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Application of polystyrene layer to railway subgrade as a countermeasure for frost heaving

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ABSTRACT: A countermeasure for frost heaving is required for application to railway subgrade containing silt and volcanic cohesive soil layers in severely cold regions in Japan. A conventional countermeasure is to replace silt and volcanic cohesive soil layer with non-frost material. The depth of replacement is calculated by a one-dimensional heat conduction analysis. However, in the foregoing regions, the cost tends to be expensive because of the thick frost depth.

A polystyrene board is used as insulation material in many buildings and houses, and the use of the board commenced as a countermeasure for frost heaving in highway and railway. However, an effect and an evaluation method of this countermeasure have yet been established.

This report examines the applicability of the polystyrene board as a new countermeasure for the frost heaving for the railway subgrade. Applicable roadbeds are of reinforced concrete roadbed and ballast roadbed. The dynamic characteristic of the countermeasure for the frost heaving with the polystyrene board has been described based on the numerical analysis and the dynamic loading test, and a design method is proposed.

1 INTRODUCTION

In northern regions in Japan, air temperatures are often downed to below zero every winter seasons. Therefore, ground consisting of clay layer tends to be frozen. The freezing of clay layer causes a frost-heaving phenomenon and the frost heaving tends damage various civil structures.

Railway tracks have been strictly controlled throughout the year. The allowable limit of track irregularity for the first-grade line, as Shinkansen is approximately 5 mm. We have to prevent excessive deformations of railway track. As the frost heaving causes a large scale of deformations, it is required to establish a protective method against the frost heaving prior to construction of structures. A conventional countermeasure is to replace clay layer with non-frost material with granular rock. The depth of replaced materials is varied by weather conditions of object regions. Therefore, in the foregoing regions, it tends to thick, and the cost of replacement method becomes expensive.

This paper describes the applicability of the polystyrene board as a new countermeasure for frost heaving for the railway trackbed.

2 COUNTERMEASURE OF FROST HEAVING USING POLYSTYRENE LAYER

2.1 *Polystyrene layer*

Usually chemical materials for insulators are selected polystyrene or urethane. Polystyrene boards are used many insulators, walls of house, roofs of some buildings and road subgrades. However, for insulators of railway civil structures, these are not selected. Especially, because of railway, trackbed supports a railway dynamic load; the polystyrene layer is requested high qualities about durability and performance of deformation. Figure 1 shows railway concrete trackbed applied the polystyrene layer. We carry out a numerical analysis and a dynamic loading test to estimate characteristics of polystyrene layer.

2.2 *Calculation of frost penetration depth*

An insulation effect of polystyrene layer is evaluated by a numerical analysis. The method of numerical analysis is advanced Berggren method. This is the most suitable method for design stage because of its simplicity. The frost penetration depth on advanced Berggren method given by the following:

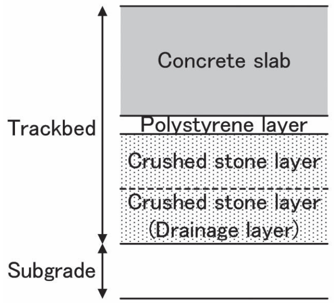

Figure 1. Trackbed applied the polystyrene layer.

$$X = C\sqrt{F} = \lambda\sqrt{\frac{172800k}{L}} \cdot \sqrt{F} \qquad (1)$$

Where: λ = coefficient of volume heat capacity, k = thermal conductivity, F = freezing index, L = latent heat.

Figure 2 shows analysis models of the typical tracbed and the trackbed including the polystyrene layer. This model is based on the concrete trackbed of Japan railway design standards. The polystyrene layer consists between the concrete slab and the layer of crushed stone. The thickness of polystyrene layer is an estimation parameter. The thermal characteristics of trackbed materials show Table 1 and analysis cases show Table 2. The thermal conductivity of soil decides from laboratory tests of the new method using small specimens. Figure 3 shows one of specimen. Analyses carry out four cases for the effect of countermeasures. Case 1, Case 2 and Case 3 adopted crushed stone layer for the frost-heaving countermeasure, which is a typical countermeasure applicable in railways in Japan. Case 4, Case 5 and Case 6 are new countermeasure method applied the polystyrene layer. Freezing indexes using analyses are 500 and 700 (°C · day) based on the 100 year and 1000 year return periods freezing index of Sapporo area in Japan and 1100 (°C · day) that is the maximum value of 1000 year return period in Japan. Figure 4 and 5 describe results of analyses. Figure 4 is the result of Case 1, 2 and 3, and Figure 5 is the result of Case 4, 5 and 6. A purpose of estimation is to determine the thickness of countermeasure layer when the freezing penetration depth is upper the subgrade. From result of Case one, two and three, crushed stone layers need a 0.2-0.35 m thickness (in the case of F = 500 or 700) and a 0.6 m thickness (in the case of F = 1100) in order to achieve this purpose. Otherwise, the countermeasure

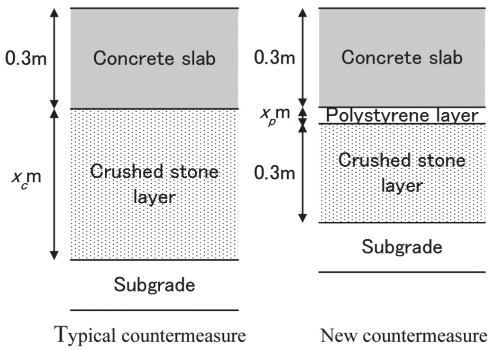

Figure 2. Analysis model.

Table 1. Input parameter.

Parameter (Unit)		Concrete	Crushed stone	Loam
Dry density	g/cm^3	2.35	1.98	1.09
Water content	%	–	6.2	52.0
Thermal conductivity	cal/cm · sec · °C	0.00611	0.00123	0.00109
Heat capacity	cal/cm^3 · °C	0.6	0.217	0.56
Latent heat	cal/cm^3	0	9.82	45.34

Table 2. Analysis cases.

Case No.	Countermeasure material	Freezing index (°C · day)
1	Crushed stone	500
2	Crushed stone	700
3	Crushed stone	1100
4	Polystyrene	500
5	Polystyrene	700
6	Polystyrene	1100

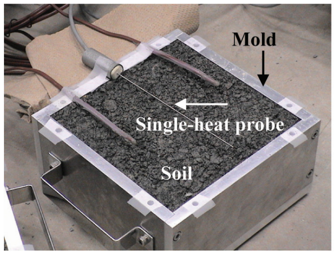

Figure 3. Specimen of laboratory test.

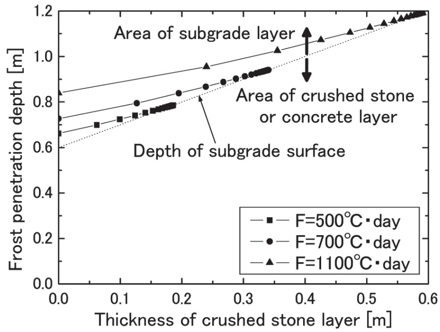

Figure 4. Result of analysis (Case 1, 2 and 3).

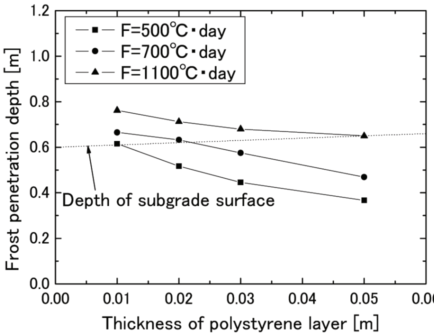

Figure 5. Result of analysis (Case 4, 5 and 6).

used the polystyrene layer satisfies this purpose to insert the board of only 0.05 m thickness in the case of F = 1100.

Therefore, the new countermeasure with polystyrene layer is economic and effective as the volume of excavation work is considerably decreased.

2.3 *Loading test*

The trackbed is adversely affected by trackload directly. In the case of application to trackbed with the polystyrene layer, the deformation characteristic of polystyrene layer is very important. The dynamic loading test on the laboratory is able to obtain the deformation characteristic of the polystyrene board. Figure 6 (1) and (2) show the dynamic loading test system. This loading system is one axis-loading unit

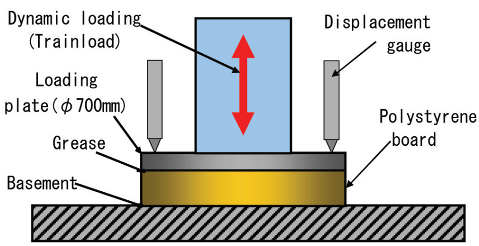

Figure 6. (1) System of dynamic loading test.

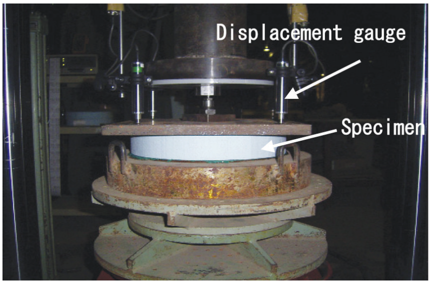

Figure 6. (2) Dynamic loading test.

and gives both static and dynamic load. The size of specimen is a 0.05 m thickness based on the result of analysis and a 0.7 m diameter from the maximum spec of this loading system. Displacements of polystyrene layer measure four gauges. Figure 7 shows the loading condition. First, static load that equals the weight of trackbed gives the specimen of polystyrene. Second, the dynamic load that is trainload gives it. The frequency of dynamic load is 20 Hz and the number of loading times is 7 million. The number of 7 million is the train load of double track of Tohoku shinkansen for about 10 year.

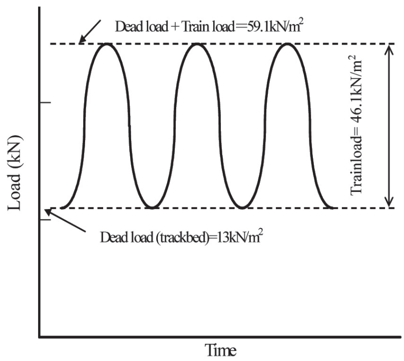

Figure 7. Loading condition.

Figure 8 shows the result of dynamic loading test. This figure is a relation of loading number and displacement of specimen. The value of displacement is the average value of four gauges. The displacement by static load is about 0.3 mm of compression. In the interval of dynamic load, it occurs only about 0.1 mm. In addition, it converges when the loading number is about 1.5-2.0 million. Therefore, the residual displacement after dynamic loading is a little. The displacement of polystyrene board does hardly reflect for the mechanism and maintenance of trackbed.

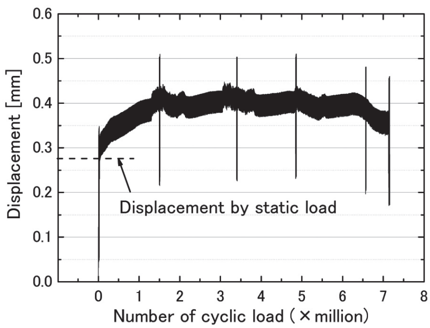

Figure 8. Result of dynamic loading test.

To obtain the characteristic of polystyrene board after dynamic loading test, one axis static load test carry out the small specimen (50 mm × 50 mm × 50 mm). The speed of loading is 1 mm/sec. Figure 9. (a), (b) and 10 are the result of loading test. Figure 9 (a) shows the stress-strain relation of the fresh specimen and Figure 9 (b) is it of the specimen to damage the dynamic load. Figure 10 shows the modulus of deformation-dynamic load relation. The stress-strain relation of polystyrene board is monotonous to compare with a fresh specimen (to not damage the dynamic load). However, the modulus of deformation-strain relation is varied. The modulus of deformation decreases about 10% by the dynamic loading test.

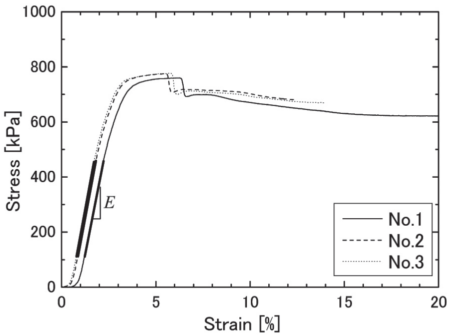

Figure 9. (a) The stress-strain relation (Fresh specimen).

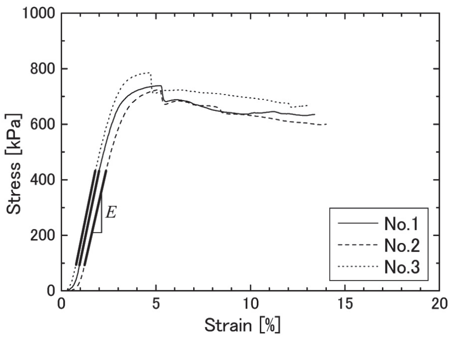

Figure 9. (b) Stress-strain relation (Specimen to damage the dynamic load).

3 CONCLUSION

The numerical analysis and dynamic loading test provide the follow conclusions.

(1) The frost-heaving countermeasure with polystyrene layer is very effective and economic method against the replacement method in the foregoing cold regions.

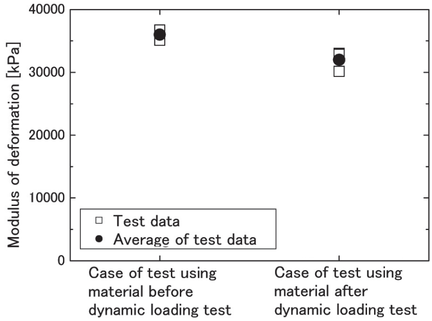

Figure 10. Modulus of deformation-dynamic load relation.

(2) Since the displacement of polystyrene board by the trainload is very limited, the polystyrene boards are applicable as trackbed materials.

(3) The modulus of deformation decreases about 10% by dynamic load. Therefore, we consider this characteristic in the design stage. In the future, with the pertinent results analyses as to roadbed structure, we attempt to establish an adequate countermeasure for the frost heaving with polystyrene layer based on the F.E. analysis.

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