Advanced Materials Research *Online: 2014-06-06*
ISSN: 1662-8985, Vols. 945-949, pp 198-202
doi:10.4028/www.scientific.net/AMR.945-949.198

The numerical simulation of the lateral inhomogeneous deformation of the permafrost subgrade

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Key words: permafrost;subgrade; inhomogeneous deformation; numerical simulation

Abstract: The Qinghai-Tibet highway subgrade inhomogeneous deformation is very serious because of the bad climate environment and the special engineering condition of permafrost.To reveal the mechanism of subgrade diseases, based on the theory of elastic-plastic deformation, the control equation of thestress and deformation field of thesubgradeis established.Weanalyze subgrade stress and deformation field by finite element software. Considering effect of the southern and northern slopes, the model of the inhomogeneous deformation of the subgrade was established. Then we calculated the variation characteristic of the lateral inhomogeneous deformation under different melting depth. The results showed that the melting interlayer, melting depth and the effect of southern and northern slopes were the key factors influencing the permafrost subgrade lateral inhomogeneous deformation.

Introduction

In permafrost regions, the climate warming and thermal disturbance destroy the thermal equilibrium state of the subgrade. The field monitoring of Qinghai-Tibet highway shows that the frozen soil subgrade produced large deformation after constructing subgrade. It was found that the subgrade diseases was mainly thawing settlement such as longitudinal cracks and inhomogeneous deformation. Mao Xuesong[1-2]applied finite element method to search the distribution regularity of deformation and stress field during soil freezing, and concluding the existence of frost-heaving zone was the direct cause of subgrade disease.Xiao Lou[3] analyzed the inhomogeneous deformation of subgrade along the Mohe-Beijicun highway. He thought the deformation was concerned withthe ice contents and the permafrost temperature. Sun Zhizhong[4] analyzedthe characteristics and causes of deformation based on in-situ monitoring data of deformation and ground temperature, then concluded deformation mainly came from thaw settlement of permafrost with high-ice content and consolidation settlement of thawed soil because of the decline of permafrost table.

This article focuses on the inhomogeneous deformation of the permafrost, analyzing the permafrost subgrade in numerical simulation using finite element software and studying on the deformation of subgrade under different melting depth and mechanical mechanism.

The control equations of frozen subgrade stress and deformation field

Temperature and humidity are the key factors which cause subgrade frost heave and thawing settlement, and it shows up as the change of subgrade stress and deformation field [5]. The calculation models of permafrost subgrade deformation and stress field are the keys to reveal the mechanism of subgrade diseases. Meanwhile they are also the premise of subgrade design and disease treatment in permafrost region. And permafrost subgrade deformation control equation is put forward based on the elastic-plastic theory.

Fundamental assumption. Subgrade soil is isotropic. Soil particles, ice and water are incompressible. The soil is the linear elastic small deformable body[6].The deformation of subgrade only occurs underthe action of the gravity and the expansive force caused by soil freezing.

Fundamental equation. When considering the effect of self-weight, the stress-strain relationship of subgrade soil is shown as Eq.1.

$$[\sigma]=[D]([\varepsilon]-[\varepsilon^v]) \tag{1}$$

Where:[D]-the elastic matrix;for plane strain problem:

$$[D]=\frac{E(1-\mu)}{(1+\mu)(1-2\mu)}\begin{pmatrix} 1 & \mu(1-\mu) & 0 \\ \mu(1-\mu) & 1 & 0 \\ 0 & 0 & (1-2\mu)/2(1-\mu) \end{pmatrix}$$

The volume deformation can be given by Eq.2.

$$\varepsilon^v = 0.09\left(\theta_0+\Delta\theta-\theta_u\right)+\left(\theta_w-n\right) \tag{2}$$

Where:θ_0-the initial volume moisture content; $\Delta\theta$-the volume moisture content of migration; θ_w-the volumetric moisture content; θ_u-the frozen soil moisture content; n-the soil porosity.

We assume the subgrade soil is isotropic, so the volume expansion deformation in every direction is equal. It is shown as Eq.3.

$$\varepsilon_x^v=\varepsilon_y^v=\varepsilon_z^v=\frac{1}{3}\varepsilon^v \quad \gamma_{xy}^v=\gamma_{yz}^v=\gamma_{zx}^v=0 \tag{3}$$

Where: $\varepsilon_x^v, \varepsilon_y^v, \varepsilon_z^v$ -normal strain component; $\gamma_{xy}^v, \gamma_{yz}^v, \gamma_{zx}^v$ -shear strain component.

Model establishment and parameters determination

Calculation model. Considering the effect of southern and northern slopes, the subgrade model was designed as full size model. The basic model was shown in Fig.1. We think permafrost base is below the subgrade base 10 m. Mesh generation of the model was shown in Fig.2.When simulating lateral inhomogeneous deformation, we designed calculation model in the presence of melt interlayer.

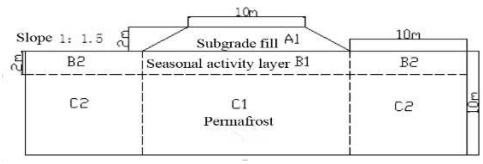

Fig.1 Geometry size of basic model

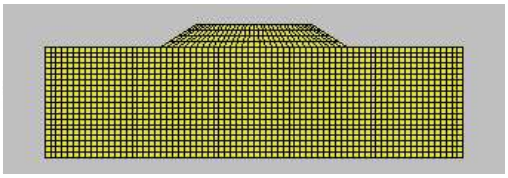

Fig.2 Mesh generation

Parameters determination. In the process of numerical calculation, we need to determine the model parameters including the thermal physical parameters of subgrade, seasonal activity layer,melting layer and permafrost, in addition the specific heat, thermal conductivity,etc.[7].The

mechanical parameters we need to determine include density, elastic modulus, bulk modulus, shear modulus, Poisson ratio, cohesive force, and internal friction angle, etc.

The subgrade filling of Qinghai-Tibet highway is natural gravel soil and the material of seasonal activity layer along Qinghai-Tibet highway is mostly clay. In the established model, its elastic modulus is 720MPa. The property of the melting permafrost layer depends on the original permafrost in the corresponding position.

The initial conditions. Take the time of the subgrade had been built as the initial moments (August 20). The temperature of the subgrade is 4℃.

The boundary conditions.

The upper boundary conditions. There is periodic boundary conditions change over time on the upper boundary of the subgrade, which can be synthesized to heat flux boundary condition and convective heat transfer boundary conditions in the calculation process.Overlay the net radiation on the evaporation heat addition, we can concludethe model of the heat flux boundary condition. Convective heat transfer coefficient and the fluid temperature are two factors of the convective heat transfer boundary conditions.Convective heat transfer coefficient can refer to the observed value.Fluid temperature is determinedaccording to the local temperature.

Left and right boundary conditions. We regard both sides of the border as adiabatic according to the engineeringexperience.

Lower boundary condition. Put the first kind of boundary conditions[8] on the bottom of the model. Fix temperature was 2℃and keep it unchanged.

The lateral inhomogeneous deformation model of the permafrost

The heat inputs to the internal subgrade through pavement and slope, causing melting of the permafrost in summer.Cold energy inputs to subgrade in winter, so the melting permafrost gradually freezes. Due to the lag of subgrade soil heat transfer, the melting interlayer would be caused. Subgrade soil moisture content would increase resulting from the existence of melting interlayer, which can lead to serious inhomogeneous deformation.

The impacts of different melting depth on the lateral inhomogeneous deformation. Analyzing the test results of the Qinghai-Tibet highway, the melting permafrost area is similar to a triangle. So it can be simplified to a regular triangle as shown in Fig.3. The melting depth of the permafrost respectively take 0.5 m, 1 m, 1.5 m and 2 m, with the rest is the same with the basic model. Boundary conditions is described above. The differential settlement of subgrade which has been built for one year is simulated.The vertical deformation of subgrade model under different melting depth is shown in Fig.4 ~ 7. The vertical displacement of the road is shown in Fig.8.

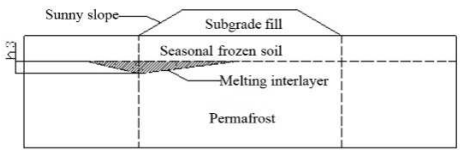

Fig.3 The subgrade deformation models

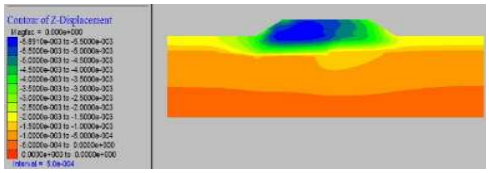

Fig.4 Vertical deformation of 0.5 m melting depth

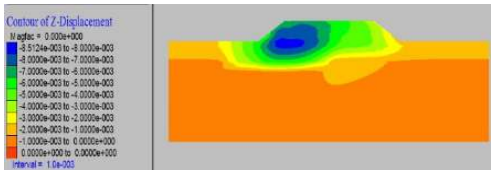

Fig.5 Vertical deformation of 1m melting depth

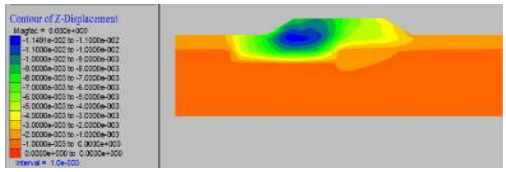

Fig.6 Vertical deformation of 1.5mmelting depth

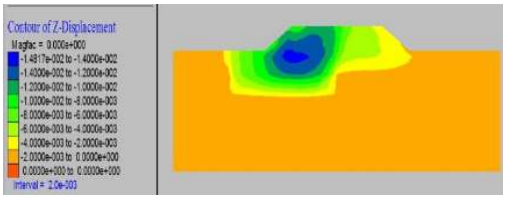

Fig.7 Vertical deformation of 2 mmelting depth

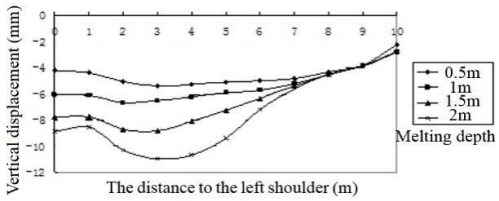

Fig.8 Vertical displacement of the road

From Fig.8, we knew extreme points of the vertical displacement of subgrade in various melting depth were in the location of 3m apart away the left shoulder. When the melting depth was 2 m, vertical settlement of road suddenly increasedto 11.33 mm, the subsidence was remarkable.When the melting depth was 0.5 meters, the settlement of the left shoulder is 4.159 mm, and the right is 2.73 mm. When the melting depth was 1.5 m, the settlement of the right shoulder was 2.726 mm, which was almost the same as the one when the melting depth was 0.5 m, but the left increased to 6.8 mm. It increased more than 50% compared the situation the melting depth was 0.5 m.The melting interlayer under the subgrade leaned to the southern slopeas a result ofthe effect of southern and northern slopes,causing soil moisture content of the left subgrade was larger than the right, so the left settlement was larger. With the increase of melting depth, the difference was more obvious.

Conclusions

The asymmetry of the state of freezing and thawing led to the result the deformation of the pavement was different in transverse direction. The lateral inhomogeneous deformation of the subgrade was mainly settlement, and the difference of left and right settlement was obvious.

Considering the effect of southern and northern slopes, we established the basic model of lateral inhomogeneous deformation of the subgrade in permafrost areas.We concluded the variation characteristics of lateral inhomogeneous deformation of the subgrade under condition of different melting depth. The thicker the melting interlayer, the inhomogeneous deformation of the subgrade was serious. The inhomogeneous deformation of the southern slope of the subgrade was more serious than the northern slope.

Acknowledgements

This project wasfunded by project Western transportation construction science and Technology(2011318223630).

Reference

[1] MAO Xuesong, LI Ning, WANG Binggang, et al. Coupling model and numerical simulation of moisture-heat-stress fields in permafrost embankment[J]. Journal of Chang'an University (Natural Science), 2006, 26(4):16–19, 62.(In Chinese)

[2] MAO Xuesong,LING Side,ZHANG Zhengbo, et al. Analysis the Influence of Hydrops along the Subgrade to Qinghai tibet Highway Subgrade Strength [J].Journal of Wuhan University of Technology (Transportation Science-Engineering),2013,37(3):456-459.(In Chinese)

[3] XIAO Lou, Dong Dehui.Analysis of Subgrade Deformation Characteristics in Circumpolar Latitude Permafrost Regions along Mohe-Beijcun Highway [J]. Highway, 2012(7):11-17.(In Chinese)

[4] SUN Zhizhong,MA Wei,DANG Haiming,et al. Characteristics and causes of embankment deformation for Qinghai-Tibet Railway in permafrost regions [J].Rock and Soil Mechanics,2013,34(9):2667-2671. (In Chinese)

[5] Li Ning,Xu Bin, Chen Feixiong. Coupling analysis of temperature, deformation and stress field for frozen soil subgrade [J]. China Journal of Highway and Transport, 2006, 19(3):1-7. (In Chinese)

[6] Man Gaofeng, Liu Jiankun. Numerical analysis of the formation mechanism of embankment longitudinal cracks in permafrost region [J]. Railway Engineering, 2007(5):51-54. (In Chinese)

[7]Xu Xuezu,Wang Jiacheng,Zhang Lixin.Frozen soil mechanics [M]. Beijing: Science press.2001.(In Chinese)

[8]Guo Kuanliang. Computational heat transfer [M]. Hefei: China Social Sciences Press.1998.(In Chinese)