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Research Paper

The coupling effect of ventilation and groundwater flow on the thermal performance of tunnel lining GHEs

Guozhu Zhang [a,b,*], Songyu Liu [a,b], Xu Zhao [c], Meixi Ye [a,b], Runfa Chen [a,b], Hualin Zhang [a,b], Junda Yang [a,b], Jiawei Chen [a,b]

[a] Institute of Geotechnical Engineering, Southeast University, Nanjing 210096, PR China
[b] Jiangsu Key Laboratory of Urban Underground Engineering & Environmental Safety (Southeast University), Nanjing 210096, PR China
[c] Key Laboratory of Urban Security and Disaster Engineering (Beijing University of Technology), Ministry of Education, Beijing 100124, PR China

HIGHLIGHTS

- Thermal response model tests under ventilation and groundwater were carried out.
- Thermal performance under ventilation and groundwater was evaluated.
- Ventilation and groundwater enhance the heat exchange rate of tunnel lining GHEs.

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ABSTRACT

Tunnel lining ground heat exchangers (GHEs) in this paper have advantages such as not requiring extra space, a low construction cost, and more efficient in heat exchange, offering a solution to the utilization of geothermal energy in central urban areas. Ventilation and groundwater flow are two important factors that significantly affect the underground temperature field. Laboratory model tests were carried out to evaluate the coupling effect of ventilation and groundwater flow on the thermal performance of tunnel lining GHEs. The test results show that (i) ventilation enhances the heat exchange process between the GHEs and the surrounding rock; (ii) the depth to which the GHEs influence the surrounding rock temperature field in the downstream of the groundwater flow field is 2.6 times higher than that in the upstream, and the ventilation and groundwater flow aggravate uneven distribution of the temperature field of the surrounding rock, so the heat exchange pipes should be installed in the upstream of the groundwater flow field; (iii) the coupling heat transfer between air and lining should be taken into consideration when the heat exchange rate of the heat exchange pipe is calculated.

1. Introduction

The high consumption of fossil energy in China has led to serious air pollution and substantial greenhouse gas emissions [1,2]. As an environmentally friendly energy source, geothermal energy is considered as an alternative to traditional fossil energy. Ground source heat pumps (GSHPs) have been wildly used in the heating and cooling of buildings [3]. However, traditional GSHPs, which extract heat from the earth through heat exchange pipes planted in the soil, have disadvantages such as high cost and a large space requirement. Therefore the application of traditional GSHPs is restricted in urban areas where the distribution of buildings is very intense. The geo-structures are constructed at certain depths where the ground temperature is stable, and there has been more interest in the application of heat exchange pipes buried in geo-structures [4–6], such as energy pile ground heat exchangers (GHEs) [7–14] and energy diaphragm wall GHEs [15,16]. Moreni et al. [7], Laloui et al. [8], Gao et al. [9], Bourne-Webb et al. [10] and Hamada et al. [11] carried out tests to investigate the thermal performance of energy pile GHEs, these studies show that the energy pile GHEs offer a good opportunity for the use of sustainable energy for building cooling and heating. The tunnels are one important component in the transportation system. The heat exchange pipes can be placed inside the tunnel lining to extract the heat energy from the surrounding rocks, providing a heat supply or refrigeration to buildings near the tunnel. Compared with existing GSHP technology, these tunnel lining GHEs have advantages such as not needing extra space, a low construction cost,

* Corresponding author at: Institute of Geotechnical Engineering, Southeast University, Nanjing 210096, PR China.
E-mail address: zhanggz@seu.edu.cn (G. Zhang).

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and more efficient in heat exchange, offering a solution to the utilization of geothermal energy in central urban areas. Recently, there has been more interest in the application of heat exchange pipes buried in tunnels. Heat exchange pipes were attached to geosynthetic and placed between the primary and secondary lining of the Vienna LT22 tunnel. Energy geotextile can be used to extract the geothermal energy from the surrounding rock and can also be used as waterproofing. Large scale tests were carried out to evaluate the thermal performance of energy geotextile [4,5]. Lee et al. [17] carried out field tests in an abandoned tunnel to evaluate the thermal performance of the energy textile installed in the tunnel. A 3-D finite volume analysis was adopted to simulate the thermal performance of the GHE in the energy textile under the groundwater flow condition. Franzius et al. [18,19] presented a system for turning segmental tunnels into sources of renewable energy and carried out a field test of tunnel lining GHEs on a new high-speed railway in Germany. Mimouni et al. estimated the geothermal potential of using the anchors of a cut-and-cover tunnel as heat exchangers for seasonal heat storage, and the influence of the soil properties and water table were investigated using finite element analysis [20]. Nicholson et al. [21] performed research on designing thermal tunnel energy segments for the

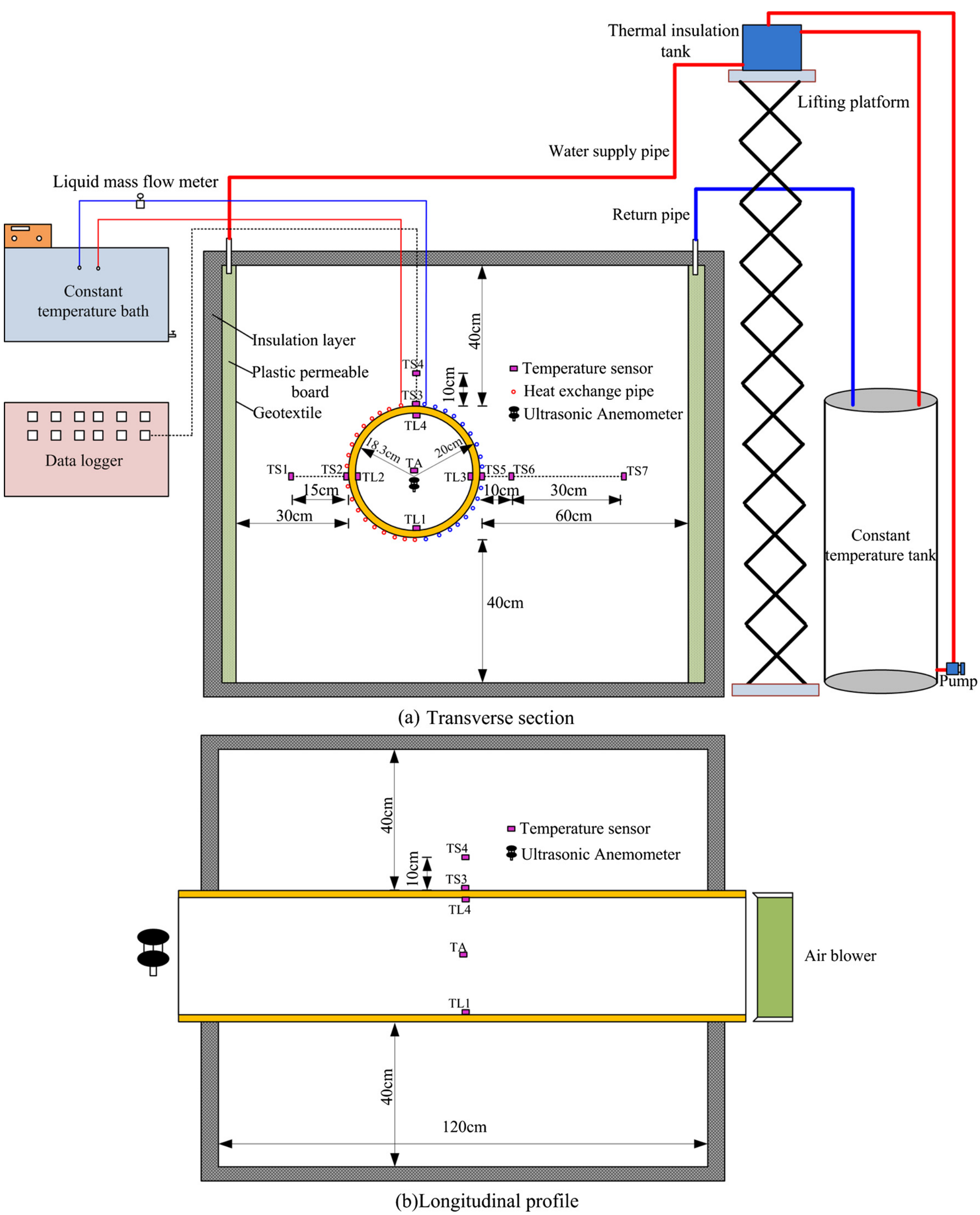

Fig. 1. Basic work principle of the laboratory model test.