R&T UPDATE
Concrete Pavement Research & Technology

Dowel Basket Tie Wires:

Leaving Them Intact Does Not Affect Pavement Performance

Since ACPA last conducted its review of state highway agencies practices in 1999, at least 3 states (Iowa, Washington, and Wisconsin) have removed the requirement for cutting the tie wires (or spacer wires) in the dowel basket assemblies prior to paving. But around 20 state agencies still require concrete paving contractors to cut the tie wires prior to placing concrete. The intent of this requirement is to eliminate or reduce the apparent potential of the steel wires to lock the joint, or for the wires to cause micro-cracking in the early ages of the concrete. The underlying belief is that the three to five small-diameter wires, when crossing the joint, will restrict the shrinkage of the early-age concrete, reinforce and prevent movement of the transverse joint, and/or cause the concrete to crack.

These requirements are not well-founded for a number of reasons. First, there are always stresses that build up in the concrete pavement due to early-age concrete shrinkage and temperature contraction. These are the same stresses that cause transverse saw cuts in jointed pavement to become working joints. The stresses have to build up to the point where they overcome the concrete strength, and then further build to overcome other restraining forces for the joints to open up. The restraining forces include friction provided by the subbase, and the amount of bonding between the concrete and the dowels themselves. Once these friction and restraint forces have been overcome, stress would be transferred entirely to the tie wires.

For this mechanism to cause the concrete to crack, the tie wires must impart stress back to the concrete, and the total stress must be greater than the concrete strength at that point in time to cause a crack. But an analysis of the mechanics shows the tie wires will fail one of two ways before they can cause damage to the concrete or lock the joint:

- The wires themselves will yield, or
- The welds holding the wires to the basket will fail.

This R&T Update presents an analysis of this issue and concludes that uncut tie wires do not cause cracking given the assumptions made herein. Other engineering analyses[1,3] have shown that the impact of not cutting the wires is negligible, and in one case[1] only results in a small increase of 5 psi (0.03 MPa) in concrete stress at the center of the slab. ACPA's position on this issue is that uncut tie wires benefit the concrete pavement by keeping the dowels and the dowel baskets in better alignment.

Discussion of Factors

Immediately after a concrete pavement is placed, the hydration begins. The concrete shrinks, and typically with corresponding decreases in temperature, it also undergoes thermal contraction. This combination of shrinkage and contraction is the reason for cutting joints in jointed concrete pavements – to control the location where the concrete cracks.

Subbase Friction. If a concrete pavement was built on a frictionless subbase, then it would be free to shrink or expand without restraint and would not crack. But since it is placed on a prepared subgrade or subbase surface, some amount of friction is present. For the sawcut to become a working joint, the restraint from friction must first be overcome. The degree of friction is dependent on the material type, as shown in Table 1 (adapted from Reference 2).

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Table 1. Friction coefficients for various subbase materials.[2]

Subbase	Coefficient of Friction
Natural subgrade	1.0
Lime-treated clay soil	1.5
Dense-graded granular	1.5
Bituminous surface treatment	3.0
Crushed stone	6.0
Asphalt stabilized (smooth)	6.0
Asphalt stabilized (rough)	15.0
Asphalt-treated open-graded	15.0
Cement-treated open-graded	15.0
Cement-stabilized	10.0
Lean concrete / econocrete	15.0

Subbase friction is important, because it is the first force that must be overcome before stress might begin to develop in the spacer wires of the basket. For example, assuming an 8-in. concrete pavement with 12-ft wide by 15-ft long slabs on a crushed stone base, the force required to overcome frictional restraint and move the pavement is 27,000 lbs.

Dowel Bar Bond. The concrete also bonds to the dowel bars, with the degree of bond dependent upon the type of dowel bar surface or the coating applied to the surface. The amount of bond can be measured using a dowel bar pullout test, such as the Kansas Department of Transportation's Test Method KT-MR-16, *Testing of Dowel Bars Placed in Concrete for Resistance to Removal (Pull Out)*. The concrete-dowel bond is the other restraining force that must be overcome before any stress might be transferred or applied to the tie wires in the dowel basket. Manufacturer-applied dowel coatings typically provide more bond-breaking action than field-applied coatings, as shown in Table 2 (adapted from Reference 3).

Assuming a typical value of 1000 lbs per bar (noting the pullout test values in Table 2 and the fact that most specifications require either a manufacturer-applied or field-applied bond breaker), 12 bars along the width of a typical pavement slab requires 12,000 lbs of force to overcome the concrete-dowel bond.

Table 2. Dowel bar pullout load test results.[3]

Dowel Bar Coating	Pullout Load Avg. of 3 Tests	
	Lbs	% of control
TECTYL 164	700	5%
TECTYL 506	930	7%
Asphalt MC-250	970	7%
SAE 30 Oil	1,600	12%
Grease	2,350	18%
Meadows Duo-Guard	6,670	50%
CONTROL – Uncoated	13,350	100%

Resistance of tie wires. Once the friction force of the subbase and the dowel coating bond has been overcome, then some amount of stress is applied to uncut tie wires on the dowel basket. Most dowel baskets have three to five tie wires that are welded in place to hold the basket aligned during fabrication, assembly, transport, handling, and installation on the grade. The wires are typically 0.177, 0.250, or 0.307 inches in diameter and are held in place by welds on the upper support of the basket. Shop drawings are available from manufacturers that show specific dowel basket dimensions.

For this analysis, conservatively assuming that five tie wires at 0.307 inches in diameter are used in fabrication of the dowel assembly, there is a total cross-sectional area of 0.37 square inches of tie steel crossing the joint. With a yield stress of 60 ksi, the tie wires require a tensile load before failure of 22,207 lbs.

Resistance of welds. A separate analysis[3] documented that the maximum force required to break a tie wire weld in shear depended on the diameters of both the tie wire and the transverse supporting wire, as shown in Table 3 (adapted from Reference 3).

Once again, assuming 3150 lbs (a conservative value) is required to break each weld, brings the total resistance of 5 wires to 15,750 lbs. Given this case, the welds will break before the tie wires yield.

Table 3. Dowel basket assembly weld shear test results.[3]

Tie Wires		Side Frame Transverse Supporting Wires	
Gauge *		1/0	2/0
	Diameter (in.)	0.306	0.331
7	0.177	**1285 lbs** **1412 lbs**	**N/A**
3	0.250	**1578 lbs**	**1694 lbs**
1/0	0.307	**2376 lbs** **3127 lbs**	**2390 lbs** **2213 lbs**

* Washburn & Moen

Shrinkage and Contraction Force. The force applied to the tie wires by the concrete as it shrinks due to hydration and drying, and contracts due to lowered temperatures, is compared to the resistance capacity of the tie wires and/or welds to determine the possibility of intact wires causing joint lock-up or other failures.

Given the same joint spacing assumption as before, (15 ft), a 30ºF temperature differential, and the coefficients as shown in Equation 5, then the joint will hypothetically open up 0.036 in. It should be pointed out that the pullout resistance of dowel bars is developed through static friction that occurs over a much shorter distance than the distance required to develop even moderate levels of stress in the wires or welds.[3] To determine the force on the wires, we used Equation 5 with the same assumptions as in previous cases. The force on each wire is 6400 lbs, which is much greater than the pullout resistance of typical dowel installations, and is also greater than the weld strength of typical tie wire welds.

Equations

Friction force: [3,4 *]

$$F_f = \frac{W \cdot (L/2) \cdot f \cdot w_l}{2} \qquad (1)$$

Where:

F_f = friction force, lbs
W = weight of slab, lb/ft^2
= $\rho_c \cdot (t/12)$
ρ_c = density of concrete, 150 lb/ft^3
t = thickness of slab, in.
L = slab length (trans. joint spacing), ft
f = coefficient of friction
w_l = lane width, ft

Dowel bar bond:

$$F_d = N_d \cdot f_b \qquad (2)$$

Where:

F_d = total dowel bond force, lbs
N_d = number of dowels per basket
f_b = pullout resistance of one dowel, lbs

Tie wire resistance:

$$F_t = N_w \cdot \pi \left(\frac{\varphi}{2}\right)^2 \cdot f_y \qquad (3)$$

Where:

F_t = tie wire resistance, lbs
N_w = number of wires per dowel basket
ϕ = diameter of wire, in.
f_y = yield strength of steel wire, psi

Weld resistance:

$$F_w = N_w \cdot f_w \qquad (4)$$

Where:

F_w = total weld resistance, lbs
N_w = number of wires per dowel basket
f_w = yield strength of one weld, lbs

Shrinkage and contraction force:

$$F_{s+c} = \frac{d_{s+c} \cdot a_s \cdot E_s}{l_t} \qquad (5)$$

Where:

F_{s+c} = force from shrinkage & contraction
d_{s+c} = displacement due to shrinkage and contraction on one side of joint
= $[\varepsilon_c \cdot (L/2 \cdot 12)] + [\alpha_c \cdot \Delta T \cdot (L/2 \cdot 12)]$
ε_c = coefficient of concrete shrinkage
= 0.0005 in/in
α_c = concrete coef. of thermal expansion
= 0.000005 in/in/ºF

* This equation is a commonly-used, crude linear approximation of the slab-subbase friction relationship. A more accurate approach can be found in Reference 1.

ΔT = change in temperature
a_s = cross-sectional area of one wire
$= \pi \cdot (\phi/2)^2$
E_s = elastic modulus of steel
$= 29 \times 10^6$ psi
l_t = tie wire length = 12 in

Benefits

Leaving tie wires intact will strengthen the dowel basket, making it more resistant to movement and deflection while paving.[5] This results in smoother pavement, as well as dowels that are better aligned. The strengthening offered by uncut wires is even more critical for taller dowel baskets used in thick pavements, such as heavy-use (> 100,000 lb aircraft) airfield pavements.

Dowel baskets that have the tie wires cut are more susceptible to spring-back problems, whereby the basket is compressed when the paver passes above it, then springs back up after the pressure is gone, resulting in a bump in the pavement.[6]

Modern dowel location detection equipment, such as MIT-SCAN, may have difficulty in accurately locating bars in baskets where the tire wires are left intact.[7] However, the equipment may be calibrated to function adequately for intact baskets. Given the choice to cut the tie wires for purposes of location verification, or to leave the tie wires to enhance pavement quality, ACPA recommends leaving the wires intact.

Summary

Although many state highway agencies require dowel basket tie wires to be cut, the need for doing so was never clearly established. There are no projects that are known to have experienced cracking due to tie wires that were left intact before paving. Analyses have shown that under typical circumstances, very little stress is added to the concrete pavement from leaving dowel baskets as they are, shipped directly from the manufacturer or supplier. The benefits of leaving tie wires intact far outweigh any remote possibility of increased risk of early distress in the concrete pavement.

Agencies or contractors that are concerned about this issue are encouraged to review shop drawings from their dowel basket manufacturers and to calculate the potential stress build-up from intact spacer wires using the method outlined in this R&T Update.

References

1. *An Evaluation of the Impact to the Behavior of a Concrete Pavement due to Corrosion and Restraint of the Dowel Basket Assembly,* The Transtec Group, Inc., 16 June 2001, provided by Mr. Steven L. Tritsch, P.E., of American Highway Technology.

2. *Early Cracking of Concrete Pavement – Causes and Repairs,* Concrete Paving Technology, TB016.01P, American Concrete Pavement Association, 2002.

3. *Shrinkage and Tie Wire Analysis,* Wisconsin Department of Transportation Materials Laboratory, provided by the Wisconsin Concrete Pavement Association.

4. Yoder, E.J. and Witczak, M.W. *Principles of Pavement Design,* 2nd Ed., John Wiley & Sons, Inc., New York, 1975.

5. *Design and Construction of Joints for Concrete Highways,* Concrete Paving Technology, TB010.01P, American Concrete Pavement Association, 1991.

6. *Constructing Smooth Concrete Pavements,* Concrete Paving Technology, TB006.02P, American Concrete Pavement Association, 2003.

7. *Dowel Bar Alignment of Typical In-Service Pavements,* report prepared by the ERES Division of ARA, Inc. for the American Concrete Pavement Association, November 2004.

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