Chapter 32

Load Transfer Coefficient of Transverse Cracks in Continuously Reinforced Concrete Pavements Using FRP Bars

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Additional information is available at the end of the chapter

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Abstract

Continuously reinforced concrete pavement (CRCP) with fiber reinforced polymer bars (FRP) shows several advantages over the conventional CRCP, such as no erosion, light-weight, and low modulus. And the load transfer performance of the transverse cracks affects its service life. As the traditional evaluation system of crack load transfer failed to eliminate the influence of pavement deflection, the simple deflection value ratios for the cracks of the load transfer coefficient are not accurate enough to evaluate the load transfer performance of transverse crack in FRP-CRCP. In order to further understand the effects and improve the current load transfer coefficient of transverse cracks in FRP-CRCP, the relationship between the deflection value and load transfer coefficient in FRP-CRCP was analyzed. Using this approach, a more accurate prediction equation has been put forward to express the load transfer capacity.

Keywords: continuously reinforced concrete pavements, transverse cracks, vehicle load, load transfer, deflection value

1. Introduction

The aim of this chapter is to modify the current load transfer coefficient of transverse cracks in FRP-CRCP and put forward an accurate formula. CRCP as a type of high performance concrete pavement has high strength, good evenness, comfortable driving, long service life, and low maintenance cost advantages. More and more people pay attention to the research and application of CRCP (Zhigang Zhou and Qisen Zhang, 2000; Changshun Hu et al., 2001). The spacing and width of transverse cracks in the pavement can influence the performance of CRCP. Tabatabaie (1978), Huang (1985), and Guo et al. (1995) developed the illi-slab, KENSLABS, JSLAB, and other 2D finite element analysis programs to analyze the rigid pavement. According to Winkler foundation of the theory of elastic thin plates, they used beam elements and spring elements to simulate the load transfer function model. At present, there are two problems in the study of load transfer coefficient of transverse cracks in FRP-CRCP. On the one hand, simulation of a transverse crack model in finite element is easy to implement, but the related research which determines the load transfer ability of transverse cracks is relatively few. On the other hand, currently it is difficult to obtain the accurate shear stiffness of transverse cracks in FRP-CRCP through the existing calculation method, and thus it is impossible to accurately given crack prediction equation.

2. Load transfer mode of transverse crack in CRCP

The transfer of shear forces depends on parameters of the shear surface aggregate. The load transfer ability depends on the transverse crack width, the shape of the aggregate, the relative stiffness of the plate and foundation, and times of load action. Virtual equivalent filler simulation is in the cracks using an equivalent filler to simulate the packing, and cracking of concrete mechanical interlock action can be carried out by adjusting the equivalent sealing material stiffness to the realization of load transfer ability of the simulation (Jian-ming and Sheng-fei, 2009).

It is assumed that there are embedded transverse cracks in concrete on both sides of a short rod and there are small shear force and bending and toque moments. In addition to the plate and the foundation of the relative stiffness, factors that influence the load transfer ability includes gap widths and dowel bar parameters and construction factors, such as spacing, diameter, length, and the elastic modulus.

3. Evaluation system for load transfer efficiency of transverse crack in FRP-CRCP

For estimate of the load transfer capacity of transverse cracks in FRP-CRCP, the method is that the wheel load is applied at the side of plate, and measures capacity of load transfer from the direct-bearing plate to the nondirect-bearing plate. The rate of load values applied on plates on either hand of crack can show intuitively the load transfer efficiency (%), as in Eq. (1):

$$K_j = \frac{P_2}{P_1} \text{x} 100\% \tag{1}$$

where k_j is the coefficient of load transference for transverse crack in pavement structure; P_1 is the load applied on half of direct-bearing plate; P_2 is the load transmit from wheel pressure to nondirect bearing plate; $P = P_1 + P_2$, the sum of P_1 and P_2 is the total wheel pressure applied on the cracking location. It is impossible to accurately given crack prediction equation.

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4. Experimental model of the FRP-CRCP

Three-dimension finite element analysis (FEA) is adopted to analyze the selected pavement structure. Running direction is along the x direction; pavement transverse section is along the y direction; and vertical upward direction of pavement is along the z direction. The calculating width of the x direction is 8 m, the calculating width of the y direction is 6 m, and the calculating width of the z direction is 2 m (exclusive of structure thickness), in order to decrease influence of boundary constraint on the stress ability of model structure, according to grounding wire size and character of perpendicular stress. Longitudinal reinforcement design for surface course in continuous reinforced concrete pavement requires that maximal crack width is less than 1 mm. Breadth of transverse fissure in this chapter is 1 mm.

In consequence of FRP bars set transversely and longitudinally in FRP-CRCP, shrinkage and temperature shrinkage in the process of hardening of concrete is contained. So, some fine transverse cracks are produced pavement in slab. The continuous reinforced concrete pavement becomes the pavement structure with cracks. So, when three-dimensional finite element model is established, influence of steel on serviceability of pavement structures must be considered. The number of model elements varies with the crack width. In order to improve computational accuracy and consider running speed, the model dimension of reinforced continuous reinforced concrete pavement plate is 0.1 m after much experimenting. The model dimension of base course, subbase course, and soil base course are 0.5 m. In this way, both computing speed and calculation accuracy are enhanced suitably. This chapter analyzes mainly the force characteristics of the structure and load transfer capacities in the same section in where sheet fissure occurs in FRP-CRCP with 0.5 m fracture interval. **Figure 1** shows the schematic diagram of pavement structure.

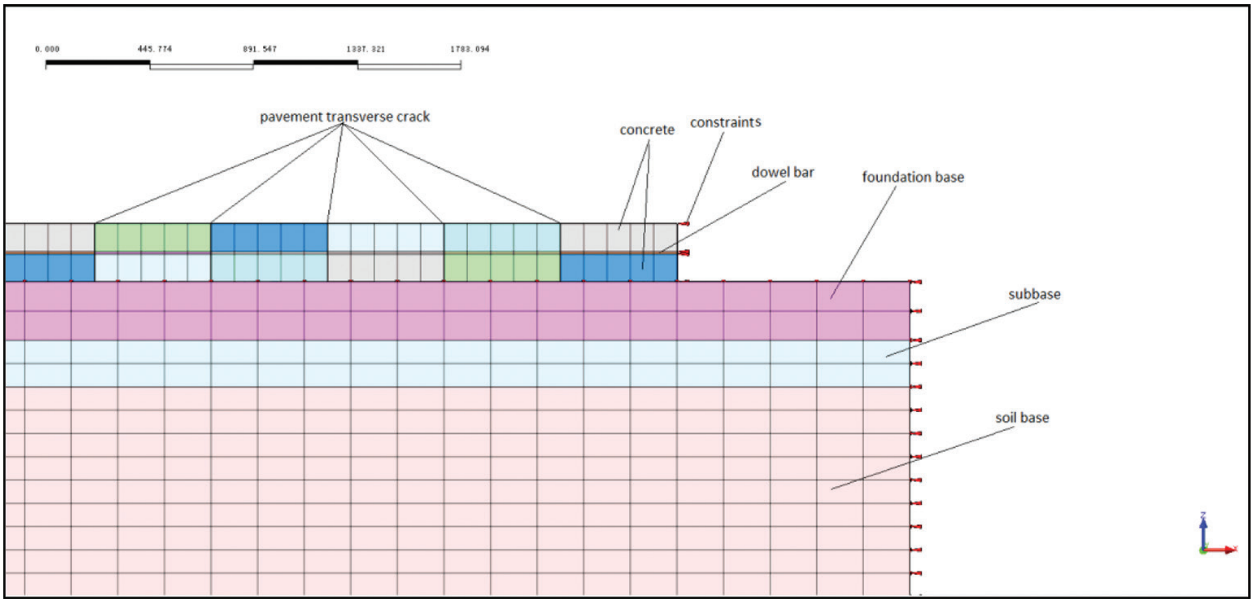

Figure 1. Schematic diagram of pavement structure.

As a numerical computation method, finite element method's computational accuracy is concerned with element size, model dimension, and so on. For pavement structure, the foundation is essentially semi-infinite elastic solid and its range is infinite in the horizontal and vertical direction. As a result of the incompatibility between the finite element method and elastic half space theory, the foundation size must be appointed. In the process of appointment for foundation size, on the assumption that the other parameters are invariable, foundation size will enlarge gradually, so stress in cement concrete pavement slab will also be stable gradually. The foundation size is the adopted value, when the result is convergent.

5. Results and discussion

To research foundation stiffness on the panel, ordinary cement was selected for the concrete pavement, load was applied in the middle of the pavement transverse crack, the pavement slab under the layer modulus was converted into an equivalent modulus and the foundation modulus was used, the selected foundation moduli were of 40, 100, 150, 200, 250, and 300 MPa. Calculation of top plate deflection variation degree difference and slab maximum principal stress with the foundation modulus, top plate deflection difference, and the maximum principal stress changes are shown in **Figures 2** and **3**.

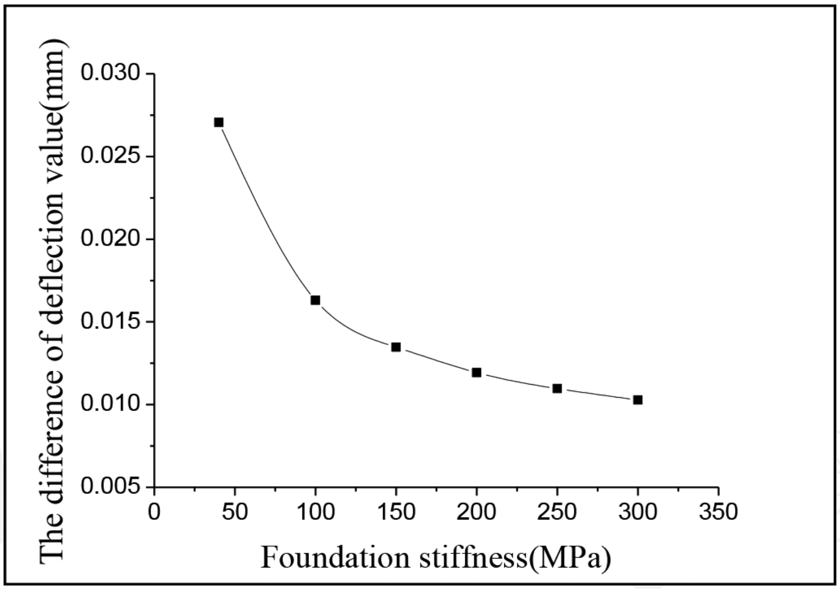

Figure 2. Relationship between the top deflection of the plate and the foundation stiffness.

Figure 2 shows that the top plate deflection differences decreases with: the increase of elastic modulus of the foundation. Foundation modulus of pavement has effect on load transfer to some extent. As the foundation modulus varies from 40 to 300 MPa, surface plate deflection difference decreases from 0.02706 to 0.01028 mm with reduction of 62%. However decreased degree of surface plate deflection difference gradually decreases with the increase of elastic modulus of the foundation. Even in the severe cracking, where there is no interlocking concrete function of load transfer and without the dowel bar load condition, the results show that the deflection difference exists between the loading plate and unloading plate. The traditional evaluation method of pavement crack load transfer coefficient has been used with no consideration for the influence of base and foundation on load transfer capacity of cracks in the pavement structure.

Figure 3 shows with the increase of foundation modulus the bottom plate of the maximum principal should stress σ_{max} reduced. When the foundation modulus from 40 to 300 Mpa, the maximum principal should stress σ_{max} from 1.3543 fell to 0.7319 MPa with 45% of reduction, but the maximum principal stress decreased with the increase of elastic modulus of the foundation and gradually weakened. Obviously, the good foundation support condition has the very big function to reduce the CRCP plate bottom stress.

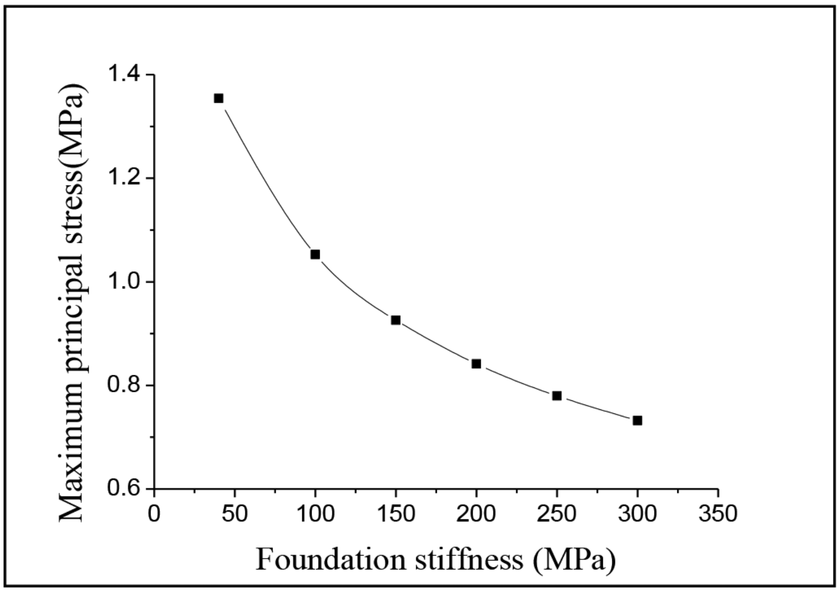

Figure 3. Relation curve of maximum principal stress and foundation stiffness.

6. Evaluation index of load transfer coefficient of transverse cracks in CRCP

For the convenience of the cracks on both sides of the bending relationship with transverse crack load transfer coefficient of deflection, so the definition of the difference of deflection value d_d and relative difference of deflection value d_r is shown in Eqs. (2) and (3):

$$d_d = d_2 - d_1 \tag{2}$$

$$d_r = \frac{d_d + 10^{-6}}{d_1} \times 100\% = \frac{(d_2 - d_1 + 10^{-6})}{d_1} \times 100\% \tag{3}$$

d_1: bending deflection value of the load plate on one side of the crack, mm;

d_2: the deflection of the load plate on the other side of the crack is not directly loaded, mm.

In the selected model to maintain constant computation parameters, single axle standard static load, tire pressure of 0.7 MPa, positions of the load for crack side plate, loose pavement without power transmission, pavement cracks in different degree of damage with different load transfer capacity and crack stiffness were used. There can be gradual changes in fracture load transfer coefficient values at different levels of damage, variation analysis deflection of CRCP pavement cracks at the time crack different stiffness and different load transfer capability. **Table 1** shows the results of simulated crack rigidity and cracks around the top plate deflection difference.

As can be seen from **Table 1**, the absolute deflection value of CRCP road surface decreases with the increase of the stiffness of the crack, and the transfer capacity can be increased. With more serious cracks and damage, crack spread load quickly decreases. When cracks lost the transmission capacity of load and dowel bar if loose, the cement panel bending heavy difference close to 0.006 mm, the continuous reinforced concrete pavement service life is greatly reduced.

Crack stiffness (%)	0	0.5	1	5	10	20	40	60	80	100
dd ($\times 10^{-3}$ mm)	3.35	2.32	1.79	0.62	0.42	0.18	0.11	0.08	0.05	0.05
dr ($\times 10^{-3}$)	2.58	1.82	1.41	0.49	0.28	0.14	0.09	0.06	0.04	0.039

Table 1. Load position when the second lower pass crack stiffness change on both sides of the plate deflection difference d_d relative deflection difference d_r.

As can be seen from **Figure 1**, simulation results of absolute deflection difference Si bearing capacity satisfy the exponential relationship, the correlation coefficient is 0.98501 that CRCP in this model of pavement structure crack bending heavy difference with crack load transfer ability with good linear relationship, the fitting formula is shown as Eqs. (4) and (5).

$$y = 0.00134\,x^{-1.09771} \tag{4}$$

$$k_C = 0.00134 \times \left(\frac{d_2 - d_1 + 10^{-6}}{d_1}\right)^{-1.09771} \times 100\% \tag{5}$$

k_C: continuously reinforced concrete pavement load transfer coefficient, %;

d_1: The deflection value of the load plate on one side of the crack directly, mm;

d_2: On the other side of the crack is not directly under the load plate deflection value, mm.

The fitting equation (5) eliminates the effects of subgrade layer by use of subtraction of deflections at the top and at the bottom, the traditional load transfer coefficient is calculated by

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falling weight deflection experiment. It is defined as the ratio of deflection for loaded and unloaded plate. No consideration is taken into account for the offset effect of the soil base to the deflection, which is influenced by the simulation (**Figure 4**).

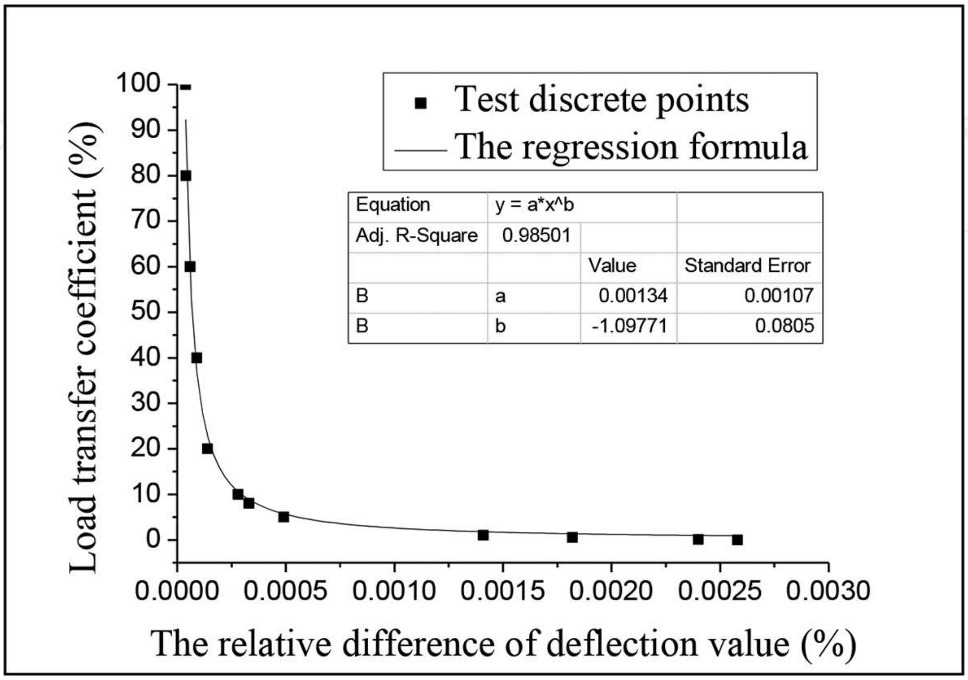

Figure 4. The relationship between the relative deflection difference and load transfer coefficient under the load.

Table 1 shows that there are large stiffness differences for the 1% prequel rod. If the material is reinforced then the transfer charge effect is very large, especially when the crack stiffness in 0% and the concrete interlocking function is lost completely. When the crack stiffness is larger, namely it there is the interlocking effect of the concrete then the force transmission is smaller compared to the interlocking concrete effect. For example, when the crack stiffness is 80% and the distribution reinforcement normal load transfer can be made on each side of the crack deflection, difference is reduced from 0.00, 006 to 0.00, 005 mm, reduced by 16%. This means at this time the dowel normal operation have less effect on load transfer coefficient of cracks compared to the concrete interlocking.

7. Conclusion

By using the basic principles of the finite element method continuously reinforced concrete pavement structural model parameters under selected conditions have been described, and the use of finite element method calculation model of continuously reinforced concrete pavement structure, the reliability of the model was validated. Considered in the model of the load transfer between the cracks of the pavement structure suffered constraints and other factors, the grass-roots and foundation factors from the model results and the impact of the difference between the deflection at the end of pavement on the maximum principal stress cracks, draw better evaluation methods to crack load transfer capabilities. The main conclusions are as follows:

(1) The basic level and the stiffness of the foundation have influences on the deflection of the pavement, top plate deflection difference between the bottom plate with the maximum principal stress and grassroots foundation stiffness increases significantly with the decrease in phenomenon. Even in severe cracks damage. There is no concrete interlocking effect on load transfer and do not set the dowel bar load transfer conditions when the load side plate crack. The results show that it is not directly affected by the load plate but directly affected by the Dutch deflection plate.

(2) When the damage degree of the transverse crack is serious, the effect of the load transfer function is relatively large. When the crack stiffness is 0%, there is complete loss of cracks of concrete interlocking action, the force transmission rod normal transmission bearing can make cracks on both sides of the curved, big difference decreases by 46.5%; crack damage to a lesser extent. The force transmission rod load transfer effect compared with interlocking concrete load transfer function produces a relatively small effect. When the crack stiffness is in 80%, the normal load transfer that can make the difference between the two sides of the crack is only reduced by 17%.

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References

Changshun, Hu. et al. 2001. Study on the test pavement of continuous reinforced concrete pavement, Highway, Chang'an University, no. 7, China.

Guo H., Sherwood J.A., Snyder, M., 1995. B1 component dowel bar model for load transfer systems in PCC pavements. Journal of Transportation Engineering, ASCE, 121(3): 289–298.

Huang Y.H., 1985. A computer package for structural analysis of concrete pavements. Third international conference on concrete pavement design and rehabilitation. Indiana: Purdue University, pp. 295–307.

http://dx.doi.org/10.5772/66809

Jian-ming Ling, Sheng-fei Guan, 2009. Analysis on load transfer efficiency of doweled joints in PCC pavement. Shanghai: Tongji University.

Tabatabaie A.M., 1978. Structural analysis of concrete pavement joints. Illinois: University of Illinois at Urbana-Champaign.

Zhigang Zhou, Qisen Zhang, 2000. A summary of the research on continuously reinforced concrete pavement, Journal of Changsha Communications University, Changsha Communications University, Changsha, China.

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