Cost Performance of Pipe Heating System by Thermal Energy in Mountain Tunnel

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1 INTRODUCTION

In order to maintain the safety road condition, traffic in the snowy season needs the facility for snow thawing. Such facility has been serviced in the heavy snowy region of Japan. Traffic accidents due to covering snow on road happen even in warmer regions where it is rarely snow. Drivers in warmer regions don't get used to drive on snowy road, and the facility is not provided as sufficient as the heavy snowy region. Road administrator bureau in such regions has small budget for removing snow on the road. They must manage to maintain the better road condition within the limited budget. Thus, more economical facilities for thawing snow are required in such regions.

Most of traffic accidents in the snowy season happen on the road condition changed from non-snowy road[1), 2)]. For example, such locations are curves, bridges, tunnel exits and so on. In other words, removing the snow on such location can be appropriate management for winter road. Warmer regions have generally higher thermal energy in natural. When the natural energy is used appropriately, the higher effect for preventing the traffic accident may be obtained with lower cost. Mountain tunnels are generally planned to enable to cross short over pass. Therefore some tunnel exits are located on the high attitude and steep slope, and bridges and sunshades are possibly located at tunnel exits. The traffic accidents often occur at such locations during snowy season in mountain road. On such locations, e.g. bridges near mountain tunnel exit, snow-removing facilities are needed in order to keep the safety traffic condition.

The present study mainly focused on the pipe heating system for applying to tunnel exit. This system has considerably economical advantage when warmer tunnel spring water is used and where sufficient spring water is available. This paper discusses on the cost performance of pipe heating system by natural energy in a tunnel, i.e. initial cost and running cost. Cost-benefit ratios of each facility are also evaluated with assumption of service interval 15 years.

2 TUNNEL FOR COST EVALUATION

Tunnel for cost evaluation in this study is Ushinogou tunnel that reported in the previous research[1)]. Ushinogou tunnel shown in **Fig.1** locates at a central mountain area in the Chugoku region of Japan. The maximum amount of snowfall reaches to 30cm/day, the slip traffic accidents often occur in this area. However, continuous snowfalls over 20cm/day rarely occur in this area, and this is a typical area in west Japan.

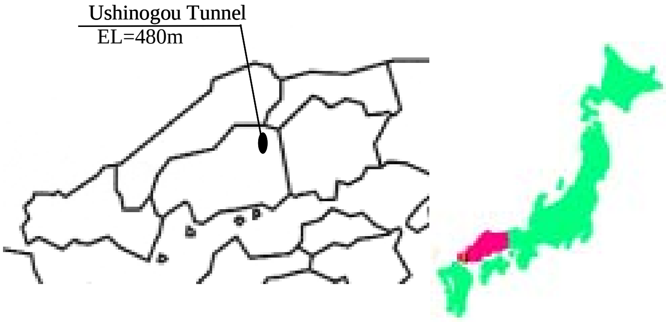


Fig.1 Ushinogou tunnel

The road for snow melting at the tunnel exit is normal road with 2850 m^2 and a concrete bridge with 650 m^2. An image of the tunnel and the snow melting area are shown in **Fig.2**. The normal road has a down slope with 3%. The bridge is a sharply curved bridge with R = 60 m, and has a down slope approximately 6%.

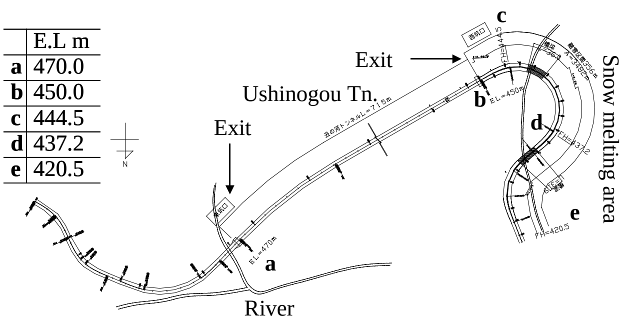


Fig.2 Tunnel exit at Ushinogou tunnel

3 SNOW MELTING SYSTEMS

This paper presents the cost performance of various snow-thawing facilities. The objective facilities in this study are sprinkled water system, electric heating system, borehole heat exchange system and pipe heating system. Each snow thawing system is explained in follows:

3.1. Sprinkled Water System –System 1-

Sprinkled water system is usually employed in the snowy region, where is relatively warm. The equipment cost of this system doesn't require much money than the other system. The employment of this system is limited in the region that has rich groundwater or river water etc.

The river water, which is a little warm in the snowy season, can be employed to this system so that a river locates near Ushinogou tunnel. The aim of present study is to evaluate the cost of this system employing the river water. This system has a possibility of re-freezing of sprinkled water, and a problem of drainage of thawing water.

3.2. *Electric Heating System –System 2-*

Electric heating system utilizes electric resisting wire to thaw snow. This system has wide application for various roads so that it can melt snow on the road conditions, e.g. steep slope. The running cost of this system, however, generally tends to be higher than the running cost of the other systems. In addition, the maintenance work is costly for inspection and repair.

3.3. *Borehole Heat Exchange System –System 3-*

Borehole heat exchange system (BHES) is illustrated in **Fig.3**. This system works by the thermal energy of ground under approximately 100 meters. The thermal energy of deep-ground is exchanged to the heat energy for snow melting. The borehole consists of twofold pipe; heating liquid in the pipe is usually employed non-freezing agent. This system requires relatively large number of boreholes for snow melting area and the initial cost tends to become higher.

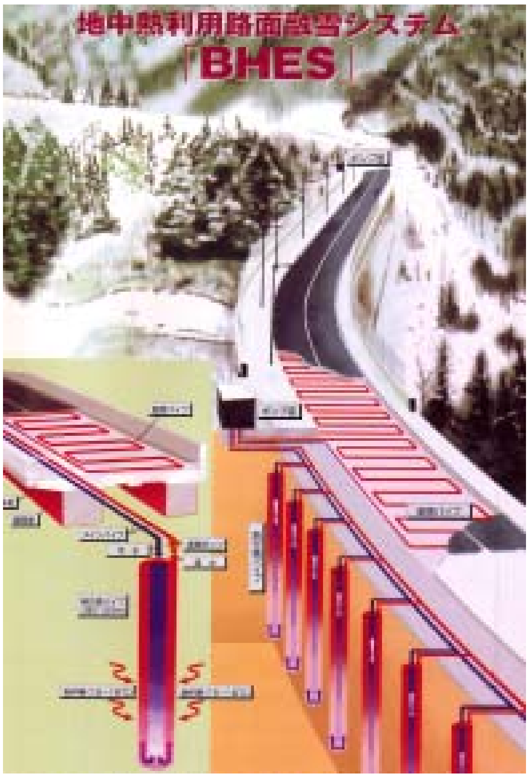
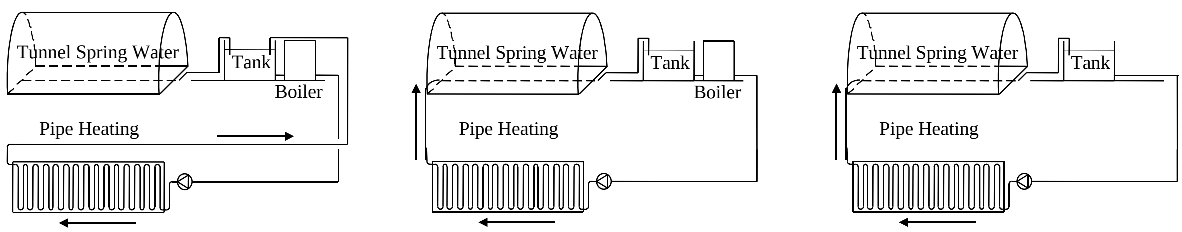


Fig.3 Borehole heat exchange system[3)]

3.4. *Pipe Heating System A –System 4-*

This system consists of heating pipe by using groundwater such as tunnel spring water. The temperature of the groundwater, however, may not sufficiently melt snow on such wide road. The groundwater is possibly heated with a boiler in order to obtain the sufficient temperature. The water for snow melting circulates to the upper stream in the heating pipe. Concept of the



System 4: T.S.W*+ Boiler System 5: T.S.W* + Geo-Heat+ Boiler System 6: T.S.W* + Geo-Heat

Fig.4 Concept of pipe heating system (*Tunnel Spring Water) pipe-heating system is summarized in **Fig.4**.

3.5. Pipe Heating System B –System 5-

The pipe heating system B is a system that geothermal energy around the tunnel is used for heating method of circulation water. This method can decrease the running cost for boiler heating. The circulation water is flowed to the opposite exit of tunnel for snow melting and the water temperature rises through the center-drainage along the tunnel[1)].

3.6. Pipe Heating System C –System 6-

This system does not use boiler for heating water, and dependent on only the natural energy of the tunnel, that is groundwater and geothermal energy. Such natural energy, however, insufficiently heats the water up to the temperature of snow melting on the road. This system probably becomes an effective system for control of anti-freezing. The present study employed this system only for cost evaluation of designing anti-freezing.

4 EVALUATION OF COST FOR SNOW MELTING

4.1. Conditions for Evaluation

The cost performance for snow melting was evaluated for Systems 1 to 5 in this section. The design conditions for snow melting in Ushinogou tunnel are given in **Table 1**. The average atmospheric temperature and quantity of snowfall is based on the statistics during 10 years at this location.

Table 1. Design conditions for snow melting

Ave. temperature	-2.6 ^{o}C
Ave. snowfall / day	73mm/day
Ave. snowfall / hour	17mm/hour
Density of snow	80kg/m^3
Heat quantity (normal)	161W/m^2
Heat quantity (bridge)	210W/m^2

4.2. Comparison of Initial Cost

The cost evaluation in this study is based on Japanese yen, and 1 US dollar is equivalent to 110 yen in November 2003. **Table 2** gives the cost evaluation for each method. The calculated results

Table 2. Cost performance for snow melting unit; 1000yen (¥)

Cost	System 1	System 2	System 3	System 4	System 5
Initial	40,128	161,737	627,164	189,324	201,214
Running	903/year	12,182/year	1,307/year	2,778/year	2,057/year
Ave.15years	3,578/year	22,964/year	43,118/year	15,400/year	15,471/year
Ratio	0.231	1.484	2.787	0.995	1.000

1 US$ = 110 yen in Nov./2003

indicate that sprinkled water system is the most economical. The initial cost of BHES is over 15 times higher than that of sprinkled water system, and it is the most expensive method. Pipe heating systems with tunnel spring water had almost equal cost for equipments; they were slightly higher than the initial cost of the electric heating system.

4.3. Comparison of Lifecycle Cost

Life of concrete pavement is dependent on cracking or abrasion, it is generally 10 ~ 20 years in Japan. The lives of each snow melting system are assumed as 15 years in the present study. The calculation for average cost of initial cost and running cost in 15 years is given in **Table 2**. **Table 2** gives the ratios of lifecycle cost when System 5 is designated as 1.0.

Table 2 represents that the sprinkled water system is the most economical method. This method is considered as the most rational method when the water on road surface is not re-iced. The running cost of electric heating system is calculated as ¥12,182*10^3/year, which is the most expensive method. BHES, which is the most expensive in the initial costs, has the lowest running cost except for sprinkled water system. Pipe heating system with natural energy needs the running cost of ¥2000~2800*10^3/year, which are slightly higher than the cost of BHES.

5 EVALUATION OF COST FOR ANTI-FREEZING

5.1. Conditions for Evaluation

The cost for anti-freezing was evaluated for pipe heating systems with natural energy, i.e. Systems 4 to 6. The design conditions for anti-freezing are given in **Table 3**. Fundamental conditions are common in all the systems for snow melting except for heat quantity.

5.2. Comparison of Initial Cost

Table 4 gives the results of cost evaluation for each method. Systems 4 and 5, which requires boiler, has almost equal cost for equipment. System 6, which does not require the artificial heating facility, has the lowest initial cost in 3 methods.

Table 3. Design conditions for snow melting

Ave. temperature	-2.6 ^{o}C
Ave. snowfall / day	73mm/day
Ave. snowfall / hour	17mm/hour
Density of snow	80kg/m^3
Heat quantity (normal)	72W/m^2
Heat quantity (bridge)	94W/m^2

5.3. Comparison of Lifecycle Cost

The running cost of System 6 was the most economical so that the pipe heating system C does not employ the boiler. The average cost of System 6 was approximately 20 % lower than the other methods when the life span is assumed as 15 years. This system can be an effective method for anti-freezing when sprinkled water system cannot be employed from some reasons.

Table 4. Cost performance for anti-freezing unit; 1000yen (¥)

Cost	System 4	System 5	System 6
Initial	174,534	175,114	152,064
Running	1,794/year	1,349/year	722/year
Ave.15years	13,430/year	13,023/year	10,860/year
Ratio	1.031	1.000	0.834

1 US$ = 110 yen in Nov./2003

6 CONCLUSIONS

This paper presents an example of cost performance of various snow-melting systems for a tunnel exit on mountain roads. Especially, the present study assumes that some of systems need natural energy for reduction in cost. The conclusions of this paper are listed as follows.

1) Sprinkled water system is the most economical in initial cost and running cost.
2) Electric heating system has relatively the lower cost at initial stage, and the running cost tends to be extremely higher than the other method.
3) BHES with natural energy in the deep ground is effective in running cost, however it requires higher initial cost.
4) Pipe heating system with natural energy from tunnel spring water or geothermal heat has higher economically than the other road heating system.

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