Thermal Behavior of Anti-freezing Pavement due to Ground Heat Extraction by HUT System

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1. Introduction

Road heating has a significant requirement for reducing winter traffic accidents at specific places such as intersections, bridges, tunnel mouths, etc. Slip accidents at tunnel mouth, for example, frequently occur in winter and cause serious danger for human life and a heavy traffic jam, because of a remarkable spatial change of snow/ice covered road surface at a tunnel mouth[1)].

Paying attention to the use of shallow ground heat inside the tunnel, a Horizontal U-Tube (HUT) road heating system was introduced at the west side mouth of Nanaori-Toge tunnel, Aizu-bange, Fukushima Prefecture for the first time in November 2002. The thermal performance of the HUT system has been analyzed through ongoing experiments since then.

This paper describes the behavior of anti-freezing pavement temperature due to the ground heat supply following the HUT system start.

2. Outline of the HUT road heating system

Fig.1 shows the HUT road heating system of Nanaori-Toge tunnel that consists of 20 HUTs installed in the shallow ground (1.2 m below the road surface) of the central part of the tunnel and an anti-freezing pavement incorporating a heat exchange pipe at the tunnel mouth. The HUT is made from acrylic resin with a diameter of 40 mm, the pitch and length of the U-shape is 0.3 m and 50 m, respectively. The anti-freezing pavement was composed of 25 concrete pavement blocks and each block (3.5m×2m) is equipped with a serpentine heat injection pipe (HIP) made of steel with a diameter of 15 mm and a length of 70 m. The HIP was placed at a depth of 70 mm below the pavement surface in the pitch of 0.1 m. Heat carrier fluid (water) circulates between the HUT and HIP as shown in Fig. 1. The anti-freezing pavement area is 175 m^2 and the circulation flow rate is 0.7 l/min per unit pavement area.

The road heating is automatically controlled according to the temperature at a depth of 10 mm below (z = -0.01m) the pavement surface. In winter, flow commences when the temperature at a point 0.01 m below the anti-freezing pavement surface falls below 4 ^{0}C and stops when it subsequently rises above 5 ^{0}C. The heat carrier fluid is warmed associated with the extraction of the shallow ground heat, while it passes through the HUT and then the extracted heat is supplied to the pavement surface as the injected heat via the HIP.

3. Field experimental results

3.1 Vertical profile of temperature

Fig. 2 shows the vertical profiles of the temperature at the anti-freezing pavement and normal pavement after the HUT system operation started at 20:05 on November 14, 2005. Before the operation start, there has already existed the difference in the pavement temperatures. The initial temperature of the anti-freezing pavement

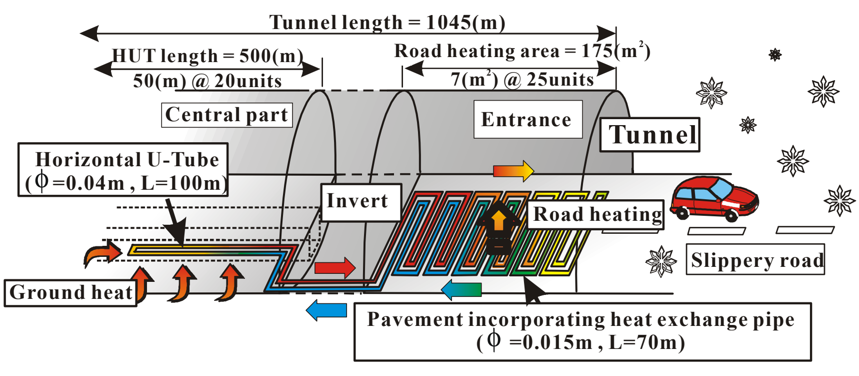

Fig. 1 Schematic view of the HUT system at Nanaori- Toge tunnel

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is higher than that of normal one, because of so called "Futon (or tunnel cover) effect" (reduction of pavement long-wave radiation due to the tunnel wall).

Fig. 3 shows the time variations of surface temperatures (z = -0.01m) of the anti-freezing pavement and of the normal pavement. After 7 hours elapsed, the former rose from 10.2 ^{0}C to about 13 ^{0}C, while the latter fell down from 8.2 ^{0}C to about 6 ^{0}C associated with the fall in the air temperature.

3.2 Heat Injection performance

Fig. 4 shows the time variation of injected heat flux per unit pavement area. The heat flux suddenly reached the maximum value of 210 W/m^2 following the HUT system start. There exists a negative correlation between the injected heat flux and road surface temperature. It is noticed that the injected heat flux decreases with the increase of the road surface temperature from the comparison of Fig. 3 and Fig. 4.

3.3 Isothermal distribution on the anti-freezing pavement

Photo. 1 shows the isothermal distribution (thermograph) on the road surface at the west tunnel mouth at 19:08 on December 24, 2005. The surface temperature on the anti-freezing pavement was about 3.5 ^{0}C, while the normal pavement temperatures just the inside and the outside of the tunnel mouth were 1 ^{0}C and -1.2 ^{0}C, respectively. From this result, it is implied that the shallow ground heat in the central part of tunnel is fully effective for the road freezing prevention at the tunnel mouth.

4. Concluding remarks

From the field observation at Nanaori-Toge tunnel in the winter of 2005, we could get valuable results on anti-freezing performance of the horizontal U-tube system. Even when the normal pavement temperature was lower than the freezing point, the anti-freezing pavement temperature connected with the HUT could always maintain positive. The shallow ground heat extracted through the HUT from the central part of the tunnel practically enables the road freezing prevention at a tunnel mouth.

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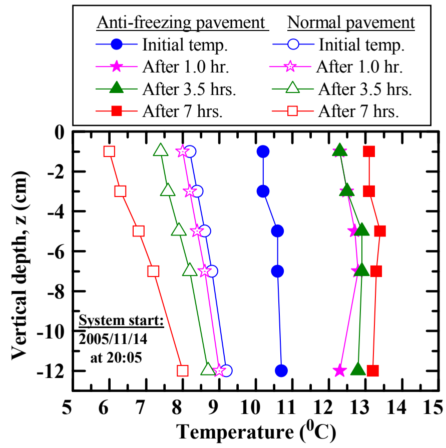

Fig. 2 Vertical profile of pavement temperatures after system operation

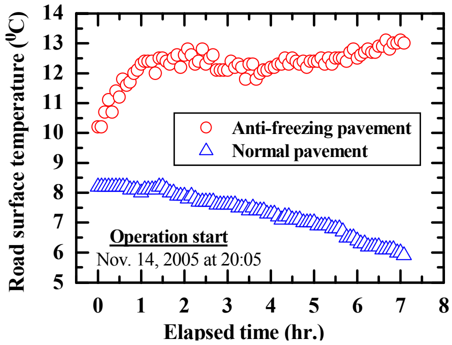

Fig. 3 Time variations of road surface temperatures after system operation

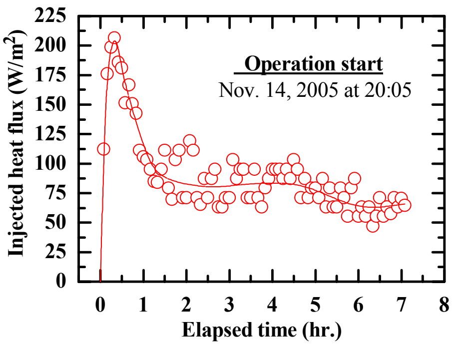

Fig. 4 Time variation of injected heat flux per unit pavement area

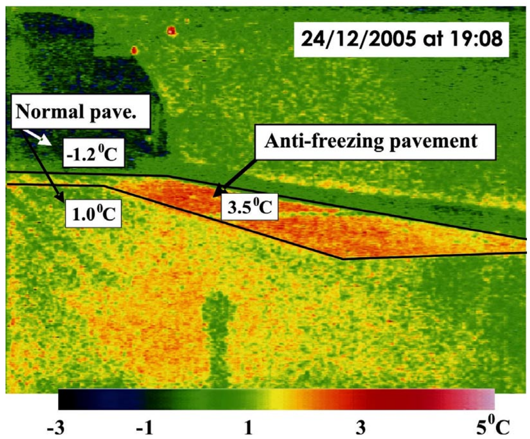

Photo 1 Isothermal distribution on the pavement surface at the tunnel mouth (at 19:08 on December 24, 2005)