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◆Research Paper◆

Mechanical Analysis of Flexible Base Durable Asphalt Pavement Structure

SONG Yang[1,2], SUN Wen-jun[1,2*], ZHU Xiao-yun[4], ZHANG Hai-feng[2,3]
1. *Hebei Engineering and Technical College, Cangzhou, Hebei, 061001, China*
2. *College of Civil Engineering, Hebei University of Technology, Tianjin 300401, China*
3. *HuaBei Expressway Co., Ltd, Beijing, 100176, China*
4. *Tianjin transportation vocational college, Tianjin, 300110, China*

Abstract: In order to provide basis for the design of flexible base durable asphalt pavement structure. The influence of all kinds of parameter combination on different control indicators was analyzed by combining the extremum of each structure-layer parameters, such as different asphalt aggregate thickness, different layer thickness under the same total thickness, and different elasticity modulus. Regression analysis was carried out based on the data in database by the using of Minitabdata analysis software. The mechanical response model was obtained. And the influence that each structure-layer parameters acting on the mechanics index of pavement structure were measured. The research shows that the total thickness of asphalt layer is the key influence parameter of tensile strain indicator of asphalt layer bottom. The flexible base layer thickness is the main influence parameters of top soil base compression strain index. The flexible subbase modulus parameter has influence on every index obviously. Soil base modulus is the main influence parameter of surfacing deflection and the top soil base compressive strain index.

Key words: flexible base; durable pavement; asphalt layer bottom tensile stress; top soil base compression strain; mechanical response model

1.Introduction

In recent years, in order to adapt to the growth of traffic volume and reduce the road maintenance and traffic delays caused by road maintenance. The concept of "durable asphalt pavement" [1] was put forward in Europe and America. The idea is that the working life of road will be 40 to 50 years. And there is no structural damage in the period of using. Functional maintenance of the surface layer needs to be carried out every 10 to 15 years. Flexible base has good high-temperature stability, anti-fatigue cracking, and good water stability. And it can greatly reduce stress intensity factor of crack at the bottom of the surface. And it can prevent the production of reflection crack effectively [2], etc. This kind of pavement structure has some features such as long service life, small harm in the early time, convenient maintenance and small influence on traffic.

The durable asphalt pavement has become a hot focus in the academic circles [3-4]. Shu Fumin [5] and other scholar analyzed the mechanics index of the asphalt pavement structure through orthogonal experiments. Sun Hongyan et al. [6] carried out the sensitivity analysis of structure-layer parameters of durable asphalt pavement through digital simulation. And there is a number of scholars have studied the index of durable asphalt pavement [7] and compared the characteristics of durable asphalt pavement in China with foreign countries to provide a reference for the follow-up study. But the related research of flexible base durable asphalt pavement is still relatively few.

In this paper, a set of various composite data of different structure layer thickness and modulus is established. The influence of different structure-layer parameters of flexible base durable asphalt pavement on different control indices is analyzed, and the mechanical response model is deduced. That can be used to rapidly design durable asphalt pavement with different demand. Composite data includes the information of structure and material, deflection shape of surface of pavement and various key strain data, which provides a reference for optimizing the design of pavement structure, in future study.

2. Analysis of the influence of the pavement structure layer parameters on the control indices

2.1 Structure parameters of durable asphalt pavement's determination

Working condition of durable asphalt pavement structure is simulated by using the ANSYS finite element analysis software. Because of the high cost of the flexible base in the initial stage, the flexible base durable asphalt pavement structure is less applied in China. Control indices which are suitable for flexible base durable asphalt pavement structure's design in China is proposed according to some existing data [8, 9], such as, the bottom of the asphalt layer strain tensile should not be more than 120με, the top of the soil base compressive strain should not be more than 280με, surfacing deflection should be less than 35 (0.01mm). In pavement structure design, if these three indicators can be satisfied, it is called durable asphalt pavement. Suppose that the form of flexible base durable asphalt pavement structure is 3~7cm SMA-13/AC-13+6~22cm SMA-16(20)/AC-20+8~16cm ATB-25+15~55cm graded broken stone. A kind of pavement structure parameters is designated according to 'Code for design of highway asphalt pavement', as shown in Figure 1 and Table 1.

Flexible base asphalt pavement consists of five layers, namely SMA-13/AC-13, SMA-13/AC-13, ATB-25, graded crushed stone and soil matrix.

Each layer with three basic parameters which are thickness, elastic modulus and Poisson's ratio.

Calculation data can be determined in the range of other structural parameters, by controlling the total thickness of asphalt layer. And then, the influences of each structure layer can be determined.

Table 1 parameters of flexible base asphalt pavement structure

Material	Thickness	Elasticity Modulus /Mpa	Poisson's ratio
SMA-13/AC-13	3~7cm	1600~2000	0.35
SMA-13/AC-13	6~22cm	1600~4000	0.35
ATB-25	8~16cm	1200~1600	0.35
graded broken stone	15~55cm		0.35
soil matrix	--	35~75	0.4

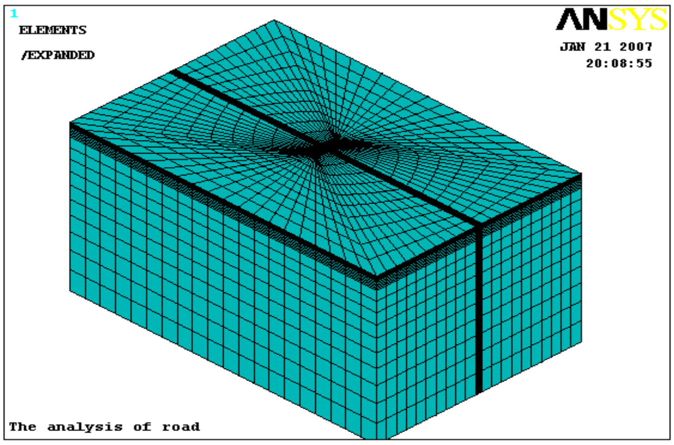

Figure 1 Schematic diagram of finite element model

The specific data setting includes: asphalt layer total thickness is 17cm to 45cm, the selected thickness for analyzing is 17cm, 19cm, 21cm, 23cm, 25cm, 27cm, 29cm, 31cm, 33cm, 35cm, 37cm, 39cm, 41cm, 43cm and 45cm.Within the same thickness, different thickness constitution of SMA-13/AC-13,SMA-13/AC-13andATB-25 is adjusted. The maximum and minimum in the range of each structure-layer parameter are combined. The parameter combination is shown in Table 2.

2.2Analysis of the influence of the total thickness of asphalt layer on the design index

In order to compare the influence of different asphalt layer thickness on each control index, according to the 'Code for design of highway asphalt pavement' [6] and actual road construction experience, this paper chooses15 types of asphalt layer thickness in the range of 17cm to 45cm.Surfacing deflection, tensile strain values of asphalt layer bottom and compressive strain values of top soil base are calculated respectively in this paper, according to different structural parameter combination. The results are shown in figure 2 to figure 4.

Table 2 Structure parameter combination table

NO.	Thickness of graded crushed stone	Upper modulus	Middle modulus	Lower modulus	K1	K2	soil base modulus
1	15	1600	1600	1200	20	0.45	35
2	15	1600	1600	1600	60	0.65	75
3	15	2000	4000	1200	20	0.65	75
4	15	2000	4000	1600	60	0.45	35
5	55	1600	4000	1200	60	0.45	75
6	55	1600	4000	1600	20	0.65	35
7	55	2000	1600	1200	60	0.65	35
8	55	2000	1600	1600	20	0.45	75

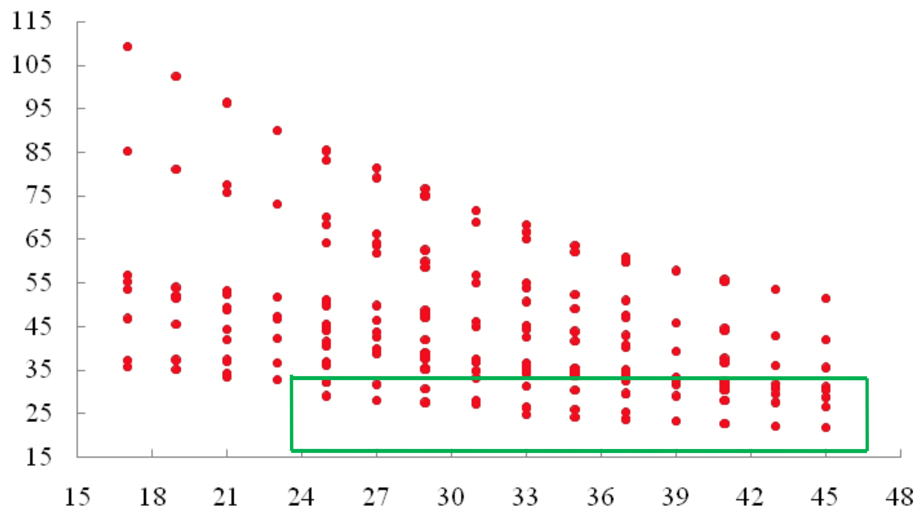

Figure 2 Effect of asphalt layer total thickness to surfacing deflection

By Figure 2, when the total thickness of asphalt layer is less than 23cm the pavement structure's pavement deflection is greater than the critical deflection value(35(0.01mm)) of asphalt pavement, which can not meet the requirement of durable asphalt pavement. When the total thickness of asphalt layer is greater than 41cm, the pavement structure's pavement deflection is smaller than the critical deflection value of asphalt pavement,, which can meet the requirement of durable asphalt pavement. When the thickness of asphalt layer is between 41cm to 23cm ,whether the indexes of structure pavement surface deflection will meet the requirements of durable asphalt pavement structure is related to the material parameters of pavement,.

As shown in figure 3,the value of tension strain at base of asphalt layer is smaller than the value of critical tension strain at base of durable asphalt pavement layer by 120με, when the total thickness of asphalt layer is less than 25cm, which can not meet the requirement of durable asphalt pavement. Most tensile strain values of asphalt layer bottom of pavement structure combination meet the requirement of durable asphalt pavement, when the total thickness of asphalt layer is greater than 43cm.whether The index of tension strain at base of asphalt layer will meet the requirements of durable asphalt pavement structure is related to the material parameters of pavement, when the thickness of asphalt layer is between 25cm to 43cm.

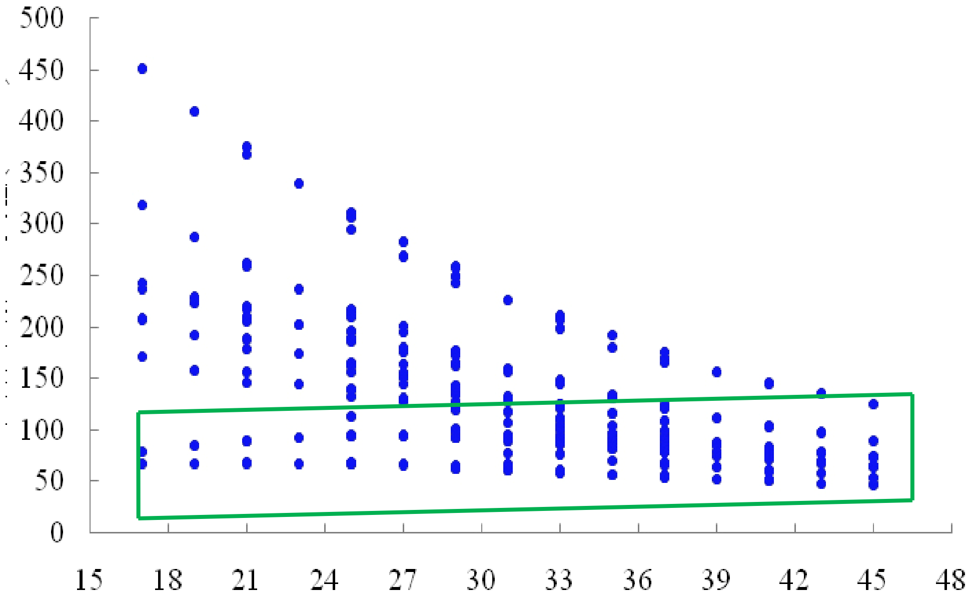

Figure 3 Effect of asphalt layer total thickness on asphalt layer bottom tensile strain value

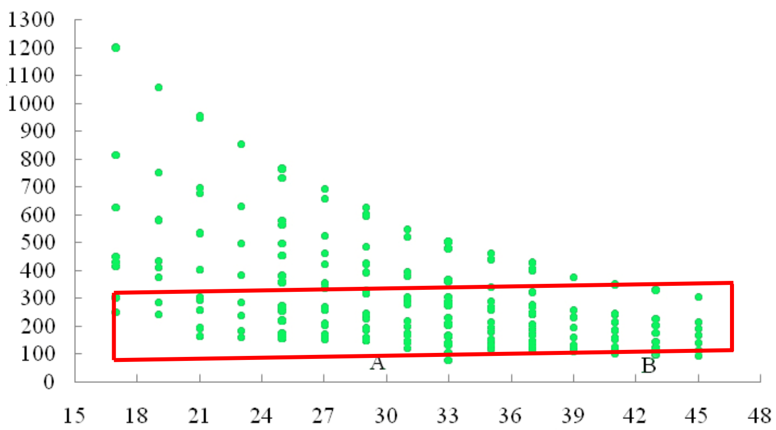

Figure 4 Effect of asphalt layer total thickness on top soil base compressive strain values

As shown in figure 4, most top soil base compressive strain values of pavement structure are greater than critical value (280με), when the total thickness of asphalt layer is less than 23cm, which cannot meet the requirement of durable asphalt pavement. Most top soil base compressive strain values of pavement structure is smaller than critical value (280με),when the total thickness of asphalt layer is greater than 43cm, which can meet the requirement of durable asphalt pavement. Whether The index of top soil base compressive strain will meet the requirements of durable asphalt pavement structure is related to the material parameters of pavement structure, when the total thickness of asphalt layer is between 23cm to 43cm.

Synthesizing above figures, it can be seen that, in general, surface deflection and top soil base compressive strain will satisfy the requirement of durable asphalt pavement, if the tensile strain values of asphalt layer bottom of asphalt pavement structures is smaller than critical value. In the range of selected control indices and structure parameters, pavement structure hardly meet the requirement of durable asphalt pavement, when the total thickness of asphalt layer is smaller than 23cm.Most index value of mechanical response are smaller than critical value, which can be thought as durable pavement, when the total thickness of asphalt layer is greater than or equal to 43cm.durable asphalt pavement structure can be achieved through designing the thickness and material modulus of each layer, when the thickness of asphalt layer is between 23cm and 43cm.

2.3Analysis the influence of flexible subbase parameters on control indexes

In order to compare the influence of flexible subbase's thickness on each control index, according to the 《Code for design of highway asphalt pavement》 and actual road construction experience,10 kinds of flexible subbase's thickness in the range of 15cm to 60cm are selected in this paper. Surfacing deflection, tensile strain values of asphalt layer bottom and compressive strain values of top soil base are calculated respectively in this paper. The results are shown in figure 5.

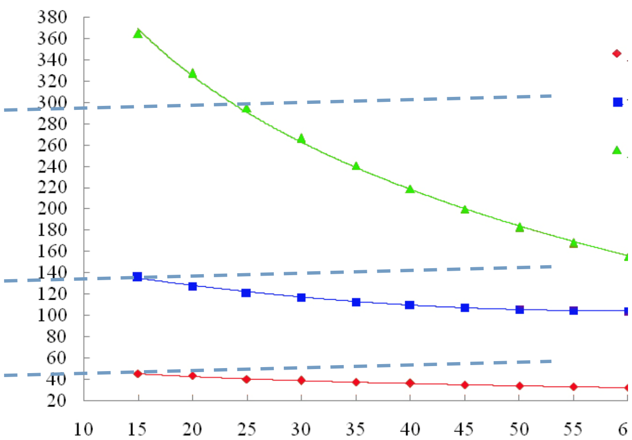

Figure 5 Relationship of flexible subbase's thickness and each index value

It can be seen from the above figure, surfacing deflection is smaller than limit deflection value (35(0.01mm)), when the flexible subbase's thickness is greater than 43cm;Values of tensile strain of asphalt layer bottom is smaller than limit bottom tensile strain values (120με), when the flexible subbase's thickness is greater than 31cm; Top soil base compressive strain is smaller than critical value (280με), when the flexible subbase's thickness is greater than 29cm;

Compressive strain of top soil base is greatly influenced by the change of flexible subbase's thickness. Along with the increase of thickness of flexible base layer Surfacing deflection, tension strain at base of asphalt layer and top soil base compressive strain values decrease gradually and the rate of decrease gradually reduce. The thickness of flexible subbase should be controlled within the range of 50cm, considering the mechanical property of pavement structure, construction cost and other factors.

In order to compare the influence of different flexible subbase's modulus on each control index, Different groups, K1 and K2 are selected. Surfacing deflection, tensile strain values of asphalt layer bottom and compressive strain values of top soil base are calculated respectively in this paper. The results are shown in table 3.

Table 3 Calculated index value based on K1 and K2

mechanics index	K2 K1	20	30	40	50	60
Surfacing deflection(0.01mm)	0.45	44.97	42.42	40.22	38.45	37.01
	0.50	43.88	41.04	38.77	36.99	35.54
	0.55	42.78	39.64	37.31	35.5	33.99
	0.60	41.4	38.14	35.8	33.94	32.47
	0.65	39.98	36.64	34.22	32.4	30.95
tension strain at base of asphalt layer($\times10^{-6}$)	0.45	161.3	146.6	132.5	120.5	110.4
	0.50	155.3	137.9	122.7	110.2	99.67
	0.55	148.8	128.7	112.4	99.42	88.27
	0.60	140.2	118.4	101.6	87.89	76.92
	0.65	131	107.7	90	76.41	65.55
Top soil base compressive strain($\times10^{-6}$)	0.45	269.1	267.0	258.8	248.5	238.3
	0.50	269.3	262.5	250.6	238.1	226.3
	0.55	267.8	255.8	240.5	226.0	212.5
	0.60	263.9	246.5	228.6	212.1	198.1
	0.65	257.6	235.4	214.7	197.4	183.0

According to the table above, index values reduced in different degree along with the increase of dynamic modulus parameters by calculating the effect of dynamic modulus parameters K1 and K2of different flexible subbaseon each index. K1 and K2 should be increased combining with the pavement structure to improve the durability of asphalt pavement.

3 mechanical response model of flexible base durable asphalt pavement structure's parameters

On the one hand, asphalt pavement structure should meet the mechanical durability standards, on the other hand, asphalt pavement structure should achieve there requirement of economic. Therefore, it is needed to meet the requirements of the structural layer material parameters and thickness.

The regression analysis was conducted for the data in the database which was established according to the above calculation by using the Minitab data analysis software. And the effect of the structure layer material parameters on the mechanics index of pavement structure is analyzed.

Because the thickness and modulus of the upper surface course have little effect on each calculation index, it is not considered in the regression analysis. The regression formula used 235 groups of data, the specific conclusions are as follows.

Surface deflection:

$$\begin{aligned}\ln l = 6.40 - 0.259\ln H2 - 0.216\ln H3 - 0.232\ln H4 - 0.0707\ln E2 \\ +0.300\ln E3 - 0.176\ln K1 - 0.457\ln K2 - 0.495\ln E4\end{aligned} \quad (1)$$

$$S = 0.0854264 \ R\text{-}S_q = 93.0\% \ R\text{-}S_q(\text{adjusted}) = 92.8\%$$

tensile strain of Asphalt layer bottom:

$$\begin{aligned}\ln \varepsilon_t = 7.69 - 0.478\ln H2 - 0.328\ln H3 - 0.210\ln H4 - 0.0064\ln E2 \\ +0.155\ln E3 - 0.486\ln K1 - 1.21\ln K2 - 0.0734\ln E4\end{aligned} \quad (2)$$

$$S = 0.157255 \ R\text{-}S_q = 89.4\% \ R\text{-}S_q(\text{adjusted}) = 89.0\%$$

soil base top compressive strain:

$$\begin{aligned}\ln \varepsilon_c = 10.8 - 0.497\ln H2 - 0.402\ln H3 - 0.612\ln H4 - 0.0372\ln E2 \\ +0.183\ln E3 - 0.231\ln K1 - 0.488\ln K2 - 0.362\ln E4\end{aligned} \quad (3)$$

$$S = 0.164755 \ R\text{-}S_q = 91.0\% \ R\text{-}S_q(\text{adjusted}) = 90.7\%$$

In the formula:

l —surface deflection (0.01mm);

ε_t —Asphalt layer bottom tensile strain values (με);

ε_c —soil base top compressive strain values (με);

S —Standard deviation of regression model's error

$R\text{-}S_q$ —The percentage of the regression model error accounting for the total errors. Values between 0% and 100%. The greater the value, the better regression model is agree with the data.

$R\text{-}S_q$(adjusted)—The value of adjustive $R\text{-}S_q$ are between 0% and 100%. The more R-Sq(adjust)close to R-Sq, the more reliable the regression model is.

$R\text{-}S_q$ The larger the value, the better. Latter $R\text{-}S_q$ is after the adjustment value by Minitab. There is an association, If the value bigger than 70%.If the value bigger than 85%, there relationship is significant.

The reliability of regression formula was tested by using 200 groups of data which are not used in the regression calculation. Compared with the results calculated bt the regression formula, the correlation coefficient is 0.9681.Therefore, the relevancy of regression formula is high, and the deviation is small.

According to the regression formula, the influence of asphalt layer modulus on each index value is smaller than the thickness on each index value. Therefore, the key point of the design of durable asphalt pavement structure's is determining the laminate construction thickness.

4 Summary

The typical flexible base durable asphalt pavement structure is selected in this paper. And computational analysis of mechanical response of structural layer parameters, surface deflection, asphalt layer bottom tensile strain and soil base top compressive strain was conducted. The mechanical response model of parameters of flexible base durable asphalt pavement structure is proposed. The conclusions are as follows:

(1) The total thickness of asphalt layer is the main influence parameter of asphalt layer bottom tensile strain indicator. The durability of pavement structure can be achieved by designing and adjusting the thickness of each structure layer and material modulus can realized, when the thickness of asphalt layer is between 27cm to 43cm.

(2) The flexible base layer thickness is the main influence parameter of top soil base compression strain index. The flexible subbase modulus parameter has obvious influence on each index. Therefore, the dynamical modulus of the flexible subbase should be increased to improve the durability of pavement structure.

(3) Soil base modulus is the main influence parameter of surfacing deflection and the top soil base compressive strain index. With the increase of soil base modulus the Surfacing deflection and soil base top compressive strain show a decreasing trend.

(4)Examined by formula, the Mechanical response models of each design indexes was remarkable, which were obtained by the regression using the Minitab data analysis software.

5. Acknowledgements

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