Basic Study on Multi-Bay Horn-Shaped Membrane Roof −Evaluation of Wind Load and Influence of Supporting System on Structural Behavior under Winds−

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Abstract

Wind loading is the most dominant load for light-weight structures such as membrane roofs. Since the multi-bay horn-shaped membrane roof has a complicated shape and is composed of several horn-units depending on the building type, basic data for the wind-force coefficient has not been reported yet. On the other hand, the multi-bay horn-shaped membrane roof is usually designed using the structural behavior of a one-unit system. Furthermore, the authors consider that the design method must be changed not only according to size and building type but also supporting systems. From the view of these problems, in this paper, the wind-force coefficients for design and analysis are clarified by the wind-tunnel test, and a design method considering the influence of supporting systems under wind loading is proposed.

Keywords: membrane structure, horn-shaped membrane roof, wind load, wind-force coefficient

1.Introduction

Wind loading is the most dominant load for light-weight structures such as membrane roofs. Since the multi-bay horn-shaped membrane roof has a complicated shape which is composed of several horn-units, the basic date for the wind-force coefficient has not been reported yet. Figure 1 shows the several supporting systems of multi-bay horn-shaped membrane roofs and examples of it. The membrane roofs shown in Figure 1 were usually designed using the structural behavior of one unit system. Furthermore, the authors consider that the design method needs to be changed not only according to size and building type but also supporting systems. From the view of these problems, the purpose of this study is to propose a design method considering the influence of supporting systems under wind loading.

In this paper, the following subjects are discussed.

1. The wind-force coefficients for design and the aerodynamic characteristics of the horn-shaped membrane roof are clarified by wind tunnel tests.
2. The basic load-resistance mechanisms of the multi-bay horn-shaped membrane roof under winds are confirmed by analysis.
3. A design method considering the influence of supporting systems for wind loading is proposed.

According to the obtained results, the authors clarify the influence of both the form of one horn-unit and the supporting type on the structural behavior under winds, and discuss about the adaptability of the generally accepted design method using the structural behavior of a one-unit system.

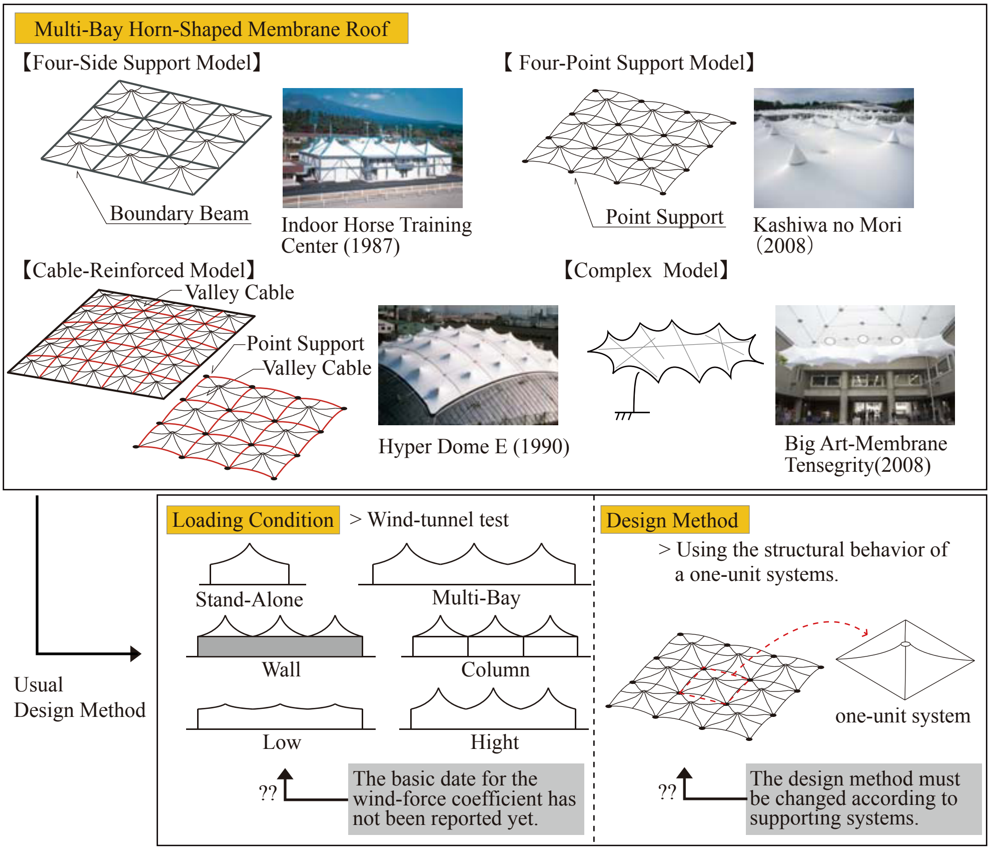


Figure 1: Usual design method and issue of multi-bay horn-shaped membrane roof

2.Wind-Tunnel Tests

2.1. Outline of tests

Table 1 shows the measuring condition of the wind pressure measurement. The test measured the wind pressure and the fluctuating wind pressure with the Gottingen type wind-tunnel (Figure 2). The tests were performed under only the uniform airflow (10m/sec, 15m/sec) because no specific building was targeted in the present research. Figure 2 shows the gradient flow depending on the influence of the floor surface at the reference wind velocity 10m/sec.

Table1: Measuring condition

Wind-Tunnel Facility	Closed Circuit Wind Tunnel
Flow	Uniform Flow
Sampling Speed	100Hz
Sampling Time	10sec
Wind Velocity	10m/sec, 15m/sec
Model Scale	5/120 (1×1 Unit)
	1/60 (5×3 Unit)

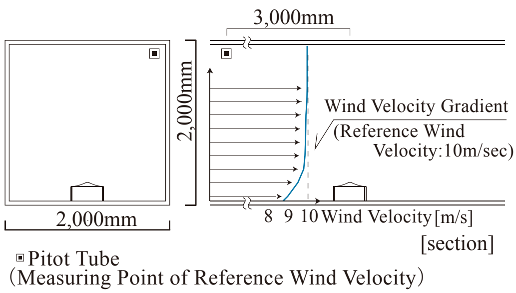


Figure 2: Wind-tunnel facility

The test used two models, namely a “stand-alone model” and a “multi-bay model” composed of a triple-bay five horn-shaped roof (Figure 3) . Three kinds of rise-span ratios and two kinds of outside walls, namely an“open type”and an“enclosed type”, were adapted to the parameter for the tests (Figure 4).

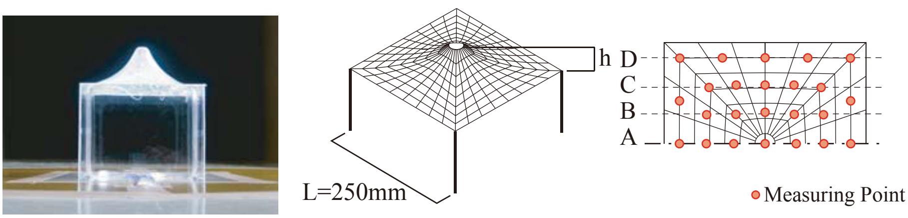
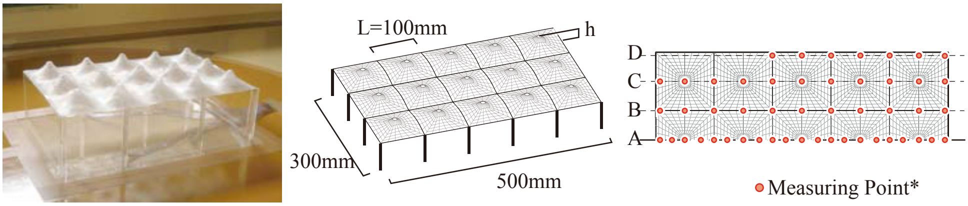


Figure 3-1: Wind-tunnel tests model (Stand-alone model)



*It was sufficient to set up measuring points on only half of the roof by using the symmetry of the model.

Figure 3-2: Wind-tunnel tests model (Multi-bay model)

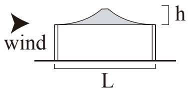
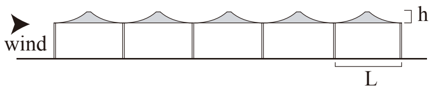
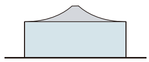
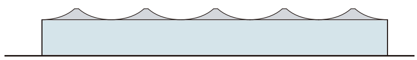
Outside Wall	Stand-Alone Mode (h/L=0.1,0.2,0.4)	Multi-Bay Model (h/L=0.1,0.2,0.4)
Open Type		
Enclosed Type		

Figure 4: Parameter for wind-tunnel tests

2.2 The smoke wind-tunnel tests

The smoke wind-tunnel tests shown in Figure 5 used the same model as the wind pressure measurement test. The purpose of these tests is to visually observe the airflow around the model. The separation of the wind grows on the leeward side as the rise-span ratios increases. Moreover, the wind turbulence also grows on the windward side in the enclosed type.

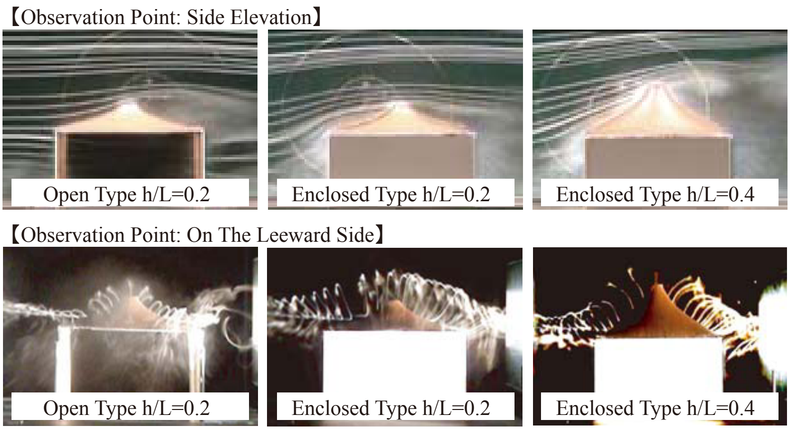


Figure 5: Photo of smoke wind-tunnel (stand-alone model)

2.3 Wind-force coefficient obtained from the tests

Figure 6 shows the comparison between the wind-force coefficient of the stand-alone model and the multi-bay model.

In the open type with h/L=0.1, the wind force coefficient of the stand-alone model and the multi-bay model show the same tendency. But, depending on the position of the measuring points, in the open type with h/L=0.2 and 0.4, the wind force coefficient of the multi-bay model exceeded that of the stand-alone model. On the other hand, in the enclosed type with h/L=0.1, the first unit of the stand-alone model exceeded the value of the multi-bay model 1.4 times, and in the enclosed type with h/L=0.2, 1.6 times, and in the enclosed type with h/L=0.4, 1.8 times.

Therefore, this comparison clarified that the evaluation of wind loading in the enclosed type should take into consideration the experience results of the multi-bay model.

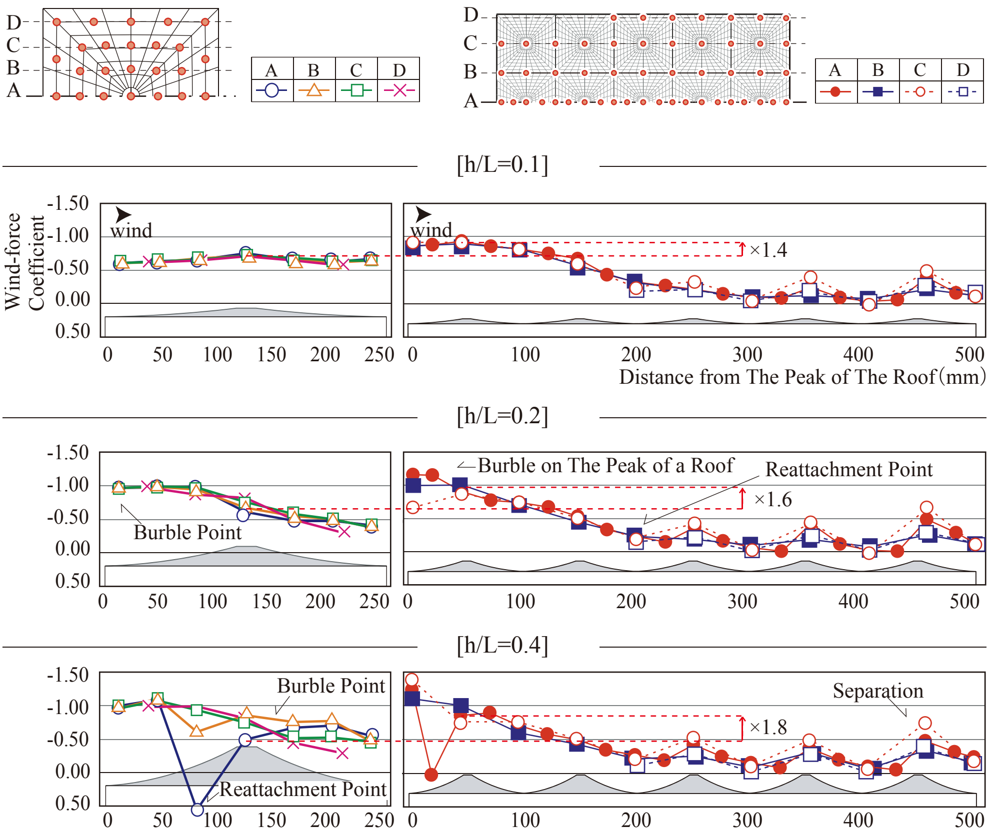


Figure 6-1: Comparing wind-force coefficient of stand-alone model with multi-bay model (Enclosed type)

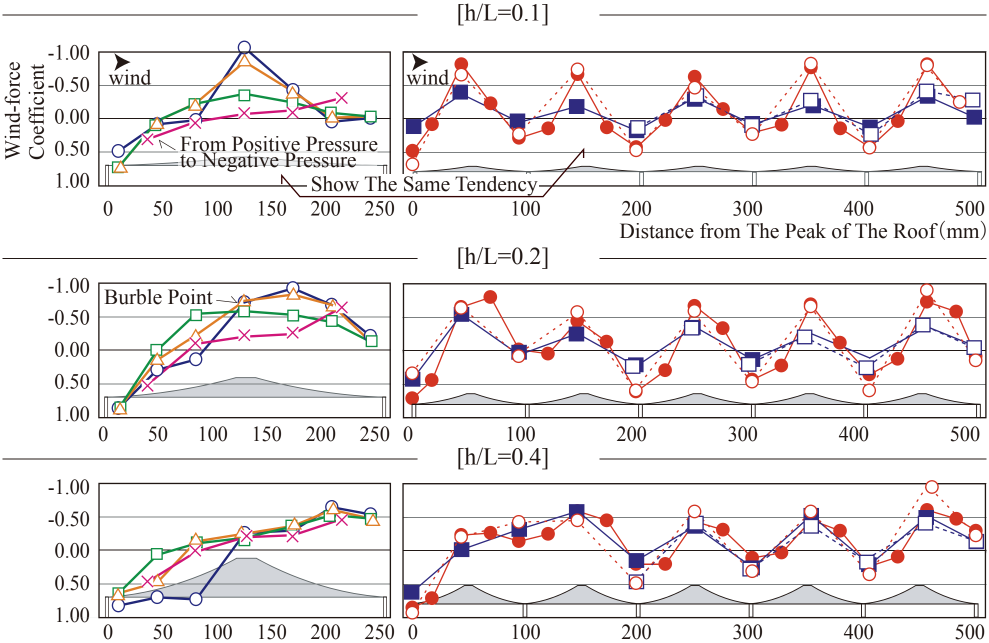


Figure 6-2: Comparing wind-force coefficient of stand-alone model with multi-bay model (Open type)

3. Comparing Difference of Loading and Supporting System

3.1 Outline of analysis

To verify the validity of this design method, the variety of loading conditions and supporting systems were analyzed.

The analysis models are shown in Figure 7. Details of the examination model are:

[A]Four-side support model: Boundary beams are arranged between units.

[B]Four-point support model: There are no boundary beams between units but the membrane is supported by columns.

[C]Cable-reinforced model: There are no boundary beams or no supporting points between units. Each unit is only supported by the strut. A cable-net is arranged on the membrane roof to resist only the upward wind loading.

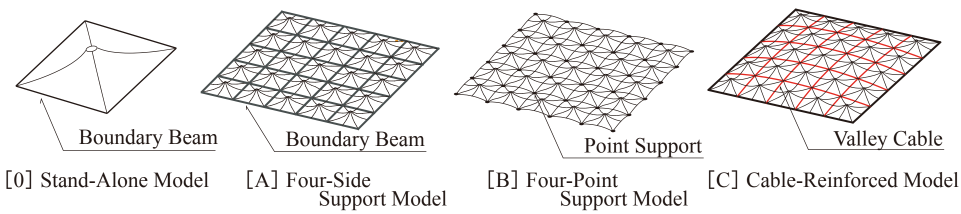


Figure 7: Analysis model

Figure 8 shows the outline of the analysis. The basic model is composed of a multi-bay horn-shaped membrane roof of 5unit×5unit (30m×30m) with 1 unit being 6m×6m. The stress and displacement analysis for wind loading were carried out after the analysis of the membrane's surface shape was determined by the shape-finding analysis.

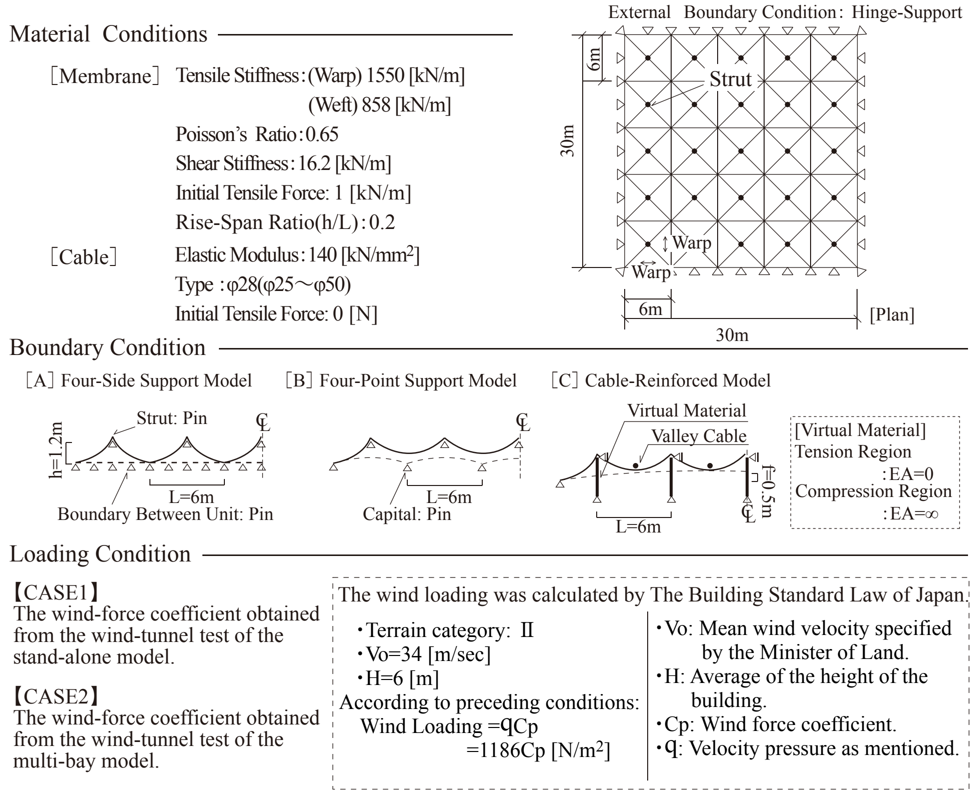


Figure 8: Analysis condition

3.2 Result obtained from analysis

Figure 9 shows the relationship between the maximum vertical displacement and the maximum membrane stress for each loading condition and supporting system, and shows the stress distribution of the membrane with mean wind velocity 34m/sec in the loading case 2. When focusing on the cable-reinforced model, as for the membrane stress, it is possible to design a multi-bay model based on the results of the stand-alone model, but as for the vertical displacement, there is a difference in the value between the stand-alone model and the muiti-bay model.

Therefore, Figure 9 shows that, as for the open type it is possible to design a multi-bay horn shaped membrane roof with four-side support model by using a stand-alone model. On the other hand, for the design of other models, the analysis result of the stand-alone model should not be used.

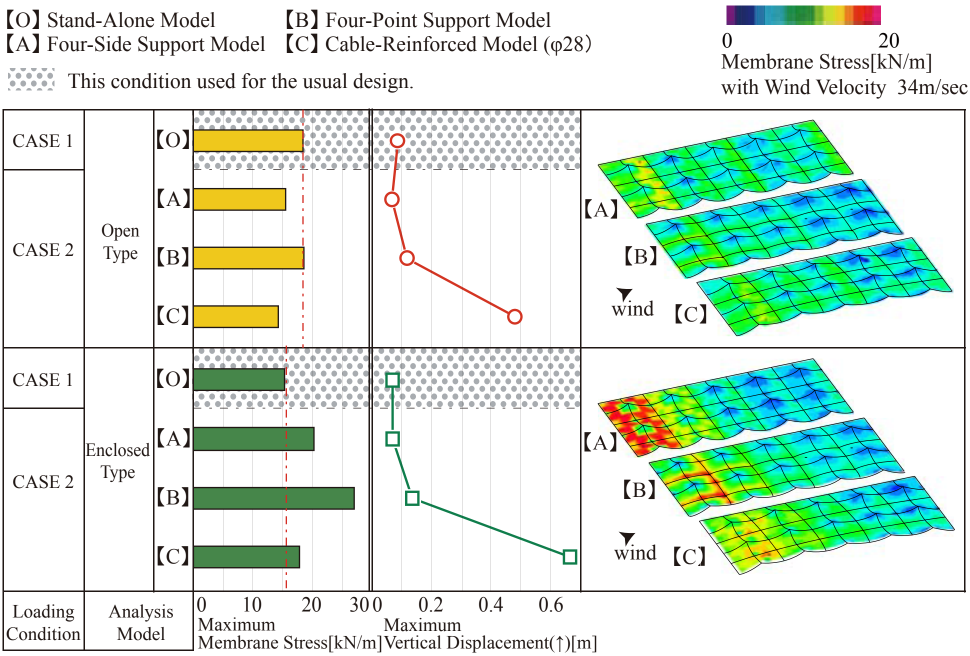


Figure 9: Relationship between loading and supporting system with wind velocity 34m/sec.

4. Conclusions

The results discussed in this paper are shown below;

(1) As for the wind loading, it was clarified that the wind-loading of the open type is almost able to use the result of the stand-alone model, but the wind-loading of the enclosed type should take into consideration the experience results of the multi-bay model.

(2) It was clarify that the design of both the four-point support type and the valley cable arranged type have not to be used structural behavior of one-unit system.

Refferences

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