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Design and Construction of Multi-bay Horn-shaped Membrane Roof
–Measuring Results Obtained from the Observation during/after Construction–

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Abstract

A horn-shaped membrane is known for his resistance against external loads owing to the curved-form resistant system and tensile forces on the membrane. This paper focuses on an existing building, which consists largely of horn-shaped membrane units that have struts (internal support poles) giving the form of the horn-shape.

In the building, the extensive membrane roof of 23,000 square meters is divided into 28 blocks and each block (less than 1000 square meters) consists of basic horn-shaped units with a 6.0×6.8m grid. Each unit is point-supported on four steel-pipe columns with a strut in the middle to which suspension rods stretched from the top of those columns. The columns arranged on the inside of the blocks to resist not against horizontal loads but vertical loads and also function as vertical gutters. The resistance against horizontal thrust from the membrane is achieved through boundary beams and cantilever columns that are located at the edge of each block.

The authors report the shape-finding method, the stress analyses, the load-resistance mechanism under additional loads and the pre-stressing method of this project. Furthermore, this paper shows measuring results of axial forces acting on the struts, which were obtained from measurements during the construction and long-term observation after construction.

Keywords: horn-shaped membrane, stress relaxation, membrane structure, construction

Photo.1 General View

Photo.2 Exterior View

Photo.3 Exterior View

Photo.4 Interior View

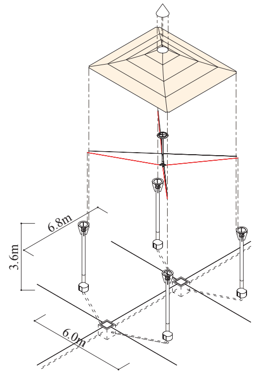

Fig.1 Unit Configuration

1. Introduction

This paper summarizes and reports the design and construction of a multi-bay horn-shaped membrane roof built in the suburbs of Tokyo. The purpose of this roof is to cover an exhibition space for the display and sale of used motorcycles. The overall construction site measures 130,000 square meters with the roof under discussion being 23,000 square meters one of the largest in its building in Japan. The roof is called “Floating Cloud”, which is named after its big white tensile force membrane roof having the image of white clouds floating over green forests[1],[2]. (Photo 1, 2, and 3)

Originally a low-cost metal roofing as roof cladding was to be used, and the technique of coating the metal roofing with membrane was proposed later. This was effectively a good opportunity to introduce the new usage of membrane structures. Since the construction schedule of the roof under discussion was required to be shorter than that of other membrane roof constructions, after working out the design, four major membrane fabricators in Japan were supposed to collaborate. Therefore, each fabricator competed to use its own technical means of production and construction, but because of time construction each fabricator was willing to share the results of the technological competition with one another. The result is that the roof was constructed using a high level of technology.

This paper discusses following subjects;

1) Outline of the membrane roof
2) Load-resistance mechanism under additional loads
3) Details and the method of construction
4) Measuring results of axial forces acting on the struts obtained from measurement during the construction and from long-term observation after construction.

2. Outline of the membrane roof

This typology is a horn-shaped membrane roof. Horn-shaped membrane resists against the external load owing to the curved-form resistant system and the tensile force on the membrane. The extensive membrane roof is divided into 28 blocks and each block (less than 1000 square meters) consists of a basic horn-shaped unit in 6.0 ×6.8m grid. This unit is point-supported on four steel-pipe columns and the strut is arranged in the centre of the unit on the suspension rods stretched from the top of the columns.

3. Membrane material and equipment planning

The membrane material consists of glass fibre coated with PVC. The cutting pattern of the membrane is divided into four in the meridian direction. The internal support pole functions as vertical gutter and piping equipment as well as structural member. A drain membrane was set up using the iron ring on the top of the poles (Photo 5), the maintenance work of which can be done from inside the roof.

Photo.5 The membrane made of the drain

Photo.6 Support pole

4. External load and load-resistant mechanism

An initial strain of 1500N/m is applied on the membrane to keep the form. The tensile force formed on the membrane surface maintains a balance on the inside of the block, so nothing else is set up except the support pole and the strut. On the other hand, the boundary beam outside the block resists against the horizontal load which is produced by the tensile force on the membrane. The column set up on the inside of the block (steel pipe), resists only against the axial force, while the column set up on the outside of the block (reinforced concrete cantilever column), resists not only against the axial force but also against the horizontal thrust from the membrane. Fig.2 shows the load-resistance mechanism against permanent loading, snow loading and wind loading.

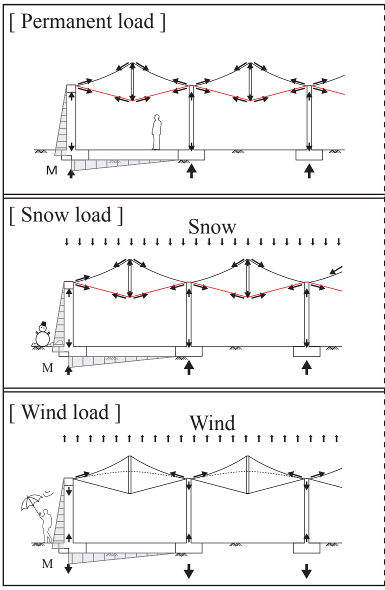

Fig.2 Load resistance mechanism

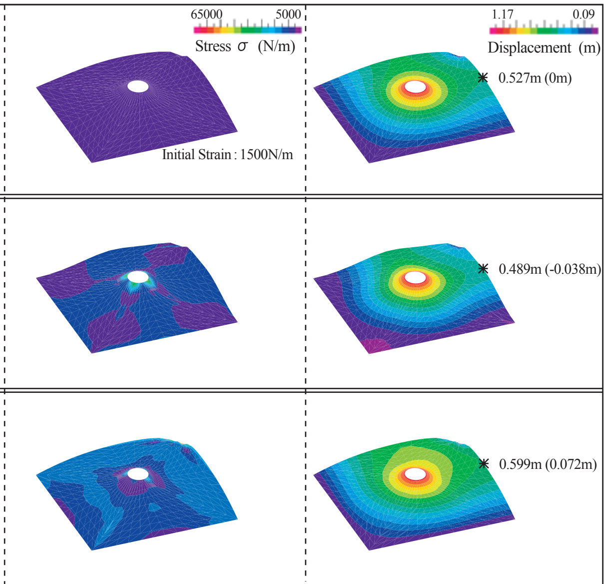

Fig.3 Contour figure

5. Detail and method of construction

After the erection of the steel framing was completed, the construction of spreading out the membrane was undertaken. The construction process was as follows (Fig.5);

1) The membrane is transported to the spot of construction in a folded state and spread out on site.
2) The membrane is fixed on the boundary beam without any force being applied to it.
3) The strut is extended and the initial strain is introduced into the membrane. The strut is telescopic structure which is easy to elongate and contract. Furthermore the strut can be thrust upward about 150mm in total.

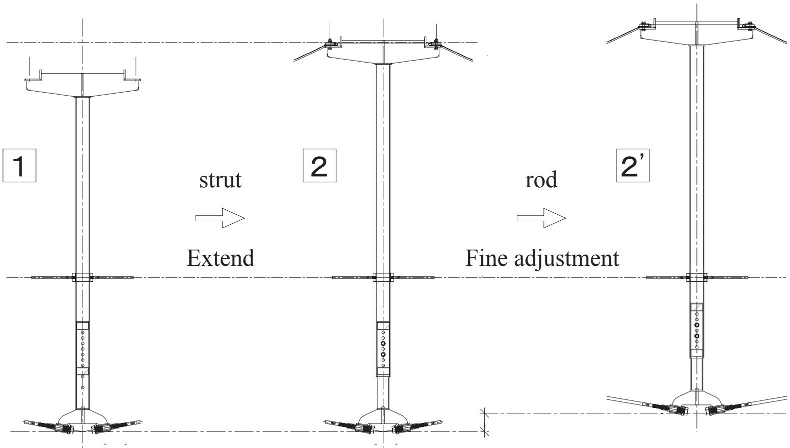

Fig.4 Strut mechanism

6. Period of construction and long-term observation

Starting with the strut in the center unit, each strut in the other units was thrust upward in a counter-clockwise rotation, as shown in Fig.6. As a result, the three strut axial forces were measured in three sets of 28 blocks. Fig.7 and Fig.8 shows the process of the strut axial forces. As the construction proceeds, the axial force comes near the target value. Meanwhile if the strut axial force was under or over the target value, the strut would be adjusted accordingly.

The strut axial forces were measured continuously for as long a period as possible, as shown in Fig.9. If the axial force decreased, strain was reintroduced. The amount of stress relaxation measured in a given time gets the largest soon after construction, and smaller as time passes.

Fig.5 Construction process

	Reduction ratio (%)		Tensile strength (kN/m)	
Membrane fabricators	warp	weft	warp	weft
Corp.B,D	0.10	0.40	90	90
Corp.C	0.10	0.35	110	101
Corp.A	0.00	0.25	83	77

Table.1 Reduction ratio and Tensile strength

Photo.7 After snowfall

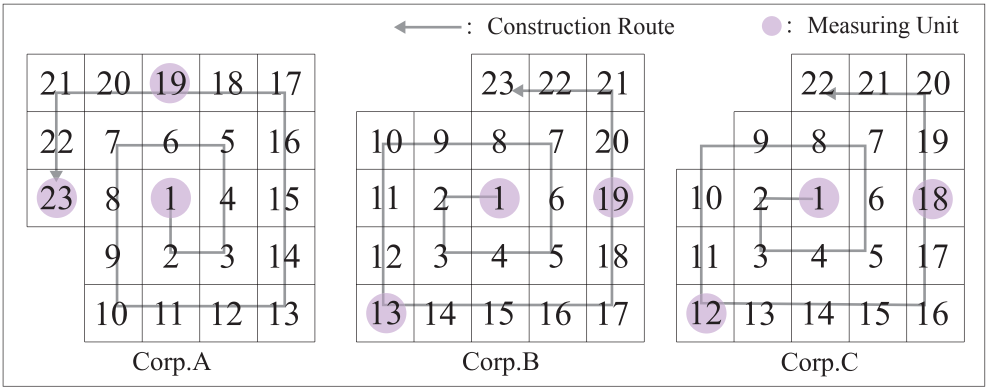

Fig.6 Construction step

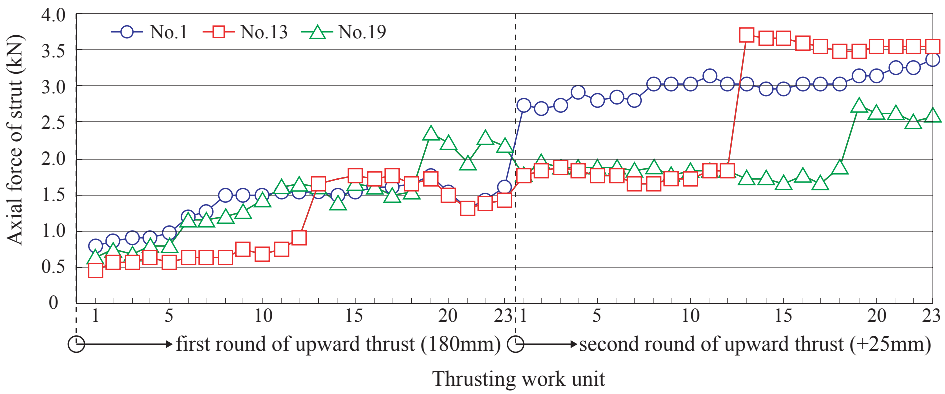

Fig.7 Transition of axial force of strut by upward thrust (Corp. B)

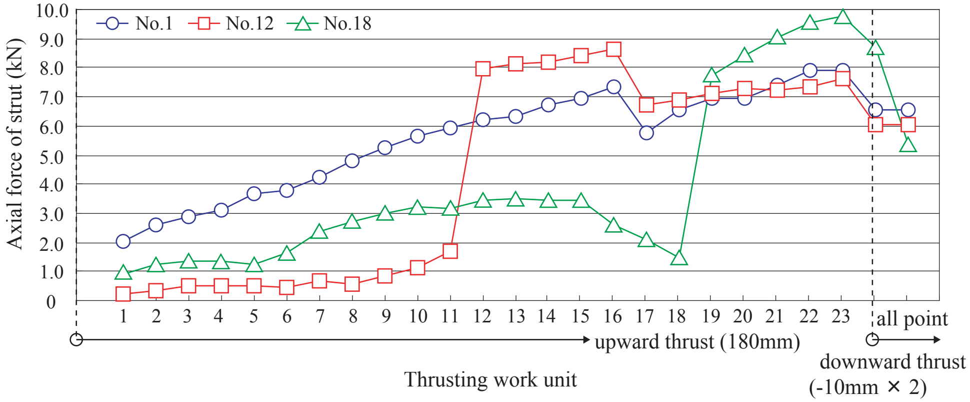

Fig.8 Transition of axial force of strut by upward thrust (Corp. C)

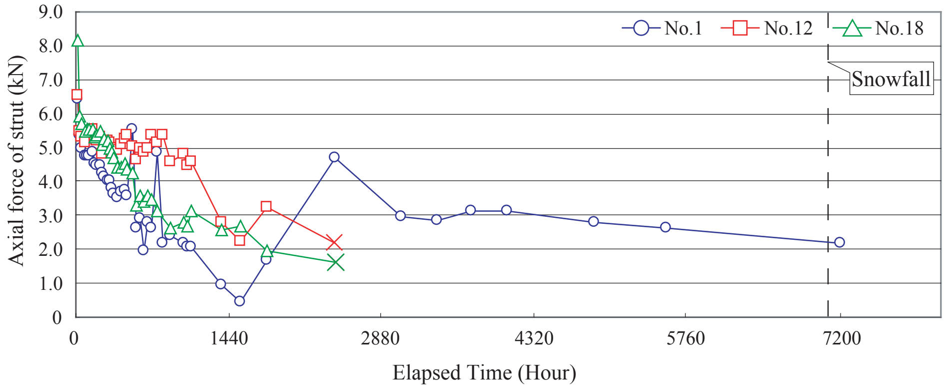

Fig.9 Transition of axial force of strut by elapsed time (Corp. C)

7. Conclusions

Membrane is a favorable material with great potential. In other words, the same membrane material can be used for various purposes such as structural, roof, waterproof and finishing material. Membrane is practical just the same considering construction and transportation. The system and the construction technique proposed in this project have broad utility in suspension-membrane structures, which are expected to prevail from now on.

References

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[2] N.Miyasato, A.Okada, M.Saitoh, S.Sugiura, "Design of Multi-Bay Horn-Shaped Membrane Roof ", 2008, Sep., AIJ, Hiroshima.