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Study on Frost Resistance Characteristics of the Large Channel Thermal Insulation Lining

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Abstract. The frost heave pattern and the frost heave design of the large channel in the cold area are still not yet fully solved. In this study, based on the large channel of Hada Mountain Water Conservancy Project, the in-situ large-scale thermal protection slope test was carried out, and the frost heave deformation law of the thermal dewatering slope was obtained. The results have certain guiding significance for the frost heave design of the large channel in the cold area.
Keywords: Cold area, Large channel, Thermal insulation lining, Frost heave

1. Introduction

The Hadashan Water Control Project is located 200m upstream from the Hadakashan Pumping Station in the Qiangguo Irrigation District on the lower reaches of the Second Songhua River. The geographical location is between 124 °35'-128 °00'E and 41 °43'-45 °23'N. Located on the eastern edge of the Eurasian continent in the mid-latitudes, it belongs to the north temperate continental monsoon climate zone, and the climate changes in the four seasons are obvious. The wind is dry in spring; it is hot and rainy in summer; the days are high in summer, and the temperature difference is large in daytime; the winter is cold and long. The temperature difference between winter and summer is very different during the year, and it is short in spring and autumn. The average daily temperature below zero is generally from the beginning of November each year to the end of March of the second year up to five months. The annual average temperature is 4.5 ℃, and the extreme lowest temperature in the calendar year is -37.8 ℃. The foundation soil of canal in the study area is mostly cohesive soil with strong to very strong frost heaving property. The frost heaving law and frost heaving design and construction of large channels in such frost heaving area is still a technical problem that has not yet been completely solved in China.

The basic principle of preventing frost heaving in large-area channel insulation slopes in cold regions is to use the relevant thermal insulation materials with low thermal conductivity to achieve the heat balance between endothermic and exothermic insulation at a certain thickness of the thermal insulation layer and the foundation soil, so as to reach the lower Drainage soil is not subject to freezing. In this study the Hadashan water conservancy project, carry out the prototype test of the

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insulation protection of Frost Heaving in the water trunk canal segment, on the basic law of deformation and frost heave resistance insulation protection, the purpose is to provide the technical basis for the design of anti-frost related channels.

2. Insulation Slope Protection Structure

The starting point of water conveyance canal is 0km+000m, the pile number gradually increases along the channel flow direction. 5 groups of frost protection and swelling protection test were set up at the pile number 2km+640m- 2km+715m and 4 km+725m - 4km+775m of the water conveyance trunk. The length of the test section is 25m, and the thickness of insulation board is 5cm and 6cm two kinds. Protective materials for cast-in-situ concrete slab. The 2km section of the concrete slab is 2mx2mx0.1m (long x width x thick), and the 4km section is 2.5mx2.5mx0.1m, slope protection structure is shown in Table 1. The thermal insulation board used for the test is a rigid polyurethane foam board, and its technical performance indicators are shown in Table 2.

Table 1. Frost protection test slope protection structure of insulation board

Distance from starting point	Slope protection structure		Insulation board thickness(cm)
	material	size(m)	
2km+640m-2 km +665m	cast-in-place concrete	2x2x0.1	6
2 km +665m-2 km +690m	fiber reinforced concrete	2x2x0.1	5
2 km +690m-2 km +715m	cast-in-place concrete	2x2x0.1	5
4 km +725m-4 km +750m	fiber reinforced concrete	2.5x2.5x0.1	5
4 km +750m-4 km +775m	cast-in-place concrete	2.5x2.5x0.1	5

Table 2. Technical Specifications of Polyurethane Foam Boards

Thickness (mm)	density (kg/m^3)	Compressive strength (kPa)	Thermal Conductivity (W/(m·K)	Size change rate (%)			Water absorption (%)
				length	Width	Thickness	
30	41	100	0.029	0.8	0.6	0.6	1.9
50	48	180	0.026	0.4	0.5	0.3	0.6

3. Frost Protection and Slope Frost Heave of Frost Protection Slope

Observation was carried out in the field test section. In 2008-2009 and 2011-2012 2km test section and 4km test section, the freezing and swelling test of the insulation board is shown in Table 3. Seen from the table, the year 2008-2009 in slope, lower slope drainage did not freeze deep, and the 2011-2012 annual 2km test and 4km test section of the freezing depth reached 63cm and 72cm, the equivalent of the lower slope heaving of 53% and 61%. This situation is related to the increase of thermal conductivity of insulation board. The insulation board samples taken from the field can be seen that the insulation board of 2km test section is severely damaged by grass root reed, and even penetrates the sample, which is the important reason for the thermal conductivity of insulation board to increase. In this view, the long-term anti freezing effect of plastic insulation board needs further study, and it should not be used under the conditions of grass roots, especially reeds.

Table 3. Frost Protection of Frost Protection Slope of Insulation Board Unit: cm

Test section	Insulation board thickness(cm)	Year	The lower part of the slope(cm)	Slope toe(cm)
2km	6	2008-2009	0	91
		2011-2012	63	93
4km	5	2008-2009	0	97
		2011-2012	72	104
	No slope protection	2011-2012	119	

The thermal insulation test section was built in the winter of 2008. It began to observe in the same year. It lasted for 4 years except for 4+750 - 4+775 test section in 2012, and some supplementary observations were made in 2013 and 2014. The test section of the past observed the maximum amount of frost heaving is visible, insulation slope has different degrees of frost heaving, frost heaving amount of upper slope (the maximum distance from the top of the slope within 2.5m 1.0cm - 3.0cm), middle slope (2.5m 7.5m distance from the top of the slope to the lower slope (5.0cm), 7.5m distance from the top of the slope to 11.5m) 5.0cm - 7.0cm.

4. The Time Process of Frost Heave on the Slope

The frost heave and thawing process of the slopes are basically the same for each year. Figure 1 is the time course of 2km line slope heave test section 2011-2012 2.0m 6.0m and 11.0m from the top of the hill, three points. It can be seen from the map that the slope began to appear frost heave after the stable freezing stage in late November. After that, the amount of frost heave continues to increase. The maximum frost heave occurred in late February to early March. After that, the frost heave gradually decreased and the slope began to sink. The amount of Frost Heaving in the middle and upper part of the canal slope is small, and it can be restored to the original position in the middle and late 4 months, while the frost heave in the lower part of the canal slope is larger. By the middle of 4 months, the frozen soil layer has not been completely melted in the middle of the canal, so there is still a part of frost heave volume, but the value is not large.

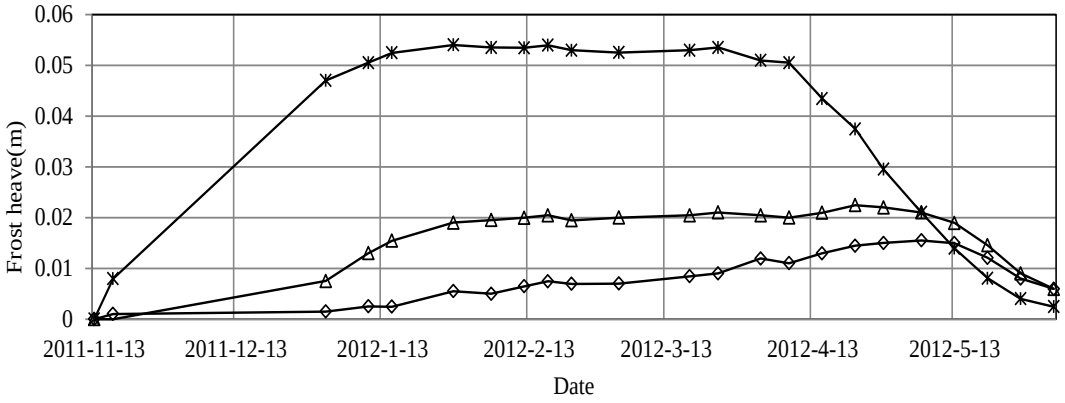


Figure 1. 2011-2012 year frost heave process line for the slope protection of the 2km test section 1 - the distance from the top of the slope 2.0m. 2 - the distance from the top of the slope 6.0m. 3 - canal slope (from the top of 11.0m)

5. Inhomogeneity of Frost Heave on Slope Surface

The unevenness coefficient of frost heaving refers to the ratio of the difference of frost heave to the distance between points at the two point, and is expressed as:

$$\eta = \frac{h_{i2} - h_{i1}}{l} = \frac{\Delta h}{l} \tag{1}$$

In the formula: the inhomogeneous coefficient of frost heave (decimal);
h_{i1}—from the top is a point 1 of the frost heave;
h_{i2}—from the top is a point 2 of the frost heave;
Δh— the difference of frost heave in point 1 and 2;
l— the distance between two points.

Large amount of frost heave and uneven frost heave are the main causes of structural damage on frost heave soil foundation. For channel revetment, because the revetment panel and foundation will be firmly frozen together, and the thickness of the revetment plate is thinner, when uneven frost heave occurs, it can not resist the effect of frost heave force, resulting in cracks or even breaks. This is why the destruction of canal slope protection is more common. The frost heave of canal slopes is in the form of small frost heave and large frost heave. Even after the frost heave, the slope surface is generally smooth, there is still non-uniformity between different points. The larger the frost heave, the greater the non-uniformity.

The destructive effect of frost heave inhomogeneity on slope protection and the ability of slope protection structure to adapt to frost heave inhomogeneity are related to the size of frost heave inhomogeneity coefficient, the structure form of slope protection, the size of protective panel, the structure of slope protection and the interface property of foundation soil. Therefore, in the study of frost heave damage of buildings, especially for lightweight structures such as concrete slab slope protection, in addition to the size of frost heave, but also to study the size of the non-uniform coefficient of frost heave. So far, there are few experimental studies in this field, only a few tests on the non-uniformity of frost heave resistance of concrete slabs have been carried out by individual units. In the current codes, only the allowable frost heave displacement requirements are put forward according to the experience of small and medium-sized channels. Therefore, it is still a problem to be studied to quantitatively determine the non-uniformity coefficient of frost heave, especially the damage effect of its size on slope protection structure. The inhomogeneous coefficient of frost heave in 2km and 4km test section thickness 5cm and 6cm slope is small. The inhomogeneity coefficient of the upper and middle slopes is about 0.01, and the maximum of the lower slope is only 0.02. The thermal insulation board has a good effect on restraining uneven deformation caused by frost heave on the slope.

6. Conclusion

1) 2008-2009 year in addition to slope, lower slope drainage did not freeze deep, and the 2011-2012 annual 2km test and 4km test section of the freezing depth reached 63cm and 72cm, the equivalent of the lower slope heaving of 53% and 61%. This is due to the fact that the thermal insulation board of the test section is seriously damaged by the root reeds and even penetrates the sample, which leads to the increase of thermal conductivity of the insulation board. Therefore, the long-term anti freezing effect of plastic insulation board needs further study, and it should not be used under the conditions of grass roots, especially reeds.

2) the frost heave in the late February to the first ten days of March reached the maximum. After that, the frost heave gradually decreased and the slope began to sink. By the end of 4, the first ten days were basically restored to the site. After 6 freezing thawing diachronic observations, the thermal insulation slope was eventually restored to the original elevation, that is, no significant residual frost heave.

3) large frost heaving and uneven frost heave are the main causes of structural damage on the frost heaving soil base. The inhomogeneous coefficient of frost heave in 2km and 4km test section thickness 5cm and 6cm slope is small. The inhomogeneity coefficient of the upper and middle slopes is about 0.01, and the maximum of the lower slope is only 0.02. The thermal insulation board has a good effect on restraining uneven deformation caused by frost heave on the slope.

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