C-1-4 Impregnation treatment with hydrophobic silane to an important stone building suffering from freezing damage in cold and heavy snowfall district

Tadateru Nishiura
Center for the Global Study of Cultural Heritage and Culture, Kansai University, Osaka, Japan.
tadateru.nishiura@gmail.com

Yasumichi Murakami
The Board of Education, Hyogo Prefectural Government, Hyogo, Japan.

Masami Fukuda
Honorary Professor, Hokkaido University, Sapporo, Japan.

ABSTRACT: An important historic stone building (1906) in a cold and heavy snowfall district, Otaru, Hokkaido, Japan, had been suffering from freezing damage because of frequent freeze-thaw cycles in early spring. In order to revive the cohesion of the damaged stones (porous tuff) and protect them from water penetration, impregnation treatment with hydrophobic silicone resin (a solution of the oligomer of methyl triethoxy silane in organic solvent) was executed. Several years later, a serious trouble occurred. The layers of some stones, into which the resin had penetrated, had become detached. Detailed investigation revealed that the cause and the mechanism of this trouble is as follows: Because the waterproofing of the roof was insufficient, snow water penetrated into the stones from the untreated side and the water froze to make ice crystals in the interface between resin-treated layer and untreated layer; the growth of the ice crystals led to the breaking of the stones. Thus, covering the roof with copper sheet was carried out. Now, for more than 30 years since the conservation work, the condition of the building is good.

KEY-WORDS: Stone building, impregnation treatment, hydrophobic silane, freezing damage, cold district, porous tuff.

STONE BUILDING

In Japan, most buildings are made of wood or concrete. Stone or brick buildings were made during a very limited period, from the end of the 19th century to the early 20th century. They are historically important in Japan.

Fig.1. Map of Otaru, Hokkaido, Japan

Fig. 2. An important historic stone building

The stone building discussed in the present paper was constructed in 1906 and is located in Otaru, Hokkaido, which is a cold and heavy snowfall district in Japan. This modern European-type building, which had been used as the office of a famous shipping line company, is beautiful and unique to Japanese history of architecture. It was designated an important cultural property of Japan in 1969. The stones of the building are porous tuff for the main parts and porous andesite for the decorative parts. Those stones had suffered from freezing damage to a great

extent. Thus, conservation work was carried out on the building from 1984 to 1987; now, it is open to the public as an important historic heritage.

STONES AND THEIR DETERIORATION

The stones of the building and their conditions before treatment are shown in Table 1.
Deterioration of the tuff is often caused by the crystallization of salts. In this case, however, considering the total condition of the stones, it was determined that deterioration was caused by freeze-thaw cycles of the water in the stones.

Table 1. The stones of the building and their conditions before treatment

Stone	Porosity (%)	Colour	Places used	Deterioration
Tuff	45-48	Grayish light brown	Walls and columns	Granulation and powdering of the surface layer
Andesite	23-26	Dark grey	Decoration of the facade	Breaking

Fig.3. Freezing damages to the stones

CLIMATE CONDITION

Fig. 4 shows the number of days on which maximum temperature was over 2℃ and minimum temperature under -2℃ within a day from December 1981 to March 1982 in Otaru. It is clear that there were quite many such days, which cause freeze-thaw cycles of water, in Otaru. It snows much in Otaru and much water is supplied to the building when the snow melts. Thus, damage by freeze-thaw cycles occurred to the stones of the building.

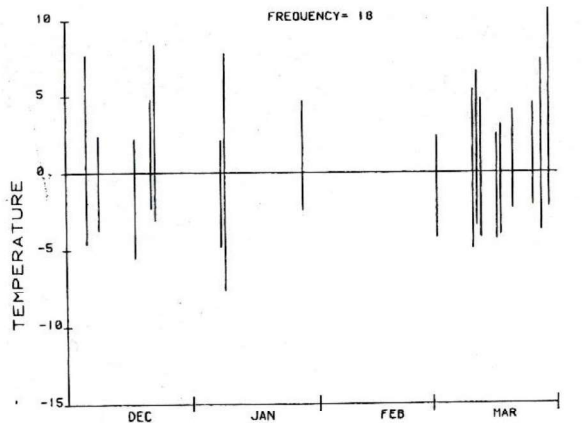

Fig.4. Frequency of the days in which temperature changes suitable for freeze deterioration

Fig.5. Winter night in Otaru with snow

CONSERVATION TREATMENT

Necessary conditions in which a stone suffer from freezing damage are as follows:
(1) Continuous penetration of water into a stone
(2) Climate condition in which freeze-thaw cycles of water occurs
(3) Insufficient cohesion of a stone against inner stress

Freezing damage of stone can be avoided by invalidating one of those conditions. In the case of the stones discussed in this paper, it is impossible to change conditions (2) and (3). As for condition (1), water penetration into a stone can be stopped by making it hydrophobic. Thus, it was decided to impregnate a solution of hydrophobic silicone resin (a solution of the oligomer of methyl triethoxy silane in organic solvent <trade name "SS-101," Colcoat Co., Ltd.> into the stones.

Considerations and experimental tests to ensure deep penetration of the solution by brushing into the stones which are the parts of the building were conducted by the Tokyo National Research Institute for Cultural Properties. Then the practical treatments at the sight were executed as follows:
(1) The stones were dried as much as possible by using a jet heater.
(2) Silicone solution was applied by brushing as much as possible (actually more than 3kg/m^2). In this case, application of the solution was not repeated but accomplished in one time so that deeper penetration was gotten, which is a very important point of this treatment.

The restoration work for the decoration parts made of andesite is not explained in this paper because it does not directly suit the theme of the present symposium.

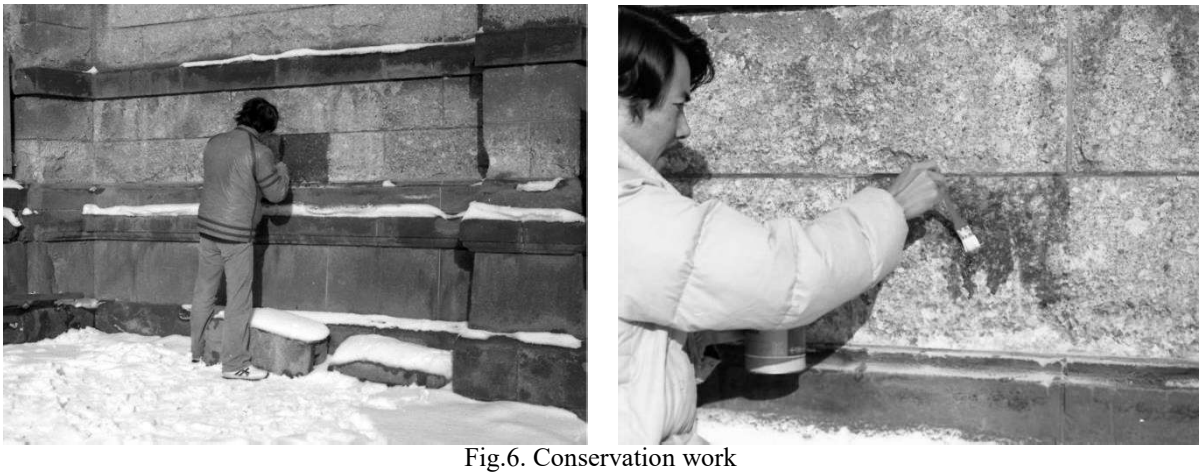

Fig.6. Conservation work

TROUBLE AFTER THE CONSERVATION TREATMENT

Two years after conservation treatment, a serious trouble occurred. Surface layers (10-15cm) that were totally impregnated with hydrophobic silicone resin were detached away from some treated stones.

Detailed investigation revealed that the cause and the mechanism of this trouble were as follows: Because the waterproofing of the roof was insufficient, snow water penetrated into the stones from the untreated side and the water froze to make ice crystals in the interface between resin-treated layer and untreated layer. The growth of the ice crystals led to the breaking of the stones.

Thus, covering the roof with copper sheets was carried out. Now, more than 30 years after the conservation work, the condition of the building is good.

DISCUSSION

As is well known, the main factor of the freezing damage of a stone is not the temporary increase in the volume of water when freezing but the continuous growing of the ice crystals when water penetrates into the stone

continuously in a cold environment (Fig. 7). In this case, if the outer side of the stone is waterproof and water penetrates into the stone from the other non-waterproof side, water in the stone becomes ice crystals at the interface between the waterproof part and the non-waterproof part (Fig. 8).
Therefore, detailed investigation is necessary when waterproofing treatment is executed on a stone against freezing damage.

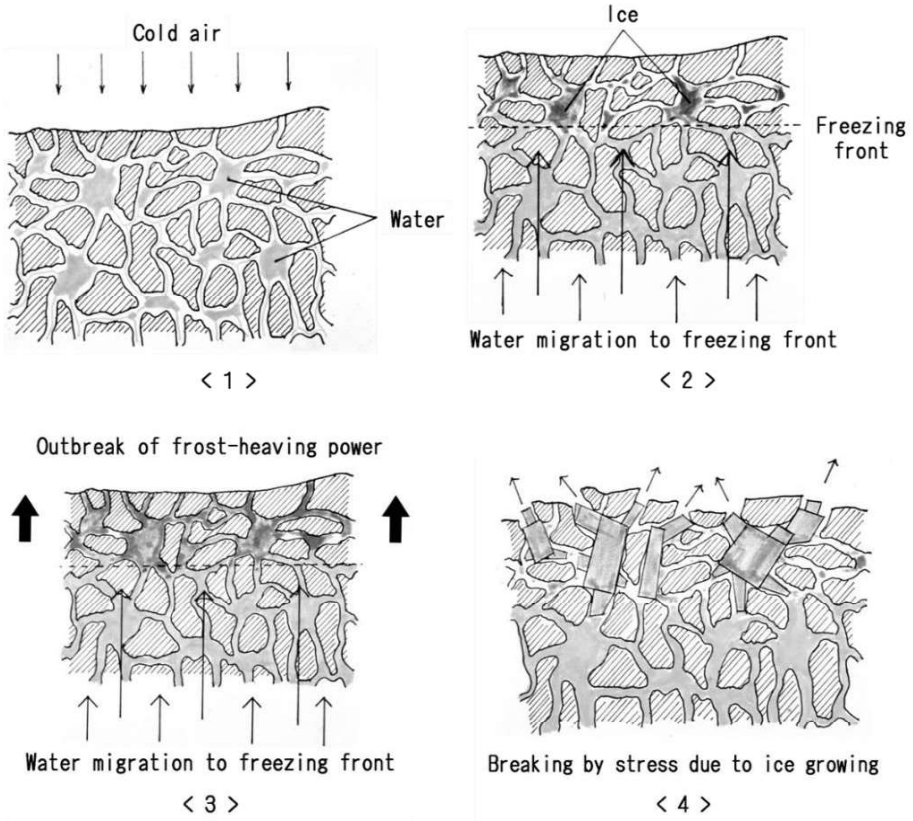

Fig.7. Mechanism of the freezing damage of stone

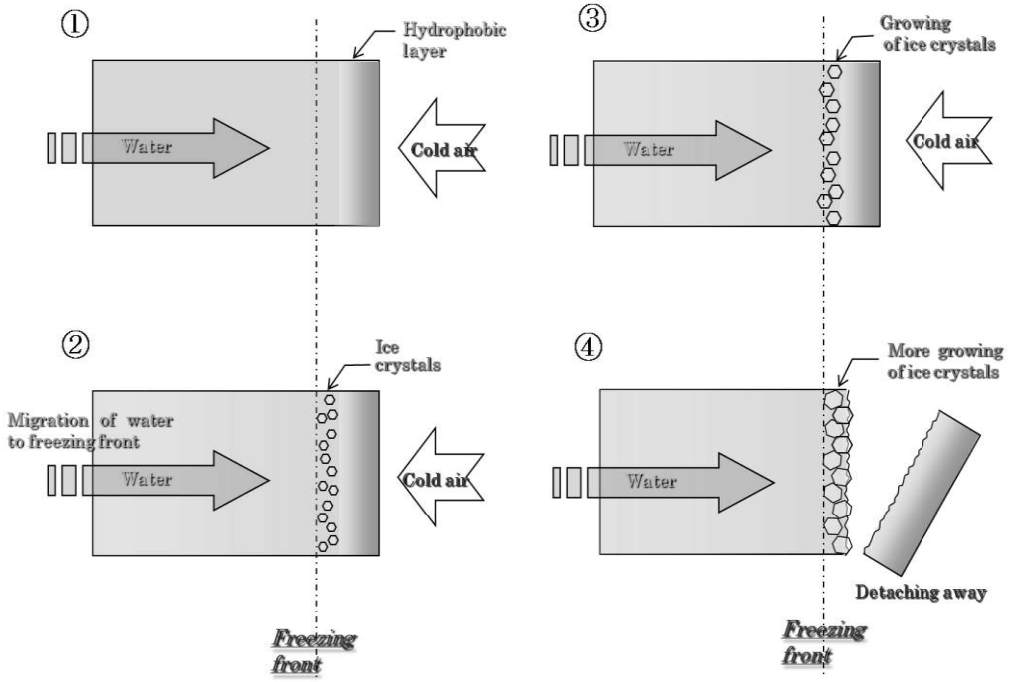

Fig.8. Special breaking of the stone treated by impregnation with hydrophobic resin under freezing condition

REFERENCES

[1] D. H. EVERETTE, *The thermodynamics of frost damage to porous solids,* Transactions of the Faraday Society 57 (1961):1541-1551

[2] M. FUKUDA, *Mechanism of rock shattering by freeze-thaw cycles,* Chikei 1(1980): 89-95

[3] M. FUKUDA, *Some observation about rock weathering by frost upon wall carvings,* Fondation Francase d'Etude Nordique Actes Document No. 6 (1979): 73-79

[4] T. NISHIURA, *Conservation of old roof tiles for reuse*, The Conservation of Stone II, Centro Cesare Gnudi, Bologna, (1981): 699-709

[5] T. NISHIURA, M. FUKUDA, S. MIURA. *Treatment of Stone with Synthetic Resins for Its Protection against Damage by Freeze-thaw Cycles,* Preprints of the Contributions to the Paris Congress, 2-8 September 1984, 156-159.

[6] C. D. OLLIER, Weathering, Oliver & Boyd Co., Edinburgh, (1969) 304.

[7] S. E. WHITE, *Is frost action really only hydration shattering?* Arctic and Alpino Research 8(1976):1-6.