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Research Article
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A Model-Based Experiment on the Prevention of Frost Heave in Canals using Soil-bags

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Abstract

To study the effects of soil-bags on the prevention of frost heave in canals in cold regions, experiments were conducted on models of soil-bags -treated and conventional canals subjected to freeze-thaw cycles. The amounts of frost heave and thaw settlement, water content and changes in temperature over time in the soil-bags-treated canals and conventional canals were studied. The experimental results showed that a significant frost heave-preventing effect was found in the soil-bags-treated canals subjected to freeze-thaw cycles, and the mechanism of the soil-bags prevention of frost heave in canals was revealed. The frost heave-preventing effect of soil-bags was achieved by inhibiting the rising of capillary water and film water, in addition to introducing a reinforcement effect. The study provides a theoretical basis for the prevention of frost heaving in canals in cold regions.

Keywords: Freeze-thaw cycles; Soil-bags model experiment; Frost heave prevention for canals

Introduction

The eastern and central routes of the South-North Water Transfer Project (SNWTP) are currently under construction. The project involves seven provinces (and municipalities), where 39 cities at the prefecture-level and above in the provinces of Beijing, Tianjin, Hebei, Shandong, Henan and Jiangsu receive the associated water. The diversion canals and associated structures are the main part of the eastern and central routes project in the SNWTP. Most of the implemented project falls in cold regions in the north. Thus, frost heaving in canals and their structures will be the main issue in the future operation and maintenance of this project. The urgency to study frost heave prevention is more prominent than ever. Studies have shown that soil type and soil temperature and water contents are key elements in the occurrence of frost heave and that frost heave in canals and their associated structures is caused by frost heave in soils [1]. Therefore, appropriate frost heave-preventing technology is of great significance to ensuring safe water transfer in the SNWTP, to safeguarding the lives and production in the water receiving areas, and to exploiting the benefit of the project. Since the 1940s, both domestic and international scholars have carried out experimental studies on the prevention of freeze-thaw frost heave in canals. Currently, the main frost heave-preventing measure in cold areas is to "adapt to, avoid, reduce or eliminate frost heave"; frost heave prevention practice is dominated by single structures, rigid materials and filling replacement. These measures deliver poor results in frost heave prevention; thus, it is very important to find a frost heave-preventing technology that has significant ability to adapt to the uneven deformation that occurs during frost heaving and that can also take advantage of the waste soil on site. At present, there are few studies on the prevention of frost heave in canals, and most of the studies focus on the prevention of frost heave in roads, railways, oil pipelines and other projects. The use of soil-bags to reinforce foundations is a new geotechnology, developed by Gangyuan Song and Sihong Li et al., who summarize the long-term application of soil-bags in engineering projects [2-4]. A significant number of experimental verification and theoretical studies have been carried out with soil-bags, completing the transition from practice to theory for this technology. Matsuoka et al. measured and analysed the reinforcement effect of soil-bags on the carrying capacity of railways using indoor model experiments [5]. Matsuoka and others measured and analysed the aseismic effect of soil-bags on the foundations of buildings and roadways using indoor and field experiments [6-8]. Liu et al. measured the expansion and deformation of wetted Nanyang expansive soils under different vertical loads, as well as the strength after expansion of these soils, to derive a fitted equation for changes in shear strength index; then, the authors applied the equation to the stability analysis of soil bags used to treat expansive soil side slopes, demonstrating the effect of using soil bags to weigh down expansive soil side slopes [9]. Bai et al. analyzed the mechanism of soil bags reinforcement under three-dimensional (3D) stress and derived a formula for the compressive strength limit of soil bags under complex 3D stress states using the generalized von Mises yield criteria and Lade-Duncan failure criterion as the theoretical basis [10] . The authors also verified that the 3D soil bags strength equation results are closer to experimental values and can be applied in a wider scope. Liu et al. modelled an experiment on the bearing capacity of soil bags reinforced soft soil foundation using the elastic-plastic finite element method (FEM) to predict the deformation behaviour of the soil bags reinforced soft soil foundations, and then, the authors combined the mechanism of soil bags reinforcement with FEM to perform numerical simulations [11]. The results of the numerical simulations were essentially consistent with the experimental measurements. To study the frost heave-prevention effect of soil bags under freeze-thaw cycles in seasonally frozen areas, Li et al. conducted indoor model experiments on soil bags and soils subjected to different freeze-thaw cycles, and the authors experimentally verified the mechanism and effects of using soil-bags to prevent frost heave [12].

The depth range of frost heave in foundation soils that causes frost heave damage in canals in cold northern regions is approximately 1.5 m. Therefore, when using Soil bags to cope with the frost heave problem in canals, it is only necessary to treat the 1.5-m-thick

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surface layer of a canal with soil bags, and similarly, only this depth must be studied to understand the frost heaving characteristics. The canals were scaled down at a certain ratio according to the structural characteristics of the canals in cold regions, and indoor freeze-thaw and frost heave experiments were conducted. Soil bags (20 cm × 20 cm, L×W) were placed on the surface of the canal side slope in a certain order, and experiments were conducted on the indoor model to study the freeze-thaw frost heaving characteristics of the soil bags-treated and conventional canals, in addition to the frost heave-preventing effect of soil-bags treatment on canals. The freeze-thaw frost heave of the embanked canals was simulated using freeze-thaw frost heaving experiments of soil-bags in a closed system; the freeze-thaw frost heave of canals in cross-section were simulated with freeze-thaw frost heaving experiments on soil-bags in an open system. In our study, freeze-thaw frost heaving experiments were conducted on soil-bags-treated and conventional canals, both of which were subjected to freeze-thaw in closed and open systems. In our study, we identify the canals that have not been treated with soil-bags as "conventional canals."

Basic Condition of Experiments

Overview of model experiment

The soil samples used in our study are Ningxia clay, and the physical and mechanical properties of the clay are shown in Table 1. The experiment used woven polypropylene bags. Each bag weighs 110 g/m^2 and is black in colour. The mechanical properties of the bags are shown in Table 2. The dimensions of each bag are 20 cm × 20 cm (warp × weft). The clay has a water content of 21.1% and a dry density of 1.62 g/cm^3. The canal model has a slope ratio of 1:1.05 and is 39 cm high. The canal is 57.3 cm long at the bottom and 20 cm long at the top, and the canal is 47 cm wide. The conventional canal and soil bags-treated canal have the same density. Soil bags (20 cm × 20 cm) were sequentially placed on the surface of the canal side slope at a slope ratio of 1:1.05. When constructing a soil bags-treated canal, the clay used should be in close contact with the soil bags; meanwhile, a conventional canal model of the same size was made using clay of the same density. Then, the geo-membrane was laid on the surfaces of the soil bags-treated canal and conventional channel models to prevent water evaporation during freeze-thaw cycles. The inner walls of the two model boxes were evenly coated with Vaseline of a certain thickness to reduce the friction between the inner wall of the model box of the conventional canal model and the soil bags -treated canal model during frost heaving and thaw settlement.

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 1: Physical Properties of the soil tested.

Experimental equipment embedding

The main pieces of equipment embedded in the model are temperature sensors, displacement sensors and a soil sampler. A total of four temperature sensors are arranged longitudinally from the top to the bottom of the canal model, and the embedding positions are 5 cm, 15 cm, 25 cm and 35 cm. There are four displacement sensors: one is placed on the top of the canal model, and the other three are laid out diagonally along the canal side slope and perpendicular to the surface of the canal side slope. The displacement sensors are connected with the temperature acquisition system, and data are collected every 30 min by the temperature acquisition system and displacement acquisition system. Figure 1 shows the layout of the measurement equipment, in which S1, S2, S3 and S4 are the locations of the embedded temperature sensors in the soil-bags-treated canal, and S5, S6 and S7 are the locations of the embedded displacement sensors on the side slope surface of the soil-bags-treated canal. S8 is the location of the displacement sensor on the top of the soil-bags-treated canal; B1, B2, B3 and B4 are the locations of the temperature sensors embedded in the conventional canal; B5, B6 and B7 are the locations of the displacement sensors in the conventional canal; and B8 is the location of the displacement sensor on the top of the conventional canal.

Freezing process

The soil-bags-treated canal and conventional canal models are made with clay that possesses a water content of 21.1% and a dry density of 1.62 g/cm^3. The models were allowed to freeze at -15°C for 48 h in a closed system and then to thaw at room temperature for 48 h. This freezing and thawing process is considered one freeze-thaw cycle. Additionally, in an open system, a 2 cm water table is retained below the bottom of the soil-bags-treated and conventional canals. To study the frost heave damage on canals that is caused by the rising of capillary water and film water in cold areas, two Mariotte's bottles are connected to the bottom of the model box to maintain the water table at 2 cm during the freezing and thawing process. The experimental set up for the model experiment on frost heave in the soil-bags-treated and conventional canals in closed and open systems is shown in Figure 2. The experimental canal models are shown in Figure 3. Figure 3a depicts the soil-bags-treated canal model, and Figure 3b shows the conventional canal model. A total of 10 freeze-thaw cycle experiments were conducted on the soil-bags-treated and conventional canal models in the closed and open systems, respectively.

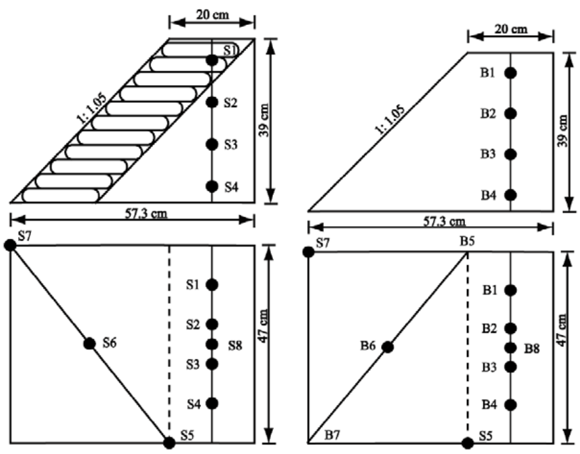
Experimental Results and Analysis

Frost heaving experiments on soil bags-treated canal and conventional canal in a closed system

Changes in the amount of frost heave in canals: The amount of frost heave is the basic characteristic value used to describe the frost heave-induced deformation of soils. The lining of canals in northern regions is very sensitive to frost heave due to the small thickness and

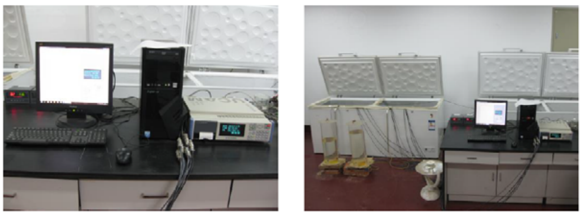
Test type	With (mm)	Length (mm)	Tensile force (k N)	Maximum extension (mm)	Tensile Strength T(kN/m)	Extension strain λ (%)
Radial	20	10	2.06	44.66	10.3	36
	20	10	1.98	31.03	9.9	
	20	10	1.55	32.32	7.75	
Latitudinal	20	10	1.33	25.88	6.65	27
	20	10	1.9	27.3	9.5	
	20	10	1.98	27.77	9.9	

Table 2: Test Conditions and results of woven bags.



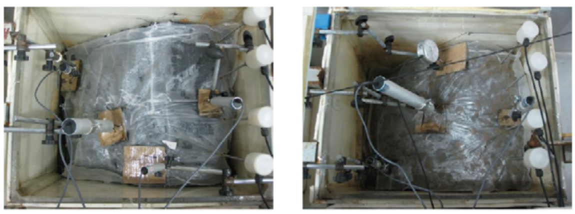
(a) Soilbags-treated Canals (b) Conventional Canals

Figure 1: Sketch of setting of soil bags-treated canals and conventional canals measuring instrument.



(a) (b)

Figure 2: The diagram of the freeze-thaw apparatus.



(a) (b)

Figure 3: The freeze-thaw model tests of soil bags-treated canalsand conventional canals.

lightweight nature of that lining. If the amount of frost heave in a lined canal is greater than the allowed displacement, frost heave damage to the canal lining can occur. Figures 4 and 5, respectively, depict changes in the amount of frost heave in the soil bags-treated and conventional canals subjected to one freeze-thaw cycle in a closed system. Four points were measured in each of the two frost heave models. Figures 3 and 4 show that for both the soil bags-treated and conventional canals, the amount of frost heave peaked at 48 h and that the frost heave on the top of the canal was greatest. The maximum amount of frost heave in the soil bags-treated canal was 0.56 cm, while that in the conventional canal was 0.96 cm. The frost heaves at S5, S6 and S7 were 0.36 cm, 0.3 cm and 0.28 cm, respectively. The frost heaves at B5, B6, and B7 were 0.88 cm, 0.90 cm and 0.67 cm, respectively. These results suggest that the soil bags-treated canal had a smaller frost heave than the conventional canal because, in a closed system, when the soil bags treatment layer in the soil bags-treated canal freezes at a sub-zero temperature, the soil inside the bags also freezes, generating a frost heave force that induces tension on the soil bags itself. In return, this process inhibits frost heave in the soils inside the soil bags. The frost heave in soils underneath the top layer was the same for both the soil bags-treated and conventional canals at sub-zero temperature.

Figures 6 and 7 illustrate, respectively, changes in the amount of frost heave in the closed-system soil-bags-treated and conventional canals subjected to10 freeze-thaw cycles. The figure shows that different degrees of frost heave occurred in both the Soil bags-treated and conventional canals, while the greatest frost heave values recorded on the top of the canal were 0.58 cm and 1.1 cm for the soil-bags-treated and conventional canals, respectively. Compared with the frost heave recorded after 1 freeze-thaw cycle, the maximum frost heave after 10 freeze-thaw cycles was not significantly different. In a closed system, without water replenishment from an external source, the water in the soils of both models was re-distributed when subjected to freeze-thaw

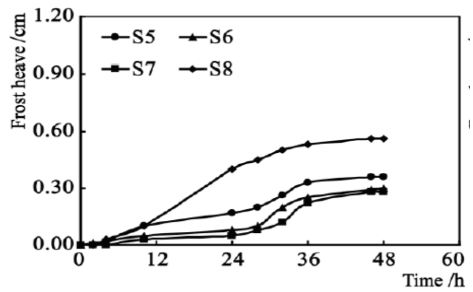


Figure 4: Soil bags-treated canalsfrost heave in a closed system 1.

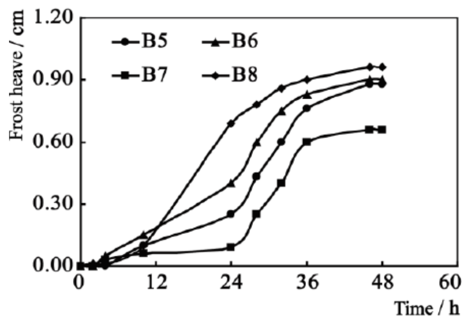


Figure 5: Conventional canalsfrost heave in a closed system 1.

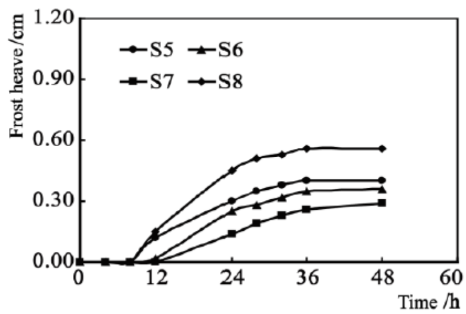


Figure 6: Soil bags-treated canals frost heave in a closed system 10.

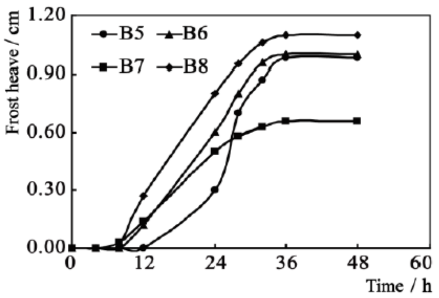


Figure 7: Conventional canalsfrost heave in a closed system 10.

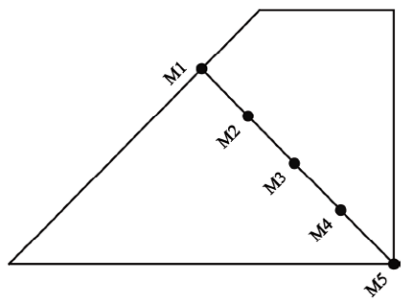


Figure 8: Sketch of observation transverse and moisture holes.

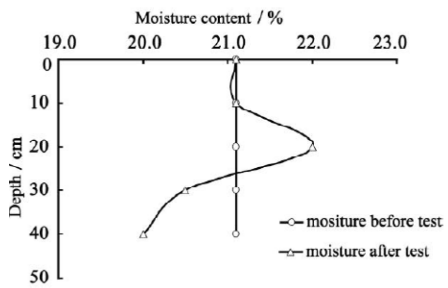


Figure 9: Soil bags-treated canals moisture content in a closed system.

cycles. Therefore, there was no significant difference in the amount of frost heave when the canal models were subjected freeze-thaw cycles.

Changes in water content of canals: Figure 8 presents the distribution map of the water content measuring points in the soil bags-treated and conventional canals in the experiment. Prior to the experiment, soil samples were taken at different depths (0 cm, 10 cm, 20 cm, 30 cm and 39 cm) along the direction perpendicular to the surface of the canal side slope to measure the water content at these depths. After 10 freeze-thaw cycles, soil samples were taken again in the same manner to measure the corresponding water content, thereby allowing a measurement of the water content changes at different depths after the freeze-thaw action. Figures 9 and 10 show the water contents at different depths in the soil-bags-treated and conventional canals in a closed system. The figure shows that for the soil-bags-treated canal, the water content of the soil at 0 cm and 10 cm below the side slope surface was the same before and after the freeze-thaw cycles, while the water content in soil at 13 cm below the surface changed significantly. Thus the depth range from 0-13 cm was the top layer of the soil-bags-treated canal. In the conventional canal, the soil water content below the surface differed from that recorded before the freeze-thaw experiment. According to Miller's secondary heave theory, when soils freeze at subzero temperatures, frost heave occurs in the soils within the frozen fringe, and pore ice continuously grows from the freezing front toward the front of the ice lens [12]. Thus, the unfrozen water is gradually thinned, generating a suction gradient that constantly attracts soil water from the frozen zone, causing the soil water to gather at the front of the ice lens and freeze; as a result, frost heave occurs. Changes in the soil water content occurred at 13 cm below the side slope surface, in both the conventional and soil-bags-treated canals. The soil water in the conventional canal migrated after the freeze-thaw cycles, resulting in the redistribution of water in the soils and changes in the soil water content. However, the water content in the top layer of the soil-bags-treated canal remained the same before and after the freeze-thaw experiment, because the soil water inside the soil-bags was not able to pass through the soil-bags and migrate to adjacent soil-bags under the temperature gradient.

Changes in thaw settlement in canals: Figures 11 and 12 illustrate, respectively, the amount of thaw settlement in the closed-system soil-bags-treated and conventional canals after 1 freeze-thaw cycle. The maximum thaw settlement in the soil-bags-treated canal was 0.57 cm, and the maximum thaw settlement in the conventional canal was 1.0 cm. The amount of thaw settlement was the greatest at the top of the canal models. The amount of thaw settlement was greater than the amount of frost heave after one freeze-thaw cycle in both the soil-bags-treated and conventional canals.

Figures 13 and 14 show the amount of thaw settlement in the closed-system soil-bags-treated and conventional canals after 10 freeze-

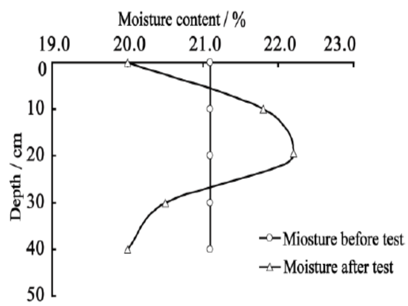


Figure 10: Conventional canals moisture content in a closed system.

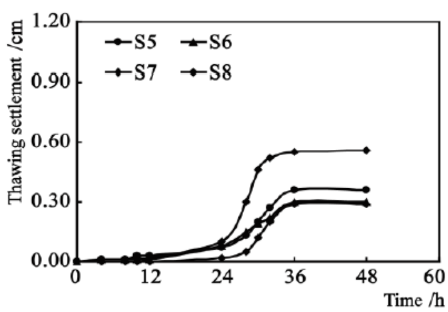


Figure 11: Soil bags-treated canals thawing settlement in a closed system 1.

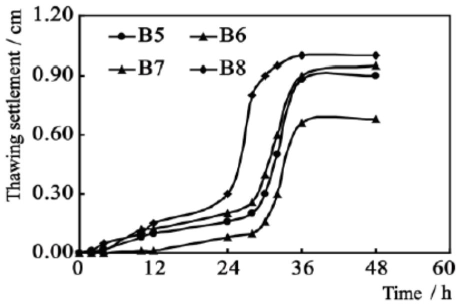


Figure 12: Conventional canals thawing settlement in a closed system 1.

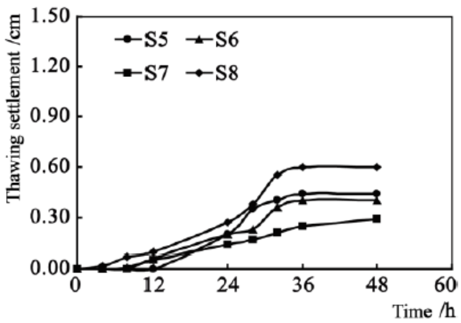


Figure 13: Soilbags-treated canals thawing settlement in a closed system 10.

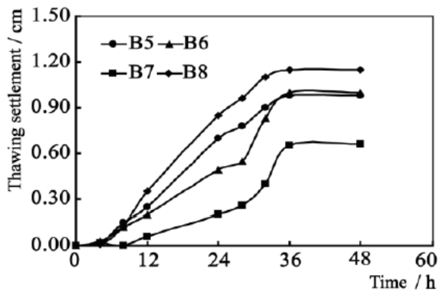


Figure 14: Conventional canals thawing settlement in a closed system 10.

thaw cycles. The maximum thaw settlement in the soil-bags-treated canal was 0.6 cm, and the maximum amount of thaw settlement in the conventional canal was 1.19 cm. In both cases, the amount of thaw settlement after 10 freeze-thaw cycles was greater than the amount of frost heave after 1 freeze-thaw cycle. Therefore, for both the soil-bags-treated canal and conventional canal, the soils were consolidated when subjected to different cycles of freezing and thawing. This is consistent with the actual situation in newly constructed canals.

Frost heave experiment on an open-system soil-bags-treated canal and conventional canal

Changes in the amount of frost heave in canals: The amounts of frost heave in the open-system soil-bags-treated and conventional canals after one freeze-thaw cycle are shown in Figures 15 and 16, respectively. The figures show that the maximum amounts of frost heave in the soil-bags-treated canal and conventional canal were 0.85 cm and 1.90 cm, respectively; additionally, the largest frost heave was recorded at the center of the canal side slope (S6, B6). Compared with the greatest frost heave recorded in the closed-system soil-bags-treated and conventional canals, the maximum frost heave in the open-system soil bags-treated canal and conventional canal was greater. The maximum frost heave values in the open-system soil-bags-treated and conventional canals are shown in Figures 17 and 18, respectively. The figures show that the maximum frost heaves of the soil-bags-treated canal and conventional canal were 1.41 cm and 2.10 cm, respectively, suggesting that the frost heave in the soil bags-treated canal was smaller than that in the conventional canal. Due to the reinforcement of the soil bags treatment layer and the frost heave deformation caused by the water migration in soils underneath, the amount of frost heave after 10 freeze-thaw cycles was greater in an open system than in a closed system for both the soil bags-treated canal and the conventional canal. Due to the rising of capillary water and film water in the canal model

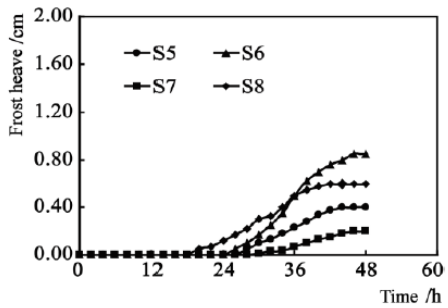


Figure 15: Soil bags-treated canals frost heave in an open system 1.

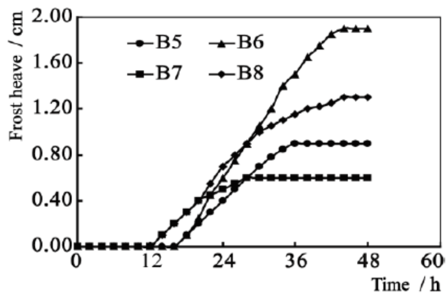


Figure 16: Conventional canals frost heave in an open system 1.

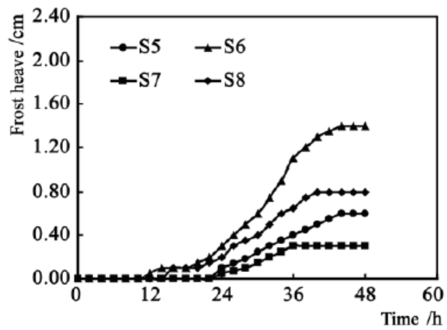


Figure 17: Soil bags-treated canals frost heave in an open system 10.

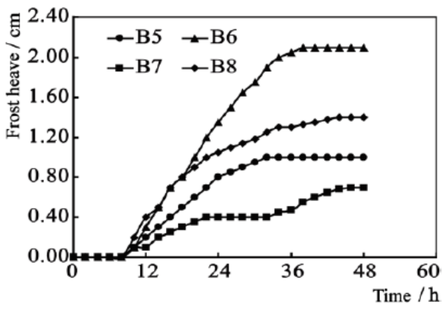


Figure 18: Conventional canals frost heave in an open system 10.

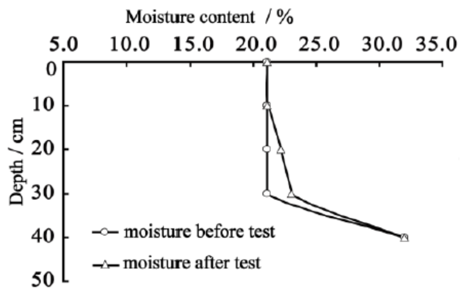


Figure 19: Soil bags-treated canals moisture content in an open system.

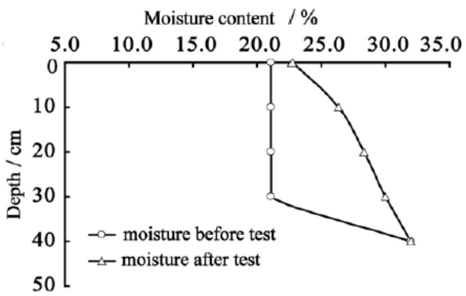


Figure 20: Conventional canals moisture content in an open system.

soils in the open system during the freeze-thaw cycle, any external water that entered the soils migrated toward the frozen fringe, forming an ice lens; the resulting volume increment was 1.09 times the volume of the migrating water, resulting in a soil frost heaving rate of several tens of percent. This is the main cause of intense frost heave in soils [1]. The experimental results show that in the open system, the largest frost heaves occurred at S6 and B6 in the soil-bags-treated canal and conventional canal, respectively. For comparison, in actual projects, the greatest frost heave occurs at 1/2 or 1/3 of the distance between the side slope surface and the bottom of the canal.

Changes in water content of canals: Figures 19 and 20 display the water contents at different depths in the open-system soil-bags-treated canal and the conventional canal system after 10 freeze-thaw cycles and before the first freeze-thaw cycle, respectively. The measurement locations in these canal models were the same as that in the closed system, as shown in Figure 18. Figure 19 shows that for the open-system soil-bags-treated canal, the water contents were 21.1%, 21.1%, 22.2%, 23.1% and 32% at 0 cm, 10 cm, 20 cm, 30 cm and 39 cm below the slope surface, respectively. Additionally, the water content of the soil-bags treatment layer was the same as that before the first freeze-thaw cycle, while the water content increased to a small degree in soils at 13 cm or more below the surface. This suggests that capillary water and film water migration occurred in soils beneath the soil-bags treatment layer, resulting in increased water content. The reason for this result is the occurrence of capillary water and film water migration in the soils of the conventional canal. The water content of the conventional canal at different depths was greater than the values recorded for similar measurements in the soil-bags-treated canal, suggesting that the amount of frost heave in the soil-bags-treated canal during freezing was smaller than that in the conventional canal. The frost heave in a lined canal changes with temperature. When the temperature decreases, ice crystals first form in the pores between the lining and the contact surface of the soil; soil water will move toward the ice crystals due to capillary force, causing the ice crystal to grow. If the temperature keeps decreasing, ice crystals will also form in the soil pores within the canal foundation. Additionally, due to capillary force, water from deeper soils migrates upward, and ice crystals gradually grow in the upper soils. As a result, frost heave also grows in the soils, and a frozen soil layer forms, resulting in an expanded soil volume and a heaving surface. Further decreases in the temperature will cause the thickness of the frozen soil layer to increase; the force of the freezing-induced frost heave can crack or heave the lining, resulting in frost heave damage in canals. Changes in the water contents of the soil bags-treated canal and conventional canal after different freeze-thaw actions demonstrate that in an open system, the soil bags treatment layer can prevent water from passing through the soil bags, thereby inhibiting the rising of capillary water and film water. Therefore, the application of a soil bags treatment to the canal side slope to a depth of 1.5 m can effectively prevent frost heave in canals in cold northern regions.

Changes in temperature of canals: Changes in soil temperature

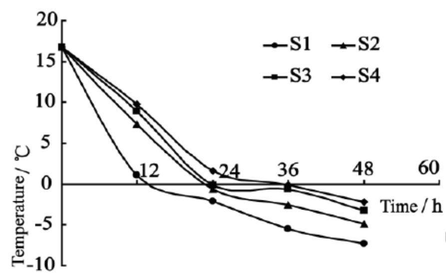


Figure 21: Soil bags-treated canals temperature in an open system.

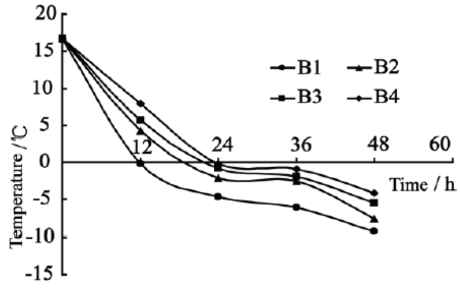


Figure 22: Conventional canals temperature in an open system.

during freezing can be divided into three phases: In the super-cooling phase, the soil water is at a subzero temperature, but no ice crystals are present. In the temperature jump phase, the soil water forms ice crystal buds, and latent heat is released during the growth of ice crystals, leading to a sudden rise in the soil temperature. Then, in the continuously cooling and freezing phase, as some of the soil water is turned into ice, the water film thickness decreases, the binding energy between soil particles and water molecules increases, and the ion concentration of the aqueous solution increases, causing the freezing temperature to continue to decrease. Figures 21 and 22 display the temperatures over time in the soil-bags-treated canal and conventional canal over 48 h in an open system. The figures show that the temperatures at 5 cm, 15 cm, 25 cm and 35 cm of depth in the soil-bags-treated canal were -7.3°C, -4.9°C, -3.3°C and -2.1°C, respectively; meanwhile, the temperatures in the conventional canal at 5 cm, 15 cm, 25 cm and 35 cm of depth were -9.3°C, -7.6°C, -5.6°C and -4.0°C. After freezing for 48 h, the temperatures at various depths in the soil-bags-treated canal were higher than that in the conventional canal. Due to the soil temperature gradient during freezing, heat was transferred from locations at higher temperatures to locations at lower temperatures. The soil-bags treatment layer in the soil-bags-treated canal reserved heat during heat transfer, resulting in temperatures at different depths of the soil-bags-treated canal model lagging behind the soil temperature.

Changes in thaw settlement in canals: The amount of thaw settlement is also an important indicator when preventing frost heave in canals. An excessively large thaw settlement in the associated soils can cause the canal lining to separate from the soils underneath; alternatively, the lining and soils can sink together and become one entity. Then, when water is flowing in the canal during operation, scouring due to the water flow and water pressure can cause the canal lining to collapse or rise, resulting in damage to the canal lining.

Figures 23 and 24, respectively, present changes in the frost heave of the soil-bags-treated canal and conventional canal subjected to one freeze-thaw cycle over 48 h in an open system. The figure shows that the maximum amount of thaw settlement in the soil-bags-treated canal after 48 h was 0.87 cm (measured at S6), while the maximum amount of thaw settlement in the conventional canal was 1.92 cm (measured at B6).

Figures 23 and 24, respectively, depict changes in the frost heave in the open-system soil-bags-treated canal and conventional canal subjected to 10 freeze-thaw cycles over 48 h. The maximum amount of thaw settlement measurements in the soil-bags-treated canal and conventional canal after 48 h were 1.21 cm (at S6) and 2.38 cm (at B6),

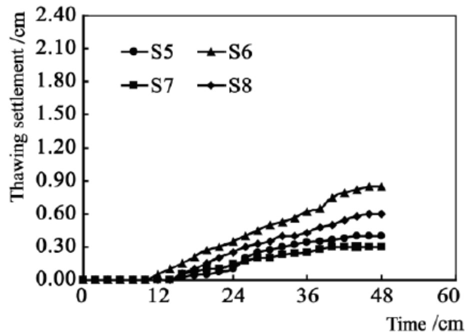


Figure 23: Soil bags-treated canals thawing settlement in an open system 1.

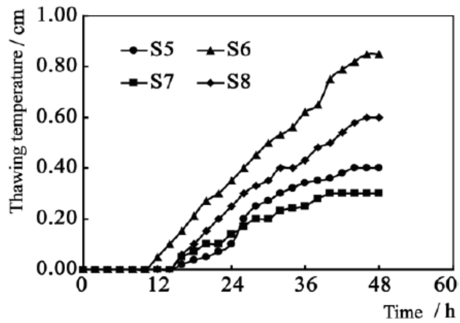


Figure 24: Conventional canals thawing settlement in an open system 1.

respectively. In comparison with the frost heave in the soil-bags-treated canal and conventional canal subjected to 1 freeze-thaw cycle, the amount of frost heave was smaller than the amount of thaw settlement after 10 cycles for both types of canals; additionally, the ultimate effect of the freeze-thaw cycles was consolidation. Changes in the amount of thaw settlement in the soil bags-treated canal were mainly caused by the consolidation of soils below the Soil bags treatment layer. The water content changes in the soil-bags treatment layer subjected to freeze-thaw cycles in the open system showed that no change occurred in the water content of the soil-bags treatment layer following the freeze-thaw cycles and that the amount of freeze heave in the soil-bags treatment layers was similar between the open system and closed system. Therefore, soil-bags treatments had a frost heave-preventing effect on the canals. The indoor model experiment has verified that soil-bags can inhibit frost heave in soils inside soil-bags, as well as the rising of capillary water and film water. In cold northern areas, the depth of frozen soils in canals is usually approximately 1.0 m. Therefore, using soil-bags to treat the soils in the top 1.0 m of a canal can produce good frost heave-preventing effects.

Conclusions

The following conclusions were drawn from the study of the characteristics of frost heave in soil-bags-treated and conventional canals subjected to freeze-thaw cycles. The mechanism of using soil-bags to prevent frost heave in canals was revealed using comparative indoor experiments; the effect of using soil-bags to prevent frost heave in canals was validated; and a new method of using soil-bags to prevent frost heave in canals was proposed. Based on the freeze-thaw model experiment on soil-bags-treated and conventional canals in open and closed systems, it was concluded that soil-bags can be used to prevent frost heave in canals. Additionally, soil-bags can reinforce the structure and inhibit capillary water and film water from passing through the soil-bags and rising. Thus, the use of soil-bags to prevent frost heave in canals is a new method. In a closed system, frost heave prevention of soil-bags-treated canals was achieved through reinforcement. The amounts of frost heave and thaw settlement of the soil-bags-treated canal were smaller than that of the conventional canal. Additionally, the amounts of frost heave and thaw settlement in the soil-bags-treated canals remained the same after 10 freeze-thaw cycles, while the amount of thaw settlement was greater than the amount of frost heave in the conventional canal. In an open system, frost heave prevention of soil-bags-treated canals was achieved by inhibiting capillary water and film water from passing through the soil-bags and rising. After 10 freeze-thaw cycles, the amount of frost heave in the soil-bags-treated canal was smaller than that of the conventional canal; the freeze-thaw cycles had certain effects on the soil-bags-treated canal; and the amount of frost heave in the soil-bags-treated canal after 10 free-thaw cycles was greater than that after 1 free-thaw cycle. Experiments on thaw settlement in soil-bags-treated and conventional canals in an open system showed that after 10 freeze-thaw cycles, the amount of thaw settlement in the soil-bags-treated canal was smaller than that in the conventional canal. A significant amount of thaw settlement can cause the canal lining to separate from the soils in the canal foundation, resulting in the collapse of the lining during water conveying. Therefore, both the amounts of frost heave and thaw settlement should be considered to prevent frost heave in canals and associated structures. The patterns of water content changes in soil-bags-treated and conventional canals varied between the closed system and open system. After 10 freeze-thaw cycles, the water content of the soil-bags treatment layer remained the same in both the closed and open systems; in contrast, in the open system, the water contents of soils underneath the soil-bags treatment layer and in the conventional canal were somewhat higher than that before the experiment, indicating that the soil-bags treatment layer can inhibit the capillary water and film water from passing through soil-bags and rising.

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