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Frost Heave Mitigation by Incorporating Expanded Polystyrene Bead into Earth Fill

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ABSTRACT: This study proposed an anti-frost geomaterial, comprising waste foundry sand (WFS), fly ash (FA), expanded polystyrene (EPS) beads, Portland cement and water, which is known as WFS-FA-EPS mixture. Twenty series of mixtures were prepared and investigated with regards to the effect of mixture component on the frost heave mitigation of the material. A freeze chamber was set up to impose frost action onto the mixtures. Results indicate that WFS-FA-EPS mixture is able to mitigate or eliminate frost heave if the mixture is properly designated. Compared with common earth fills, the mixture presents high micro-porosity, small frost heave, and low thermal conductivity. The frost heave mitigation of the mixture mainly depends on the volumetrically buffering capacity of EPS beads and cohesion force by cement content.

INTRODUCTION

Frost heave is unanimously ranked one of the top distresses occurred to most earth fills used for infrastructure works in seasonal frozen regions. In this context, it is of great importance to develop sustainable earth fill, in particular, frost heave mitigation fill, when subjected to frost action. Expanded polystyrene (EPS) block or foam has been selected as the ideal thermal isolation material (Sheng *et al*., 2006). Geocomposite was also installed within the earth fill to barrier capillary permeation (Evans *et al*., 2002). These technologies perform favorably in the field, if construction machines and space are unconstrained, which, however, may not be met in some circumstances.

An anti-frost geomaterial was proposed, which blends waste foundry sand (WFS), fly ash (FA), EPS beads, Portland cement and water in proportions. In association with the EPS bead inclusion, the WFS-FA-EPS mixture hardens into a foam geomaterial and is able to reduce thermal conductivity, buffer freezing expansion and thus mitigate frost heave, relative to common earth fills. A testing program was carried out to investigate the effect of mixture component on frost heave mitigation, in particular, the mechanism associated with the mitigation.

TESTING PROGRAM

Twenty series of WFS-FA-EPS mixtures were prepared by proportioning contents of FA, EPS, water and EPS bead by mass as a percentage of WFS content by mass. The percentages over WFS content are 0, 13%, 30% and 53% for FA content, 0%, 0.6%, 1.1%, 1.5% and 1.9% for EPS content, 0%, 4%, 6%, 8% and 12%, and 20%, 25%, 30% and 35 % for water content, respectively. The scaled components were blended homogeneously and placed into a cylindrical mold (60 mm in diameter and 80 mm in height) with light compaction. After demolded, the specimen was conditioned in a chamber (20±0.5 °C and 100% humidity) for 28 days before subjected to frost action.

Fig. 1 shows the diagram of the freeze chamber used to impose frost action onto the specimen. The freezing operation was configured one unidirectional (upward) run, having fixed temperature (−10 °C at the bottom) and slow freezing rate (1.3 °C/h), non-surcharged, and with or without water supply. The ambient temperature was maintained at 1 °C throughout the freezing operation. A thermocouple measurement was probed into the specimen at the top to monitor the temperature advance.

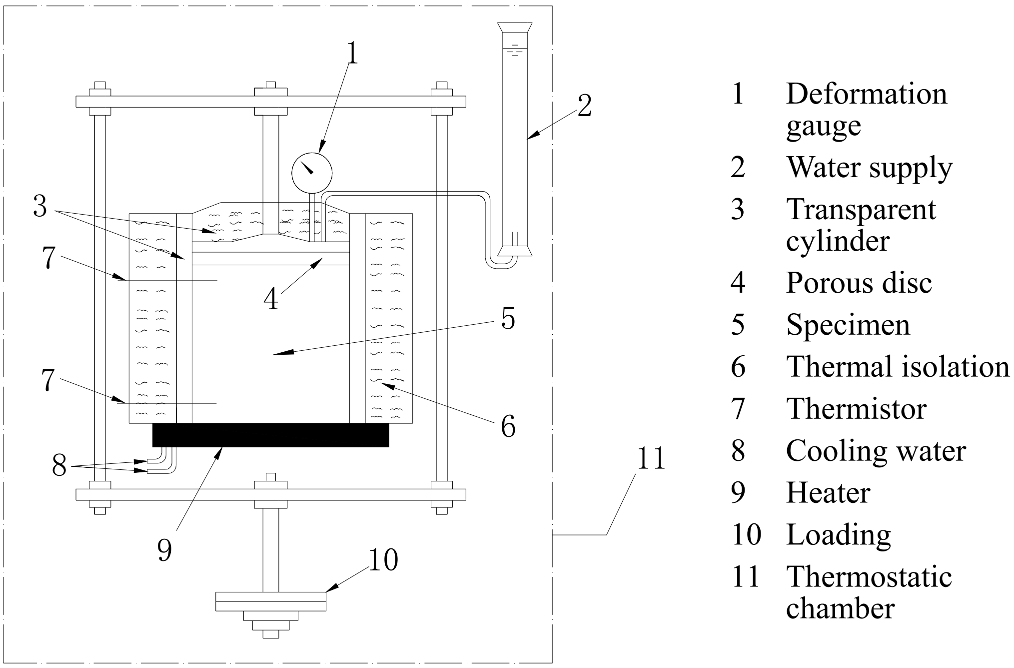

FIG. 1. Schematic of freeze chamber.

Data acquisition was automatic, including vertical displacement (i.e., frost heave) and thermal advance. The frost heave ratio η was calculated in accordance with $\eta = \Delta h / H \times 100\%$, in which Δh and H represent the final vertical displacement and the initial height of the specimen, respectively. Each series included at least two specimens, the average result of which was used as the final one. The entire freeze run for a specimen took up to 17 hours, after which the temperature at the point 1 cm below the specimen top generally reached down to −2 °C.

RESULTS AND DISCUSSION

Fig. 2 presents the effect of EPS content on frost heave ratio η, all other variable maintained constant. As expected, the increase of EPS content leads to a drastic mitigation of frost heave. When the EPS content ranges from 0.6% to 1.9%, the frost heave ratio decreases from 0.57% to −0.07%, which is well below the comparable earth fills, e.g., 4.3% for in-situ clay, 3.36% for disturbed soil, and 0.96–3.16% for lime soil (Zhang 2004). The negative value of η is associated with the mixture with EPS content of 1.9%, in the context of which the EPS freezing contraction probably outweighs the water freezing expansion. EPS content of 1.5% is a transitional ratio, beyond or within which leads to mixture frost heave or subsidence, respectively.

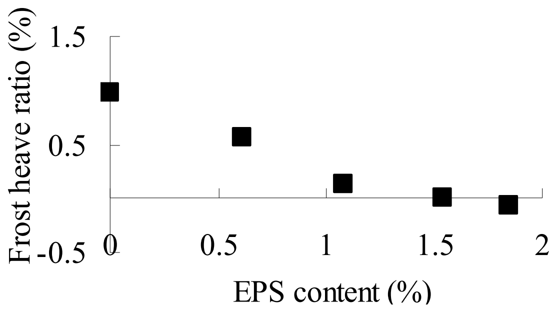

FIG. 2. Frost heave ratio versus EPS content.

Table 1 presents the results of frost heave ratios of four series of mixtures, prepared in consideration of EPS bead inclusion and water supply, all other variables maintained constant. Inclusion of EPS bead substantially mitigated the frost heave of mixtures ($\eta \leq 0.86\%$), whether or not the water was supplied. The frost heave ratios for the mixtures without EPS inclusion are of great difference, increasing by 11 folds, from 0.98% if water was not supplied to 11.69% if supplied. That is, given the water supply, EPS bead significantly buffered the freezing expansion, which is paramount for earth fills exposed to moisture permeation in the field.

Table 1. Frost Heave Ratio in Consideration of EPS Inclusion and Water Supply

Series	Without Water supply	With Water supply
EPS=1.1%, C=8%, FA=30%, W=30%	0.12%	0.86%
EPS=0%, C=8%, FA=30%, W=30%	0.98%	11.69%

C: cement content, W: water content.

Inclusion of EPS beads mitigates the frost heave by volumetrically buffering the freezing expansion. It is well known that frost heave is basically associated with freezing free water into ice crystals or lens, which increases the water volume by 9%. As a foamed matter, EPS bead contains numerous micro-porosity which leads the matter elastic if exposed to pressures. The frost heave mitigation is particularly clear if the matrix is open for water supply to permeate. It is seen that the heave ratio is mitigated from 11.69% to 0.86%, if solely adding 1.1% EPS bead into the matrix.

Fig. 3 presents the effect of cement content on frost heave ratio η for two series (i.e., EPS content=0% and 1.1%), all other variable maintained constant. The frost heave decreases along with the increase of cement content, which means that the cement hydration is able to mitigate the freezing expansion. Such fact also stands for series excluding EPS inclusion. Plus, in the context of EPS inclusion, 0–4% cement content in the mixture leads to a sound mitigation of frost heave. As the frost heave is clearly controlled given the inclusion of EPS beads, it is implicated that EPS inclusion outweighs cement with regards to the capacity of frost heave mitigation.

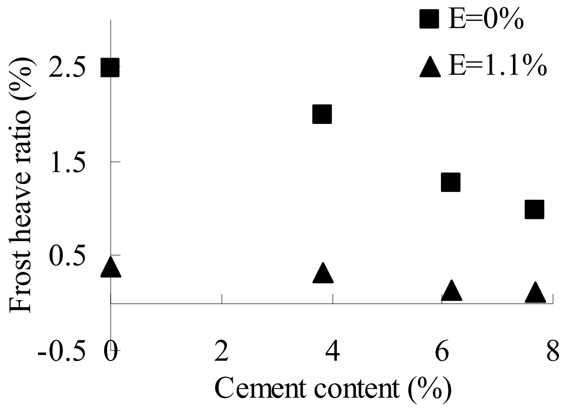

FIG. 3. Frost heave ratio versus cement content.

The mitigation of frost heave by cement content is possibly ascribed to gain in two properties, i.e., cohesion and densification. Cohesion gain suppressed the volumetric expansion upon frost action. In addition, the unfrozen water content is reduced due to the cement hydration, which controls the water supply used to grow ice crystals or lens. The gain in densification due to cement hydration reduces free water volume and permeation channels in the mixture, and thus controls the water supply to grow ice crystals or lens.

Fig. 4 presents the effect of water content on frost heave ratio η, all other variable maintained constant. Albeit frost heave increases with water content increase, the frost heave ratios of the mixtures are relatively low and vary marginally, ranging from 0.1–0.25%. That is, every 1% increase in water content leads to 0.01% increase of frost heave ratio, which is favorable compared to the much higher increase for common earth fills, e.g., clay 0.48% for silty clay (Zhang 2004). The frost heave mitigation is related to the EPS inclusion of 1.1% and cement content of 6% for the series of mixtures presented in Fig. 4. As aforementioned, EPS bead inclusion and cementation cohesion enhance the mitigation of frost heave. In this context, frost heave by water content increase is well offset by the anti-frost resistance rendered by EPS bead and cement.

Besides heave magnitude, frost heave rate can also be mitigated, if the freezing advance rate is controlled. Fig. 5 presents the effect of EPS content on thermal conductivity, all other variable maintained constant. Fig. 6 presents thermal (freezing) front advance at the point 1 cm above the specimen bottom, for the same series of mixtures upon frost action. It is seen that increase of EPS inclusion leads to the decrease of thermal conductivity and thus the thermal advance in the mixtures, which is favorable if ambient frost action lasts shortly and limitedly, e.g., controlled frozen depth, less water permeation, and marginal frost heave. The controlled thermal advance is ascribed to the low thermal conductivity of EPS matter, which is around 0.041 W/m·K.

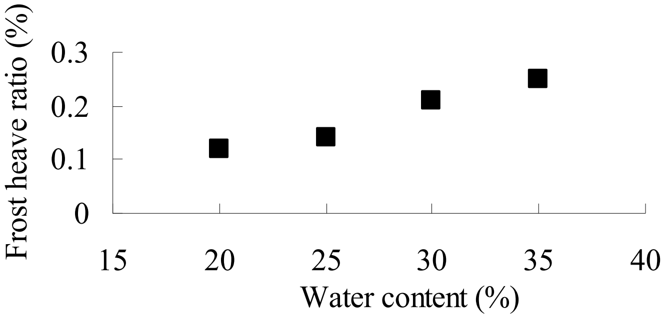

FIG. 4. Frost heave ratio versus water content.

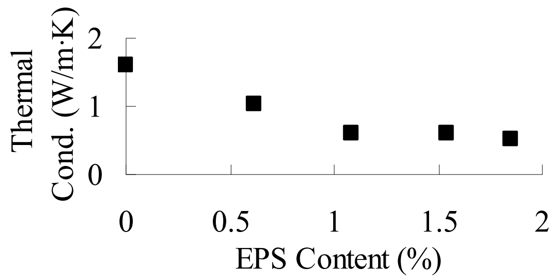

FIG. 5. Thermal conductivity versus EPS content.

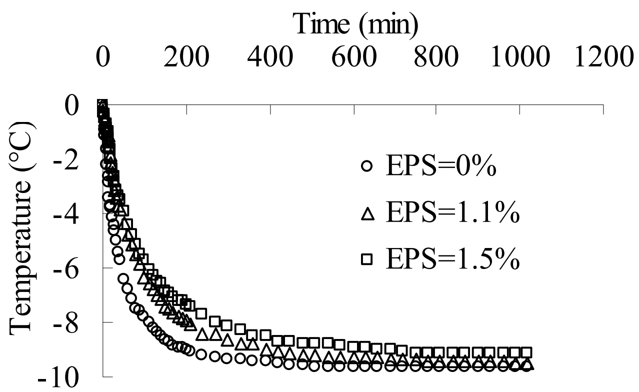

FIG. 6. Thermal advance versus EPS content.

Table 2 lists the frost heave ratios of common earth fills, including the WFS-FA-EPS mixtures investigated in this study. Freeze configuration was set comparable, i.e., one freeze run with water supply. It is seen that WFS-FA-EPS mixture demonstrates mitigated frost heave compared to common fine soils or artificial geomaterials, and is recognized as a choice of non-frost susceptible material in seasonal freezing regions.

Table 2. Frost Heave Ratio of Common Earth Fill

Earth Fill	Frost Heave Ratio (%)
Granitic aggregate with varied kaolinte content [a]	2.8–11.0
Clay to silty clay [b]	2.48–9.16
Silty Sand [b]	0.15–0.50
Tibetan laterite [c]	0.2–3.4
WFS-FA-EFS mixture	0.86

Sources: [a] Konrad and Lemieux (2005); [b] Zhang (2004); [c] Zhou *et al*. (2009).

Frost heave is one of common distresses occurred to most earth fills for infrastructure works constructed in seasonally frozen regions. As a foam material, WFS-FA-EPS mixture mitigates the frost heave mainly through the buffering capacity of a good number of EPS beads incorporated into the earth fill matrix. The capacity is associated with the elastic behavior and the low thermal conductivity of EPS matter. Besides the buffering capacity of EPS bead, the frost heave is also mitigated, excluding the cementation factor, through the cementation cohesion and densification, which resists the freezing force and suppresses the growth of ice crystals or lens.

CONCLUSIONS

WFS-FA-EPS mixture presents enhanced resistance against frost heave compared to the common earth fills. Frost heave can be mitigated, in both magnitude and rate, by increasing EPS bead content up 1%, cement content up to 4%, and decreasing water content down to 20–25%, based on the mass of WFS. The frost heave is mainly associated with the buffering capacity and low thermal conductivity of EPS beads.

ACKNOWLEDGMENTS

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REFERENCES

Evans, M.D., Henry, K.S. and Hayden, S.A. *et al*. (2002) "The use of geocomposite drainage layers to mitigate frost heave in soils." *Cold Regions Engineering Cold Regions Impacts on Transportation and Infrastructure*, ASCE, Reston/VA: 323-335.

Konrad, J.M. and Lemieux, N. (2005). "Influence of fines on frost heave characteristics of a well-graded base-course material." *Can. Geotech. J.*, Vol. 42(2): 515-527.

Sheng, Y., Wen, Z., Ma, W., *et al*. (2006). "Long-term evaluations of insulated road in the Qinghai-Tibetan plateau." *Cold Regions Sci. & Technol.*, Vol. 45(1): 23-30.

Zhang, T. (2004). "Frost-Heaving and Thaw-Weakening Behavior of Artitical freezing Soil." *A Thesis of Nanjing Forestry University*, 2004, Nanjing: pp. 62. (in Chinese)

Zhou, G.Q., Hu, K. Shang, X.Y., *et al*. (2009). "Test and numerical simulation on frost heave in frozen soils in intermittent freezing mode." Procedia Earth & Planet. Sci., Vol. 1(1): 512-518.