ROAD HEATING USING NATURAL ENERGY

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Abstract

The Koriyama National Highway Work Office, Tohoku Regional Bureau, Ministry of Land, Infrastructure and Transport is making various efforts for environmentally friendly road management. Eco-Road, a road development project on National Highway 289 in Fukushima Prefecture between Iwaki City and Nishi-Shirakawa Gun is one of these efforts. Other examples on National Highway 49 are a road-heating system that uses electricity generated by wind-power generator which is installed at the entrance of Nakayama Tunnel, and a road heating system that uses lake water as a heat source and is scheduled to be installed at the Nagurayama snowshed.

National Highway 49 is a 245.6 km arterial road that extends from Iwaki City in Fukushima Prefecture to Niigata City, connecting the Pacific Ocean side of Honshu to the Japan Sea side. 85 % of the highway runs through cold, snowy regions, and winter-road maintenance including snow removal needs to be conducted on most of the road to secure winter-traffic safety.

Nakayama Tunnel at the boundary of Koriyama City and Inawashiro-cho, suffers the most serious visibility deterioration at its both entrances due to blowing snow and road-surface freezing, both of which result from its high location and strong seasonal winds. Solutions to these issues are required, to secure traffic safety in winter.

The highway section around the Nagurayama snowshed also was traffic-accident prone in winter. The highway section is characterized by high location, snowiness, a series of curves by Lake Inawashiro, shady geography, and no blockage against strong seasonal winds. These result in road surface freezing that is likely to cause vehicle skidding accidents.

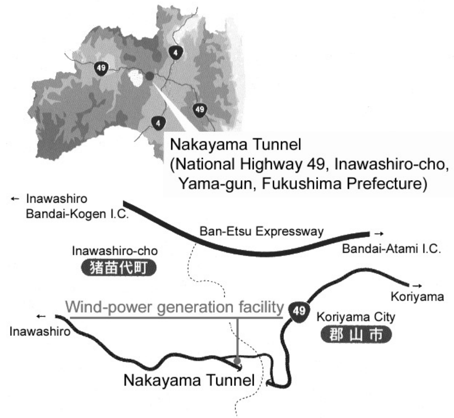

Figure 1 Location of the wind-power generator at Nakayama Tunnel

Photo 1 Site of the wind-power turbine generator

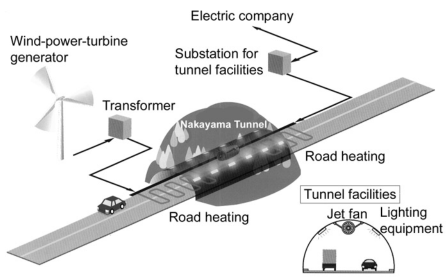

Figure 2 Outline of the wind-power generation system

Introduction

As countermeasures to these issues, the Koriyama National Highway Work Office developed road heating systems that use natural energy.

This paper reports the outline, performance and development process of the road heating systems.

I 1. Outline of the wind power generation facility for road heating at Nakayama Tunnel

The wind power generation facility supplies electricity in winter mainly to the road-heating system at the entrances to the tunnel. During summer and other seasons that do not need road snow melting, the electricity generated by the facility is used to manage systems of Nakayama Tunnel such as a jet fan and lighting equipment. The surplus electricity is sold to an electric company. The wind-power turbine generator's rated output is 250 kW (three-blade propeller type made in Germany).

The energy generated by the wind-power turbine generator depends on the wind force, so the snow-melting system needs to be designed to avoid influences of unstable electricity supply. For instance, the snow-melting system needs to be designed such that it can keep working, even when the wind turbine generator stops. To identify the most effective snow-melting system, on-site performance tests were conducted.

Snow-melting performance and snow-melting continuity of two types of road-heating system, an electric heating-wire system and a heat accumulation system were tested. Although the tests identified the heat-accumulation system was superior to the electric heating wire system, the electric wire system was adopted because of the lower costs and shorter installation time. The road is a main trunk road with daily traffic of 15,000 vehicles, so it was difficult to install the system by blocking the traffic on one of the two lanes for long time. For a newly constructed road, adoption of the heat-accumulation system might be an possible option, and close examination would be required to determine which system would be more appropriate.

(1) Road section where the road-heating system was installed

Inside the tunnel, the road-heating system was installed on, 120 m of the lane bound for Iwaki City and 100 m of the lane bound for Niigata City from the Inawashiro side entrance. The road-heating system was installed also on the road outside the tunnel . Its coverage area was determined by referring to the cost and the area of previous works.

(2) Control system

The road-heating system was divided into several sections so as to make it possible to change the number of working sections depending on the available power generation output.

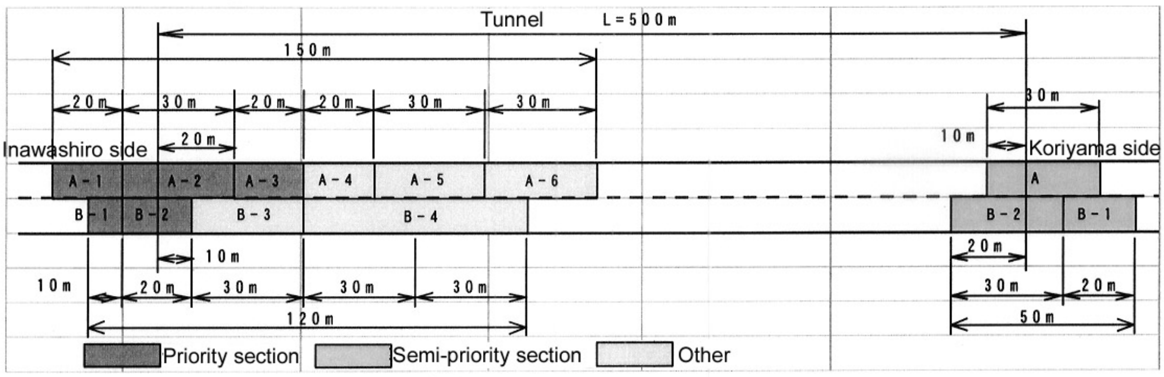

Figure 3 Road-heating control system by dividing the road into sections

(3) Electric heating-wire road-heating system

This type of road-heating system has been in conventional use. However, there were few examples of the road-heating system being installed on a national highway keeping trafficability during the installation work. To install the system, the heating cable was chosen by considering its ease of installation. The heating element is either electric wire (cupper - nickel alloy) which has been conventionally used or fiber (heating fiber). In this project, fiber was used for the section at the Inawashiro-side entrance and the electric wire was used for the section at the Koriyama-side entrance.

(4) Pavement structure for the road-heating system

1) Intermediate layer (protective layer)

In general, a protective layer needs to be installed to protect the heating cable and to facilitate the installation of the surface layer. For the protective layer pavement, asphalt mixture with less aggregate was used to prevent fracture of the heating cable coating. The protective layer is typically 30 to 40 mm thick. The asphalt mixture for the protective layer was As13T, recycled dense-graded asphalt for Traffic C (a Japanese standard of traffic volume: daily traffic volume of 1000 to 3,000 vehicles) because it is unlikely to cause pavement flow which effects the surface pavement and its heat resistance is relatively great. Its thickness was 40 mm, which was verified by tests to be appropriate.

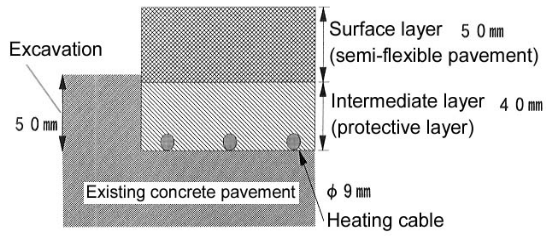

Figure 4 Pavement Structure

2) Surface layer (semi-flexible pavement)

Semi-flexible pavement was installed as the surface layer because of its ease of in-tunnel installation. The semi-flexible pavement consists of open-graded asphalt concrete with high void ratio, into which cement paste was infiltrated. In this work, after surface layer installation, the road section's exposure to traffic for three to four days was required before the concrete paste infiltration into the surface-layer. Therefore, a test was conducted to identify the change of the void ratio of the surface layer pavement depending the number of the days exposure to traffic before the concrete paste infiltration. The test specimens were two type of open graded asphalt: developed Type II asphalt (mixed with thermoplastic elastomer and rubber) and high-viscosity asphalt. A wheel tracking test machine was rotated on the track where the test specimen was set. Its number of rotations was set to produce cumulative load equivalent to the expected number of large vehicles passing the road during the pavement work. The air temperature of the testing room was kept at 20℃, supposedly the same temperature as that when the work would be conducted. After the test, the void ratio of the vertical section of the specimen where the wheel tracked was measured. The void ratio decrease rate of the high-viscosity asphalt was smaller than that of developed Type II asphalt, so that the high viscosity asphalt was used for the surface layer pavement.

3) Installation

Road-heating system installation was conducted alternately on each of two lanes during the night. Each lane was open to traffic after installation. Works in a series from installation of the road-heating system to installation of the surface pavement were conducted on each road section, with the sections divided up to allow continuous work operation. Concrete paste was infiltrated into the pavement by setting 30 m road section as a work unit. This was the shortest road length possible for concrete paste infiltration. The concrete paste was the quick-drying type.

2. Status of the wind-power turbine generator and electricity consumption of the road-heating system

Operational status of the wind-power-turbine generator and electricity consumption of the road-heating system for two years after their installation follow.

(1) Electric power generated by the on-site generator, the surplus electricity sold to an electric company, and electricity purchased for the road-heating system (from 1 April 1999 to 31 March 2001)

Table 1

Item	Power generation (unit: 10,000 Kw/year)		Fee (unit: 1,000 yen/year)		Notes
	2000	1999	2000	1999	
Total electric power generated on site	41.6	36.3	6, 200	5, 500	
Electricity bought fromTohoku Electric Power Co., Inc.	22.8	21.4	3, 400	3, 200	
Electricity consumed by the tunnel management facilities	26.4	21.9	3, 900	3, 200	
Electricity consumed by the road-heating system	17.2	15.8	2, 600	2, 500	From Dec. to Mar.
Surplus electricity sold to Tohoku Electric Power Co., Inc.	20.8	20.0	3, 100	3, 000	

Note: Figure 5 shows that on-site power generation increased when the road-heating system was in use.

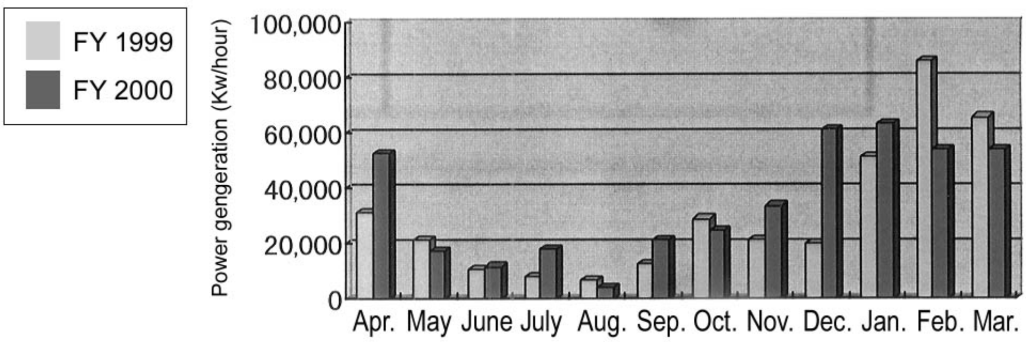

Figure 5 Change in the on-site power generation.

(2) Power supply and power consumption of the tunnel facilities

Table 1 shows that the wind-power-turbine generator generated enough power to supply most of the electricity consumed by the road-heating system, road lighting equipment, and air conditioning facilities of the tunnel. It was indicated by the fact that almost the same amount of power as that purchased from the electric company was sold to the electric company (Table 1). The power generation system effectively reduced the operating cost of the tunnel facilities.

(3) Advantages of wind-power generation for the road-heating system

In comparison of power supply and power consumption by month, power consumption of the road-heating system increased from February 2 to March 3, 2000, and the power generation increased in correlation with the power consumption. During the coldest period, the road-heating system frequently worked. Power generation increased concurrently due to strong winds resulting from the winter weather systems that commonly appeared. The weather that demanded full operation of the road-heating system was almost the same as that which enabled the wind-power turbine to work. This suggests that the location is suitable for installation of road-heating system operated by electricity generated by wind-power-turbine generator.

(4) Snow-melting status

As shown by Photo 2 and Photo 3, the road-heating system worked effectively to melt snow at each entrance to Nakayama Tunnel. However the snow at the Inawashiro-side entrance in the west, was not always completely melted because the west entrance is colder than the Koriyama-side entrance.

In addition to severe and highly changeable weather conditions around Nakayama Tunnel resulting from the tunnel's location at a mountain pass, seasonal winds blowing from the west into the tunnel make the Inawashiro side the colder of the two sides. Thus, the road-heating system has sometimes faced difficulty in melting snow on the Inawashiro-side road section.

Photo 2 Snow-melting at the Koriyama-side entrance

Photo 3 Snow-melting at the Inawashiro-side entrance

(5) Road-surface temperature at Nakayama Tunnel

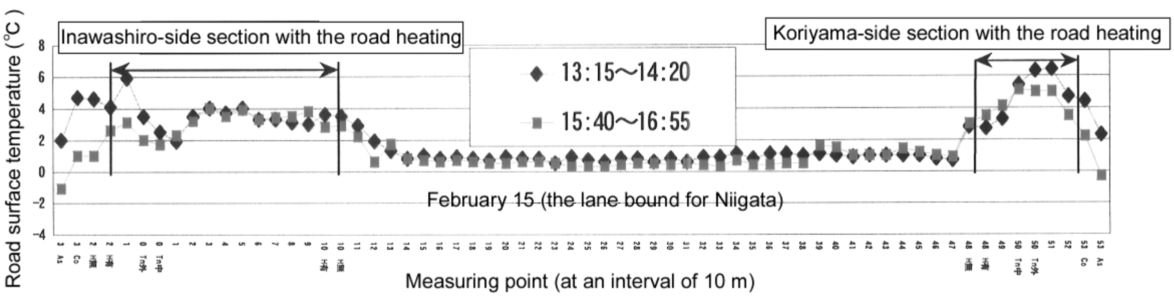

Figure 6 Change of the road-surface temperature inside and outside Nakayama Tunnel

Issues to be solved in the future

1) Snow-melting of the section without road heating.
   Melt water produced by the road heating sometimes is brought by vehicles into the tunnel and freezes.
2) Securing a power source for road heating when the wind is not strong enough to yield sufficient power.
3) Unstable road-heating performance due to highly changeable weather
4) Wind and snow blowing into the tunnel.

After installation of the road-heating system, issues requiring solution were identified. The weather that may cause the above problematic conditions is not frequent. However, systems and measures to achieve more effective operation need to be developed, because Nakayama Tunnel plays an important role in connecting the Tokyo metropolitan area to Aizuwakamatsu City to the north and not a few drivers from the Tokyo area fail to become accustomed to driving on a snowy road.

(6) Carbon dioxide mitigation

In comparison of the amount of carbon dioxide generated by road heating with wind-generated electricity to that generated by road heating with commercial electricity, the former is estimated to be one-fifth the latter (based on actual operation data).

Ⅱ. Outline of road heating by lake water heat

This system uses water heat of a lake absorbed by heat exchange between an antifreeze solution circulating in polyethylene heat-exchange spiral coils submerged in the lake and the lake water. The water heat absorbed into the heat exchange coil is sent to a heat pump to be utilized for road heating. The heat pump consists of a vaporizer, a compressor, a condenser, and an expansion valve. The heat within the heat pump is transmitted by a refrigeration medium.

The features of this system follow:

1) It is environmentally friendly: Use of lake water avoids the ground subsidence caused by pumping up ground water, and it does not generate carbon dioxide because the heat to melt snow is obtained without burning fossil fuels.
2) The operating cost including that for heat pump operation is one-third that of a road-heating system using electric heating wire, because the energy source is natural lake water heat.
3) Use of water from a lake or a reservoir near the site affords lower facility installation cost compared to the use of ground water.
4) Both the heat exchange pump and the heat pump are largely free of problems such as accretion of impurities to the inside of the pump or pump erosion, because the antifreeze fluid for heat exchange is enclosed in the pumps.
5) Stable heat supply is possible because the temperature of the water at the bottom of a lake or a reservoir is constant, however much the air temperature may drop.

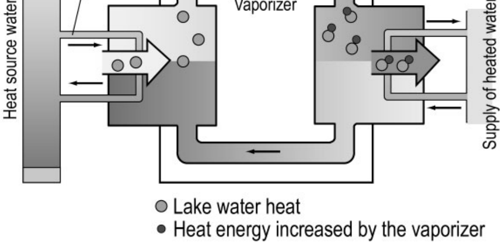

Figure 9 Heat-pump operation system (mechanism of raising temperature of heat source water to be used for road heating)

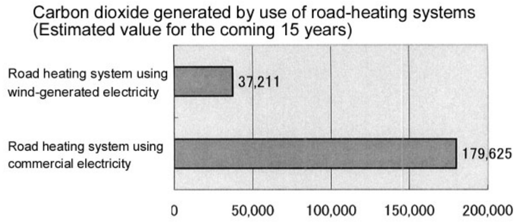

Figure 7 Carbon dioxide generation reduction of the wind-power road-heating system

Photo 4 Nagurayama snowshed

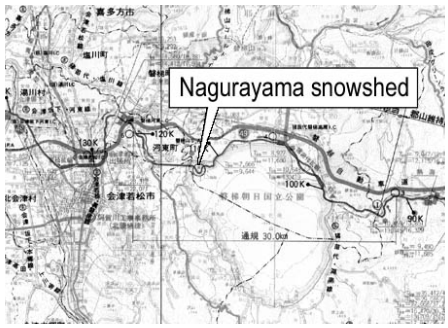

Figure 8 Lake water heat distribution map

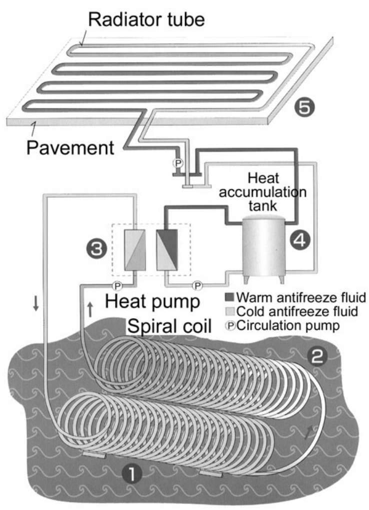

Figure 10 Outline of the road-heating system using lake-water heat

(1) Observation of the change of the lake-water temperature and the weather

The temperature of the lake water, the most important condition for practical application of the road-heating system, was measured from mid December 1999 to March 2000. The weather conditions also were observed during the same period. During this period, the air temperature around the Nagurayama snowshed at 6 a.m., the coldest time of day, was below zero almost every day other than in early January, although there were slight fluctuations in temperature.

Despite great changes in air temperature as a result of changes in daylight hours, the lake water temperature remained constant. The water temperature of Lake Inawashiro, which does not freeze, varied between 2℃ and 6℃.

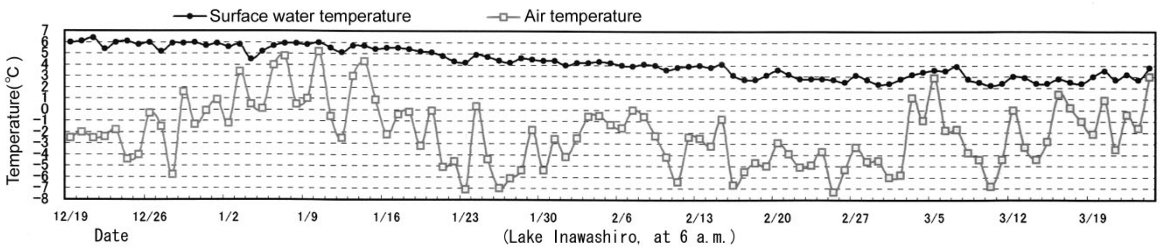

Figure 11 Daily change of the lake water temperature and the air temperature (at 6 a.m.)

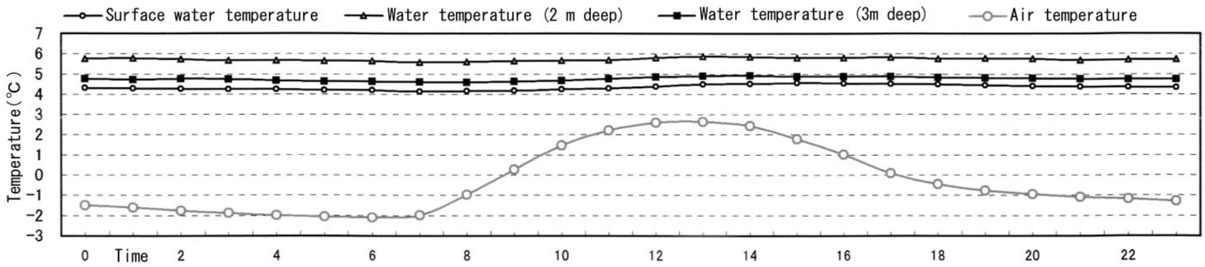

Figure 12 Daily fluctuation in lake water temperature and air temperature

(2) Outline of the performance test

To identify snow-melting performance of the road-heating system, a spiral coil for absorbing the lake water heat was submerged about 70 m off the coast of Lake Inawashiro and a section of test pavement embedded with radiator tubes was placed by the national highway.

Three units of spiral coil, each 100 m long, were used. The heat pump was of the 2.2kW class. The system was operated under these conditions: temperature of the heat accumulation tank was 25℃ and the pavement surface temperature was 2℃ when the system operation started. During the performance test, water temperature around the spiral coil, the surface and inner temperature of the pavement, and the snow depth on the pavement without the heating system also were measured.

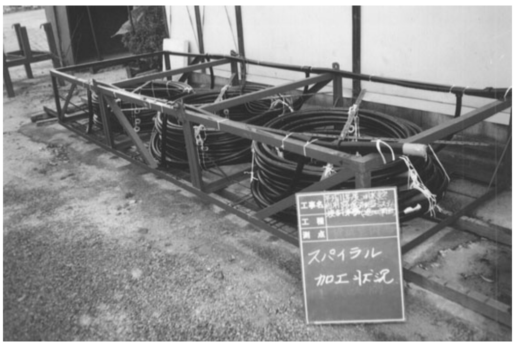

Photo 5 Heat exchange spiral coil

Photo 6 Test pavement

(3) Results of the performance test

Although the weather conditions during the performance test were sometimes strong winds and snowfall for a few days, the pavement surface temperature was kept at 6 to 8 ℃ and most of the snow was melted throughout the test period.

The mean thermal output of the road-heating system averaged 280W/m^2. The mean lake water heat was 210W/m^2. This indicates that 75% of the heat used to melt snow was from the lake water.

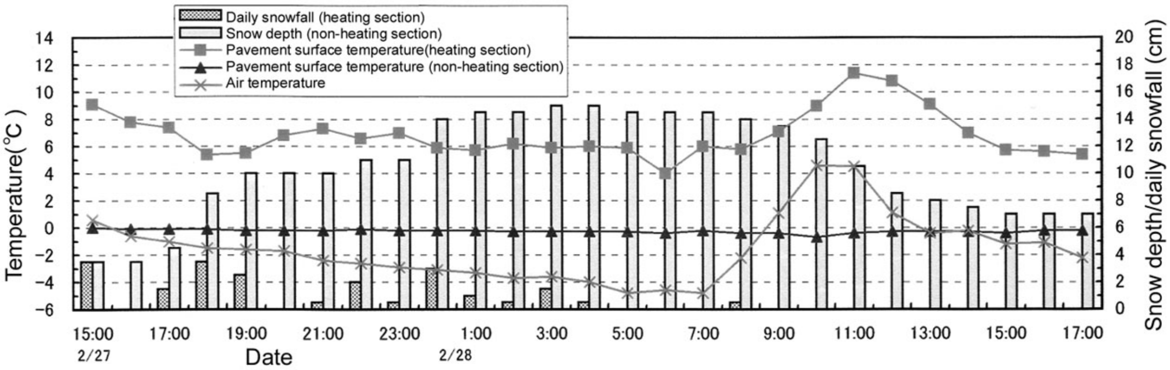

Figure 13 Change of the pavement surface temperature

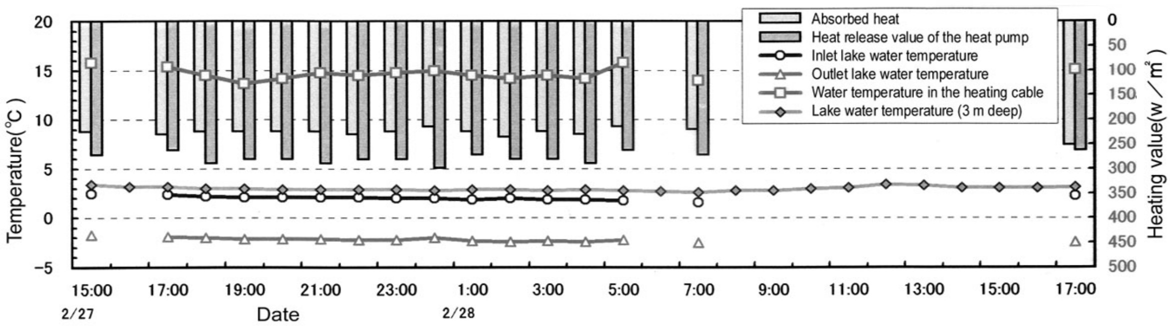

Figure 14 Change of the heat absorption value and the heat release value

Figure 12 and Figure 13 show the pavement surface temperature, the heat absorption value and the heat release value from February 27 to 28. When the road area for the snow-melting is 1, 500 m^2, the initial cost for the road-heating system using lake water heat comes to 80, 000 yen/ m^2, 1.5 times more than that for electric road heating system.

The annual maintenance cost of the former, including the expense for electricity, is 1, 000 yen/ m^2, or 40 % of the latter, so the cumulative cost of the former will be lower than that of the latter from the fifteenth year.

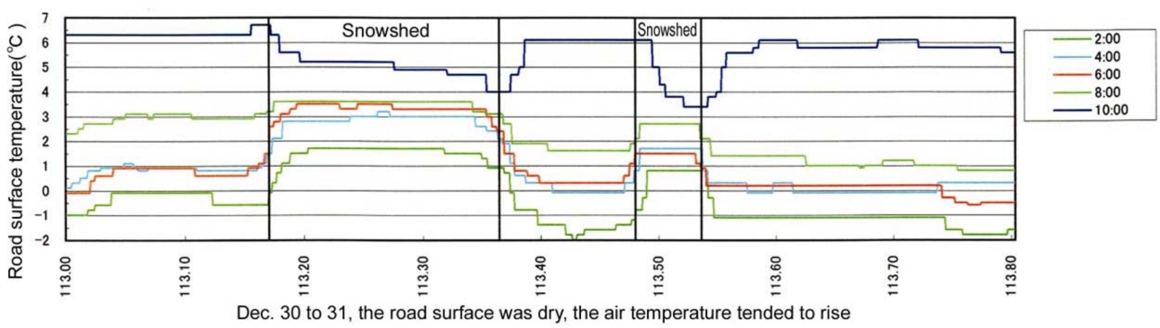

Figure 15 Road-surface temperature over time

(4) Snow-melting range

Thermal mapping was conducted by infrared emission thermometer to identify the temperature variation of the road surface inside and outside the snowshed.

Thermal mapping indicated that the temperature inside the snowshed stayed low because the snowshed blocked sunshine. Once the road surface freezes due to low temperature, it does not melt even if the weather recovers, and the road surface condition difference inside and outside the snowshed results in dangerous road condition. The presence at Nagurayama of two snowsheds near each other increases the danger that results when rapid weather changes produce variation in road surface conditions within the short section of the two sheds. The snow-melting road section included that under and between the two snowsheds to keep the road as safe as other sections.

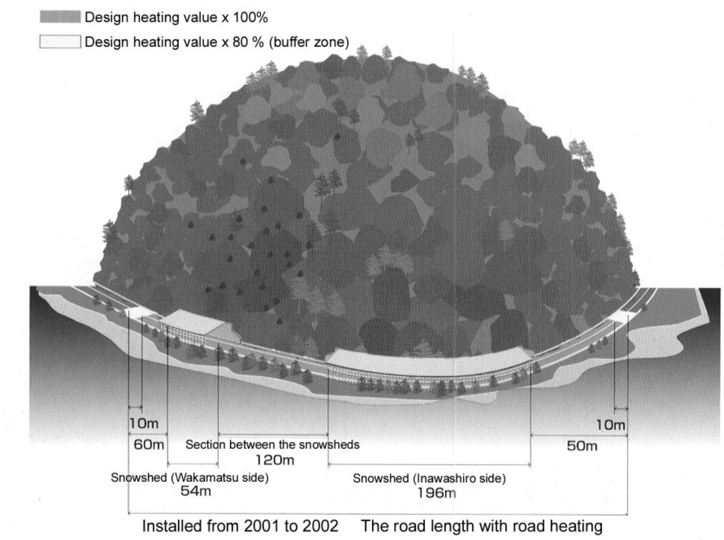

Figure 16 Plan view of the section installed with road heating

Conclusion

Development of the road facilities demanded by road users is undoubtedly the vital mission of road administrators. Effective road maintenance measures suitable for various road conditions including improvement of snow-removal level for roads and automatic spreading of snow-melting agents are being sought. To implement the measures, they need to be comprehensively examined by taking into consideration issues such as environmental friendliness and cost effectiveness.

The two examples introduced in this paper are solutions to frequent traffic accidents caused by road-surface freezing. The two types of road-heating systems were environmentally friendly countermeasures to this problem. They use on-site natural advantages of strong seasonal winds and the water of Lake Inawashiro, which is in a national park.

Road-heating by wind generated electricity was ordered as a public work on the basis of value engineering. The road heating system using lake water heat was discussed by the Board for Examination of Road Heating by Lake Water Heat. In determination of these projects, technologies of private companies were compared and experts' advice was asked.

We road administrators will keep seeking road facility development that uses natural energy on site.

Lastly, we would like to extend our deep appreciation for the efforts of the many people involved in the projects from their design to installation.