Analysis for Dowel Bar’s Set Interval of Cement Concrete Pavement

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ABSTRACT

Through comprehensively considering transverse joint load transfer, dowel bar shearing, dowel bar bending, concrete’s borne dowel bar pressure and impact on pavement slab bottom’s flexural-tensile stress, adopting R·D·Bradbury dowel bar practical design checking formula and cement concrete pavement three-dimensional finite element analysis program EverFE for discussion of dowel bar’s set interval and combining with testing observation, I view that, dowel bar interval can be appropriately increased when pavement slab thickness is greater than 24cm which has practical significance for saving consumption for reinforcing steel bars of dowel bar and reasonably controlling highway construction cost.1

INTRODUCTION

Traditional cement concrete pavement “transverse precutting contraction joint” mainly relies on built-in extruding and friction of aggregate at side of concrete slab contraction joint and rigidity of base to transmit load. Due to repeated roles including water’s saturating (scouring), temperature cycling and wheel load, etc, such load-transmitting way appears a certain problem and it is easy to cause increased deflection for slab edge and slab angle and mud pumping, slab staggering and slab bottom hollowing, etc. Main effective method to solve these problems is to additionally set dowel bar in contraction joint. Relevant researches and practices at home and abroad show that, for cement concrete pavement, role for joint dowel bar is extremely crucial: A. The joint is the weakest place for cement concrete pavement. Slab edge deflection and great temperature stress buckling and

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deformation in joint are important factors for pavement’s easily occurring fracture; B. In such high and cold region as Heilongjiang Province, yearly maximum temperature difference can reach 77.6-84.0℃, just relying on built-in locking force and frictional force of aggregate at side of“ transverse contraction joint ”is unable to maintain long-term stable joint load-transmitting effect and reduction of load-transmitting capacity will lead to increase for deflection of slab edge and slab angle and load stress will be then increased; C. Increase for deflection of slab edge and slab angle enables free water infiltrated into joint to appear strong pump suction phenomenon and scour surface of semi-rigid base which has accelerated formation of slab bottom hollowing; D. Joint appears slab staggering due to pump suction phenomenon and driving comfortableness for cement concrete pavement has been greatly reduced though early-stage slab staggering is very small; E. Setting joint dowel bar is important measure to eliminate “clicking” phenomenon of joint on existing ordinary cement concrete pavement and maintain pavement flatness for a long time.

When setting joint dowel bar, its laid interval is an important target. Length for dowel bar of cement concrete pavement is generally 40-70cm, set interval is 20-50cm (China’s adopted length is 40-50cm and maximum interval is 30cm) and determination for interval of dowel bars needs to consider needs of joint transmitting load and impact on pavement slab stress.

**SELECTION FOR INTERVAL OF DOWEL BARS BASED ON LOAD TRANSMISSION AMONG PLATES**

Strained condition for dowel bar is more complicated, including shearing and bending caused by load and bearing pressure of concrete, etc., many countries determine size and arranged interval for dowel bars in accordance with thickness of pavement slab. This text adopts analytic method, namely dowel bar practical design checking formula proposed by R·D·Bradbury for relevant calculation and analysis. Two coefficients are involved in analysis, namely “needed effective coefficient” and “practical effective coefficient”.

Needed effective coefficient refers to needed total effective coefficient distributed to dowel bar system by load which is actually required for transmission and it is ratio between actually required transmitted load and single dowel bar’s maximum carrying capacity; Practical effective coefficient refers to total of effective coefficients distributed to various dowel bars when dowel bar system distributes dowel bar’s borne practical vehicle wheel load in accordance with effective coefficient after it is completely arranged. When “practical effective coefficient” is > “needed effective coefficient”, arrangement plan for dowel bars meets requirements.

In accordance with theoretical analysis proposed by H·M·Westergaard, Friberg·B·F proposed that, force’s effective range for dowel bar system is 1.8 times
of pavement relative rigidity radius. Therefore, interval of dowel bars is great, then number of dowel bars which can be arranged within such range is reduced and sum of effective coefficients (namely practical effective coefficient) which can be distributed is diminished, and conversely it is increased. We apply VB6.0 Software to have worked out aided analysis program, among which, length and diameter for dowel bar is in accordance with existing provisions and relationship between interval of dowel bar and effective coefficient is calculated which is as shown in Figure 1.

![Figure 1. Relationship between Interval of Dowel Bars and Effective Coefficient.](image)

We can know from Figure 1 that, practical effective coefficient is rapidly decreased with increase for interval of dowel bars and interval of dowel bars taking 30cm can better meet checking conditions for effective coefficient when pavement slab thickness is 24cm below. However, when pavement slab thickness is ≥24cm, practical effective coefficient is much higher than needed effective coefficient, the former is 24.5%-151% higher than the latter in the figure and the thicker surface slab is, the greater it exceeds. Therefore, when surface slab thickness is more than 24cm, interval of dowel bars shall be appropriately
increased. In accordance with checking result and referring to foreign relevant experiences, suggest that maximum interval of dowel bars is calculated by 40cm, coordination between practical effective coefficient and needed effective coefficient is more reasonable at this time, consumption for reinforcing steel bars of dowel bar can be thus reduced for about 27%.

Above checking has taken shearing and bending for reinforcing steel bars of dowel bar and concrete’s local compression role into account. Additionally, change for interval of dowel bar will produce a certain impact on stress of concrete pavement which is further analyzed as follows.

### TABLE 1. CALCULATION PARAMETERS FOR CEMENT CONCRETE PAVEMENT.

| Parameters of Concrete Material | Size of Surface Slab (cm) | Base | Foundation Reaction Modulus (MPa) | Dowel Bar | Temperature Gradient (℃/m) |
|---------------------------------|--------------------------|------|-----------------------------------|-----------|--------------------------|
| Flexural-tensile Modulus (MPa)  | Poisson's Transverse Width (cm) | Longitudinal Length (cm) | Thickness Poisson's Ratio (cm) | Modulus of Resilience (MPa) | Diameter (mm) | Length (cm) | Interval (cm) |
| 31000                           | 0.15                      | 450  | 500                               | 26        | 20                       | 0.25          | 1300       | 0.03         | 32          | 50          | 30/40       | 85          |

### INCREASE FOR INTERVAL OF DOWEL BARS’IMPACT ON PAVEMENT SLAB BOTTOM'S TENSILE STRESS

As a component part for load transfer among cement concrete pavement plates, change for interval of dowel bars will produce a certain impact on load stress of cement concrete pavement. Cement concrete pavement three-dimensional finite element analysis program EverFE (Software for the 3D Finite Element Analysis of Jointed Plain Concrete Pavements) jointly developed by American University of Washington and University of Maine State is hereon adopted for calculation and analysis of pavements lab bottom’s flexural-tensile stress under circumstance of above-mentioned two intervals. Main calculation parameters are as shown in Table 1.

For situation of dual-lane without hard shoulder, when single-axle dual-wheel group axle load (100kN) is affected on pavement transverse joint edge’s central location and longitudinal joint edge’s central location, slab bottom’s flexural-tensile stresses for corresponding cross-section are as shown respectively in Figure 2 and Figure 3.

For situation of dual-lane with cement concrete hard shoulder (hard shoulder width: 1.5m and thickness: 26cm), when single-axle dual-wheel group axle load (100kN) is affected on longitudinal joint edge’s central location, slab bottom’s flexural-tensile stresses for corresponding cross-section are listed in Table2.
We can know from Figure 3 that, when axle load is affected on transverse joint edge’s central location, other conditions remain unchanged, interval of dowel bars is calculated by 30cm and 40cm, distribution curves for flexural-tensile stresses in such cross-section’s concrete slab bottom are very similar, among which, peak-value stresses differ each other for about 0.5%.

We can know from Table 2 and Figure 4 that, when axle load is affected on longitudinal joint edge’s central location (right wheel is located in traffic lane outside’s longitudinal joint edge’s central location), if other conditions remain unchanged, interval of dowel bars is calculated by 30cm and 40cm, numerical
values for flexural-tensile stresses of such cross-section’s concrete slabs are very similar, generally speaking, stresses during interval of 40cm are diminished, they differ for 0.3-1.0%, and the closer to traffic lane outside’s longitudinal joint edge’s central location, the smaller they differ, namely, flexural-tensile stresses for slab bottoms in unfavorable load positions differ little.

![Graph](image)

**Figure 3. Slab Bottom’s Flexural-tensile Stress for Central Cross-section of Longitudinal Joint Edge (Right Wheel Affected on Outside Longitudinal Joint Edge’s Central Location).**

**INCREASE FOR INTERVAL OF DOWEL BARS’IMPACT ON LOAD TRANSFER COEFFICIENTS**

Above checking has in fact considered joint’s load transfer, dowel bar shearing, dowel bar bending and concrete’s borne dowel bar pressure and impact on pavement slab bottom’s flexural-tensile stress. During construction for relevant road sections, to verify increase for interval of dowel bars’ impact on joint’s load transfer coefficients, when constructing transverse precutting contraction joint with 30cm interval of dowel bars, 3 transverse precutting contraction joints with 40cm interval of dowel bars are additionally set. After over 4 years of tracking surveys, the former’s joint load transfer coefficients are changed between 0.85 and 1.00, the latter’s are changed between 0.87 and 0.98, both sides are basically identical, produced difference lies in that number of transverse precutting contraction joints for 30cm interval of dowel bars is more (96 ones), therefore, observed data changing range is greater, while a portion of load transfer coefficients without dowel bar contraction joint has been reduced to 0.7 below and appeared sign of slab bottom hollowing.
CONCLUSIONS

Cement concrete pavement possesses advantages including long service life, small maintenance workload, small energy consumption, environmental protection and strong suitability for traffic rating and environment, etc. and it had been widely used for China’s construction of high-grade highways. However, because problems including insufficient durability, etc. exist, more structural damages have appeared in recent years and its flatness and comfortableness have been declined seriously, its application has been greatly affected. Improvement for durability of cement concrete pavement needs to make a compromise for durability for two aspects including concrete material and pavement structure. “Full contraction joint dowel bar technology” is one of the most direct and also the most simple and effective means to improve durability for structure of cement concrete pavement: On basis of extensive collection of American and European countries’ using experiences, Permanent International Association of Road Congress (PIARC) proposes applicable scope for contraction joint without dowel bar when pavement performance meets a certain standard, namely, for frozen and wet regions, base is cement or asphalt is stable, trucks’ traffic volume (axle load: 13t) shall not be more than 150 vehicles/day (or 300 vehicles/day for 9-10t trucks); Such traffic volume’s threshold value can be increased by 1-2 times if abrasion resistance for base’s top surface can be assured; It can be re-increased by 1-2 time if internal drainage system has been provided; Japan stipulates that, in principle, all of “ordinary cement concrete pavements” use reinforcement bar mesh (3kg/m2) and edge-reinforced reinforcement bar, when construction is difficult under circumstance of traffic volume for large vehicles T < 250 (vehicles/day), reinforcement bar mesh can be omitted (such reinforcement bar mesh’s role is to restrain extension of cracks and prevent angle of rupture and slab staggering and structural strength of pavement slab cannot be thus expected for improvement), however, dowel bar and pull rod shall also be set at this time.

Interval of dowel bars adopted by various countries is not fully the same, for which, this text discusses and proposes recommended interval. For maximum interval of dowel bars, it adopts 30cm when pavement slab thickness h ≤24cm and recommend adopting 40cm when pavement slab thickness h >24cm. Namely, interval of dowel bars can be correspondingly increased when pavement slab thickness is greater. Adopting reasonable interval and selecting appropriate diameter possesses positive significance for reducing consumption for reinforcing steel bars of dowel bar and saving highway construction cost.
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