Research Journal of Applied Sciences, Engineering and Technology 7(5): 1029-1032, 2014
DOI:10.19026/rjaset.7.354
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 31, 2013 Accepted: March 02, 2013 Published: February 05, 2014

Research Article

Asphalt Pavement Deflection due to a Circular Load and Temperature Modified Coefficient

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Abstract: This study proposed an approximate computation method of pavement deflection due to a circular and regression formulas among temperature modified coefficient to deflection, the average temperature of surface course and pavement structure parameters. Based on theoretical solution of pavement deflection which is beneath the center of the load due to a circular load applied on a homogeneous half-space, by introducing structure parameter modified coefficient *ζ*, approximate computation method of pavement deflection due to a circular applied to a two-layer or multilayer pavement was given. Most regression formulas of temperature modified coefficient to deflection were dependent of testing data, we studied on influence factors of temperature modified coefficient to deflection from a theoretical view and then established an approximate formula among modified coefficient *K*, the average temperature of surface course *T* and pavement structure parameters are then established. The results show that temperature modified coefficient to deflection was dependent of the average temperature of surface course and pavement structure parameters. The calculation results using regression formulas in this study can be satisfied with engineering precision requirements.

Keywords: Asphalt pavement, deflection, modulus of surface course, temperature modified coefficient

INTRODUCTION

Pavement deflection has long been used to evaluate structural capacity of the asphalt pavement. When calculating pavement designed deflection, the dynamic modulus of the asphalt layer is the modulus when the average temperature of the asphalt layer is 20°C. But if construction quality inspection, engineering acceptance and pavement structure performance assessment, pavement temperatures have an important impact on deflection measurement. At this time, temperature modified coefficient to deflection will be used to modify the value of deflection measurement. Many design methods and valuable researches have been done at home and abroad. Ministry of transport in China, Chen (2006) and AASHTO (1993) have established the formulas among temperature modified coefficient to deflection, the midpoint temperature and the thickness of the asphalt layer, respectively. Cha (2002) and Lu (2002) have believed temperature modified coefficient to deflection is only dependent of pavement temperature. Lukanen *et al*. (2000) have given a relationship formula between temperature modified coefficient to deflection and deflection values of different points based on testing data of LTPP (Long Term Pavement Performance). Zhong (2000) has studied temperature modified coefficients to deflection at different points. It can be seen from above studies, there are many differences on influence factors of temperature modified coefficient to deflection because they haven't research on influence factors of temperature modified coefficient to deflection in essence and their regression formulas are only based on different testing data.

In this study, we have established an approximate computation method of pavement deflection firstly, then studied on influence factors of temperature modified coefficient to deflection from a theoretical view and given a regression formula of temperature modified coefficient to deflection. Research results have an important significance for predicting deflection values and testing and accepting deflection.

MATERIALS AND METHODS

Deflections of two-layer structures: Figure 1 shows a two-layer pavement structure and a circular load sketch. δ is load radius; q is uniform pressure; E_1 and E_0 are modulus of surface course and sub grade respectively; μ_1 and μ_0 are Poisson's ratios of surface course and sub grade respectively; h_1 is the thickness of surface course; z is the direction of surface course thickness. The origin point is at point O which is on the top of surface course beneath the center of a circular load. The ranges of parameters: q = 0.7 MPa, h_1 = 0.1~0.7 m, E_1 = 2000~25000 MPa, E_0 = 20~200 MPa, μ_1 = 0.15 and μ_0 = 0.35.

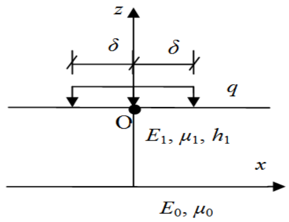


Fig. 1: Two-layer pavement structure and load

Table 1: Regression coefficients A, a, B, b

$\hat{\lambda}_{E_{10}}$	Interlayer contact condition	A	a	B	b
>10	Un-bonded	0.922	0.478	0.329	0.246
	Bonded	1.145	0.419	0.310	0.286
≤10	Un-bonded	0.458	-1.169	0.362	0.239
	Bonded	0	-	0.390	0.260

When a circular load is applied on a homogeneous half-space, deflection w_0 which is beneath the center of the load can be expressed as Yao (2001):

$$w_0 = \frac{2q\delta}{\hat{E}_0} \qquad \hat{E}_0 = \frac{E_0}{1-\mu_0^2} \tag{1}$$

As to a two-layer pavement structure, deflection w at point O which is on the top of surface course beneath the center of a circular load can be obtained through correcting w_0, as shown in Eq. (2):

$$w = \frac{w_0}{\zeta} \tag{2}$$

where ζ can be referred to structure parameter modified coefficient.

Further studies show, ζ is dependent of generalized modulus ratio of surface course and sub grade $\hat{\lambda}_{E_{10}} = (E_1(1-\mu_0^2))/(E_0(1-\mu_1^2))$ and the ratio of the surface course thickness and load radius $\lambda_k = h_1/\delta$. Regression expression of ζ is:

$$\zeta = A\lambda_h^a \left(\hat{\lambda}_{E_{10}}\right)^{B\lambda_h^b} \quad \text{when } \hat{\lambda}_{E_{10}} > 10 \tag{3}$$

$$\zeta = \left(1 - Ae^{a\lambda_h}\right)\left(\hat{\lambda}_{E_{10}}\right)^{(B+b\ln\lambda_h)} \quad \text{when } \hat{\lambda}_{E_{10}} \le 10 \tag{4}$$

where A, a, B, b are regression coefficients related to interlayer contact conditions and $\hat{\lambda}_{E_{10}}$.When $0.6<\lambda_h<5$, the values of A, a, B, b are shown in Table 1.

A comparison result of pavement deflections calculated by the above mentioned method and the theoretical values show that relative errors of them are no more than 5% and it can be satisfied with engineering precision requirements.

Deflections of multilayer structures: If a pavement contains base course, it is necessary to combine the surface course and base course into a single layer. The total stiffness radius l_g of surface course and base course can be determined by:

$$l_g = \sqrt[3]{2D_g(1-\mu_0^2)/E_0} \tag{5}$$

where, D_g is the total bending stiffness of surface course and base course.

If there is bonded between surface course and base course, the total bending stiffness of surface course and base course can be determined from:

$$D_g = \frac{\hat{E}_1 h_1^3}{12} + \frac{\hat{E}_2 h_2^3}{12} + \frac{(h_1+h_2)^2}{4} e k_u \qquad e^{-1} = \frac{1}{\hat{E}_1 h_1} + \frac{1}{\hat{E}_2 h_2} \qquad \hat{E}_1 = \frac{E_1}{1-\mu_1^2}; \hat{E}_2 = \frac{E_2}{1-\mu_2^2} \tag{6}$$

where, E_2, h_2, μ_2 are the modulus, thickness and Poisson's ratio of base course, respectively. k_u is interlayer contact coefficient. If interlayer contact is bonded, $k_u = 1$. If interlayer contact is un-bonded, $k_u = 0$.

If there is un-bonded between surface course and base course, there are no axial forces for surface course and base course. But sectional surface deformation due to the vertical stress and shear stress will lead bending curvatures for surface course and base course to be unequal. It is necessary to introduce bending moment distribution coefficient of surface course and base course φ to consider the impact. The total bending stiffness of surface course and base course $\widehat{D}_g$ can be can be determined from:

$$\tilde{D}_g = \frac{\varphi \hat{E}_1 h_1 + \hat{E}_2 h_2}{\hat{E}_1 h_1 + \hat{E}_2 h_2} D_g \tag{7}$$

The bending moment distribution coefficient of surface course and base course φ is related to generalize modulus ratio of surface course and base course, $\hat{\lambda}_{z_{12}} = (E_1(1-\mu_2^2))/(E_2(1-\mu_1^2))$ thickness ratio of surface course and base course h_1/h_2 and load radius δ. When $\hat{\lambda}_{E_{12}} = 5\sim150$, $h_1/h_2 = 0.2\sim2$, $h_1/\delta = 0.5\sim4$, regression formula of φ shows as Eq. (7):

$$\varphi = 13.365\left[\ln\left(\hat{\lambda}_{E_{12}}\left(\frac{h_1}{h_2}\right)^3\left(\frac{\delta}{h_2}\right)^3\right)+10\right]^{-1.122} \tag{8}$$

If a pavement is composed of more than two layers, it is necessary to convert the pavement to a two-layer structure. Firstly, the total bending stiffness of the top layer and the second layer should be calculated using Eq. (6) or (7) and the modulus Ex and thickness hx of the equivalent layer can be obtained using Eq. (9):

$$E_x = \frac{h_1^2 \hat{E}_1 + h_2^2 \hat{E}_2}{h_1^2 + h_2^2}$$
$$h_x = \sqrt[3]{12 D_g / E_x} \tag{9}$$

Then the total bending stiffness of the top layer, the second layer and the third layer and the modulus and thickness of the equivalent layer of them can be obtained later and so on. Until the whole pavement is converted to a two-layer structure, the total stiffness radius l_g of the pavement can be calculated using Eq. (5). Pavement deflection can be obtained according to Eq. (2) at last.

Temperature modified coefficient to deflection: Pavement temperatures affect the modulus of asphalt mixtures directly and then the whole pavement stiffness will be influenced. As a result, the temperatures have an effect on pavement deflection finally. The variation of asphalt pavement deflection caused by the variation of surface course temperatures can use temperature modified coefficient to deflection *K* to represent. *K* can be determined by:

$$K = \frac{w_T}{w_{20}} \tag{10}$$

where,

w_{20} : Pavement deflection when the average temperature of the asphalt layer is 20°C, mm
w_T : Pavement deflection when the average temperature of the asphalt layer is *T*, mm

The modulus of the asphalt mixtures when the temperature is 20°C can be obtained easily, but it is difficult to obtain the average temperature of asphalt surface course. So the relationship formula between modulus of surface course and temperature modified coefficient *K* is established firstly, then according to BELLS model as show in Eq. (11), the relationship among temperature modified coefficient *K*, average temperature of surface course and pavement structure parameters can be given finally:

$$E(T) = E_{20} \times 10^{-\alpha(T-20)} \tag{11}$$

where,

E_{20} : The modulus of asphalt mixtures when the temperature is 20°C, MPa
α : Thermal coefficient of asphalt mixtures and it is dependent of mixing ratio of asphalt mixtures and thermodynamic properties

α varies from 0.015 to 0.03. Generally α is 0.02.

An asphalt pavement is composed of three layers (e.g., an asphalt surface course, a base course and a sub grade) generally. A three-layer pavement structure model is used to calculate temperature modified coefficient to deflection *K*. E_1 = 2000~25000 MPa, h_1 = 0.10~0.25 m, μ_1 = 0.30; E_2 = 300~600 MPa for flexible base course, E_2 = 2000~10000 MPa for semi-rigid base course, h_2 = 0.2~0.6 m, μ_2 = 0.20; E_0 = 40~150 MPa, μ_0 = 0.35. There is un-bonded between surface course and flexible base course, bonded between surface course and semi-rigid base course and un-bonded between base course and sub grade.

The calculation results show: for flexible base course pavement, temperature modified coefficient to deflection *K* decreases with the increase in E_1, E_2 and h_2 and increases with the increase in h_1 when $E_1<E_{20}$. The variation rules of *K* are opposite when $E_1 \geq E_{20}$.

For semi-rigid base course pavement, *K* increases with the increase in h_1 when $E_1<E_{20}$. The variation rules of *K* are also opposite when $E_1 \geq E_{20}$. When the modulus of base course E_2 = 2000~10000 MPa, the variation of the value of *K* is no more than 5%; when the thickness of base course h_2 = 0.2~0.6 m, the variation of the value of *K* is no more than 2%, so all of them can be ignored.

Furthermore, when sub grade modulus E_0 = 40~150 MPa, the variation of the value of *K* is no more than 4%. It also can be ignored.

Studies find that the relationship between temperature modified coefficient and pavement structure parameters is as follows:

$$K = \left(\frac{E_1}{E_{20}}\right)^b \tag{12}$$

where *b* is related to pavement structure parameters. For flexible base course:

$$b = -0.049\left(\ln\left(\frac{E_{20}}{E_2} * \left(\frac{h_1}{h_2}\right)^3\right) + 5\right) \tag{13}$$

For semi-rigid base course:

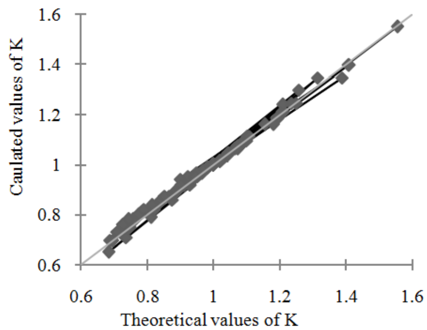
$$b = -0.11(\ln(h_1) + 3.8) \tag{14}$$

RESULTS AND DISCUSSION

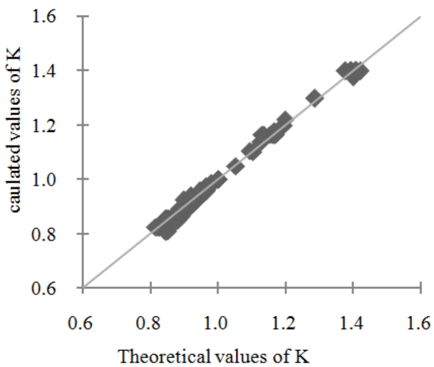
Figure 2 gives a comparison of temperature modified coefficient *K* calculated by using Eq. (8) with the theoretical values when E_{20} = 8000 MPa, E_1 = 2000~25000 MPa, h_1 = 0.10~0.25 m, μ_1 = 0.30, E_2 = 300~600 MPa for flexible base course, E_2 = 2 000~10000 MPa for semi-rigid base for course, h_2 = 0.2~0.6 m, μ_2 = 0.20, E_0 = 40~150 MPa and μ_0 = 0.35.

It can be seen from Fig. 2 that temperature modified coefficient *K* varies from 0.7 to 1.6 for flexible base course pavement and from 0.8 to 1.5 for semi-rigid base course pavement. Data points are concentrated at 45° contour and that shows the regression results have a high accuracy.

If surface course or base course is composed of two or more layers, it is necessary to combine multilayer



(a) Flexible base course



(b) Semi-rigid base course

Fig. 2: Comparison of values of K calculated with the theoretical values

surface course or multilayer base course into a single surface layer or a single base layer by using conversion method of multilayer in the second section. Then substitute thicknesses and modulus of surface layer and base layer converted into Eq. (12). Thus temperature modified coefficient to deflection can be calculated.

Substitute Eq. (11) (The value of α is 0.02 in this equation) into Eq. (12), then the relationship expressions among modified coefficient *K*, the average temperature of surface course *T* and pavement structure parameters are as follows:

For flexible base:

$$K = 10^{0.00098(T-20)\left(\ln\left(\frac{E_{20}}{E_2}\cdot\left(\frac{h_1}{h_2}\right)^3\right)+5\right)} \tag{15}$$

For semi-rigid base:

$$K = 10^{0.0022(T-20)(\ln(h_1)+3.8)} \tag{16}$$

CONCLUSION

Pavement deflection due to a circular load applied on a two-layer structure can be obtained by modified theoretical solution of pavement deflection when a circular load applied on a homogeneous half-space.

For calculating pavement deflection of multilayer structure, multilayer structure should be converted to a two-layer structure firstly and then it can be calculated by using the method of two-layer structure.

The variation of asphalt pavement deflection caused by the variation of surface course temperatures can use temperature modified coefficient to deflection *K* to represent. *K* is related to surface course average temperature and pavement structure parameters. For flexible base course, *K* is dependent of the thickness of surface course and base course and the modulus of base course. For semi-rigid base course, *K* is only dependent of the thickness of surface course. Sub grade modulus has a relatively small effect on *K*, so it can be ignored.

The rules of temperature modified coefficient to deflection *K* caused by pavement structure parameters are summarized. The regression formula among *K*, the average temperature of surface course and pavement structure parameters are established.

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