Numerical simulation of double deck pavement for long-span cable-stayed bridge

Kun Guo1*, Junwei Liang3, Xin Han2, Guangning Pu2

1 Highway and municipal facilities industrial construction technology of National and Local joint Engineering Research Center, Xining, Qinghai, 810000, China
2 Zhengping Road & Bridge Construction Co .,Ltd., Xining, Qinghai, 810000, China
3 Qinghai highway and municipal steel structure engineering research center, Xining, Qinghai, 810000, China

*Corresponding author’s e-mail: gk_changan@163.com

Abstract. The double-deck pavement of the long-span cable-stayed bridge was set as the research object, by setting the load position, load condition and reference point on the bridge deck, the parametric analysis of the elastic modulus, thickness and temperature of the pavement material was performed. Then Pavement structure parameters suitable for the bridge were get. The finite element software was used to simulate the pavement effect of the No. 1 bridge of Haidong Avenue under the actual load, which provided reasonable optimization measures for the construction method of large-span steel bridge deck pavement in high and cold areas.

1. Introduction
Steel bridges have the advantages of light weight and large span, and have become the first choice for modern bridges (Lu Z et al., 2000; Wang X et al., 2001; Qian Z et al., 2002). Orthotropic steel bridge decks are usually used for large-span steel bridges (Hu G et al., 2001). The deck pavement is an important part of steel deck. The pavement layer is located on the orthotropic bridge deck, which has higher requirements on construction technology, mechanical performance and durability. In recent decades, domestic and foreign scholars have conducted research on how to effectively combine flexible bridge deck pavement with rigid steel bridge deck, but good solutions have not been improved to solve the problem of steel bridge deck pavement (Huang W., 2008). In recent years, bridge deck pavement mainly apply type of cast-in-situ asphalt concrete + modified SMA or double-layer epoxy asphalt concrete and double-layer SMA (Gu X., 2002). It can be seen that the stress layer is divided into "upper layer + lower layer"(Huang P. et al., 1994). In this paper, Haidong Venue No. 1 Bridge was taken in analysis, which is a steel box girder cable-stayed bridge, with double pavement for the deck pavement. And a simplified finite element model is used to analyze the above-mentioned pavement stress to obtain reasonable pavement parameters. The overall structure of the bridge is shown in Figure 1.
2. Basic assumptions
The local box girder cross-section was taken as the research object, including steel box girder stiffeners, pavement, steel plates, partitions, to analyze the mechanical mechanism of steel box girder deck pavement, and assumptions as following (Hu G. et al., 2002; Li C. et al., 2000):

- Pavement materials and steel decks are continuous and uniform isotropic elastomers (Tong L. et al., 1997).
- The interface between the pavement layer and the upper layer and the pavement layer and the steel panel are completely in contact.
- Ignoring the influence of the self-weight of the pavement.
- No horizontal displacement of the pavement, steel plates and longitudinal stiffeners, and the bottom is fully constrained.

3. Structural modeling

3.1. Basic data
Taking asphalt concrete pavement and orthotropic steel deck as the calculation model, it's assumed that asphalt concrete and steel bridge deck are uniform and continuous isotropic materials, and the orthotropic steel bridge deck system model is used for analysis. The model takes three partition lengths in the longitudinal direction and eight u-rib widths in the lateral direction, and applies the rear wheel shaft of the 14t load vehicle to the model area. The parameters are shown in Table 1. The modulus of elasticity's shown in Table 2, thickness's shown in Table 3, temperature's shown in Table 4.

| Table 1. Model dimensions |
|---------------------------|
| Roof thickness /mm | Diaphragm thickness /mm | U rib thickness /mm | U rib spacing /mm |
| 16 | 14 | 6 | 600 |

| Diaphragm spacing /mm | Elastic modulus /Mpa | Poisson's ratio |
|------------------------|----------------------|-----------------|
| 3 300 | 2.1×10^3 | 0.3 |
### Table 2. Elastic modulus changing condition

| Serial number | Modulus of elasticity of lower layer /Mpa | Elastic modulus of upper layer /Mpa |
|---------------|------------------------------------------|-----------------------------------|
| 1             | 1000                                     | 1200                              |
| 2             | 1000                                     | 1600                              |
| 3             | 1000                                     | 1800                              |
| 4             | 1200                                     | 1200                              |
| 5             | 1600                                     | 1600                              |
| 6             | 1800                                     | 1800                              |

### Table 3. Thickness variation condition

| Serial number | Thickness of lower layer /cm | Thickness of upper layer/cm |
|---------------|------------------------------|-----------------------------|
| 6             | 3                            | 4                           |
| 7             | 3.5                          | 3.5                         |
| 8             | 4                            | 3                           |

### Table 4. Temperature change condition

| Serial number | Temperature variation                        |
|---------------|---------------------------------------------|
| 9             | The lower layer is 10°C lower than the upper layer |
| 10            | The lower layer is 20°C lower than the upper layer |
| 11            | The lower layer is 30°C lower than the upper layer |

3.2. Model establishment

In the model, the steel structure is simulated by shell 63 elements, the pavement is simulated by solid 65 solid elements, and the surface load is equivalent to the vehicle load. The geometric model is shown in Figure 2 below.

![Figure 2. Geometric model of finite element](image)

4. Result analysis

The horizontal stress, longitudinal stress and deflection cloud of the upper pavement are shown in Figure 3-5. Under working condition 6, the horizontal stress, longitudinal stress and deflection clouds of the lower layer are shown in Figure 6-8.
According to the calculation results of each working condition, the stress singular points in the load concentration area are taken out, and the sorting results are shown in Table 5.
Table 5. Calculation results

| Serial number | Maximum transverse stress /Mpa | Maximum longitudinal stress /Mpa | Deflection /mm |
|---------------|-------------------------------|-------------------------------|----------------|
|               | Upper layer                   | Lower layer                   | Upper layer    | Lower layer    |
| 1             | 0.255                         | 0.034                         | 0.075          | 0.078          | 0.988          | 0.976          |
| 2             | 0.291                         | 0.067                         | 0.096          | 0.031          | 0.946          | 0.939          |
| 3             | 0.305                         | 0.062                         | 0.105          | 0.030          | 0.930          | 0.924          |
| 4             | 0.255                         | 0.095                         | 0.076          | 0.041          | 0.976          | 0.965          |
| 5             | 0.291                         | 0.113                         | 0.097          | 0.053          | 0.918          | 0.911          |
| 6             | 0.305                         | 0.120                         | 0.107          | 0.058          | 0.895          | 0.889          |
| 7             | 0.304                         | 0.160                         | 0.107          | 0.068          | 0.896          | 0.891          |
| 8             | 0.305                         | 0.140                         | 0.107          | 0.063          | 0.895          | 0.890          |
| 9             | 0.098                         | 0.012                         | 0.056          | 0.049          | 0.997          | 0.989          |
| 10            | 0.034                         | 0.123                         | 0.112          | 0.098          | 0.993          | 0.991          |
| 11            | 0.083                         | 0.018                         | 0.017          | 0.015          | 0.993          | 0.993          |

Through the analysis, it can be concluded that:

- It can be seen from the working conditions 1, 2 and 3 that when the elastic modulus of the lower layer remains unchanged while the upper layer gradually increases, the change range of the transverse shear stress of the upper layer is (4.8%, 14.1%) The change interval is (9.4%, 28%). The change interval of the transverse shear stress of the lower layer is (-7.5%, 97%), and the change interval of the longitudinal shear stress is (3.3%, 60.3%). By analysis, the stiffness of the upper pavement and the steel bridge deck are both larger than the lower pavement. The lower pavement is the "weak layer" of the "force transfer layer", which conduct an effect of sudden change in the stress mode between the two large stiffness structures.

- It can be seen from the working conditions 4, 5 and 6 that with the gradual increase of the asphalt modulus, the Horizontal maximum stress of the upper pavement increases by 14.1% and 4.8%, and the longitudinal maximum stress increases by 27.6% and 10.3%, The decrease in deflection value was 6.3% and 2.5%, while the increase in elastic modulus was 33.3% and 12.5%, respectively. It also can be seen that the influence of asphalt modulus on the pavement stress is very obvious, which is reflected in the pavement deflection, the reduction of lateral and longitudinal tensile strain, etc.

- Under conditions 6, 8, and 7, the thickness of the upper layer gradually changed from 3 mm to 4 mm, while the stress and deformation of the upper layer change nothing. While the thickness of the lower layer gradually changed from 4mm to 3mm, the horizontal increment ranges are 16.7% and 14.3%, and the longitudinal increment ranges are 8.6% and 7.9%.

- The effect of temperature on deformation is linear, well the longitudinal and horizontal stresses of the pavement are non-linear, which is essentially different from the elastic modulus and thickness factor. The stress changes in working conditions 9, 10, and 11 indicate that each pavement layer exhibits a reverse deformation curve, which is similar to some uneven curves appearing in the first working state.

- The stress area of the pavement structure caused by temperature changes has also undergone a fundamental change. No matter the vertical or horizontal direction, as the temperature difference gradually increases, the equivalent stress area will continue to increase, and
gradually expand from the load point to the entire sidewalk panel, the maximum effect area gradually moves to the diaphragm and the sidewalk edge.

5. Conclusion

- The greater the modulus of the pavement layer, the greater the shear stress between the pavement layer and the steel plate. The growth rate of horizontal stress is greater than that of longitudinal stress. In most cases, the horizontal shear stress is 2 or 3 times the longitudinal shear stress. If the bond strength cannot meet the requirements of shear stress, the bond between the pavement layer and the steel plate will no longer be completely continuous, and the pavement layer will delaminate. Therefore, the modulus of the pavement layer is not as large as possible.
- The stress of the upper pavement is less affected by the thickness, which does not mean that the thickness of the upper is not important; the stress of the lower pavement is greatly affected by the thickness, and it does not mean that the thickness can be very large. The increase in the thickness of the pavement will increase the difficulty of the contact between the pavement and the steel plate, and it is difficult to ensure the construction quality.
- When the bridge deck is double structure, it is recommended that the upper pavement thickness between 30-35mm and the lower pavement thickness between 40-45mm. The total thickness of the pavement should be 70-80mm. It is recommended that the bridge deck pavement elasticity modulus is 1200-1800 MPa, and the elasticity modulus of lower pavement is 1600-2000 MPa.

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