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Snow Melting System Using Spring Water from Tunnel Construction in the Mountain Area of Japan

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ABSTRACT

Tunnels, which pass through underground and mountains are critical infrastructures for our modern social activities. During construction, spring water from tunnels flows out, which is drained without using in many cases. Kuriko tunnel which was constructed between the mountains area in Fukushima and Yamagata Prefecture for Tohoku Chuo Express Way by Ministry of Land and Infrastructure, and Transport and Tourism (MLIT) in Japan was opened on 4th, November 2017. Snow melting system using spring water from a tunnel was introduced to support safe and secure winter road traffic.

1. INTRODUCTION

A large part of Japan is subject to severe weather in winter. Currently, 20 % of the population in Japan, which is approximately 25 million people live in those regions of 230,000km2, which is about 60 % of the total area of Japan.

In 1957, the Act on special measures concerning maintenance of road traffic in specified snow coverage and cold districts was introduced in Japan, which enable the means to solve snow-related problems in these regions. However, traffic accidents and the isolation of cities due to heavy snowfall and icy roads remained serious problems.

In 1961, a new snow melting system was introduced in which groundwater was used, sprinkled from pipes installed on the roads directly over the snow for melting. This system became the primary snow melting technology especially in the Hokuriku region which is middle part of Japan and along the coast of the Japan Sea.

As this system use a large amount of groundwater and the water was not recharged, groundwater level dropped and land subsidence became a severe issue in the areas with the snow melting system. Hence, a new and better solution was needed and the snow melting system without sprinkling groundwater was developed.

2. SNOW MELTING SYSTEM WITHOUT SPRINKLING GROUNDWATER

This system melts snow and prevents road from freezing by heat radiation pipes installed under pavement, with groundwater as the heat source. Since it does not spray groundwater, it provides for smooth and convenient traffic. After using the heat energy, groundwater is recharged into the aquifer, so that it does not affect the water supply, nor does it causes land subsidence.

For example, in Yamagata City, in northern Japan, the temperature of 100 m depth groundwater is around 15℃, which is almost equal to the average annual air temperature. After the release the heat energy of groundwater, temperature of the road surface becomes 1℃, and it can melt snowfall and prevent freezing.

This system consists of a pumping well, heat radiation pipes, and recharge well. The pumping well extracts groundwater and pipes it to the heat radiation areas. Heat radiation pipes have installed under the pavement that transfers heat energy from groundwater. The heat energy of groundwater melts the snow and prevent roads from freezing. A reinjecting well is used, leading the groundwater back into the aquifer without contacting the atmosphere, shown in Figure 1.

2.1 Snow melting system using a ground source heat pump

Though snow melting system using groundwater became pervasive in Japan, it is not easy to get groundwater at mountainous areas and some towns have strict regulations concerned with groundwater pumping. So, snow melting system using ground source heat pump became an alternative solution.

This system uses circulation liquid instead of groundwater. The former transports the heat energy of ground source. The temperature of the circulation liquid must lower than groundwater, and ability of snowmelt must have the limit depend on the load for melting. Whenever more temperature is needed, heat pump is required to improve snow melting, illustrated in Figure 2.

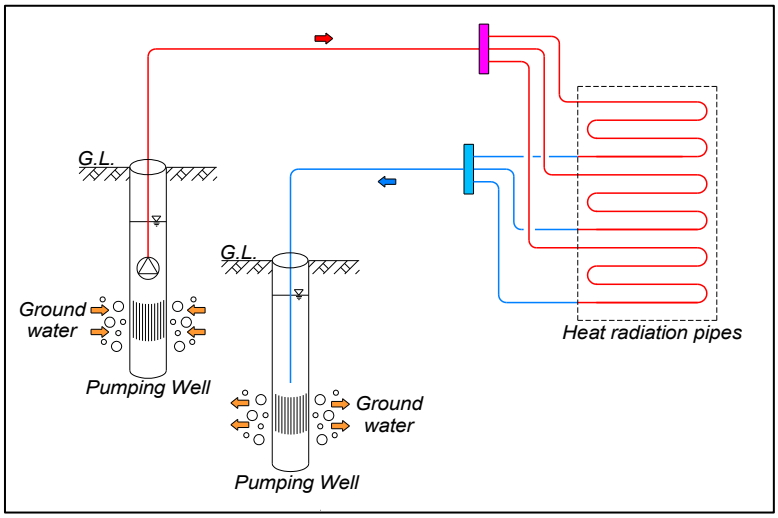

Figure 1: Flow of snow melting system without sprinkling groundwater.

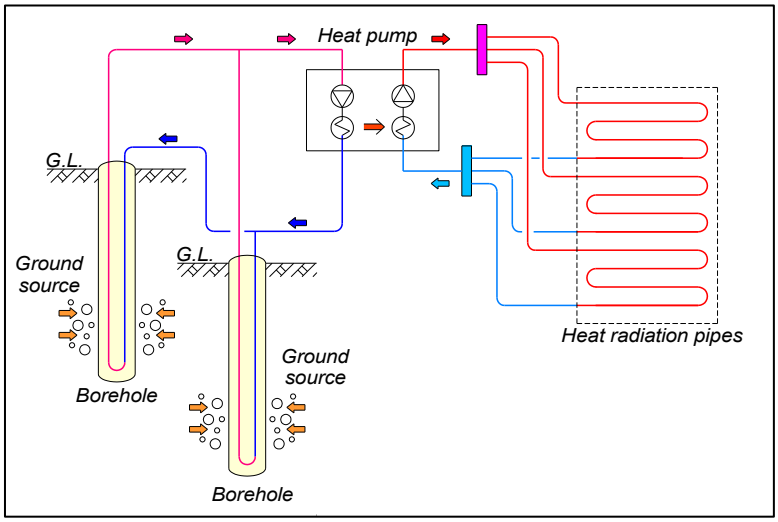

Figure 2: Flow of snow melting system using a ground source heat pump.

3. COMPARISION OF SNOW MELTING SYSTEM

There are various snow melting system being adopted in Japan, the largest one using groundwater installed more than 1.3 million m^2. The greatest feature of this system is its environmental friendliness, producing low carbon dioxide emissions when compared with the electric system and boiler which uses fossil fuel to melt snow. Advantages of snow melting system using groundwater are energy savings, low running costs because heat source required is only groundwater, listed in Table 1 and 2.

Comparison of the costs of snow melting systems are shown below: (Table 1)

	INICIAL COST (JPY/m^2)	RUNNING COST (JPY/m^2)
USING GROUNDWATER	70,000	600
USING GROUNDWATER HEAT PUMP	90,000	1,000
USING GROUND SOURCE HEAT PUMP	170,000	1,200
USING AIR SOURCE HEAT PUMP	90,000	1,400
USING ELECTRICITY	60,000	3,000
USING KEROSENE BOILER	70,000	2,500
REVIEW CONDITIONS : HEAT REQUIREMENT = 170W/m^2 SNOW MELTING AREA = 1,500m^2		

Table 1: Comparison of the costs of the snow melting systems

Comparison of 15 years total cost and CO2 emissions of each snow melting systems are as follows; (Table 2)

	OPERATING HOURS (h)	POWER CONSUMPTION (kW)	AMOUNTS OF FUEL (L)	15 YEARS (t-CO2)	15 YEARS TOTAL COST (JPY/m²)
USING GROUND WATER	1,000	18.5	NONE	145	79,000
USING GROUNDWATER HP	700	57.0	NONE	309	105,000
USING GROUND SOURCE HP	700	78.0	NONE	424	188,000
USING AIR SOURCE HP	800	97.0	NONE	604	111,000
USING ELECTRICITY	700	300.0	NONE	1,641	105,000
USING KEROSENE BOILER	700	14.0	24,000	896	108,000
OPERATION HOURS : USING GROUNDWATER → 700 hours (Snow melting operation) + 300 hours (anti freezing operation) = 1,000 hours USING ELECTRICITY → 700 hours (Snow melting operation) + 100 hours (defrosting operation) = 800 hours					

Table 2: Comparison of the 15 years total cost and CO2 emissions of each snow melting systems

4. SNOW MELTING SYSTEM USING SPRING WATER FROM TUNNEL CONSTRUCTION AT THE MOUNTAIN AREA IN JAPAN

In the vicinity of the outlet of the Kuriko tunnel between Fukushima-Ozasou Interchange and Yonezawa-Kita Interchange of Tohoku Chuo Express Way, which was opened on the 4th, November 2017, snow melting system using the heat energy of spring water from tunnel construction was introduced to support the safe and secure winter road traffic. The section is going to illustrate the features of the snow melting system (Figure 3).

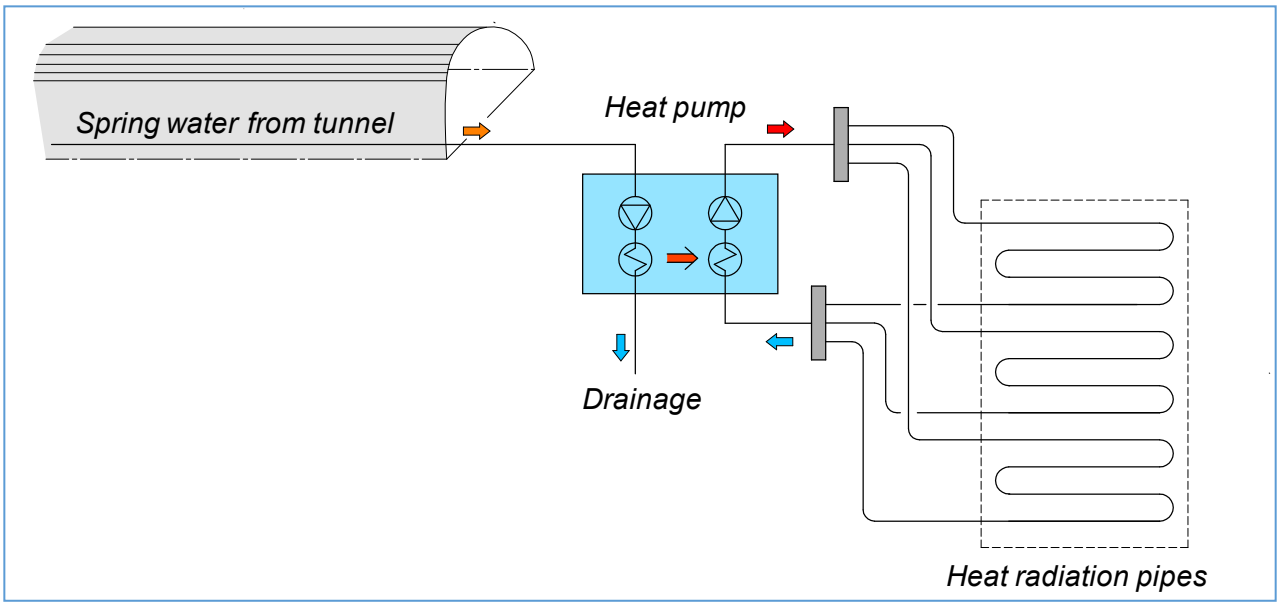

Figure 3: Flow of snow melting system using spring water from the tunnel

4.1 Effective use of abundant spring water from tunnel construction

Tohoku Chuo Express Way between Fukushima-Ozasou Interchange and Yonezawa-Kita Interchange is the high standard road connecting Fukushima –City to Yonezawa-City. Length of this section is 35.6km. This project was controlled by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in Japan (Figure 4).

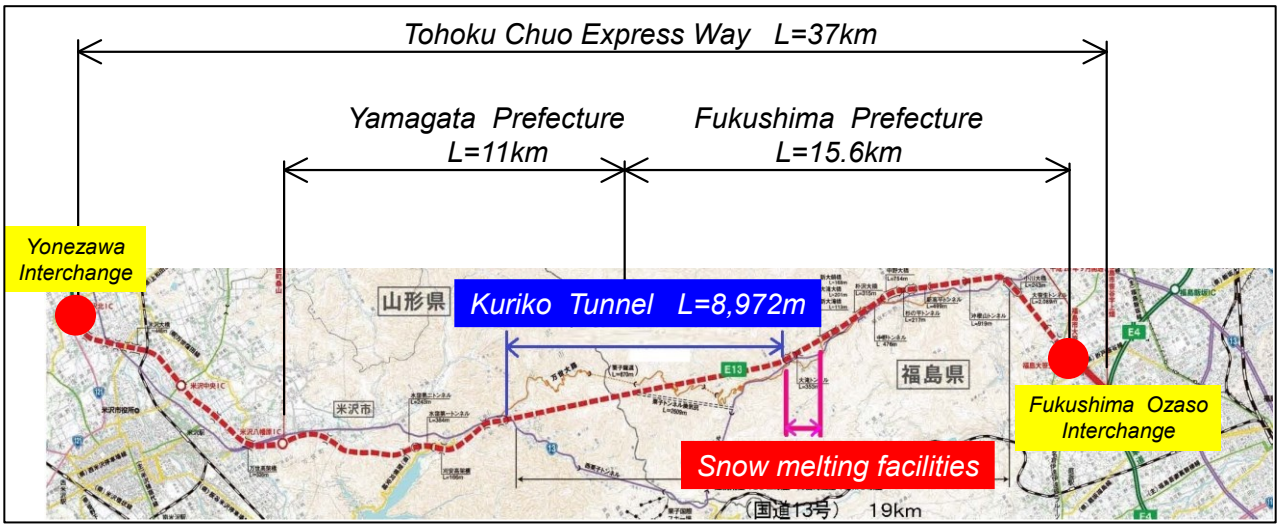

Figure 4: Overview of Tohoku Chuo Express Way.

National route 13 was used as the transportation pathway between Fukushima and Yonezawa before the highway was constructed, which passes through the border and mountainous area of Fukushima and Yamagata prefecture. Because the maximum slope was 6% and the steep curve continued, 130 vehicles were shut down during the winter period annually, and traffic stoppage occurring four times in a year is average; because of the heavy snowfall and the cold temperature (Figure 5).

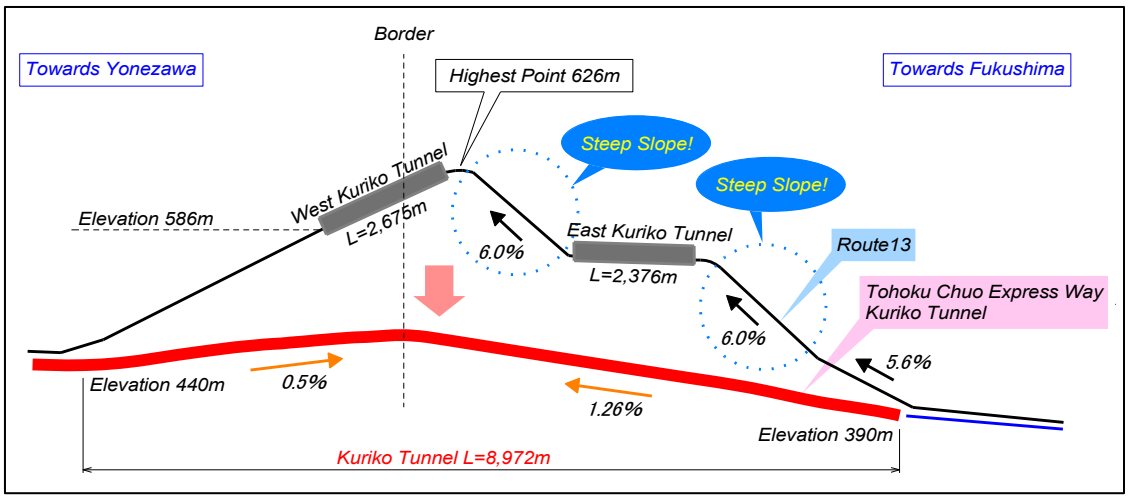

Figure 5: Sectional plan of Tohoku Chuo Express Way.

A solution to solve the problems in winter, Kuriko tunnel was constructed by MLIT. The total length of this tunnel is 8972m, the maximum slope is 1.26%, and snow melting facilities was installed successfully even there were problems such as snowfall and freezing.

After the construction, 10,000m^3/min of spring water comes out from the Fukushima side, and the temperature of spring water was 15°C. As a result of investigation, MLIT decided to use spring water as a heat source for snow melting facilities.

MLIT used to make use spring water directly for melted snow, but the weather condition of this area is very severe. So, MLIT decided to use heat pump for heating to increase the temperature of antifreeze liquid, and finally snow melting system with spring water with heat pump has introduced the section to the Otaki chain basement and right in front of the Shin Otaki bridge towards Fukushima City.

4.1.1 Outline of the snow melting facilities

The snow melting facility is divided into two sections. One section amounting to 2,970m^2 has installed a heat pump using 546kW of heating capacity, and another section of 2,970m^2 has installed a heat pump using 548kW of heating capacity. These heat pump recovers the heat from spring water and melts the snow by sending an antifreeze liquid. The temperature of the liquid becomes 19℃. This system is controlled by a snow sensor operated in accordance with air temperature and road surface conditions (Figure 6).

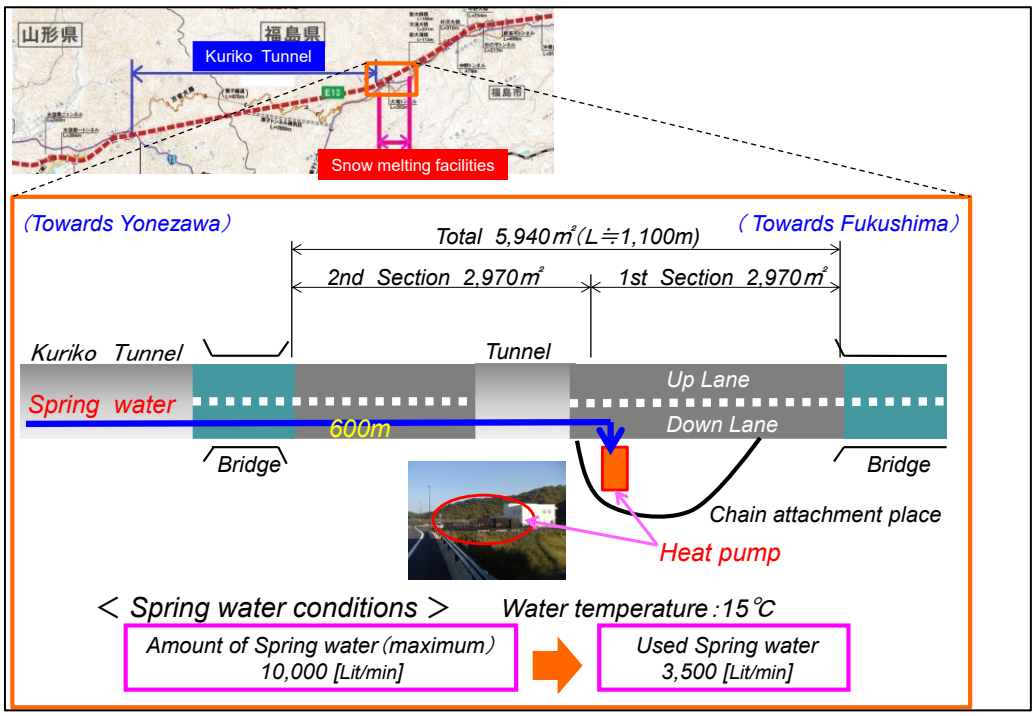

Figure 6: Outline of snow melting facilities.

5. CONCLUSION

Snow melting facilities installed in Tohoku Chuo Express Way has already experienced winter in two years, and these facilities support smooth and safe traffic. MLIT refers to the possibility of adopting the same method in the future if there any points where there are taking into consideration the conditions such are spring water quantity and cost-effectiveness. Snow melting system using spring water also draw the attention of other regions that suffer from snow problem (Picture 1 & 2).

Picture 1: During construction

Picture 2: Snow melting operation in January 2018

According to the "Long-term outlook for National Land" announced by the MLIT in February 2011, Japan has already reached its peak population in 2004 at approximately 127.48 million people. The population is expected to decline rapidly in the near future, declining to an estimated population of 115 million people by 2030.

Although the aging rate in 2004 was 19.6%, it will be 31.8 % in 2030, which is an acceleration of the aging society. Problems stemmed from cold and snowy regions will need attention.

In recent years, snow melting facilities of the road are becoming more sophisticated from just being safe, convenient, and comfortable for users. In order to solve problems in winter along with functioning in a user-friendly and environmental-friendlyway; it is vitally important to plan and construct the snow melting facilities in Japan, not individually, but in an integrated manner for unification.

In order to maintain a safe and secure winter life in cold and snowy regions, snow melting facilities are one of the solutions to increase a simpler lifestyle. Nonetheless, it is necessary to reduce the initial and management costs of the facilities and to reduce the CO2 emission. Using groundwater and ground source for heat energy to melt snow, as illustrated, is to be one of the most beneficial solutions.