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Effects of interlayer bonding conditions between semi-rigid base layer and asphalt layer on mechanical responses of asphalt pavement structure

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Abstract

Shear spring compliance was adopted to simulate interlayer bonding conditions between semi-rigid base layer and asphalt layer. The parametric sensitivity of the thickness and modulus of base layer and surface layer, and the horizontal force on deflection, tensile stress, shear stress was analyzed by orthogonal method under different interlayer bonding conditions. The effects of different interlayer bonding conditions and asphalt layer thicknesses on shear stress, tensile stress were further studied. The results show that when interlayer contact conditions change from the full bonding to half bonding or full slipping condition, the variation amplitude of interlayer maximum shear stress is the largest and its value is 0.48 MPa, and tensile stress is the second, and the variation of deflection is the smallest. When the pavement structure is affected by horizontal force, pavement mechanics index is sensitive to asphalt layer thickness, and 12 cm is the unfavorable thickness for mechanical response of pavement structure. When the interlayer horizontal shear coefficient is between 10^7 N/m^3 and 10^{11} N/m^3, the interlayer between semi-rigid base layer and asphalt pavement layer is in half bonding condition, and the variation of each pavement mechanics index is very prominently.

Keywords: Asphalt pavement; Interlayer contact; Interlayer horizontal shear coefficient; Mechanical response

1. Introduction

Nowadays, the semi-rigid base asphalt pavement accounts for more than 90% of highways in China. The bonding conditions between semi-rigid base layer and asphalt pavement layer become a weak link because of asphalt material and semi-rigid base material exhibit significantly different mechanical and physical properties [1,2]. Therefore, asphalt pavement can easily generate shear failure, such as interlayer stripping, delamination, with repeated effects of traffic and climate, which seriously affect the road service level and life [3–5]. A lot of studies were conducted about this issue. The results show that the interlayer shear failure has a close relationship with the mechanical response of a pavement structure [6–10]. Huang et al studied shear stress of a composite pavement structure under different interlayer bonding conditions. They found that reasonable interlayer treatments can effectively avoid interlayer shear failure [11]. Li et al investigated the effect differences of interlayer contact model and continuum model on mechanical response of asphalt pavement struc-

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ture by comparative analysis. The results show that the contact model agree with the actual pavement working status well [12]. Guan et al verified the feasibility of using horizontal shear coefficient evaluating bonding conditions between semi-rigid base layer and asphalt surface layer [13]. Zhang et al analyzed the mechanical response of interlayer bonding conditions and debonding conditions of various pavement structures by Bisar and Matlab software [14]. However, existing research results on the effects of the interlayer contact between asphalt layer and semi-rigid base layer on the pavement mechanical response analysis were not sufficient, the most of them only studied the mechanical response of interlayer contact conditions under the full bonding and full slipping, and there is little mechanical response analysis of the asphalt pavement structure under any contact conditions, and the effects of different horizontal force coefficients, pavement structure material parameters on the mechanical response of an asphalt pavement structure is not considered. Therefore, the effects of the base layer thickness, surface layer thickness and corresponding modulus under different interlayer contact conditions on mechanical response of asphalt pavement structure by orthogonal method were investigated in this study. The relationship of the interlayer horizontal shear coefficient and mechanical indexes of asphalt pavement were analyzed with different asphalt layer thickness.

2. Simulation test

2.1. Pavement structures and calculating parameters

The interlayer bonding between asphalt surface and semi-rigid base plays an important role on the integrity of asphalt pavement structure, and for design purposes it is typically assumed that full bonding exists between the pavement layers. The main objective of this study is to discuss and analyze the effects of interlayer contact conditions between the asphalt surface layer and semi-rigid base layer on mechanical response of asphalt pavement structures. Therefore, the pavement structure was only divided to surface layer, base layer and subgrade when the pavement structure models were established, and full bonding between the semi-rigid base and subguade was assumed. The thickness of surface layer and the base layer is the total thickness of the asphalt concrete and the semi-rigid base, respectively. The contact condition parameter between asphalt layer and semi-rigid base was described using shear spring compliance from Bisar3.0 software [5]. Then mechanical responses of different combination of thicknesses and modulus under different interlayer contact conditions were analyzed.

In order to ensure the accuracy of calculated results, the variation scope of calculating parameters was selected according to the recommended value from the current asphalt design specification in China (JTG D50-2006). The calculating parameters are shown in Table 1. The values inside and outside brackets are the compressive modulus of materials at 20 °C and 15 °C, which were utilized to calculate pavement structure deflection and the stress, respectively.

Pavement surface deflection, tensile stress at the bottom of the asphalt layer and shear stress between adjacent layers were selected as the mechanical indices, based on the Specifications for Design of Highway Asphalt Pavement (JTG D50-2006) and the actual failure mode of pavement structure resulted from the condition of interface between the surface layer and the base layer.

The standard double-axle load in China with a wheel pressure of 0.7 MPa, a radius of 10.65 cm, a double circle center distance of 15.975 cm. Horizontal force coefficients of 0, 0.3, 0.5, 0.7 were used and horizontal force was calculated as formula (1).

$$\begin{cases} T_1 = fP \\ T_2 = \varphi P \end{cases} \tag{1}$$

where, T_1 and T_2 are the horizontal force under wheel braking and no braking, respectively. f is sliding friction coefficient, φ is rolling friction coefficient. P is vertical load.

2.2. The index of interlayer contact condition

The index of shear spring compliance from Bisar 3.0 software was chosen to describe interlayer contact conditions [5,15]. The interface between two (horizontal) pavement layers is represented by an infinite thin inter-layer of which the strength is described by means of a spring compliance. Physically it assumes that the shear stresses at the interface cause a relative horizontal displacement of the two layers, which is proportional to the stresses acting at the interface.

The physical definition of the standard shear spring compliance, AK, is given by formula (2).

$$AK = \frac{\text{relative horizontal displacement of layers}}{\text{stresses acting in the } interface} \tag{2}$$

where, AK is the shear spring compliance, m^3/N, which can be converted by sliding coefficient α in calculating progress of Bisar 3.0 software. The relationship formula is shown as (3).

$$\alpha = \frac{AK}{AK + \frac{1+\nu}{E} \cdot r} \tag{3}$$

where, r is the load radius; E is the elasticity modulus of the above layer of calculating layer, Pa; ν is the Poisson's ratio of calculating layer; α is the sliding coefficient, $0 \leqslant \alpha \leqslant 1$, friction force is the largest when $\alpha = 0$, which means $AK = 0$ and interlayer contact condition is the best. Friction force is zero when $\alpha = 1$, which means interlayer contact condition is the worst.

In addition, the current research showed that the shear spring compliance AK expresses a reciprocal relationship to interlayer horizontal shear coefficient K_s. To easily express the interlayer bonding condition on the abscissa,