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# Mechanical influence of pavement thickness on concrete bridge located in mining area

*The mechanical properties of concrete bridge located in mining area are influenced by the mining area environment and thickness of pavement. The unreasonable design of pavement layer will easily lead to the concrete bridge deck cracking. Based on FEM (finite element method), Jiaozuo Bridge is taken as an example to study on mechanical influence of pavement on concrete bridge deck with different thicknesses. A three-dimensional finite element model is built to simulate the bridges with three kinds of thickness of concrete deck pavement respectively. The results show that the maximum longitudinal and lateral tensile stresses in girder increase with the thickness of deck pavement which will cause the girder cracking while the maximum lateral tensile stress in concrete deck pavement decreases. When the thickness of waterproofing layer of deck pavement is 11cm, the stresses in deck pavement are all the least ones among the three cases respectively. The possibility of being crack in deck pavement is the lowest. And the design scheme which the thickness of waterproof concrete pavement is 11cm will be the best.*

***Key words:*** *Concrete bridge, mining area, pavement thickness, finite element method.*

## 1. Introduction

Cracks of prestressed concrete bridge generally take place in deck pavement firstly, if strengthening method has not been made in time, damage would further expand to cause the destruction of the main girder. In traditional bridge design, the deck pavements are not considered to participate in the load. And the thickness of deck pavement is chosen only by experience. When the deck pavement is destroyed, it is rebuilt by thickening. In that the influence of thickness of deck pavement on the bridge has not been considered. However, the pavements participate in some or all deformation and loading with the main girder in engineering.

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In recent years some scholars have paid attention to the mechanical characteristics of bridge deck pavement [1]. Based on their experiences and damage investigation they use steel fiber reinforced concrete or other new high strength materials to strengthen pavement [2,3], but few researches were conducted on the mechanical characteristics of bridge affected by the thickness of pavement. In fact, it is of great importance to study influences on the bridge caused by thickness variation of pavement for prevention and treatment of disease in pavement [4-6]. Since this type of bridge exists abundantly in our country, the research has great reference significance to strengthen the similar bridges [7,8].

The paper creates a three-dimensional finite element model to simulate Jiaozuo Bridge by ANSYS software. Based on the analysis of effects of pavement thickness on bridge some suggestions are given for designing of this type of bridge.

## 2. General situation of bridge

Jiaozuo Bridge is the pretensioned partial-prestressed concrete structure of low-altitude box girder bridge which is located in the mining area of Jiaozuo City. Each span is composed of eight box girders. The girder is 2.1m of width, 0.75m of high and 16.0m of span. The thickness of deck pavement is 8cm with C30 grade of concrete strength. The bridge was designed in January 1999 according to the old technical norm - "General code for design of highway bridges and culverts (JTJ 02l-89 1989)[9,10]. Now, with the development of economy, the road vehicle flow rises sharply and bridge overload is serious, which result in the local disease in deck pavement (Fig.1).

Up to now the pavements have been repaired many times (Fig.2). But if only according to the newly norm (JTG D60-2004 2004), the influence of thickness variation of pavement on the bridge could not be computed.

## 3. Three-dimensional finite element model

The finite element model has two kinds of elements to simulate the original structure: Solid 45 simulating girder, asphalt concrete paving, waterproofing concrete pavement and other solid members, link 8 simulating prestressed reinforcing bars. The model has a total of 72292 nodes, 57824 elements with 5 kinds of materials. The three-dimensional finite element

Fig.1 Disease in deck pavement

Fig.2 Repaired deck pavement

models of a single girder and one span of the bridge are shown in Fig.3 and Fig.4 respectively.

In the computation three kinds of schemes with different thickness of pavement have been studied. The schemes are:

(a) Scheme 1. The thickness of waterproof concrete pavement is 8 cm.

(b) Scheme 2. The thickness is 11 cm.

(c) Scheme 3. The thickness is 14 cm.

In all schemes the thickness of asphalt pavement is 3cm. The vehicles loads are arranged to cause the stresses of pavement in most unfortunate state.

## 4. Analysis of stresses in main girder

### 4.1.The extreme value of longitudinal tensile stress in main girder

Affected to prestress, the main girders are generally compressed in longitudinal direction in all cases, and only

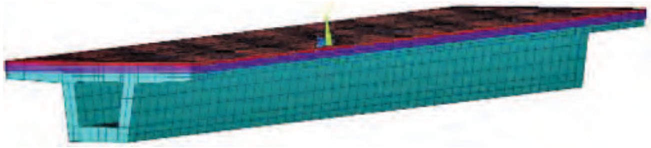

Fig.3 The 3D FEM model of a single girder

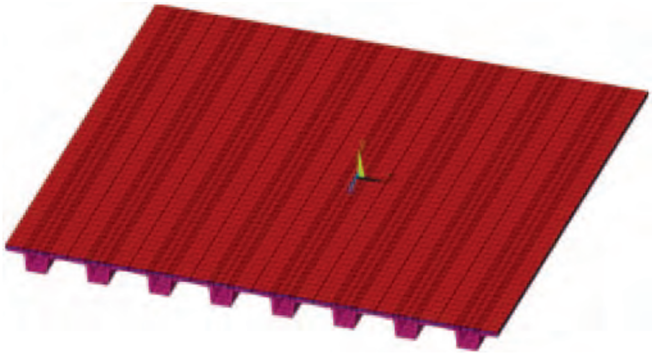

Fig.4 The 3D FEM model of one span of bridge

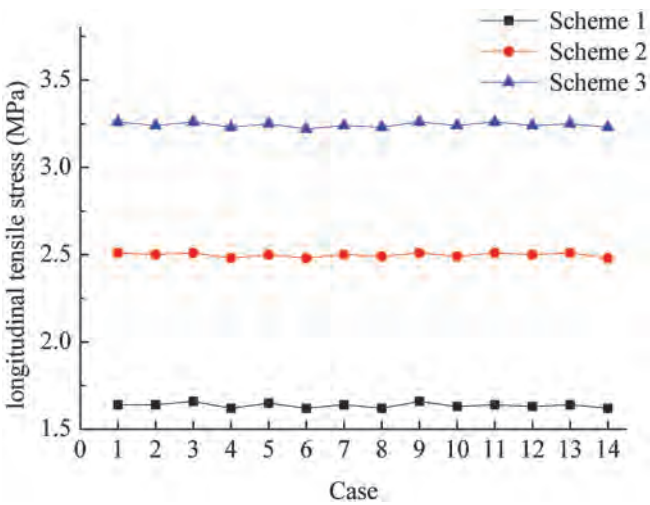


Fig.5 The longitudinal tensile stress in girder

locally tensioned in roof. The extreme values of longitudinal tensile stress in main girder are close in all cases of the same scheme. As shown in Fig.5, the maximum value is 1.66MPa in scheme 1, 2.51 MPa in scheme 2, and 3.26 MPa in scheme 3 respectively.

It can be seen that the extreme value of longitudinal tensile stress in main girder increases with the increase of thickness of deck pavement. The main reason is because the weight of superstructure rises with the increase of thickness of deck pavement which leads the longitudinal tensile stress to add. In all cases the extreme longitudinal tensile stress in main girder mostly locates at the top layer of the flange of box girder at the end-span of the bridge which is closely related to the damage of anchorage zone of expansion joint and the lamination between main girder and deck pavement. So, it is important to take some specific measures in design.

4.2.The extreme value of lateral tensile stress in main girder

As shown in Fig.6, the change tendency of lateral tensile stress in girder is different in various schemes. The extreme values are 1.26MPa in scheme 1, 1.47MPa in scheme 2, and 1.70MPa in scheme 3 respectively. In all cases the extreme stresses are at the bottom of the flange of the box girder where it is under the place of vehicle load. It can be seen that with the increase of thickness of deck pavement the lateral tensile stress in girder increases which is disadvantageous to the crack resistance properties of the bridge and may cause the longitudinal crack comes into being.

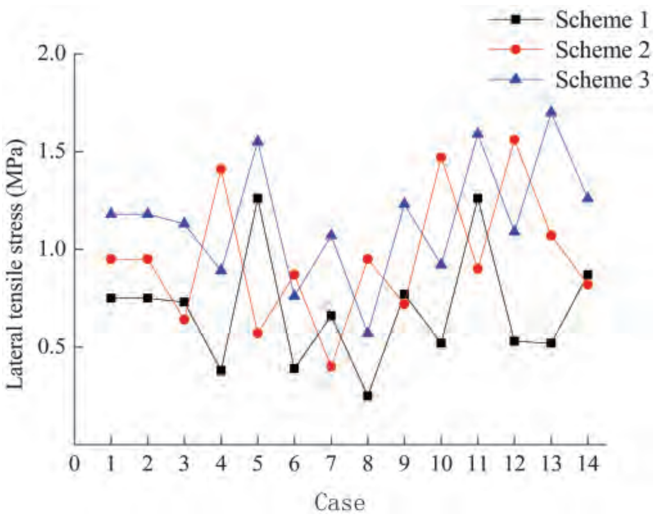


Fig.6 The lateral tensile stress in main girder

4.3.The extreme value of the 1st principal stress in main girder

Fig.7 shows the 1st principal stress in main girder changes obviously. The maximum 1st principal stress gets to 3.26 MPa, 2.36 MPa, 2.35 MPa in scheme 1, scheme 2, and scheme 3 respectively. All the extreme stresses locate at the top layer of flange of the girder in middle span. When the thickness of waterproof concrete deck pavement is 8cm, the 1st principal stress in main girder is the biggest and when the thickness was 11cm, the 1st principal stress was the least. It can be seen that decreased the thickness of pavement is unfavourable to the crack resistance properties of inclined section of girder.

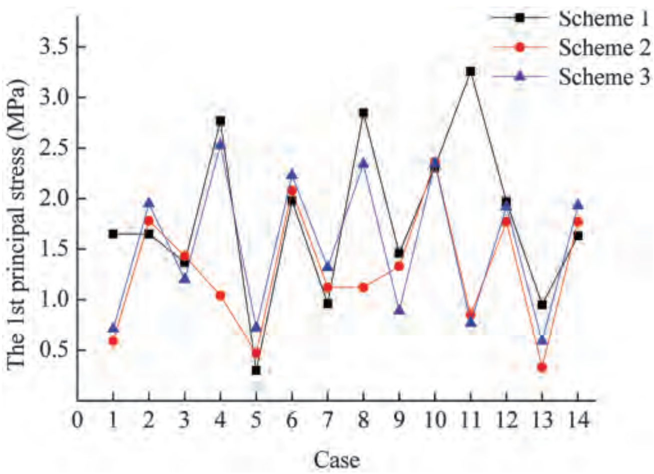


Fig.7 The 1st principal stress in girder

## 5. Analysis of stresses in concrete deck pavement

5.1.The extreme value of the 1st principal stress in deck pavement

The extreme values of the 1st principal stress in deck pavement are shown in Fig.8. It can be seen when the thickness of waterproof concrete deck pavement was 11cm the 1st principal stress in deck pavement was the least. In all cases the extreme 1st principal stresses are in the bottom layer of deck pavement at the middle span. When the thickness of waterproof concrete deck pavement is bigger than 11cm, with the increase of thickness the rigidity of deck pavement increase which lead to enlarge its load sharing and raise the 1st principal stress in waterproof concrete deck pavement. This is unfortunate to the crack resistance properties of deck pavement.

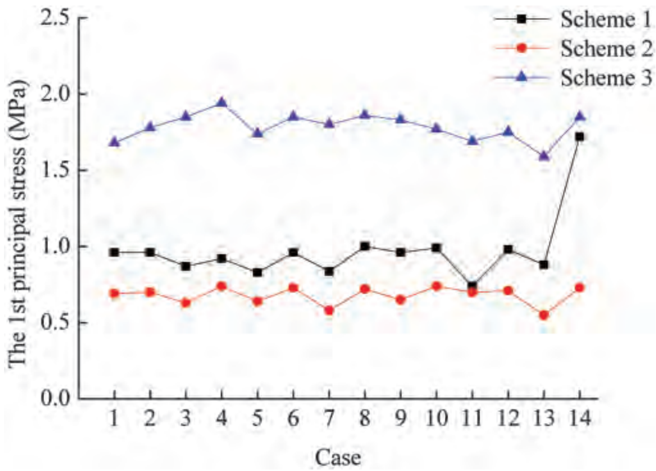


Fig.8 The 1st principal stress in deck pavement

5.2.The extreme value of longitudinal stress in deck pavement

The extreme values of longitudinal tensile and compressive stresses in concrete deck pavement are shown in Figs.9 and 10 respectively. Fig.9 shows the longitudinal tensile stresses are small in all schemes. In scheme 1 the maximum value of tensile stress is 0.84MPa in case 9 while in scheme 2 it is 0.7MPa in case 10, in scheme 3 it is 0.92MPa in case 7. All the extreme longitudinal tensile stresses are at the bottom layer of joint between two girders at the end-span.

It can be seen that with the increase of thickness of deck pavement, the extreme value of longitudinal tensile stress is quite complex and would increase or reduce. In the design, we should select the best thickness of deck pavement as far as possible to reduce the longitudinal tensile stress. Overall,

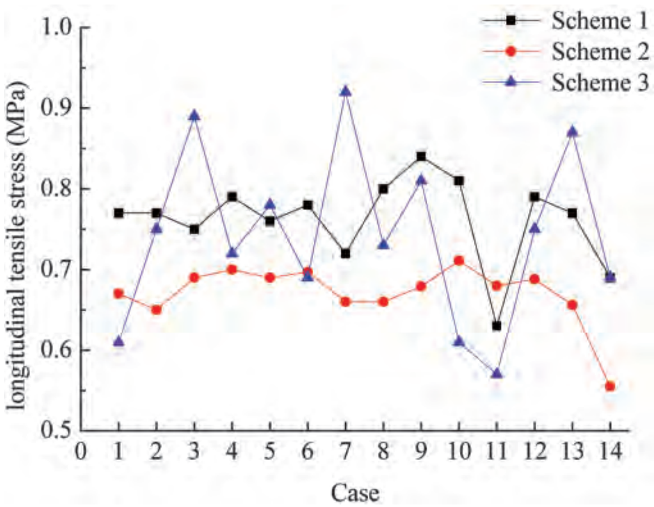


Fig.9 The longitudinal tensile stress in deck pavement

when the waterproof concrete deck pavement is 11cm of thickness, in scheme 2 the extreme values of longitudinal tensile stress are smaller and distributed more regularly than any other schemes. So scheme 2 is the most reasonable one in 3 schemes.

As can be seen from Fig.10, the longitudinal compressive stress increases with the increase of thickness of deck pavement. In the same scheme, the extreme values of longitudinal compressive stress are very close. The maximum compressive stress in scheme 1 is 5.56MPa, in scheme 2 it is 5.97MPa in case 7, and in scheme 3 it is 6.07MPa in case 1. The maximum values of longitudinal compressive stress are all in the top layer of deck pavement at mid-span.

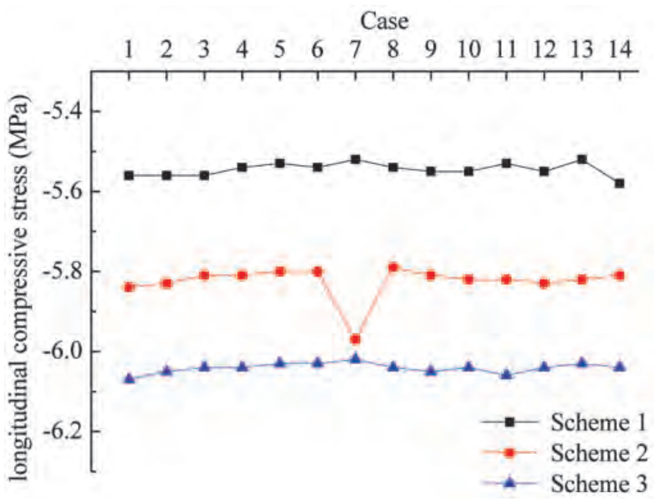


Fig.10 The longitudinal compressive stress in deck pavement

### 5.3.The extreme value of lateral stress in concrete deck pavement

In all cases the extreme values of lateral tensile and compressive stress in concrete deck pavement are shown in Figs.11 and 12 respectively. Fig.11 shows the extreme values

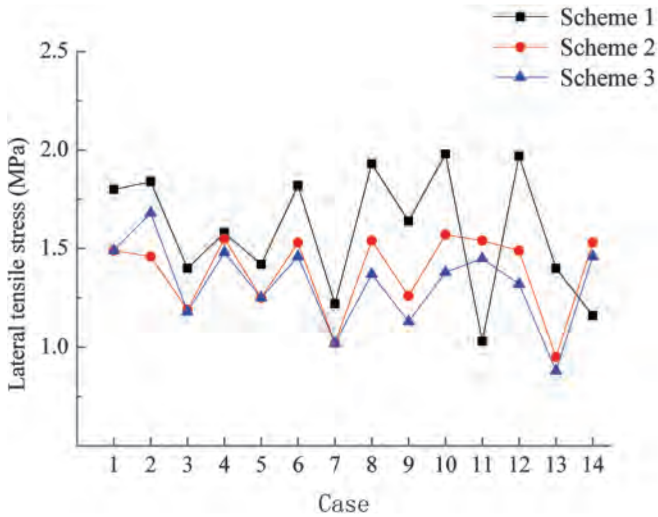


Fig.11 The lateral tensile stress in deck pavement

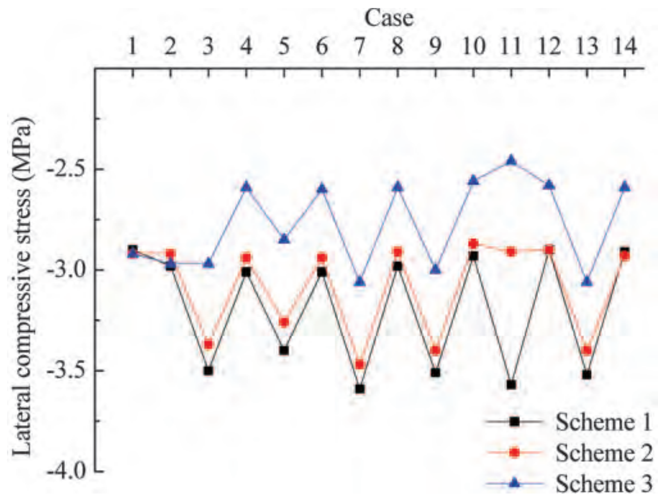


Fig.12 The lateral compressive stress in deck pavement

of lateral tensile stress changes obviously in the three schemes. In scheme 3 the lateral tensile stresses are generally smaller than the other schemes, while the stresses in scheme 1 are the biggest. In scheme 1 the maximum lateral tensile stress is 1.97MPa in case 12, in scheme 2 it is 1.57MPa in case 10, and in scheme 3 it is 1.68MPa in case 2. It could be seen that with the increase of thickness of deck pavement the lateral tensile stresses decrease. In each case, the maximum lateral tensile stress is in the joint of adjacent box girders at end-span of the bridge. These stresses are closely related to the longitudinal crack in deck pavement. When the pavement thickness is small enough, the deck pavement of bridge would be prone to longitudinal cracks. In addition, the extreme lateral tensile stresses are all at the bottom layer of deck pavement, so it is very important to enhance the connection between the deck pavement and the girder in design.

Fig.12 shows the extreme values of lateral compressive stresses in concrete deck pavement in scheme 1 are quite close to them in scheme 2. The maximum value of lateral compressive stresses is 3.06MPa in case 7 of scheme 3 while it was 3.59MPa in scheme 1. In each case, the extreme lateral compressive stresses are in the top layer of deck pavement at mid-span.

## 5. Conclusions

The three-dimensional numerical simulation method is used to research the effects of change thickness of deck pavement on the bridge. The conclusions are as follows:

1. With the increase of thickness of deck pavement, the extreme value of longitudinal tensile stress in girder increases. The stress is closely related to the damage of anchor belt of expansion joint and the lamination between girder and deck pavement. In the design, some specific measures may be taken. In addition, the lateral tensile stress in girder increases with the increase of thickness of deck pavement too, which is harmful to the crack resistance property of the bridge and may produce longitudinal crack. When the thickness of waterproofing layer of deck pavement is 11cm, the 1st principal stress in girder is the least among the three schemes.
2. When the thickness of waterproofing layer of deck pavement is 11cm, the 1st principal stress, lateral and longitudinal tensile stresses in deck pavement are all the least ones among the three schemes respectively. On the whole, scheme 2 is more reasonable than schemes 1 and 3. The possibility of being crack in deck pavement is low.

## Acknowledgements

This work was supported by Basic and Advanced Technology Research Project of Henan Province (No.152300410241), China, Science and Technology Project of Zhengzhou (No.131PPTGG410-13), Science and Technology Project of Education Department of Henan Province (No.13B130110?), and Key Scientific Research Projects in Colleges and Universities of Henan Province (No.17B130001).

## References

1. Wang, E. B. (2005): "Strength Characteristic Analysis of Box Girder Bridge Pavement." *Journal of Shandong University (Engineering Science)*, 38(2),71-76.
2. Liang, Z. H. (2014): "Three-dimensional Finite Element Analysis of the Layer Steel Fiber Reinforced Concrete Pavement:A New Type of Pavement Material." *Construction & Design for Engineering*, 7:113-116.
3. Achilleos, C., Hadjimitsis, D. and Neocleous, K. et al. (2011): "Proportioning of Steel Fibre Reinforced Concrete Mixes for Pavement Construction and Their Impact on Environment and Cos." *Sustainability*, 3(7):965-983.
4. Karvussi, A. and Babazadeh, A. (2008): "The influence of pavement layers behaviour on thickness design using Kenlayer program." *International Journal of Pavement Engineering & Asphalt Technology*, 9:35-48.
5. Collop, A. C. (2000): "The Effect of Asphalt Layer Thickness Variations on Pavement Evaluation Using the Falling Weight Deflectometer." *International Journal of Pavement Engineering*, 1(4):247-263.
6. Wei, H. Y., Zhou, W. F. and Sun, J. Y. (2014): "Analysis on Mechanical Response for Asphalt Pavement Based on Thickness Variation for Transition Layer of Graded Crushed Rock." *Applied Mechanics & Materials*, 505-506:244-250.
7. Yang, S., Hao, P. and Tang, L. et al. (2011): "The Force Impact Analysis of Steel Bridge Deck Pavement Layer Modulus and Pavement Thickness to Pavement System." *Highway Engineering*, 368-373:289-292.
8. Liu, L. P., Sun, L. J. (2003): "The Influence of Different Overlay Thickness Combination on the Optimum Thickness of Pavement Structure within Analysis Period." *Journal of Highway & Transportation Research & Development*, 58(3):410-426.
9. JTG D60-2004 (2004): "General code for design of expressway bridges and culverts." China Communications Press, Beijing.
10. JTJ 02l-89.(1989): "General code for design of highway bridges and culverts." China Communications Press, Beijing.