SNOW-MELTING AND DE-ICING SYSTEM ON ROAD USING NATURAL THERMAL ENERGY SOURCES

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1. Introduction

Snow-melting systems using groundwater have been in common use in the Hokuriku and Tohoku districts in Japan. Their overuse has caused ground subsidence. In view of energy saving or environmental conservation, new snow-melting systems using less groundwater and alternative ones using natural thermal energy sources other than groundwater are in demand.

2. Saving groundwater used for snow-melting [1)]

We melted snow experimentally with various types of equipment including metal or polyethylene heat dissipation pipes. We used high or low thermal conductivity of the pavement, changing the temperature and the velocity of the water flowing through the heat dissipation pipe. In every case, the water temperature measured at the outlet of the dissipation pipe was within 1℃ of the one calculated by considering the thermal resistance between snow cover and flowing water. Both results show that water at 8℃ flowing through a metal pipe embedded 3cm deep and spaced 10cm apart as in fig.1 in a concrete pavement of a silica aggregate whose conductivity was 6W/mK - three times that of a regular aggregate - is sufficient to melt snow at a speed of 200W/㎡.

Most snow-melting systems had been controlled by snowfall sensors. In order to save

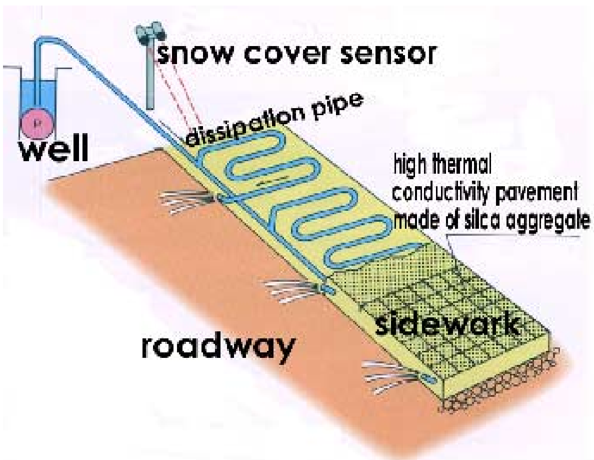

Fig.1 Outline of cascade SMS using underground water

Fig.2 Snow cover sensor controlling SMS

Fig.3 View of a cascade SMS using underground water in Fukui City

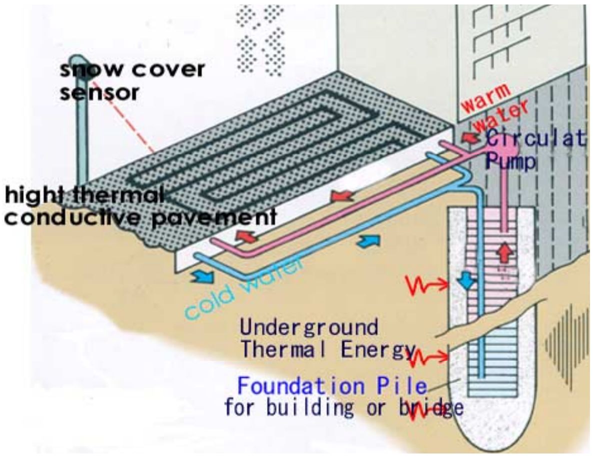

Fig.4 Outline of SMS using underground thermal energy collected by foundation piles

running time and energy, a new sensor monitoring snow cover on the pavement was developed in 1987. The snow cover sensor shown in fig.2, which rotates to scan the road surface from the center to the side, controls the snow-melting equipment that sprinkles groundwater directly on the roadway. These particular snow-melting systems controlled by the snow cover sensor usually run only intermittently, but continued to run after the end of a heavy snowfall. As a result, the snow cover sensor reduced the running time by a third without any trouble for one winter season. In the daytime it reduced the running time by a seventh. Such snow cover sensors have been in practical use for “water saving” reasons in Fukui, Niigata, Ishikawa Prefectures and among others.

In order to save groundwater, a snow-melting system shown in fig.1 was developed by combining the three elements described previously: (1) Snow on a sidewalk was melted by flowing groundwater through heat dissipation pipes in the pavement, and then snow on the roadway was melted by sprinkling used water from these pipes. This method is called "heat cascading". (2) Precast concrete panels that embedded a heat dissipation pipe and had high thermal conductivity of silica aggregate were placed in the sidewalk. The concrete panels were designed to be easily removed to allow others to dig the ground beneath them. (3) This snow-melting system was controlled by the snow cover sensor monitoring the snow-melting panels.

Though snowfall sensors sometimes had a delayed start, the new snow cover sensors controlled the system without any trouble, because its concrete cover was thinner.

Elements of this system have spread from Fukui to Ishikawa, Toyama and Yamagata Prefectures.

3.Snow-melting system using underground thermal energy collected by foundation piles

A new snow-melting system with circulating water shown in fig.4 where underground thermal energy is collected by foundation piles has been developed[2,3]. By a circulation pump, cold water from the dissipation pipes flows to the bottom of each pile through a polyethylene pipe in the foundation piles. Then the water flows through the hollow of the pile to its head, collecting underground thermal energy. After that, the water, now warm, flows

Fig.5 Snow melting condition in the test area

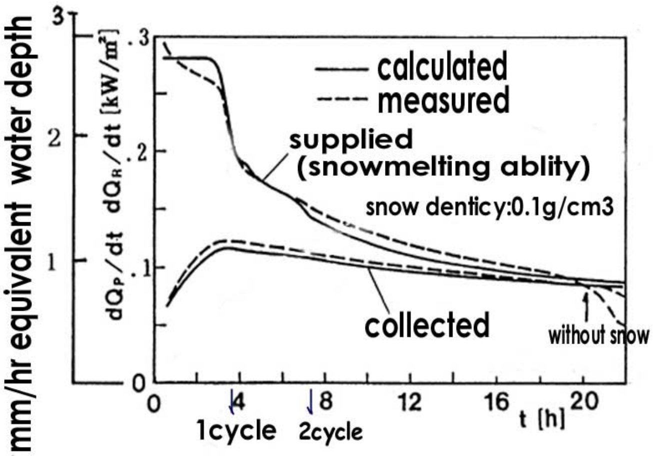

Fig.6 Change in the snow-melting capacity

Fig.7 Effect of thermal resistance between circulating water and road surface

Fig.8 Snow melting condition in the hardest snowfall for 5years

through the dissipation pipe, melting the snow on the pavement.

In the experiment, a snow covered concrete-surfaced test section of 20.8m^2 area was melted by the thermal output from two concrete piles of 0.31m inner diameter and 22m length. Heat dissipation pipes were burred in 3cm concrete cover made of silica aggregate. It was demonstrated that this snow-melting system operated effectively for intermittent snow-falls in Fukui City. The test area was kept snow free during the experimental period (Jan.-Mar.1991) when Fukui had an accumulated snowfall depth of 187cm and a maximum thickness of snow cover of 60cm. Fig.5 shows that this system had excellent snow-melting capacity.

A numerical simulation was also designed to evaluate the system, where the piles and the heat dissipation pipes buried in the concrete-surfaced area section were treated as a connected system. The thermal output from a pile and the amount of heat collected from the surrounding soils were calculated. Fig.6 shows that the snow-melting capacity decreased after the first water circulation cycle, but that the snow-melting capacity hardly decreased after that because it balanced with the amount of heat value collected from the surrounding soils. Its effectiveness depends on the ratio of the surface area to the number of piles, the length and

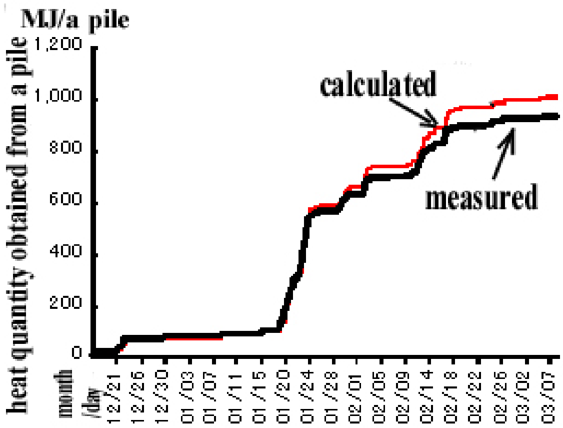

Fig.9 Heat quantity obtained from a pile

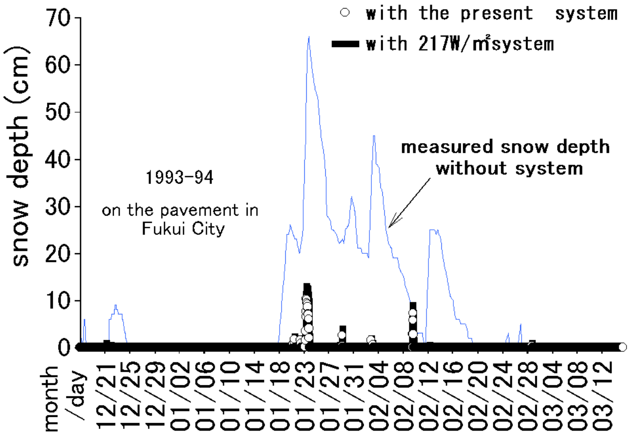

Fig.10 Result of snow melting simulation


Fig.11 View of a parking lot without SMS

Fig.12 Works at a building pile

diameter of the piles, the material and diameter of the dissipation pipe, the thermal conductivity of pavement, the depth of the dissipation pipe, the underground temperature and so on. Furthermore, the calculated results agreed well with the experimental ones (Fig.6). Snow on the area shown with the arrow in fig.7 was not melted because the dissipation pipes of the area were laid 8cm under the pavement whose thermal conductivity was not as good. It is important to make thermal resistance between flowing water and road surface small.

When the snow-melting capacity was higher, the sensor shown in fig.8 operated circulation pump intermittently. When lower, the sensor operated the circulation pump continuously after snowfalls until the snow on the pavement was melted. Thus this system operated without any trouble, though its capacity changed as it was running.

This system has been in practical use in places such as parking lots. For example, in a snow-melting area of 400m^2 where 45 piles of 0.27m inner diameter and 35m length and one 2.2kW circulation pump were used, the depth of snow was kept at less than 6cm for 5 seasons even through the depth of snow was kept as much as 66cm depth in the surrounding areas.

Fig.9 shows that the measured heat quantity obtained from one building pile agrees well with the result calculated by the numerical simulation for one season. Fig.10 shows the snow depth with the new system, with a 217W/m^2 system and without any system at all, for the season. In fig.10, the calculated maximum snow depth with the new system is 9cm and less

Fig. 13　Works at building piles

Fig. 14 Works of dissipation pipes

Fig. 15 Snow melting condition

Fig.16 Works beneath an abutment

than the one with a 217W/m^2 system. Fig.8 shows a view of the maximum snow depth with the new system in the parking lot and fig.11 shows one without any system at the same time.

Plumbing works were not difficult as shown in figures 12, 13 and 14, since the communication between the plumber and the foundation worker was good.

The initial cost was approximately a third of the other snow-melting system using underground thermal energy in Japan, because of high cost of digging vertical boreholes. The initial cost of the new system using building piles was equal to that of a conventional system using primary energy. The electricity used by circulation pump was approximately 1/40 that of an electric heating system. A snow-melting system using a heavy oil boiler and the new system were installed in Fukui prefectural music hall. The operator said, " The boiler system was not able to be operated without an operator because of the fire risk. So, in the morning, the snow on the pavement with the new system was melted as in fig.15, though the snow with the boiler system was not melted".

At present, snow-melting/de-icing area of 1300m^2 on a bridge and its surrounding road where 36 steel piles of 0.5～0.8m inner diameter and 45m length are to be placed under the two bridge abutments, is under construction (fig.16). In this case, the piles were fitted with

Fig.17 Frost on bridge

Fig.18 Traffic accident due to difference of road surface condition

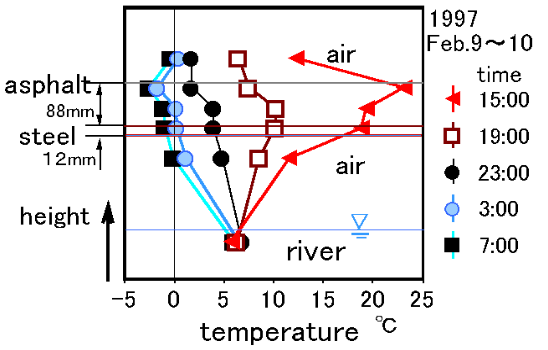

Fig.19 Change of temperatures at various points on a steel deck bridge

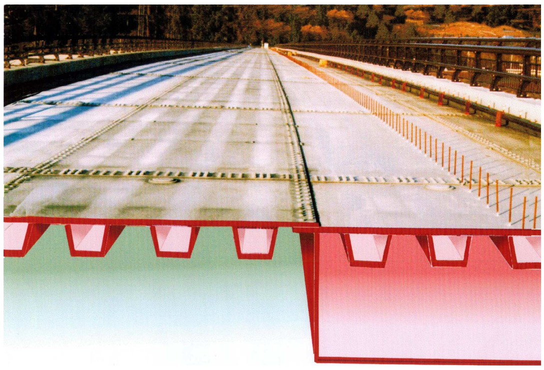

Fig.20 Frost condition on steel deck bridge

drills at their bases and rotated into the ground. The heat storage volume in this case is larger than that of concrete building piles because the inner diameter of steel piles for bridges is larger. Therefore, not only underground thermal energy, but also solar energy collected by operating the circulation pump on warm days in winter, will be used. That is why this system will be more cost effective.

4. De-icing system with phase change material on bridge road [4,5,6)]

The road surfaces on steel deck bridges more frequently become frosty and slippery during winter due to low temperatures than those on concrete decks (fig.17). These conditions cause traffic accidents like in fig.18. An investigation was made on the influence of the structural details under the bridge deck on this phenomenon by measuring temperatures at various points on a steel deck bridge. The main conclusions obtained are as follows:

(1) Fig.19 shows the four-hourly temperatures of the bridge, air and river in the section on a frosty day in Fukui City. In fig.19, the road surface temperature on the steel deck was lower than that of the river and of the surrounding air between midnight and dawn on a frosty day. Therefore, the radiation heat from the river surface and the convection heat from the air, warmed up the deck so as to make the road surface less vulnerable to freezing.

(2) Therefore, the daily minimum road surface temperature on the deck with insulators or closed-shaped ribs (so called "U-shaped ribs") was lower than that with opened-shaped ribs

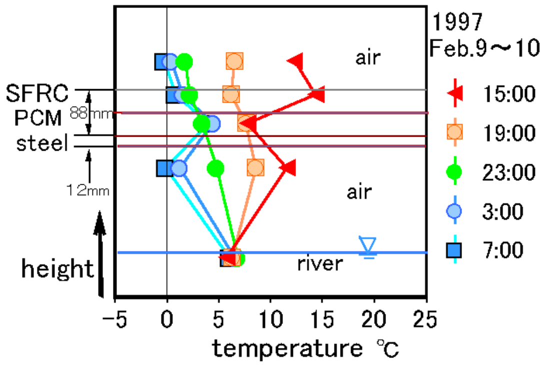

Fig.21 Change of temperature at various points of steel deck bridge with PCM

Fig. 22 Steel pipes full of PCM

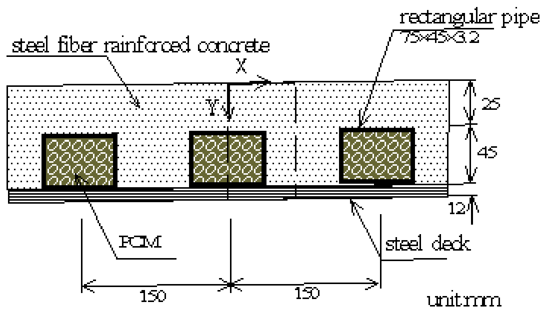

Fig. 23 Section of steel deck with PCM

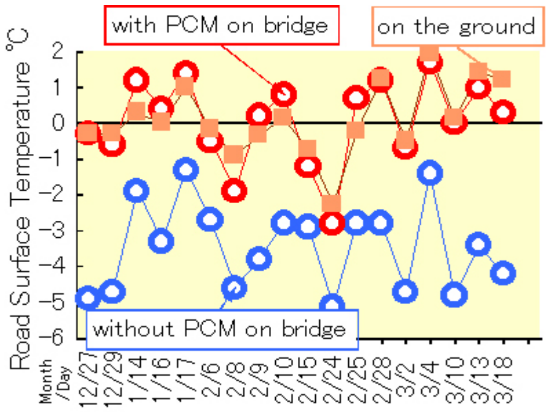

Fig. 24 Daily minimum road surface temperatures

(so called "I-shaped ribs") on a frosty morning. Fig.20, with a photograph and a cross section, shows that the deck surface had a lot of frost only on the U-shaped ribs and the box girder.

(3) Reinforced concrete bridge decks are thicker and therefore have greater heat capacity than steel decks. Therefore, the heat flux from the river and the air to the concrete deck is negligible.

By these conclusions, it was confirmed that if steel deck bridges had more heat capacity at just above the freezing point of water its road surface would be as good as any other ones. In order to increase its heat capacity, rectangular steel pipes filled with phase change material (the paraffin of the false solidity) of 18liter/m^2 of pavement which had 130joule/cm^3 latent heat capacity at 3.1℃, was set in the pavement on the steel deck with opened-shaped ribs in Fukui city. Fig.21 shows the result of the experiment. In fig.21, PCM temperature did not change at 3℃ for a long time. Therefore, the road surface with PCM was 2.5℃ higher than one without PCM at the coldest point, compared with fig.19 measured on the same day. The PCM saved solar energy in the daytime and prevented its surface from freezing.

The next year, this de-icing system with PCM set up on an other steel deck bridge with

Fig.25 Snow melting condition on steel deck with and without PCM

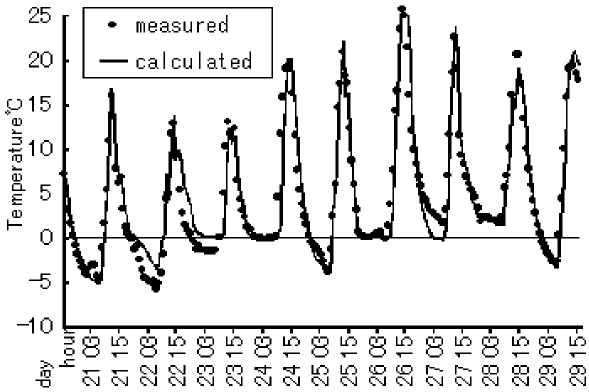

Fig.26 Road surface temperatures on steel deck bridge without PCM

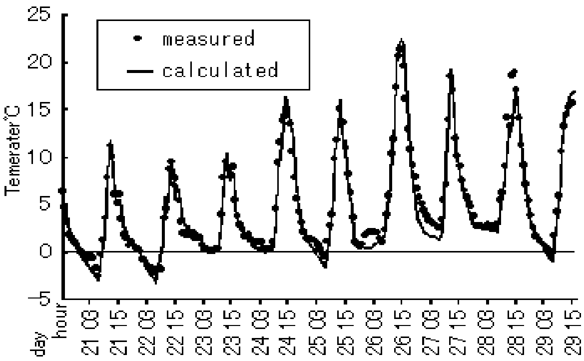

Fig.27 Road surface temperatures on steel deck bridge with PCM

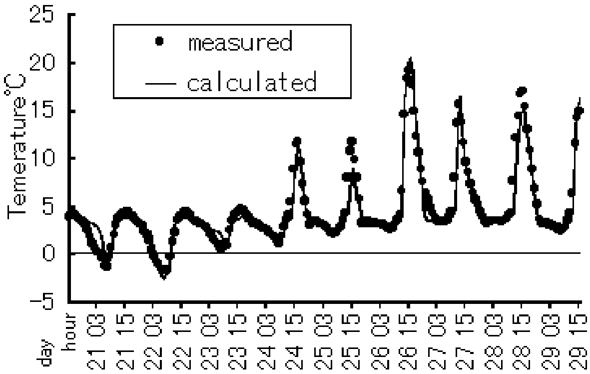

Fig.28 PCM temperatures on steel deck bridge

closed-shaped ribs in Fukui City practically (fig.22 and fig.23). Fig.24 shows daily minimum road surface temperatures with and without PCM and on the ground on the site on a frosty winter morning. Road surface temperatures with PCM were more than 3℃ higher on average, than ones without. Furthermore, the road surface temperatures on the bridge with PCM were similar to the ones on the ground. Though just a few cm of snowfall can be melted, the road surface condition on the bridge can be improved to the same as front and back by PCM (fig.25). Therefore very dangerous conditions disappear.

Simulations of the road surface temperatures with and without PCM are useful for popularizing this system in other regions. The numerical simulations were carried out, taking into account radiate, sensible, latent and conductive heat fluxes that were estimated using weather data collected by the Meteorological Observatory. Figures 26-29 show the calculated and measured data of road surface temperatures, PCM temperatures and snow depth respectively for 10 successive days, which had a mixture of frosty and snowy conditions. The calculations agree with the measured results. The simulation model using AMeDAS (Automated Meteorological Data Acquisition System) Weather Data can calculate road surface temperature, depth of snow cover and amount of frost on any type of bridge and on

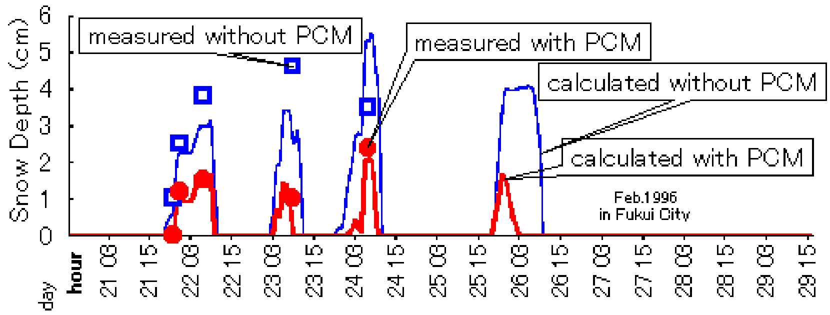

Fig. 29 Snow depth on steel deck bridge with and without PCM

the ground at specific points of AMeDAS.

This system costs approximately ¥40,000/㎡. It was confirmed by a wheel-running test that a structure with rectangular steel pipes and steel fiber reinforced concrete on a still deck slab has more durability[7]. Furthermore, the thickness of a steel deck can be reduced from 12mm to 10mm, because this structure can be designed as a composite slab of steel deck and steel fiber reinforced concrete. This system is useful not only in snowy regions but also other regions where frost forms frequently.

5.Conclusions

We can save groundwater used for snow-melting substantially, and use snow-melting/de-icing systems using natural thermal energy sources other than groundwater ones, if we combine sensors, plumbing, piles, pavement, storage of energy, simulations, etc. and adapt the devices to the conditions on the site.

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