Design and Construction of Highway Pavement Joint Systems

Dowel and Tie Bar Design Considerations

Part 1

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INTRODUCTION: THE NEED FOR MECHANICAL LOAD TRANSFER
Load Transfer

- Ability of a slab to share load with neighboring slabs through shear mechanism(s)

- Factors affecting load transfer:
  - Load transfer mechanisms:
    - Dowels/Tie Bars
    - Aggregate Interlock
    - Keyways
  - Edge support
    - Widened lanes, tied concrete shoulders or curb and gutter
    - Decrease edge & corner stresses & deflections
  - Foundation shear (stiffness)
Deflection Load Transfer

0% Load Transfer

Wheel Load

Direction of Traffic

Approach Slab

Leave Slab

100% Load Transfer

Wheel Load

Direction of Traffic

Approach Slab

Leave Slab

Unloaded

LT (%) = Loaded X 100

LT (%) = Loaded X 100
Concrete Pavement Deflections

12 ft Lanes

<table>
<thead>
<tr>
<th>Undowedeled Transverse Joint</th>
<th>Outside Pavement Edge</th>
<th>Doweled Transverse Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 $D_i$</td>
<td>3 $D_i$</td>
<td>2 $D_i$</td>
</tr>
<tr>
<td>5 $D_i$</td>
<td></td>
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</table>

Longitudinal Centerline (acts as tied PCC Shoulder)
LTE as a measure of equivalence?

LTE is a measure of system behavior, not dowel equivalence.

LTE is worthless without overall deflection reference

Example #1: dUL = 0.025mm, dL = 0.05mm, LTE = 50% … but is this bad?

Example #2: dUL = 4mm, dL = 5mm, LTE = 80% … but is this good?
## Joint Load Transfer Considerations

**LTE vs. Relative Deflection**

<table>
<thead>
<tr>
<th>Support Condition</th>
<th>(d_l), mils</th>
<th>(d_{rel} = 0.5) mil</th>
<th>(d_{rel} = 1) mil</th>
<th>(d_{rel} = 1.5) mil</th>
<th>(d_{rel} = 2) mil</th>
<th>(d_{rel} = 5) mil</th>
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<tr>
<td>Stiff</td>
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<td>88</td>
<td>75</td>
<td>63</td>
<td>50</td>
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<td>5</td>
<td>90</td>
<td>80</td>
<td>70</td>
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<td>Stiff</td>
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<td>92</td>
<td>83</td>
<td>75</td>
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<td>Stiff</td>
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<td>95</td>
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<td>Medium Stiff</td>
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<td>94</td>
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<tr>
<td>Softer</td>
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<td>Softer</td>
<td>20</td>
<td>98</td>
<td>95</td>
<td>93</td>
<td>90</td>
<td>75</td>
</tr>
</tbody>
</table>

Source: Shiraz Tayabji, Fugro Consultants, Inc.
Joint Stability

ACI 360 definition: “… a joint’s ability to limit differential deflection of adjacent slab panel edges when a service load crosses the joint … (t)he smaller the measured differential deflection number the better the joint stability.”
ACI 360.R-10):
  - < 0.010 in. (0.25 mm) (small, hard-wheeled lift truck traffic)
  - < 0.020 in. (0.51 mm) (larger, cushioned rubber wheels)

What is appropriate for road pavements?

Should the criterion vary with functional applications (e.g., streets vs highways)?

Should the criterion vary with foundation design and environmental conditions (e.g., stabilized vs unbound base, and wet vs dry climate)?
Transverse Joint Load Transfer Systems

- Originally: aggregate interlock
- 1920s – present: mainly round steel dowels
  - Some trials of different shapes and materials
  - Pre-positioned using baskets
  - Automatically placed using DBIs
Aggregate Interlock

Shear between aggregate particles below the initial saw cut

May be acceptable for:
- Few heavy loads
- Hard, abrasion-resistant coarse aggregate
- Joint movement <0.03”
Q: How Long Have Dowels Been In Use?
A: 100 Years! (Almost As Long as PCCP)

- 1865 – First concrete pavement in the world built in Inverness, Scotland
- 1893 – First concrete pavement built in the U.S. (Court Street, Bellefontaine, OH)
- 1917-1918 – First use of dowel bars in concrete pavement transverse joints in the U.S.
A Brief History of U.S. Dowel Design

- First U.S. use of dowels in PCCP: 1917-1918 Newport News, VA Army Camps
  - Two $\frac{3}{4}$-in dowels across each 10-ft lane joint
- Rapid (but non-uniform) adoption through ‘20s and ‘30s
  - 1926 practices: two $\frac{1}{2}$-in x 4 ft, four $\frac{5}{8}$-in x 4 ft, eight $\frac{3}{4}$-in x 2 ft
- By 1930s, half of all states required dowels!
- Numerous studies in ‘20s, ’30s, ‘40s and ‘50s (Westergaard, Bradbury, Teller and Sutherland, Teller and Cashell, and others) led to 1956 ACI recommendations that became de facto standards into the ‘90s:
  - Diameter – D/8, 12-in spacing
  - Embedment to achieve max LT: 8*dia for 3/4-in or less, 6*dia for larger dowels. 18-in length chosen to account for joint/dowel placement variability.
- Recent practices:
  - Trend toward increased diameter, some shorter lengths
Current Dowel Bars (Typical)

- Typical length = 18 in
- Typical diameter
  - Roads: 1.0 - 1.5 in
  - Airports: 1.5 - 2.0
- Epoxy or other coating typically used in harsh climates for corrosion protection
Illustrates recent trend toward larger dowels to reduce bearing stresses and minimize joint faulting and deflections.

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<th>Slab Thickness (in)</th>
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<th>6.5</th>
<th>7.0</th>
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<th>8.0</th>
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Dowels: Critical Structural Components of JCP

- Provide Load Transfer
  - Reduce slab stresses
  - Reduce slab deflections, potential for erosion of support
- Restraint of Curl/Warp Deformation
- Influence Dowel-Concrete Bearing Stress

Need to last for expected pavement service life (corrosion resistance, other durability)
- 20 – 35 years for conventional pavement and repairs
- 40 - 100 years for long-life pavements
Dowel Load Transfer System Design Considerations

- Dowel Diameter/Cross-Section (including plate dowels)
- Dowel Bar Length
- Dowel Alignment Requirements
  - Vertical Translation
  - Longitudinal Translation
- Dowel Spacing and Number of Dowels
- Corrosion Protection
  - Epoxy Coatings
  - Alternate Dowel Materials and Coatings
    - Stainless Steel
    - Microcomposite Steel
    - Zinc Alloy-Sleeved Steel
    - FRP/GFRP
    - FRP/GFRP over Steel
- Dowel Bar Lubrication/Bond-breaker Materials
- Use of Expansion Caps/Joint Forming Materials
CONSIDERATION OF DOWEL SHEAR, BENDING AND BEARING STRESSES
**Dowel LT Design Considerations**

- LT achieved through both shear and moment transfer, but moment contribution is small (esp. for joint widths of \( \frac{1}{4}'' \) or less).

- Shear capacity of **dowel** is not critical, but...
  - Shear capacity of concrete (cover)?
  - Bearing stress at joint/crack face?

- Maximum load transferred varies with slab thickness, foundation support, dowel layout, load placement, etc.

  *Bearing stresses can be critical to performance!*
Dowel Diameter

- Not a standard, not tied to pavement thickness
- A part of concrete pavement system design
  - Impacts faulting, IRI and other performance measures through resulting bearing stress, differential deflection, deflection energy, etc.
Estimating Critical Dowel Load

\[ \ell = \left( \frac{E_C h^3}{12k(1 - \mu^2)} \right)^{0.25} \]

Typical critical dowel load < 3000 lbs
\[ P = K_y \]
Timoshenko & Lessel’s Wire Deflection Equation

\[
y = \frac{e^{-\beta x}}{2 \beta^2 \frac{E_s I}{<}} [ P_{\text{Crit}} \cos \beta x - \beta M_o (\cos \beta x - \sin \beta x)]
\]

- \(y\) = Deflection in steel
- \(\beta\) = Relative stiffness of steel-concrete system
- \(x\) = Distance from face of concrete
- \(M_o\) = Bend. moment at face of concrete \((M_o = -P_t z/2)\)
- \(z\) = Crack width
- \(P_{\text{Crit}}\) = Load transferred by critical wire
Friberg's Dowel-Concrete Bearing Stress

\[ \sigma_b = K y_0 = K P_t (2 + \beta z)/4\beta^3 E_d I_d \]

\[ \beta = (K d/4E_d I_d)^{0.25} \]

\[ I_d = = \pi d^4/64 \text{ for round dowels} \]
ACI 325 (1956)

\[ f_b = f'_c (4 - d)/3 \]

where:

- \( f_b \) = allowable bearing stress, psi
- \( f'_c \) = PCC 28-day compressive strength, psi
- \( d \) = dowel diameter, inches

- Provided factor of safety of 2.5 to 3.2 against bearing stress-related cracking
- Withdrawn from ACI 325 in 1960s, no replacement guidance provided
- Still commonly cited today ...
Impact of Dowel Diameter on Joint Faulting

Example for 10-in slab with specific traffic and climate ... not a design chart!
COPES Model: Bearing Stress vs Joint Faulting

Graph showing the relationship between concrete bearing stress from dowel and joint faulting in inches. The equation for the line is:

\[ F = 10^{(5.1 \times 10^{-4} S - 2.0)} \]

The graph includes a point at 18-kip single axle at joint and 8 inches slab.
Recommendations: Dowel Diameter

- Not a standard, not tied to pavement thickness
- A part of concrete pavement system design
  - Impacts faulting, IRI and other performance measures through resulting bearing stress, differential deflection, deflection energy, etc.
- Manufacturers of all products should produce standard diameters (to facilitate use of standard basket sizes)
DOWEL DESIGN:
DIMENSIONS, PLACEMENT AND MATERIALS
Dowel Length

- Standard typically 18 in (since 1950s)
- Based on embedment requirements to match behavior of Timoshenko 1925 analysis (semi-infinite embedded bar)
- A few states successfully use shorter dowels (e.g., 14 inches in MN)
- Shorter embedment lengths are supported by research dating to 1950s
- Shorter lengths may be feasible for retrofit dowels and full-depth repairs where dowel position is well-controlled
Teller and Cashell, 1959

Khazanovich et al, 2009
Recommendations: Dowel Length

- For round, metallic dowels, provide a minimum of 4 inches of embedment on each side of joint.
- Select dowel length to include embedment requirements and tolerances for placement and joint sawing variability.
- Shorter dowels are possible for retrofit and full-depth repairs where dowel placement and joint location are known more precisely.
Dowel Vertical Position in Slab

- Typically required to be placed at mid-depth
  - Maximize concrete cover (top and bottom)
- Dowel load and moment do not change significantly with vertical placement – reduced cover is feasible, if necessary
Recommendations: Dowel Vertical Location in Baskets

<table>
<thead>
<tr>
<th>Dowel Bar Diameter, in</th>
<th>0.75</th>
<th>1.0</th>
<th>1.25</th>
<th>1.5</th>
<th>1.75</th>
<th>2.0</th>
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</thead>
<tbody>
<tr>
<td>Height to Dowel Center, in</td>
<td>2.5</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
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<td>Intended Slab Thickness, in</td>
<td>5 – 6</td>
<td>6 – 8</td>
<td>8 – 10</td>
<td>&gt;10</td>
<td>&gt;12</td>
<td>&gt;12</td>
</tr>
<tr>
<td>Distance Between Dowel Center and Slab Mid-Depth, in</td>
<td>0 – 0.5</td>
<td>0 - 1</td>
<td>0 - 1</td>
<td>0 - ?</td>
<td>0 - ?</td>
<td>0 - ?</td>
</tr>
</tbody>
</table>

- In-range or upsize placements within 1 inch of mid-depth
- Downsize use placements within 2 inches of mid-depth (closer to bottom than top)
- Vertical translation tolerances supported by testing and experience
“OPTIMIZATION” OF DOWEL LOCATION
“Optimized” Dowel Spacing

- Trend toward reducing standard dowel installations from 12 dowels per 12-ft lane to 11
  - Increase distance from lane edge to outside dowels to reduce incidence of paver-induced misalignment
- Concentrated dowels in wheel paths
  - Common in dowel bar retrofit applications
  - Some trends for new construction
- Evaluate bearing stresses for alternate spacings using DowelCAD software
“Optimized” Dowel Designs

- Reduce bearing stress while holding cross-sectional area constant (or reducing it)

- Examples:
  - Elliptical Dowels
  - Plate Dowels
  - Hollow Dowels (MnDOT)
## DowelCAD 2.0

### Dowel Comparison Analysis and Design

<table>
<thead>
<tr>
<th>Dowel Spacing:</th>
<th>12 inches</th>
<th>Joint Opening:</th>
<th>0.25 inches</th>
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</thead>
<tbody>
<tr>
<td>Concrete Elastic Modulus:</td>
<td>4000000 psi</td>
<td>Wheel Load:</td>
<td>9000 lbs</td>
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<tr>
<td>Slab Thickness:</td>
<td>12 inches</td>
<td>Tire Pressure:</td>
<td>90 psi</td>
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<tr>
<td>Slab Support Reaction Modulus:</td>
<td>300 psi/inch</td>
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<td></td>
</tr>
</tbody>
</table>

**Legend:**
- Green = Acceptable Option
- Yellow = Acceptable for Wide Lanes, Tied Shoulders, Good Support, and/or Low Traffic
- Red = Unacceptable Option

### Dowel Diameter(s) (inches):

<table>
<thead>
<tr>
<th>Diameter</th>
<th>1</th>
<th>1.25</th>
<th>1.5</th>
<th>1.75</th>
<th>2</th>
<th>1.41</th>
<th>1.66</th>
<th>1.98</th>
</tr>
</thead>
</table>
| Load Transfer (%) -
| Deflection LTE: | 71.6 | 77.2 | 80.8 | 83.2 | 84.8 | 75.3 | 75.9 | 79.1 |
| Stress LTE: | 26.1 | 30.1 | 33.1 | 35.4 | 37.1 | 28.6 | 29.0 | 31.6 |
| Effectiveness: | 46.2 | 47.0 | 47.5 | 47.8 | 48.0 | 46.7 | 46.8 | 47.2 |
| Bearing Stress (psi) -
| Edge Loading: | 1479 | 1060 | 788 | 602 | 469 | 1246 | 758 | 565 |
| Corner Loading: | 2469 | 1744 | 1284 | 975 | 755 | 2060 | 1252 | 926 |
Restraint of Movements in Area Pavements
Restraint of Odd-shaped Panels and Roundabouts
Various Plate Dowel Assemblies

Source: ACI 360 R-10
Plate Dowel Geometries for Contraction Joints

Sawcut at boundary of installation tolerance

Formed void space on vertical sides of plate
Plate Dowels at MnROAD: Preliminary Test Results

- >2.5 million ESALs to date
- Performance Summary
  - Joint performance is good
  - Joint deflection less than round dowels
  - Consolidation is good
  - LTE in acceptable range
  - Less cracking

Core sample showing consolidation above and below plate

3/8” x 12” PD³ basket assembly
Plate dowels for slip-formed or ‘new-to-existing’ joints
Epoxy-grouted CoVex™ Plates
Plastic debonding sleeves installed
Super-Paver – A Re-usuable Urban Pavement (RUP) System

- Light weight
  - 6’ x 6’ weighs 2 T
- Vertically removable & replaceable
- Warped as required to fit any surface
  - Standard warps are in stock
- Removable and reusable

(Designed specifically for utility-intensive urban highways and intersections)

Source: The Fort Miller Company, Inc.
Slab Removal & Replacement

1. Drill out (clean port holes)
2. Remove grout plug & dowel
3. Remove bedding grout
4. Remove dowel only
5. Apply bond breaker
6. Epoxy anchor new dowel

Source: The Fort Miller Company, Inc.
PREVENTION OF CORROSION-RELATED PROBLEMS
The Corrosion Problem

- Corrosion - the destruction or deterioration of a metal or alloy substrate by direct chemical or electrochemical attack.
- Corrosion of reinforcing steel and dowels in bridges and pavements causes cracking and spalling.
- Corrosion costs an estimated $276B per year in the U.S. alone!

Corroded dowels obtained from in-service JCP.
Effects of Corrosion on JCP Dowels

- Loss of Cross-Section at Joint
  - Poor Load Transfer
  - Reduced Curl-Warp Restraint

- Joint Lockup (Corrosion Products)
  - Spalling
  - Crack Deterioration
  - Premature Failure
Dowel Corrosion Solutions: Barrier Techniques

- Form Oil, Grease, Paint, Epoxy, Plastic
  - Coating breach → corrosion failure
- Stainless Steel Cladding and Sleeves
  - Relatively expensive
  - Corrosion at coating breaches (including ends), accelerated due to galvanic reaction.
Dowel Corrosion Solutions: Corrosion-Resistant/Noncorroding Materials

- Stainless Steel (Solid, Tubes)
  - Expensive (solid bars and, to a less extent, grout-filled tubes)
  - Deformation and slab cracking concerns (hollow tubes only)

- “Microcomposite” Steel
  - Sufficient corrosion resistance?

- GFRP Products
  - Not yet widely adopted
  - Concerns over behavior, durability
Dowel Corrosion Solutions: Barrier/Cathodic Protection

- Galvanic (Sacrificial)
  - Inexpensive and self-regulating
  - Appears well-suited for pavement dowel applications (zinc cladding or sleeve)
Epoxy Coatings

- Most common approach to corrosion prevention since 1970s
- Long-term performance has varied with environment, coating properties, construction practice and other factors
  - Sometimes unreliable for long performance periods.

Photo credit: Tom Burnham, MnDOT

Photo credit: Washington State DOT
Dowel Epoxy Coatings

- Typical product: AASHTO M254/ASTM 775 (green, “flexible”)
- ASTM 934 (purple/grey, “nonflexible”) has been suggested
  - Perception of improved abrasion resistance (but green meets same spec requirement)
  - Mancio et al. (2008) found no difference in corrosion protection

What is needed:
- Durability, resistance to damage in transport, handling, service
- Standardized coating thickness
Epoxy Coatings for Dowels: Better Stuff is Available!

Simplex Supply Armour Coat – 2-layer fusion-bonded system
Recommendations: Epoxy Coating

- Remains least expensive, potentially effective option
- Only effective if durable and applied with sufficient and uniform thickness
  - Consider use of improved epoxy materials
- 10-mil nominal minimum thickness meets or exceeds requirements of all surveyed states
  - Would allow individual measures as thin as 8 mils if average exceeds 10 mils
- Probably not necessary to specify upper limit
  - Self-limiting due to manufacturer costs
  - Potential downside is negligible for dowels
Dowel Bar Materials

Many materials are suitable

- Selection should consider environmental conditions, design requirements (performance life), cost considerations

Structural, behavioral considerations favor continued use of metallic products

- no design adjustments needed (dowel diameter, spacing)
- For LLCP, stainless steel (316L) and zinc-sleeved products offer the best combination of predictable structural behavior and corrosion resistance
- Microcomposite steel is less corrosion-resistant; epoxy coating may be appropriate for long-life applications

What about FRP dowels (E of FRP is 20% of steel E)?
## Modifying FRP Dowel LT System Design for Structural Equivalence with Metallic Dowels

<table>
<thead>
<tr>
<th>Dowel Type</th>
<th>Diameter (in)</th>
<th>Dowel Modulus, E (psi)</th>
<th>Applied Shear Force (lbs)</th>
<th>Dowel Deflection at Joint Face (in)</th>
<th>Bearing Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>1.50</td>
<td>29,000,000</td>
<td>1940 (12-in spacing)</td>
<td>0.0009</td>
<td>1405</td>
</tr>
<tr>
<td>Sch 40 Pipe</td>
<td>1.66</td>
<td>29,000,000</td>
<td>1940 (12-in spacing)</td>
<td>0.0009</td>
<td>1421</td>
</tr>
<tr>
<td>FRP</td>
<td>1.50</td>
<td>5,600,000</td>
<td>1940 (12-in spacing)</td>
<td><strong>0.0015</strong></td>
<td><strong>2185</strong></td>
</tr>
<tr>
<td>FRP</td>
<td>1.93</td>
<td>5,600,000</td>
<td>1940 (12-in spacing)</td>
<td>0.0009</td>
<td>1393</td>
</tr>
<tr>
<td>FRP</td>
<td>1.50</td>
<td>5,600,000</td>
<td><strong>1293 (8-in spacing)</strong></td>
<td>0.0010</td>
<td>1456</td>
</tr>
</tbody>
</table>
Many studies of FRP dowels ...

- Davis and Porter (1998)
  - Similar joint LTE for 44-mm FRP @ 8 in and 1.5-in steel @ 12 in

- Melham (1999)
  - 1.5-in FRP performed comparably to 1.0-in steel

- FHWA TE-30 (IL, WI, IA, etc.)
  - IL (Gawedzinski, 2004): FRP LTE lower and more variable
  - IA (Cable and Porter, 2003): FRP dowel max spacing 8-in; horizontal delamination observed in core.
  - WI (Crovetti, 1999): Significantly reduced LTE for FRP dowels, but no performance differences in short term

- Larson and Smith (2005): “… low LTEs of FRP dowels in less than 5 years is a serious concern.”

- Odden et al., Popehn et al., 2003 (U-Mn)
Guide and Tech Brief
Now Available!

National Concrete Pavement Technology Center at Iowa State University
Summarizes factors and design theories that should be considered in dowel load transfer system design
Includes practical considerations and results of NCC surveys and discussions concerning dowel basket design and fabrication
Discusses alternate dowel materials
Presents recommendations for widespread adoption (i.e., standardization)
  - Basket wire sizes
  - Basket height as function of dowel diameter
  - Does NOT recommend dowel diameter for various pavement thicknesses
  - Dowel length and spacing
Appendices with additional support documentation
DESIGN AND EVALUATION OF TIE BAR SYSTEMS
JRCP Reinforcement Design: “Subgrade Drag Theory”

\[ A_s(\text{min}) = \frac{T}{f_s} \]

- \( A_s(\text{min}) = \) Minimum area of steel required (per foot width of pavement) to hold cracks tight
- \( f_s = \) Allowable working stress = 0.75(yield stress of steel)
- \( T = \) Max. Tensile Force developed in steel (per foot width)
  \[ = \frac{L}{2} \times \text{(unit width)} \times h_c \times \gamma_c \times F \]
- \( L = \) Distance between working joints or pavement edges, ft
- \( h_c = \) Slab thickness, ft
- \( \gamma_c = \) Unit weight of concrete, pcf (140-150 pcf)
- \( F = \) friction coefficient between slab and underlying layer (see 1993 AASHTO p II-28)
Figure 3.13. Recommended maximum tie bar spacings for PCC pavements assuming 1/2 diameter tie bars, Grade 40 steel, and subgrade friction factor of 1.5.

Example: Distance from free edge = 24 ft.
D = 10 in.
Answer: Spacing = 16 in.

Figure 3.14. Recommended maximum tie bar spacings for PCC pavements assuming 5/8-inches diameter tie bars, Grade 40 steel, and subgrade friction of 1.5.

Example: Distance from free edge = 24 ft.
D = 10 in.
Answer: Spacing = 24 in.
ACPA M-E Tie Bar Designer App

### MECHANISTIC-EMPIRICAL TIE BAR DESIGNER ###

#### LOCATION DETAILS ####

- **State:** Illinois  
- **Location:** Chicago

#### CONCRETE MATERIAL DETAILS ####

- **Cement Type:** Type I
- **Cementitious Materials Content (lb/yd³):** 564.0
- **Coefficient of Thermal Expansion (10⁻⁶/°F):** 5.50

#### CONCRETE PAVEMENT STRUCTURE DETAILS ####

- **Concrete Pavement Thickness (in.):** 12.00
- **Lane Configuration:** Four Tied 12-ft Lanes
- **Subbase Type/Thickness:** Asphalt Treated Subbase (ATB) - 6 in.

#### CONSTRUCTION DETAILS ####

- **Month of Construction:** August
- **Curing Procedure:** Curing Compound

#### CALCULATED DESIGN ####

- **Total Free Strain:** 750  
  (Rounded up from 704)
- **Tie Bar Size:** #6  
  (Tie Bar Spacing: 30)
- **Tie Bar Length:** 24  
  (Steel Grade: 60)

**Note:** The longitudinal joint in this design contains 0.177 in² of steel per foot; this value may be used to determine equivalent designs for alternate tie bar sizes.
LONGITUDINAL JOINT CONNECTION

#6 DAYTON SUPERIOR EPOXY COATED D-108 HEADED DOWEL-IN @ 2'-0" O.C. & 6 3/4" LONG.

#6 DAYTON SUPERIOR EPOXY COATED DB-SAE @ 2'-0" O.C. & 1'-6" LONG.

1"x1" FOAM GASKET

1"x1" CHAMFER ALONG ALL BOTTOM EDGES

APPROVED HIGH STRENGTH STRUCTURAL GROUT

Source: The Fort Miller Co., Inc.
**Test Results**

- **6-inch headed ties:**
  - Average pullout = 22.2 kips (range = 18.16 – 25.32)
  - Keyed average: 22.71 kips
  - No-key average: 21.41 kips

- **7-inch headed ties:**
  - Average pullout = 25.9 kips (range = 24.02 – 27.26)
  - Keyed average: 25.75 kips
  - No-key average: 26.13 kips

- **TxDOT Std 361.3** requires $0.75 \times$ yield strength (19.9 kips for #6 bars, Grade 60 steel) for repair work

*But what do we really need???

Source: The Fort Miller Co., Inc.*
Dowel/Tie Bar Vertical Position in Slab

- Typically required to be placed at mid-depth in U.S.
  - Maximize concrete cover (top and bottom)
- Germany places tie bars 2/3 from top
- Dowel load and moment do not change significantly with vertical placement
Beware of Dowel-Tie Interference!!

Hold tie bars at least 15” from transverse joints (many states use 30” ... )