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Field Experiment of Ice Dome Spanning 20∼30 Meters

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ABSTRACT

Aiming at the realization of a large ice shell to be used for a variety of architectural facilities in winter, experimental studies of ice domes spanning 20∼30 m have been carried out at Tomamu since 1999. Two field studies of a 20-m-span ice dome (17-m base diameter and 6.5-m height) were developed in 1999–00. These test domes showed a high structural efficiency, so in the winter of 2001 the experimentation was taken a step further by carrying out a field study focusing on both the construction and creep test of a 30-m-span ice dome (25-m base diameter and 9.2-m height). Based on the findings from these studies, it can be concluded that the application of an ice dome spanning 20∼30 m should be feasible.

INTRODUCTION

Snow and frigid conditions enable the application of an ice shell, which would provide an efficient solution to certain problems common in cold and snowy regions. The shell is thin, and its structural material is ice. A new type of ice structure based on modern structural engineering, it can cover an area larger than the classic snow-ice structures such as the Japanese *kamakura* or the igloo. It was suggested that the ice shell, as a concept in architectural technique in cold and snowy regions during winter, could be used to create a unique built environment (Kokawa, 1985). Since experimentation in the construction of ice shells for architectural space began in Tomamu, Hokkaido in 1997 (Kokawa et al., 2000), many ice shells have been made for actual use, providing a unique built environment for visitors for about 3 months each winter. Taking architectural safety into consideration, the size of these shells had been limited to no more than a 15-m span. However, extensively interpreting the results of the past studies, a large ice shell with a span between 20 m and 30 m would also be possible to use as an architectural structure. And then, two field studies on a 20-m-span ice dome (17-m base diameter and 6.5-m height) were carried out at the same site in Tomamu in 1999–00. These test domes showed a high structural efficiency. Following the experiments with 20-m-span ice domes, a field study on both the construction and creep test of a 30-m-span ice dome (25-m base diameter and 9.2-m height) was carried out at the same place during the winter of 2001, assessing the possibility of its realization from the aspect of architectural engineering. Based on the results of these studies, it is concluded that the application of a 20∼ 30 m-span ice dome for an architectural facility would be practicable.

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KEY WORDS: 20∼30-m-span ice dome, field experiment, construction test, creep test, winter architecture.
N.B.: "30-m span" refers to the diameter of the membrane bag used in the formwork before inflation.

SIMPLE CONSIDERATION

According to the membrane shell theory, the compression stress at the apex of a spherical shell (with a 30-m base diameter and 130° open angle) under the dead type of loading (ice density 0.85 g/cm^3) is computed as 7.0 N/cm^2, which corresponds to about 1/60th of the uniaxial compressive strength of ice. Thus, the 30-m-span ice dome has enough strength to stand, theoretically. This is the reasoning behind the field experiment of the 20∼30-m-span ice dome concerning the construction technique—and the structural safety, which was subsequently conducted.

OUTLINE OF CONSTRUCTION METHOD

The *kamakura* and igloo are classic snow-ice structures, but it seems that these structure have neither construction rationality nor structural efficiency in the case of a large span. A *kamakura* is a traditional Japanese snow hut where children play house during the New Year holidays; it is formed by scooping out snow from a small mound of snow. An igloo is a snow hut built by arranging snow blocks hemispherically. In contrast, the ice shell is constructed by following a simple, quick and economical method:

1. building up the 3-dimensional formwork by inflating a 2-dimensional membrane bag covered with ropes anchored to the snow-ice foundation.
2. covering the membrane with a thin snow-ice sherbet layer (1 cm) by blowing the milled snow with a rotary snowblower, spraying water with a high-pressure adjustable nozzle, then letting it freeze naturally where temperatures remain at −10°C.
3. repeating the application of snow and water until the desired shell thickness (1/100th of the span) is reached, then removing the bag and ropes for reuse.

The ice quality of the completed dome can be judged satisfactory if there is sufficient outward transmission of light from the lighted interior.

FIELD TEST OF 20-M-SPAN ICE DOME

Theoretically, the use of an ice dome with a span between 20 and 30 m is feasible. However, the actual proof test of an ice dome this large had not been done before, except for the field experiment of a 20-m-span ice dome in 1985 (Kokawa and Murakami, 1986); more work was necessary to demonstrate its structural reliability for use as an architectural structure. Thus, with an eye