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Superficial Layer Landslide Deformation Features in northern part of Lesser Khingan Region, China

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***Abstract*—In recent years, permafrost in the northeast of China is being severely degraded. Bei'an-Heihe Expressway crosses northwest part of the Lesser Khingan Range region. The landslide is located in an area of the island's permafrost. Due to atmospheric precipitation, the presence of permafrost, regional climate conditions, and special geological conditions, landslides occur annually from late May to early November. The area is in a relatively stable state during winter. These seasonal landslides have seasonal, gradual, low angle characteristics. By January 2014, the landslide had moved a distance of up to 113.32 m (in the rear), and 26.4 m (at the leading edge). With cumulose soil at rear of landslide decreasing, and the recorded movement of the landslide over time, the landslide deformation appears to show an apparent attenuation trend. This article combines a geological survey and over three years of monitoring surface deformation. Research results show that: water infiltration of rainfall, melting snow and permafrost melting is stopped by frozen soil and impermeable barriers, leading to local moisture content rapidly rising, water erosion along interface between the permeable layer and water-resisting layer forms the sliding surface. Sliding velocity of the landslide is large different in different seasons. Within the same cross section of landslide, the sliding displacement of center is largest, and near landslide flank is smallest.**

***Keyword*—high latitude permafrost, landslide, deformation monitoring, freeze-thaw action**

I. Foreword

Landslides are common along highways constructed in mountain areas due to their geology, geomorphology, hydrology, and climatic conditions[9,11]. It is one of the main diseases of mountainous area highway[1]. In China, the study on cold regions landslide mostly focused on seasonal frozen region, but less about permafrost regions slope mechanism and sliding characteristics, and mainly in high altitude permafrost region of Qinghai-Tibet Plateau[5,6,7]. The thaw slumping leading to slope instability was the focal point. Ma Lifeng and Niu Fujun studied the causes of thaw slumping of Qinghai-Tibet Plateau, and analyzed its inducing relationship with the permafrost physical conditions and external force. Finally they analyzed landslide formation and motion mechanism of permafrost regions[1]. Li Tonglu researched on the landslide along the Sichuan-Tibet Highway. He concluded that the storm, steep hills and earthquake were the main reasons of the landslide in the slide[2]. Gu Tianfeng and Wang Guding through the laboratory test and the finite element analysis, it is concluded that the terrain characteristics, landslide zone of low soil shear strength and inappropriate human activity were the main influence factors of formation and development of landslide of Qinghai-Tibet Plateau[3].

At present, research on the characteristics of the formation of mountainous landslides at high latitudes in the Lesser Khingan Range of Heilongjiang province is in its infancy. It is high latitudes permafrost regions, the ground slope in landslide area is low. And permafrost in the northeast of China is being severely degraded[4,12]. The formation mechanism and movement characteristics of landslide have their regional particularity[8,10]. This article combines the results of a geological survey over three years that monitored surface deformation, slope soil geothermal changes with the effects of the landslide itself. Large scene surveys such as this can provide precious information on the landslides that occur at high latitudes in permafrost areas.

II. Regional Natural Geographical Conditions

The landslide of interest is located in the central region of the Lesser Khingan Range, China. Spring in the study area is brief, warming quickly followed by summer, which is hot and rainy. With the onset of autumn, temperature fall rapidly and the short season leads into, winter that is cold and long. The annual average temperature in the area is -0.6 °C. The average annual precipitation is 510–572 mm. Rainfall is concentrated in the months of July to September, and accounts for about 60% of total annual precipitation. The first snow is generally in the last third of October; the last snow is generally at the end of March or early April. During winter, the maximum seasonal frozen depth is 2.30–2.50 m below the ground. The geomorphology of the study area is mainly dominated by low mountains and hills; topographic relief is large in the high latitude permafrost region.

The landslide scene photos are shown in Fig. 1. The landslide is located on the left-hand side of the road embankment. Road abandon soil and subgrade filling soil slide along the gully. The 178+530 landslide presents a tongue shape, and its width is 20–30 m, its acreage is about 5000 m^2,

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the distance from toe to rear edge is about 200 m, the elevation of toe is 254 m, and the elevation of rear edge is 285 m. The leading edge of the landslide pushes up humus soil of the original ground surface, which consequently slides forward. The arcuate dislocation in the rear edge was in the range of the wider subgrade. There, the trees tilt at the leading edge of the landslide.

Figure 1. Landslide scene photos: 1) Panoramic view of landslide; 2) The trailing edge of landslide; 3) The leading edge of landslide

III. Geology of the Study Area

In order to gain insight into the subsurface character of the landslide, we conducted a drilling exploration, drilling four holes, the depths of these drill holes ranged from 14 to 26 m, and their arrangement is shown in Fig. 2.

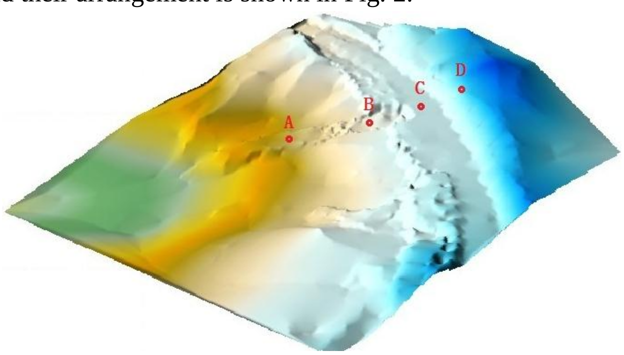

Figure 2. Boreholes A – D drilled in the area

In the research section, the soil distribution is listed as follows: Quaternary loose sediment, Tertiary pebbly sandstone, Cretaceous mudstone, and sandstone. The geological cross section as shown in Fig. 3. Subgrade filling soil or road construction waste is yellow and waterlogged; it comprises mainly loose material including Tertiary pebbly sandstone, Cretaceous mudstone, and sandy mudstone. Clay in the soil is yellow, soft, and plastic when saturated, and tough and strong when it is dry. Silty clay is located at depths of 1.5–3.8 m in upper section of the landslide, and at depths of 0–6.7 m in the middle to lower sections. More than one intercalated sand layers exist within the silty clay layer; the thickness of a single sand layer is ranges from 1–10 cm. The presence of these sand layers greatly increases the permeability of the soil. Tertiary pebbly sandstone is located at depths of 3.8–4.5 m on the upper sector of the landslide. The components of the pebbly sandstone include large clasts and sand minerals. The layer is weathered, slightly wet, and unconsolidated with loose sand and good gradation, with good water permeability. The weathered siltstone is yellow in colour and is located at depths of 4.5–14.3 m at the upper sector of the landslide. The siltstone has a sandy structure with bedding and poor water permeability. The weathered mudstone is yellow or black-grey and it has a muddy and layered structure, poor water resistance, and poor water permeability. The strongly weathered mudstone is unconsolidated, black-grey with a layered and muddy structure. The moderately weathered mudstone is brown and black-grey with a muddy and layered structure.

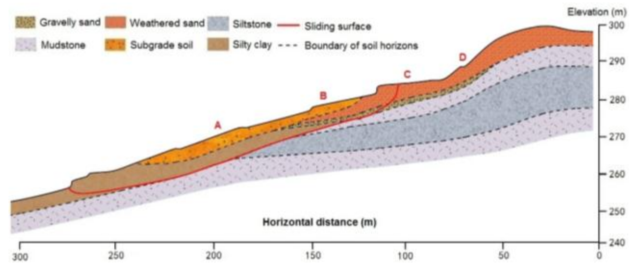

Figure 3. Geological cross section of K178+530

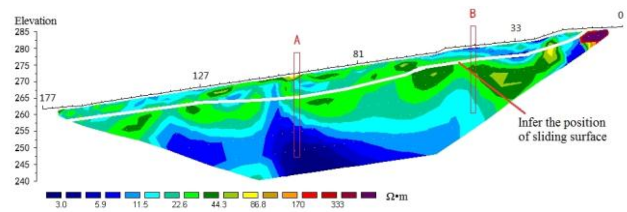

Figure 4. High density resistivity image of K178+530 landslide

The resistivity value at the slip surface location showed significant stratification, and the resistivity values of its upper and lower were more obvious differences. According to the typical characteristic of the slip surface, we can infer the position of sliding surface as shown in Fig. 4.

Based on drilling and high density resistivity explore, we know the landslide geologic feature. The slip surface of the upper section of the landslide is at a depth of 4.5 m, located at the interface between gravel sand and siltstone. The slip surface of the middle and lower sections is at a depth of 6.5 m, at the interface of silty clay and mudstone.

During the rainy season and the thawing period in spring, landslides are particularly feasible. Tympanites cracks on the landslide are beneficial to permeate and stockpile. Highly permeable surface soil, grit, and silty clay provide passage for water infiltration. The infiltration capacity of the lower mudstone and siltstone is very small, forming an impermeable layer. The infiltration of rainfall, snowmelt water, fissure water, and thawed frozen soil are cut off by frozen soil and the lower impervious layer in the process of infiltration. This impedance to the flow of groundwater is the main cause of landslides in the area. The landslide first began moving in late July 2010.

IV. GPS Monitoring Sites Arrangement

On September 13, 2010, two deformation monitoring pipes and sensors on the landslide body were bored at respective depths of 4.2 m and 6.5 m. We employed GPS to monitor movement of the landslide by arranging nearly 49 GPS gauge piles at different positions on the landslide (Fig. 5).

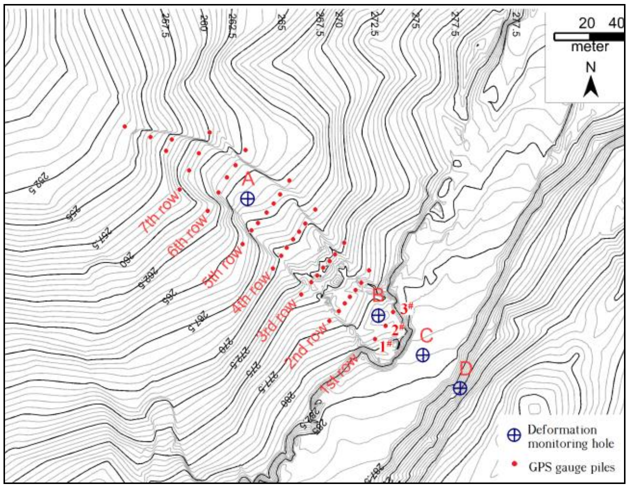

Figure 5. The layout of GPS gauge piles along the landside

From the rear edge of landslide to the leading edge, we arranged 10 rows of gauge piles on both sides of the outside of the landslide, as well as at the centre of the top and close to the rear edge of the landslide. The distance from the first row to the rear edge of the landslide is 15 m and gauge numbers run from 1–3 (left to right). The distance from the second row to the rear edge of landslide is 30 m, and from the third row to the seventh row to the rear edge of landslide is 50 m, 70 m, 93 m, 119 m, and 134 m, respectively. The rest of the gauge piles are distributed along the leading edge of the landslide. These GPS monitoring piles can monitor the sliding conditions at the proximal, middle, and distal sections of the landslide, as well as laterally across it. Data collection was conducted from September 13, 2010 to January 17, 2014, a total of 1222 days in total.

V. Gauge piles Motion Characteristic at Different Positions

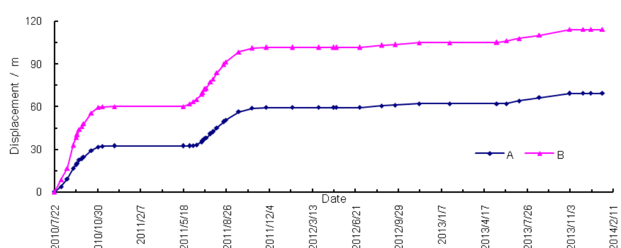

Figure 6. Horizontal sliding displacement curve of deformation monitoring pipes A and B

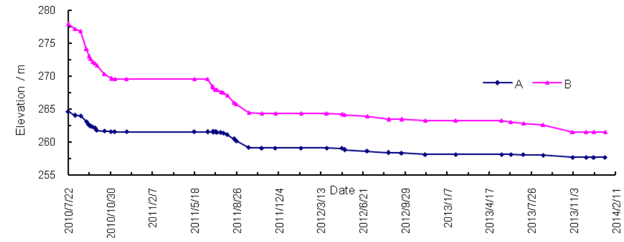

Figure 7. Vertical sliding displacement curve of deformation monitoring pipes A and B

Fig. 6 and Fig. 7 show horizontal and vertical sliding displacement curves of monitoring pipes A and B. We know that the landslide started moving on July 22, 2010 and continued until mid-November 2010. After that, towards winter, the ground surface began to freeze and remained in stable state until May 2011, at the end of which, the sliding commenced again. The displacement values for two monitoring points did not occur in harmony, resulting in different displacement values. For example, in late May 2011, monitoring point B had already started to slide, but monitoring point A was still stationary. This shows that the trailing edge was the first to begin sliding. After more than ten days, the leading edge of the landslide began to slip, showing increased displacement relative to the front of the landslide. These sliding and deformation characteristics show that the landslide is a push-type landslide.

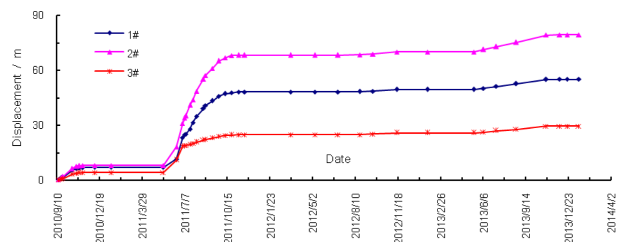

Figure 8. The first row of gauge piles to slide are shown on this displacement graph

Fig. 8 shows the first row of gauge piles to slide in the study area. From September 13, 2010 to November 2010, 1#, 2#, and 3# gauge piles were displaced by 6.90 m, 8.05 m, and 4.12 m, respectively. In early June 2011, the landslide began to activate again. And by January 17, 2014, sliding displacements of 1#, 2# and 3 gauge piles was 54.90 m, 79.15 m, and 29.34 m, respectively (in 1222 days of monitoring). In the middle of the landslide body, the slip rate in a central location (2# gauge pile) exhibited a higher slip rate than nearer to the edge (1# and 3# gauge piles).

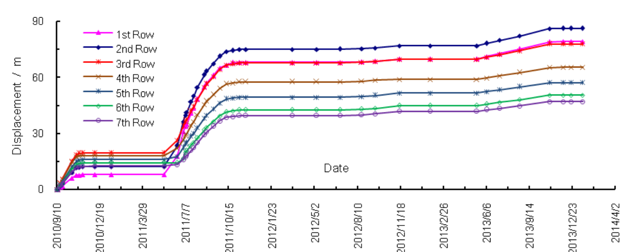

Figure 9. Gauge pile displacement curve along the middle of the landslide

From the longitudinal section in the centre of the landslide (Fig. 9) we observed that from September 13, 2010 to January 17, 2014, the gauge pile displacement from the first row to the seventh row, respectively, are 79.15 m, 86.18 m, 77.91 m, 65.35 m, 57.28 m, 50.48 m, and 47.04 m. This slide displacement is different for the different gauge pile positions at the same time. Sliding displacement of the middle and upper sections is the greatest.

VI. The Variations in the Perimeter of the Landslide

K178+530 landslide external form is rendered as a band, with the formation and development of the landslide, apparent form of landslide is constantly changing, slide range is gradually increasing. As shown in Fig. 11 for the October 2010 landslide image, landslide area is 1.5 times of the 2004 landslide area (in Fig. 10), landslide occurred greater deformation in recent years.

Figure 10. The 2004 landslide area (Google image)

Figure 11. The October 2010 landslide area (Google image)

Fig. 12 shows K178 + 530 landslide perimeter variation, this figure shows that landslides' trailing edge has been expanding towards the road, which will eventually result in a road hazard. From July 2010 to November 2010, the landslide front moved forward advancing 15.5 m, and from July 2010 to January 2014, the landslide advanced by 26.4 m. The landslide slope gradient on July 2010 was 8.07°, which dropped to 6.2° on January 2014.

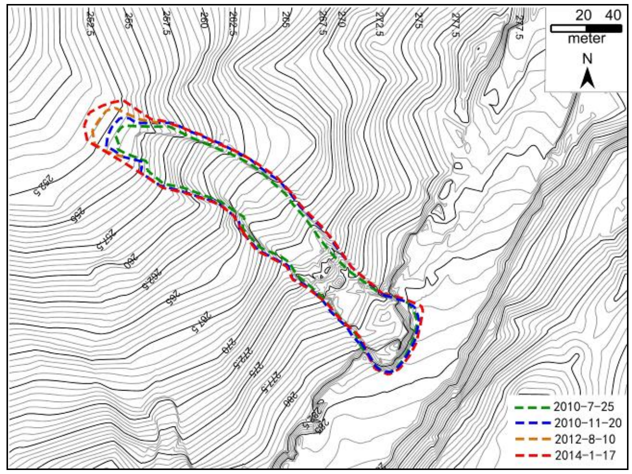

Figure 12. Topographic map showing the variations in the perimeter of the K178+530 landslide

VII. Conclusions

- The landslide is superficial, occurring parallel to bedding. water infiltration of rainfall, melting snow and permafrost melting is stopped by frozen soil and impermeable barriers, leading to local moisture content rapidly rising, water erosion along interface between the permeable layer and water-resisting layer froms the sliding surface.
- The landslide is located in an area of the island permafrost. Due to atmospheric precipitation, the presence of permafrost, regional climate conditions, and special geological conditions, landslides occur annually from late May to early November. The area is in a relatively stable state during winter. These seasonal landslides have seasonal, gradual, low angle characteristics.
- Landslide displacement occurs at different rates in different sections, as shown by bedding plane displacement. Within the same cross section of the landslide, the sliding displacement in the centre is largest and the sliding displacement near the flanks is smallest. The trailing edge of the landslide creeps continuously towards the road, increasing the hazard that this erosional feature poses to commuters.

Acknowledgements

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