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Original Research Paper

Sensitivity analysis of longitudinal cracking on asphalt pavement using MEPDG in permafrost region

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ABSTRACT

Longitudinal cracking is one of the most important distresses of asphalt pavement in permafrost regions. The sensitivity analysis of design parameters for asphalt pavement can be used to study the influence of every parameter on longitudinal cracking, which can help optimizing the design of the pavement structure. In this study, 20 test sections of Qinghai–Tibet Highway were selected to conduct the sensitivity analysis of longitudinal cracking on material parameter based on Mechanistic-Empirical Pavement Design Guide (MEPDG) and single factorial sensitivity analysis method. Some computer aided engineering (CAE) simulation techniques, such as the Latin hypercube sampling (LHS) technique and the multiple regression analysis are used as auxiliary means. Finally, the sensitivity spectrum of material parameter on longitudinal cracking was established. The result shows the multiple regression analysis can be used to determine the remarkable influence factor more efficiently and to process the qualitative analysis when applying the MEPDG software in sensitivity analysis of longitudinal cracking in permafrost regions. The effect weights of the three parameters on longitudinal cracking in descending order are air void, effective binder content and PG grade. The influence of air void on top layer is bigger than that on middle layer and bottom layer. The influence of effective asphalt content on top layer is bigger than that on middle layer and bottom layer, and the influence of bottom layer is slightly bigger than middle layer. The accumulated value of longitudinal cracking on middle layer and bottom layer in the design life would begin to increase when the design temperature of PG grade increased.

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1. Introduction

Cracking is one of the most important types of distresses in asphalt pavement, especially in permafrost regions, and the performance and service quality of asphalt pavement descend because of cracking (Zhu et al., 2013). In many countries, the cracking performances are incorporated into pavement design and maintenance systems (Teltayev, 2014). Therefore, conducting the multi-position research to the cracking based on various parameters and data statistics in permafrost regions has some prominent meanings. Lu et al. (2014) used three-dimensional finite element (FE) model of the tire tread rubber-block to describe the stress–strain field of the pavement with TDC, and discussed the effect law of fracture characteristics for the longitudinal crack affected by the multiple loading parameters simultaneously. The result found there was a nonlinear relationship between the equivalent stress intensity factor of the pavement and the load parameters. The longitudinal distance has a great influence on the equivalent stress intensity factor. Chou and Sheng (2014) focused on how the sunny–shady slope contributed to longitudinal crack formation under different mean annual air temperatures, roadbed surface materials, embankment heights and strikes in permafrost regions. The results show the mean annual air temperature and embankment height were the main factors to the longitudinal crack, and the longitudinal crack position was related to the shady-sunny slope effect. The greater the shady–sunny slope effect, the nearer the longitudinal crack position to the embankment sunny shoulder. Park et al. (2014) verified the capability of the layered viscoelastic pavement analysis for critical distresses (LVECD) model to capture crack initiation locations, propagation propensity, and cracking severity by comparing the simulation results with the field core observations and the field condition survey of in-service pavements in North Carolina. The result shows the agreement rate between the result of field core observations and field condition survey and the predicted LVECD simulation result is about 78% in terms of cracking direction and severity. Dong and Huang (2014) used Weibull hazard function to evaluate the influence of different factors on the crack initiation of resurfaced asphalt pavement with long-term pavement performance (LTPP) data. It was found that traffic level was a significant factor for all four types of cracks. High traffic level accelerated the initiation of cracking. Thick overlay delayed the initiation of cracking except for the non-wheel path longitudinal crack, which was mainly caused by poor construction technique. Total pavement thickness only retarded the initiation of wheel path longitudinal cracking. Through reviewing the most recent research of the cracking of asphalt pavement in domestic and foreign, the research was mainly based on cracking evaluation model, cracking variation trend, traffic impact analysis of cracking and so on. Very few studies on how a particular parameter such as air voids content or percent binder were investigated for cracking during the service life.

There is widely distribution of frozen soil over northwest China and Qinghai–Tibet Plateau. The region annual mean temperature is −2 °C to −7 °C, and it has about 8 months frost period every year. The annual precipitation is about 400 mm in this region, mainly during the period from June to September. Longitudinal cracking is the main distress of asphalt pavement in permafrost regions, and the research of longitudinal cracking analysis of material parameter is rarer. This research takes the Qinghai–Tibet Highway as an example, and adopts Mechanistic-Empirical Pavement Design Guide (MEPDG), which was developed recently through the National Cooperative Highway Research Program (NCHRP) 1-37A project, to study the development rule of longitudinal cracking in permafrost regions. The Latin hypercube sampling (LHS) technique (Wu et al., 2010), Excel solver and multiple regression analysis were applied to conduct a single factorial sensitivity analysis of longitudinal cracking on material properties parameters (Orobio, 2010).

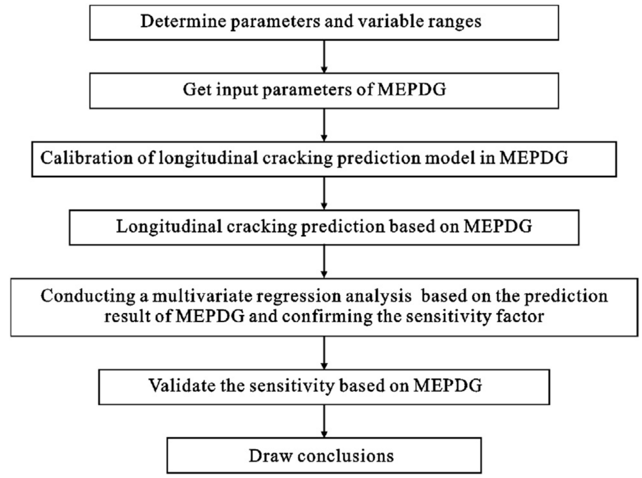

Fig. 1 – Research technical route.

2. An introduction of MEPDG

The NCHRP 1-37A project according to the observation result of 2200 LTPP test section in USA and development of the 2002 guide for design of new and rehabilitated pavement structures was completed in 2004. The MEPDG and its software were obtained from this project. This mechanistic-empirical pavement design procedure is based on mechanistic-empirical analysis of the pavement structure to predict the performance of the pavement under different sets of conditions (traffic, structure and environment). MEPDG takes into account the advanced modeling concepts and pavement performance models in performing the analysis and design of pavement (NCHRP, 2004).

The predictive equation used in the MEPDG to predict cracking in the asphalt mixtures is based upon a field calibrated statistical analysis of laboratory repeated load tests. The final model is listed in Eq. (1)

$$C = 10.56\frac{c_3}{1 + e^{c_1 - c_2 \lg D}} \tag{1}$$

where C is longitudinal cracking (m/km), D is fatigue damage, c_1, c_2 and c_3 are calibration coefficients which vary with