Research and demonstration of application the geosynthetics to the canal revetment protection engineering in seasonal frozen soil region

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ABSTRACT: The freeze-thaw action often causes the collapse of the bank revetment in Seasonal Frozen Soil Region. Main traditional revetment structure is the concrete board which doesn't solve the frost heaving breakage problem effectively. Based on the engineering example of Ji Lin Provincial Hadashan Hydraulic Project Ⅰ in China, the practical effect of several flexible revetment protection methods applied to the large canal in seasonal frozen soil region are studied and discussed in this paper, such as Reno mat structure and geocell gravel structure. The tests shows the porous flexible revetment system can effectively reduce the water content before freezing and lighten the frost heaving breakage comparing with the traditional concrete structure. Flexible revetment system can not only improve the ability of adapting to the freeze-thaw transmutation of the foundation but also restore the environment.

1 FOREWORD

Songliao Basin in Northeast China is the deep seasonal frozen soil region. Drought in spring is a typical feature in the area. In recent years, some large water diversion projects have constructed. While satisfying water flow conditions of the canal operation period, the demanding one to solve is the frost heaving, thaw settle, ice-pushed damage and a series of problems of the canal slope. In particular, the freeze-thaw deformation affects the slope revetment more powerfully with high underground water level. Therefore, protection of the canal slope of the powerful frost heaving soil is the key to the slope protection of the large hydraulic project.

Most traditional canal slope protection methods employ tough concrete board with the geotextile, masonry stone with the geotextile and other protection systems, after many years' freeze-thaw reactions, the concrete plate is likely to break and crash, even collapse of the foundation soil. Under high underground water level, the damage is more severe. To discuss the slope protection issue of large canals in the deep seasonal frozen soil areas, new flexible slope protection structures are used in the design of Hadashan Hydraulic Project in Songyuan City in China, such as geocell gravel, Reno mat and etc. Through the observation from 2008 to 2009 in winter, the characteristics of the flexible structures are good drainage, the whole structure, which can improve not only the stability of the canal but also the ability of adapting to the freeze-thaw distortion.

2 DESIGN PRINCIPLES

For the severe environmental conditions, design principles of the project are offered below：

(1) The porous structure is adopted. For the high underground water level, the structure with good penetration can reduce the uplifting pressure from the lining system. The opening system can improve water preservation status of the foundation soil after out supply of the water and relieve frost heaving damage of the foundation soil.

(2) The flexible structure is taken to adapt to the frost heaving. Because of the powerful frost heaving of the foundation soil, the flexible structures adapting to the freeze-thaw deformation of the foundation soil are adopted, such as the geocell gravel structure, Reno mat and etc.

(3) For increasing toughness and stability of the integral structure, the chained structures are adopted to resist the ice-pushed force from the freezing of the residual water in the canal in winter and frost heaving force from the foundation soil to the slope.

3 STRUCTURE

3.1 *Reno mat structure (Herve, P. 2004)*

From Fig.1, Reno mat structure is the high-strength galvanization and low carbon steel wire filled with stones which has successful experience in cold Russia. The features are described below:

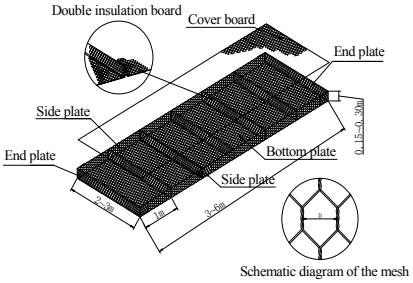

Figure1.Reno mat structure

(1) Reno mat structure is flexible that can well adapt to the settlement deformation of the foundation soil and breakage from external forces. For high underground water level in Hadashan trunk canal project, the problems such as freeze-thaw action of the foundation soil, ice row colliding, static ice pressure and etc. can be well solved by Reno mat structure. The application of the structure in Hadashan Project is shown in Fig.2 and Fig.3.

(2) The porous structure can permeate the water from the slope of itself without any other drainage facilities which is of benefit to the long-term stability of the slope structure under high underground water level conditions.

(3) Binding wire or sewing is applied between each structural unit to make the Reno mat integral, which will not be out of structural stability for local damage.

(4) Desirable durability, the aluminum and zinc coating and low carbon steel wire resists corrosion and has a long service life.

(5) Ecological and environment protection, for the Reno mat is porous structure, which is beneficial for survival of living creatures and combines with surrounding colonies.

(6) Economical, the construction is environmental and economic. For the structure adapts to the frost heaving very well, the late-stage maintenance cost is low and is superior in the long-term economic benefit.

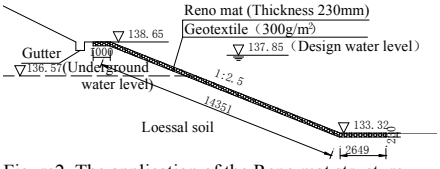

Figure2. The application of the Reno mat structure

Figure3. Effect after construction with Reno mat

3.2 *Geocell gravel structure*

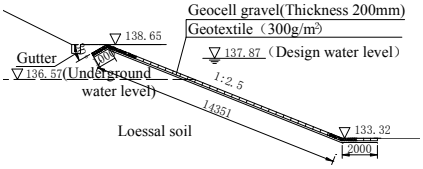

Figure4. The application of the Geocell gravel structure

Figure 5 Effects after construction with geocell gravel

The geocell gravel structure is the slope protection system filled with gravel-soil mixture in the geocells. The application of the structure is shown in Fig.4 and Fig.5.The characteristics are described as below:

(1) The geocells is the main supporting frame taking full advantage of its holistic structure. The geocells are filled with gravel and soil mixture, combining gravity stability of gravel and integral slope protection performance of the geocells, and geotextile can insulate the soil and play the role of the reverse filter to protect the slope.

(2) Each independent and enclosed cell can be taken as the baffles to keep the gravel filled with to relieve the flow erosion and impact from the waves on the slope to protect the slope.

(3) Geocells are filled with the gravel of certain graduation and planting soil can be refilled in the pores. Green plants can grow from the surface of the protection system. The plants from the surface can also relieve the scouring and reserve filter of the flow on the slope.

(4) Proper height and welding interval of the geocells are selected in accordance with the gradient to obtain the best effects and economic benefits.

4 FROST HEAVING EXPERIMENT AND ANALYSIS-TAKING EXAMPLE FOR RENO MAT

4.1 *Frost-heaving amount calculation and frost-heaving classification of canal foundation soil*

The frost-heaving amount and frost heaving classification of the foundation soil (X.M. Qu & B. Zhang 2008) are offered below in accordance with 《Design code for anti-frost-heave of canal and its structure (SL23—2006)》(Water Resources Ministry of China,2006).

When there's some residual water in Reno mat lining canal in the freezing period, the maximum frost-heaving amount is 9.08cm, which is located between the water surface (ice surface) and 0.5m above is level III. The maximum frost-heaving amount for 0.5m to 1m above the water surface (ice surface) is 4.79cm and is level II.

4.2 *Frost-heaving adaptation test and analysis*

Frost-heaving adaptation test of Reno mat is carried out in the model testing box with dimensions of 4.5m×3.0m×1.5m, with the soil layers, boundary and initial conditions controllable, and single-direction freezing and double-direction thawing conditions are realized. See Fig. 6~9 on the experiment results.

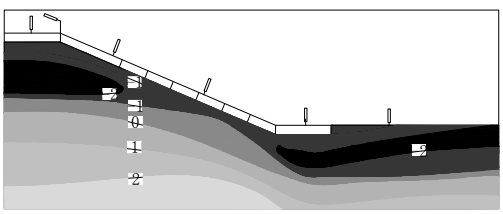

Figure 6. Distribution of temperature field inside the canal with maximum frozen depth

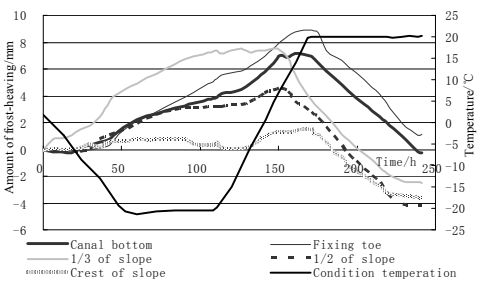

Figure 7. Curves of frost-heaving amount of foundation soil on the canal sections

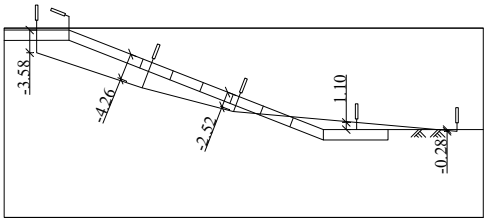

Figure 8 Curves of residual distortion on the canal sections after freeze-thaw period

The experiment results show that, under the high underground water level, the thermal resistance is increased, the freezing depth is decreased, temperature of the soil body under the mat is uniform, but frost-heaving amount at the canal bottom is increased after comparing the soil body temperature field, slope displacement and deformation and etc. in the freeze-thaw cycling; under the conditions of sufficient water supply, the maximum frost-heaving amount occurs at 1/3 of the canal slope; under the conditions of insufficient water supplementation, the maximum frost-heaving amount occurs at the fixing toe of the canal slope; maximum residual frost-heaving amount occurs at the slope toe of the canals. The flexible Reno structure can attenuate the frost-heaving force and well adapt to the freeze-thaw deformation at the canal slope and slope toe.

5 IN SITU OBSERVATION RESULTS AND CONTRAST ANALYSIS

The observation is carried out during a freeze-thaw cycling from 2008 to 2009 after the construction of the demonstration project completed.

5.1 *Climate conditions*

The main irrigation canal of Hadashan Hydraulic Project in Songyuan City is located at the deep seasonal frozen soil region. Axial direction of the demonstrated canal on the slope is east to west; the project site is EL 124°35′ -128°50′ and NL 41°43'-45°23′ . The underground water level of the tested section is 3.25m higher than the canal bottom, and the canal bottom is 28m wide. The canal bottom foundation soil is low-liquid limit powder soil, which is of strong frost heaving. The maximum frozen depth in past years is 2.03m. The standard frozen depth is 1.8m.

According to the data from the weather station, the freezing period is from November 15, 2008 to March 4, 2009 during the observation cycle, which took 109 days. During the period, average temperature in January is -15.1℃, the lowest temperature occurred on January 9, 2009, and the mean daily temperature is -20.8℃ which is shown in Tab. 1.

Table 1. Eigenvalues of temperatures in months of the freezing period from 2008 to 2009

Date	Lowest temp.		Max. temp.		Monthly average
	Value (℃)	Time	Value (℃)	Time	
Nov., 2008	-8.3	7:00	-1.8	13:30	-5.20
Dec., 2008	-13.8	7:00	-6.1	13:30	-10.69
Jan., 2009	-18.95	7:00	-8.93	14:00	-15.10
Feb., 2009	-15.1	6:00	-4	14:00	-10.60
Mar., 2009	-8.15	6:00	2.6	14:00	-3.08

According to statistics of local climate information from 1970~2008, the freezing period in average is 122 days, 140 days in maximum and 102 days in minimum. So it is warmer in this period from 2008 to 2009.

5.2 *Maximum frost-heaving amount and residual deformation results*

See Table 2 and Table 3on observation results.

Table2. Eigen values of freeze-thaw deformation amount of the testing structures at 47km section (shady slope)

Structure	Value(cm)	Measurement points				
		Crest	1	2	3	Toe
Fabric form 1	Max.	3.3	5.3	8.2	13.6	20
	Residual	1.9	8	9.8	14.6	14.5
Fabric form 2	Max.	-0.6	7.8	12.8	19.6	26.2
	Residual	-0.6	6.1	9.6	11.4	9.2
without lining	Max.	1.1	7.3	9.1	13.8	*
	Residual	0.6	-0.5	1.7	2.5	2.4
Reno mat1	Max.	-0.1	3.4	4.3	5.9	*
	Residual	-1.2	-1	1.8	1.2	-0.2
Reno mat2	Max.	-0.1	5.1	9.8	13.2	19.4
	Residual	1.0	1.8	3.4	1.6	2.4
Geocell gravel	Max.	0.9	5.8	7.8	14.8	19
	Residual	-0.5	-0.2	-0.7	1.2	-5.8
Note : "*" means the value occurs below the ice surface.						

Table3. Eigen values of freeze-thaw deformation amount of the testing structures at 47km section (sunny slope)

Structure	Measurement points					
	Value(cm)	Crest	1	2	3	Toe
Fabric-form 1	Max.	3.4	14.9	16.4	18.7	*
	Residual	1.7	2.8	3.2	5.7	5.7
Fabric-form 2	Max.	1.8	8.8	11.1	15	*
	Residual	0.5	1.9	1.5	2.3	1.7
without lining	Max.	0.2	4.7	3.7	5.2	*
	Residual	-0.3	0.3	-1.3	-0.4	1.6
Reno mat 1	Max.	1.4	4.1	11.3	13.8	*
	Residual	0.5	1	2	2.1	-5
Reno mat 2	Max..	-0.5	2.3	7.7	13	*
	Residual	-0.5	0.7	0.4	-0.8	-1.6
Geocell gravel	Max.	0.3	5.2	7.4	9.3	21.1
	Residual	-0.9	2.3	2.8	3.1	3.3
Note : "*" means the value occurs below the ice surface.						

The observation shows the frost-heaving amount and residual deformation of the Reno mat and geocell gravel are smaller than that of the structure without lining and fabric form structure. It is consistent with the results obtained in the laboratory which shows that the porous structure can adapt to the freeze-thaw deformation in cold climate conditions, especially under high underground water level.

6 CONCLUSIONS

Large canal projects in seasonal frozen soil region suffer from high water content of foundation soils, high frost heaving and ice-pushing force because of high underground water level. The new flexible anti-freezing slope protection techniques can ensure the stability under high underground water level. The experiment and demonstration of the project shows:

(1) The Reno mat structure and geocell gravel structure can effectively adapt to the freeze-thaw deformation of the canal slope. The whole protection system is stable. Measures of the design are more effective than the previous。

(2) To the porous protection structure, the temperature field of the soil body under the structure is uniform, which is of advantage to reduce the uneven frost-heaving of the foundation soil. The results of the tests indoor and field observation indicate that, Reno mat and geocell gravel structures can effectively reduce water content of the foundation soil before freezing, stabilize the temperature field and reduce the frost-heaving amount.

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