

ICE SHELL - CONTEMPORARY 'KAMAKURA'

Tsutomu Kokawa¹, Koji Watanabe¹, Tohru Watanabe²

¹ Tokai University, Japan

² Hoshino Resort Corporation, Japan

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Introduction

Snow and ice can be used as a structural material for temporary architecture in snowy and cold regions. "Kamakura" in Tohoku district of Japan is a traditional snow hut where children play house during the New Year holidays, and is formed by scooping out snow from a small mound of snow. It is a very fantastic instant dome, however it is generally very small in size because its structural material is snow which mechanical property is very low.

On the other hand, the ice shell in Hokkaido, which is thin curved plate-structures made of ice, can cover a much wider space than "kamakura". It is

a new type of ice structure based on modern structural engineering. It was suggested that the ice shell, as a concept in architectural technique in cold and snowy regions during winter, could be used for creating a unique built environment [1].



Fig. 1: "Kamakura"

<http://pics.livedoor.com/u/kamebugofukuten/4584147>

Construction Method

The construction method for the ice shell is technically simple, mechanically reasonable and economical as stated below referring to Fig.2.

- (1) Building up a 3-dimensional formwork by inflating a 2-dimensional membrane bag covered with reticular ropes anchored to the snow-ice foundation.
- (2) Covering the membrane with a thin snow-ice layer ($\leq 1\text{cm}$) by blowing milled snow with a rotary snow blower, spraying water and letting it freeze naturally at temperatures below -10°C .
- (3) Repeating the application of snow and water until the desired shell thickness is reached, then removing the bag and ropes for reuse.



Fig. 2: Construction sequences of 15m ice dome* constructed by students of Tokai University [2]

Current Applications

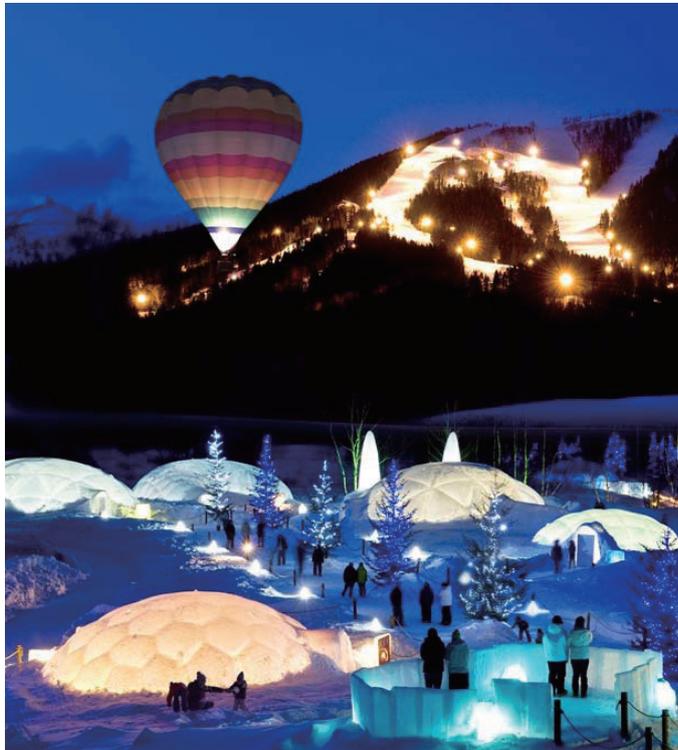
Almost 30 years since 1980s, the shells have been practically used inland Hokkaido with sufficient snow and low temperature for a variety of temporary structures such as a winter storage of vegetables, a factory house for making Japanese "sake", an indoor space for an ice fishing on a frozen lake and event facilities for winter festival etc.[3]. As the typical examples of the applications, two examples, 'Ice Village in Tomamu' and 'Ice Pantheon Project in Asahikawa' are described here referring to Table 1.

Table1: Meteorological Data (1981-2010)(<http://www.jma.go.jp/jma/index.html>) and Usage

Construction site	January~February		Usage (year)
	Average air temp.(C°)	Precipitation (mm)	
Tomamu	-9.8	92.9	Leisure-recreation (1997~)
Asahikawa	-7.0	120.9	Sake factory-storage (1989~), Winter festival (2008~), Ice pantheon project (2009~)

Ice Village in Tomamu

Since 1997 in Tomamu, many ice shells, especially 10~15m ice domes* which use 10~15m diameter of circular membrane bag are being used each winter for about 75 days as leisure-recreational facilities in a ski resort.



(a) Outside view (2008-2009 winter)



(b) Ice hotel



(c) Café bar

Fig. 3: Ice Village in Tomamu

Ice Pantheon Project in Asahikawa Campus of Tokai University

In addition to the numerical results of a theoretical analysis [2], the past construction experiences and the field experiments of 20~30m ice domes [4], [5], [6] would support the realization of a huge ice dome spanning 40 meters never existed before, which has comparable same size as Pantheon in Rome well known as one of the biggest classical stone dome. The ice dome is easier to construct than the stone dome and the strength/density of the ice is almost same as that of stone in short term loading, so it could be possible for students as amateur to construct a 40m ice dome* if they gradually experience the construction from small domes. Towards the realization of the ice dome, so called 'Ice Pantheon', the students started to go on an exciting, thrilling and wonderful voyage under the technical guidance by the authors of Tokai University. In winter of 2009, as the first step toward this end, a small size of 10m ice dome* was constructed. In winter of 2010, a non-spherical 15m ice dome* was constructed by them and used as event architecture. And then in this winter the students tried to construct a non-spherical 20m ice dome* which was not practically used before, although three 20m ice domes* were constructed for creep experiments in the past. Fig. 4 shows three ice domes constructed in IPP2009-2011.



(a) IPP2009 10m Ice dome* (base diameter=8.6m, height=3.0m)



(b) IPP2010 15m Ice dome* (base diameter=12.6m, height=5.0m)



(c) IPP2011 20m Ice dome* (base diameter=16.0m, height=6.3m)

Fig. 4: IPP (Ice Pantheon Project) 2009-2011

And then, in winter of 2012, a non-spherical 25m ice dome* was constructed successfully. Fig.5 shows the photos of the working sequences up to the completion.



(1) 25m square polyethylene blue sheet



(2) Gluing for 25m diameter 2-D circular membrane bag



(3) Manufacturing for polypropylene cover rope

(a) Preparation for pneumatic formwork



(1) Site surveying



(2) Putting snow and pouring water

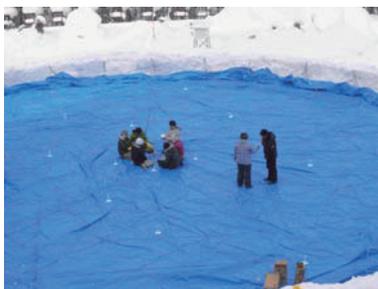


(3) Completion

(b) Construction of snow-ice foundation ring



(1) 2-D membrane



(2) Setting cover rope



(3) 3-D air inflated formwork

(c) Setting pneumatic formwork



(1) Blowing snow



(2) Pump engine for high pressure



(3) Spraying water

(d) Application of snow and water



(1) Switch off air blower



(2) Removing rope

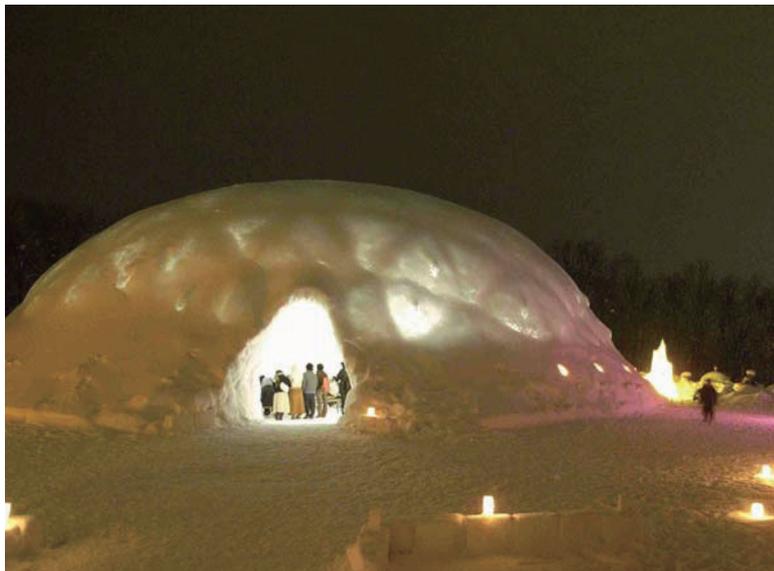


(3) Folded membrane

(e) Removing pneumatic formwork

Fig. 5 Work record of 25m ice dome constructed by students of Tokai University in IPP2012

After the completion of 25m ice dome*, the dome was lighted up and then used for jazz piano concert as shown in Fig.6.



(a) Outside view



(b) Jazz piano concert

Fig. 6 25m ice dome (base diameter=21m, height=8.1m) used for event

Ending Remarks

Ice shells, which are thin curved-plate structures made of ice, have been used as temporary winter structures since 1980s in inland Hokkaido with sufficient snow and low temperature. The construction method of blowing snow and spraying water onto the pneumatic formwork consisting of a 2-dimensional membrane bag and a reticulated cover rope has constructional rationality. The ice structure has also high structural efficiency as a shell.

And then the shell creates a beautiful space in the environment from the translucent thin plate and the unique curved surface shape. The interior space has a translucent atmosphere with full of natural light in daytime, and the exterior looks like a gigantic illuminator in the dark at night. Also, the shell is environmentally compatible because it simply returns to the earth as water in spring.

Although there still remain to be studied in more detail about the construction technique, the structural design and the maintenance method of the ice shell as a special temporary structure, it has a possibility to become a useful structure common in not only inland Hokkaido but also severe cold regions all over the world.

Note

*. 'Xm ice dome' means the ice dome constructed by using Xm diameter of circular membrane bag in the formwork before inflation.

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