EFFECT OF GIRDER SHRINKAGE AND CREEP ON THE STRESSES IN DECK PAVEMENT OF LONG-SPAN BRIDGES

LIU XIAO-YAN, WANG GUANG-HUI, WEI CHENG-LONG and OUYANG XIANG-SEN

School of Bridge & Structure Engineering, Changsha University of Science & Technology, Changsha 410076, China

ABSTRACT

Damage to bridge deck pavement in China is regarded as a serious problem in highway engineering, which has many economical and social implications. The main objective of this paper is to present a calculation method and to analyse the stresses in pavement under long-term loads. Shrinkage and creep of concrete increase the vertical deflection of bridge girders. The deck pavement has the same displacement as the girder because they are bonded. Thus the shrinkage and creep of the girder concrete of a bridge will cause stresses in the deck pavement. This paper applies a finite element method to analyse the girder deflection by the shrinkage and creep of the concrete. It deduces a formula to analyse the stresses in the deck pavement and uses the Bu-Liu River bridge as a numerical example to investigate the loading characteristics of deck pavement. The computational results show that the tension stress and shear stress, which result from the shrinkage and creep of the girder concrete, should not be ignored.

1. INTRODUCTION

In China, damage to the deck pavement of long-span bridges has become an increasingly serious problem. Some kinds of damage, such as cracks, tracks and sloughs, occur after the bridge has been used for a few years. Even though the deck pavement may be well constructed, many cracks occur under the fatigue loads. Many government projects have been carried out to maintain the pavement, which have led to severe financial losses and a negative influence on society. In view of this, bridge deck pavement has become a key engineering technology issue in highway construction (Xu wei, 2003). The stresses in deck pavement differ greatly from those in road pavement. To a large extent, the pavement structure is restricted to the girder distortion. The traditional methods of design and construction cannot meet the requirements of the deck pavement of a long-span bridge. When a bridge is designed, the stress in its deck pavement should be analysed in detail. This paper presents a calculation method to analyse the stresses in the pavement. The bridge deck pavement is a structural layer which is laid on the girder. It has the important function of protecting the girder, but it is exposed to the weather and bears vehicle loads directly. The deflection of the girder has a strong impact on the bridge deck pavement. Therefore the stresses in the pavement are very complicated. The rolling, pushing and shear of vehicle wheels probably also have an influence. Temperature variations, rain water erosion and frost have an influence on the stress in the pavement or cause damage. The loading, shrinkage and creep of the main beam concrete cause curving, squeezing, extending and shearing between the layers of the bridge deck pavement. This paper aims to analyse the stress of bridge deck pavement under long-term vehicle load, especially the effect of concrete creep on the stresses. The stress characteristics of bridge deck pavement are presented through the example of the Bu-Liu River bridge in Guangxi province, China.

2. BRIEF DESCRIPTION OF THE BRIDGE AND ASSUMPTIONS FOR THE CALCULATION

2.1 Brief Description of the Bridge

The Bu-Liu River bridge is a continuous, rigid-frame bridge with high piers. Design loads are the Auto-20 and the Trailer-100 (Chinese standards). The span arrangement is 145 m + 235 m + 145 m. The total length is 537.08 m and the cross-section width is 8.3 m. The superstructure is a non-uniform box girder, with a cross-section of single box and single cellular girders. The height of the main beam changes from 12.86 m to 4.26 m. The height of the highest pier is 97 m.

2.2 Assumptions for the Calculation

According to the stress characteristics of the bridge deck pavement, several assumptions are made as follows (Luo li-feng, Zhong ming and Huang zhao-cheng, 2002). Firstly, the bridge deck pavement, without regard to the shrinkage and creep of the pavement itself, is tightly bonded to the main beam and deforms together with the main beam. Secondly, during operation, the main beam only undergoes vertical deflection because of the shrinkage and creep of the concrete. Finally, the stress along the thickness of the deck pavement is uniformly distributed because the bridge deck pavement is much thinner, in other words, the bridge deck pavement is in a membrane stress condition.

3. CALCULATION OF THE SHRINKAGE AND CREEP OF THE CONCRETE

3.1 Calculation of the Shrinkage and Creep of the Main Beam Concrete

In long-span concrete bridges, deformation of the structure due to creep is perhaps two to three times greater than that due to structural loads (Guo zhen-hai, 1999). Therefore large creep will cause redundant stress on the indeterminate structure on the one hand, and an increase in the deformation of the main beam on the other hand. The deformation and internal force will be produced in the deck pavement because it co-deforms with the main beam. The creep of the concrete is thought to be linear because the stress in it is generally no more than 40%～50% of the concrete's ultimate strength. Hence this paper uses linear creep theories for calculating the creep effect of the concrete. In order to easily develop a plane finite element program for the analysis of the creep effect, the creep coefficient is fit as an exponential function to establish the recursion equation. The initial strain method is used to calculate the amount of creep deformation of the main beam in each time interval (Li chuan-xi and Xia gui-yun, 2002). The creep coefficient can be obtained from equation (1).

$$\varphi(t,\tau) = \beta_a(\tau) + \sum_{i=1}^{6} C_i(\tau)[1 - e^{-q_i(t-\tau)}] \qquad (1)$$

where each parameter refers to the documentation (Li chuan-xi and Xia gui-yun, 2002).

3.2 Establishment of the Calculation Model

The bridge piers were constructed with the cast-in-site method, and the girder with the cantilever method, so the construction was more difficult. However, the construction period was quite short. Consequently, much shrinkage and creep of the girder concrete took place after the bridge had been completed, and this must be properly taken into account. The pavement, whose average thickness is 10 cm, was constructed with pitch-concrete. Firstly, according to the main beam segment construction method, the shrinkage and creep of the concrete were calculated from construction to final completion stages. Then in the operational stage, the finite element program was used to set up the calculation model as shown in Figure 1. There were 159 nodal points and 158 finite elements in total in the model. The main beam had 128 finite elements and 129 nodal points. The numbers of nodal points selected at two pier roofs were 36 and 94. The concrete strength grade for the main beam was C55 and C45 for the pier.

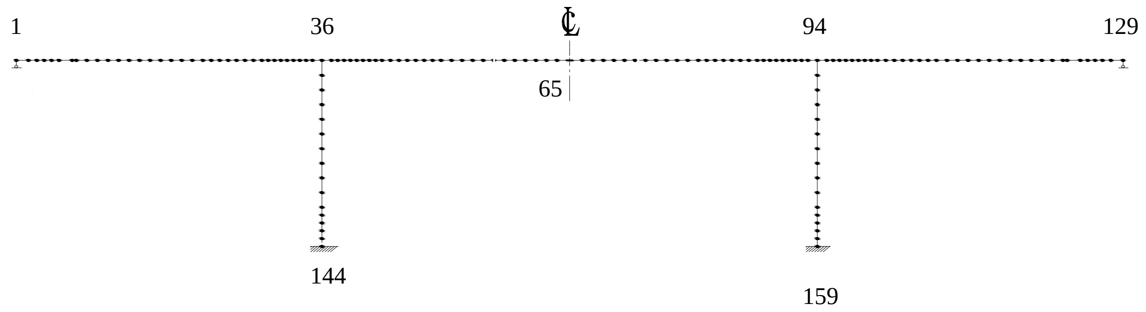

Figure 1. Calculation model of the Bu Liu He bridge.

3.3 Calculation Results of the Vertical Deflection

The deflection caused by the shrinkage and creep of the concrete is shown in Figure 2 after the bridge had been open for half a year, one year, 2 years, 3 years and 5 years. Figure 2 shows that the maximum additional deformation in the mid-span caused by the shrinkage and creep of the concrete is 0.245 m. The beam deflection is consistent with dead load deformation.

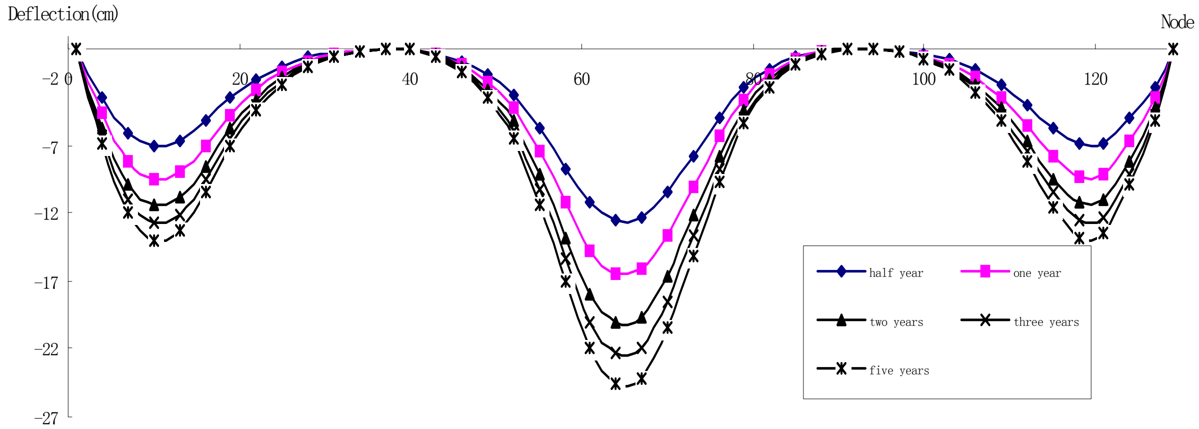

Figure 2. Deflection of the main beam.

3.4 Fitting of the Creep Deformation Curve

According to the deflection at every nodal point of the main beam and the distance from the pavement layer to the section neutral axis, the mathematics software Mathematica was used to fit the creep deformation curve. The fitting result shows the change law of the deflection curve y(x) and the distance function h(x) from the pavement layer to the section neutral axis. In order to fit precisely, different curves are adopted for the side-span and the mid-span deflections. The curves are adjusted again and again as high-order polynomials composed of circular functions.

4. STRESS ANALYSIS OF THE BRIDGE DECK PAVEMENT

4.1 Calculation of the Normal Stress of the Pavement

According to the deformation of the girder and the assumptions of the calculation, equations (2) and (3) are applied.

$$M = EIy''(x) \qquad (2)$$

$$\sigma = \frac{M}{I} h(x) \qquad (3)$$

Then equation (3) can be restated as equation (4).

$$\sigma = Ey''(x)h(x) \qquad (4)$$

where E is the elasticity modulus of the material of the bridge deck pavement, σ is the normal stress, y(x) is the deformation curve function due to the shrinkage and creep of the girder concrete and h(x) is the distance from the bridge deck pavement to the geometric centre of the section.

The normal stresses along the axial direction of the bridge pavement can be calculated by using equation (4) as shown in Figure 3. It shows that the normal stresses cause the compressive and tensile stresses to be different. The maximum tensile stress in the pavement occurs about 15 m away from the pier in the mid-span and its value reaches 1.35 Mpa. The maximum compressive stress appears in the mid-span, reaching 1.2 Mpa. It is obvious that the tensile stress in the pavement is greater than the compressive stress under long-term load.

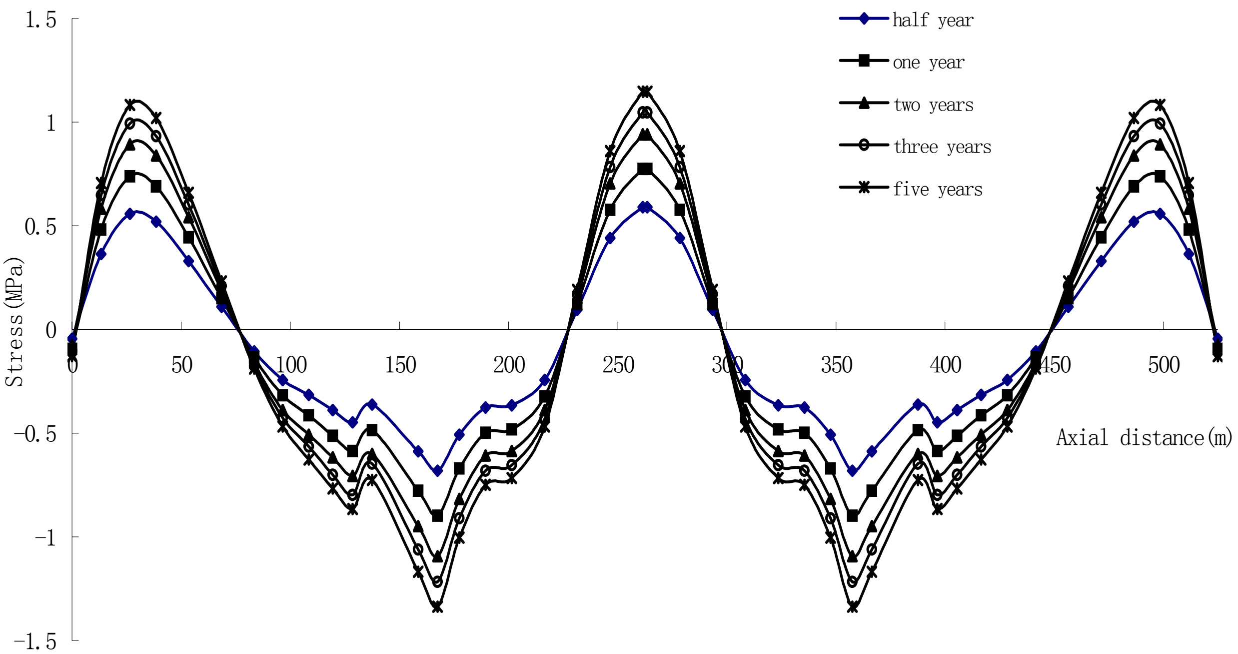

Figure 3. Stresses in the pavement along the axial direction of the bridge.

4.2 Analysis of the Inter-Layer Shearing Stress

When a vehicle travels on the bridge at normal speed, it will apply horizontal force, about 0.3 times as great as the vertical wheel pressure, on the surface of the pavement layer in order to overcome the various resistances. During emergency braking, abrupt acceleration, going uphill or downhill, the maximum horizontal force is perhaps 0.7 - 0.8 times as great as the vertical wheel pressure, reaching about 2.0 Mpa, which will undoubtedly cause inter-layer shear between the girder and the deck pavement. Inter-layer shearing stress caused by the effect of shrinkage and creep of the concrete cannot be ignored, so inter-layer shear stresses must be analysed properly. A micro segment of the pavement at the direction of the bridge span was removed to calculate the inter-layer shearing stress, as shown in Figure 4.

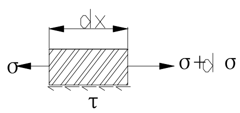

Figure 4. Micro segment of the deck pavement.

According to the balance condition, equation (5) is obtained.

$$\sigma \cdot B \cdot t + \tau \cdot dx \cdot B = (\sigma + d\sigma)B \cdot t \qquad (5)$$

Where τ is the inter-layer shearing stress, B is the width of the micro segment and t is its thickness.

Based on equation (5), τ can be expressed as equation (6).

$$\tau = \frac{d\sigma}{dx} t \qquad (6)$$

Combining equations (4) and (6), τ can then be stated as equation (7).

$$\tau = \frac{d\sigma}{dx} t = E y''' h(x) t + E y'' h'(x) t \qquad (7)$$

Using equation (7), the value of the inter-layer shearing stress along the length of the bridge can be obtained as shown in Figure 5.

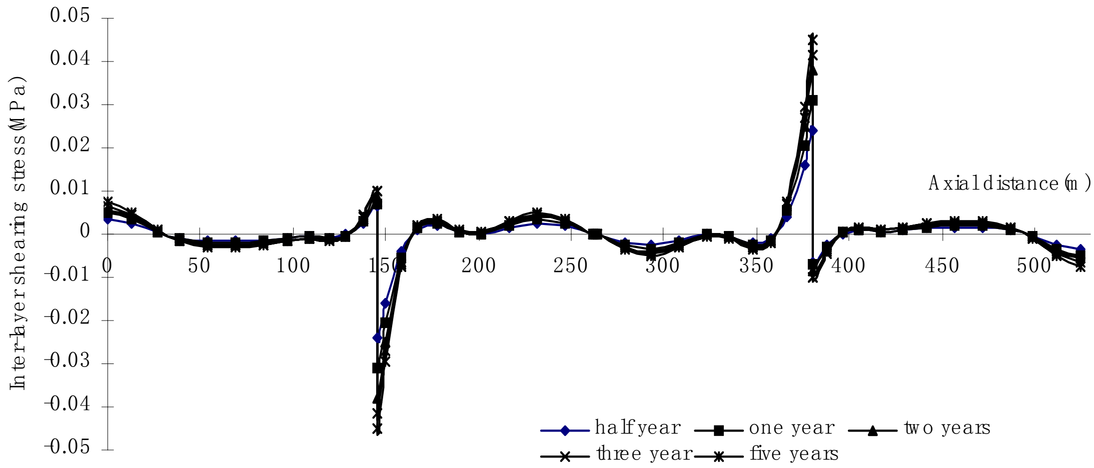

Figure 5. Distribution of the inter-layer shearing stress along the bridge axis.

Figure 5 shows that the maximum shearing stress of about 0.05 Mpa appears at the two piers. The shearing stress is caused by many factors, such as braking force, temperature, and shrinkage and creep of the concrete. This will perhaps make it ineffective for the bridge deck pavement to be bonded to the main beam, so more attention should be paid to the inter-layer shearing stress.

4.3 Stress Analysis in Pavements Made of Different Materials and Temperature Effects

If the pavement is made of different materials, its tensile strength and anti-shearing strength differ greatly and the elasticity modulus of the material also differs greatly. However, the elasticity modulus of the material has a great effect on the stress in the pavement. From equations (4) and (7) it can be deduced that the values of the tension stress in the pavement and the inter-layer shearing stress are directly proportional to the elasticity modulus of the material.

As to the pitch-concrete, its elasticity modulus and tensile strength differ greatly when the temperature changes. With a temperature increase, the elasticity modulus of the pitch-concrete becomes increasingly lower and its strength decreases. The pavement strength in low or high temperatures should receive more attention.

5. CONCLUSIONS

Several conclusions can be drawn from the stress analysis and calculation in this paper. Firstly, the shrinkage and creep of the concrete in the main beam have a great impact on the tension stress and shear stress in the bridge deck pavement. Therefore the interaction of shrinkage and creep should be considered to be as important as the material and structure. Secondly, the inter-layer shearing stress between the deck pavement and the girder of a bridge should be checked when the pavement is designed. Finally, because of the weakness of the pitch-concrete, its characteristics and strength need to be improved in order to meet the special requirements of deck pavement.

6. ACKNOWLEDGEMENT

This project was funded by the Natural Science Foundation of Hunan Province, China, under Grant 04JJ6027. The authors greatly appreciate this support.

7. REFERENCES

[1] ACI Committee 209, Prediction of Creep, 1971. Shrinkage and Temperature Effect in Concrete Structures. ACI SP-27.p.51~93.

[2] Bathe, K J, 1982. Finite Element Procedures in Engineering Analysis. Prentice Hall.

[3] Guo zhen-hai, 1999. Principle of steel concrete. TsingHua University Press, China.

[4] Li Chuan-xi and Xia Gui-yun, 2002. Computational theory of the long-span bridge structure. China Communications Press.

[5] Luo Li-feng, Zhong Ming and Huang Zhao-cheng, 2002. Research of the design method of cement concrete bridge deck pavement. Journal of South China University of Technology. 30(3), p.61-65.

[6] Meyers, B L and Thomas, E W, 1983. Elasticity, shrinkage, creep and thermal movement of concrete. In: Kong, F K et al. Handbook of Structural Concrete. London, Pitman, p.11-1~11-33.

[7] Neville, A M, Dilger, W H and Brooks J J, 1983. Creep of plain and structural concrete. Construction Press, London and New York.

[8] Wang Wei-an, 2005. Effect analysis of the shrinkage and creep of high-pier and long-span continuous rigid frame bridges. Thesis for Master's degree of Changsha University of Science & Technology.

[9] Xu Wei, Bai Hai-tao, Zhang Xiao-ning, 2003. Mechanical numerical modeling analysis of the deck pavement of long-span cable-stayed bridges. Journal of Harbin Institute of Technology, 35(6), p.750-754.