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Effects of parameters of asphalt concrete surfacing on mechanical property of paving layer

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Abstract: The important parameters that influence the mechanical property of the paving layer on an orthotropic steel bridge deck are the paving layer thickness and modulus of the asphalt concrete surfacing. Three important indices that control the typical failures of the paving layer are the maximum tensile stress of paving layer, the maximum shear stress between the steel deck and the paving layer, and the maximum deflection on the paving surface. In this paper, the analytical model of paving systems on orthotropic steel bridge deck is established, and the finite element method is adopted to study the stress and strain of paving system. With the variation of asphalt concrete modulus in high or low temperature season, the influences of paving layer thickness on three control indices are researched. The results provide a theoretical basis for the determination of thickness of the paving layer on the steel bridge deck.

Key words: paving layer; othotropic steel deck; stress; strain; surface deflection; finite element

Today, orthotropic steel decks and asphalt paving layers are widely used in long-span suspension bridges and cable-stayed bridges. Paving layer is an important part of the traveling system on steel bridge decks, its performance directly influences the security and amenity of traveling. Cracking and shear slippage are typical failures of the paving layer. The detail analysis of the stress and deformation of the asphalt paving system was established in order to determine the reasonable thickness of the paving layer, and make measures to reduce the deterioration of the pavement and extend the service life of the orthotropic steel deck paving.

1 Analytical Model of Orthotropic Steel Deck Paving

The cracking of asphalt concrete paving layer is directly related to the local deformation of steel deck[1]. In the process of mechanical analysis of the paving layer, the asphalt paving and orthotropic steel deck are regarded as a system to undertake the vehicle load. Assume that the asphalt concrete paving layer and the steel deck are all homogeneous, continuous and isotropic materials. The analytical model of the orthotropic steel deck paving system consists of the paving layer, steel deck, stiffening rib, longitudinal beam and transversal plate, as shown in Fig.1.

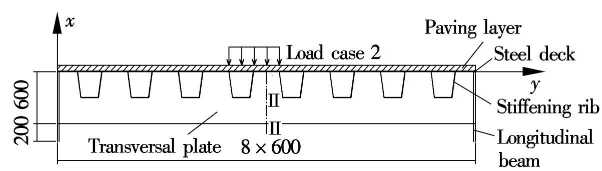

Fig.1 Analytical model of orthothropic steel deck surfacing (unit: mm)

In the analytical model, a part of the orthotropic steel deck paving structure which is influenced by the tire load[2] was chosen with a 4.8 m width (including 8 trapezoidal stiffening ribs) and a 9.06 m length (0.03 m + 3 × 3 m + 0.03 m, the space between transversal plates is 3 m). The material of the steel deck, trapezoidal stiffening ribs, transversal clapboards and longitudinal beams are all 16 Mnq steel, the modulus of which is 210 GPa and the Poisson's ratio is 0.3. The thicknesses of the paving layer, steel deck, transversal plate and longitudinal beam are 50, 14, 10 and 20 mm, respectively. The dimension of trapezoidal stiffening ribs is 300 mm × 280 mm × 8 mm. The added tire load is uniform, the load area is 0.6 m × 0.2 m and the pressure value is 707 kPa. The load is symmetric along the longitudinal direction. The transversal placement of the load is the critical load case (the composite force of the uniform load on the top of the trapezoidal stiffening rib).

In this paper, the stress of asphalt concrete paving layer is analyzed using the finite element analysis program SUPERSAP93[3,4]. Half of the orthotropic plate paving system structure is selected due to symmetry along the longitudinal direction. In the simulation, block elements in SUPERSAP93 are

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selected, and the areas near high stress, such as the load area and the top of the stiffening rib, are subdivided.

2 Effects of Paving Layer Thickness on Tensile Stress of Paving Layer

Box-girder has a small thermal capacity so that heat can be conducted very fast in it. In high-temperature regions where the temperatures of the top coat and bottom coat of asphalt paving system are very high, the modulus of asphalt concrete is greatly affected by the temperature. Therefore, it is necessary to consider the change of the modulus of asphalt concrete in analyzing the mechanical property of the paving system. For the convenience of the calculation, a coefficient of modulus ratio n is introduced to define the ratio of modulus of steel plate to that of the asphalt concrete paving layer, that is $n = E_{\text{steel}}/E_{\text{paving}}$. In nature, the change of the coefficient of the modulus ratio n reflects the change of the modulus of asphalt concrete.

From the curve in Fig.2, when the thickness of the paving layer is given, the maximum transversal tensile stress $\sigma_{y\max}$ in the paving layer decreases as the modulus ratio n increases. Because the rigidity of the paving layer is reduced, the rigid share of the paving layer in the entire composite structure is also reduced. However, the maximum transversal tensile stress decreases slowly as the thickness of the paving layer increases, the change of the modulus of asphalt concrete (that is also the change of the modulus ratio n) has a much greater effect on the transversal tensile stress in a thin paving layer than that of a thick paving layer. In addition, when the modulus ratio n is very large, the thickness of the paving layer has less influence on the maximum transversal tensile stress.

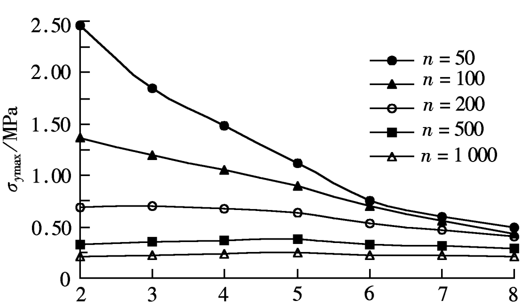

Fig.2 Effects of paving layer thickness on maximum transversal tensile stress of paving layer

It is well known that cracking of the paving layer on steel bridge decks often occurs during constant temperature seasons or low temperature seasons when the modulus ratio n is small. Because the maximum transversal tensile stress is a main index to control the cracking failure, the thickness of the paving layer should be increased to reduce the maximum tensile stress in the paving layer. However, the thickness value should avoid being the value corresponding to the peak of the tension stress curve. Further more, it is harmful to choose a reasonless large thickness because overloading will increase stress in the steel bridge structure. Fig.2 shows that the effect of reducing the maximum transversal tensile stress will lessen when the thickness is very large.

3 Effects of Paving Layer Thickness on Interlayer Shear Stress

The bonding failure between the paving layer and the steel deck is another kind of common failures. Interlayer shear stress is the main index to control bonding failure. Fig.3 shows the curve of the maximum transversal shear stress $\tau_{y\max}$ between the paving layer and the steel deck corresponding to different thicknesses and moduli of the paving layer. It can be seen that the maximum transversal shear stress $\tau_{y\max}$ decreases gradually with the increase of the modulus ratio n when thickness is given (the modulus of the asphalt concrete also decreases). In addition, when the thickness varies, the change of the maximum transversal shear stress $\tau_{y\max}$ is very complex. When the modulus ratio $n \leqslant 200$, the curve of $\tau_{y\max}$ is an overhead curve and the thickness corresponding to the shear stress peak value of the curve is not fixed under different modulus ratios; when $n = 50$, the thickness corresponding to the shear stress peak value of the curve is 3 cm; when $n = 100$, the thickness is 5.5 cm; when $n = 200$, the thickness is 6 cm; when $n > 200$, the shear stress curve is a monotone increasing curve, maximum transversal shear stress $\tau_{y\max}$ between the paving layer and the steel deck increases as the thickness grows.

During periods of high temperature, the bonding coat materials are in a slime state and bond strength decreases greatly. Therefore, shear and slipping failures tend to occur between the paving layer and the steel deck. The modulus of the asphalt concrete decreases greatly and the modulus ratio n increases accordingly. Fig.3 shows that the interlayer shear stress increases as the thickness of asphalt concrete

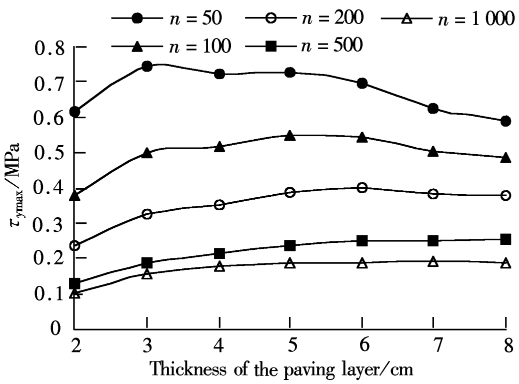

Fig.3 Effects of paving layer thickness on maximum interlayer shear stress

paving layer grows. Therefore, the thickness should not be very large and should not be the peak value of the curve corresponding to different modulus, such as 3 cm thickness.

4 Maximum Surface Deflection of Paving Layer

A shallow layer of the asphalt concrete is usually used as the paving layer on the steel bridge deck. Although the support of the paving layer is an orthotropic steel deck, not the subbase or earth base used in common roadway, the deflection of the paving layer can reflect the whole strength and rigidity of the paving layer and orthotropic steel deck and can also reflect the service performance of the paving layer. Accordingly, the surface deflection of the paving layer is an important control index in the mechanical analysis of the paving layer on a steel bridge deck.

For different thickness and modulus of paving layer, the curve of maximum surface deflection ω_{max} of the paving layer is shown in Fig.4. When the asphalt concrete module grows, the rigidity of the entire asphalt concrete paving structure increases accordingly, and so does the rigidity of the composite structure of the orthotropic steel deck. Under the same load conditions and given thickness of the paving layer, as the modulus of asphalt concrete increases, the maximum surface deflection of the paving layer decreases.

In Fig.4, as the thickness of the paving layer increases, when the modulus ratio $n \leqslant 500$, the maximum surface deflection of the paving layer decreases, however, when $n > 500$, the maximum deflection increases. The reason for this phenomenon is that the surface deflection consists of the deflection of steel plate and vertical displacement of local

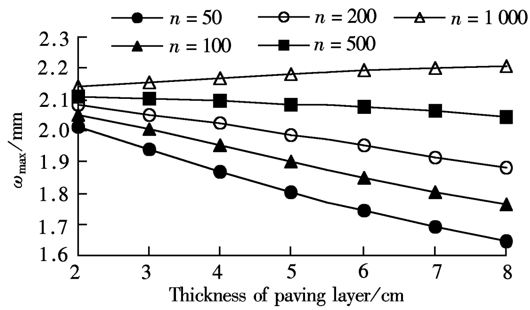

Fig.4 Effects of paving layer thickness on maximum deflection of paving surface

deformation of the paving layer. When the thickness of the paving layer grows, the rigidity of the entire structure increases (that is I of EI) and the deflection of the structure reduces. But if the modulus of the paving layer is small, the deflection of the paving layer is so great that the overall deflection of the structure increases with the increase of paving thickness. In high temperature seasons, asphalt concrete is viscoplastic and in weak strength so that rutting failure is prone to taking place. Therefore, it is unreasonable to choose a very thick paving layer.

5 Conclusions

1) The cracking failure of the paving layer on steel bridge decks usually happens during low temperature seasons or constant seasons. The thickness of paving layer can be increased to decrease the maximum transversal tensile stress. However, a reasonless large thickness will add an overload in the steel bridge structure. And, when the modulus ratio n is very large, the increase of the paving layer thickness has less influence on the maximum transversal tensile stress.

2) In high temperature, the module of asphalt concrete decreases greatly and the modulus ratio n increases accordingly. The interlayer shear stress grows with the increase of the thickness of the paving layer. Therefore, the thickness of the paving layer should not be very great and should not be the peak value of the curve according to different modulus ranges of the paving materials.

3) In high temperature seasons, asphalt concrete is very weak and shows viscoplasticity. Rutting and other failures are more likely to occur with the increase of the deflection of the paving layer due to a too thick paving layer. For those reasons mentioned above, a 4 - 6 cm paving layer is recommended to effectively control failures of the paving layer.

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沥青混凝土铺装层各参数对铺装层力学性能的影响

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摘　要　影响正交异性钢桥面铺装层力学性能的重要参数有铺装层的厚度和沥青混凝土铺装层的模量.铺装层典型破坏的3个控制指标是铺装层的最大横向拉应力、钢板和铺装层间的最大剪切应力和铺装层的最大挠度.本文建立正交异性钢桥面铺装体系分析模型,用有限元方法进行了铺装体系的受力分析,研究在高、低温季节沥青混凝土模量变化的情况下,不同铺装层厚度对三大控制指标的影响.研究结果对钢桥面铺装层厚度的确定提供了理论依据.

关键词　铺装层; 正交异性钢桥面板; 应力; 应变; 表面弯沉; 有限元

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