Moisture behavior on gabion faced reinforced soil wall in cold, snowy environment

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ABSTRACT: In cold, snowy regions, the gabion work has been often done as emergency or restoration measures against surface layer failures of the cut slopes arising from frost heaving or freezing-thawing. There has been developed a reinforced soil wall that has the gabions as walls and is reinforced with woven metallic wires integrated with gabions. This reinforced soil wall is expected to become popular as a reinforced soil wall suited for the cold regions, due to the high degree of drainage and following capability of the gabions. In this paper, based on the analysis of seepage flow, evaluation was made on how the change in capacity of drainage system to lower the water level in backfills affects the water level in the backfills. The result of seepage analysis of demonstrates that the drainage blanket works effective for lowering the groundwater level in backfills.

Keywords: Gabion faced reinforced soil wall, Drainage blanket, Seepage analysis

1 INTRODUCTION

In the earth retaining walls and the reinforced soil walls constructed in Hokkaido, Japan and other cold districts, heat insulating effects due to snow coverage cannot be expected because of their vertical or steep wall faces. In case where the earth filled behind the walls is susceptible to frost, the backfills can suffer from frost heaving due to the cold of the walls. In fact, broken walls and other damage have occurred due to the frost-heaving force and resultant dislocation. With this background, the manuals for design and construction of retaining walls have increasingly become to include the specifications that frost restraining layers and/or heat insulations made from highly permeable materials of high quality should be installed behind the faces of walls. In addition, in the cold districts, many cases of damaged faces of slope due to frost heaving and/or freeze-thaw cycles have been reported, and as the emergency damage control works and reconstruction and recovery works, the mattress basket (gabion) works have been adopted in many cases. The gabions are typically fabricated by steel meshes and gravels and thus, they are expected to provide high drainage capability for the snow melt in early spring and subsoil water. Additionally, they are considered capable to flexibly accommodate frost heaving and thawing-induced subsidence owing to their adequate weight. As a result, the gabion works have been widely recognized in the cold districts as effective technique against frost heaving.

On the other hand, the reinforced soil walls have been already developed which use the gabion baskets as materials for wall faces and the steel wires of hexagonal mesh as reinforcements (or wall reinforcing materials) integrated with the gabions (hereinafter referred to as gabion faced reinforced soil walls) (Gharpure et al. 2012). In consideration of the advantages available with the gabion baskets, the drainage capability and the ability to accommodate the backfills, the structural stability attained by the integrated reinforcing materials, and possible construction even in the locations of steel slope, the gabion faced reinforced soil walls are expected to become widespread as appropriate reinforced retaining walls for cold districts.

In this study, gabion faced reinforced soil walls were experimentally constructed to determine the freeze-thaw and water behaviors and also deformation behaviors and then the reinforced soil walls were evaluated for the applicability in snowy cold environment. As a results, 1) Although the permeability coefficient of the permeable heat insulating material decreases due to clogging, it is larger than the water permeability coefficient of the embankment material, 2) Deformation of the wall is small due to the progress of freezing, which is the effect of wall weight and flexibility, 3) When installing the permeable insulation material, the freezing area in the embankment is small (Kawamata et al. 2016). Therefore, the arrangement of the water permeable heat insulating material can expect long-term deformation suppression effect.

In this paper shows discussion focusing on the water behavior in the reinforced soil walls exposed to record-breaking heavy rainfall. In addition, based on the analysis of seepage flow, evaluation was made on how the change in capacity of drainage system to lower the water level in backfills affects the water level in the backfills.

2 OUTLINE OF CONSTRUCTION AND MEASUREMENT

Photo 1 shows the execution process of gabion faced reinforced soil walls constructed early in November 2015 at a soil sampling site in Bihoro-cho, Abashiri-gun, Hokkaido, Japan. In addition, Figure 1 provides a summary of dimensions of reinforced soil walls, installed points of measuring equipment and other related information. As shown in Photo 1a)), a gabion basket is 2 m-wide and 1 m-long to form one unit partitioned with a diaphragm wall in the middle, thus looking like a rectangular parallelepiped composed of two cubes, each with one-meter side length, arranged side by side. In addition, the reinforcement is 3 m in length (from the wall face). The reinforced soil wall was constructed at two locations where the slope face of cut was partially excavated in the soil sampling site (Photo 1b)). One reinforced soil wall had only conventional nonwoven fabrics (1 cm in thickness) installed behind the wall for the primary purpose of preventing drawout (Case A), and the other had permeable heat insulation materials installed on the back of baskets (Case B). The permeable heat insulation materials were intended to prevent possible freezing of soil behind the baskets due to the cold invaded from the wall faces to the backfills, while maintaining the drainage capability, an advantage of the mattress baskets, thereby enhancing the applicability to cold districts. Thus, Case B had no nonwoven fabric installed. In addition, the materials were made of expanded polystyrene of 10 cm in thickness (Photo 1c)). Each Case consisted of two (2) units per stack. In

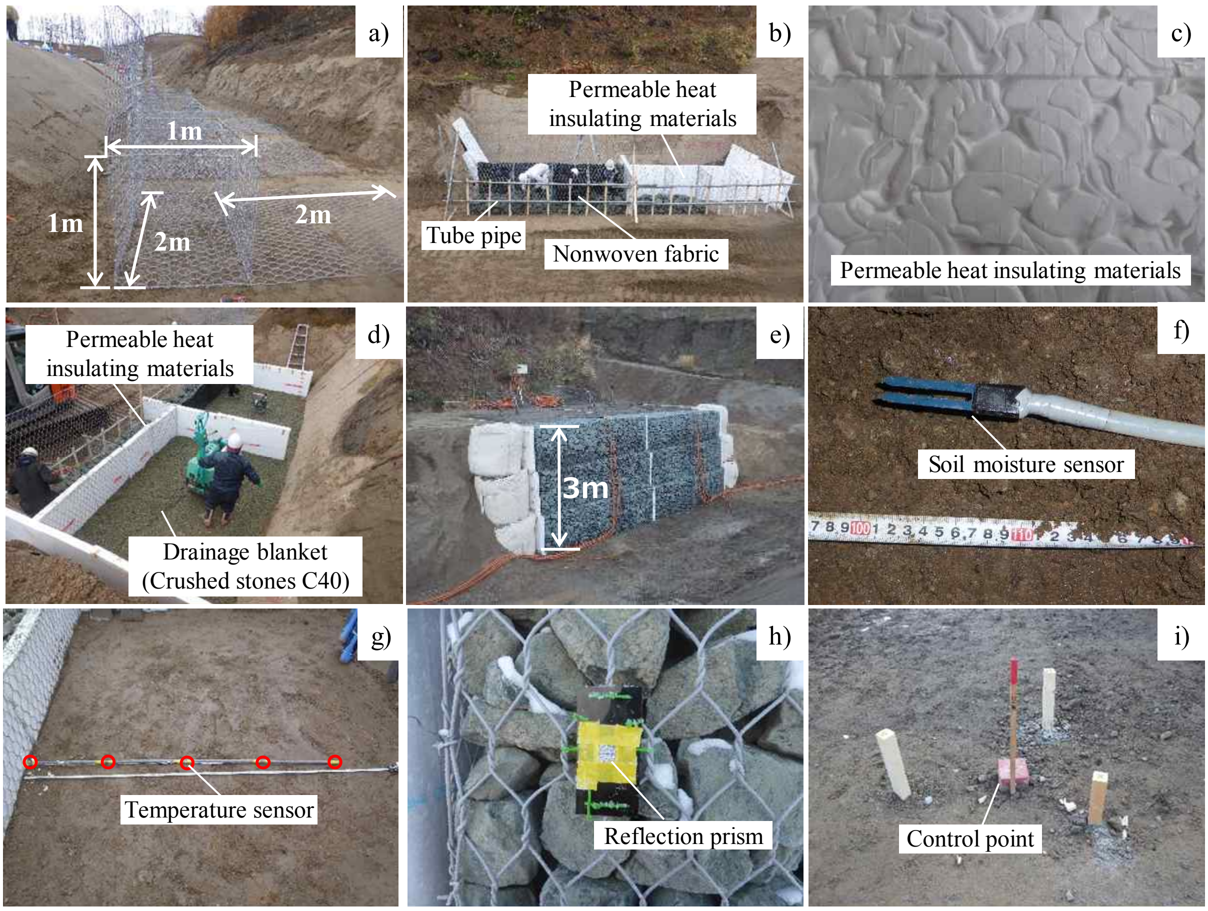
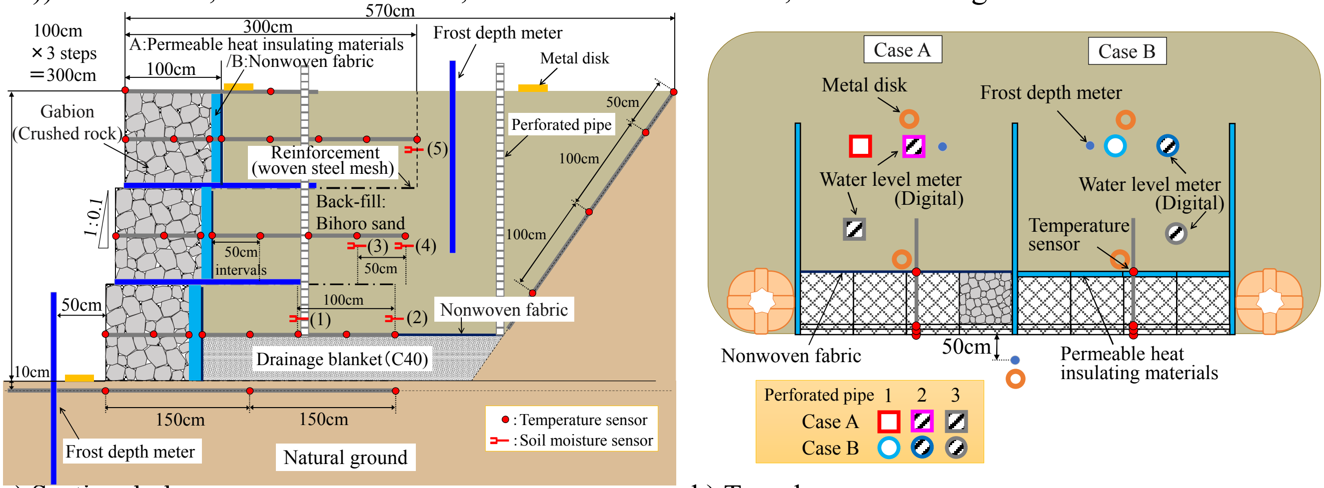


Photo 1. Caption of a typical figure. Place the caption underneath the figure.

order to prevent transverse widening in advance, securing the finished work quality using tube pipes first, the baskets were filled with cobble stones (Photo 1b)). Then, backfill materials were spread and leveled behind the baskets and rolled and compacted to a thickness of each layer of 25 cm by small vibrating rollers and/or plate compactors. In practice, however, in the both Cases, the drainage blanket was installed with crushed stones (C40) filled in a thickness of 50 cm above the base (Photo 1d)), above which nonwoven fabrics (1 cm in thickness) were laid to prevent possible drawout. The reinforced soil walls finally became 3 m in height (3 stacks) with the gradient of wall face reaching 1:0.1 (see Fig. 1 and Photo 1e)). In addition, between the Cases, and in the sides of walls, heat insulating materials were installed.



a) Sectional plan b) Top plan

Figure 1. Sectional and top plan of gabion faced reinforced soil walls

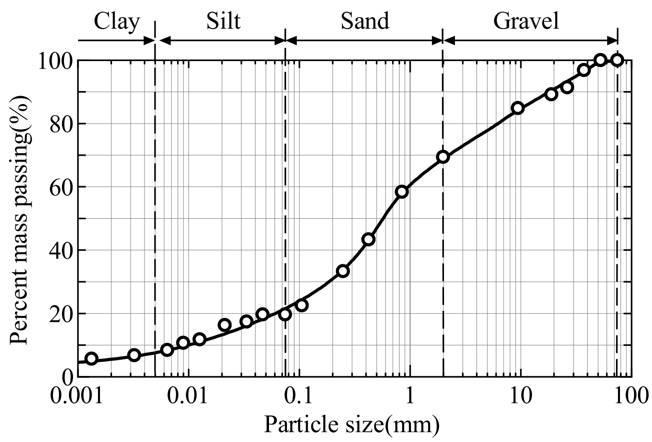


Figure 2. Grain size distributions

During the construction of reinforced soil walls, soil moisture sensors (Photo 1f)), temperature sensors (Photo 1g)), and methylene blue frost penetration depth meters were laid underground at the specified positions shown in Fig. 1. The temperature sensors were of thermistor design and they were installed at sand-filled PVC pipes at the specified intervals. Then the pipes were installed in advance in not only the reinforced soil walls but also the base (natural ground) and rear of the walls at the constructed sites to allow acquisition of thermal property values of constructional elements based on heat transfer analysis. The soil moisture sensors were arranged to allow identification of changing water contents in the backfills with rainwater and snowmelt. The methylene blue frost penetration depth meters were arranged to allow identification of any changes in frozen layers and thawed layers in the reinforced soil walls. Regarding the temperature sensors and the soil moisture sensors, continuous measurement was conducted on an hourly basis by a logger installed in the measurement box located nearby. In addition, on the wall faces, plastic plates with a seal-type reflecting prism affixed were installed (Photo 1h)) to allow measurement of displacement from the two (2) reference points defined in front of the reinforced soil walls at regular time intervals by the total station (Photo 1i)). Besides, at the levee crown and on the natural ground, metallic disks were installed for leveling with a spirit level and also measuring the amounts of frost heaving and subsidence. Furthermore, for the purpose of checking the state of drainage from walls primarily in snow melting season, two (2) stationary observation cameras were installed in front of the reinforced soil walls (see Fig. 1).

Figure 2 shows the grain size distributions of backfill materials used in the reinforced soil walls. The backfill materials are sandy soil collected in the soil sampling site (hereinafter referred to as Bihoro sand), which is classified as fine-grained gravelly-sand. The degree of compaction, D_c obtained from the sand replacement method conducted for the top after execution is found 85%. And, Bihoro sand conducted in accordance with the Japanese Geotechnical Society Standards. As the test result, the frost-heaving rate is found 0.25 mm/h and the frost susceptibility is evaluated as "moderate" (Japanese Geotechnical Society, 2009).

3 WATER BEHAVIOR AND SEEPAGE ANALYSIS

3.1 *Results of observation for water behavior*

Figure 3 shows comparison in the period from start of measurement to July 2017 for daily mean temperature, depth of precipitation and snow depth measured in the surroundings of the reinforced soil walls, changes in volumetric water content measured with soil moisture meters installed in the backfill materials, and water level in the backfills measured with perforated pipes installed behind the walls (see Fig. 1). The figure only includes the results from two (2) perforated pipes installed far from the wall face, though the perforated pipes installed closer to the wall face did not provide any observation showing water levels equal to or higher than the foundation drainage level during the measurement period (after December 2016). In addition, since the rain gages used did not have any capability of snow melting, the snowfall in winter season shown in the figure was not measured accurately, but the snow depth was based on the results of regular measurement near the walls.

From the figure, particularly the volumetric water content is found to have greatly varied in the twice snow-melting and rainy seasons. Next, taking a look at the water level in the backfills, similar to the volumetric water content, not only in the twice snow-melting seasons but also at the time of torrential rain in Hokkaido in August 2016 when Bihoro-cho suffered the largest ever 72-hour depth of precipitation (183 mm in Aug. 21, 2016) in the recorded history and even in the rainfall in June 2017 (72-hour depth of precipitation of 62.5 mm recorded in June 1, 2017), water level observation was successfully conducted with immersion rope-type water level indicators. The figure also includes the results of measurement with digital water level indicators (after December 2016), and the results from the both types of water level indicators are found showing the similar tendency. In addition, based on the comparison of water level in the backfills between the two Cases, there is no significant difference identified in the tendency between the both Cases except the greater increase observed in April 2016 in Case B. This increase may be attributed to the topographic feature that Case B includes the thick permeable layer behind the wall. However, there is also a possibility of localized infiltration of snowmelt runoff from the perforated pipes and surroundings. Thus, it is considered unclear whether this water level was formed in the entire area around the wall. In practice, however, whatever the reasons, the water level rising above the drainage blanket may have occurred in the twice snow-melting seasons and record-breaking heavy rainfalls mentioned above.

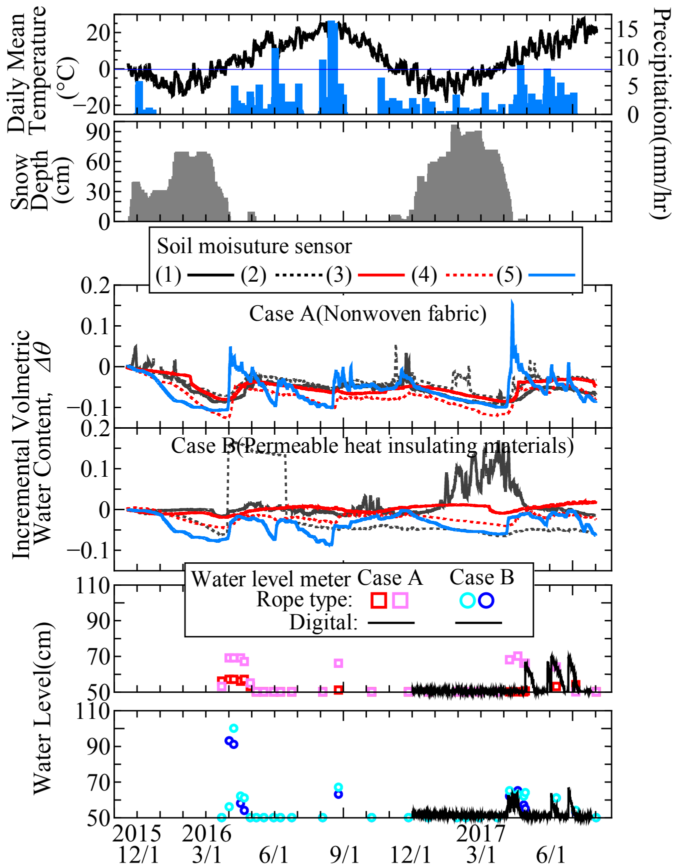


Figure 3. Time history of observation date

3.2 *Results of numerical analysis for water behavior*

The water level in the backfills can greatly affect the stability of the backfills. Under the reinforced soil walls constructed for the present study, the drainage blankets were installed with the intent to allow the groundwater level in the backfills to be lowered. However, it is unknown to what extent the length of drainage blankets affects the water level rising. Then, for the purpose of identifying how the length of drainage blankets affects the water level rising, the two-dimensional (2D) seepage analysis was conducted as discussed below.

Table 1 shows a summary of input parameters to the 2D seepage analysis conducted. The saturated hydraulic conductivity was determined with reference to the laboratory tests carried out in the past for the backfill and heat insulating materials and the other study results for the drainage blankets. For cobble stones (gabions), an extremely large value was selected on the assumption that in the seepage analysis, water level would not be formed in gabions. In addition, the analysis software used was SEEP/W (GEO-SLOPE International Ltd, 2007), a powerful finite element software product for modeling groundwater flow in porous media, the model equation for soil moisture characteristic curve was based on the van Genuchten (VG) method (Van Genuchten, 1980), and the specific permeability coefficient model was based on the Mualem-van Genuchten Formulation (Mualem, 1988).

Table 1. Parameters of seepage analysis

Material	Residual volmetric water content θ_r(m^3/m^3)	Saturated volmetric water content θ_s(m^3/m^3)	α(1/kPa)	n	Saturated hydraulic conductivity k_s(m/day)
Gabion	0.049	0.22	0.030	1.63	3×10^7
Crusher run stones	0.130	0.28	0.093	1.61	5.10
Back-fill	0.057	0.41	1.260	2.28	2.29

Figure 4 shows the analytical results of seepage flow assuming Case A in the simulation of water levels measured immediately after the record-breaking amount of rainfall in August 2016. The boundary conditions are included in the figure. On the assumption that the water level immediately after the construction of reinforced soil wall is equal to the natural ground, the analysis was conducted by exposing the levee crown and parts of the back, defined as permeable boundaries, to the rainfall and seepage. As a result of examination assuming that the daily inflow from behind the wall is equivalent to integral multiples of the daily rainfall applied to the top, selection of the multiple of 15 was found to make the water level obtained from the analysis on the day similar to the actually measured value as shown in the figure.

Figure 5 shows the results of seepage analysis when the length of drainage blanket L_B was changed. The figure refers to the comparison of the results in August 25, 2016 when the depth of precipitation was greatest. As L_B decreases, the water level tends to rise and it has risen by about 50 cm at maximum in the range of this analysis. This demonstrates that the drainage blanket works effective for lowering the groundwater level in the backfills. Additionally, adoption of stability evaluation including the seepage analysis would facilitate the construction of cost-effective reinforced soil walls, while ensuring the secure safety.

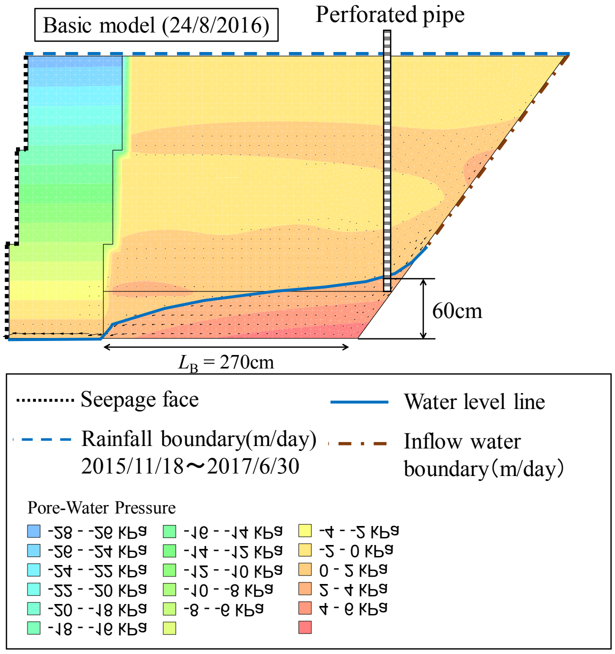
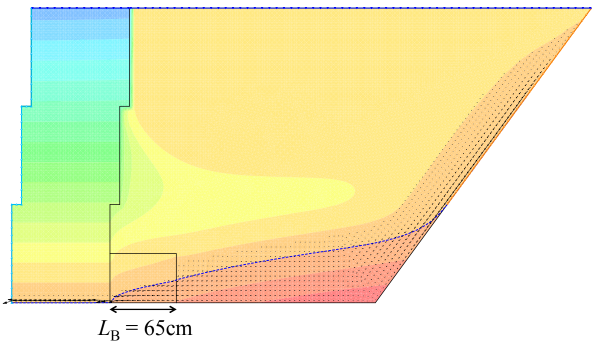
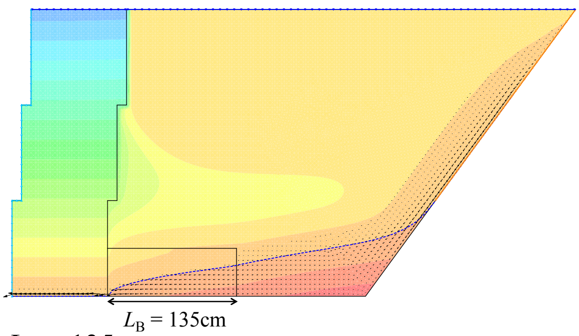


Figure 4. Seepage analysis result of basic model



a) L_B = 65cm



b) L_B = 135cm

Figure 5. Seepage analysis result of change in L_B

4 SUMMARY

- From the seepage analysis based on the assumption that daily inflow from the original earth behind the backfills is equivalent to integral multiples of daily rainfall, the simulation was successfully made to identify the water level in backfills in the event of exposure to a record-breaking amount of rainfall.
- As the length of foundation drainage layer decreases, the water level tends to rise and it has risen by about 50 cm at maximum in the range of the analysis. The result demonstrates that the foundation drainage layer works effective for lowering the groundwater level in backfills.

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