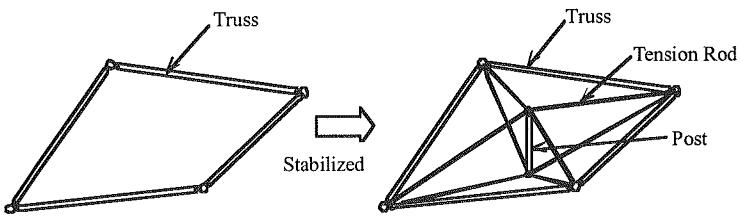


Fig. 1:Tension truss unit

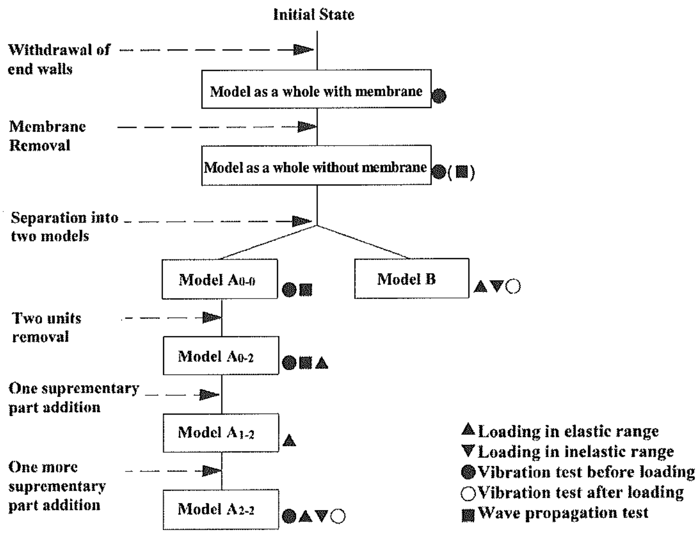


Fig. 2:Flow of experimental process

Photo 1:Tension truss dome
(Model as a whole with membrane)

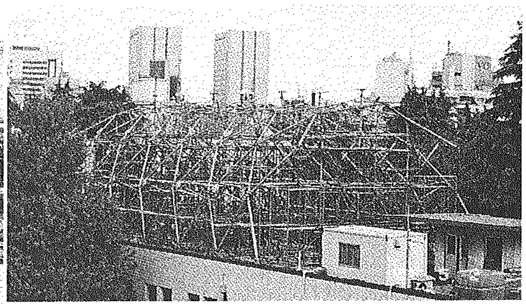


Photo 2:Tension truss dome
(Model as a whole without membrane)

2.2 Experimental method

The experiment was performed by using the method to release initial displacement produced by hanging weight. The top part (90-degree position) of an arch and its 45-degree position were chosen for the hanging position of weight in consideration of vibration mode. The former will be called initial displacement 1 and the latter will be called initial displacement 2. The hanging position is shown in Figs. 3 and 4. Hanging state of the weight is shown in Fig. 5. As shown in the figure, weight was not hung from one joint but was hung from two adjoined joints using the wire rope like a V character type. One of the joint from which the wire rope was hung is shown in photo 3. Since it was difficult to hang like a V character type in the case of initial displacement 1 for the models as a whole mainly because of the frame of scaffold, the wire rope was taken down to the roof level perpendicularly and the weight was hung through a stick (single pipe for scaffold). In the vibration experiment of other cases, weight was hung through thin wire at the lowest part of the wire rope of a V character type. Thin wire was cut in an instant for each experiment and the weight was dropped. Since there was no covering on the concrete roof, a sponge of about 15cm thickness was used for softening the impact of dropping.

In order to investigate the relationship between vibration properties and amplitude of the displacement, three kinds of total weight, 100kg, 150kg, and 200kg, were adopted. The state of weight hanging in case the total weight is 200kg (model as a whole, initial displacement 2) is shown in photo 4. Fall of weight was performed so that at least three effective data might be obtained for each case. Moreover, since the rigidity of the model after loading became lower, the vibration experiment by human power was performed for the model.

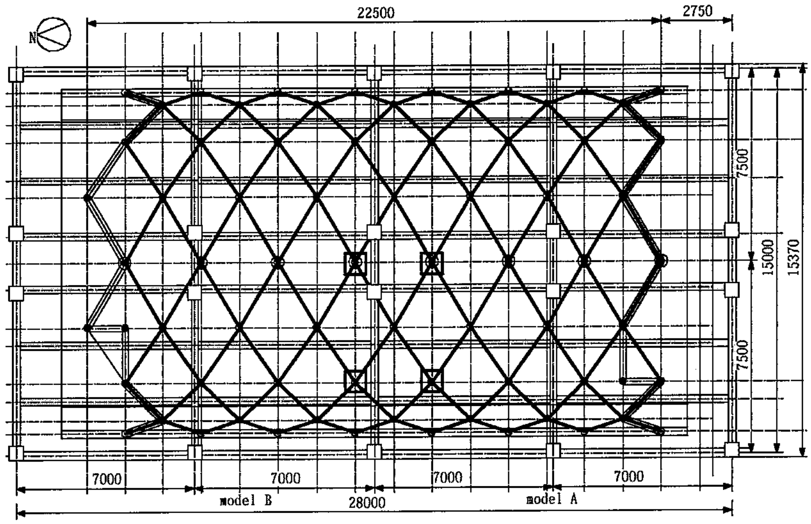


Fig. 3:Plan of a tension truss dome (□: wire rope hanging position)

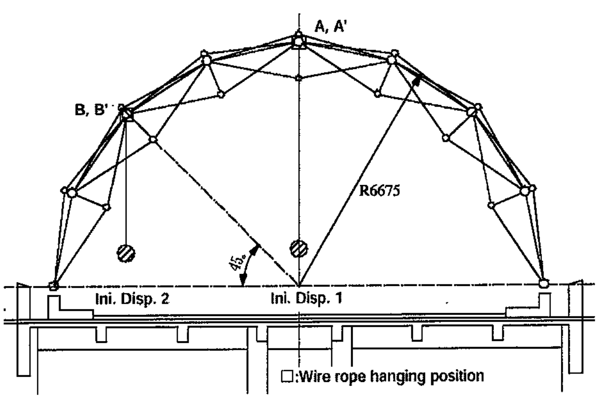


Fig. 4:Section of a tension truss dome

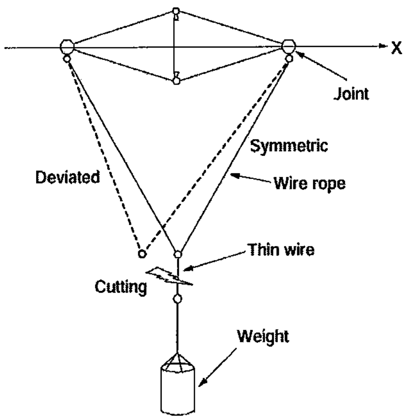


Fig. 5:How to hang the weight

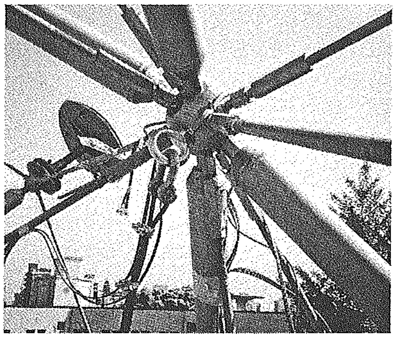


Photo 3:The joint from which the wire rope was hung (initial displacement 2)

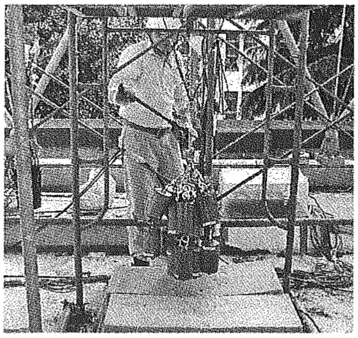
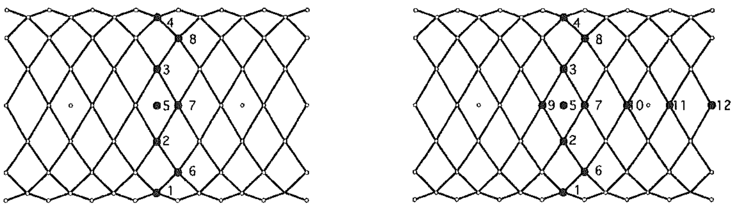


Photo 4:Cutting of the weight (Model as a whole, initial displacement 2, 200kg weight)

2.3 Measuring method

Strain gauge type accelerometers (max. 5G) were used for measurement and acceleration responses on some joints were measured. According to the condition of the joint, the accelerometer was fixed on the upper part or the lower part of the joint with the quick-drying glue, and, in any case, the direction was outward normal to the arch. Arrangement of accelerometers of model as a whole is shown in Fig. 6, and the actual attachment is shown in photo 5. The multi-trigger module (MP200:minimum sampling time is 1 μs) of the multi-pro series made from NICOLET was used for taking the data to PC. The main sampling time is 5 ms and the Nyquist frequency is 100 Hz and the number of sampling data is from 2000 to 12000 (according to the continuation time of responses) and total sampling time is from 10 sec to 60 sec. Measurement was performed by setting so that sampling might be started when the acceleration response of the accelerometer put on the joint of weight hanging position exceed a setting trigger value. In human power vibration experiment, the trigger was set as the accelerometer put on the joint used as loading point. Recording of data was continued until the response of free vibration damped fully after loading.



(a) Model as a whole with membrane (b) Model as a whole without membrane

Fig. 6:Plans of an arrangement of accelerometers

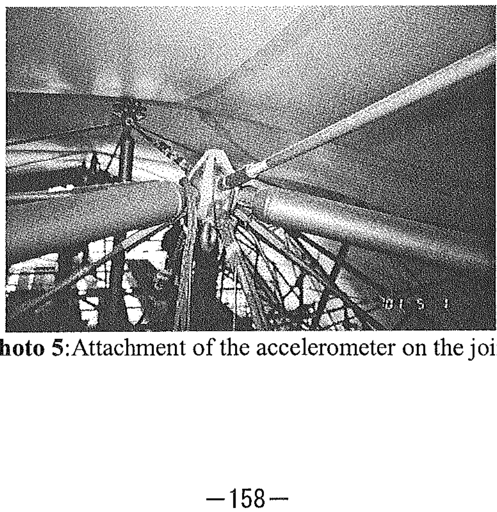


Photo 5:Attachment of the accelerometer on the joint

3. Experimental results

3.1 Model as a whole with membrane

The weather of the day performed the vibration experiment of model as a whole with membrane was cloudy, the wind was a breeze and the maximum temperature was 16℃. Although we were anxious about the influence of a wind for the experiment of a structure with membrane at the beginning, the weather of the day was fortunately very fine so that the influence of a wind was not so much. Sampling time of measurement is 5 ms, the number of data was 2000 and the period was 10sec. Eight accelerometers were used for measurement as shown in Fig. 6 (a).

As an example of the result of initial displacement 1, time history of the acceleration response in case of 100kg weight and those averaged Fourier amplitude spectrum are shown in Fig. 7(a) and Fig. 7(b), respectively. In case of initial displacement 1, the response was large especially at the measuring points 7 and 8 that are the positions of hanging weight. Similarly, time history of the acceleration response in case of 200kg weight, initial displacement 2 and those averaged Fourier amplitude spectrum are shown in Fig. 8(a) and Fig. 8(b), respectively. It is shown that the responses of the points located at nearly 45-degree position where the weight was hung, such as the measuring points 6 and 8, were larger than others. The peak frequency under initial displacement 1 and initial displacement 2 are different, and it is presumed that each case is corresponded to the secondary mode and the first mode, respectively.

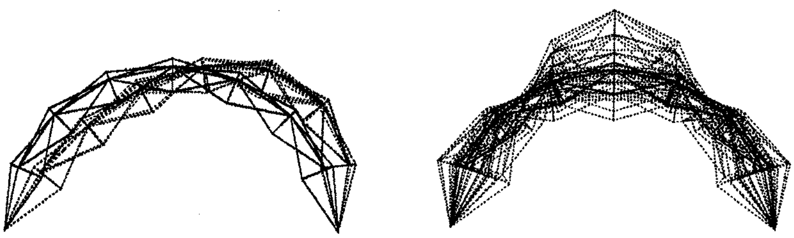
3.2 Model as a whole without membrane

The model that removed the membrane from model as a whole with membrane is called as model as a whole without membrane. The weather of the day performed the vibration experiment of model as a whole without membrane was fine and windy, and the maximum temperature was 26.5℃. Sampling time of measurement is 5 ms, the number of data was 2000 and the period was 10sec. Twelve accelerometers were used as shown for measurement in Fig. 6 (b).

Each time history of acceleration response and Fourier amplitude spectrum under initial displacement 1 and initial displacement 2 are shown in Fig. 9 and 10, respectively. Although it was expected that the influence of a wind was small on the model after removing membrane, acceleration response that cannot be disregarded was observed and many noises were contained in the data. The results of natural mode analysis of model as a whole without membrane are shown in Fig. 11.

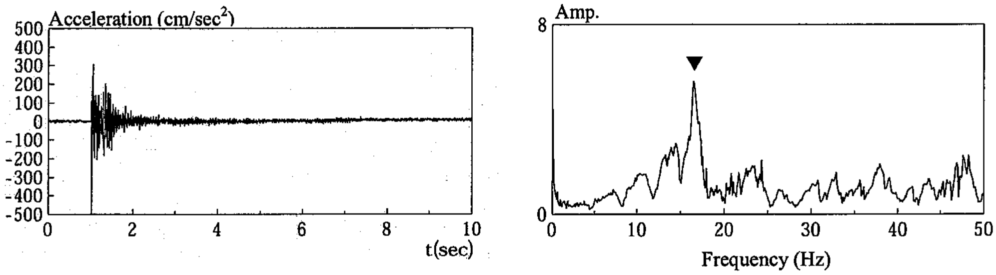
3.3 Comparison of the results of model as a whole with membrane and without membrane

The natural frequency and damping constant that were obtained from the vibration experiment of two models as a whole are collectively shown in Table 1. Damping constants was evaluated from the results of averaged Fourier amplitude spectrum by using single degree of freedom method. It turns out that natural frequency of model as a whole with membrane is higher and damping constant is larger than those of the model as a whole without membrane. The analytical results and the experimental results show good coincidence in the first natural frequency of model as a whole without membrane.



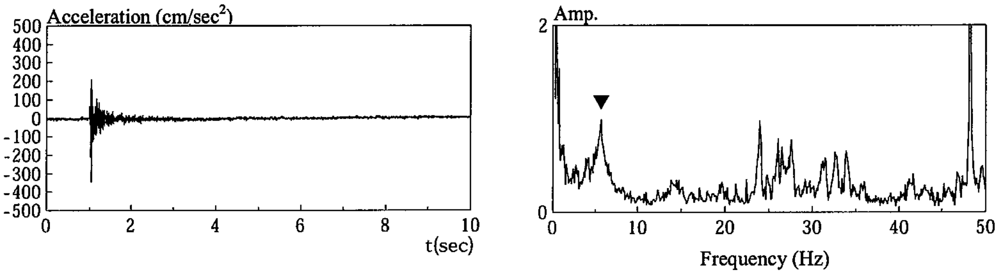
(a) First mode (6.13 Hz) (b) Secondary mode (13.08 Hz)

Fig. 11:Natural frequency and natural mode of a model as a whole without membrane



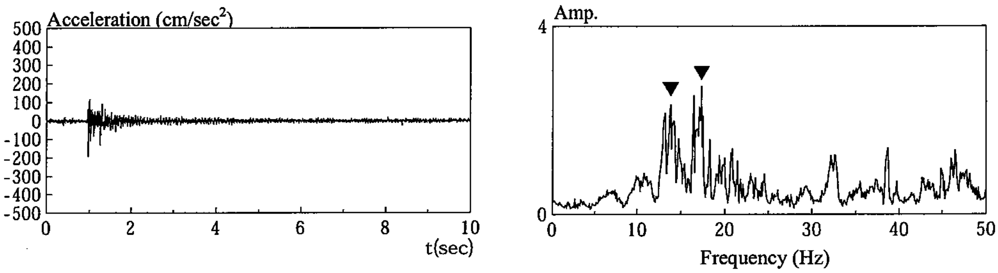
(a) Time history of acceleration response (b) Fourier amplitude spectrum

Fig. 7:Model as a whole with membrane under initial displacement 1(100kg weight, joint 7)



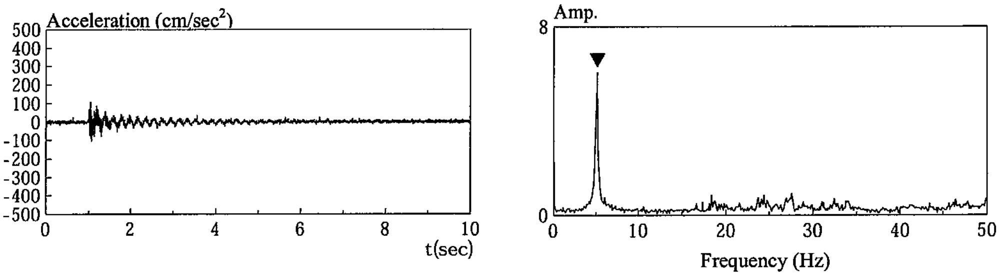
(a) Time history of acceleration response (b) Fourier amplitude spectrum

Fig. 8:Model as a whole with membrane under initial displacement 2(200kg weight, joint 8)



(a) Time history of acceleration response (b) Fourier amplitude spectrum

Fig. 9:Model as a whole without membrane under Initial displacement 1(100kg weight, joint 7)



(a) Time history of acceleration response (b) Fourier amplitude spectrum

Fig. 10:Model as a whole without membrane under initial displacement 2(200kg weight, Joint 8)

Table 1:Comparison of dynamic properties

		with membrane	without membrane
initial displacement 1	natural frequency(Hz)	16.5	13.9(13.08)
	damping constant	0.025	0.013
initial displacement 2	natural frequency(Hz)	5.76	5.17(6.13)
	damping constant	0.047	0.018

(inside values of parenthesis are analytical results)

References

1) K. Kawaguchi, K. Oda and Y. Hangai, "Experiments and Construction of Truss Structure Stabilised by Cable Tension", Proc. of International Symposium on Shell & Spatial Structures, Vol.1, pp.421-429, 1997.11.

2) Y. Hangai, K. Kawaguchi and K. Oda, "Structural Behaviour and Design of Truss Structures Stabilized Cable Tension", Report of The Institute of Industrial Science, The University of Tokyo, Vol.36, No.2, 1991.5.