

The cooling effect of crushed rock structures on permafrost under an embankment

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ABSTRACT

Based on the analysis and comparison of soil temperature, thermal regime and permafrost table under the experimental embankment of crushed rock structures in Beiluhe, results show that crushed rock structures provide an extensive cooling effect, which produces a rising permafrost table and decreasing soil temperatures. The rise of the permafrost table under the embankment ranges from an increase of 1.08 m to 1.67 m, with an average of 1.27 m from 2004 to 2007. Mean annual soil temperatures under the crushed rock layer embankment decreased significantly from 2005 to 2007, with average decreases of -1.03 °C at the depth of 0.5 m, -1.14 °C at the depth of 1.5 m, and -0.5 °C at the depth of 5 m. During this period, mean annual soil temperatures under the crushed rock cover embankment showed a slight decrease at shallow depths, with an average decrease of -0.2 °C at the depth of 0.5 m and 1.5 m, but a slight rise at the depth of 5 m. After the crushed rock structures were closed or crammed with sand, the cooling effect of the crushed rock layer embankment was greatly reduced and that of the crushed rock cover embankment was just slightly reduced.

Keywords: cooling effect; crushed rock structure; permafrost

1. Introduction

Railway or highway construction will inevitably change the energy balance of the ground surface because of the built embankments. If no measurements are taken to ensure permafrost thermal stability, the permafrost table under the embankment will decrease and permafrost will be quickly warmed due to the thermal disturbance from engineering and climate warming (Wu and Tong, 1995; Tong and Wu, 1996; Wu *et al.*, 2002). As a result, permafrost changes under embankments will cause thaw settlement of the roadbed. Thus, it is crucial to ensure the stability of the permafrost table raised under the embankment and decreasing permafrost temperature for roadbed stability in permafrost regions.

Along the Qinghai-Tibet Railway, ice-rich and warm permafrost is defined as permafrost with temperature at the depth of the zero annual amplitude higher than -1.0 °C and volume ice content greater than 20 percent. It is very difficult to maintain permafrost table stability and decrease permafrost temperature under the embankment. To solve the problems of thermal stability of the roadbed, measures to cool the roadbed were used, including adjusting and controlling solar radiation, heat convection and heat conduction (Ma *et al.*, 2002; Cheng *et al.*, 2003; 2005; 2007, Wu *et al.*, 2006a). Crushed rock structures, including crushed rock-based embankments, crushed rock covered embankments, and U-type crushed rock embankments, were the most typical techniques used to cool the roadbed, and have been widely applied in ice-rich and warm permafrost regions (Cheng *et al.*, 2007; Zhang *et al.*, 2008). Data monitored from the Qinghai-Tibet Railway have shown that crushed rock structures can effectively lower permafrost temperature (Sun *et al.*, 2005; Wu *et al.*, 2006b; Ma *et al.*, 2008a; Ma *et al.*, 2008b; Wu *et al.*, 2008).

For the design of crushed rock-based and crushed rock cover embankments, it is important to determine which type of embankment best cools the roadbed and what is the cooling effect after the crushed rock structure is crammed with sand. These are difficult questions to answer because of the lack of monitoring data in the areas of the embankments.

Experimental sections of various crushed rock structures were constructed in Beiluhe in 2004, and the variation of permafrost temperature and the thermal regime under the embankment were monitored. So, in this article, we use about four years of soil temperature data from under the centerline of the crushed rock structures embankment to analyze and compare the difference of the cooling effect among these crushed rock structures.

2. Experimental design

The experimental sections were constructed in Beiluhe along the Qinghai-Tibet Railway in 2004. The mean annual ground temperature of permafrost is about -1.4°C , the permafrost table ranges from 1.45 m to 1.6m, and the ice-rich permafrost exists at a depth of 1.5 m to 10 m below the ground surface (Niu *et al.*, 2002). These ice-rich and warm permafrost conditions are representative of the Qinghai-Tibetan Plateau and are troublesome for engineering construction.

The experimental sections are 240 m long, and include the crushed rock cover embankment section, the crushed rock-based embankment section, the U-shaped crushed rock embankment section, the debris cover section, and the reference embankment section without the crushed rock layer for comparison (Figure 1). The entire experimental section is northeast-southwest in orientation (201°). Each experimental section is about 30 m long. The crushed rock cover embankment includes three types: (1) 80 cm thick crushed rock cover in an open system; (2) 80 cm thick crushed rock cover in a closed system, and (3) 120 cm thick crushed rock cover in an open system (see 1, 2 and 3 in Figure 1b).

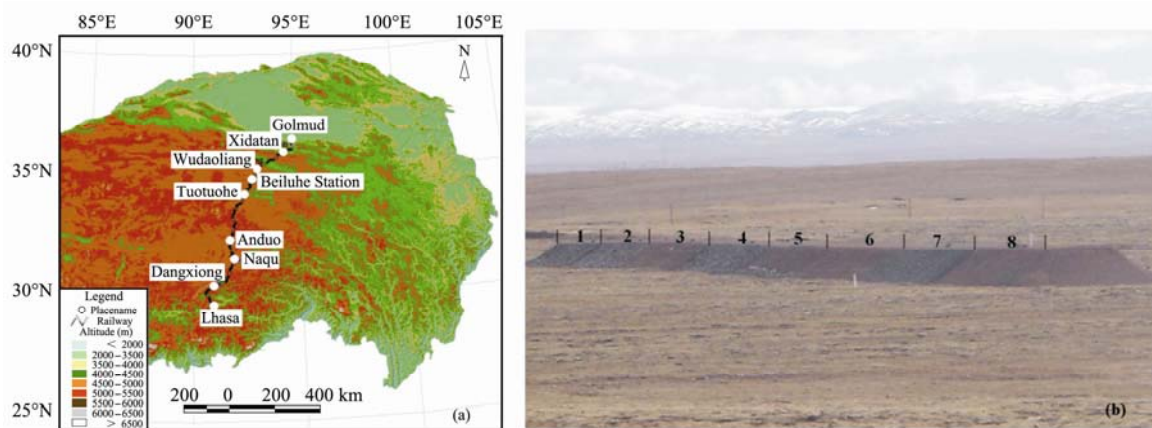


Figure 1 Experimental section in Beiluhe

There are two types of crushed rock-based embankments: one in an open system and the second with a closed system (see 5 and 6 in Figure 1b). We define an open system as one where the surface of the crushed rock layer is directly exposed to the atmosphere so air can freely enter the crushed rock layer. A closed system is where air cannot enter the crushed rock layer because a clay soil layer overlies the crushed rock layer.

The U-shaped crushed rock embankment is the crushed rock-based embankment with the crushed rock cover (Cheng, 2005) (see 4 in Figure 1b) and the debris rock cover embankment is the soil embankment with the debris cover (Cheng *et al.*, 2007) (see 7 in Figure 1b). All embankment sections are scaled according to actual dimensions of embankments of the Qinghai-Tibet Railway.

Construction began on the experimental sections on May 25, 2004, and was completed on September 25, 2004. The crushed rocks and fill soils used in the experimental sections came from sites about 10 km and 30 km away from Beiluhe, respectively. The design height of all embankments is about 3.5 m with a slope of about 1:1.5. For the crushed rock-based embankment, about 120 cm of thick, ungraded crushed rocks with diameters of about 20 to 30 cm were randomly piled up on the natural ground surface with a porosity of 40%, as determined by experimental research (He *et al.*, 2007). A fabric material was then laid over the crushed rock layer to prevent any soil particles from falling in the crushed rock pore space. About 20 cm of thick grained sand was laid on the fabric material, and finally, about 2.1 m of thick sandy soils were compactly laid on the grain sand layer. For the crushed rock cover embankment, a 3.5 m thick embankment was constructed, and then a layer of 0.8 to 1.2 m thick ungraded crushed rock with diameter of about 20 to 30 cm and a porosity of 40%, as determined by experimental research (He *et al.*, 2007), was randomly piled on the embankment slope.

During the crushed rock layer construction, the crushed rocks smaller than 20 to 30 cm in diameter was removed to ensure a larger pore space within the crushed rock layer. For the debris covered embankment, about 80 cm of thick ungraded debris with diameters of about 8 to 10 cm was randomly piled up on the slope of the embankment.

3. Monitoring method

In this work, we monitored the variation of soil temperature under the embankment in the middle of each experimental section for all the experimental sections being installed. During the construction, thermistor strings were installed into boreholes in the experimental sections before the embankment was completed. Thermistor strings were installed at the centerline, and the left and right shoulders of the roadbed. Soil temperatures under the embankment were measured from 0.50 to 15.0 m depth along the centerline boreholes and from 0.50 to 10.0 m along the left and right shoulder lines beneath the original natural ground surface at intervals of 0.50 m. Thermistors were made by the State Key Laboratory of Frozen Soil Engineering (SKLFSE) with an accuracy of $\pm 0.05^{\circ}\text{C}$. Soil temperatures were recorded every three hours with a data-logger (DT500 made in Australia). Daily average temperature is derived from the average value from the data collected eight times per day. The monitoring data of soil temperature under the left and right slope of the embankment were only obtained from September 26, 2004 to May 12, 2007, due to problems with the data logger. So, we used soil temperature data under the centerline of the embankment from September 26, 2004 to October 30, 2008, in this paper.

4. Cooling effect of the crushed rock-based embankment

The three types of crushed rock structures are the U-type crushed rock embankment (UCRE), the crushed rock-based embankment opened (CREO), and the crushed rock-based embankment closed (CREC). In this article, the cooling effect of these three crushed rock structures is discussed. Figure 2 shows the variation of soil temperature at a depth of 0.5 m under the UCRE, the CREO, and the CREC. The variation of soil temperature under the UCRE is similar to that the variation under the CREO, only slightly lower. In 2005, the first winter after the experimental section was constructed, the lowest soil temperature was about -6.5°C and in 2007, about -9.5°C . The soil temperature under the CREC was significantly different from temperatures under the UCRE and CREO, with the lowest soil temperature only about -2.0°C in 2005, and about -4.0°C in 2007, indicating that the cooling effect is reduced when the crushed rock layer is closed or crammed with sand. The trend of lowered temperature over time under the UCRE, CREO and CREC is clear, indicating that the crushed rock structure has a cooling effect on the soil under the embankment (Figure 2).

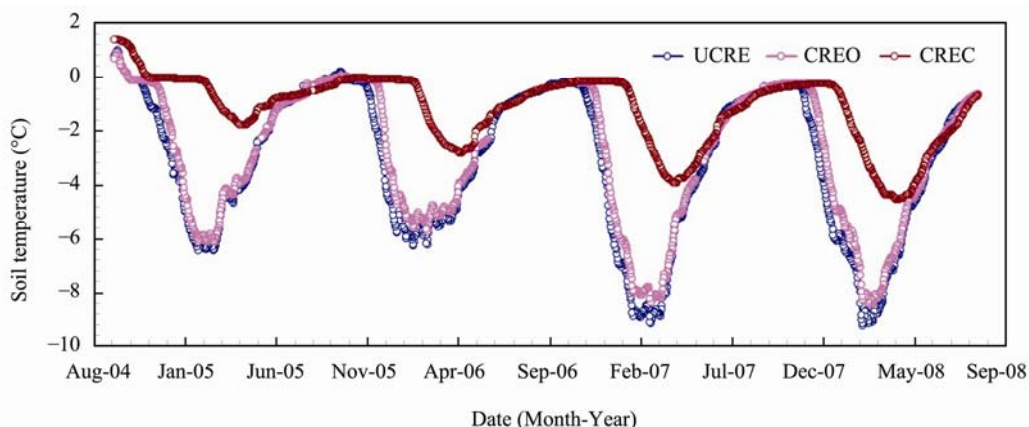


Figure 2 Soil temperatures at the depth of 0.5 m under the UCRE, CREO and CREC

Figure 3 shows the variation of soil temperature at the depth of the original permafrost table under the natural surface. Soil temperatures at the depth of the original permafrost table under the ground surface were in the state of stably lowering over time, the lowest soil temperature ranged from -4.2°C in 2005 to -7.2°C in 2007 for the UCRE, -4.0°C in 2005 to -6.8°C in 2007 for the CREO, and -1.0°C in 2005 to -3.0°C in 2007 for the CREC. The trend of lowering soil temperature indicated that the

accumulated cool energy was enough to maintain the stability of the permafrost table.

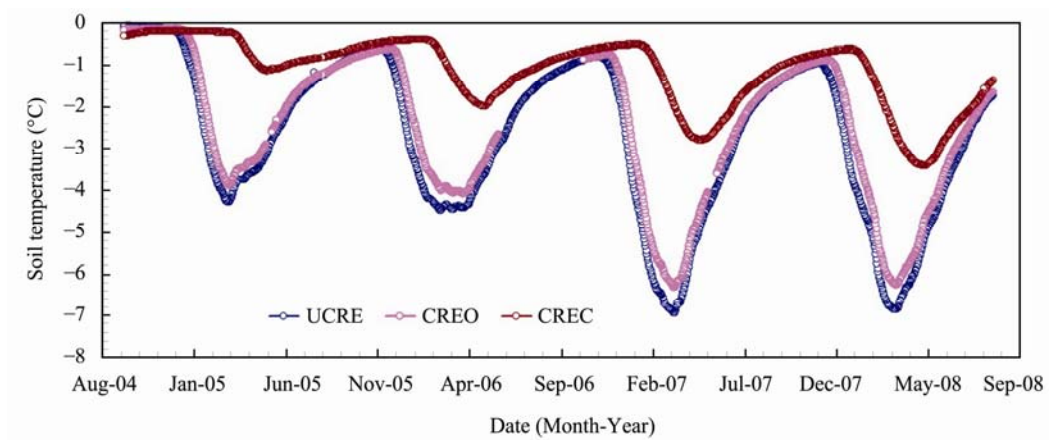


Figure 3 Soil temperatures at the depth of the original permafrost table under the natural surface

Figure 4 shows the variation of permafrost temperature at the depth of 10.0 m under the embankment. The permafrost temperature shows a significant decrease for the UCRE and CREO, but an obvious rise for the CREC. Figure 4 indicates that the cooling effect of the UCRE is superior to that of the CREO, and the difference gradually increases with time. The difference between the cooling effect of the UCRE and CREO may explain the obvious cooling effect of the crushed rock cover. The cool energy accumulation of the UCRE and CREO produced enough to lower the permafrost temperature at the depth of 10 m under the embankment. The cooling energy accumulation of cooling effect of the CREC only lowered the permafrost temperature at the depth of 4.5 m to 5.0 m, indicating that the cooling effect largely decreased after the crushed rock layer was closed or crammed with sand. In spite of the reduced cooling effect, soil temperatures at the depth ranging from 0.5 m to 5 m under the CREC gradually decreased (Figures 2 and 3), indicating the CREC’s obvious cooling effect.

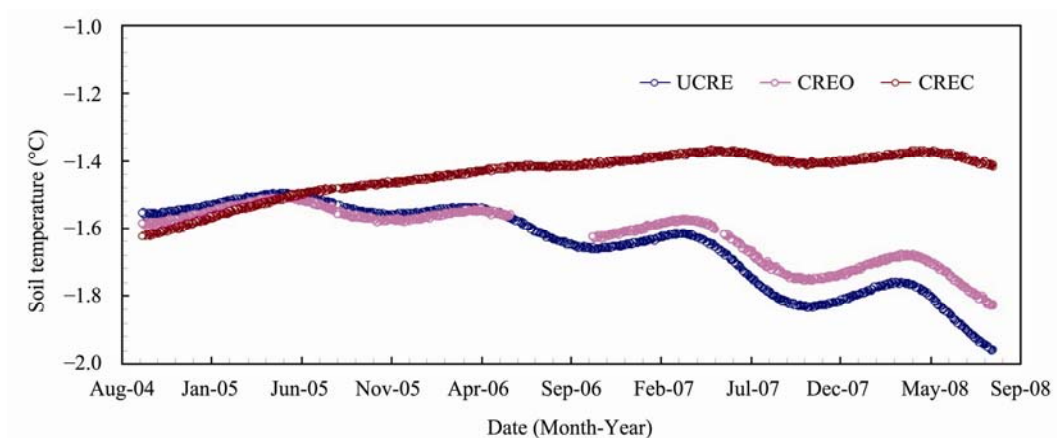


Figure 4 Permafrost temperatures at the depth of 10.0 m under the UCRE, CREO and CREC

Figure 5 shows the thermal regime under the UCRE (a), CREO (b) and CREC (c) on October 5, and May 10 of every year, respectively. The day October 5 is about the time of maximum thaw depth, and the day May 10 is the day when the ground surface start to be thawed. From the left map in Figure 5a, 5b and 5c, the permafrost table under the UCRE, CREO and CREC was gradually raised, but only with slight differences among the three crushed rock structures. The difference between the thermal regimes under the UCRE and CREO is very small. Permafrost temperatures above the depth of 14 m under the embankment decreased gradually, and soil temperatures deeper than 14 m have not basically varied (Figure 5a and 5b). But, the cooling effect was reduced after the crushed rock structure was closed or crammed with sand.

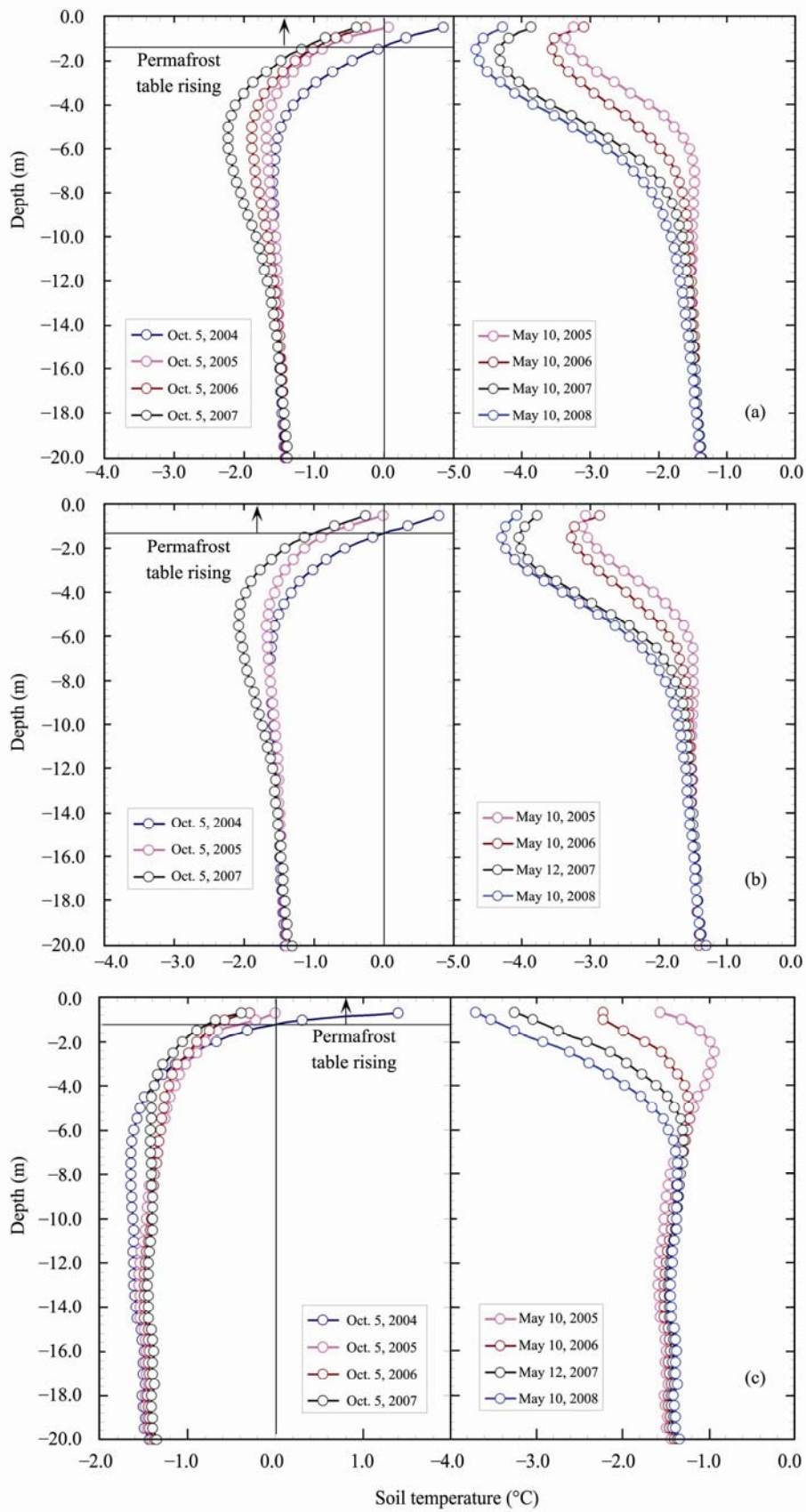


Figure 5 Thermal regime of soil under the UCRE (a), CREO (b) and CREC (c)

Soil temperature was quickly raised after the CREC was constructed, but soil temperature rise was gradually controlled by the cooling effect of the CREC from the beginning of 2005 (seen in the right side of Figure 5c). The depth of lowering soil temperature was gradually increased from the beginning of 2005. For example, the depth of lowering soil temperature under the CREC was above 2 m on October 5, 2005, above 3 m on October 5, 2006, and above 7 m on October 5, 2007 (seen in the left side of Figure 5c). From the view of the thermal regime under the CREC, the crushed rock structure has a better cooling effect on the permafrost under the CREC in spite the fact that the cooling effect is reduced after the crushed rock structure is closed or crammed.

5. Cooling effect of the crushed rock cover embankment

The crushed rock cover embankment includes the crushed rock cover-wider (CRC120), crushed rock cover opened (CRCO80) and closed (CRCC80), and the debris covered embankment (DC80). The cooling effect produced for all four types of crushed rock or debris covers are similar (Cheng *et al.*, 2007). So, in this article, the cooling effect of the four structures is discussed together.

The variation is similar for the four cover types but with one outstanding difference (Figure 6). For the debris cover structure (DC80), the thermal exchange between the embankment and the soil under the original ground surface was small from 2005 to 2006 after the embankment was constructed, but smaller than that of the crushed rock cover, and extensive thermal exchange between the embankment and the soil under original ground surface occurred after 2007 (Figure 6). This indicated that the cooling effect produced by the debris cover is slower than that produced by the crushed rock cover. For the crushed rock cover (CRC120, CRCO80 and CRCC80), thermal exchange between the embankment and the soil under the original ground surface was larger after the first year after the embankment was constructed, and the thermal exchange of the CRC120, especially in winter, was larger than that of the CRO80 and CRC80 in 2005 (Figure 6). The thermal exchange difference among the four cover types has been gradually reduced since the summer season of 2006. The soil temperature at the depth of 0.5 m under embankment has shown a strong decreasing trend despite the fact that the cooling effect produced by the crushed rock or debris cover occurred slowly.

Figure 7 shows the variation of soil temperature at the original permafrost table under the centerline of the embankment of the CRC120, CRCO80, CRCC80 and DC80.

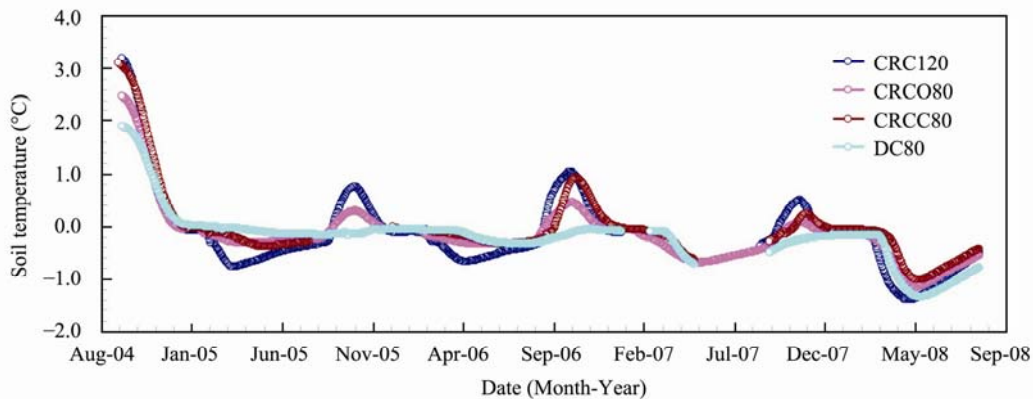


Figure 6 Soil temperatures at the depth of 0.5 m under the CRC120, CRCO80, CRCC80 and DC80

The soil temperatures at the original permafrost table under the centerline of the embankment gradually decreased with time (Figure 7). The soil temperature variation difference among the four covers was very small during the beginning period when the embankment was constructed, but gradually increased as over time. The decreasing trend of soil temperature at the original permafrost table indicated that the cooling effect produced by the debris cover is larger than that of the crushed rock cover (Figure 7). For cooling effect, the DC80 is superior to CRC120, CRC120 superior to CRCO80, and CRCO80 superior to CRCC80.

Figure 8 shows the variation of permafrost temperature at the depth of 5m under the centerline of the embankment of the CRC120, CRCO80, CRCC80 and DC80.

The permafrost temperature at the depth of 5 m shows an obviously rising trend for the debris cover and the crushed

rock cover. But, this rising trend was delayed following the winter when the embankment was constructed, indicating that the cooling effect produced by the debris cover and the crushed rock cover gradually controlled the permafrost warming.

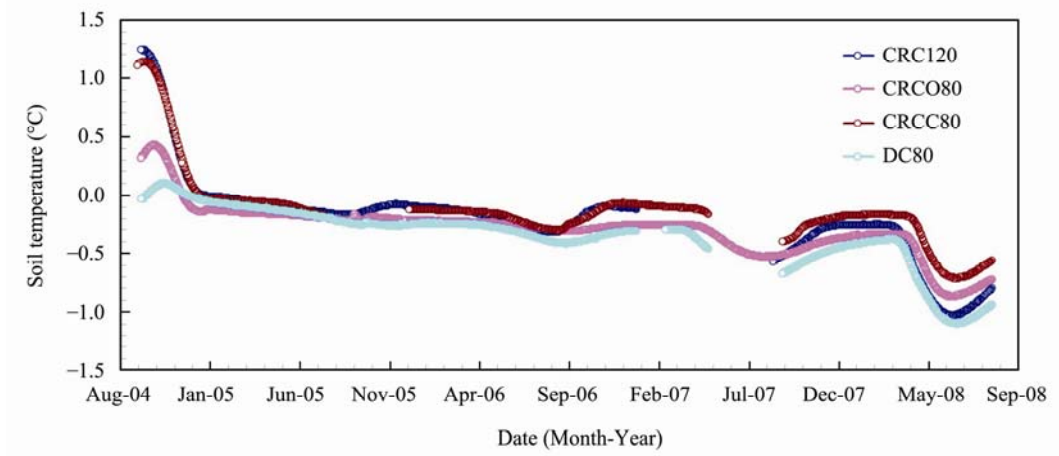


Figure 7 Variation of soil temperature at the original permafrost table under the centerline of embankment of the CRC120, CRCO80, CRCC80 and DC80

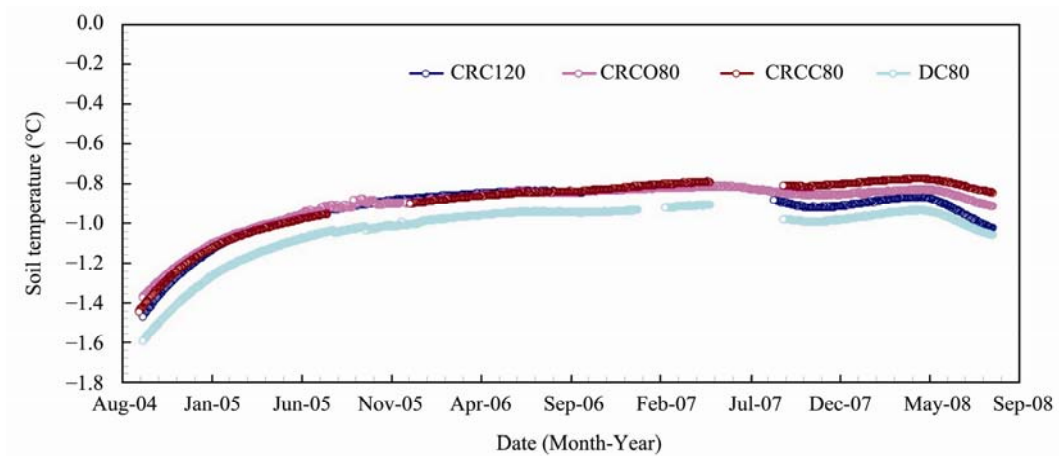


Figure 8 Variation of permafrost temperature at the depth 5 m under the centerline of the embankment of the CRC120, CRCO80, CRCC80 and DC80

Figure 9 shows the thermal regime of the soil under the centerline of the embankment for the CRC120 (a), CRCO80 (b), CRCC80 (c) and DC80 (d) on October 5, and May 10 of every year, respectively. From the left side of the map in Figure 9, the gradual rise of the permafrost table can be seen, but the magnitude of the permafrost table rise under the CRCC80 and DC80 was larger than that under the CRC120 and CRCO80. While the permafrost table was raised, permafrost temperatures also rose (Figure 9). But, soil temperatures at the depth ranging from 0.5 m to 6.0 m were gradually decreased (Figure 9), indicating that the rise of permafrost temperature was controlled by the cooling effect produced by the crushed rock cover and debris cover.

6. Discussion

The soil temperatures at the depth of 0.5 m under the centerline of the crushed rock structure embankment were significantly decreased and the magnitude of soil temperature lowering was more apparent from 2007 to 2008 than from 2005 to 2006 (Figures 2 and 6). The soil temperature decrease is completely contrary to the air temperature rise from 2007 to 2008 (Figure 10), indicating that soil temperature is lowered by the cooling effect produced by the crushed rock structure. Under this cooling effect, the permafrost table under the embankment rises, ranging from 1.08 m to 1.67 m with an average of 1.27 m (Figure 11) from 2004 to 2007. Except for the DC80, where the permafrost table rise was the greatest, the embankment with the crushed rock layer showed a larger rise of the permafrost table than that under the crushed rock cover embankment.

For the embankment based on the crushed rock layer, the permafrost table rose significantly every year from 2004 to 2007 (Figure 11), with the permafrost table rise ranging from 1.22 m under the CREO to 1.32 m under the UCRE, with an average of 1.27 m. The difference of permafrost table rising among the UCRE, CREO and CREC is small. The crushed rock-based closed or crammed with sand seems to have little effect on permafrost table rise since the rising magnitude under the CREC is larger than that under the CREO.

For the crushed rock cover embankment, the permafrost table rose significantly in the first year, 2005, after the embankment was constructed, and slowly rose from the second to third year, and the magnitude of permafrost table rising was still larger to 0.8 m. The permafrost table rising ranged from 1.08 m under the CRC120 to 1.18 m under the CRCC80, with an average of 1.13 m. The crushed rock cover closed or crammed with sand appears to not affect the permafrost table rising since the magnitude of the permafrost table rise under the CRCC80 is larger than that under the CRCO80.

For the debris cover embankment (DC80), the rising magnitude of the permafrost table is the largest of all the crushed rock structures, up to 1.67 m. However, the cooling effect of the UCRE, CREO and CREC is much better than that of the debris cover, DC80. This anomaly of permafrost table rising cannot be explained.

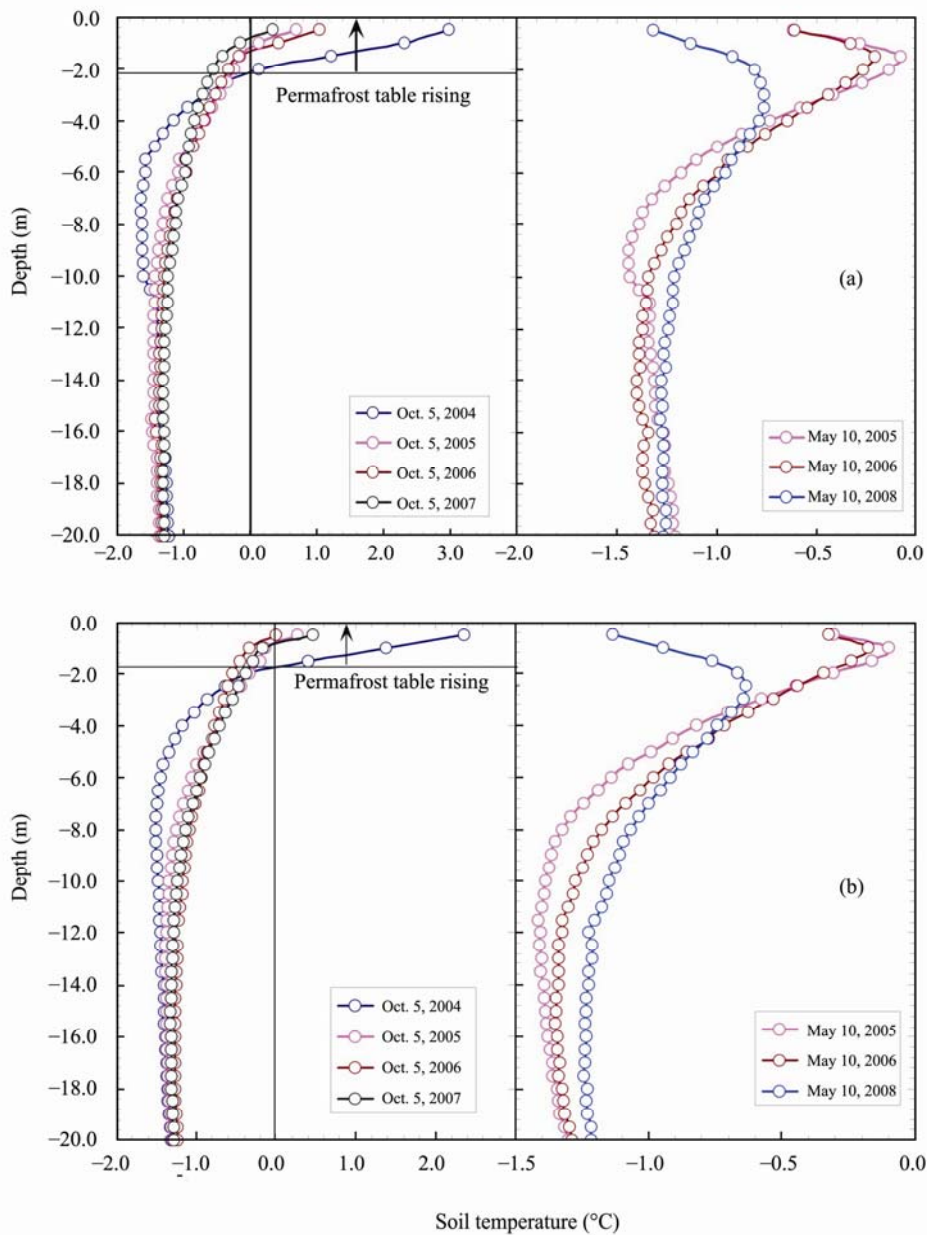


Figure 9 Thermal regime of the soil under the centerline of the embankment for CRC120 (a), CRCO80 (b), CRCC80 (c), and DC80 (d) (to be continued)

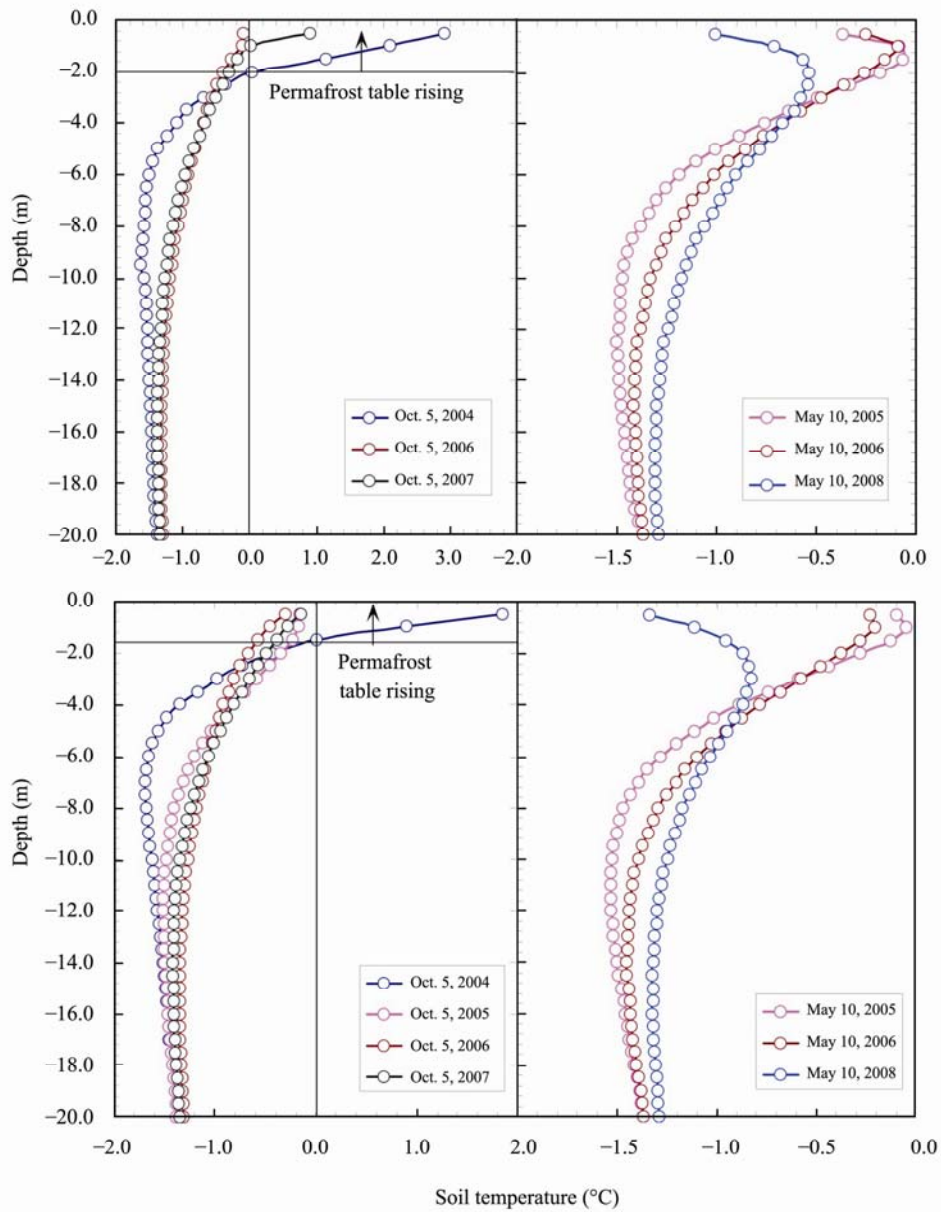


Figure 9 Thermal regime of the soil under the centerline of the embankment for CRC120 (a), CRCO80 (b), CRCC80 (c), and DC80 (d)

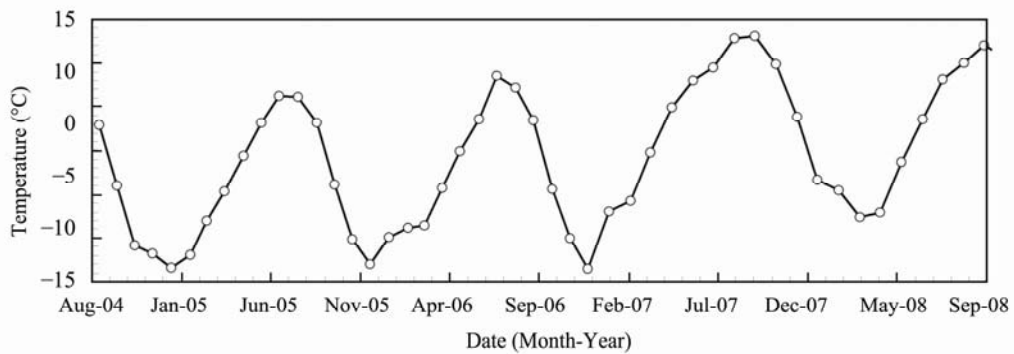


Figure 10 Variation of air temperature from 2004 to 2008 in Beiluhe

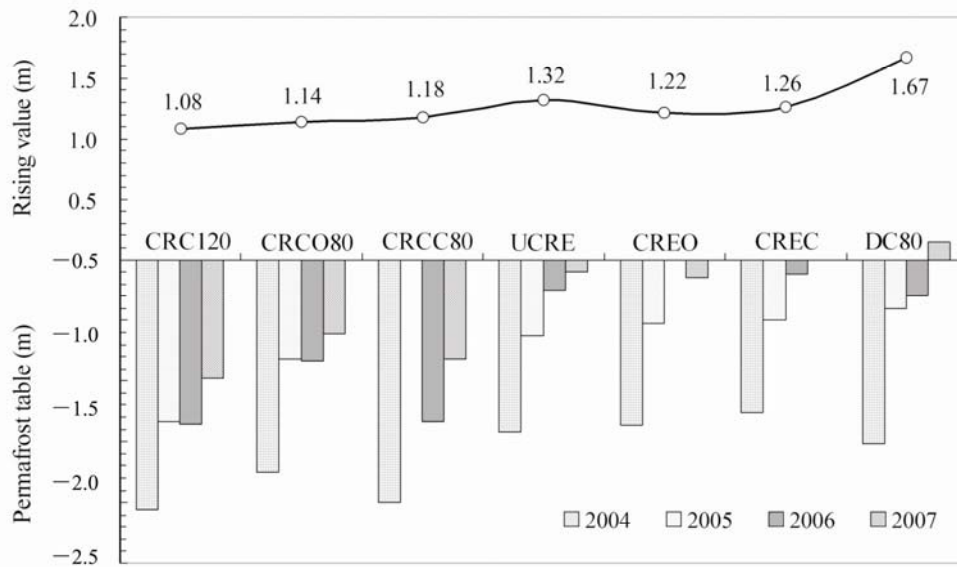


Figure 11 Permafrost table rises from 2004 to 2007. The permafrost tables larger than 0.5 m under the embankment are estimated by the thermal regime of the soil.

Table 1 shows the annual mean soil temperature at the depth of 0.5 m, 1.5 m and 5 m under the embankment from 2005 to 2007. The crushed rock layer embankment showed the largest annual mean soil temperature decrease from 2005 to 2007 (Table 1). The variation of annual mean soil temperatures at the depth of 0.5 m under the UCRE ranged from $-2.54\text{ }^{\circ}\text{C}$ in 2005 to $-3.70\text{ }^{\circ}\text{C}$ in 2007 with a decrease of $-1.16\text{ }^{\circ}\text{C}$, that at the depth of 1.5 m under the UCRE ranged from $-1.88\text{ }^{\circ}\text{C}$ in 2005 to $-3.33\text{ }^{\circ}\text{C}$ in 2007 with a decrease of $-1.45\text{ }^{\circ}\text{C}$, and that at the depth of 5 m ranged from $-1.57\text{ }^{\circ}\text{C}$ in 2005 to $-1.92\text{ }^{\circ}\text{C}$ in 2007 with a decreasing of $-0.35\text{ }^{\circ}\text{C}$. The variation of annual mean soil temperature at the depth of 0.5 m under the CREO ranged from $-2.27\text{ }^{\circ}\text{C}$ in 2005 to $-3.27\text{ }^{\circ}\text{C}$ in 2007 with a decreasing of $-1.0\text{ }^{\circ}\text{C}$, and that at the depth of 1.5 m ranged from $-1.77\text{ }^{\circ}\text{C}$ in 2005 to $-2.96\text{ }^{\circ}\text{C}$ in 2007 with a decreasing of $-1.19\text{ }^{\circ}\text{C}$, and that at the depth of 5 m ranged from $-1.58\text{ }^{\circ}\text{C}$ in 2005 to $-2.16\text{ }^{\circ}\text{C}$ in 2007 with a decreasing of $-0.58\text{ }^{\circ}\text{C}$. The variation of annual mean soil temperature at the depth of 0.5 m under the CREC ranged from $-0.57\text{ }^{\circ}\text{C}$ in 2005 to $-1.49\text{ }^{\circ}\text{C}$ in 2007 with a decreasing of $-0.92\text{ }^{\circ}\text{C}$, and that at the depth of 1.5 m ranged from $-0.61\text{ }^{\circ}\text{C}$ in 2005 to $-1.40\text{ }^{\circ}\text{C}$ in 2007 with a decreasing of $-0.79\text{ }^{\circ}\text{C}$, and that at the depth of 5 m ranged from $-1.22\text{ }^{\circ}\text{C}$ in 2005 to $-1.35\text{ }^{\circ}\text{C}$ in 2007 with a decreasing of $-0.13\text{ }^{\circ}\text{C}$. The variation of annual mean soil temperature indicates the extensive cooling effect of the crushed rock layer, with the cooling effect of the UCRE better than that of the CREO, and that of the CREO better than that of the CREC. The cooling effect is significantly reduced after the crushed rock layer is closed or crammed with sand.

Table 1 Annual mean soil temperature at different depths under the embankment ($^{\circ}\text{C}$)

Depth (m)	0.5			1.5			5		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
UCRE	-2.54	-2.79	-3.70	-1.88	-2.50	-3.33	-1.57	-1.92	-2.36
CREO	-2.27		-3.27	-1.77		-2.96	-1.58		-2.16
CREC	-0.57	-0.99	-1.49	-0.61	-1.00	-1.40	-1.22	-1.23	-1.35
CRC120	-0.20	-0.11		-0.09	-0.18		-0.98	-0.85	
CRCO80	-0.12	-0.10	-0.32	-0.18	-0.26	-0.38	-0.97	-0.85	-0.84
CRCC80		-0.01			-0.17			-0.85	
DC80	-0.11	-0.16		-0.19	-0.31		-1.07	-0.95	

For the crushed rock cover embankment from 2005 to 2007, the annual mean soil temperature showed little decrease above the depth of 5 m under the embankment and only minor rising below the depth of 5 m (Table 1). The variations of

annual mean soil temperatures at the depth of 0.5 m and 1.5 m under the embankment show a small decrease of about -0.2 °C, and at the depth of 5 m a small rise of 0.1 °C. Among the CRC120, CRCO80, CRCC80 and DC80, differences of annual mean soil temperature lowering by the cooling effect are insignificant. Although annual mean soil temperatures above the depth of 5 m under the embankment show only slight decrease of -0.2 °C, annual mean soil temperatures below the depth of 5 m show only a slight rise of 0.1 °C, indicating that the cooling effect produced by the crushed rock cover gradually mitigated permafrost warming after the embankment was constructed.

7. Conclusions

Important results were obtained from the analysis and comparison of soil temperature at the depth of 0.5 m and near the original permafrost table before embankment constructed, permafrost temperature at the depth of 5 m under the centerline of the embankment, the thermal regime at the time of maximum thaw depth, and ground surface warming and permafrost table rise.

(1) After the crushed rock structure embankment was constructed, the permafrost table under the embankment rose significantly, ranging from 1.08 m to 1.67 m with an average of 1.27 m from 2004 to 2007. For the embankment based on the crushed rock layer, the permafrost table rise ranged from 1.22 m under the CREO to 1.32 m under the UCRE, with an average of 1.27 m. For the crushed rock cover embankment, the permafrost table rise ranged from 1.08 m under the CRC120 to 1.18 m under the CRCC80, with an average of 1.13 m. For the debris cover embankment (DC80), the rising magnitude of the permafrost table was the largest in all of the crushed rock structures, up to 1.67 m.

(2) After the crushed rock structure embankment was constructed, the soil temperatures under the embankment clearly decreased from 2005 to 2007. For the embankment based on the crushed rock layer, the average decrease of annual mean soil temperature under the embankment ranged from -1.03 °C at the depth of 0.5 m, -1.14 °C at the depth of 1.5 m, and -0.5 °C at the depth of 5 m. The annual mean soil temperature at the depth of 10 m under the UCRE and CREO obviously decreased by -0.16 °C and that under the CREC rose 0.11 °C. For the crushed rock cover embankment, the annual mean soil temperatures at the depth of 0.5 m and 1.5 m under the embankment showed a small decrease of about -0.2 °C, and at the depth of 5 m showed a small rise, ranging from 0.2 °C to 0.1 °C.

(3) The cooling effect produced by the crushed rock structure is dominant in decreasing soil temperatures and permafrost table rise. And the permafrost table rise and the variation of soil temperature under the embankment show the cooling effects produced by the different crushed rock structures. The cooling effect of the UCRE, the CREO and the CREC are much better than that of the CRC120, CRCO80, CRCC80 and DC80. The cooling effect of the UCRE on permafrost under the embankment is slightly better than that of the CREO, and the cooling effect of the CREO is better than that of the CREC. The cooling effect of the debris cover is only slightly better than that of crushed rock cover.

(4) After the crushed rock structures are closed or crammed, the cooling effect of the embankment based on crushed rock layer is greatly reduced and that of the crushed rock cover embankment is slightly reduced. The influence of the cooling effect on the rise of the permafrost table is small and that on the decrease of permafrost temperature is large. The permafrost at the depth of 10 m under the crushed rock-based opened embankment was still in the decreasing state, while the permafrost at the depth of 6 m under the crushed rock-based closed embankment was in the state of rising.

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