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Effect of dowel bar position deviation on joint load-transfer ability of cement concrete pavement

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Abstract

A double-layer structure model of pavements that considered interlayer contact status was established to manage the dowel-bar position deviation problem in rigid pavements. The deviation effect of three-dimensional positions, such as horizontal angle, vertical angle, and embedded depth, on joint load-transfer capacity was analyzed. A load-transfer capacity prediction model that considered dowel bar position deviation was established via ternary nonlinear regression. Load correction factor and its range were also proposed. This prediction model can effectively reflect the joint load-transfer capacity during dowel position deviation after verification via falling weight deflectometer testing. The horizontal angle of the dowel bar minimally affected joint load-transfer coefficient. By contrast, the joint load-transfer coefficient decreased almost linearly as the vertical angle increased. The coefficient reduced by approximately 12% when the vertical angle was 15°. Meanwhile, the load-transfer coefficient was maximized when a dowel bar was embedded in the middle of a surface. The coefficient would decline either upward or downward. The coefficient particularly decreased by 10% when the position was 2 cm downward.

Keywords: Road engineering; Prediction model; Finite element; Load-transfer capacity; Dowel bar; Position deviation

1. Introduction

A cement concrete pavement was divided into regular rectangular plates. A dowel bar connected the plates to one another. The weakest part of the pavement structure was the joint. The load-transfer capacity of the joint directly affected pavement performance [1]. The dowel bar end should be horizontal and smooth to guarantee that the dowel bar was free and could meet shear transfer requirements among plates. ZOLLINGER [2], IOANNIDES [3] and ZHOU [4] have established the relationship among joint load-transfer capacity, joint load-transfer stiffness, structure parameters, and cement concrete pavement load based on a Winkler foundation elastic plate. ZHOU [5] has established the correlation between joint load-transfer coefficient and stress reduction factor of a slab edge based on Winkler foundation assumptions. These studies did not consider the actual position deviation of a dowel bar. Additionally, the effect of load level on deflection was also disregarded by these studies. Dowel bar position was actually always deviated, which often caused function loss on itself [6]. The horizontal angle, vertical angle, and vertical displacement of the dowel bar

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significantly affected the joint load-transfer capacity [7]. Meanwhile, the load-transfer capacity was correlated to test load [8]. Thus, the effect of dowel-bar position deviation (horizontal angle, vertical angle, and vertical displacement) on the joint load-transfer capacity was analyzed based on a double-layer pavement structure model on the Winkler foundation. A load-transfer capacity prediction model that considered dowel-bar position deviation was established via ternary nonlinear regression. After the measured data were verified via falling weight deflectometer (FWD), the load-transfer coefficient prediction model was considered after amendment to effectively reflect the actual load-transfer capacity of rigid pavements.

2. Simulation experiment of joint load-transfer capacity

2.1. Experimental methods

Generally, a dowel bar mainly considers transferred shear only. Load-transfer mode was determined via joint shear stiffness C_w. The load-transfer capacity and efficiency were characterized via load-transfer coefficient L_T and stress reduction factor λ_σ. C_w, L_T, and λ_σ were related to the spatial location of a dowel, deflection test load, and combination status between a dowel bar and concrete[9]. The load-transfer capacity was determined in this study according to load-transfer coefficient L_T.

$$L_T = \frac{w_u}{w_l} \tag{1}$$

where, w_u is the maximum deflection of the unloaded slab, and w_1 is the maximum deflection of the loaded slab.

When aggregate interlocking was equal at the joint, the deflection load-transfer coefficient was related to the dowel bar horizontal angle, vertical angle, embedded depth, testing load, dowel bar bending stiffness, and combination status between the dowel bar and concrete. Therefore, the deflection load-transfer coefficient was $LTE = f(x_1, x_2, x_3, x_4, x_5, x_6)$, where x_1, x_2, x_3 are the dowel bar horizontal angle, vertical angle, and embedded depth, respectively. x_4 is the testing load. x_5 is bending stiffness of the dowel bar. x_6 is the combination status between the dowel bar and concrete. x_6 can be characterized by the horizontal constraint and vertical support moduli.

Three assumptions were formulated according to deflection test conditions and engineering practice to determine the effect of six factors on the deflection load-transfer coefficient. First, the testing load was similar. Second, the bending stiffness of the dowel bar was the same; and the diameter, length, and modulus were 500 mm, 32 mm, and 200 GPa, respectively. Third, the dowel bar status combined with concrete was similar. The horizontal constraint modulus was 0 MPa, while the vertical support modulus was 10,000 MPa. The effect of horizontal angle x_1, vertical angle x_2, and embedded depth x_3 on the deflection load-transfer coefficient was then calculated individually via finite element. The deflection load-transfer coefficient prediction model was also determined via the multivariate linear regression technique.

Pavement structure deflection was initially calculated both under temperature and vehicle load to accurately determine the deflection at both transverse joint sides and compare it with actual data under such circumstances. Deflection was then calculated only under temperature load. Finally, deflection was obtained under vehicle load alone.

The joint load-transfer coefficient was calculated through the finite element method. Calculation software Ever FE 2.25 was used.

2.2. Calculation model

The calculation model was a double-layer structure model based on the Winkler foundation, which considered the interlayer contact status. The model of pavement structure is shown in Fig. 1. It contained two slabs which were arrayed along the driving direction (x direction). The model can respond to the effect of dowel bar position deviation, such as horizontal angle, vertical angle, and depth deviation, on joint load-transfer capacity, where h_1, E_1, and μ_1 are the thickness, elastic modulus, and Poisson's ratio of the slab, respectively. Meanwhile, h_2, E_2, and μ_2 are the thickness, elastic modulus, and Poisson's ratio of the base, respectively. K is the foundation reaction modulus. P is the ground pressure. The slab was connected by a dowel bar. The joint load-transfer was completed via aggregate interlocking and a dowel bar. The bonded status between the dowel bar and the slab concrete was characterized by the horizontal constraint and vertical support modulus. The contact status between the slab and the base was improved through the Coulomb model.

A rectangle load acted on the transverse joint center or edge to amplify the effect of load-transfer capacity, as shown in Fig. 2. The equivalent load area was 20 cm × 15 cm. Additionally, the ground pressure was set to three grades, namely, 500, 700, and 900 kPa.

2.3. Calculation parameter selection

The calculation pavement structure was a cement concrete slab with a lean concrete base. The slab and base

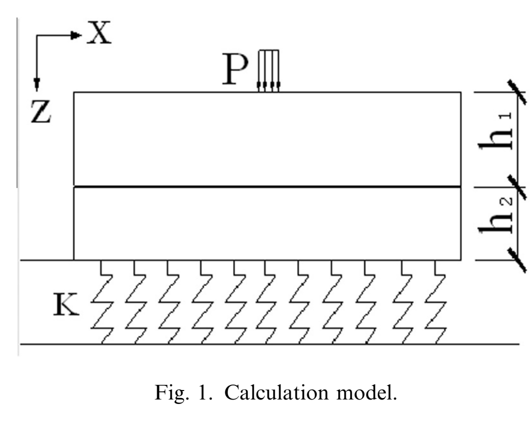

Fig. 1. Calculation model.