Dowel and Tie Bars in Concrete Pavement Joints: Theory and Practice

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November 2, 2011
2nd International Conference on Best Practices for Concrete Pavements
Presentation Outline

- Introduction
  - Pavement joints, dowels, and tie bars
- Benefits of dowel and tie bars
- Dowel and tie bar design
- Construction
- Summary
Dowel bars

- Placed across transverse joints at the mid-depth of the slab
- Transfer load from one slab to another without preventing the joint from opening
- Commonly made of round, smooth, epoxy coated steel bars
- Reduce joint faulting and corner cracking
Tie bars

- Placed across longitudinal joints at the mid-depth of the slab
- Prevent lanes from separation and differential deflections
- Made of deformed epoxy coated steel
- Reduce transverse cracking
Dowels and Tie Bars

Longitudinal construction joint

Transverse contraction joint

Tie bars

Dower bars

Courtesy of Dr. Darter
Presentation Outline

• Introduction

• **Benefits of dowel and tie bars**
  • Theory
    • Mechanism of load transfer
    • Effect on deflections and stresses
    • Effect on performance
  • Practice
  • Cost

• Dowel and tie bar design

• Construction

• Summary
Why do we need tie bars?

None or inadequate tie bar design

Lane separation
Effect of tie bars on pavement responses

No tie bars
High stresses
High deflections
Pavement distresses

Tie bars
Low stresses
Low deflections
Good joint performance
80 kN single axle load
Deflections without Tie Bars

Nontied joint
Max Deflection = 0.54 mm
Deflections with Tie Bars

Tied joint
Max Deflection = 0.33 mm
Effect of Tie Bars on PCC Stresses

Nontied joint
Max Stress = 2051 kPa

Tied joint
Max Stress = 1603 kPa
Why do we need dowels?

None or inadequate dowel bar design

Faulted Joint
Effect of dowels on pavement responses

No dowels

Aggregate interlocking

High stresses
High deflections

Pavement distresses

Approach slab

Rapid slab rebound

Leave slab

Traffic direction

Rapid movement of materials backward

Loss of support

Aggregate interlock

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Effect of dowels on pavement responses

Traffic direction

Dowels

Traffic direction

Low stresses
Low deflections

Good joint performance

No differential deflection,
No faulting
Effect of Dowels on Stresses and Deflection
Effect of Dowels on Deflections

Nondoweled joint
Max Deflection = 1.02 mm
Effect of Dowels on Deflections

Doweled joint
Max Deflection = 0.6 mm
Effect of Dowels on Stresses

Principal Stresses at the Slab Bottom

Nondoweled joint
Max Stress = 1120 kPa

Doweled joint
Max Stress = 812 kPa
Federal Highway Administration Long Term Pavement Performance Studies

1. Evaluation of Joint and Crack Load Transfer (Khazanovich and Gotlif 2002)


Almost 150 pavement sections located throughout USA
Effect on Load Transfer Efficiency

Joint Load Transfer Efficiency, percent

Cumulative Percentage of Passes

Doweled
Nondoweled

Good
Poor

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Effect of Dowels on Faulting

Cumulative percent of sections

Faulting (mm)

Nondoweled

Doweled

Good

Normal

Poor

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Smith et al. 1990

Dowels increase the initial cost between 5 and 8 percent, but increase the load carrying capacity over 100 percent.

Gharaibeh and M. I. Darter 2001

The use of dowel bars increases the initial pavement life by about 60 percent and results in similar total Life Cycle Cost reduction than not using dowels.
Presentation Outline

- Introduction
- Benefits of dowel and tie bars
- Dowel and tie bar design
  - Diameter
  - Length
  - Spacing
- Construction
- Summary
Dowel Diameter

Germany

25 mm

USA

Concrete thickness  Dowel diameter
<200 mm  25 mm
200 - 250 mm  32 mm
>250 mm  38 mm

MEPDG – based on the maximum allowed faulting
Effect of Dowel Diameter on Faulting

Design period: 20 years
Slab thickness: 200 mm.

Number of Trucks per day

Faulting (mm)

- Nondoweled
- DD=25 mm
- DD=32 mm
- DD=38 mm

Khazanovich et al. 2004
# Effect of Dowels Diameter on Bearing Stresses

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<table>
<thead>
<tr>
<th>Dowel Diameter, mm</th>
<th>Concrete Bearing Stress, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>17.3</td>
</tr>
<tr>
<td>32</td>
<td>12.7</td>
</tr>
<tr>
<td>38</td>
<td>9.3</td>
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</table>
Dowel Length and Spacing

- Dowel length
  - Germany: 500 mm
  - USA: 450 mm
  - Minnesota: 380 mm

- Dowel spacing
  - Germany: 250 mm in wheel path
    500 mm outside of the wheel path
  - USA: 300 mm
    non-uniform
Non-uniform Dowels Spacing

5 @ 300 MM   900 MM   5 @ 300 MM

Dowels in the wheel paths only
• Tie bar diameter

  Austria: 14 mm
  Germany: 20 mm
  USA: 12.5 and 16 mm
• Tie bar length
  Austria: 700 mm
  Germany: 800 mm
  USA: 760 mm

• Tie bar spacing
  Austria: 3 bars/slab
  Germany: construction joints: 5 bars /slab
           contraction joints: 3 bars/slab
  USA: table
Bar diameter: 12.5 mm
Steel yield strength: 280 MPA

<table>
<thead>
<tr>
<th>PCC thickness (mm)</th>
<th>Distance to free edge (mm)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>3000</td>
</tr>
<tr>
<td>225</td>
<td>650</td>
</tr>
<tr>
<td>250</td>
<td>600</td>
</tr>
<tr>
<td>275</td>
<td>550</td>
</tr>
<tr>
<td>300</td>
<td>500</td>
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</table>
Bar diameter: 16 mm  
Steel yield strength: 280 MPa

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<tr>
<td></td>
<td>3000</td>
</tr>
<tr>
<td>225</td>
<td>1050</td>
</tr>
<tr>
<td>250</td>
<td>950</td>
</tr>
<tr>
<td>275</td>
<td>850</td>
</tr>
<tr>
<td>300</td>
<td>775</td>
</tr>
</tbody>
</table>
Introduction

Benefits of dowel and tie bars

Dowel and tie bar design

Construction
  – Installation
  – Common problems
  – Evaluation
  – Fixing

Summary
• Dower bars
  – Dowel baskets
  – Dowel bar inserter (DBI)

A bond breaker (typically, grease) must be applied prior to placement

• Tie bars
  – Machine-place
  – Placed by hand
  – Chairs
  – Drilled and grouted
Dowel Baskets
Dowel Bar Inserter

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Tie Bar Installation

Drilled

Tie bar chairs

photo courtesy of Gomaco Corp., Inc.
Happy families are all alike;
every unhappy family is unhappy in its own way.

Todas as famílias felizes são iguais.
Todas as famílias infelizes são diferentes.

Lev Tolstoy “Anna Karenina”
Common Installation Problems

- Bars are missing or misplaced
  - Poorly adjusted equipment
  - Damaged dowel baskets
  - Improper basket anchoring
- Concrete around bars is poorly consolidated
  - Poorly adjusted equipment
  - Too stiff mix (often caused by mix delays)
Common Problems

– Dowel and tie bar misplacement
– Dowel and tie bars are too close to each other
– Poor consolidation of concrete around dowels and tie bars
Vertical Position Problem

A tie bar is too far from the mid-depth.
Concrete cover is too low.
Vertical Position Problem

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Cracking occurred near the joint the next morning
Common Problems

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The tie is too close to the dowel
The tie is too close to the dowel
The tie is too close to the dowel
The PCC mix was way too stiff due to paving delays. 300 meters had to be removed and replaced.
Three Ways to Achieve Good Placement
Non-destructive Methods for Bar Location
- Magnetic (MIT SCAN)
- Ground-penetrating radar (GPR)
- Ultrasound tomography
• Advantages
  • Simple
  • Accurate
  • Relatively fast

• Disadvantages
  • Must be calibrated for specific dowels and tie bars
  • May be have problems when dowel baskets are used
  • Cannot determine condition of concrete around dowel or tie bars
Ground-Penetrating Radar (GPR)

Advantages
• Fast – can be used for initial screening/gross bar misplacements

Disadvantages
• Data interpretation is time-consuming
• Resolution is not very high

Rister and Graves 2011
Advantages
• Determines not only bar position but also condition of concrete around dowel/tie bar

Disadvantages
• Relatively slow
Ultrasound Tomography

Pavement-Base Interface

Dowels

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Alignment Tolerances

Washington DOT tolerances for tie bars

- Vertical translation: 25-mm
- Horizontal translation: 25-mm
- Vertical tilt: 25 mm
- Horizontal skew: 25 mm
Ministry of Transportation of Ontario (MTO 2007) tolerances for tie bars

- **Depth tolerance**
  - PCC thickness 200 mm: -6 mm / +12 mm
  - PCC thickness 250 mm: -15 mm / +25 mm

- **Longitudinal translation**: 50-mm

- **Vertical tilt**: 15 mm

- **Horizontal skew**: 15 mm
NCHRP 10-69 Study
University of Minnesota
(Prime Contractor)

Lev Khazanovich
Kyle Hoegh
Mark Snyder

Field Testing of 60 pavement sections across USA

- The majority of joints had dowel misalignments within the following limits:
  - Vertical translation – +/- 13 mm
  - Horizontal skew – +/- 13 mm
  - Vertical tilt - +/- 13 mm
  - Longitudinal translation - +/- 50 mm

- Dowel misalignment within these limits does not appear to significantly affect pavement performance.
Laboratory Testing

- 16 beams, 64 dowels with precise misalignments
- Pullout test
- Shear test
  - Ultimate one time load application
  - Repeated load application

Pullout Test

Shear Test
Analytical Modeling

Plane of Symmetry

Joint

60”
180”
8”

Exaggerated joint opening
**Analytical and Laboratory Results**

- Dowel greasing is very important!
- Dowel alignment

<table>
<thead>
<tr>
<th></th>
<th>Good</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical position</td>
<td>Mid-depth +/- 13 mm</td>
<td>Concrete cover &lt;50 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete cover &lt; saw cut depth</td>
</tr>
<tr>
<td>Embedment length</td>
<td>&gt;175 mm</td>
<td>&lt; 50 mm</td>
</tr>
<tr>
<td>Rotation</td>
<td>&lt; 25 mm/450 mm</td>
<td>&gt; 75 / 450 mm</td>
</tr>
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</table>

- Dowel misalignment has the same apparent effect on joint performance as a reduction in dowel diameter
Equivalent Dowel Diameter Concept

\[ d_{eq} = r_{emb} \times r_{cc} \times r_{vt} \times r_{hs} \times d_0 \]

- \( r_{emb} < 1 \) if longitudinal translation is greater than 50 mm
- \( r_{cc} < 1 \) if vertical translation is greater than 12.5 mm
- \( r_{vt} < 1 \) if vertical tilt is greater than 12.5 mm
- \( r_{hs} < 1 \) if horizontal skew is greater than 12.5 mm
- \( d_0 \) = nominal dowel diameter

MEPDG Faulting Prediction, mm

- \( D = 33 \) mm
- \( D = 38 \) mm

- Pink: Equivalent dowel diameter = 1.32 in
- Blue: Nominal dowel diameter = 1.5 in
- Red: Faulting Limit
If the Bars Misplaced ..

• It is NOT OK to have dowel positioned out of specification
• Do not harm – try to minimize invasive treatment

• How to react
  • Carefully evaluate the problem (determine actual bar location)
  • Evaluate short-term and long-term effects
  • Develop remedy plan
If the Bars are Misplaced ..

• Case A: a dowel or tie bar is to close to the top surface (<50 mm)
  • Cut the dowel through
  • Develop penalty and/or retrofit dowels or tie bars
• Case B: Other types of misplacements
  • Evaluate effective dowel/tie bar diameter
  • Predict performance
  • Develop penalty and/or retrofit dowel or tie bar
• If properly designed and installed, dowels and tie bars significantly improve performance of pavement joints
• Although they increase the initial cost, dowel and tie bars reduce Life Cycle Cost
• Both dowel baskets and dowel bar inserters are good installation alternatives
• Improper dowel installation may reduce effectiveness of the dowels and tie bars
• Nondestructive testing methods give an opportunity to trouble shoot the problems and determine their extent
• The best approach is to use NDT during construction to identify and fix the problem