Study on structural optimization of latex cement mortar pouring composite pavement based on finite element method

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Abstract: Pouring composite pavement is one new type of pavement structure, which has excellent resistance to permanent deformation. However, due to the difference in the properties of cement-based materials and asphalt-based materials, the interfacial adhesion is not sufficient, which makes the pouring composite pavement have cracking defects. The adhesion of mortar modified by latex agent can improve the crack resistance of composite pavement. In this paper, the mechanical behavior of pavement is simulated by finite element method, and the deflection, bending, tensile stress / strain, shear stress / strain and so on of latex cement mortar pouring composite pavement with different thickness structures are calculated and analyzed. The mechanical control index of pouring composite pavement is obtained, and the thickness of semi-flexible pavement structure which meets the mechanical requirements of pavement is optimized at the same time.

1. Introduction
Pouring composite pavement is one new type of pavement structure, which is formed by pouring special slurry with cement as the main component into the base asphalt mixture (void ratio 20%-35%) pavement. The strength of the material is formed by the mutual extrusion between aggregates and the pouring cement mortar, which improves the ability of the structural layer to resist the load, and has the characteristics of "combination of rigidity and flexibility" and so on[1]. It not only has the characteristics of high strength and high temperature deformation resistance of cement concrete pavement, but also can solve the common high temperature deformation diseases of asphalt pavement, and has the advantages of continuous driving of asphalt pavement. In addition, some characteristics, such as oil resistance, acid resistance, heat resistance, water resistance, skid resistance and easy coloring are easily found in it[2]. The application research of the pouring composite pavement material was first carried out in France, as early as 1954, the construction method of open graded asphalt concrete pavement with grouting cement" was successfully developed and tested on the runway of jet aircraft at Konek (Cognac) Airport as a heat-resistant pavement. This kind of pavement was introduced to Japan in 1961. In February of the following year, 1000 m$^2$ experimental pavement was paved on the junction section of Hakone New Road by the Japan Road Corporation. After France, Japan applied for a patent under the name of "Semi-flexible Pavement and Semi-flexible Pavement Construction Method". Since then, this kind of pavement has developed rapidly in Japan and was formally listed as a special construction method in the asphalt pavement construction code in 1978[3].

However, some researchers found that cement mortar pouring semi-flexible pavement still has the shortcomings of pavement cracking, and the main reason is that the sensitivity of cement mortar to
temperature is different from asphalt and aggregate, and the poor interfacial cohesion of cement mortar-asphalt-aggregate. Therefore, the researchers began to carry out a preliminary study on the modification of cement mortar for semi-flexible pavement, and some results were obtained. Ding used rubber powder to improve the crack resistance of cement mortar. It was found that adding a certain amount of rubber powder could improve the volume stability of cement mortar and improve the bond property between cement mortar and asphalt interface\cite{4}. In 2009, Ling carried out an experimental study on the mobility and mechanical strength of resin, emulsion and other polymer modified cement mortar. It is recommended that the emulsion cement mortar with 4.7% cement ratio as the most cost-effective admixture scheme\cite{5}. In the same year, Li made an experimental study on the formulation, consistency and viscosity of waterborne epoxy resin modified cement mortar. It was concluded that the optimum content of waterborne epoxy resin 2.5% could improve the fluidity of mortar\cite{6}. Zhong prepared latex cement mortar by introducing latex modifier, which improved the effect of cement mortar pouring on the low temperature deformation ability of the mixture\cite{7}. At present, the structure design of latex-poured pavement is still lack of research. Therefore, optimize in structural designation, decrease in thickness of structural layer, economize in construction can be totally seen in this paper through finite element technology. By the way, the proposed control index can provide guidance for the structure design.

2. Research scheme and model construction

2.1 Research plan

Because the mechanical properties of the pouring composite pavement are different from those of the conventional asphalt pavement, it is necessary to calculate the mechanical properties of the pouring composite pavement so as to analyze the stress state of the pouring composite pavement in the pavement structure layer, and to provide a theoretical basis for the application of the pouring composite pavement in the asphalt pavement. Therefore, in this numerical simulation of mechanical properties, the following three schemes are carried out respectively, combined with the thickness of six kinds of pavement structure layers (Table 1) commonly used in expressway:

- Scheme one: Mechanical calculation of conventional asphalt pavement: SBS modified asphalt pavement is used in the upper and lower layers.
- Scheme two: Mechanical calculation of single layer pouring composite pavement: the upper layer adopts SBS modified fine grain asphalt pavement, and the lower layer adopts pouring composite pavement;
- Scheme three: Mechanical calculation of double layer pouring composite pavement: the pouring composite pavement is used in the upper and lower layers.

| Structural Form        | Structure 1 | Structure 2 | Structure 3 | Structure 4 | Structure 5 | Structure 6 |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Upper layer            | 4           | 4           | 4           | 5           | 5           | 5           |
| Lower layer            | 6           | 8           | 10          | 6           | 8           | 10          |
| Water-stabilized base  |             |             |             |             |             |             |
| Soil foundation        |             |             |             |             |             |             |

The pavement surface is 5 m long and 4 m wide. In order to reflect the characteristics of semi-infinite space foundation, the foundation is simulated by enlarged size. The finite element model is established as shown in Figure 1.
2.2 Load and boundary conditions

Load is the standard axle load BZZ-100 (single axle and double wheel axle load 100kN) stipulated in the current pavement design code of our country. The tire grounding pressure is 0.7MPa, the radius of the two loads is 1δ (10.65cm), and the center distance is 3δ (31.95cm), as shown in Figure 2. The boundary conditions assume that the roadbed surface is completely fixed and there is no lateral and vertical displacement; only vertical displacement exists around the road surface and roadbed.

2.3 Determination of material parameters

The elastic modulus and Poisson's ratio of asphalt pavement, single-layer and double-layer pouring composite pavement are tested when calculating and analyzing the pouring composite pavement. Specific parameters are shown in Table 2, Table 3 and Table 4.

| Structural Form       | Structural Type Compressive Rebound Modulus E(MPa) | Poisson's Ratio μ |
|-----------------------|----------------------------------------------------|-------------------|
| Upper layer           | 1200                                               | 0.20              |
| Lower layer           | 1600                                               | 0.20              |
| Water-stabilized base | 1800                                               | 0.30              |
| Soil foundation       | 60                                                 | 0.30              |

| Structural Form       | Structural Type Compressive Rebound Modulus E(MPa) | Poisson's Ratio μ |
|-----------------------|----------------------------------------------------|-------------------|
| Upper layer           | 1200                                               | 0.20              |
| Lower layer           | 1600                                               | 0.25              |
| Water-stabilized base | 1800                                               | 0.30              |
| Soil foundation       | 60                                                 | 0.30              |
Table 4. Basic material parameters of each layer of double layer pouring composite pavement

| Structural Form       | Structural Type Compressive Rebound Modulus E(MPa) | Poisson's Ratio $\mu$ |
|-----------------------|---------------------------------------------------|-----------------------|
| Upper layer           | 1600                                              | 0.25                  |
| Lower layer           | 1600                                              | 0.25                  |
| Water-stabilized base | 1800                                              | 0.30                  |
| Soil foundation       | 60                                                | 0.30                  |

3. Result analysis

3.1 Stress analysis at the bottom of each layer

Based on the assumption of material parameters and calculation model, the stress at the bottom of each layer under the action of standard axle load is calculated. Because the stress distribution of different schemes is basically the same at the bottom of each layer under the action of standard axle load, the influence area of stress distribution at the bottom of pavement is a rectangular area with a distance of 1.5m from the axle load. Considering the most disadvantageous situation, the maximum stress values of each floor under different schemes are calculated. The results are shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6.

Fig 3. Summary diagram of transverse tensile stress at the bottom of the layer above

Fig 4. Summary diagram of transverse tensile stress at the bottom of the layer below
The data in the analysis diagram are as follows: According to the calculation results, the stress of pavement structure layer changes, but it has little effect on the overall force of pavement, which indicates that the pouring composite pavement structure can be applied to all structural layers of expressway.

It can be seen from the figure that the increase of the thickness of the lower layer makes the transverse and longitudinal tensile stress of the upper and lower layer decrease gradually. For example, in Figure 4, the decrease of the double-layer asphalt pavement is the most obvious, compared with structure two, its structure three decreases by 0.0952mpa. In the single layer pouring composite pavement, the structure two is reduced by 0.05mpa relative to the structure one, and in the double layer pouring composite pavement, the structure two reduces the 0.0404mpa relative to the structure one. The increase of the thickness of the upper layer also reduces the transverse tensile stress of the upper layer, but has little effect.

### 3.2 Displacement analysis of each layer

In the same way, the rectangular dangerous area is the main consideration when analyzing the displacement distribution of the top surface of each layer in the road structure of the pouring composite pavement. The maximum displacement of the top surface of each layer under different schemes is calculated. The results are shown in figs. 7 and 8.
Fig 7. Summary of the maximum displacement of the top surface of the layer above

Fig 8. Summary of the maximum displacement of the top surface of the layer below

Data in the analysis diagram are available: Compared with the conventional road structure, the maximum displacement of the top surface of the pouring composite pavement decreases with the increase of thickness under the action of standard axle load, but the effect is not significant, and is smaller than that of the conventional asphalt pavement structure, which indicates that the structural layer has better deformation resistance.

4. Conclusion
In this paper, a three-dimensional finite element model is established, and the stress distribution at the bottom of the composite pavement and the maximum vertical displacement at the bottom are taken as the evaluation indexes. The mechanical properties of the latex-modified composite pavement structure are analyzed and evaluated. The main conclusions are as follows:

(1) Comparing the distribution of stress and displacement at the bottom and vertical displacement at the top of each layer of the pouring composite pavement structure, it can be seen that the distribution of stress and displacement at the bottom of each layer is basically the same, and is consistent with the distribution of common road structure, but the stress and displacement values are different.

(2) Stress calculation shows that with the increase of the total thickness of the surface layer, the transverse and longitudinal tensile stress at the bottom of the layer decreases. At the same time, the maximum displacement of the top surface of the pouring composite pavement is less than that of the conventional asphalt pavement structure under the action of standard axle load, which indicates that the structure layer has better deformation resistance than the conventional asphalt pavement structure.

(3) Under the condition of considering the technical difficulty and cost of construction, several schemes are considered synthetically. The structure three of double-layer pouring composite pavement is the best scheme, its thickness is moderate, and the transverse tensile stress at the bottom is the smallest. And with the increase of thickness, the decrease of stress is not obvious.
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