ISSN: 2414-1895 DOI: 10.6919/ICJE.202105_7(5).0053

Force Analysis of Orthotropic Steel Bridge Deck Pavement under Two-Wheel Loads

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Abstract

In view of the current related research, which is mostly carried out in the simplified mode of single-wheel substitution, the two-wheel wheel load research is relatively substituted; in order to explore the mechanical properties of the multiple heterogeneous steel plate paving layer under the two-wheel substitution and the influence of related parameters, a finite element model based on ANSYS is established , Carried out the static load and dynamic load numerical simulation analysis, and analyzed the impact of vehicle changes.

Keywords

Orthotropic Steel Plate; Pavement Layer; Two-wheel Load; Vertical Displacement; Stress.

1. Introduction

Steel bridge orthotropic slabs are mostly composed of longitudinally continuous U-shaped stiffeners and vertical diaphragms or beams, panels and the uppermost pavement layer, which benefit from its small weight, large bearing capacity, and high construction efficiency. Outstanding superiority, this structural form has been rapidly developed in the construction and long-span bridges [1-3]. However, the orthotropic steel plate has serious problems such as its complex structure and local stress concentration. Under the repeated rolling action of the wheel load, fatigue cracking, pavement damage and other diseases sometimes occur. As the pavement layer is an object that directly bears the vehicle load, its mechanical properties are very important compared to the entire structural system.

2. Calculation model

In this paper, the analysis of orthotropic steel bridge deck mainly uses solid elements and plate and shell elements for geometric modeling and finite element analysis. For the steel bridge deck, diaphragm and longitudinal stiffener, Shell63 unit is used to simulate; for the pavement layer, Solid45 unit is used for simulation. The bridge deck takes seven U-shaped stiffeners along the transverse direction of the bridge, and three spans along the longitudinal direction of the bridge, including four transverse partitions [4-7]. The relevant parameters of the model are shown in Table 1, and the local finite element model is shown in Fig. 1.

Table 1. The size of each component of the model

Project	Geometric size
Bridge deck thickness /mm	14
Thickness of paving layer/mm	50
Diaphragm height/mm	8×10^2
Diaphragm thickness/mm	12
Diaphragm spacing/mm	3×10^3
U-shaped stiffener height/mm	2.7×10^2
U-shaped stiffener thickness/mm	8
U-shaped stiffener spacing/mm	5.8×10^2
U-shaped stiffener opening width/mm	3×10^2
U-shaped stiffener closed width/mm	1.6×10^2

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Table 2. Material parameters of each component of the analysis model

Project	Parameter
Poisson's ratio of steel plate/MPa	0.3
Steel plate elastic modulus/MPa	2.0×10^5
Density of steel plate/kg/m^2	8.7×10^3
Elastic modulus of pavement/MPa	6.7×10^2
Poisson's ratio of pavement	0.25
Density of pavement/kg/m^2	2.5×10^3

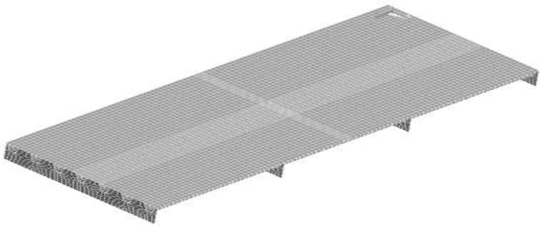

Fig. 1 ANSYS local finite element model

3. Vehicle loads

3.1 Simplification of vehicle load

Refer to the relevant regulations of «Highway Engineering Technical Standard» (JTG B01-2003), this paper selects a standard car with a rear axle load of 140kN and a single axle with 4 wheels, and the single tire pressure is 0.72MPa[8-9]. Considering that the actual contact surface of the wheel is approximately a rectangle, this paper will simulate the load of two wheels with two rectangular uniform loads, and the transverse dimension of the rectangle will be taken as 20cm with reference to the relevant literature. It is further calculated that the longitudinal dimension of the rectangle is about 25cm, the distance between the rectangles is 10cm, and the wheel load is shown in Fig. 2.

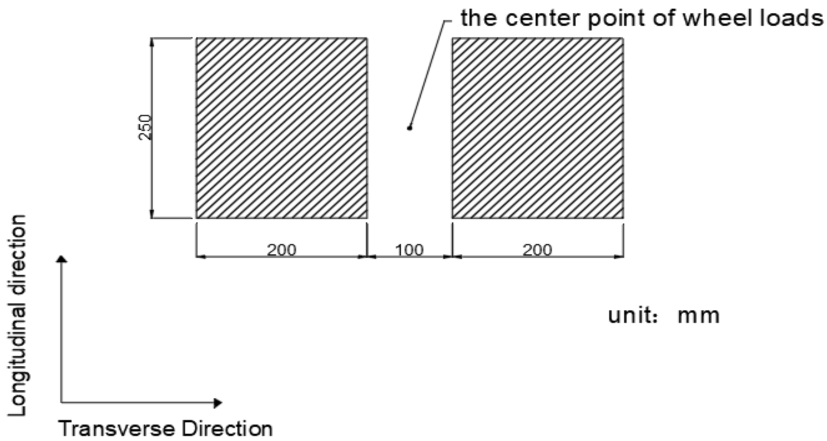

Fig. 2 Simplified wheel loads

3.2 Loading method of vehicle load

In view of the actual situation of the vehicle driving, the triangular loading mode can be used [10]. Among them, the longitudinal bridge has an interval of 46cm between adjacent double wheel load center points as a load step. Then, according to the specific value of the specific vehicle speed and bridge length, the specific value of the time interval t1 corresponding to each load step can be calculated.

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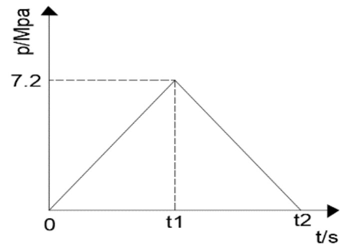

Fig. 3 The loading mode of wheel loads

4. Static analysis

Taking into account the structural characteristics of the orthotropic steel bridge deck, the wheel load is applied to the middle of the longitudinal transverse ribs of the bridge as the most unfavorable load position of the longitudinal load [11]; due to the symmetry, the three U-shaped ribs in the middle of the transverse direction can be taken into consideration. Three different loading conditions, as the loading position in the transverse direction, are loaded separately to obtain the most unfavorable load position in the transverse direction, as shown in the figure below.

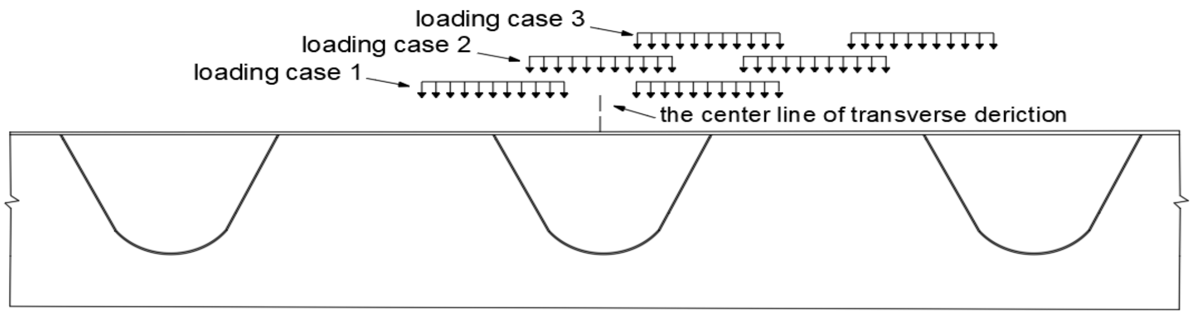

Fig. 4 Lateral loading location

The stress analysis results under the three loading positions are shown in Table 3; the deflection analysis results are shown in Table 4; the shear stress analysis results between the steel plate and the pavement layer are shown in Table 5.

Table 3. Maximum tensile stress and principal stress of pavement under different loading cases

Loading case	Maximum principal stress /MPa	Maximum transverse tensile stress /MPa	Maximum longitudinal tensile stress /MPa
1	0.320	0.310	0.074
2	0.477	0.446	0.112
3	0.117	0.107	0.060

Table 4. Maximum vertical displacement of pavement under different lateral loading cases

Loading case	Maximum vertical displacement /mm
1	1.060
2	1.130
3	0.836

Table 5. Maximum share stress of pavement under different lateral loading cases

Loading case	Maximum transverse shear stress /MPa	Maximum longitudinal shear stress /MPa
1	0.150	0.136
2	0.446	0.275
3	0.149	0.097

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The following conclusions are drawn from the static analysis results:

Under the direct action of the two-wheel load of the vehicle, the force of the steel bridge deck pavement exhibits strong local force characteristics. The vertical displacement is larger at loading positions 1 and 2 and maximum at load position 2. value.

From the stress results, the maximum principal stress is the largest, the transverse maximum tensile stress is second, and the longitudinal maximum tensile stress is the smallest. Based on the existing related research, the damage of the pavement layer is mainly concentrated in the longitudinal bridge cracks. At the same time, considering that the direction of the maximum principal stress is not easy to determine, the maximum transverse tensile stress can be used as the control normal stress in the transverse direction.

At the same transverse loading position, the maximum transverse shear stress between the pavement layer and the steel bridge deck is much greater than the maximum longitudinal shear stress, so the maximum transverse shear stress can be used as the control shear stress in the transverse direction.

The analysis shows that when the two-wheel load acts on the lateral loading position 2, the force of the orthotropic steel bridge deck pavement is the most unfavorable.

5. Dynamic analysis

In view of the fact that there have been many studies on the sensitivity of bicycle moving loads and related parameters, combined with the development of today’s society towards high-speed and heavy-duty, and most of the current single-wheel load simplification models, this paper adopts two-wheel load Carry out simulations to supplement related research.

According to the previous static analysis results, the dynamic analysis takes load position 2 as the most unfavorable load position, and then carries out the longitudinal bridge movement loading, and selects the maximum vertical displacement of the pavement layer, the maximum transverse tensile stress, and the maximum transverse shear stress as this paper. Related research analysis parameters. The two-wheel load moves longitudinally along the most unfavorable load position. In order to explore the influence of the speed change on the mechanical performance of the pavement, according to the principle of single variable, the vehicle load (simulated by tire pressure) is set to 0.72MPa, and the speed is set to 40km. /h, 60km/h, 80km/h, 100km/h. Use ANSYS transient dynamics analysis function for dynamic analysis, the analysis results are summarized as follows.

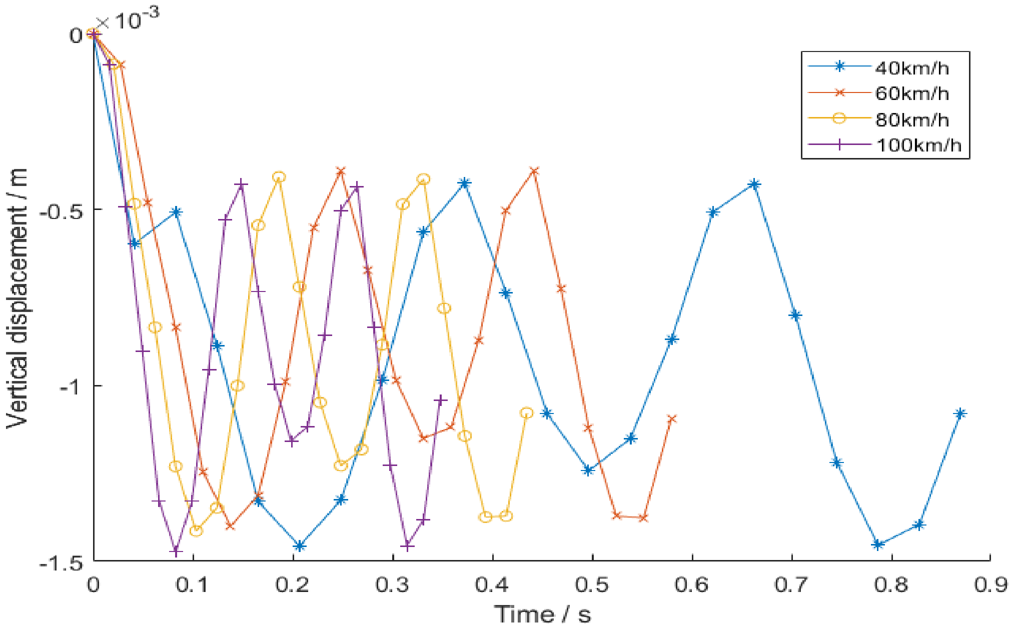

Fig. 5 Time history curve of vertical displacement of pavement under different speeds

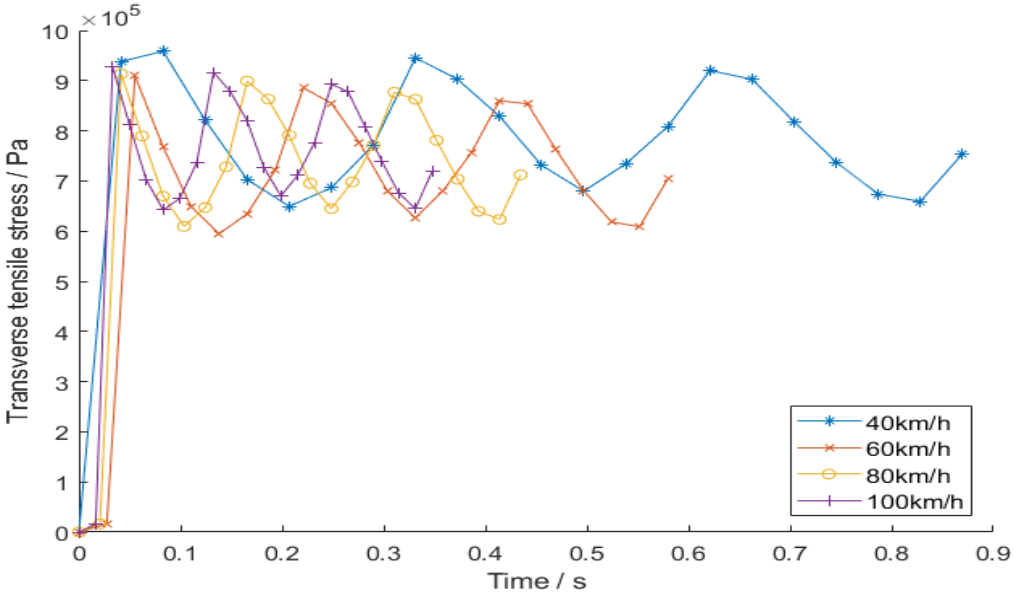

Fig. 6 Time history curve of transverse tensile stress of pavement under different speeds

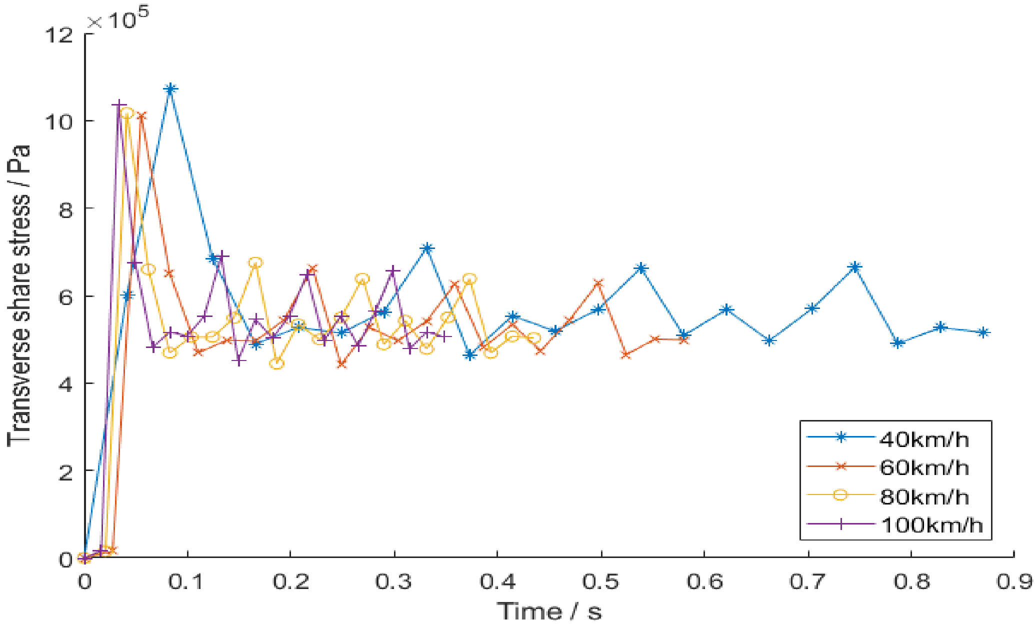

Fig. 7 Time history curve of transverse share stress of pavement under different speeds

6. Conclusion

Through the static and dynamic analysis of the orthotropic steel bridge deck pavement under two-wheel load, the following conclusions are drawn:

Under the direct action of the two-wheel load of the vehicle, the vertical displacement of the pavement layer shows a wave-like change trend as a whole, and the position of the maximum value moves forward with the increase of the vehicle speed, and the maximum value increases slightly with the increase of the speed.

The transverse tensile stress shows a fluctuating trend as a whole, and the position where the maximum occurs moves forward with the increase of vehicle speed, and the maximum value remains basically unchanged with the increase of speed.

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The transverse shear stress fluctuates greatly in the early stage, and gradually stabilizes in the later stage, and the position of the maximum value moves forward with the increase of vehicle speed, and the maximum value remains basically stable.

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