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Deterioration of the wall of a historic stone building in a cold region and measures to protect it

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Abstract

In the northern part of Japan, the air temperature decreases to -10 degrees Celsius in the winter. The outside walls of historic stone buildings deteriorate due to frost damage. We studied the deterioration of historic buildings and their environmental conditions in Otaru and Sapporo in Hokkaido. This paper reports on the observation of the deterioration of the building materials of an important cultural property, the *Nihon Yusen Building*. We also measured the temperature and humidity inside and outside the building as well as the water content of the wall surface. From these observations, it was revealed that the main cause of deterioration was damage to and rusting of the roof and chimney, which allowed rain water and snow-melt water to enter the rooms. The speed of deterioration is considered to be increasing. In particular, parts of the outside stone wall made of Otaru tuff under the roof on the north, west and south sides have deteriorated; this phenomenon was not observed at the time of the previous restoration. Rain water had penetrated into the stone mainly through the deteriorated part of the roof and rain water gutters as well as through the deteriorated part of the outside wall. Part of the water that had penetrated remained under the roof, on the borders previously mentioned, and between the stone blocks. The freeze and thaw cycles of the water in these areas caused the deterioration of the building materials in winter. As a protective measure, it is necessary to prevent the penetration of water into the building materials so as to avoid frost damage in the winter. It is also necessary to restore the roof, chimney and rain gutters immediately to prevent further damage to the building materials.

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1. Introduction

A historic stone building, the Nihon Yusen Building, which was designated an important cultural property, is located in Otaru city in Japan (Fig. 1). Otaru city is in Hokkaido and is located in the northern part of Japan. Otaru city was an important port city during the Meiji period when many Japanese people came to Hokkaido to explore the wilderness. During this period, many stone buildings and storages were built by well-known architects using new technology. Construction of the Otaru Branch of the Nihon Yusen building was started in 1904 and completed in October 1906. It is a two-story building made of stone in the French Renaissance style with a zinc-plated iron roof. In September, 1906, a meeting was held in this building to determine the border between Russia and Japan on Sakhalin Island after the Russo-Japanese War. Seventy years after its construction, various parts of the building had deteriorated due to frost damage. Otaru city carried out restoration work for 33 months from October 1984 to June 1987 [1]. Twenty years after this restoration, the Otaru tuff building material had deteriorated under the roof on the north and south sides, and cracks were found at the borders between places where water repellent material had penetrated and where it had not. Wall paper, known as *kinkarakawakami*, had also deteriorated due to the penetration of rain water through the roof. In addition, fungi were found on the wall surface and color changes were observed on the ceiling.

Fig. 1 Nihon Yusen Building in Otaru

2. Deterioration of the building

2.1. Deterioration of the outside walls and ceilings

Fig. 2 shows the deteriorated condition of the walls facing north and east. The left photo was taken in June 2009 and the right photo was taken in October 2011. The white parts are places where the surface stone had peeled off or fallen. These pictures show that the surface area of the deteriorated parts rapidly increased in about 2 years.

Fig. 2 Deterioration of stone wall surface (left: June 2009, right: October 2011)

Fig. 3 shows the deterioration of the surface stone on the lower part of the column near the entrance. The right photo is an enlarged image of this part. The white part near the surface is where water repellent material penetrated, and the black part shows where it did not. On the surface of the upper part of this column, the trace of water fall is found. Water may penetrate into the stone through this deteriorated part, and the deterioration will continue due to the freeze and thaw cycles in the winter season [2].

On the whole part of the roof, abrasion due to the movement of snow and ice in winter was found. Corrosion of the metal roof was also found. This could be due to the sea breeze which contains salts from sea water.

Fig. 4 shows the deterioration of the roof. The left photo shows the corrosion of metal near the junction between the roof and the gutter on the west side of the building. In winter, snow accumulates on this area, and melt water may leak through this part into the inside roof. The right photo shows the damage to a 45 x 60 cm area on the east side of the roof. When this part was observed on a rainy day, it was found that rain flew down from the damaged part. This is considered to be the source of the water that increases the water content of the stone of the side wall.

Fig. 3 Deterioration of stone wall surface (right: enlarged image)

Fig. 4 Deterioration of the roof (left: corrosion of the metal at the junction of the roof and gutter; right: cracks in roof)

2.2. Deterioration of the inside walls

The inside wall and wall paper were damaged by the water that penetrated through the roof as shown in the previous section. This leakage occurs during typhoon season and during the winter. The most damage was found from the middle of February to the end of March when the snow on the roof melts. Fig. 5 shows the blistering of the lime plaster surface. Cracks were also observed to appear in the lime plaster surface of the wall. Wall paper known as *kinkarakawakami* also deteriorated due to the penetration of rain water through the roof. In addition, fungi were found on the wall surface and color changes were observed on the ceiling.

Fig. 5 Blistering of the lime plaster wall surface

3. Temperature and humidity measurement

In order to obtain data related to the number of freeze-thaw cycles that the outside stone wall undergoes, temperature data loggers were located on the outside walls facing north, east, south and west. The outside temperature and humidity were measured by a temperature and humidity data logger. Temperature and humidity data were also obtained inside of the building. These data were obtained every hour. Fig. 6 shows the locations of the temperature and humidity data loggers. Points labeled WallTN, WallTE, WallTS and WallTW shows the locations of temperature sensors on the outside wall facing north, east, south and west, respectively. The point labeled T&RH shows the location of the temperature and humidity data loggers for measuring the outside environment. The points labeled 1F1, 1F2 and 1F3 show the location of the temperature and humidity data loggers inside the building.

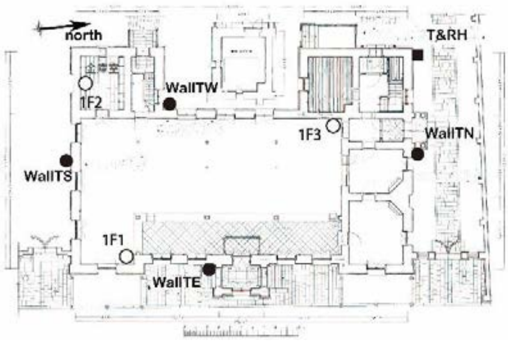

Fig. 6 Locations of temperature and humidity data loggers

Fig. 7 shows the temperature and humidity changes outside of the building over 3 years from 2008 to 2011. The lowest temperature was recorded at around -10 degrees Celsius in winter.

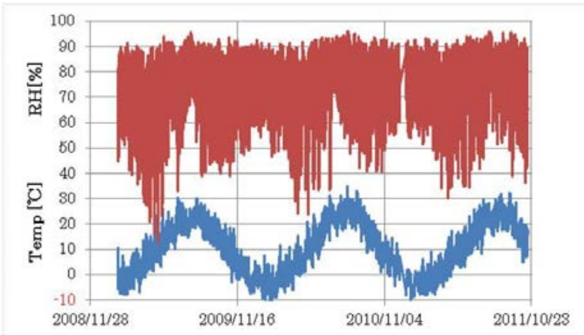

Fig. 7 Temperature and humidity changes outside of the building (2008-2011)

In addition to the temperature and humidity measurements, the temperature profile of the wall surface was measured using a thermo viewer in March, 2009. The left photo in Fig. 8 shows the deterioration of the wall near the gutter under the roof. The right photo shows the temperature profile of the wall. The color of the location near the gutter under the roof shows that the temperature is low in this region. This temperature profile also shows that the water content in this area is higher than the surrounding region due to rain water penetration.

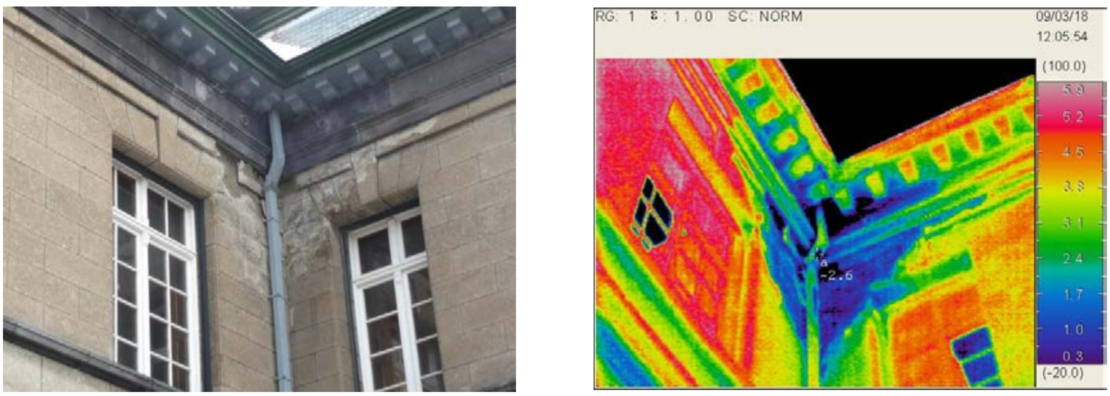

Fig. 8 Deterioration of stone wall surface (left) and the corresponding thermos viewer image (right)

4. Cause of the deterioration of the wall

Fig. 9 shows a schematic diagram of a cross-section of the lower part of the roof. As shown in the previous section, the damage to the roof and gutter is severe, and leakage of rain water through the roof occurred during rainy days and during the snow melt season. In the summer of 2010, Otaru city carried out temporary restoration work to cover the holes in the gutter. However, since this temporary restoration work was only done on limited areas, it was not a final solution to the problem of the leakage through the roof. In March 2011, the leaked rain water penetrated into rooms on the first floor. Some of the rain water and snow melt water that penetrated through the deck flows out from the eave ceiling, and the rest remains inside the deck and penetrates the stone walls, as indicated by the arrow in Fig. 9. It was considered that this leaked water penetrated into the stone wall. In winter, the surface stone was subjected to freeze and thaw cycles. Since the water content of the stone wall was high, ice lens segregated inside the stone wall, which resulted in severe damage to the surface stone wall [3]. We found cracks at the borders between places where water repellent material had penetrated and where it had not. This shows that the water repellent materials are not effective when water flows from inside of the stone wall.

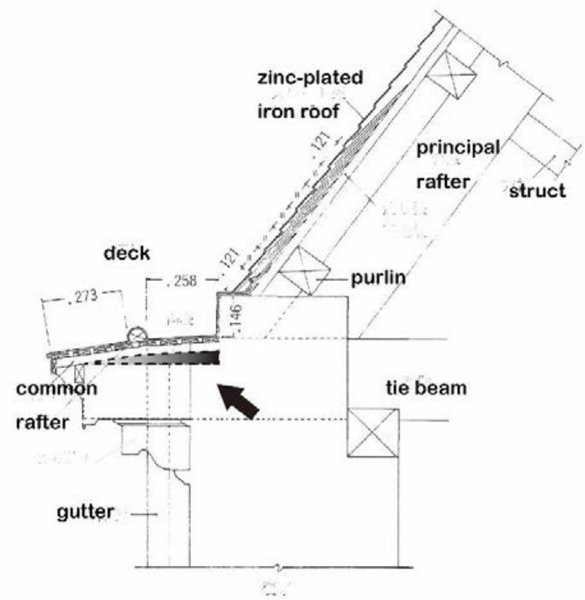

Fig. 9 Schematic diagram of a cross-section of the lower part of the roof.

5. Protective measures

The previous restoration was carried out about 30 years ago. In the restoration, water repellent materials were applied to the surface of the stone wall to prevent rain water penetration. However, as shown in the previous section, the rain water penetrated through the roof to the stone wall. In order to prevent this penetration of rain water, it is necessary to check the present condition of the roof and repair it and to increase the roof's water tightness. It has been reported that frost damage increases as the water content of the stone increases. Therefore, it is necessary to reduce the water content of the stone wall to prevent frost damage.

6. Conclusions

We studied the deterioration of historic buildings and their environmental conditions in Otaru and Sapporo city. Our observation of the historic *Nihon Yusen Building* revealed that the main cause of the deterioration of the stone wall of the building was frost damage. At the previous restoration carried out about 30 years ago, water repellent materials were applied to the stone wall to prevent rain water penetration. However, the water content of the stone wall increased due to the penetration of rain water through the roof. The stone wall was subjected to the freeze and thaw cycle and severely damaged. In order to prevent frost damage, it is necessary to reduce the water content of the stone wall by increasing water tightness of the roof of this building.

The restoration work of 30 years ago in which water repellent material was applied to the stone wall could be appropriate for preventing rain water penetration from the outside. However, this method was not appropriate when the water penetrated from inside the stone wall as shown in this paper.

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