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EXAMPLE OF MEASUREMENT FOR FROST HEAVING FORCE ACTING ON FULL-SCALE GROUND ANCHOR AND SOIL NAILING

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ABSTRACT: In snowy and cold regions such as Hokkaido, ground anchor and soil nailing are damaged by frost heaves, and their functions are considered to be degraded, which is a problem in maintenance. However, the relationship between the degree of frost heaving power and the time of action and damage has not been clarified. For this reason, a design method and a maintenance management method that consider frost heave prevention technology have not been established for slope structures. To understand the mechanism of damage caused by frost heave and to study the technology for countermeasures against frost heave, a full-scale test and construction were performed on the ground anchors and the soil nailing, and the applied load was measured. For ground anchors, we focus on the free length, introduced tension load, and the pressure receiving area, and for soil nailing, we focus on the length of the reinforcing material and the area of the pressure receiving plate. As a result of the measurement, the frost heaving force exceeding the design load was applied to the ground anchors, and the ground reinforcement soil works in the winter period. It was also found that the freezing depth could be reduced by covering the ground with continuous fiber-reinforced soil and rubber mat.

Keywords: Frost heaving force, Ground anchors, Soil nailing, Frost depth, Full size

1. INTRODUCTION

In cold, snowy regions such as Hokkaido, frost heave damages ground anchors and soil nailing, reducing the functionality of these structures. Administrators have considered this damage as an issue to be addressed to improve maintenance and management techniques for these structures [1]. Studies and research have been performed in this area focusing on frost heaving pressure and the timing of damage [2-4]. However, the relationship between the degree and the period of frost heave force acting on these structures and the resulting damage has not been clarified. Therefore, design methods and maintenance and management methods that consider frost heave countermeasure technologies for slope retaining structures have not been established. To clarify the mechanism behind frost heave damage to ground anchors [5] and soil nailing [6], we constructed full-scale experiment models for these two types of soil nailing and measured the loads acting on the structures. As investigation items for ground anchors, we focused on the free length, the initial tension load, and the area of the pressure plate. For soil nailing, we focused on the length of reinforcing materials and the area of the pressure plates. We investigated a frost heave countermeasure for ground anchoring and soil nailing. The pressure plates of the ground anchors and the soil nailings were covered with continuous fiber-reinforced soil or rubber mats, which were the insulating materials and we measured and compared the temperatures of the ground under each insulation material to those without a countermeasure [7,8]. This paper summarizes the results.

2. RESEARCH SIGNIFICANCE

In cold snowy regions, frost heave damages ground anchors and soil nailing, reducing the functionality of these structures. Administrators have considered this damage as an issue to be addressed to improve maintenance and management techniques for these structures. Therefore, to solve this we conducted two types of full-scale test construction of ground anchors and soil nailing, clarified the mechanism behind frost heave damage, and examined frost heaving countermeasure technology.

3. TEST METHODS

3.1 Basic Data for the Ground Anchor Systems and The Soil Nailing

To measure the frost heave force that acts on ground anchor and soil nailing using soil nailings,

Table 1 The basic data for the constructed ground anchors

	Type	Anchoring load (kN)	Allowable load (kN) 0.6Tus(JIS) Ordinary condition	0.9Tys(JIS) During earthquakes	0.9Tys Test table	Apparent free length (m)	Anchoring length (m)	Area of pressure plate (m^2)
GA-1	PC steel wire φ15.2	70	156.6	199.8	227	7.00	10.0	3.13
GA-2						14.00	4.0	
GA-3	PC steel wires φ9.5×7	235	428.4	547.2	648	18.85	6.0	5.62
GA-4								
GA-5								
GA-6		400				18.71		4.14

Tus: Tensile load   *Tys: Yield load*

Table 2 The basic data for the constructed soil nailing.

	Type	Anchoring load (kN)	Allowable load (kN)	Anchoring length (m)	Area of pressure plate(m^2)
RB-1	SD345-D25	20	137	7.0	0.16
RB-2				5.0	
RB-3				7.0	0.10
RB-4				5.0	

Fig. 1   Installation location of ground anchor and soil nail

we constructed these two types of structures at an experiment site in Tomakomai, Hokkaido, the northernmost prefecture of Japan. The basic data for the constructed ground anchors and the soil nailing are shown in Tables 1 and 2.

The ground anchor and the soil nailing were installed at the locations shown in Fig. 1. Investigations were done comparing the target parameters set for the 6 ground anchors. The difference based on the free length was tested using GA-1 and GA-2. The difference based on the tensioning strength was tested using GA-3, GA-4, and GA-5. The difference based on the area of the pressure plate was tested using GA-5 and GA-6. Comparison investigations were also done for the soil nailing. RB-1 and RB-3 were for comparison of different lengths of reinforcement materials. The difference in the areas of the pressure plates was examined by using the pair of RB-1 and RB-3 and that of RB-2 and RB-4. The design area of the pressure plate is determined depending on the bearing capacity of the ground (the bearing power of soil), on which the pressure plate is installed, and on the design load. In the experimental installation in this study, pressure plates with different areas were used to investigate the possibility of reducing the frost heave force acting on the pressure plates according to the differences in the area. The pressure plates used with the ground anchors were steel and those used with the soil nailing were glass fiber or carbon fiber composite reinforced plastic grids.

3.2 Construction Method

We installed the ground anchors and soil nailing in-ground whose geologic columnar section is shown in Fig. 2. To equalize the conditions for frost heaving force for the ground anchors and soil nailing, we replaced the soil layer at the installation site. A 90cm- deep soil layer was replaced with frost susceptible material that has the basic physical properties shown in Table 3. When ground anchors and soil nailings are constructed on the slope, water supply from the back of the structures affects frost heaving, depending on the height of the structure on the slope. In this study, we constructed the ground anchors and soil nailing on flat ground to equalize the frost heaving conditions for all structures. The replaced material had a high frost susceptibility, with a freezing rate of 0.78mm/h [9]. The cone index of this material with natural water content was 667kN/m^2. Construction machines such as bulldozers were able to travel on this material safely; however, roller compaction machines such as tier rollers were not [10]. Because of the strength properties of the material, the testing ground was prepared by using a bulldozer. We considered that installing these structures on the slope would not result in equal water supply conditions because of the different installation heights of the structures. Therefore, we constructed the ground anchors and the soil nailing on flat ground. The covering materials were a layer of 20cm-thick continuous-fiber reinforced soil and a 2cm-thick rubber mat. Each covering material is 2m long and 2m wide, and the construction area is 4m^2.

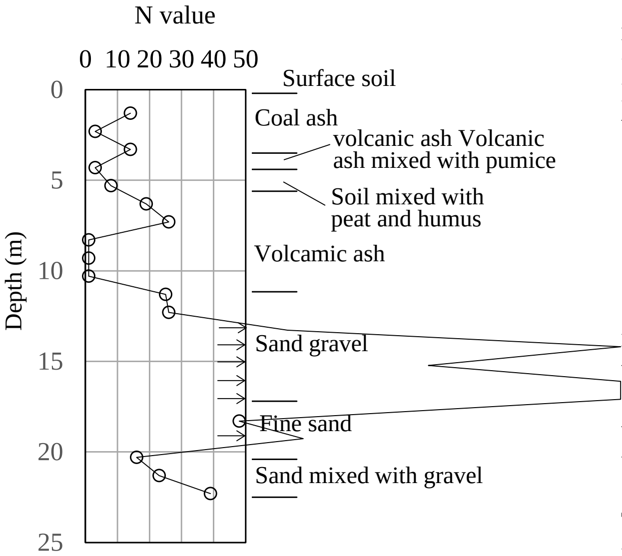

Fig. 2 Columnar section of construction site.

3.3 Measurement Method

The load acting on the pressure plate was assumed as the frost heaving force acting on the ground anchors or soil nailing. This load was measured by installing a hollowed load cell between the pressure plate and the bearing plate of each structure. To understand the freezing conditions of the ground, soil temperatures were measured by using temperature sensors installed at an interval of 10cm in the depth direction from the ground surface. The air temperature at the height of 1.5m was also measured. The load and temperatures were automatically measured every hour. The frost heave-induced displacements for the ground

Table 3 Basic physical properties of the frost susceptible material

Physical characteristics		Value
Soil particle density ρ_s (g/cm^3)		2.678
Natural water content w_n (%)		50.0
Grain size characteristics	2mm-(%)	25.6
	75µm-2mm (%)	30.9
	-75m (%)	43.5
Ground material classification		SFG
Liquid limit w_L(%)		63.3
Plastic limit w_P (%)		42.4
Cone index q_c (kN/m^2)		667
Frost-susceptible	Frost heave rate (mm/hr)	0.78
	Degree of compaction (%)	94.6
Max. dry density ρ_{dmax} (g/cm^3)		1.125
Optimum moisture content w_{opt} (%)		42.9

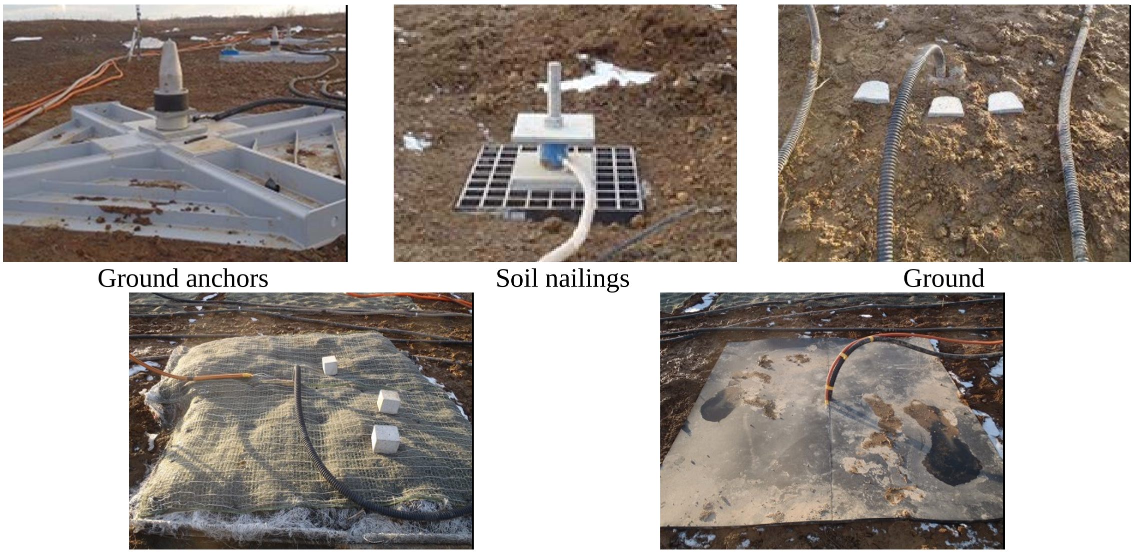

Fig. 3 Measurement position.

anchors and soil nailing were surveyed every two weeks at the locations shown in Fig. 3. The snow depth was measured at the same time as these measurements. To measure the changes in height, concrete blocks were placed as markers on the continuous fiber-reinforced soil and the ground without a reinforcing structure, and marks were painted on the rubber mat.

4. TEST RESULTS

4.1 Deformation of The Ground Anchors and The Acting Load

Fig. 4 shows the air temperature, snow depth, and freezing conditions of the ground. Fig. 5 shows the displacements of the ground anchors and Fig. 6 shows the loads acting on the ground anchors. When the ground started to freeze and the cumulative daily average air temperatures were negative, the load acting on the pressure plate started to increase. Which indicated that the frost heaving force was starting to act on the structure. After reaching the maximum, the frost heaving force gradually decreased. When the daily average air temperatures became constantly above the freezing point, the frost heaving force of the ground anchors became smaller than the fixing load. The displacement of GA-2, whose free length is greater than that of GA-1, was greater than the displacement of GA-1. The load acting on GA-2 was slightly lower than that acting on GA-1. The frost heave force was thought to be controlled in GA-2, whose free length was great. The greater displacement of GA-2 is thought to have absorbed the frost heave force. In the comparison among the ground anchors with different tension strengths

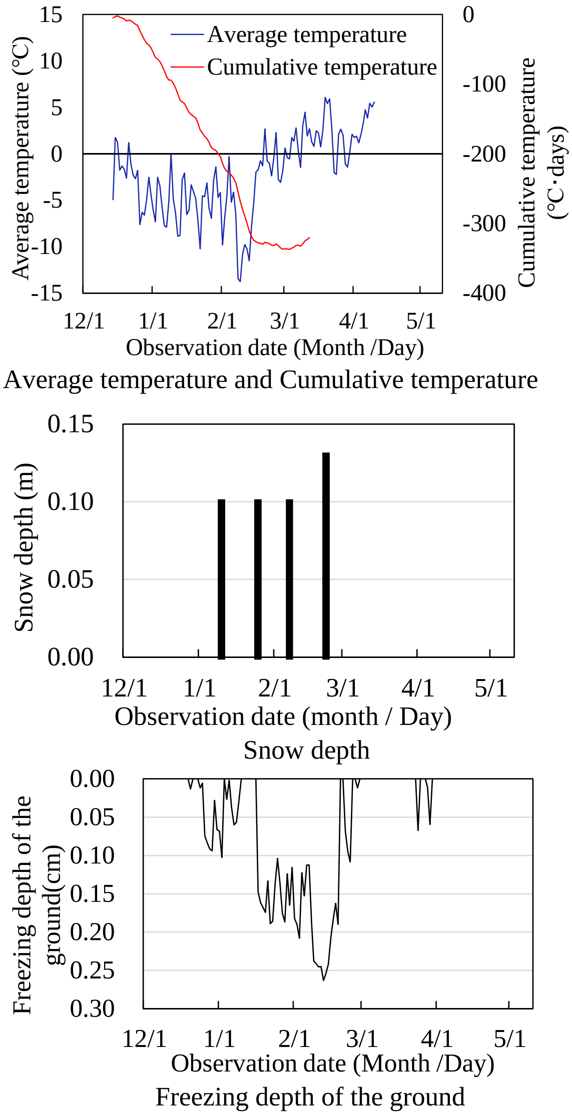

Fig. 4 Status of measurement points.

(GA-3, GA-4, and GA-5), the load was greater for GA-5, whose tension strength was the greatest. From this, we found that it is necessary to be careful about setting the tension strength of the ground anchors when installing them in the ground where frost heave force may act on them. The frost heave force acting on the unit area of the pressure plate under the same soil and freezing conditions is equal. For GA-5 and GA-6, in which the areas receiving pressure were different, the frost heave force acting on the ground anchors, whose pressure-receiving area was small, was considered to be small. In the measurement, we found that the frost heave force at GA-6, whose pressure-receiving area was small, was slightly smaller than that of GA-5. The displacement in GA-6 was also smaller than that of GA-5. In constructing ground anchors, if we only consider the frost heave force, it is possible to control that force by designing the pressure plate such that its area is small. We also found that loads that were far greater than the normal-time allowable load acted on five of the pressure plates, excluding

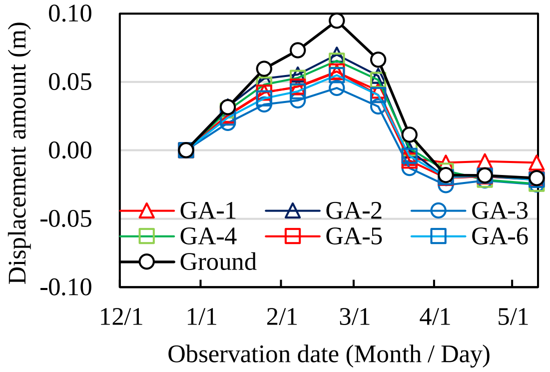

Fig. 5 Displacement amount of ground anchors.

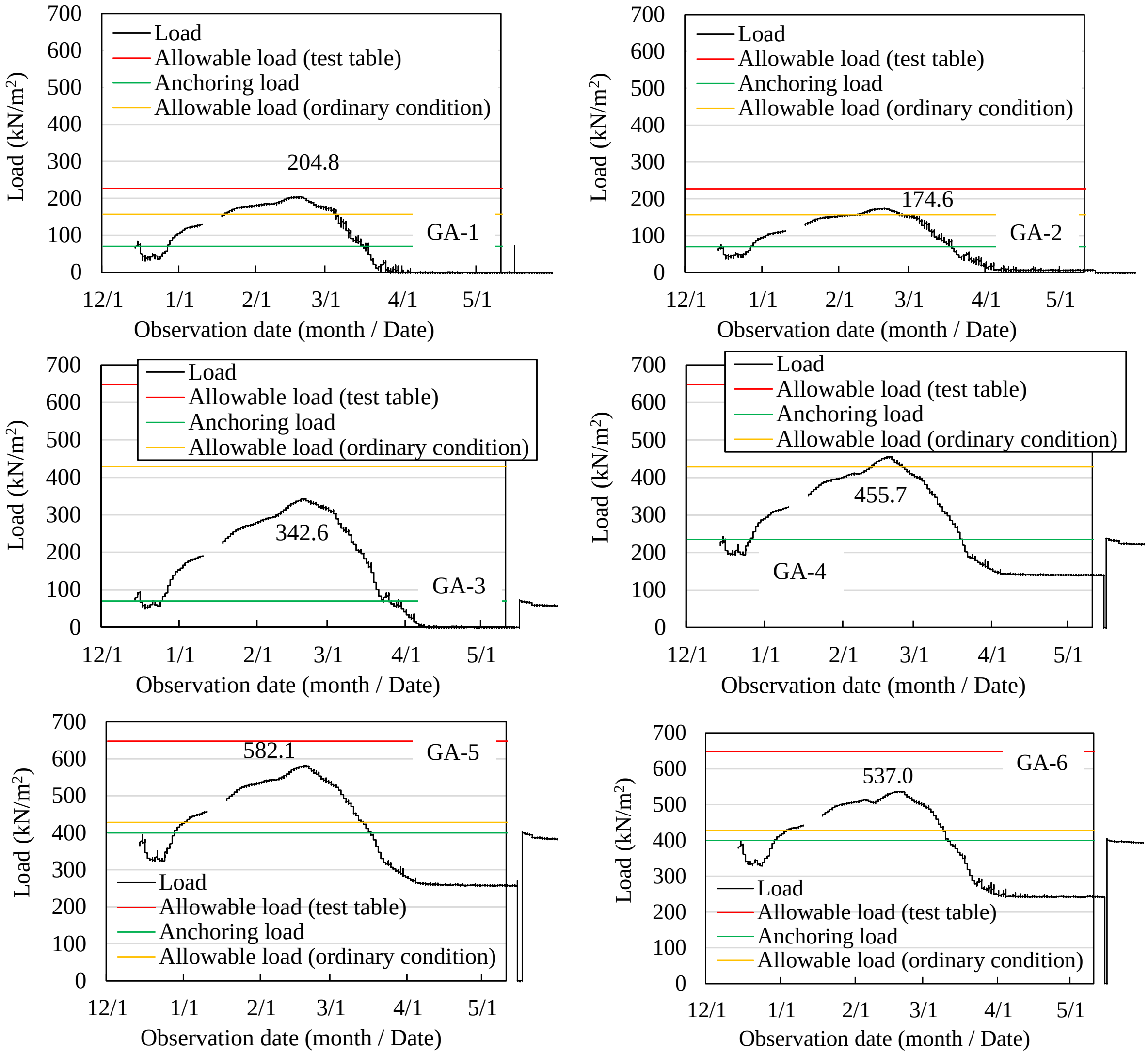

Fig. 6 Loads acting on the ground anchors.

that for GA-3. When the air temperature rose and the ground started to melt at each ground anchor, the frost heave force became small, even smaller than the original fixing load. The displacement at this time indicated that the heights of the markers were lower than the original heights. It is considered that the real fixing load for the ground anchor was smaller than the design fixing load because the ground around the ground anchors at the application of the initial tension was slightly frozen. This initial state of the ground is also considered to be why the final heights of the markers were lower than those at the start of the observation. The construction and tensioning of ground anchors should be done before the ground freezes.

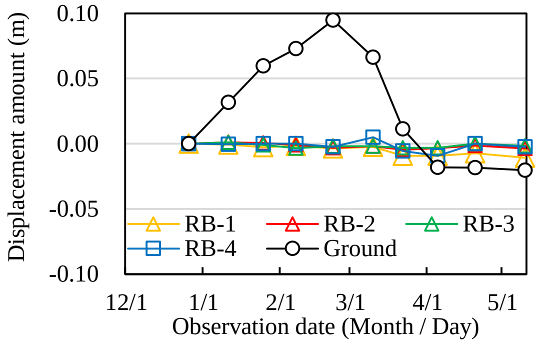

Fig. 7 Displacement amount of soil nailing

4.2 Deformation of The Soil Nailing's and the Acting Load

Fig. 7 shows the displacement of the soil nailing, and Fig. 8 shows the loads acting on the soil nailing. There was almost no displacement due to frost heaving in soil nailing. Similar to the load condition of the ground anchors, the load acting on the pressure plates of the soil nailing started to increase when the ground around them started to freeze and it became small when the frozen ground melted. It is understood that frost heave force acted on the pressure plates.

The loads acting on RB-1 and RB-2 (soil nailing with greater areas) were compared with those acting on RB-3 and RB-4 (soil nailing with smaller areas). It was found that the loads acting on the pressure plates with greater areas were slightly smaller than those acting on the pressure plates with smaller areas. When the areas of the two pressure plates were equal but the lengths of the reinforcement material were different, the loads acting on them were nearly equal.

4.3 Deformation from Frost Heaving of The Covered Structures, And Control of The Loads Acting on The Structures

The displacement of the ground depending on the difference in coverage is shown in Fig. 9. The

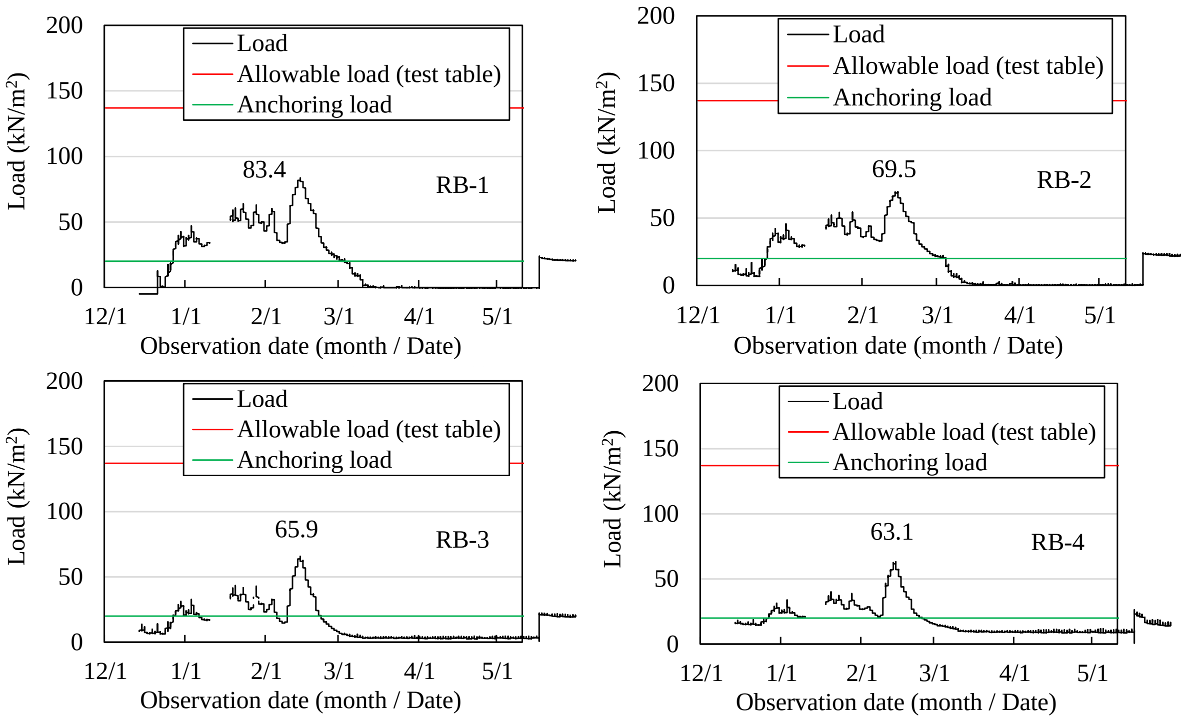

Fig. 8 Loads acting on the soil nailing

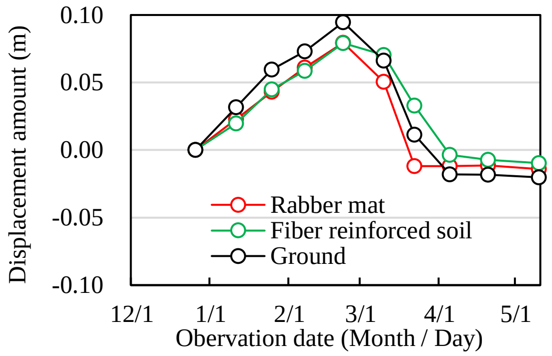

Fig. 9 Displacement of the covering part

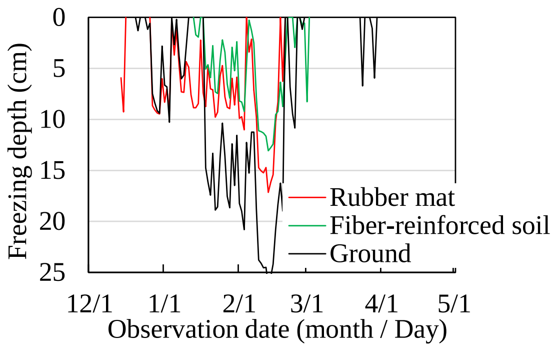

Fig. 10 Freezing depth of the ground at the covered area

frost penetration depth of the ground depending on the difference in coverage is shown in Fig. 10. The heights of the continuous fiber-reinforced soil and the rubber mat started to increase at the same time that the displacement of the ground without covering started to increase from frost heaving and these heights started to decrease when the heaving from freezing in the ground without covering started to decrease. The two test structures with covering had lower heights at the end of the measurements than before the start of measurements. This is thought to be because the ground was already frozen on the day when the measurement was started. The displacements of the soil nailings with covering were about 2cm smaller than those of the soil nailing without covering. The soil nailing covered with a rubber mat returned to its original height about two weeks earlier than the ground without covering did. The continuous fiber-reinforced soil took longer than the other two to return to its original height. The frost penetration depth of the ground without covering was the greatest, that of the rubber mat covering was next and that of the continuous fiber-reinforced soil was the shallowest. In controlling the frost penetration depth and the deformation from frost heaving, is considered effective to cover the structures with rubber mats or continuous fiber-reinforced soil.

5. CONCLUSION

Ground anchors and soil nailings were constructed on the frost-susceptible ground and deformation of the structures from frost heaving was investigated. The effects of covering on the structures were also investigated. The findings are as follows.

[1] Frost heave force that exceeded the design load (normal time) acted on the ground anchors. The pressure plates of the ground anchors were lifted with the increase in the frost heaving. The frost heave force acting on the pressure plate was greater for greater free lengths, greater tension strengths, and greater areas of the pressure plate.

[2] The frost heave force of the ground acted on the soil nailing; however, no considerable deformation from frost heaving was observed. For the pressure plate of the soil nailing with a greater area, the frost heave force was slightly greater.

[3] Covering the structures with rubber mats or continuous fiber-reinforced soil was found to be effective in controlling the frost penetration depth and the deformation from frost heaving.

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