II − 2 Approximate Formulas for Calculating the Deflection on the Surface of Flexible Pavement

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Abstract: Approximate formulas for calculating the deflection on the surface of flexible pavement are presented by regression analysis. A number of results calculated by the approximate formulas show good accuracy in comparison with those by elastic multilayer theory.

key words: elastic properties, deflection, regression analysis, flexible pavement, elastic multilayer theory

Introduction

Surface deflection of flexible pavement is an important index of pavement design and evaluation. It is a complex function of the thickness of structural layers, material moduli, load and so on. The calculation of surface deflection of pavement is usually very complex. There are two methods mostly in used in calculating deflection. One is to use the program of elastic multilayer theory[1], another is to use the nomogram of elastic multilayer theory pavement structures (i.e. thickness, material moduli). Because these methods are also difficult to use in optimal design and evaluation of pavement structure and pavement reliability design, many researchers paid attention to study approximate formulas for calculating pavement design indexes and evaluation indexes .

The approximate formulas for calculating the surface deflection of normal three-layer flexible pavement bearing the double circular load are presented on the base of elastic multilayer theory and regression method in this paper. These approximate deflection formulas can also be used in multilayer pavement system provided that it be converted to three-layer structure by the equivalent deflection method. A number of results calculated by approximate formulas show good accuracy in comparison with solutions of elastic multilayer theory. In most cases, the relative error between approximate formulas solution and multilayer theory solution is less than 2%. These formulas can also be applied in theory research and engineering design. calculation model and suitable rang to approximate formulas calculation model of flexible pavement is shown in figure 1. This is the typical three layer structure used by many design methods. Point A is the calculation position of deflection, p is the type pressure, D is the radius of equivalent load circles, H_1 and H_2 are respectively the thickness of surface course and base course. E_1 and E_2 are respectively the elastic moduli of surface course and base course, E_3 is the modulus of resilience of subgrade. ν_1, ν_2 and ν_3 are respectively their poisson's ratios.

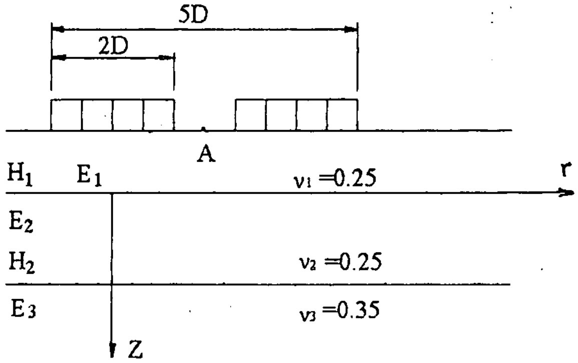

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Figure 1 Typical Three-layer Pavement

The solution of surface deflection of pavement structure on base of elastic layer theory is a very complex function of the moduli E_i and thickness for various layers of the pavement structure. It is very difficult to obtain the approximate formulas of the deflection suitable for all ranges of parameters E_I and H_i. According to the requirement ts of engineering and normal parameters of pavement structures. It is simple and with enough accuracy to study approximate formulas for normal ranges of parameters of pavement structure. The normal ranges of parameters of flexible pavements are designated as $E_2/E_1 = 0.3 \sim 2.0$, $E_3/E_2 = 0.02 \sim 0.2$, $H_1/D = 0.4 \sim 5.5$, $H_2/D = 1.5 \sim 5.4$.

Approximate Formulas of Deflection Coefficient

See also reference [3] about the studying method for determination of approximate formulas of deflection coefficient, The formulas are as follows:

$$\ln(\varpi) = 0.066 - 0.1538\ln(x) + 0.7\ln\left[\left(1 - \frac{1}{\sqrt{1+h_1^2}}\right)\frac{E_3}{E_2} + \left[\frac{1}{\sqrt{1+h_1^2\left(\frac{E_1}{E_2}\right)^{0.07}}} - \frac{1}{\sqrt{1+\left(h_1\sqrt{\frac{E_1}{E_2}}+h_2\right)^{1.85}}}\right]\frac{E_3}{E_2} + \frac{1}{\sqrt{x}}\right] \tag{1}$$

in equation (1), $h_1 = 0.8\,H_1/D$, $h_2 = 0.8\,H_2/D$, $x = 1 + \left[h_1\left(\frac{E_1}{E_3}\right)^{0.285} + h_2\left(\frac{E_2}{E_3}\right)^{0.285}\right]^{1.9}$

ϖ = theoretic deflection coefficient, the formula for theoretic deflection is as follow:

$$l = \frac{2pD}{E_3}\varpi \tag{2}$$

Equivalent Deflection Conversion Method

Based on Equal Vertical Deflection Concept, the method for conversion from Multilayer system over three layers into typical three-layer system can be obtained. The conversion method is shown in Figure 2 and Equation (3)

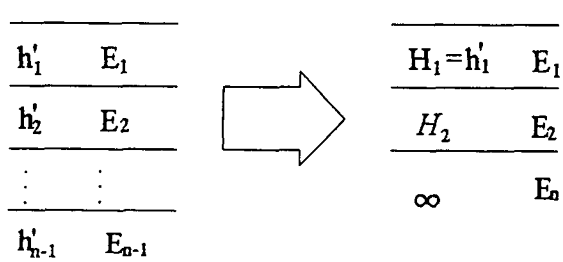


Figure 2 Equivalent Deflection Conversion Method

$$H_2 = \sum_{i=2}^{n-1} h_i'\sqrt[2.4]{\frac{E_i}{E_2}} \tag{3}$$

A number of results show good accuracy of this conversion method.

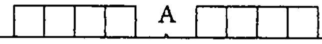
Checking Accuracy

A number of pavement structures in suitable range of parameters are calculated respectively by the approximate formulas and elastic multilayer theory for checking accuracy. The accuracy is great satisfaction in comparison with solutions of elastic multilayer theory, and the relative errors are usually less than 3%. Table 1 shows the comparison of approximate formulas solutions with those of elastic multilayer theory in wide rang of pavement structure parameter. the accuracy of approximate formulas is very good according to Table 1.

Table 1 Comparison the Results by using Approximate Formulas with Analytic Solutions

$\frac{E_2}{E_1}$	$\frac{E_3}{E_1}$	$\frac{H_1}{D}$	$\frac{H_2}{D}$	Approximate formulas solution ϖ_1	Analytic Solution ϖ_2	Error(%) $\frac{(\varpi_1 - \varpi_2)}{\varpi_2}$
0.3	0.006	1.6	1.5	0.13076	0.13520	-3.29
0.4	0.008	3.6	5.5	0.05459	0.05395	0.011
0.5	0.025	0.6	5.5	0.12596	0.12539	0.24
0.6	0.03	0.7	1.5	0.26968	0.27006	-0.14
0.7	0.035	0.8	1.5	0.26294	0.26493	-0.75
0.8	0.04	0.9	1.5	0.26674	0.26908	-0.80
0.9	0.045	1.6	5.5	0.11443	0.11549	-0.91
1.0	0.050	2.0	1.5	0.19713	0.19933	-1.1
1.1	0.072	2.2	1.5	0.21294	0.21345	-0.24
1.2	0.114	2.4	5.5	0.15419	0.15545	-0.81
1.3	0.123	2.6	1.5	0.24269	0.23841	1.58
1.4	0.133	3.0	5.5	0.16933	0.17201	-1.55
1.5	0.165	3.2	1.5	0.25203	0.24618	2.34
1.6	0.176	3.4	5.5	0.17476	0.17916	-2.46
1.7	0.111	3.6	1.5	0.19958	0.19567	2.0
1.8	0.117	3.8	5.5	0.13509	0.13752	-1.77
1.9	0.209	4.6	1.5	0.24875	0.24500	1.53
2.0	0.220	4.6	5.5	0.18585	0.19000	-2.18

Example Given a five-layer system with thickness, elastic moduli, and Poisson's ratios of each layer shown in Figure 3, is subjected to a two-wheel load, each loaded area has a radius of 10.65 cm and a contact pressure of 0.7MPa, Using approximate formulas and elastic layer theory, determine the vertical surface deflection at point A.



h_1=7cm	E_1=1500MPa	ν_1=0.25
h_2=8cm	E_2 =700MPa	ν_2=0.25
h_3=15cm	E_3 =700MPa	ν_3=0.25
h_4=20cm	E_4 =500MPa	ν_4=0.25
	E_5=25MPa	ν_5=0.35

Figure 3 Five-layer System

Solution:

(1) Converting five-layer system into three-layer system

$$H_2 = h_2 + h_3 + h_4 \sqrt[2.4]{\frac{E_4}{E_2}} = 8 + 15 + 20\sqrt[2.4]{\frac{500}{700}} = 40.38\ (cm)$$

using Formulas (1), $\varpi = 0.176$

$$l = \frac{2pd}{E_5}\varpi = \frac{2 \times 0.7 \times 10.65}{25} \times 0.176 = 0.1050(cm)$$

(2)Using program of elastic-layer theory: $\varpi = 0.176$

$$l = \frac{2pD}{E_5}\varpi = \frac{2 \times 0.7 \times 10.65}{25} \times 0.176 = 0.1050(cm)$$

It can be seen that the solution by approximate formulas check very well with those by elastic theory.

Appendix 1-References

1. Yang H Huang, "Pavement Analysis and Design" Prentice Hall, Englewood Cliffs, New Jersey 07632.
2. The Ministry of Communications, The People's Republic of China, "Specifications of Flexible Pavement Design for Highway " (JTJ 012-94)
3. Huang Wei, "Regression Formulas of Tensile Stress in the Middle Layer of Three-layer Flexible Pavement" , Journal of Southeast University, Vol.23 No.6 Nov. 1993