AN OUTDOOR EARTH-TANK EXPERIMENT ON THE IDENTIFICATION OF FACTORS BEHIND THE DEFORMATION OF REINFORCED EARTH WALLS MADE USING GEOTEXTILE MATERIALS AND RELATED PREVENTIVE MEASURES

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ABSTRACT

An increasing number of applications are being found for reinforced earth walls made using geotextile materials, which enable the effective use of surplus soil and the construction of steep slopes on road embankments and in other land development work. While the deformation of such walls due to frost heaving has been reported in cold regions, few studies have addressed countermeasures for the phenomenon. Accordingly, full-size models were created in an outdoor earth-tank, and strain/deformation were monitored over a period of three years to obtain measurements of the reinforced walls deformed in freezing conditions. Simultaneously, measures focusing on replacement, drainage and heat insulation were implemented to control deformation caused by frost heave, and were compared with the standard method. As the data obtained confirmed that the heat insulation measure had some effect, it was used in frost-heave control work around existing reinforced earth walls to prevent freezing. Full-size reinforced earth walls were also constructed on the ground with a focus on the heat insulation method, and the results were compared with those of the standard method.

The outcome showed that strain and deformation caused by frost heave continued after thawing, and worsened when freezing occurred the following winter. In contrast, the replacement method proved to be the most effective approach for controlling frost heave-related deformation of reinforced earth walls made using geotextile materials. It was also revealed that the technique was effective for controlling frost heave in existing reinforced earth walls with the installation of insulating materials.

Keywords: Frost-heaving, experiment, geotextile, reinforced earth walls

INTRODUCTION

In cold regions, cases of frost heave-related deformation in soil walls reinforced with geotextiles have been reported. An example of this is seen in Fig. 1a, in which wall surface materials are exposed and the wall surface has detached due to frost heave. To support the establishment of measures against this problem, a full-size model was built with focus on displacement, drainage and heat isolation, and the related distortion and deformation effects were measured. Comparison of the measurement results with those for the standard construction method showed that transformation caused by frost heave can be prevented using the displacement and heat insulation methods. Two types of frost heave prevention works based on the heat isolation method were also applied outside a pre-installed reinforced soil wall, and their effectiveness was evaluated. This report outlines the process of the experiment.

EXPERIMENT METHOD

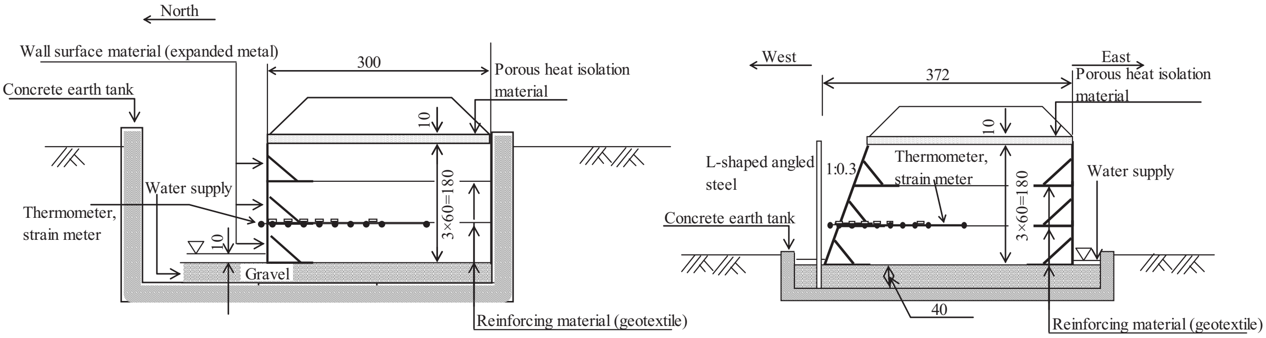
Reinforced Soil Wall Structure

At the Tomakomai construction site of the Civil Engineering Research Institute for Cold Region, three types of frost heave prevention works (displacement, drainage and heat insulation) were installed using a transition-adjustable experimental earth tank for a geotextile-reinforced soil wall with the soil shown in Table 1 as a banking material. This material is highly workable volcanic ash with a cone index of 3,000 kN/m^2 or greater, determined by traffic ability test. However, the risk of frost heave in such soil is considered medium, meaning that the frost heave may occur. In addition, a heat isolation measure was taken in 2009 to prevent frost heave in the reinforced soil wall. Furthermore, a full-size reinforced soil wall was built above ground with a focus on the heat isolation method to enable comparison with one built using the standard method.

Fig. 1a Reinforced soil wall deformation

Table 1 Basic properties of the banking soil material

Sample		Volcanic ash
Soil particle density ρs (t/m^3)		2.470
Natural water content wn (%)		46.98
Consistency limit		N.P.
Ground material classification symbol		SVG
Frost heave	Frost heave progression rate (mm/h)	0.27
	Freezing expansion rate (%)	18.1
	Risk of frost heave: medium	Medium
Hydraulic conductivity k (cm/sec)		2.34×10^{-5}
Maximum dry density ρdmax (t/m^3)		Undefined

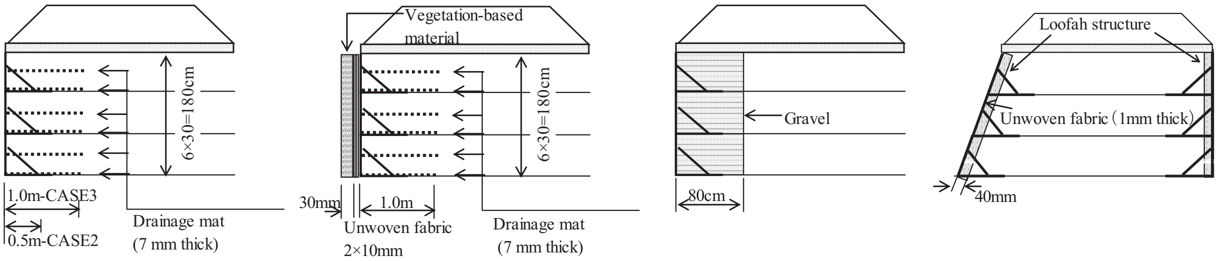


Unit: cm

a Cases 1 through 5

b Case 6

Fig. 1b Reinforced soil wall shapes



Case 2, Case 3 (2008)

Case 3 (2009)

Case 5 (2008)

Case 6 (2009)

Fig. 2 Experimental cases

Figures 1b and 2 show typical cases with a reinforced soil wall installed, and Table 2 shows the specifications of the frost heave prevention work. On the drainage sand layer in the earth tank, a reinforced soil wall composed of three layers of banking soil (each 60 cm thick per stage of the steel wall surface) was constructed. In 2008, the standard method (Case 1) with no frost heave prevention measure, the drainage method (Case 2, Case 3), the heat isolation method (Case 4) and the displacement method (Case 5) were implemented. In 2009, the heat isolation measure – the easiest of the methods to apply – was implemented. In 2008, three sheets of 10-mm-thick unwoven fabric were laid on a drainage mat in Case 2, and two sheets of 10-mm-thick unwoven fabric (20 mm in total) and a 30-mm-

Table 2 Frost heave prevention work specifications

CASE	Specifications	Year	Remarks	Wall surface direction	Slope
1	Standard	2008	Earth tank	North	Vertical
2	3 sheets of 10-mm-thick unwoven fabric Drainage mat (7 mm thick, 0.5 m long)	2009 2008	Earth tank	North	Vertical
3	2 sheets of 10-mm-thick unwoven fabric + 30-mm-thick vegetation-based material Drainage mat (7 mm thick, 1.0 m long)	2009 2008	Earth tank	North	Vertical
4	Heat insulation material on the wall surface (30-mm-thick coconut mat)	2008	Earth tank	North	Vertical
5	Displacement with sand (0.8 m from the wall surface)	2008	Earth tank	North	Vertical
6-1 6-2	Nil (standard) 80-mm-thick loofah structure + 1-mm-thick unwoven fabric	2009	Above ground	East, west	Vertical, 1:0.3

thick vegetation-based material were laid in Case 3. In 2009, a reinforced soil wall was also constructed (CASE6) with a combination of two sheets with a 40-mm-thick loofah structure and 1-mm-thick unwoven fabric installed on the back of the soil wall material. The inclinations of the slope in Case 6 were vertical (eastward) and three minutes (westward).

On actual sites, frost heave may occur when water is supplied from the back of the reinforced soil wall. As no such supply was possible here due to the structure of the earth tank, a state of water immersion up to the top surface of the reinforced soil wall was maintained until frost heave began, water was drained off immediately before frost heave, and the water level was lowered to approximately 10 cm above the drainage sand layer in Case 1 through Case 5. In Case 6, as the banking soil of the reinforced soil wall could not be immersed in water, running water was supplied from its top surface until freezing began. In all cases, to allow cooling only from the wall surface, the top of the banking soil was covered with a 20-cm-thick heat insulation material, which was then covered with 50 cm of thick volcanic ash.

Measurement Items

For each reinforced soil wall, the specifications shown in Table 3 were used to measure the temperature around the bottom of the second-stage banking soil, distortion at the top and bottom surfaces of the geotextiles installed at the bottom surface of the banking soil, the earth temperature

Table 3 Measurement items and intervals

Measurement item	Measurement location	Measuring instrument	Measurement method	Measurement interval
Temperature	In the air 10 cm outside the second-stage wall surface	Thermocouple	Auto	1 hour
Geotextile distortion	Top and bottom faces of the second-stage reinforcement material 10, 30, 50, 70, 90 and 140 cm from the wall surface	Distortion gauge	Auto	1 hour
Earth temperature	Around the top surface of the second-stage reinforcement material 10, 30, 50, 70, 90 and 140 cm from the wall surface	Thermocouple	Auto	1 hour
Horizontal displacement of the wall surface material	Top and bottom of the first and second stages from the top of the reinforced soil wall	Rule	Manual	1 week (freezing season) 2 weeks (thawing season)

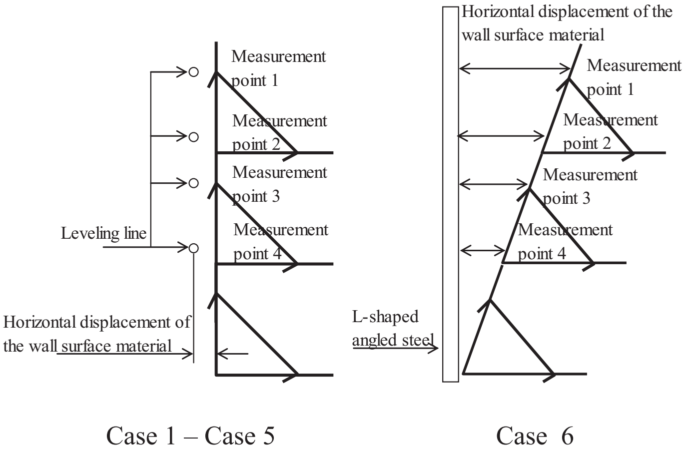


Fig. 3 Displacement measurement location

(see Fig. 1) and the horizontal displacement of the wall surface material. In Case 1 through Case 5, the horizontal displacement of the wall surface material was measured at the locations shown in Fig. 3, and in Case 6 the position from the angled steel installed in the concrete earth tank was measured.

TEST RESULTS

Freezing Depth of the Reinforced Soil Wall's Banking Soil

Figure 4 shows the freezing depth of the reinforced soil wall's banking soil. The depth was averaged among the positions where the temperature changed from above-zero to sub-zero values, and was set at the position where the temperature was zero degrees. Table 4 shows the freezing index at the test construction site.

The effects of the drainage measure in Case 2 and Case 3 were compared with those seen in Case 1. In 2008, the freezing index and freezing depth increased in the order of Case 1, Case 2 and Case 3. Accordingly, there is a low likelihood that the drainage measure reduces the freezing depth. Case 2 and Case 3 involved a heat isolation measure taken from the outside of the reinforced soil wall constructed in 2009. At that time, when the measure was taken, the freezing depth was 10 cm less than that seen with the standard construction method for both Case 2 and Case 3 even though the freezing index was large. As the same result was also observed in 2010, the heat isolation measure is assumed to be effective for at least two years after its implementation.

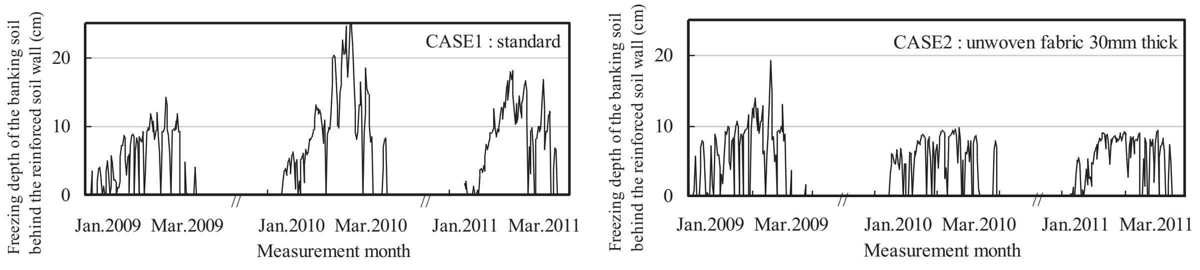
In Case 4, where the heat isolation measure was implemented in 2008, the freezing index was larger than in Case 1, Case 2 and Case 3 but the freezing depth was small, indicating that coconut mats are effective for heat insulation. In 2009 and 2010, however, only the freezing depth decreased by about 5 cm and the heat isolation measure became less effective than in the first year. Since coconut mats are made of natural plant fiber, their heat isolation capability may have decreased with time. The duration over which a heat isolation effect can be expected may therefore be short.

In Case 5, no freezing was observed in the banking soil after construction, indicating the effectiveness of the displacement measure.

In Case 6, the freezing depth achieved by applying the heat isolation measure for vertical slopes was about half that seen with the standard construction method, both in 2009 and 2010. For the slope with an inclination of 3 minutes (not shown here), the freezing depth achieved by applying the heat isolation measure was a quarter of that seen with the standard construction method. The effectiveness of the heat isolation measure was thus confirmed.

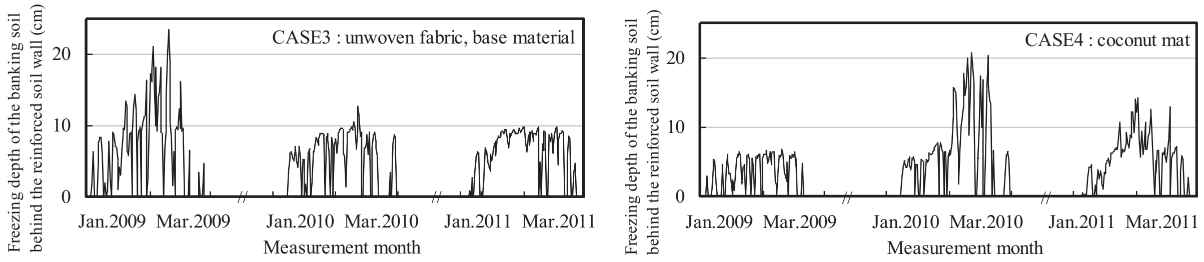
Horizontal Displacement of the Wall Surface Material

Figure 5 shows Case 1, Case 4 and Case 5 as examples of horizontal displacement in the wall surface material. Overall, the material began to undergo displacement toward the outside as it froze, moved slightly back toward the inside when the banking soil material thawed completely, and was then displaced toward the outside of the banking soil again in the next freezing season. Horizontal displacement of the wall surface material was accumulated when freezing was repeated. Figure 6 shows the maximum horizontal displacement in the observation year for each case. With the standard construction method used in Case 1 and Case 6, the



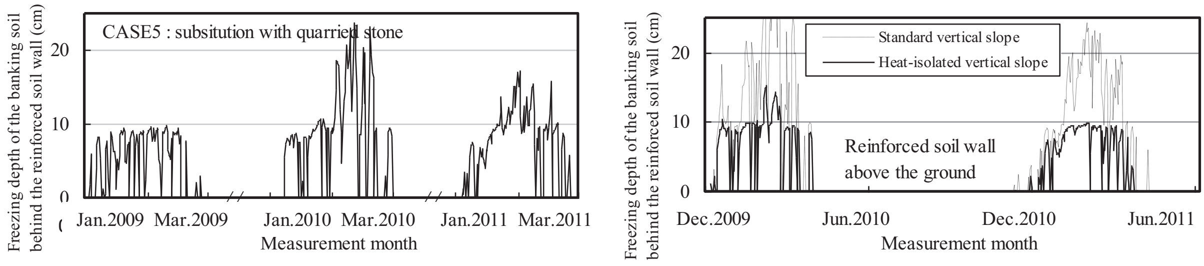
a. Case 1

b. Case 2



c. Case 3

d. Case 4



e. Case 5

f. Case 6

Fig. 4 Freezing depth of the banking soil behind the reinforced soil wall

Table 4 Freezing index of the test construction site (°C・days)
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Observation year		2008	2009	2010
Earth tank	CASE1	106.0	159.9	130.0
	CASE2	204.3	255.7	219.9
	CASE3	227.3	275.8	306.5
	CASE4	244.9	359.8	407.4
	CASE5	234.4	365.6	369.6
Above ground	Vertical heat isolation		360.5	374.8
	Vertical standard		390.0	404.9
	3-minute heat isolation		368.9	233.7
	3-minute standard		323.6	233.9

horizontal displacement in the first freezing season was large, and slightly decreased in the second season.

In Case 4, first-year displacement was smaller than that seen with the standard construction method, but the second- and third-year values were larger and the total displacement was second only to that in the standard method.

In Case 5, the displacement was the smallest of all the structures. The reinforced soil surface banking soil did not freeze at all during the measurement period. The horizontal displacement of the reinforced soil wall may have been caused by frozen fine particles in the purchased sand.

In Case 2 and Case 3, where heat isolation measures were taken after construction, displacement in the former with thicker unwoven

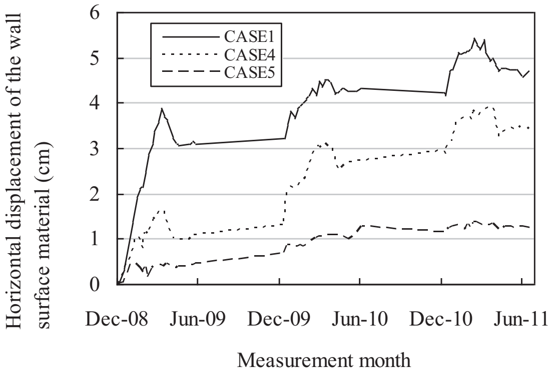

Fig. 5 Horizontal displacement of the wall surface material (CASE1, CASE4, CASE5)

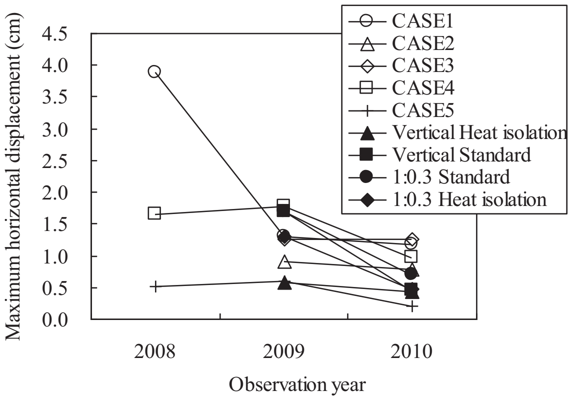

Fig. 6 Construction year and maximum horizontal displacement

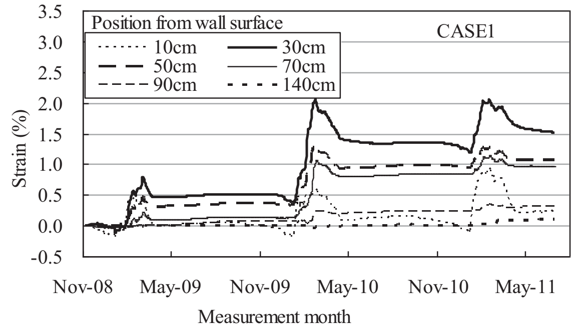

Fig. 7 Strain in the reinforced material (Case 1)

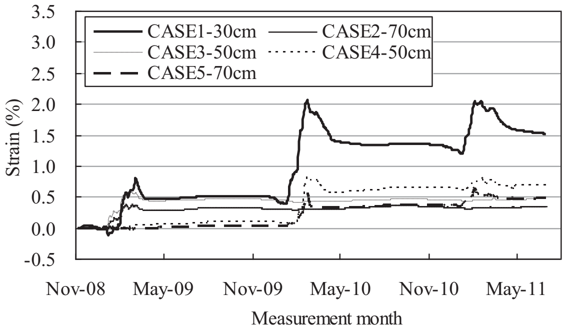

Fig. 8 Maximum strain in each case

fabric was smaller than that in the latter. Although the vegetation-based material was 30 mm thick, the heat isolation effect was lower than that of the 10-mm-thick unwoven fabric. The horizontal displacement seen in 2010 was about half that observed in 2009. The heat isolation effect is thus confirmed.

In relation to the freezing depth of the banking soil in Fig. 4, horizontal displacement tended to increase with greater depth. With the heat isolation measure, although the displacement prevention effect and the retention of the heat isolation effect differ with the type of heat isolation material used, horizontal displacement is considered to be smaller with all measures than that seen with the standard construction method.

Residual Strain in Reinforcing Material

Figure 7 shows Case 1 as an example of residual strain in the reinforcing material. Even when the banking soil material had thawed, hardly any strain was observed in the reinforcing material at a position 90 to 140 cm above the wall surface. This indicates that there is a particular depth at which strain occurs.

At other positions of 0 cm, 30 cm, 50 cm and 70 cm, strain occurred on the tension side from around the time when the banking soil froze, and decreased at around the time when it thawed. Then, the freezing season for the banking soil began with tension strain remaining, and the strain increased as the banking soil froze. This was true for all cases.

Figure 8 shows the change in strain at the location of the largest strain in the wall surface material for each reinforced wall. In Case 2 through Case 5, the occurrence of strain caused by frost heave was relatively small, indicating the effectiveness of the measure.

Figure 9 shows the maximum strain for each year at every location where the largest strain occurred in each case. With the heat isolation method for the locations of Case 2 and Case 3, little strain was observed after the implementation in 2009.

In Case 6, the strain of the reinforced soil wall with the heat isolation measure was smaller than that seen with the standard construction method, indicating the effectiveness of the measure.

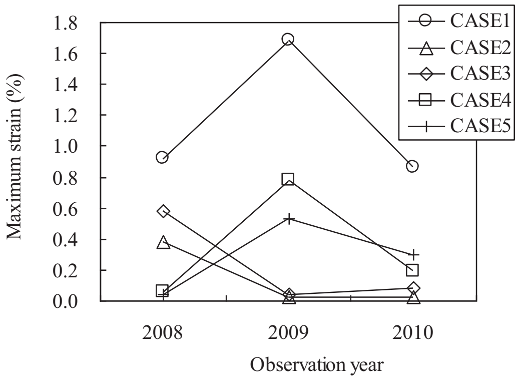

Fig. 9 Construction year and maximum strain

CONCLUSIONS

In this study, experiments on frost heave prevention measures for geotextile-reinforced soil walls in cold regions were conducted. The results can be summarized as follows:

(1) Displacement and/or strain may occur in geotextile-reinforced soil walls due to frost heave. These phenomena tend to remain and accumulate even after the banking soil thaws if frost heave recurs.

(2) Application of the substitution method using anti-frost heaving materials is very effective as a measure against frost heave in such walls. As heave can occur even with these materials if they contain large amounts of fine particles, types with a low or zero fine-particle content should be used. The substitution should also be made as deep as possible at a level equivalent to that of the maximum freezing depth; otherwise, displacement and strain caused by frost heave will not disappear and the original state will not be restored.

(3) The installation of heat isolation materials is also effective as a measure against frost heave in such walls. However, as natural materials may not provide a stable heat insulation effect, it is necessary to select appropriate materials. Additionally, installing heat isolation materials outside the reinforced soil wall may be effective against frost heave in existing structures.

(4) Although the deformation of reinforced soil walls can be prevented if the water supply to the banking soil can be stopped, drainage measures involving the use of drainage mats may not be effective in cold regions such as Hokkaido.

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