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Experimental study on the effect of frost heave prevention using soilbags

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ABSTRACT

This paper introduces a new method to prevent frost heave in cold regions using soilbags (bags filled with soils). The mechanism of the proposed treatment method is introduced. A number of tests of soilbag frost heave, thawing settlement and strength were conducted in the laboratory on soilbags filled with soils. The results showed that soilbags exhibit less frost heave and thawing settlement than soils for the same conditions. In addition, the strength of soilbags was not affected by increasing the number of freeze–thaw cycles. These findings indicate that soilbags can not only prevent frost heave but also inhibit capillary water and film water migration through soilbags.

1. Introduction

The cold regions of the world cover large parts of Asia, northern Europe, Alaska, Canada and approximately a third of the USA. In China, permafrost and seasonal frozen ground cover 68.4% of the land, this area covering 29 provinces, in these regions, foundations, buildings and geotechnical structures are subject to freezing and frost heave in the winter and thaw settlement and weakening in the spring. Freeze–thaw action can cause severe damage to foundations and buildings in northern China. It is estimated that in northern China, some provinces may spend over million US dollars every year in work to repair the damage due to frost heave buildings and foundations. So the management agencies pay a great deal of attention to research work on the prevention of frost heave in engineering.

In recent years, some measures were put forward and investigated in the construction of highway and railway in cold regions, to ensure the stability of railway embankment and protect the underlying permafrost, a series of cooling techniques were employed e.g. duct-ventilated embankment, crushed-rock embankment and thermosyphon embankment (Cheng et al., 2009; Ma et al., 2002), and their cooling effects have been proved by practical engineering (Niu et al., 2006; Sun et al., 2005) different embankment structures and geometries on the underlying permafrost thermal regime along Qinghai–Tibetan Railway were analysed (Zhang et al., 2005).

Soilbags are commonly used to raise embankments during floods and to construct temporary structures during reconstruction after disasters. Soilbags are filled with granular materials such as sand, crushed stone, and recycled concrete. Granular soils wrapped with bags exhibit the typical characteristics of cohesive-frictional materials (Matsuoka and Liu, 2003). In recent years, soilbags have been used primarily for soil reinforcement in permanent or semi-permanent civil engineering works and found to be feasible and effective (Khalili and Khabbaz, 1998; Matsuoka and Liu, 2003). A new earth reinforcement method using soilbags has recently been developed (Matsuoka and Liu, 1999, 2003, 2005; Matsuoka et al., 1998, 2000). The reinforcement mechanism and a three-dimensional (3D) model for the ultimate compressive strength of soilbags have been suggested in these studies. This new model has been used successfully to predict soilbags' compressive strength, and the predicted values have been found to be much closer to experimentally measured values from compressive tests on soilbags than values predicted from two-dimensional (2D) strength models (BAI Fu-qing et al., 2010). A method for reinforcing slope surfaces using soilbags has been developed and used to analyse the stability of an expansive soil slope reinforced with soilbags (Liu et al., 2010). A numerical analysis of soft foundations reinforced with soilbags has been conducted by applying an elasto-plastic finite element analysis. The numerical results show that the predicted values are in good agreement with observed values. The method combines the principles of soilbag reinforcement with an elasto-plastic finite element model (Liu et al., 2012). Matsuoka and Liu (2003) summarised the advantages of reinforcing soil with soilbags, as follows:

(1) Bags are cheap and easy to acquire.
(2) Soilbags have almost the same unit weight as foundation soils.
(3) The materials inside soilbags can be various construction wastes, such as crushed concrete, asphalt and tile wastes. Soilbags thus contribute greatly to the recycling of waste materials.
(4) No special construction equipment is required. Soilbags can be assembled solely by human labour.

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(5) Earth reinforcement using soilbags is environmentally friendly because cement and chemical agents are avoided.
(6) Less noise and vibration are produced by soil reinforcement with soilbags than by the pile-driving method that is commonly used in soft/weak foundation reinforcement.
(7) Soilbags have high compressive strength, approaching 3 MPa, nearly a tenth that of normal concrete.
(8) The bearing capacity of a soft ground can be increased by 5–10 times using soilbags.

They are mainly focus on the effect on the bearing capacity improvement of soilbags, vibration damping effect of soilbags, and improving the stability of an expansive soil slope with soilbags. However, soilbags have not yet been applied to the prevention of frost heave of foundations and buildings in cold regions. In this background, the authors designed frost heave prevention using soilbags in the laboratory.

In this paper, the principle of frost heave prevention using soilbags is introduced. A series of laboratory experiments conducted on soilbags filled with soils to study their frost heave and thawing settlement responses to multiple freeze–thaw cycles are described. Based on the results of the laboratory experiments, a new method for preventing frost heave of foundations and buildings with soilbags is proposed. The soilbags considered in this paper are woven polypropylene bags filled with soils.

2. Experimental investigation

2.1. Specimen preparation and sample freezing–thawing procedure

The moisture content and density of the tested clayey soil in this study were 17.6% and 1.67 g/cm^3, respectively. The engineering properties of the tested clayey soil are listed in Table 1. The grain size distribution for the tested clayey soil is shown in Fig. 1. The saturated moisture content was 38.1%.

In this study, tensile strength tests of soilbags were conducted on an extension–compression apparatus. The tension test results are tabulated in Table 2. To investigate the efficacy of soilbags in preventing frost heave, freeze–thaw cycles were applied to test specimens using a programmed freeze–thaw apparatus. The samples were used in three groups of tests in the laboratory. The three groups of samples were processed as follows.

The soilbags and soil in the first group of samples were placed in a closed system (without an external moisture supply), in which the soils and soilbags were frozen at a temperature of −15 °C for 72 h (Fig. 2). The temperature in the cabinet was then increased to 15 °C so that the samples could thaw for 72 h. The samples were subjected to four freeze–thaw cycles.

The soilbags and soil in the second group of samples were placed in an open system (with moisture supplied from a Mariotte bottle), in which the soils and soilbags were frozen at a temperature of −15 °C for 72 h (Fig. 2). The temperature in the cabinet was then increased to 15 °C so that the samples could thaw for 72 h. The samples were subjected to four freeze–thaw cycles.

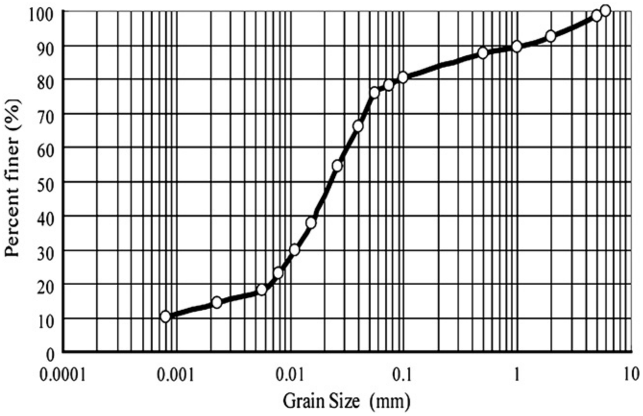

Fig. 1. Grain size distribution for the soil tested.

The third group of samples were woven bags that were placed in a box. The box was injected with water to cover the woven bags, then the box was placed in a freezing apparatus, and the woven bags were frozen at a temperature of −15 °C for 72 h. The temperature in the cabinet was then increased to 15 °C so that the samples could thaw for 72 h. The woven bags were subjected to twenty freeze–thaw cycles.

The prepared samples were placed in two boxes and then put into an environmental apparatus for freeze–thaw testing in closed-system conditions (without an external moisture supply) or open-system conditions (with moisture supplied from a Mariotte bottle). The inner walls of the box were covered with Vaseline to reduce the effect of friction on frost heave and thawing settlement of the samples. The test boxes were covered with insulation materials, and the samples were frozen unidirectionally from the top under a constant temperature. Temperature transducers were placed through small holes into the soil at intervals of 5 cm in the temperature measurement zone, to measure temperatures with 0.01 °C precision. The Mariotte bottle was a constant head device, which provided a moisture supply and capillary water migration for the open system conditions. To record the amount of frost heave and thawing settlement of each specimen, three dial indicators with a precision of 0.001 mm were placed along the diagonal of each specimen. Frost heave and thawing settlement values were taken as the averages of the measurements obtained from the three dial indicators. Freezing rate was 6.7 mm/h. To determine the tensile strength and maximum extension strain of the bags, tensile tests of the bags were conducted on an extension–compression apparatus with an electronic digital control device. The pulling speed was controlled at 20 mm/min. The tensile force-settlement relationship of two woven bags is shown in Table 2. The permeability

Table 1
Physical properties of the soil tested.

Physical parameters	Nanjing clayey soil
Dry density	1.42
Liquid limit W_L(%)	36.4
Plastic limit W_P(%)	16.6
Plastic index I_P(%)	19.8

Table 2
Test conditions and results of woven bags.

Test type	With (mm)	Length (mm)	Tensile force (kN)	Maximum extension (mm)	Tensile strength T (kN/m)	Extension strain λ (%)
Radial	20	10	2.06	44.66	10.3	36.0
	20	10	1.98	31.03	9.9	
	20	10	1.55	32.32	7.75	
Latitudinal	20	10	1.33	25.88	6.65	27.0
	20	10	1.9	27.3	9.5	
	20	10	1.98	27.77	9.9	