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Optimal design on dowel length for cement concrete pavement

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Abstract

In order to compute the optimal dowel length in cement concrete pavement, semi-infinite beam on elastic foundation was deduced and modified for the analysis of dowel bars. The dowel deflection, bending moment and shearing were analyzed for dowel bars under the traffic loading, dowel length based on the second inflexion distance was computed and a relationship between dowel length and dowel diameter was established. The theoretical analysis found that the dowel length in Chinese specification is conservative. A finite element model was also established to simulate the dowel load system. Based on the result of maximum value and variation tendency of mises stress for different dowel diameters and dowel lengths, it is feasible to shorten dowel length specified in JTG D40-2002 by 50%. However, considering the construction tolerances in the making and sawing of joints in new pavement construction, which might add 50–150 mm to the required overall dowel length, it's more appropriate to reduce the dowel length by 20% in practice.

Keywords: Dowel bar; Mechanical analysis; Length design; Cement concrete pavement; Finite element model

1. Introduction

The performance of cement concrete pavement depends largely upon how well the joint was constructed. The joint function is greatly related to the dowel bars [1]. Three main damage types of cement concrete pavement (slabcracking, faulting and joint deficiencies) are all relevant with dowel bars. It is significant to conduct the dowel length design for pavement joint. Too short a dowel bar will restrict the loading transfer capability across the joint, which will potentially cause the uneven settlement between slabs and even rehabilitation, while too long a dowel bar will be a waste of resource. Since early 2000, the price of steel dowel bar is always going higher and higher [2].

Some studies have been conducted on dowel bar design. Jiang [3] analyzed the strain distribution along the dowel length based on finite element method. Zhang [4] calculated the deflection of dowel bar based on energy variation principle and pointed out both bending moment and shearing force should be taken into account for the dowel analysis. Bradury [5] assumed the stress along the dowel bar bean was linear while the assumption was not demonstrated. Friberg [6] established a model for dowel bar analysis including five parameters: loading, dowel bar diameter, elastic modulus of dowel bar, bending rigidity of dowel bar and joint width. The model proposed by Friberg was intended for expansion joints initially, while the contraction joint is much shorter than the expansion joint. Therefore, the Friberg model is not suitable for the pavement contraction joint analysis [7–9].

In this paper, the Timoshenko model of infinite beam on elastic foundation was modified to analyze dowel bar. Based on the theoretical solution for deformation, bending moment and shearing force of dowel bar, the second

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inflexion distance was proposed to be used as dowel embedment length. Moreover, in order to verify the theoretical result, a finite element model was established to analyze the effect of dowel length on dowel-concrete bearing stress. Optimal dowel length was obtained based on the above calculation.

2. Domestic and foreign dowel bar sizes

Before 2003, there was no stringent requirement for dowel bar within the contraction joint, which led to many serious problems in China. Therefore, the pavement design specification (JTG D40-2002) required all contraction joint to be installed with dowel bars for heavy volume highways [10] and the dowel diameter was increased. The spacing and size of dowel bar specified in the new and old specification [10–11] are listed in Table 1.

The dowel bars size suggested by Portland Cement Concrete Pavement Association [12] is listed in Table 2.

The dowel bar size required by several states [12] is listed in Table 3.

Table 1
Dowel size and spacing.

	Slab thickness (cm)	Dowel diameter (cm)	Minimum length (cm)	Maximum spacing (cm)
JTG D40–2002	22	2.8	40	30
	24	3	40	30
	26	3.2	45	30
	28	3.5	45	30
	30	3.8	50	30
JTJ 012–94	<20	2	40	30
	21–25	2.5	45	30
	26–30	3	50	30

Table 2
Dowel size recommended by Portland Cement Association.

Slab thickness (cm)	Dowel diameter (cm)	Dowel embedment length (cm)	Dowel length (cm)
12.5	1.6	12.5	30
15	1.9	15	35
20	2.2	15	35
20	2.5	15	35
22.5	2.8	17.5	40
25	3.1	18.8	45
27.5	3.5	20	45
30	3.8	22.5	50

Table 3
Dowel size in different states in the U.S.

State	Dowel diameter (cm)	Dowel length (cm)	Dowel spacing (cm)
Alabama	3.8	45.7	30.5
Florida	1.9–3.2	38.1	30.5
Minnesota	3.2–3.8	38.1	30.5
Indiana	3.2–4.4	30.5	30.5
New Jersey	3.2	43.2	20.3–30.5

There is no significant difference for spacing requirements by foreign and domestic specifications, while dowel length requirement varies among different specifications. Therefore, it is necessary to conduct the analysis on dowel bars to get an optimized dowel length, which will guide the joint and dowel design within cement concrete pavement.

3. Theoretical model

The deformation of beam (Fig. 1) due to bending moment can be expressed as:

$$1/\rho = M/\mathrm{EI} \tag{1}$$

where ρ is curvature radius of neutral surface, M is bending moment, E is elastic modulus of beam, I is second axial moment.

Considering the beam deformation is very small compared to the beam height, the curvature can be calculated with Eq. (2)

$$\frac{1}{\rho} = \pm \frac{d^2 y}{dx^2} \tag{2}$$

where y is beam deflection, x is distance from joint face.

Generally, the upper concave curvature was negative

$$\mathrm{EI}\frac{d^2 y}{dx^2} = -M \tag{3}$$

In the case of Fig. 2

$$\frac{dM}{dx} = Q \tag{4}$$

where Q is shear force.

Assume that a beam AB, loaded by a distributed load q, is supported along its entire length by a continuous elastic foundation (See Fig. 3). When the beam is deflected, the reaction of elastic foundation at every section is proportional to the deflection at that section. Under such condition, the reaction per unit length of the beam can be represented by the expression ky in which k, called the modulus of the foundation denoting the reaction per unit length.

In order to study the beam deformation, second derivation of Eq. (3) was taken:

$$\mathrm{EI}\frac{d^4 y}{dx^4} = -\frac{d^2 M}{dx^2} = -\frac{dQ}{dx} \tag{5}$$

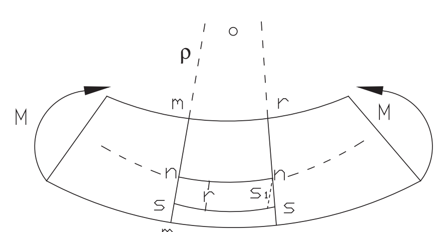

Fig. 1. Pure bending of the beam.