Discussion on Dynamic Reaction Model of Asphalt Pavement

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Abstract

With the development of basic subjects and the improvement of new theories, dynamic theory and viscoelastic material model theory have been studied deeply. In this paper, research status and outstanding achievements on dynamic response of asphalt pavement at present are summarized and analyzed by literature research methods.

Keywords

asphalt pavement, dynamic load, hemodynamic patterns.

1. Introduction

In China, the allowable rebound deflection as design index has been used since 1986. The idea that pavement deflection index is an indicator of the overall structure of the pavement has been the same. At that time, with the extensive application of Backman bean deflection tester, most of the scholars in China had studied the physical and mechanical meaning of the static deflection of the pavement structure. In a series of studies on the empirical design method and the mechanics experience design method, how to characterize pavement structure load capacity is a key to design. Mechanics experience method is developed on the basis of the concept of deflection. Measurement and evaluation of deflection is important for prediction about pavement performance and theoretical behavior. Deflection will continue to be used as a means of evaluation of pavement capacity until there is a better means. In 1990s, scholars began to turn to study the dynamic deflection with the promotion of FWD.

2. Domestic Present Situation

At first, the domestic scholars studied pavement structure load capacity based on statics and elastic system. Not only that, more and more researchers believed that there are more information about the pavement structure in the dynamic deflection value obtained by FWD. Among them, using static multilayer elastic theory, some scholars analyzed the constitutive relation between the modulus of various structural layers of semi-rigid base asphalt pavement and road surface deflection basin parameters. The study found that the dynamic deflection basin data obtained by FWD has a high correlation with modulus of asphalt surface layer, radial tensile strain at the bottom of the bottom layer, subgrade modulus and its top surface compressive strain. These provided a reference for further research on dynamic characteristics of asphalt pavement.

With the improvement of the development of basic disciplines and new theory, more scholars found the assumptions made by previous studies are too rough to simulate the actual situation better. Therefore, the problems about FWD deflection basin have been studied by some scholars using the kinetic theory and the viscoelastic material model.

Based on the analysis of linear elastic theory and static response, Yanqing Zhao et al.[1], taking into account the dynamic load of pavement structure under the action of high speed traffic load, decided to analyze a particular structure of asphalt pavement by dynamic viscoelasticity in order to reflect the behavior characteristics of asphalt pavement more objectively. They assumed that the asphalt mixture as thermal viscoelastic and granular base and subgrade as linear elastic material. Based on the principle of superposition principle of Prony, the Boltzmann series and the Hamilton variational principle, the basic equations of finite element for dynamic problems can be formed associated with overall mass, damping, stiffness and external dynamic loads. The density of all kinds of materials is characterized by the mass matrix. The two key frequencies of the damping matrix were the low values of the pavement self vibration frequency and the high value of the load frequency. The load frequency is used to characterize the driving speed. Through the analysis of the finite element model established above, they found that the temperature has a significant effect on the dynamic viscoelastic response of the deflection. With the increase of temperature, the creep performance of asphalt mixture and the deflection of asphalt mixture are increased. Not only so, when the temperature increases, the viscous component of asphalt mixture as a viscoelastic material also increases, which increase the damping, in the process of vibration more energy is lost, so the rate of vibration decay faster. After comparing with the deflection peak value obtained by dynamic analysis and quasi-static analysis, they found that the effect of damping ratio on the peak bending is very small. With the increase of the damping ratio, the peak of the deflection decreases slightly and the time of the deflection of the peak value appears. Damping ratio has a greater impact on the damping ratio. When the damping become greater, the attenuation will be faster.

Owing to the use of two-dimensional algorithm, because the actual road surface is a three dimensional strip structure, there is lots of internal assumption in the process of two-dimensional simplification. Thus calculated results have many limitations. For the use of FWD, Yun Hou et al.[2] use basic method of 3D finite element modeling and Newmark integral method to analyze the mechanical response of multilayer elastic system caused by the load of FWD and road surface deflection value of each measuring point in different loading cycles. They found that when the load cycle is smaller, the maximum dynamic deformation is also smaller. With the increase of the cycle, the maximum dynamic deformation is increasing, and the deformation will reach the maximum value in a certain period. But as the load cycle continues to grow, the dynamic deflection will be closer to the static deflection. Along with the increase of the distance from the loading source, the deformation appears hysteresis. When the period is shorter, the hysteresis phenomenon is more obvious. The deformation hysteresis disappears gradually with the increase of the period. In the course of vibration, the damping effect is mainly influenced by the internal friction of the material, so it is important to accurately measure the damping of the material. But so far, there are still some problems in the research of damping, which needs further discussion. As for the effect on the modulus of subgrade, Yuanshuai Dong et al.[3] use ABAQUS finite element program, the nonlinear constitutive model of soil and dynamic modulus of other structural layers to calculate the theoretical deflection. For soil and pellets, they use prediction equation to predict the modulus of elasticity of material by simple material experiment such as particle analysis, limitation water content test and compaction experiment. For each layer of material, the dynamic modulus test is used to test the dynamic resilient modulus of asphalt mixture. Finally, based on the regression analysis, the F correction formula is obtained, which is based on the parameters of the deflection basin, in order to improve the acceptance criteria of pavement quality for the dynamic parameter design method of asphalt pavement.

Asphalt mixture is a typical viscoelastic material which is used in the mechanical response analysis and structural design of asphalt pavement structure. For viscoelastic materials, the mechanical response at any moment is not only related to the loading condition of the moment, but also to the loading history of the pavement structure. The use of elastic layer theory will inevitably result in errors. In order to get the actual mechanics of flexible base asphalt pavement structure response, using viscoelastic model, Yanqing Zhao et al. transform the complex modulus of asphalt mixture determined by experiments to the creep compliance to solve viscoelastic mechanical response such as pavement structure road surface deflection in the static load model and load or unload model. Their study shows that viscoelastic analysis can behavior characteristics and failure mechanism of asphalt pavement more scientifically. Because of the creep and relaxation properties of the asphalt mixture, under constant load, road surface deflection and soil base top surface compressive strain increase with time and the tensile strain at the bottom of the base layer increases with time and then decreases. All kinds of responses are gradually stabilized with time. Nor only that, at the early stage of unloading, road surface deflection and soil base top surface compressive strain can recover fast, but with the increase of time, the recovery gradually slows down. After unloading, the tensile strain at the bottom of the base is changed into the compressive strain. The compressive strain is gradually reduced with the pavement structure up to the top. When the unloading time is long enough, the response is close to 0.

In addition to the study on the material itself, based on the theory on elastic layered system and the state between pavement structural layer and interlayer bonding, Yu Tang[4] uses BISAR to analyze how the paving technology affects road surface deflection basin. The research shows that the increase of the modulus and thickness of the structure layer will reduce the road surface deflection. In terms of the thickness of the structure, the influence of the thickness of the structure layer decreases with the increase of the distance. In terms of the bond condition between layers, road surface deflection basin is affected greatly by bonding state between surface layer and base layer. The center deflection of the road surface increases dramatically when the interlayer bonding state occurs. In terms of Modulus and thickness of gravel subbase in flexible asphalt pavement, the decrease of road surface deflection basin is small.

3. Current Situations of Foreign Countries

In foreign countries, the Analytical method of curved basin is proposed in 1940s. Performance status of various structural layers of pavement can be evaluated by the relationship between quantitative analysis of parameters of FWD curved basin and ecaluation index of mechanical property of pavement structure.

The parameters of the curved basin are summed up in four aspects by horak[5]. First, the center deflection basin of the bearing plate reflects the overall stiffness of the pavement structure. Second, the slope and the difference of the curved slope near the center of the loading center reflect the relative stiffness of the upper structure of the pavement. Third, the slope and the difference of the curved basin in the vicinity of 300-900mm reflect the relative stiffness of the lower structure or pavement base. Fourth, the end deflection of the curved basin reflects the stiffness of subgrade.

After the introduction of dynamics, Yung-Chien lee et al.[6] use the shape factor and deflection basin area to determine the damage degree of pavement structure and use area of curved basin, load center deflection and modulus of subgrade and pavement to predicate modulus of surface layer through finite element method to calculate the deflection basin data.

In view of FWD, some scholars think that the dynamic effect of pavement is related to the pulse width of the load and the stiffness of he subgrade. The research finds that the deflection of the position of the measuring point far away from the load center is greatly influenced by the FWD impact load. Combining with viscoelastic properties of asphalt mixture, Uddin et al. [7] use 3D finite element model to simulate the FWD to mechanical response mechanism of asphalt pavement and analyze the effects of loading time and load deflection in detail. Micro model for predicting creep modulus of asphalt mixture is established based on test results in creep compliance. For pavement structure layers contact, Samir[8] uses 3D finite element modeling to simulate the mechanical response law on elastic composite pavement structure under FWD impact load. A method for determining the time history curve of the contact state between layers is proposed.

In conclusion, the literature research on the dynamic deflection basin has been relatively well abroad. The scholars all over the world are studied from three aspects such as the dynamic characteristics, the viscoelastic properties of asphalt mixture and the contact between the pavement structure layers. In terms of dynamic characteristics, dynamic sine load mode such as load size, load frequency and load time is used to research. In the asphalt mixture viscoelastic properties, based on the material itself, the viscoelastic material is characterized by dynamic modulus and creep compliance from experiment. In addition to the material itself, the outside temperature and loading frequency are also its influence factors. In the pavement structure layer and interlayer contact, the selection of constitutive model between base and subgrade, force reflection phenomenon and uneven phenomenon of interlayer contact are all considered.

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