Properties of Embankments Constructed in Winter

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ABSTRACT: In snowy cold regions, embankments constructed in winter may cause settlement and collapse of slopes in the thawing season in early spring. One of the reasons may be unavoidable suspension of the work due to work schedules while constructing an embankment during a cold winter. Accordingly, assuming such construction, a test construction was conducted in the winter season. For the constructed embankment, its inside temperatures and strength were measured. Also, after the embankment melted it was cut open and the density and water content were measured. As a result, it was found that 1) even in a 30cm high embankment, frost and moisture movement occur, 2) a frozen embankment is strong but a non-frozen one is not strong, 3) depending on the embankment construction method, layered frost remains and the number of layers increases with the increase of construction days, and 4) when the embankment freezes the density and water content decrease.

KEY WORDS: Embankment, construct, winter, density, strength.

1 INTRODUCTION

There is a case where deformation such as settlement or slope collapse occurs when a frozen or frost-heaved embankment melts. One of the reasons may be unavoidable suspension of the work due to work schedules while constructing an embankment in a cold winter. For example, because construction is done in the daytime and not at night, the surface of the embankment being constructed is exposed to cold air. Accordingly, assuming such a condition, we decided to construct a test embankment in winter and check its properties. Also, after the frozen embankment melted, the embankment was cut open to check its condition. This report summarizes this process.

2 CONSTRUCTION AND INVESTIGATION METHOD

At the Tomakomai construction test field of the Civil Engineering Institute for the Cold Region, an embankment of 4m in top width, 1.8m in height, 1:1.5 in slope inclination, and 5 to 7m in length was constructed. Table 1 lists the basic physical properties of the embankment materials. They are classified as non-freezing materials in particle size

Table 1 : Basic physical properties of embankment material

Soil particle density ρs(t/m^3)		2.626
Natural moisture content wn(%)		40.47
Particle size property	2mm or more (%)	7.8
	75μm～2mm(%)	74.6
	75μm or less (%)	17.6
Consistency limit		N.P.
Class symbol of ground material		S-FG
Maximum dry density ρdmax(t/m^3)		1.270
Optimum moisture content wopt(%)		35.0
Cone index qu(kN/m^2)		1403

distribution. Since the natural moisture content is slightly higher than the optimum moisture content but the cone index is high, these materials are easy to compact.

Six types of embankments were constructed (1 to 6). Table 2 shows the construction conditions. 1 and 2 were constructed in mid December when the number of construction projects is largest in winter earthwork, and 3, 4, 5, and 6 were constructed in mid January, the coldest season in Hokkaido. For 1 and 3, six layers up to the embankment completion cut plane were constructed in a day. For 2 and 5, one layer was constructed per day to complete the embankment in six days. For 4 and 6, two layers were constructed per day to complete the embankment in three days. Consequently, only the embankment top was exposed to cold air for 1 and 3, the top and the embankment being constructed were exposed five times for 2 and 5, and the top and the embankment being constructed were exposed twice for 4. For 2, 4, and 5, even when the embankments were frozen in the morning before construction, the embankment of the next layer was constructed. For 6, the next layer was constructed after the frozen portion was removed before construction of the embankment. Thickness of a single layer was 30cm.

Table 2 : Construction conditions

Embankment No.	1	2	3	4	5	6
Construction period	During December		During January			
Daily number of layers constructed	6	1	6	2	1	2
Removal of frozen portions	No				Yes	

For each embankment, a methylene blue frost depth meter and a temperature sensor were installed. The ground surface displacement, soil temperature, outside air temperature, frost depth, moisture content, density, and N value were measured using the method shown in Table 3 beginning with the construction of embankments in mid December. The N value of the embankment was measured in early February, early March, and early April. Also, the embankments were cut open in early June to measure the density and moisture content.

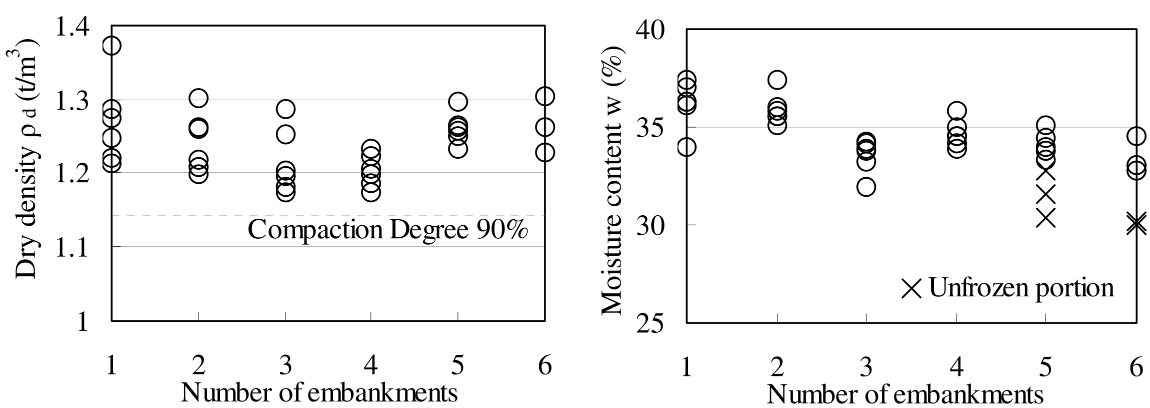
Table 3 : Outside test measurement items and measurement interval

Item	Measurement instrument	Measurement method	Measurement interval
Ground surface displacement	Level	Manual	1 week
Soil temperature	Thermo couple	Automatic	1 hour
Outside air temperature			
Frost depth	Methylene blue depth meter	Automatic	7 days
Moisture content, density	Sand replacement	Manual	When constructed When cut open
N value	Standard penetration test	Testing machine	3 times/winter

3 TEST RESULTS

3.1 Density and Moisture content during Construction

Fig.1 shows the dry density and moisture content of the embankment during construction. The moisture content is close to the optimum moisture content. For the density after compaction, the compaction degree was 90% or more at every measured point. Depending on night temperatures, 4 to 5cm thick frost columns or about 7 to 9cm thick



a.Dry density b. Moisture content

Fig. 1 : Density and moisture content during construction

frost were found on the surface on the day following the construction of the embankment. Therefore, for 6, the frozen portion was peeled off and the moisture content of the underneath unfrozen portion was measured. This is shown by "+" in Fig. 1. In the unfrozen portion under the frozen portion, the moisture content was 3 to 5% lower than that before freezing, meaning that water in the soil was moved upward by freezing.

3.2 N value of Embankment

Fig. 2 shows the N value of the embankment. N values at locations 80 cm or more in depth are about 5 to 10 which is small. However, N values of the frozen embankment surface measured on February 4 and February 29 are large. Particularly, for 1 and 2 constructed in December, N values obtained in the study on February 3 are very large. The daily average air temperature on February 3 was –13°C and that on February 29 was –1°C so the N value measure on the colder February 3 was larger. For the embankments 3, 4, 5, and 6 constructed in January, N values of 3 and 4 were almost the same and N values of 5 and 6 were smaller. On April 25, there were slightly frozen portions in the embankments but N values in the entire embankment were smaller.

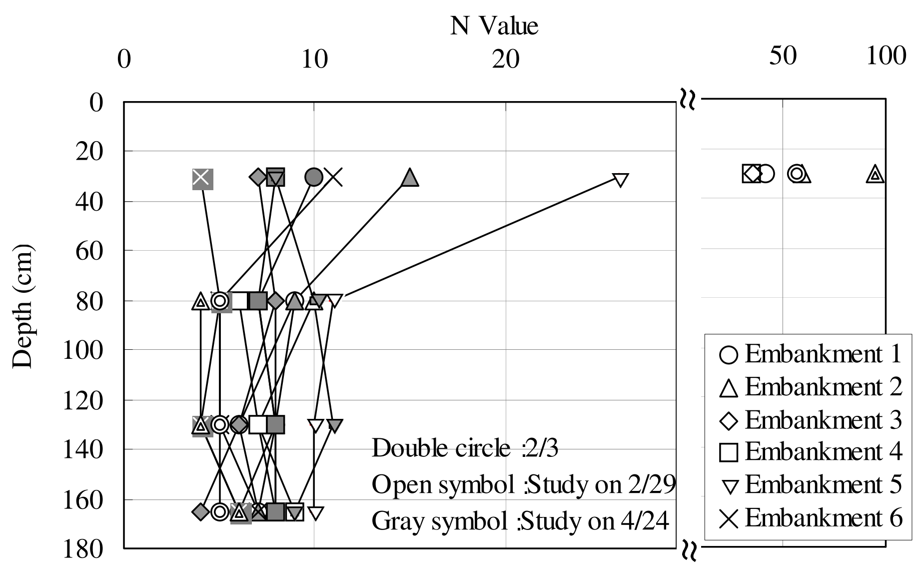


Fig. 2 : N value of embankment

3.3 Frozen state of the Embankment

Fig. 3 shows the area of the embankment where temperatures are below zero in its temperature distribution. For embankments 1 and 3 where six layers were constructed in a day, frost depth increases with time after construction. For embankment 2 constructed in six days, the layers 1, 2, and 3 were constructed at an average temperature of about –3°C. On the day following the construction, frost columns were formed on the surface of the embankment but there was no frozen portion in the embankment. Frost columns

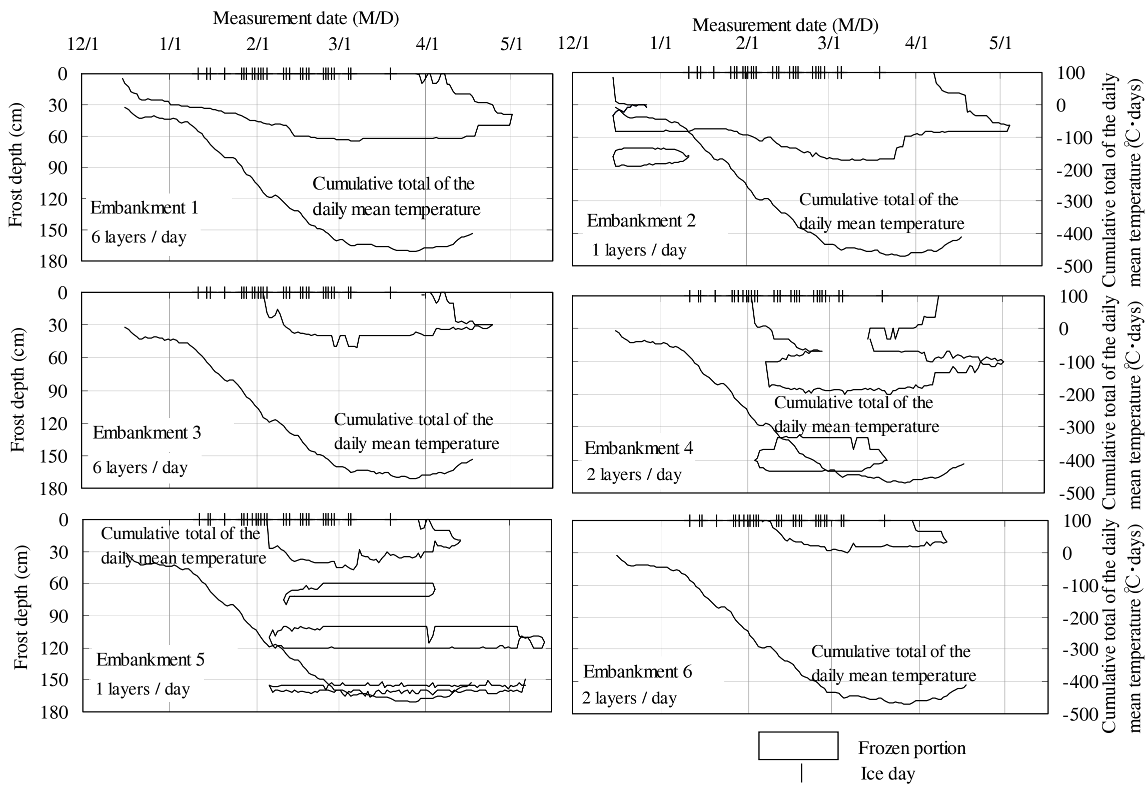


Fig. 3 : Frozen state of embankment

formed during the construction of the embankment may have been melted by the embankment materials added for embankment construction. However, since the layers 4, 5, and 6 were constructed at average temperatures –5 to –10°C, the frozen portion of the already constructed embankment may not have been melted. Consequently, frozen portions were found in the embankment. Frost depth was deeper than in embankment 1 that was constructed in 1 day.

3.4 State of the Thawed Embankment

3.4.1 Change in Density

Fig. 4 shows the density of the embankment during construction and when thawed. Out of 30 measurement points, 20 points were frozen and 10 points were not frozen. For 7 of the 10 unfrozen points, the density during construction and that when thawed were almost the same. For the 20 frozen points, the density when thawed was lower than during construction at 15 points. This means that density tends to decrease when the embankment melts and tends not to decrease when it does not melt. The compaction degree of the embankment was 90% or more during construction but became 85% or more when thawed. The embankment decreases in density when freezing and melting are repeated. Therefore, even if the standard value is satisfied during construction it may not be satisfied when the frozen embankment melts.

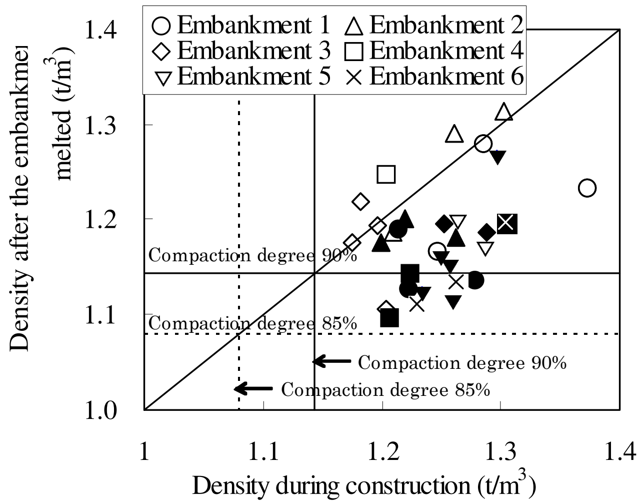


Fig. 4 : Moisture ratio of the embankment during construction and when melted

For the embankment 6, the next layer was constructed after frozen portions were removed. At this time, compaction was done after the frozen portions were removed. In this case, compaction degrees decreased uniformly. This means that even if frozen portions are removed, embankment density decreases unless it is compacted.

3.4.2 Change in Moisture Content

Fig. 5 shows the moisture content of the embankment during construction and when thawed. The moisture content when thawed is lower than during construction. Particularly, the moisture content of the embankment surface decreases the most.

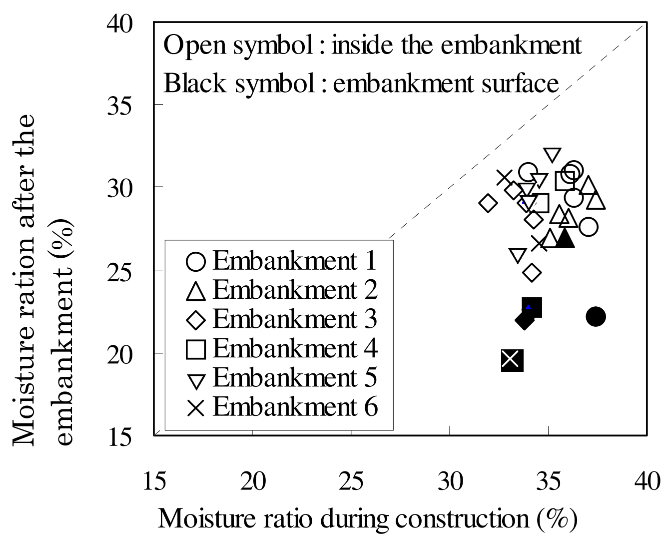


Fig. 5 : Moisture ratio of during construction of and after-melted embankment

4 CONCLUSION

The analysis made so far has revealed the following:

1) Even in a 30cm high embankment, frost heave occurs and water moves in the embankment.
2) Frozen embankments are strong but unfrozen portions are not strong.
3) Depending on the embankment construction method, layered frost remains in the embankment and the number of layers increases with the increase in construction days.
4) If the embankment is frozen and thawed by constructing it in winter, the density and moisture content decrease.

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