The monitoring of soil pore water pressure and soil temperature in cutting slope before and after aufeis

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ABSTRACT
In northeast China, the cutting slope in road segments of Bei'an to Heihe Highway often occur aufeis. In winter, Icings are formed by refreezing at the surface of emergent discharge from the cutting slope, which destroyed the slope surface and threaten road traffic safety. Monitoring points of ground temperature and pore water pressure were laid out on the cutting slope where aufeis ever happened. The results show that, when soil temperature dropped below 0 °C, the soil pore water pressure rised rapidly to a maximum value. With the water outflow, soil pure water pressure declined slowly. When soil temperature rised above 0 °C, the soil pore water pressure declined rapidly. In same depth, soil temperature where aufeis ever happened is higher than those never had aufeis. Aufeis had the characteristic of seasonal cycles and uncertainty location.

RESUME
Dans le nord de la Chine, des glaçages se produisent régulièrement dans les zones en déblai le long de l'autoroute de Bei'an à Heihe. Durant l'hiver, ces glaçages qui se forment par le gel de l'eau souterraine qui jaillit des zones en déblai endommagent ces zones et menacent la sécurité du trafic. Le suivi de la température du sol et des pressions interstitielles dans les zones en déblai a été effectué où des glaçages se forment. Lorsque la température du sol descend sous 0 °C, les pressions interstitielles augmentent rapidement. Suivant le jaillissement de l'eau, ces pressions diminuent lentement. Lorsque la température du sol augmente au-dessus de 0 °C, les pressions interstitielles diminuent rapidement. Pour une profondeur donnée, la température du sol où les glaçages se forment est toujours supérieure à celle où il n'y a pas de glaçage. Ces glaçages ont une périodicité saisonnière et leur localisation est incertaine.

1 INTRODUCTION

Aufeis is the unique phenomenon in cold area, its mechanism is: at low temperature in winter, the stored or flowing water underground suffer the pressure caused by upper freezing layer going down and lower aquitard layer (dense soil or frozen soil) presence, they would outflow from some weakness place and was refreeze as its flowing, the ice could be increase continually. Due to the different topography and environmental hydrothermal conditions, the ice has different forms. Aufeis is also be named as icefall, ice cone, ice hill, ice river etc. Significant aufeis is commonly observed in the permafrost regions of the northern hemisphere such as Alaska (Sloan et al., 1976; Slaughter, 1982), Arctic Canada (Pollard, 2005), Yukon Canada (Harris et al., 1983), Svalbard (Liestøl, 1977), Greenland (Yde and Knudsen, 2005), Siberia (Alekseev and Tolstikhin, 1973), Mongolia (Froehlich and Slupik, 1982) and Tibet (Zhou et al., 2000).
Microwave data (SAR), thermal infrared, short wave infrared, and visible and near-IR bands were all used to studied the spring and aufeis (icing) hydrology in Brooks Range, Alaska (Yoshikawa et al., 2007). Kane, D. L., et al. studied the relationship between permafrost and regional groundwater flow in NE Alaska (USA)(Kane et al.2013). Jeffy simulated the aufeis shape through blowing experiments in laboratory (Jeffrey and Robert,2002). Matti Seppala, McFadden introduced the aufeis encountered in highway the construction in Finland(Matti,1999). Some scholars of former Soviet relying on Siberian Railway, the Baikal-Amur Railway carried out many studies on aufeis such as thermal equilibrium, quantitative evaluation, dynamic computing, control measures, roads reliability(В.А.1991;С.Д.1991;Б.Н.1991;Болъшаков,1981; Е.А.1981; И.А.1981). T.Vinson summarized the feature of the aufeis in the road of Alaska Denali Park and put forward preventive measures(Vinson,2003). Yu, WB analyzed the reason of the aufeis in the highway of Greater Xing'an Mountains and also proposed preventive measures(Yu et al.,2005).

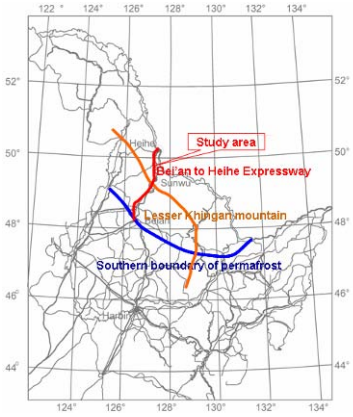

Figure 1. The Location of the study area

In this paper, in K161 + 800-K162 + 000 section of Bei'an to Heihe Highway Extension Project, the monitoring data of soil body temperature and soil pore water pressure and the data of air temperature and precipitation in Sunwu County meteorological station were used to analysis the relationship between aufeis in cutting slope and environmental conditions during year period.

2 BACKGROUND

This study area is located in Northeast China high latitude permafrost regions south (Fig. 1), the annual average temperature of -0.6 ℃, the lowest temperature of -48.1 ℃, the highest temperature of 35.2 ℃. Continental monsoon climate, warmer spring short fast, warm and rainy summer, fall short cooling fast, the long cold winter. October each year into the earth freeze, frozen ground in time to reach the maximum depth of the end of May, the maximum freezing depth of 2.26 ~ 2.67m. Surface begins to melt in April next year, from April to September for the season of melting permafrost, dry areas in early July about all season permafrost melting, in the swamps of the thick layer of peat and compost areas, seasonal frozen soil can be extended by the end of October to all the ablation. Seasonal frozen soil in this area is very developed, and in some valleys there are lots of island permafrost distribution.

The area is located in the tectonic clouds - Zeya new rift with its south of Shuhe uplift belt, north of the rare atmospheric fold bundle. Surface exposed strata from the old to the new are: the Upper Cretaceous Nenjiang, Tertiary Pliocene in Sunwu group, Quaternary Holocene modern river alluvium. Layered rocks cemented weak, poor wind resistance capabilities, greater depth of weathering near-surface part of the basic all-weathered. Groundwater The aqueous medium, occurrence, recharge and discharge conditions, divided into Quaternary pore water, pore water Tertiary, Cretaceous pore water categories.

China Bei'an to Heihe highway secondary roads in the original basis, in 2009, the expansion of the highway widening. The fall of 2009, on the K161 + 640-K162 + 200 on the left slope of the mechanical excavation, the position shown in Fig. 2, after excavation slope shown in Fig. 3.

In early February 2010, the aufeis occur largely in the cutting slope excavated, which is shown in Fig.4. In May 2010, drilling exploration was conducted at the top of the hill, soil samples of the drilling was conducted particle analysis and penetration tests, the results are as shown in Fig.5, Fig. 6 and Tab.1 .

Figure 2. The Location of cutting slope (photo from Google earth)

In July 2010, at the second floor of the slope, a ditch with 0.8m width and 3.5m depth was excavated, then the ditch was backfilled by gravel with 2.0m depth, laid by geotextile above gravel and then covered by humus with 1.5m depth, finally the layers were compacted by small mechanical, as shown in Fig.5.

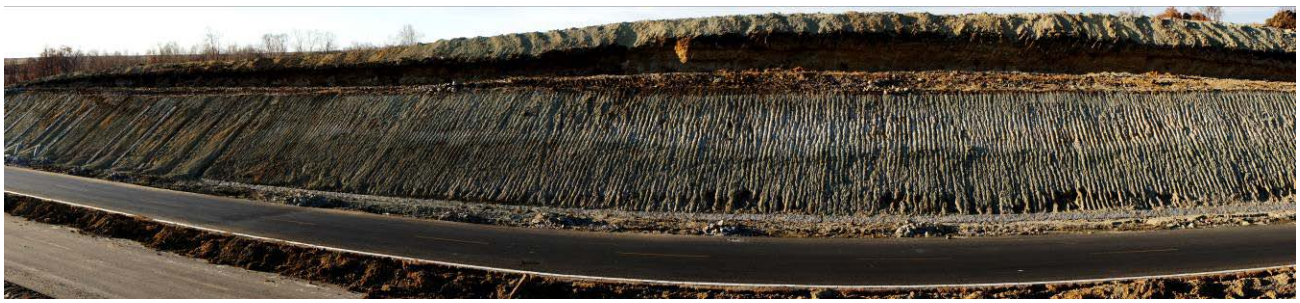

Figure 3. The cutting slope after excavated (2010.09)

Table 1. Soil physical indicators in monitoring section of the slope

Layer	Category	Rock types	Thickness (m)	Permeability coefficient (cm / s)
1	Quaternary loose layer	silty clay	0.8~1.0	3.84×10^{-8}
2	Quaternary loose layer	muddy sandstone	2.5~3.0	6.49×10^{-6}
3	Tertiary sandstones	pebbly sandstone	1.0~1.2	2.11×10^{-5}
4	Cretaceous mudstone	mudstone	＞5	2.09×10^{-8}

Figure 4. Aufeis on the cutting slope (2010.03)

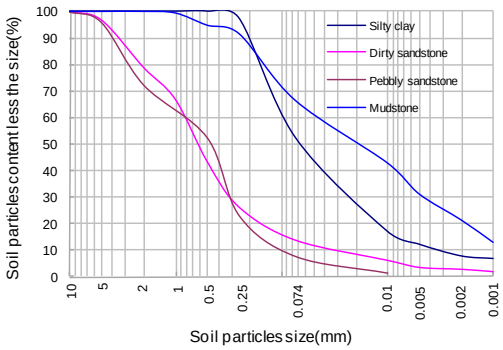

Figure 6. Soil particle curve of K161 + 860 section

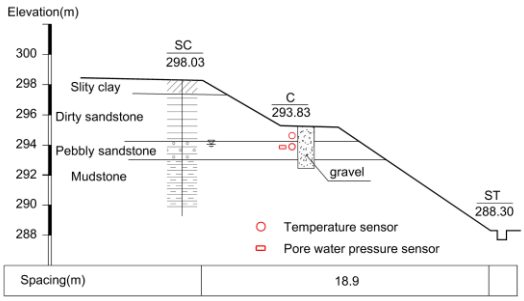

Figure 5. Geological profile of left cutting slope in K161 + 860 section

3 METHOD

In October 2010, at the second floor of the left slope and near the toe of the slope, four drilling borehole was set , the position is shown in Fig.7. The sensors of soil temperature, water content, pore water pressure was installed in the borehole, the position is shown in Fig.5.

The relationship curve between soil temperature, pore water pressure and time was obtained from the monitoring data. It is shown in Fig.8 and Fig.9.

It should be noted that there wasn't pore water pressure increasing in K161 + 780 section during the monitoring period; In K161 + 820 section, there were two water pressure increasing in January 2013 and January 2014 respectively, and in the summer water pressure there are negative value, which indicate the soil is non-saturated soil.

Next the monitoring result of soil temperature and pore water pressure in K161 + 860, K161 + 900 section will be analyzed and discussed.

Figure 7. The position of monitoring borehole on left slope of K161 + 640-K162 + 200 section

4 RESULTS AND DISCUSSION

In K161+860 section(Fig.8), in early three years, regarding soil pore water pressure, its increasing occurred three times when soil temperature reaches 0 ℃, time of occurrence were on January 28, 2011, January 13, 2012, and January 24,2013 respectively, the pore water pressure value at that time were 139kPa、190 kPa、113 kPa respectively, then their the pore water pressure value return to 0 kPa on May 18, 2011, July 10, 2012, August 23, 2013 respectively, the duration for the soil suffering the pressure is 101 days, 172 days, 211 days respectively. Regarding soil temperature, the time of 0 ℃ temperature were on May 18, 2011, May 8, 2012 and May 17, 2013, when soil temperature is near 0 ℃, the duration for the soil suffering the pressure is 101 days, 109 days, 113 days respectively, the minimum value of soil temperature was -0.2℃、-1.20℃、-0.6℃respectively. In later two years, the soil pore water pressure had no significant increasing, the duration of soil temperature lower than 0 ℃ were 97 days(2013.12.24~2014.04.01) and 121 days (2014.12.27~2015.04.20)respectively, the minimum value of soil temperature was -4.4℃ and -1.8℃ respectively.

In K161+900 section(Fig.9), soil pore water pressure increasing only occur in 2012, the duration of soil pore water pressure increasing was 171 days (2012.01.20~2012.07.10), the duration of soil temperature lower than 0 ℃ were 118days (2012.01.20~2012.05.08), when soil temperature is near 0 ℃, the duration for the soil suffering the pressure is 53 days. the minimum value of soil temperature in this three years was 0℃, -0.2℃ and -0.3℃respectively. But in 2004 and 2005, the minimum value of soil temperature was -3℃ and -1.2℃respectively, the duration of soil temperature lower than 0 ℃ were 124days and 104 days respectively. From above data combined with field observations and weather data, the following rules can be found:

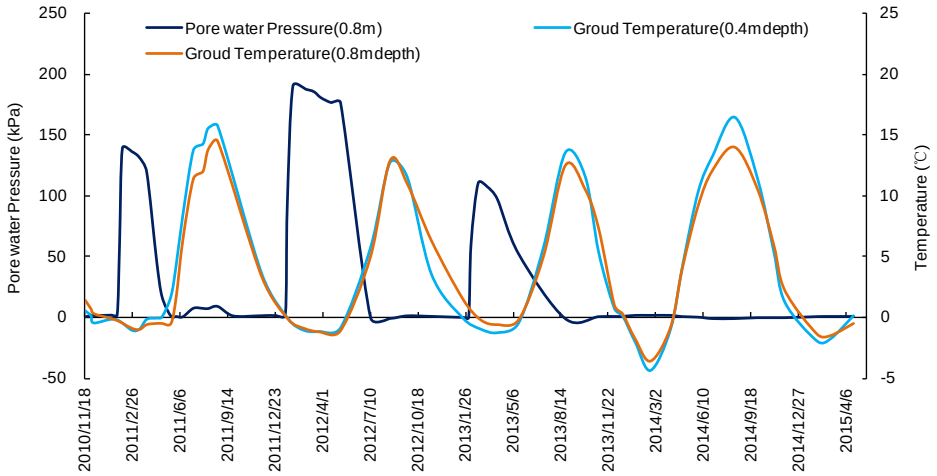

Figure 8. The relationship curve between soil temperature, pore water pressure and time in K161 + 860 section

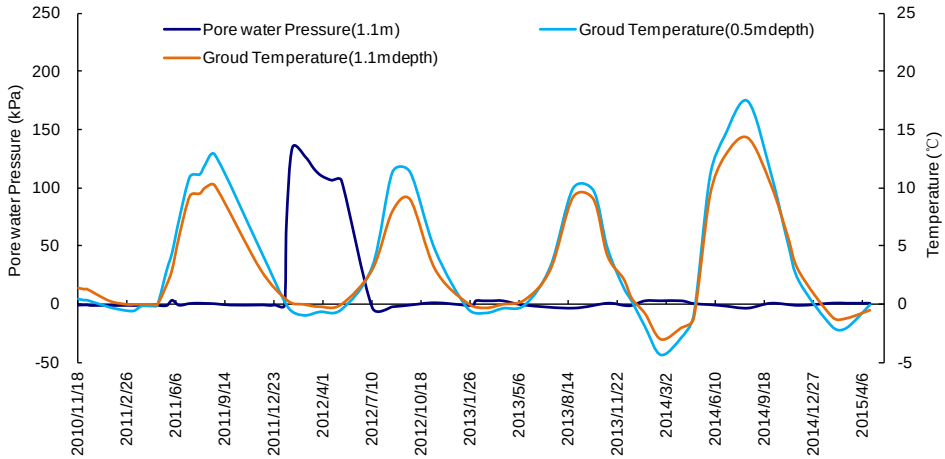

Figure 9. The relationship curve between soil temperature, pore water pressure and time in K161 + 900 section

1. In the cold season, the obvious signal of aufeis is a sudden increasing of soil pore water pressure accompanied by freezing temperature occurrence. Under the situation of no protective measures on the slope, aufeis will expose and grow up on the slope.

2. Aufeis may appear when soil temperature dropped to 0 ℃, the size of the aufeis is related to soil pore water pressure around here.

3.In winter, in same depth, soil temperature where aufeis ever happened is higher than those never had aufeis. In summer, soil temperature where aufeis ever happened is lower than those had no aufeis. In same place, in the year the aufeis happened, the temperature difference between Max. Temperature and Min. Temperature is small, in the year no the aufeis happened, this temperature difference is bigger.

4. In same place, if there is aufeis for several years, the size of the aufeis will increase year by year, and the time of ice thawing also increase. After some years, the aufeis will disappear. For the whole slope, the place and the size of the aufeis on it is uncertainty.

As unique geological phenomenon in cold regions, the aufeis on the cutting slope has a serious impact on slope stability and road operations. In this paper, through five years monitoring on the cutting slope having aufeis, the relationship between soil temperature and soil pore water pressure was studied. In the future, based the phenomenon that the soil temperature will be abnormal where the aufeis will happen, the forecast of aufeis will come to be true if using the method of ground monitoring and remote sensing.

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REFERENCES

Alekseev, V. R., and O. N. Tolstikhin. 1973. Questions of terminology in study of naleds, edited by V. R. Alekseyev, pp. 187– 191, U.S. Army Cold Reg. Res. Eng. Lab., Hanover, N. H.

В.А.Деметънев:Вероятностый медот пронозирования расчетный параметров нале дей Проплемы наледеведения,1991г.116-23.

С.Д.Невский:Математическая моделъ количественоой оценки наледей Пръблемы наледеведения, 1991г.95-103.

Е.А.Румяцев:Сфера и эффективностъ применения различных типовпротивоналедных мероприятий на жеелезных дорогахюНлледи Сибири и далънесо Вастока，1981，Новосибирск.

Froehlich, W., and J. Slupik .1982. River icings and fluvial activity in extreme continental climate: Khangai Mountains, Mongolia, in Proceedings of the Fourth Canadian Permafrost Conference, pp. 203– 211, Natl. Res. Counc. of Can., Ottawa, Ont.

Harris, S. A., R. O. Van Everdingen, and W. H. Pollard. 1983. The Dempster Highway: Dawson to Eagle Plain, in Guidebook to Permafrost and Related Features of the Northern Yukon Territory and Mackenzie Delta, Canada, edited by H. M. French and J. A. Heginbottom, pp. 65– 86, Univ. of Alaska, Fairbanks.

Jeffrey T. Streitz and Robert Ettema. Observations from an aufeis windtunnel. Cold Regions Science and Technology, 2002,34(2):85-96.

Kane, D. L., et al. 2013. "Regional groundwater flow in an area mapped as continuous permafrost, NE Alaska (USA)." Hydrogeology Journal 21(1): 41-52.

Liestøl, O. 1977. Pingos, springs, and permafrost in Spitsbergen, Aarb. Nor. Polarinst., 1977, 7 –29.

Matti Seppälä. Geomorphological aspects of road construction in a cold enviroment, Finland. Geomorphology, 1999,31(1-4):65-91.

Pollard, W. H. 2005. Icing processes associated with high Arctic perennial springs, Axel Heiberg Island, Nunavut, Canada, Permafrost Periglacial Processes, 16, 51–68.

Sloan, C. E., C. Zenone, and L. Mayo. 1976. Icings along the trans-Alaska pipeline route, U.S. Geol. Surv. Prof. Pap., 979, 1– 31.

Slaughter, C. W. 1982. Occurrence of and recurrence of aufeis in an upland taiga catchment, in Roger J.E. Brown Memorial Volume—Proceedings of the 4th Canadian Permafrost Conference, edited by H. M. French, pp. 182–188, Natl. Res. Counc. of Can., Ottawa, Ont.

Vinson T S. Denali Park access road icing problems and mitigation options.Proceedings of the 8th International conference on permafrost, 1189-1194,July 21-25,2003,Switzerland.

Yde, J. C., and N. T. Knudsen. 2005. Observations of debris-rich naled associated with a major glacier surge event, Disko Island, west Greenland, Permafrost Periglacial Processes, 16, 319– 325.

Yoshikawa, K., et al. 2007. "Spring and aufeis (icing) hydrology in Brooks Range, Alaska." Journal of Geophysical Research-Biogeosciences 112.

Yu, W.B.,et al. 2005. "Icing problems on road in Da Hinggangling forest region and prevention measures." Cold Regions Science and Technology,2005,42(1):79-88.

Zhou, Y., D. Guo, G. Qiu, G. Cheng, and S. Li. 2000. Geocryology in China, 448 pp., Cold and Arid Reg. Environ. and Eng. Res. Inst., Chi. Acad. of Sci., Beijing.

Б.Н.Дейкин:Тепловой и водный баланс наледей Пръблемы наледеведения,1997г.76-89.

Болъшаков С. М.:Принцины и методы протцвоналедный мероприятий наледи Сибири и Далънего,1981Востока,Новосибирск.192-198.

И.А.ЗалотаРо, С.Д.Невский: Иннеенерно-гелогический прогноз наледных процессов и оценка надежости дорог в усровиях наледеопразаванияналеди Сибири и Далънего Востока, 1981.Новосибирск, 206-216.