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A physical model experiment for investigating into temperature redistribution in surrounding rock of permafrost tunnel

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ABSTRACT

The temperature distribution is one of the most important issues which should be considered in permafrost tunnel design. In order to investigate the influence of temperature disturbance caused by construction and boundary temperature on temperature distribution of surrounding rock in permafrost tunnel, a physical model experiment had been completed. A heater was working for half an hour to simulate the heat which was from construction. Both the inner face of tunnel and model top were exposed to air of test box. The results showed that the boundary conditions were successfully set up. The non-uniform force would act on support structure of tunnel because there were not uniform temperature distributions near the tunnel. The temperature distributions near the tunnel also would be affected by the temperature of ground surface if there is an enough small buried depth. In addition, the heat should be prevented to store in surrounding rock. Speeding up construction and installing reasonable insulation layer may be the effective methods. The results would contribute to understand frost damages mechanism and provide help for permafrost tunnel researches and design.

1. Introduction

The safety of permafrost tunnel is heavily threatened by frost damages. The frost damages may be caused by frost-heaving force. The negative temperature of surrounding rock is the important factor to cause frost-heaving force. The frost-heaving force should not be ignored in permafrost tunnel design. This was proved by the mathematical mechanical model which included the temperature, seepage and stress fields with phase change (Lai et al., 1998). Thus, temperature distribution of surrounding rock is very important for preventing frost. Zhang et al. (2002a, 2002b) got finite element formulas of three-dimensional temperature fields from Galerkin's methods based on the governing differential equations of the problem on temperature field with phase change. Lai et al. (2002) divided the surrounding rock into frozen zone and unfrozen zone and obtained an approximate analytical solution by dimensionless and perturbative method.

Water is another important factor to cause frost damages. Tan et al. (2013) set up different unfrozen water content in frozen zone, freezing zone and unfrozen zone. And it was found that this was a simple and effective method to calculate the temperature distribution with ice-water phase change occurring in porous media. The frozen depth of surrounding rock is largely influenced by seepage. Lai et al. (1999) derived the governing differential equations of the coupled problem of temperature and seepage fields with phase change. Tan et al. (2011) established the thermos-hydro (TH) coupling model which included the effects of thermal conductivity, latent heat of phase change and the seepage velocity on temperature distribution. And it also contains the effects of water flow in porous resulted by Soret effect and segregation potential on seepage velocity and water pressure distribution. Zhang et al. (2017) found that groundwater flow could aggravate uneven temperature distribution of surrounding rock in physical model experiments.

Air flow is another important influenced factor for temperature distribution of surrounding rock. Zhang et al. (2006) presented a three-dimensional coupling calculational model which contains temperature, moisture fields of surrounding rock and heat convection between the air and tunnel. Tan et al. (2014) developed a temperature field model which included temperature control equations of the surrounding rock, air temperature field control equations in the tunnel and wind flow control equations of the turbulence field. Zhou et al., 2016 developed an unsteady-state finite-difference computing model to study the heat convection between the air and the tunnel wall as well as the heat transfer in the surrounding rock and at interfaces between different materials of the tunnel structure.

In addition, construction seasons and initial temperature could influence the frozen and thawed depths of surrounding rock (Zhang et al.,

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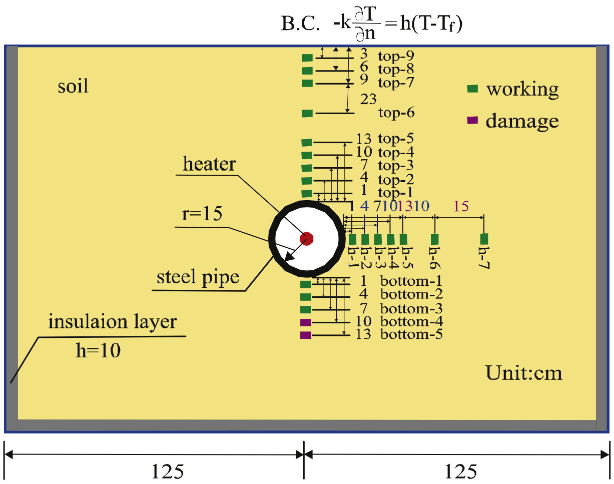

Fig. 1. Distribution of temperature sensors and physical model.

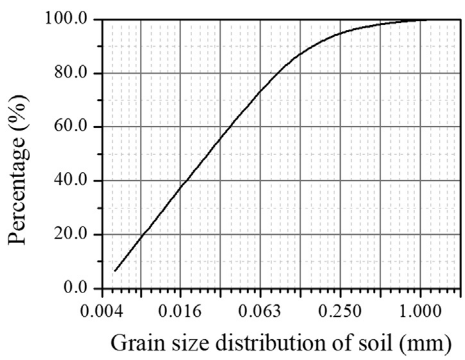

Fig. 2. Grain size distribution of soil.

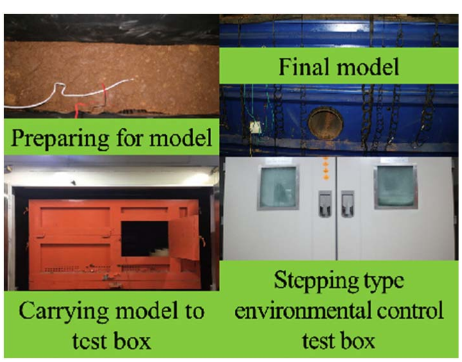

Fig. 3. Physical model and experimental equipment.

2002a, 2002b). And the refreezing of thawed range which caused by construction could be predicted by numerical models (Zhang et al., 2004). Recently, some larger laboratory models than before were used to research on the temperature distribution of surrounding rock. For example, Feng et al. (2016) took the Yuximolegai tunnel as an example to study the reliability of the freeze resistant design.

On the whole, researches of full mathematic solutions and physical model experiments on temperature distribution of surrounding rock are less than numerical calculation. There are only a few researches on full mathematic solutions and physical model experiments. Because the full mathematic solutions are difficult to obtained and it would take lots of cost and time to finish physical model experiments. This study is different from other experiments. Firstly, the heat from construction was simulated by a heating equipment. Then, both the inner face of tunnel and the model top were exposed to air in test box. In fact, the

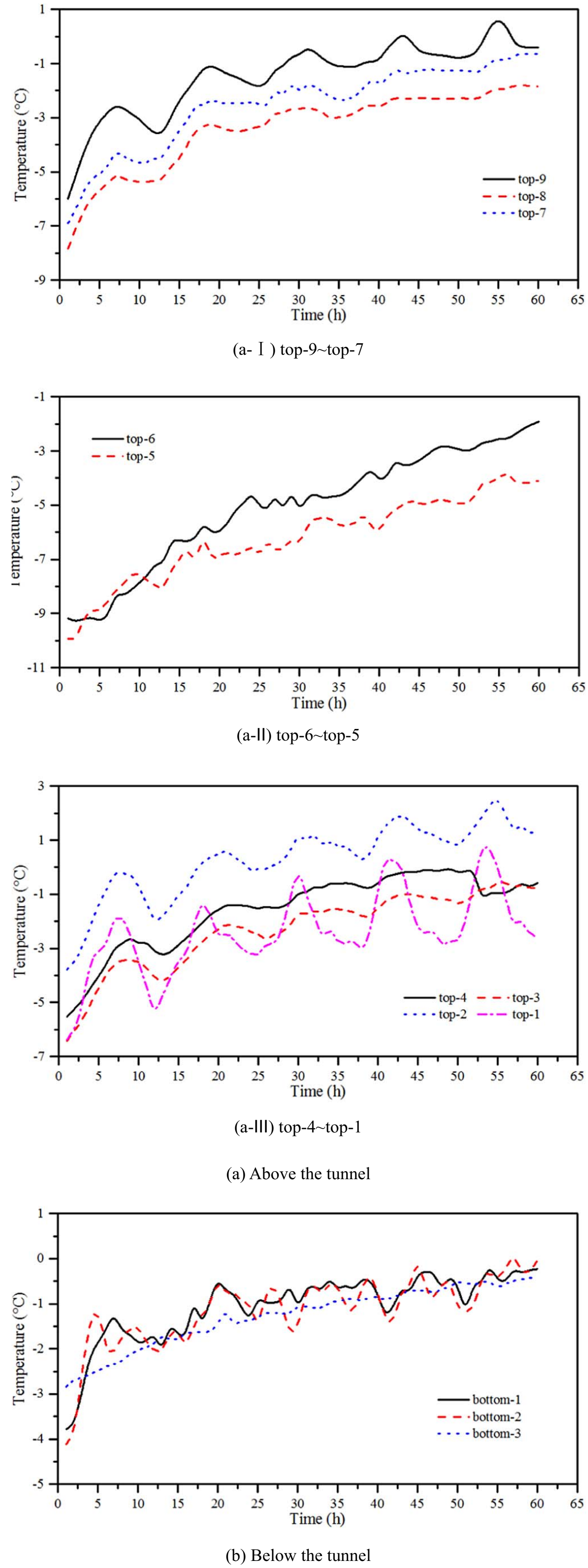

Fig. 4. The temperature changes along vertical direction.