A New Earth Reinforcement by “Panel and Nail” for Slope Protection in Cold Region

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Abstract. Newly developed earth reinforcement for slope protection was applied in cold region. The reinforcement by this method is making use of precast concrete panels with insulation and anchor nails. The precast concrete panel is economical, of high quality, durable for weathering, earthquake-resistant and of good appearance, which contribute shortening construction period and less life cycle cost. We can construct for nearly vertical slope by placing panels downward from top of slope at the same time of slope cutting, and for reinforcing of existing retaining wall by simply covering and nailing as well. Practical case of design and construction is explained, and measurement results of temperatures, forces at anchor head during cold season are shown to ensure the protection. Especially concrete panels are designed with insulation for low temperature, and the result of thermal analysis and field measurement shows the insulation works well to stop freezing front going into ground.

1. Introduction

In steep slope areas and in narrow spaces in a city, the reinforcement method is increasingly used from the viewpoint of effective and economical use of land. The earth reinforcement method is known as a highly safe structure with few damages caused by a huge earthquake or heavy rain. On the other hand, in areas where the winter temperature frequently drops below 0 °C, frost heave of ground has been damaging road structures such as concrete retaining walls and slope protections for many years. In recent years, investigation and design for slope protection methods in cold region have been discussed in the Japanese Geotechnical Society Hokkaido Branch. One of the discussion points is a necessity for considering the frost heave pressure in the design of ground anchors and ground reinforcement earthworks. The mechanism of generation of frost heave pressure to the structures was investigated, and a new design method has been proposed. It is well known that the frost heave of ground occurs when the conditions are satisfied on “temperature”, “soil property” and “moisture”. Therefore, the replacement method and the heat insulation method are frequently used in practical constructions. For this reason, it is reasonable to use the earth reinforcement method together with heat insulation material to stop the freezing line entering the ground.

Authors have performed measuring temperatures and forces of the reinforcement structures with the thermal insulation material. In this report, we show the measurement results of the soil temperature, the change of the force acting on the wall and temperature analysis, which indicates “Panel and Nail” slope protection method can be used effectively in cold region.
2. Construction and measurement of earth reinforcement works

2.1. Earth reinforcement and construction method
The advantages of this method are a) safe procedure with inverted construction technique, b) short construction period with precast panels and c) highly stable structure for slope protection. Inverted construction is performed sequentially from the top of the slope, so that the reinforced soil at the top can be kept stable during the next excavation. We can reduce the excavation area and carry out a safe excavation during construction by using this process. Figure 1 shows a schematic diagram of the general structure of “Panel and Nail” for frost protection. One unit of this structure is consisted of a steel rod and a concrete panel with width of 1800 mm and height of 1200 mm. A rigid rod (core material) is fixed at the center of the wall and a grout material is injected around the rod, so that it is closely contacted to the slope surface and holds wall in place. Photo 1 shows the construction procedure. First, the concrete is installed (Photo 1a) as a temporary base, and wall material is built in (Photo 1b and 1c). An insulating material is pasted on the back of the wall in advance. After that, the center of the wall (Photo 1d) is drilled for installing the core rod, then the rod is inserted and filled by grouting. Finally, core rod is tighten using nuts and washers (Photo 4e). After removing the temporary base concrete, we proceed excavation for the next step downward (Photo 4f). Photo 4g and Photo 4h shows appearances after construction finished.

2.2. Wall structure and measurements
The “Panel and Nail” reinforcement was constructed with a width of 70 m and an area of 240 m². As a protection against frost heaving at this site, a 100-mm-thick thermal insulation was used, which is installed behind every wall unit.

We measured, as shown in Figure 2, temperatures of ground beside the anchor rod, and forces acting on the top of anchor rod. The thermocouples were installed in a PVC pipe (outside diameter φ 25 mm) in an outer pipe (outside diameter φ 48 mm). The gap between the PVC pipe and the outer pipe, and the outer pipe and ground were backfilled with grout material. In addition, thermocouples were installed at front and back surface of the insulation materials. Load cell for measuring force was installed at the top of core rod which is protected by cap with stuffed insulation foams.

![Figure 1. Structure of “Panel and Nail”](image)

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**Figure 1.** Structure of “Panel and Nail”.
3. Frost susceptibility of ground
The main factors that cause frost heave are “temperature”, "soil property", and "moisture condition". The results of investigations about these influences at the construction site are shown below.

3.1. Temperature
The frost heave is caused by the ice lens formed by the water transported through the unfrozen film water which comes from the unfrozen part of the ground. A freezing index $F$ (°C-days) is practically used to decide the possibility of frost heave with considering the history of frost heave damages of existing roads [1].

| $n$-years | 10   | 20   | 30   | 40   | 50  |
|-----------|------|------|------|------|-----|
| $F_n$     | 508  | 563  | 595  | 618  | 636 |

Photo 1. Construction Procedure.

Figure 2. Measurements of temperatures and forces

Table 1. $n$-year probability freezing index $F_n$. 
We had to estimate the freezing index $F$ of the site because there was no temperature record necessary for the preliminary survey. The freezing index $F$ obtained from the temperature data of the nearest Observatory of Japan Meteorological Agency was used with an altitude correction. Table 1 shows the $n$-year probability freezing index $F_n$ for the construction site. The 10-year probable freezing days (115 days) from 2005 through 2015 was used to estimate the $n$-year probability freezing index $F_n$. From the results as shown in the Table 1, the $F_n$ of the construction site is more than 500 (°C·days), where frost heave protections are required according to the standard for road construction earth works [1].

3.2. Soil property

Figure 3 shows the typical profile of the construction site, and Table 2 shows the physical properties of soil. Depth of 0.00 m to 4.15 m is classified as embankment (Bk), a range of 4.15 m to 5.50 m is Diluvial clay (Dc), and a range of 5.50 m to 8.00 m is Diluvial gravel (Dg). The soil for the reinforcement contains embankment layer. The natural water content $w_n$ of the embankment is 28.4%. It was difficult to decide the frost susceptibility of the ground material because the depth of 0.00 m to 0.15 m is humic soil and the depth of 0.15 m to 4.15 m is gravel mixed silt. We examined the frost susceptibility of the soil using two different methods: indirect judgment based on grain size distribution and laboratory frost heave test for frost susceptibility of soil.

3.2.1. Indirect judgment method based on grain size distribution. Frost susceptibility of soil can be determined by the curve of the particle size distribution. Fig. 4 shows the relationship between frost susceptibility and grain size distributions [2], and the results of grain size analysis. Both the embankment (Bk) and the Diluvial clay (Dc) are judged to be a frost susceptible material as they pass through the region I.

3.2.2. Frost heave test for frost susceptibility of soil. Frost susceptibility of the materials was determined in laboratory tests. The frost heave test was performed in accordance with the “Test method for frost susceptibility of soils” [3], which categorizes the frost susceptibility of soils into three levels according to a frost heave rate $U_h$ (mm/hour) obtained in the laboratory test. The frost susceptibility of both materials is judged to be "medium frost susceptible" determined from the value of frost heave rate $U_h$. 

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### Table 2. Soil properties.

| Depth          | 2.0 – 3.0 | 4.5 – 5.5 | 7.0 – 8.0 |
|----------------|-----------|-----------|-----------|
| Density of soil particle | Mg/m³     | 2.610     | 2.585     | 2.684     |
| Natural water content | %         | 28.4      | 33.3      | 25.8      |
| Gravel          | %         | 57.3      | 30.8      | 65.1      |
| Sand            | %         | 21.1      | 33.5      | 14.8      |
| Silt            | %         | 12.7      | 25.2      | 11.4      |
| Clay            | %         | 8.9       | 10.5      | 8.7       |
| Maximum particle size | mm       | 37.5      | 37.5      | 37.5      |
| Coeff. of uniformity | -         | 1969      | 99        | 2912      |
| Liquid limit    | %         | 68.0      | 78.0      | 55.5      |
| Plastic limit   | %         | 26.3      | 29.6      | 20.4      |
| Plasticity index| -         | 41.7      | 48.4      | 35.1      |

Symbols

- Bk
- Dc
- Dg
3.3. Moisture condition
The possibility of water supply to the freezing front is one of the essential factors for frost heaving. Preliminary surveys by drilling could not confirm the groundwater level, nor found any spring water during construction. However, as mentioned above, the water content of the embankment is relatively high.

Above investigations show that the ground materials for the earth reinforcement at the construction site have a risk of frost heaving, and effective protections for frost heave are required.
4. Results of Measurement

4.1. Temperature

Figure 5 shows the changes in temperature on front and back of the insulation, and in the ground. The lack of data from February 18 to March 15, 2018 is due to power loss caused by snow covered. The temperature at the front of insulation fluctuates significantly within a day, according to the change in outside air temperature. On the other hand, the temperature change at the back of the insulation is much smaller than at the front. This result indicates the heat insulating works well behind the wall. The temperature fluctuation at the front of the insulation of the bottom panel is smaller than in the top panel since January 13, and has been around 0 (°C) since early February. This can be due to the effect of snow cover in front of the wall at the bottom level.

The temperatures of the ground behind the wall are also indicated in Figure 5. The soil temperature at the beginning of measurement was between 10 (°C) and 15 (°C). The temperature of soil drops according to the air temperature, but keeps above 0 (°C) through the season even behind the top level panel. This result could be due to the effect of insulation behind walls.

4.2. Force at the top of reinforcement rod

Figure 6 shows the change over time in the force at the top of reinforcement rod. The initial (immediately after installation) value of the reinforcing force is about 5.0 (kN) which comes from the initial manual tightening of nut. The forces at top and bottom level panels are kept very low values, less than 10 (kN). The force at middle level panel shows rather higher compared to others. The reason is not clear why the rod force at middle panel increased, but this is not due to frost heave because the freezing line did not enter into the ground as shown above. We should investigate specific factors other than frost heave in this case although the value of the force in Figure 6 does not damage to the structure. It was found that the temporary increase in the reinforcement force had returned to the almost initial value after winter season.

![Figure 6. Force at top of reinforcement rod.](image)

5. Numerical analysis of temperature

5.1. Analysis model

An analysis on temperature has been done by FEM. Figure 7 shows the analysis model. Model size is 10 m wide horizontally from the wall and vertically 10 m in depth. The anchor structures are not modeled.

5.2. Analysis parameters

Table 3 shows the analysis parameters for each material. The thermal conductivity and heat capacity of insulation are those of XPS (extruded foamed polystyrene), and the data of water content and dry density were used to assume the thermal properties of the soil behind wall.
Table 3. Parameters for analysis.

|                  | Thermal conductivity W/mK | Heat capacity kJ/m³K |
|------------------|---------------------------|---------------------|
| Concrete panel   | 2.558                     | 2520                |
| Insulation       | 0.040                     | 45.2                |
| Backfill mortar  | 2.558                     | 2520                |
| Ground           | 1.209                     | 2034                |

5.3. Input temperature data

The observed data on the front of the insulation at each panel height is used for input temperature of the wall. The temperature at the bottom panel surface is used for ground surface temperatures considering covered snow. The lack of data due to power loss in the measurements are properly interpolated using a meteorological relationship between the construction site and the nearest Observatory.

5.4. Verification by measurements

Figure 8 shows the results of FEM analysis and measurements of temperatures at the front and back surface of the insulation, and at the points beneath insulation. As shown in the figure, the measurement and the analyzed value are coincided well. Especially it is proved analytically that the 0°C line does not pass through the insulation into the backfill ground, so that frost heave was protected even though the soil of slope was frost susceptible.

Figure 9 indicates the 0-degree contour line on the coldest day. The 0°C line reaches into the ground at the top and bottom surfaces where exposed to air, but it stays inside the insulating material behind panel which prevents causing displacement and additional force to the wall due to frost heave.

![Figure 7. Analysis model.](image)

![Figure 8. FEM analysis and measurements of temperatures.](image)
6. Summary

1) Newly developed earth reinforcement for slope protection using “Panel and Nail” was introduced and construction practice was shown in detail in cold region.

2) Measurement of temperatures at the front and behind the walls, and forces at anchor rod was carried out to ensure the durability of the structure under low temperature, and the observed data was compared with the analytical results.

3) The panel with insulation works well to protect frost heave of frost susceptible back ground, which suggests this construction method can be used economically and safely for slope protections in cold region.

References

[1] Japan Road Association 2001 Principle of road construction earth work p 202
[2] ISSMFE TC 8 (currently ISSMGE TC 216) 1989 Grain size distribution as a frost susceptibility criterion of soil VTT Symposium Vol 1 p 29-32
[3] Japanese Geotechnical Society 2018 Test method for frost susceptibility of soils JAPANESE GEOTECHNICAL SOCIETY STANDARDS Laboratory Testing Standards of Geomaterials Vol 3 JGS 0172

Figure 9. Temperature contour line at the lowest date.