Influence of Heating Pipe on Snow Melting and Mechanical Properties

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1. INTRODUCTION

The region of west Japan has relatively warmer climate in winter and it rarely has continuous snowfalls over 20cm/day. Even in such warmer region, slip traffic accidents often occur due to a sudden change of road condition, especially on the bridge and tunnel-exit.

Pipe heating system is an example of the snow-removing facility. This system has an economical advantage when natural energy is used. It is relatively easy to obtain the natural energy from warmer spring water and geothermal heat. When such energy is used appropriately for the pipe heating system, the traffic accident can be reduced at lower cost.

The authors had reported the fundamental data for designing of pipe heating system by natural energy[1)-3)]. The purpose of this study is to provide the fundamental data for the rational design of the pipe heating system. This paper presents the experimental results on snow melting and mechanical properties. The snow-melting test was carried out to investigate the pipe arrangements, and loading tests were conducted in order to study the strength of the concrete with pipes.

2. ROLE OF PIPE FOR SNOW-MELTING

2.1. Objective of Snow-Melting Test

There are several parameters in rational design of the pipe heating system. The most important parameters are embedded pipe arrangement and running water temperature. However, little is known about the relation between snow melting and these parameters. This section provides the effect of the pipe spacing for the snow melting.

2.2. Specimen for Snow Melting Test

The specimens for pipe heating are detailed in **Fig.1**. The size of specimen is 600*500*200mm of width, length and thickness, respectively. Copper pipes were embedded with spaces of 100mm, 200mm and 300mm, and thermocouples for temperature measurement were arranged as shown in

Fig.2. The embedded pipes had an internal diameter of 15mm and an external diameter of 18mm. The cover of pipes was provided as 80mm. This cover was determined from the thickness of the concrete pavement thickness (50mm) and the protective cover (30mm) not to damage the pipe at pavement repair.

Table 1 gives the mix proportion of concrete. Concrete materials were mixed with the ordinarily Portland cement with a density of 3.15 g/cm^3, sea-sand with a density of 2.60 g/cm^3 and crushed andesite rocks with a density of 2.72 g/cm^3 respectively.

2.3. Experimental Program

The snow melting tests were carried out in the testing freezer that can control the room temperature with an error of 0.5^{o}C in error. In order to maintain the specimen and room at a constant temperature, the specimen was put in the freezer in the day before the experiment. The specimens were located on the stage to simulate the weather in the room to the actual bridge. In this experiment, the snow of 50mm thickness was directly mounted on the surface of specimen.

Fig.3 shows the flow in testing system of snow melting. Hot water, temperature of which was controlled by heater in the outside water tank, was flow in the embedded pipe by pressure.

The amount of water is determined as 327cm^3/sec, which results in the velocity of 138cm/sec. The snow height was measured every hour, and the temperature data from the embedded thermocouples was recorded every ten minutes.

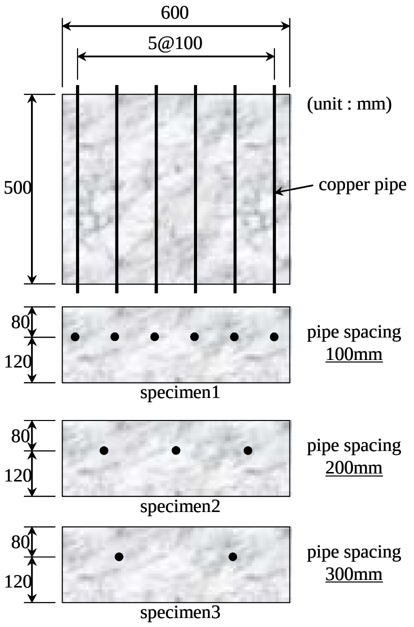


Fig.1 Specimen for pipe heating

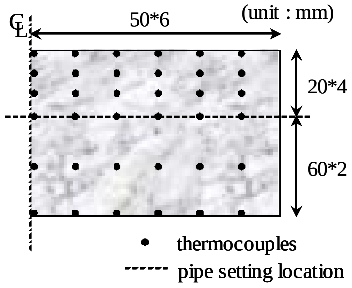


Fig.2 Embedded thermocouples

Table1 Mix Proportion

Water-Cement Ratio	54 %
Sand percentage	45 %
Water	162 kg/m^3
Cement	300 kg/m^3
Fine Aggregate	811 kg/m^3
Coarse Aggregate	1048 kg/m^3
Admixture	0.6 *l*/m^3

2.4. Experimental Results and Discussion

Some temperature distributions in specimens are shown in **Fig.4**. Narrower space such as specimen1 supplies uniform heat to the specimen surface. On the contrary, a temperature contour line of 5^{o}C in specimen3 with a pipe spacing of 300mm was narrower, and the internal temperature was significantly influenced by the outside temperature.

Fig.5 shows that the height of snow on the specimen under a condition of the outside

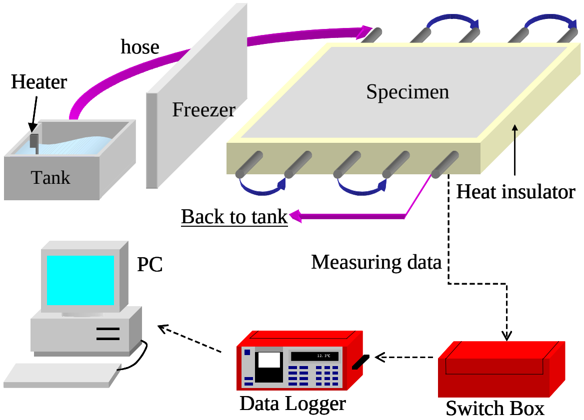
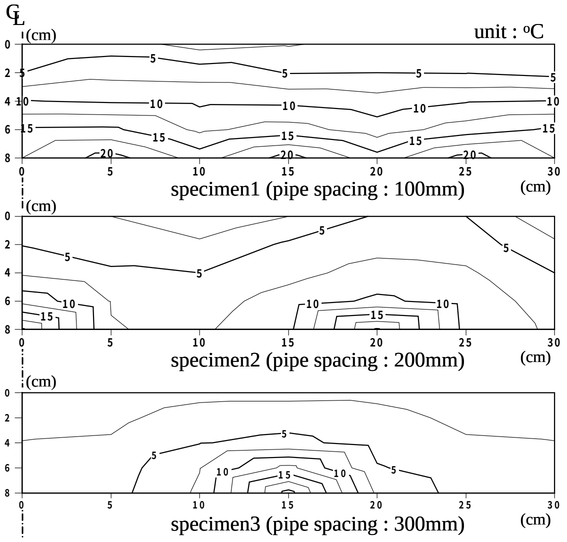


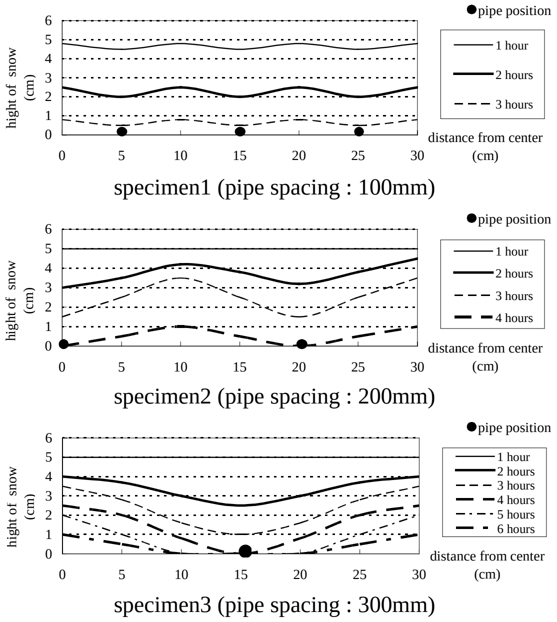
Fig.3 Flow of snow melting test in laboratory

temperature of 0°C and the water temperature of 30°C. The narrower pipe spacing could melt the snow uniformly. On the other hand, the snow melted well only above the embedded pipe for the specimen with wider pipe spacing. In actual traffic on the bridge, the traffic activity prevents the snow on road from bumping. To exposure 50% of the road surface can be regarded as sufficient for prevention of the traffic accidents$^{4)}$. The snow on specimen3 was melted approximately 50% after 6 hours.



Outside temperature: 0°C
Temperature of water: 20°C

Fig.4 Internal temperature condition



Outside temperature: 0°C
Temperature of running water: 30°C

Fig.5 Height of remaining snow

3. INFLUENCE OF THE EMBEDDED PIPE IN CONCRETE

3.1. Objective of Loading Test

Previous studies on the pipe heating mainly focused on the effective utilization of heat energy. Few studies had dealt with the mechanical durability of pipe heating slab. Embedded pipes in concrete possibly become a structural defect of concrete slab. This section presents the failure pattern and compressive strength of rectangular specimens with pipes.

3.2. Specimen for Loading Test

In order to determine to the specimen size, stresses were obtained around the embedded pipe, which was calculated by 2 dimensional FEM. Analytical conditions are illustrated in **Fig.6**.

As the calculated results, the embedded pipe influences stresses within a range around 15mm of the embedded pipe. Based on this result, size of the specimen was determined as 200x200x200mm, and the pipe was embedded at the center or 50mm from the center of the specimen, which means the specimens A and specimens B.

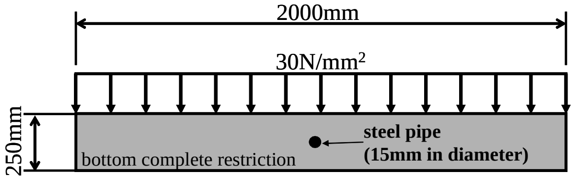


Fig.6 Model of the stress condition analysis

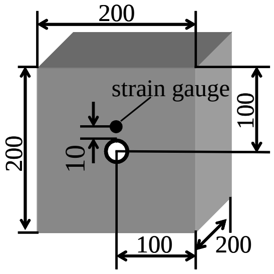


Fig.7 Embedded pipe location (specimens A)

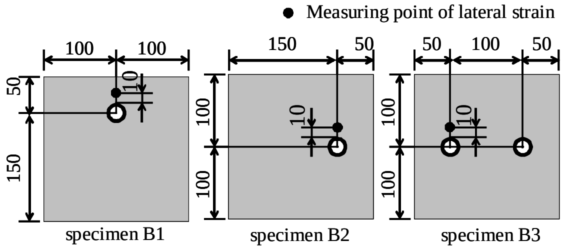


Fig.8 Pipe embedded location (specimens B)

3.3. Detail of Embedded Pipe

Table 2 gives size of the embedded pipe in the experiment of strength test. A steel pipe and a copper pipe are generally used for pipe heating system. A sheath for pre-stressed concrete and a vinyl chloride pipe, which were more flexible than normal pipes, were also embedded in specimens A. The steel rod with full section was embedded for comparison of strength of the specimen.

The external diameter of these pipes is nearly from 16 to 26mm. From the analytical result of stresses, such difference of these diameters might influence little to the strength.

Table 2 Size of embedded pipe (unit : mm)

Sort	External diameter	Internal diameter	Thickness
Steel pipe	21.8	16.0	2.9
Copper pipe	16.0	14.0	1.0
PC Sheath	24.5	23.0	0.8
Vinyl chloride pipe	26.0	19.8	3.1
Steel rod	17.0	---	---

Fig.7 shows the embedded pipe location in specimens A. Each pipe given in **Table 2** was embedded at the center of the concrete specimen. Compressive loading test in specimens A was conducted in order to investigate the failure pattern. Compressive loading test were conducted to specimens B with various pipe locations shown in **Fig.8**. The pipe was a steel pipe in specimens B. For the comparison, the loading test was carried out with the plain concrete specimen without the embedded pipe.

3.4. Loading Method

Fig.9 illustrates the compressive loading test. In order to decrease the friction of edge side, a rubber plate was set between the specimen and the loading plate. Strains of

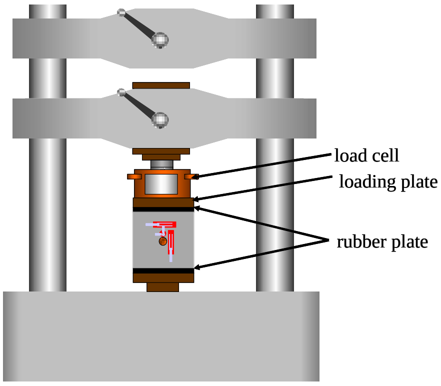


Fig.9 Compressive loading test

1) Plain **2)** Copper pipe **3)** Failure section

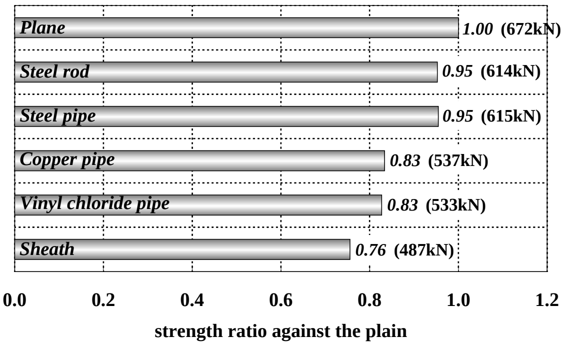
Picture 1 Failure pattern (specimens A)

concrete near the embedded pipe were measured by every load of 20kN.

3.5. Experimental Results and Discussions

3.5.1. Specimens A

Failure pattern of the plain concrete specimen and the specimen with copper pipe in specimens A is shown in **Picture 1**. All specimens in specimens A were cracked at the center due to splitting brittle failure. The embedded pipes were hardly damaged as shown in **3)** of **Picture 1** .



( ): average of failure load

Fig.10 Failure load and strength ratio (specimens A)

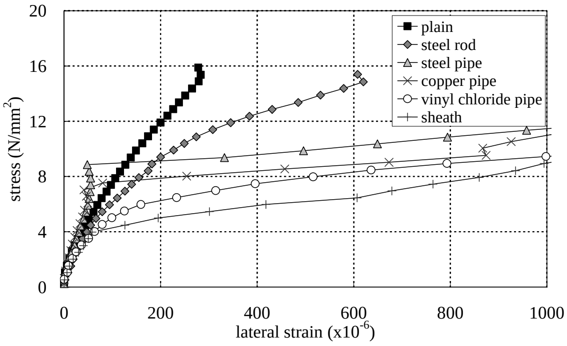


Fig.11 lateral strain above the pipe (specimens A)

Fig. 10 shows the strength ratios against the plain concrete specimen without embedment in specimens A. This figure represents the average failure load of three specimens. The failure load was range from 468 to 698kN, and the strength of plain concrete was the highest in specimens A. On the contrary, the failure load of specimens with a sheath was the lowest. The strength ratio of specimen with a steel rod was also 5% lower than the strength of plain concrete. The strength ratio of the specimen with any pipe was within 95 to 75% to the strength of plain.

The lateral strain above the embedded pipe is presented in **Fig.11**. The lateral strains of the plain specimen or the specimen with steel rod had no sudden change. On the other hand, the specimens with some pipe had the sudden change, which obviously increasing the lateral strain. Such sudden change was occurred due to the local cracks.

The failure load of specimen with a steel pipe is higher than the specimen with the other embedded pipe, and it has lower strength by only 5% than the strength of plain concrete. Based on these results and previous results on snow melting test[2), 5)], steel pipe can be regarded as an appropriate material for pipe heating.

3.5.2. Specimens B

In order to investigate the failure pattern and loads at failure of specimens with various pipe locations, compressive loading tests were conducted to some specimens with steel pipe.

Fig. 12 illustrates the crack pattern in specimens B. Specimens B1 with the pipe near the surface, had fractured from a center crack around the embedded pipe similar to specimens A. Specimen B2 and specimen B3 cracked in various ways, that is, cracked around the pipe or other location.

One of reasons was resulted from higher stiffness of steel pipe than other specimen, which acted as reinforcement material against compressive stress. The embedded pipe in concrete has the effect of reinforcement similar to reinforcing bar, and it is not always a structural defect, though the interface between concrete and pipe is possibly a defect.

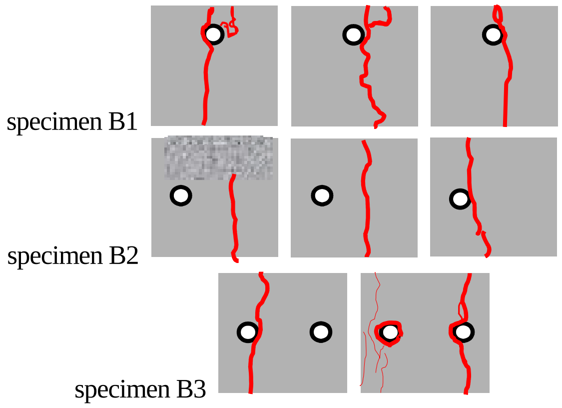


Fig.12 Crack pattern (specimens B)

Table3 Load at failure (specimens B)

specimen B1	600 kN	603 kN	605 kN
specimen B2	623 kN	624 kN	703 kN
	720 kN	723 kN	740 kN
specimen B3	805 kN	733 kN	---

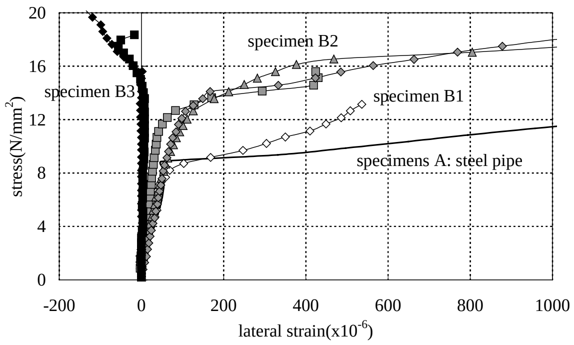


Fig.14 Lateral strain above the pipe (specimens B)

The failure loads in specimens B show in **Fig. 13**. Some specimens had the strength more than the maximum load of the plain concrete, while the strength of the plain concrete was the highest in specimens A. Especially, the maximum load of specimens with two embedded pipes, whose location was rather less stress concentration, was approximately 10-25% higher than the strength of plain concrete.

The lateral strains above the embedded pipe in specimens B were presented in **Fig.14**. Though the sudden change of the lateral strain in specimen B1 and specimens A occurred at almost the same load, the stress at sudden change of specimen B2 was higher. Little lateral strains due to cracking was measured in specimen B3 and lateral strains became in compression before the cracking. The embedded pipe has two characteristics as roles of reinforcement and structural defects for the stress concentration.

4. CONCLUSIONS

This paper presented the fundamental data for rational design of pipe heating system in the pavement. Especially, the present study focused the snow melting ability in the various pipe spacing and the failure conditions in various pipe arrangements. The conclusions of this study are summarized as follows.

(1) The narrower pipe spacing provides uniform temperature distribution to the surface, consequently it can melt the snow uniformly.

(2) All specimen having pipe in center were failed from a center crack near the pipe. The strength were influenced by stiffness of embedded material, the concrete with steel pipe had 5% lower than strength of plain concrete. Steel pipe was appropriate material for pipe heating due to higher durability and snow melting ability.

(3) The embedded pipe in concrete has the effect of reinforcement similar to reinforcing bar, and it is not always a structural defect, though the interface between concrete and pipe is possibly a defect.

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