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Evaluation of frost heave pressure characteristics in transverse direction to heat flow

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Abstract

The freezing method for underground construction has been attracting attention owing to its non-polluting characteristics. This method requires precise forecasting of freezing behavior and countermeasure technology against frost expansion. To improve this method, it is necessary to know the expansion characteristics in a transverse direction to heat flow as well as in the heat flow direction. In this study, we developed a new apparatus for frost heave experiments that can measure the pressure due to expansion in the transverse direction. As a conclusion, we successfully evaluated the characteristics of frost heave pressure in the transverse direction to heat flow through experiments.

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Keywords: frost heave; measuring method; frozen soil

1. Background and Object

Nowadays, the freezing method is a promising application for underground constructions owing to its non-polluting characteristics. However, during the process of ground freezing, frost heave would seriously affect the ambient infrastructure [1, 2]. Frost heave is a phenomenon that is caused by not only the volume expansion of phase-change, but also the migration of water from the non-frozen side to the freezing fringe [3]. In this phenomenon, a one-dimensional experimental formula, derived from indoor frost heave experiments, is widely applied for the

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evaluation of volume expansion and pressure confinement. However, the study of expansion in a transverse direction to heat flow is very limited. In the future, the forecasting of expansion in complicated underground spaces and the evaluation of frost heave pressure characteristics in the heat flow direction and in the transverse direction to heat flow becomes more important. In this study, we designed an innovative apparatus for frost heave testing to measure expansion in transverse direction, and evaluate frost heave pressure characteristics in the transverse direction to heat flow by using an open system with a water supply.

2. Development of the Apparatus

2.1. The apparatus to measure stress in transverse direction to heat flow

We selected a strain gauge and a small-sized water pressure gauge as instruments to measure the stress in the transverse direction to heat flow. We adopted sensors that are frequently used in frost heave experiments for the measurement of frost heave displacement in the vertical direction. Small-sized water pressure gauges with a diameter of 6 mm were buried in the frost heave test cell in order to measure the transverse pressure Fig. 1. The strain gauge had a length of 10 mm, was placed in the heat flow direction, and had the same thermal expansion coefficient as the acrylic material that was used in the frost heave test cell. We placed this instrument over the outer part of the frost heave test cell and calculated the inner radial stress by the outer strain based on the thick layer shell theory (Fig. 2).

Fig. 1 Installation of small-sized water pressure gauge

Fig. 2 Installation of strain gauge

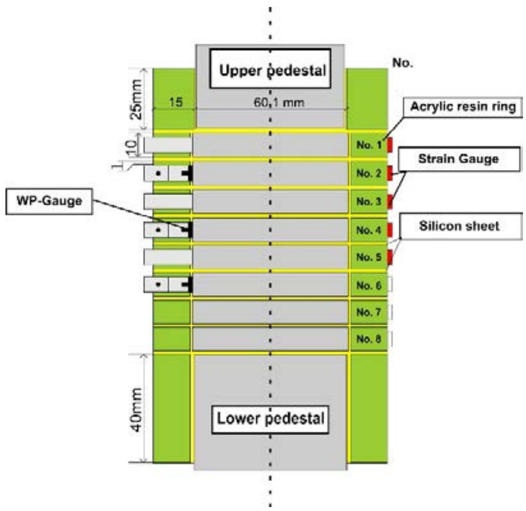

Fig. 3 Schematic diagram of frost heave test cell

2.2. Frost heave cell

Fig. 3 shows the schematic diagram of the frost heave test cell. The cell was made of an acrylic material, which had a similar thermal conductivity to Dotan, a Neogene silty soft rock. We piled up eight acrylic rings to form the frost heave test cell. The height of each acrylic ring was 10 mm with a thickness of 15 mm. We set strain gauges and thermometers in all of these eight rings in order to obtain the thermal distribution. The small-sized water pressure gauges were set in ring numbers 2, 4, and 6. We set a 1-mm silicon sheet between each ring to prevent water from leaking [4].

2.3. Performance test of measuring instruments

As the temperature of the specimen during the frost heave test changes from a positive to a negative value (°C),