The Tsugaru-kokusetsu-Dome
Harmonizing with The Nature
(Creation Founding on Tsugaru-area)

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The "Tsugaru-kokusetsu-Dome" completed in March 2002 in Goshogawara City is the 4th dome undertaken as a full turnkey construction work by Mitsubishi Heavy Industries, Ltd. (MHI) Steel Structures & Construction Headquarters. It is a retractable roof dome with a distinctive feature of the retractable roof getting entirely removed as well as covering the ground section to allow to do sport activities under the severe weather conditions (viz. snowstorm) in winter at Tsugaru in addition to the other activities under the sun in fine weather. Further, in order to surmount the severe condition of snowstorm, countermeasure against snow load and various measures to maintain the environment were confirmed through experiments and analyses. As the result, the light and unique retractable roof to accommodate all weather conditions and the maintenance-free facility were realized at low cost.

1. Introduction

The "Tsugaru-kokusetsu Dome" is a project acquired by MHI and AXS SATOW Inc. after the draft presented by the two companies won the best award in the design and construction competition sponsored by Aomori Prefectural Government and participated by seven teams in December 1998. The basic design was carried out until March 1999 and the execution design until March 2000, while the construction work started in April 2000 and completed in March 2002, with the opening ceremony held in August. MHI took part in the project right from the stage of basic design and realized light and retractable roof structure to accommodate all weather conditions in spite of the geographical condition of heavy-snow area through various experiments and analyses. The retractable roof dome only needing low maintenance cost has been realized through effective use of natural energy and adoption of an epochal system of the ground getting automatically expanded as the roof gets retracted.

2. General elements of the dome

The dome is of membrane structure with the ground area of about 8 700 m², a space large enough to accommodate two soft-ball grounds. The 1st floor accommodates office rooms and dressing rooms while the 2nd floor has the orbital passages and approximately 340 seats for the audience, with the total area amounting approximately to 16 000 m². The dome has a retractable roof with the retractable section made of membrane and the fixed section made of metal. The dome adopts a dynamic retractable structure system allowing the roof (covering entirely over the ground) to get completely opened in fine weather, enabling sport activities and other events under the sun. Besides, the dome is equipped with a ground expansion mechanism that combines the lawn square outside the dome automatically with the ground for a joint use when the roof is opened, ensuring a space large enough to play the regular baseball game. The dome adopts a barrier-free design throughout the facility taking into consideration of the weak, and uses clay ground to minimize the adverse effect to the users. The dome is, therefore, a "facility gentle to man." Fig. 1 shows the photograph of the dome with the retractable roof closed, while Fig. 2 the photograph with the roof opened. The dome makes use of various...
natural energies to reduce the maintenance cost, taking
the environment into full consideration.

MHI has applied various technologies that it has so
far amassed in building the facility, and has made effec-
tive use of the "land and nature of Tsugaru." This paper
describes the special technologies used for the structure,
facility, and movable mechanism of the dome.

3. Shape and site planning

3.1 Dome shape

Wind environment in the surroundings get changed
when a building is newly built, calling for a wind tunnel
test in order to avert such problems and impediments in
the surroundings. The problems and impediments re-

(1) The strong snow drift in the winter that makes it
impossible to use the building

(2) The strong wind in seasons other than winter that
causes traffic obstruction of the users

The wind tunnel tests were, therefore, conducted to
investigate the wind conditions surrounding the facility
with a view to minimizing the effect of the snowdrift,
and the optimum shape was decided. The visualization
result of the optimum shape is shown in Fig. 3. The dome
shape was selected to give the roof a roundish, soft shape
less vulnerable to the strong and tearing upwind, mak-
ing it difficult from the standpoint of hydrodynamics for
the snow to pile up.

3.2 Plan for plantation in the facility

There are two ways to handle the snow: (1) positive
snow plowing and (2) leaving the snow piled up without
removing it.

In view of the aforesaid points, the wind tunnel tests
on snowdrift were carried out to make proper arrange-
ment of trees, ponds, and ditches in the facility.

Fig. 4 shows the model situation before the start of
the test and Fig. 5 the state 30 minutes after the powder
supply. The visualization test shows that because of the
wind blowing along the roof, the snow is less likely to

pile up at the upwind side and piles up at the downwind
side because of the tearing flow of the wind.

As a result, due attention was paid to the items given
below at the time of arrangement planning inside the
dome.

(1) Making a thaw pond for snow plough to the east of
the dome, where the snow is more likely to pile up.

(2) Locating the entrance gate to the north of the dome
where the snow is less likely to pile up to provide an
optimal area to the users.

(3) Allocating the south side of the dome, which is less
frequently used during the winter season, as the ex-
ternal ground for the snow to pile up.

4. Structure Planning

4.1 Outline of structure

The dome has a 42.2-m high steel structure expand-
ing 113 m in the north-south direction and 135-m in the
east-west direction, and is composed of two retractable
roofs laid symmetrically at the east and west with a span
of 93-m and a 26-m high fixed roof. The roof is made of
two types of material: the retractable roof being made of
ethylene tetrafluoride resin coated fiberglass cloth (A
type) and the fixed roof made of galvalume fluorine
coated steel. The retractable roof has its center of rota-
tion at the revolving shaft at the top of the fixed roof
and opens/closes as the bogie supporting the retractable
roof column pedestal makes horizontal swing on the
girder for moving.

4.2 Snow-resisting design

Since the dome is located in a heavy-snow falling dis-
trict, where the maximum vertical depth of snow is
specified by the Special Administrative Agency to be
190 cm, a method of applying forced vibration to the
membrane to enable the design snow pile of 100 cm was
adopted in order to reduce the weight of the roof steel.
This is a device to rotate the eccentric load called vi-
bilation generator using a motor in order to apply
vibration to the membrane. To verify this performance a half-size roof model was used to carry out experiment both in the laboratory and on the site, and it was confirmed through the experiment that the snow could be effectively removed using 24 Hz and 50 Hz. Fig. 6 shows the experimental state and Fig. 7 the state of installation of the vibration generator. This led to the reduction of steel weight by approximately 300 ton.

4.3 Wind-proof design
The wind force and pressure coefficients were computed from the wind tunnel test result. The wind tunnel test was conducted by using 1/200-size model, with the measurement made at 154 points on the outer surface and 92 points on the inner surface of the building. The design was carried out both for fully open and fully closed state of the retractable roof.

The static stress analysis against the set wind load was carried out in 8 wind directions at an interval of 45°, and the result obtained was used as the base for design. Further, it has been confirmed that the fluctuating pressure component against the wind load of the time history obtained from the wind tunnel test is sufficiently strong to withstand the framework.

4.4 Earthquake-proof design
The earthquake-proof design of the dome is based on two static analyses: primary design and final design. The dome is confirmed to be sufficiently strong to withstand the 22.5 kine (cm/s) for primary design (elastic design) and 45 kine (cm/s) for ultimate strength design (elastoplastic design).

5. Facility Planning

5.1 Environmental maintenance of a large space
The dome is designed under various fully worked-out plans to maintain a comfortable space for sport both in the seasons of severe cold and sweltering heat with the retractable roof completely closed.

First, a ground air-conditioning system called thermal ground is adopted to protect the players from the bone-chilling cold. This system uses tubes buried under the ground to pass hot water in order to prevent the ground and the vicinity from getting excessively cooled down so as to provide the players with a comfortable space. The system was initially planned to be installed near the tennis courts, but was later changed through consultation with the customer to the places where people gather such as near the (players') benches. Fig. 8 shows the installation of thermal tubes under the ground.

As for the environmental maintenance of the seats for the audience, air outlets are installed at the foot of the seats, and the air temperature through these outlets is controlled to provide optimum environment for the audience. The circulating water used for the aforesaid thermal ground system and the air used for air-conditioning the seats for the audience are recovered in advance by the tubes laid in the underground aquifer called heat exchanging tubes, with the cold water (air) recovered in summer and hot water (air) in winter. The system thus uses the geothermal energy, taking due account of the fact that the underground aquifer has a constant temperature throughout the year.

The membrane roof permeates sunrays and contributes to the reduction of power consumption for lighting in the day time and to the reduction of roof steel weight. However, it has a shortcoming that it easily causes dew formation in cold regions. In this dome, therefore, a system to form a mild-air stream near the membrane roof is adopted. The mild-air stream is generated using a box beam steel called "front keel" for the air-conditioning
duct, where a circular nozzle is installed to face the membrane roof (Fig.9). The outlet direction and flow rate were thoroughly analyzed before design so as to generate a uniform stream over the entire membrane roof. It has been confirmed that the mild-air flows throughout near the membrane roof at the rate of 10 cm/s.

5.2 Utilization of natural energy

In order to cut down on the maintenance cost during operation, various natural energies are effectively used. The concept of the utilization of natural energy is shown in Fig.10.

In the first place, as mentioned above, tubes are laid on the underground aquifer to recover the heat for air and water to make the effective use of the geothermal energy. This system uses the steady heat of approximately 11°C river-bed water flowing the gravel aquifer at the base section of the dome. This system has been adopted in the SHELLCOM SENDAI constructed by MHI, and has been proved effective.

The heat exchanging tubes for air and water are laid in the gravel aquifer, with the outside air fed into the air heat exchanging tubes for room ventilation and dew prevention. When the outside air passes through the heat exchanging tube, it is cooled by the thermal energy for cooling and heated using the thermal energy for heating the room, the seats for the audience, and near the membrane. Further, the water heat exchanging tubes make use of the rainwater and snow water from the dome roof collected in this rain water storage tank for circulation. The stored water is heated and circulated in winter for snow melting at the entrance plaza and as circulating water for thermal ground and cooled to use as the cooling water in summer. However, since the excavated floor of the dome base (foundation) is used for burying the heat exchanging tubes, the required material cost is limited to the labor cost for laying the tubes, contributing to the reduction in construction cost. Fig.11 shows the laid tubes. Experiment was made before construction to make sure of the effectiveness of the heat exchanging tubes. The experiment was limited to the water heat exchanging tubes because of the construction process, but the result showed that the ground temperature remained almost constant at 12°C in spite of the variation in outside air temperature between 0 and 10°C, with the inlet water temperature of the heat exchanging tube standing at 7–8°C and the outlet water temperature...
8–9°C. Thus the heat equivalent to 1°C was confirmed to be recovered constantly, indicating that the water could be safely used as the cooling water in summer (Fig. 12).

In addition to the utilization of natural energy mentioned above, various measures are taken to reduce the costs for water, lighting and heating, such as the adoption of the membrane roof that enables natural lighting and reduces the power consumption for artificial lighting, the adoption of natural ventilation to prevent temperature inside the dome from rising, the utilization of rain water and snow water for the water used in toilets, for sprinkling water outside and on the ground and so on.

6. Movable mechanism planning

6.1 Ground expansion mechanism

The newly developed and adopted technology used in the dome is the ground expansion mechanism, which can be counted as one of the features of this dome. In the new system, the parting section opening between the inner and outer grounds at the border of the retractable roof bogie traveling section of the conventional system is covered with a lid to integrate the two grounds into one.

As shown in Fig. 13 the system is composed of an artificial lawn panel as the lid, the hinge that supports the panel at the time of opening/closing, the guide pipe that opens/closes the panel, and the sleeve roller that makes the contact between panel and guide pipe smooth. There are 83 pieces of artificial lawn panel only on one roof, making it possible to combine the inner and outer grounds thoroughly into one ground when the roof is fully opened.

The operation of the system is described in Fig. 14. The guide pipe installed to the retractable roof opens/closes the artificial lawn panel as the roof moves forward or backward. The end of the guide pipe slides into the sleeve roller bottom when the panel is closed, causing the panel to be pushed up. The guide pipe is displaced to height H and distance L as the roof travels 1.3 m, causing the panel to be pushed up to the OPEN position. (Fig. 14 Operation of ground expansion mechanism)
The resin material used as the sleeve roller prevents wear with the guide pipe and vibration. Further, the joint adjustment of the artificial lawn pasted on the artificial lawn panel at the time of opening/closing is carried out by the lawn pressing roller installed to the retractable roof.

6.2 Other movable mechanism

The movable mechanism other than the aforesaid ground expansion mechanism for this dome is the conventional retractable roof bogie and going-up and-down formula pitcher mound.

The retractable roof bogie installed for supporting and moving the roof is composed of the self-propelled drive bogie that runs along the rails on the ground and the driven bogie that is driven along the rails. In this dome, there are in all 6 units of bogie in one roof: 2 units of drive bogie and 4 units of driven bogie, covering the distance of 70 m in about 15 minutes.

The going-up and-down formula pitcher mound is installed for multi-purpose use of the ground and makes the mound fit for both baseball and flat specifications. It consists of an automatic lifting-up and-down mechanism using the built-in lift. In order to allow the clay on the mound to go-up and-down rubber sheet and skid platform are installed between clay and lift.

7. Conclusion

We would like to extend our gratitude to AXS SATOW Inc., Aomori Prefectural Government, and the related enterprises for their cooperation in design and construction of the dome. Hopefully, the dome will prove an outstanding facility for the people not only in Aomori Prefecture but also in the Tohoku districts.