Design of Longitudinal Joints

National Concrete Consortium
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ACPA
AMERICAN CONCRETE PAVEMENT ASSOCIATION

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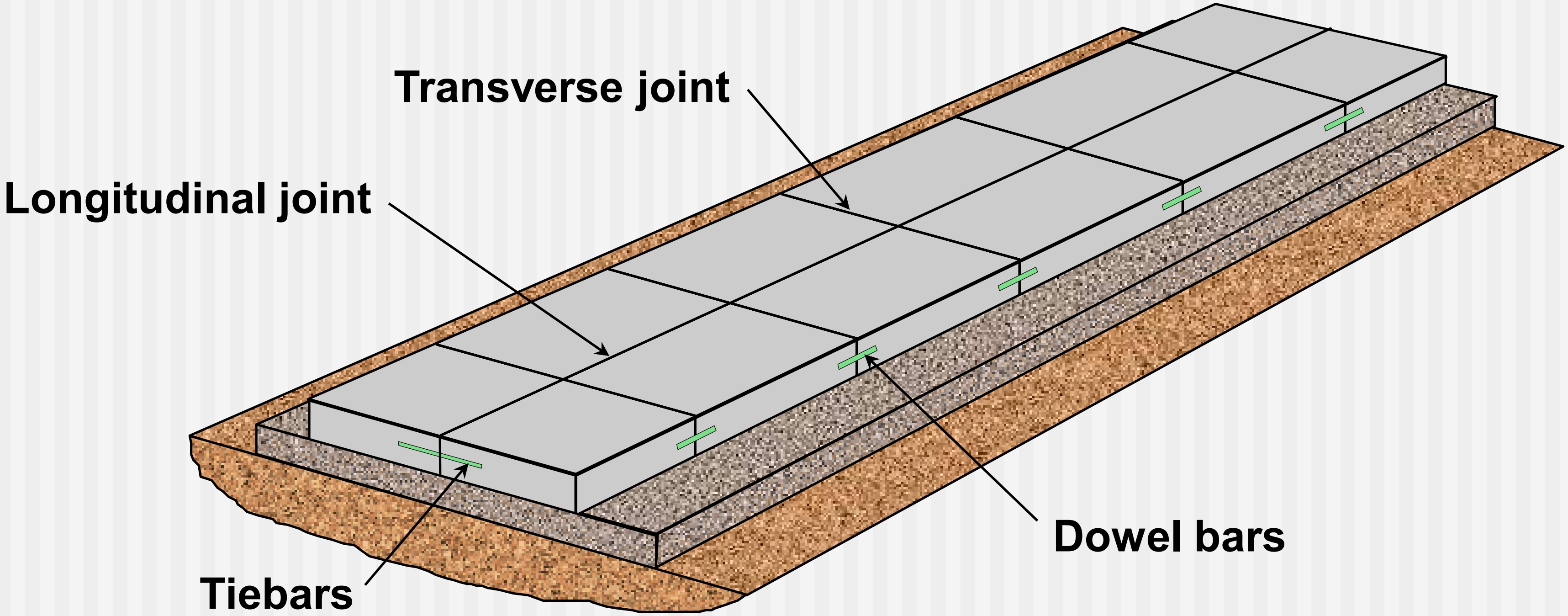
Presentation Overview

- Design of and Details for Longitudinal Joints
  - Typical Tiebar Practices
  - AASHTO (93) Tiebar Design Methodology
  - ACPA M-E Recommended Procedure & Example
- SPS-2 Experience
- Longitudinal Joint Repair– Cross Stitching

Jointing in JCP



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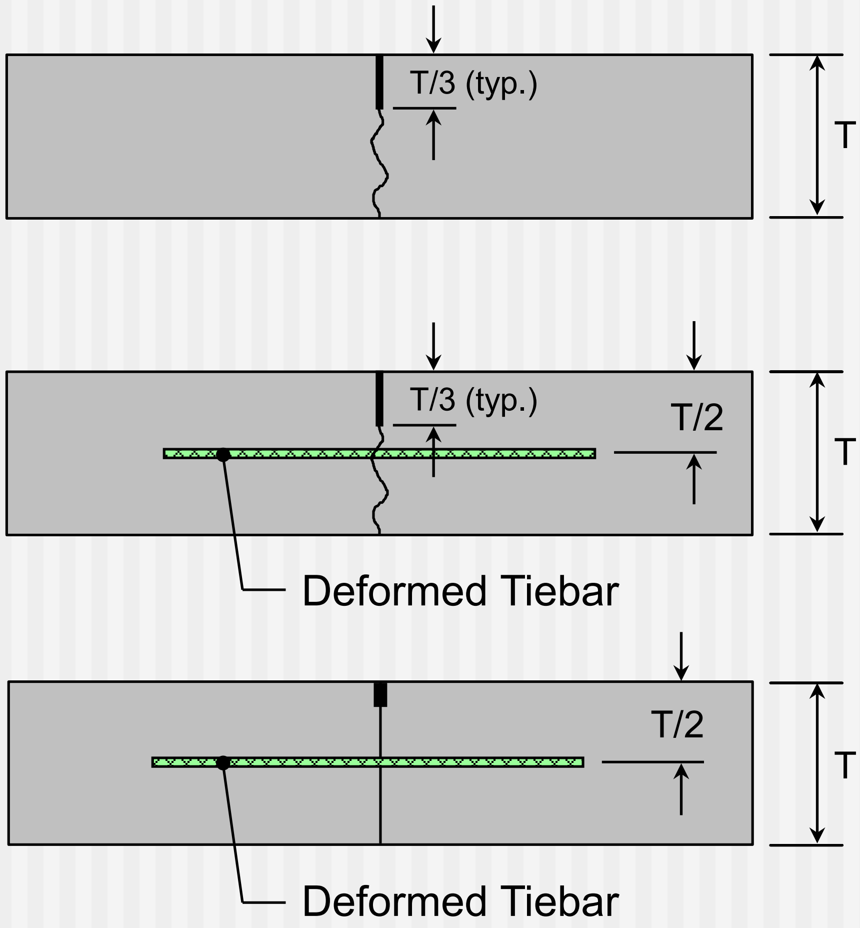
Longitudinal Joints in JCP

Untied Contraction

Tied Contraction

Tied Construction



Purpose of Tiebars

- Load Transfer Along Longitudinal Joints
- Edge Support From Adjacent Slabs / Shoulders
- Prevent Slabs From Drifting Apart
- Minimize Differential Settlement / Heaving

Agency Designs

- State Agencies Typically Use Standard Design Details
  - Tie Bar Size
  - Depth of Embedment
  - Spacing
- Design and Installation Practices Vary Among States

State Experience – In General

- Typically deformed bars, ½ to ¾ in. diameter (#4 to #6), 24 to 30 in. long, and spaced at about 24 to 36 in.
- Typical state spec:
  - Grade 40 or 60 (ksi)
  - #5 bar (0.625 in.)
  - 30 in. long
  - 30 in. spacing

Regardless of the width of pavement tied together!

State Experience

California (Caltrans)

- Stopped using tiebars in mid-1960's
  - Some projects built 1960-1990 experienced unacceptable joint opening, others performed fine
- Started using again in early 1990's
  - Some projects built 1995-present have experienced longitudinal cracking

State Experience

Illinois (IDOT)

- Interstate 74, experimental PCC shoulders after 10 years of service *
  - Tiebars, keyway, granular base: 97.8% load transfer efficiency (LTE)
  - Tiebars, keyway, no subbase: 70.2% LTE
  - No tiebars, keyway, with granular base: 16.0% LTE

* Ref: FHWA/RD-81/122

AASHTO (93) TieBar Design Approach

- **Simply Put**: Determines The Quantity of Steel Required to Drag a Concrete Slab Over an Underlying Layer Without the Steel Yielding or Pulling Out

AASHTO Tiebar Design Methodology

Subgrade drag theory

$$A_s = \frac{F \cdot L \cdot W}{2 f_s}$$

Where:

- A_s = cross-sectional area of steel per ft. of slab
- F = friction factor
- L = distance between joints (2 x dist. to free edge)
- W = weight of slab (12.5 psf per inch of thickness)
- f_s = allowable stress in reinforcement ($0.75 f_y$)

ACPA Concerns Prior to M-E

- Over-designed tiebars (large diameter, closer spacing) can result in:
  - Longitudinal joints that do not open
  - Excessive restraint
  - Longitudinal cracking

- Stabilized bases help keep joints tight & slabs together, therefore requiring less tiebar steel
- Stabilized bases also help load transfer

ACPA Concerns Prior to M-E

- Using subgrade drag theory, higher friction bases (i.e. AC- or PC-stabilized) give tighter spacings – doesn't make sense…base keeps slabs together!
- Some projects around the country have had problems with longitudinal cracking
- ACPA sponsored study "Longitudinal Joint Requirements for Concrete Pavements" to Develop New Tiebar Design Criteria

Field Experience

- Longitudinal Joints Can Widen Over Time if Not Properly Designed and Installed
- Widening of the Joint Can Cause
  - Increased Risk of Transverse Cracking
  - Loss of Load Transfer
  - Safety Issues if it Becomes Excessive

Need for an Improved Design

- Current Method Does Not Account for:
  - Effects of Temperature Drop
  - Drying Shrinkage
  - Loading Conditions on Tie Bar
- Push Off Tests Suggest Slab Thickness Does Not Influence Maximum Frictional Stress at the Interface
- ACPA Hired ARA to Develop M-E Tie Bar Design

ARA Approach to M-E Design

- Literature Search
  - Experimental Investigations to Characterize Concrete slab/supporting Layer Friction were Conducted in the Mid1980s
  - Most of the Numerical Models Developed were Based on the Results of Pull-out Tests
- Field Investigations (width ranged from 22ft to 100ft)
  - Collected Anecdotal Failure Modes: Faulting or Separation
  - Temperature Effects on Joint Opening and Load Transfer

Field Investigations (10 States)

Photos Courtesy ARA

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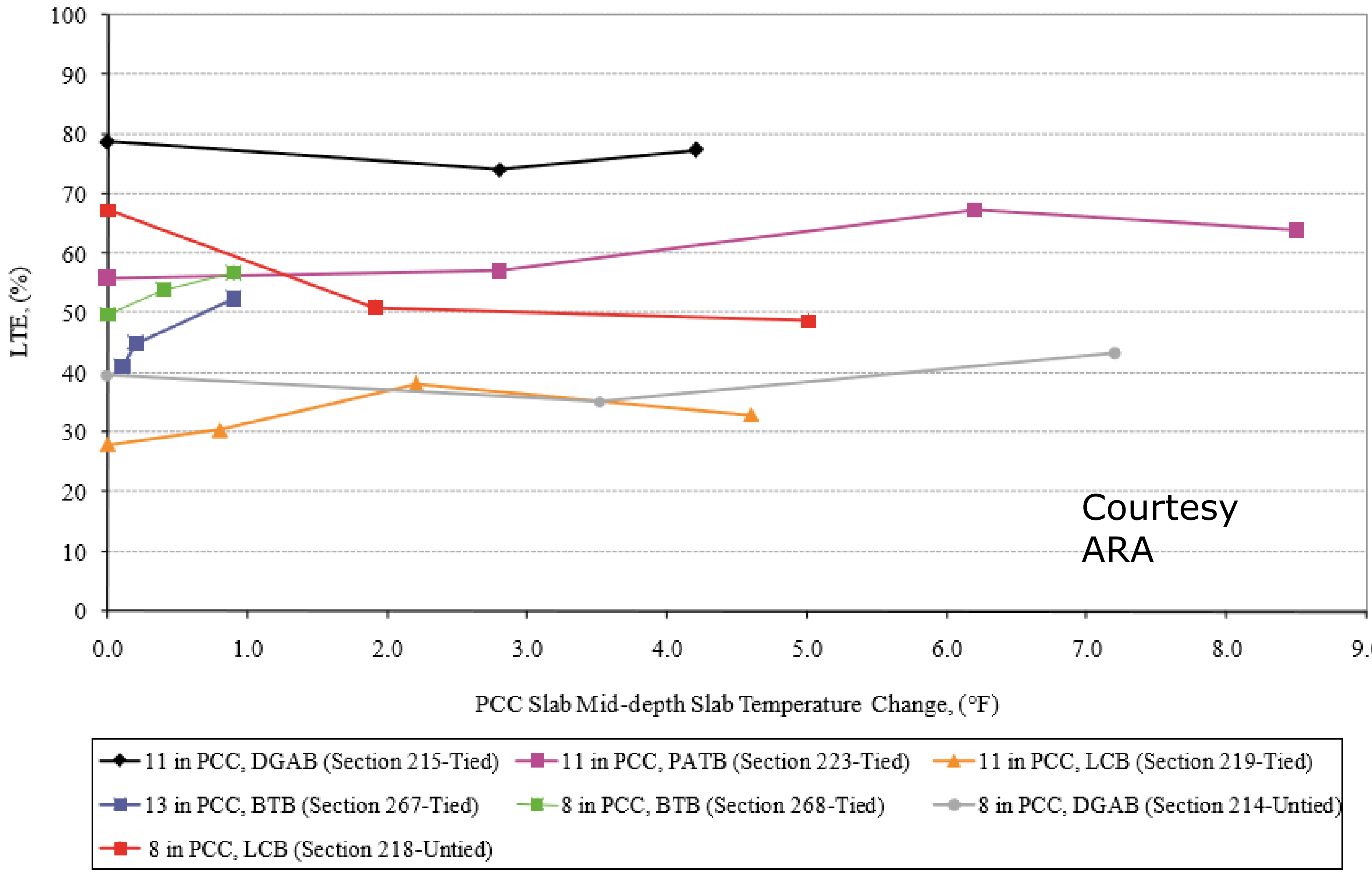
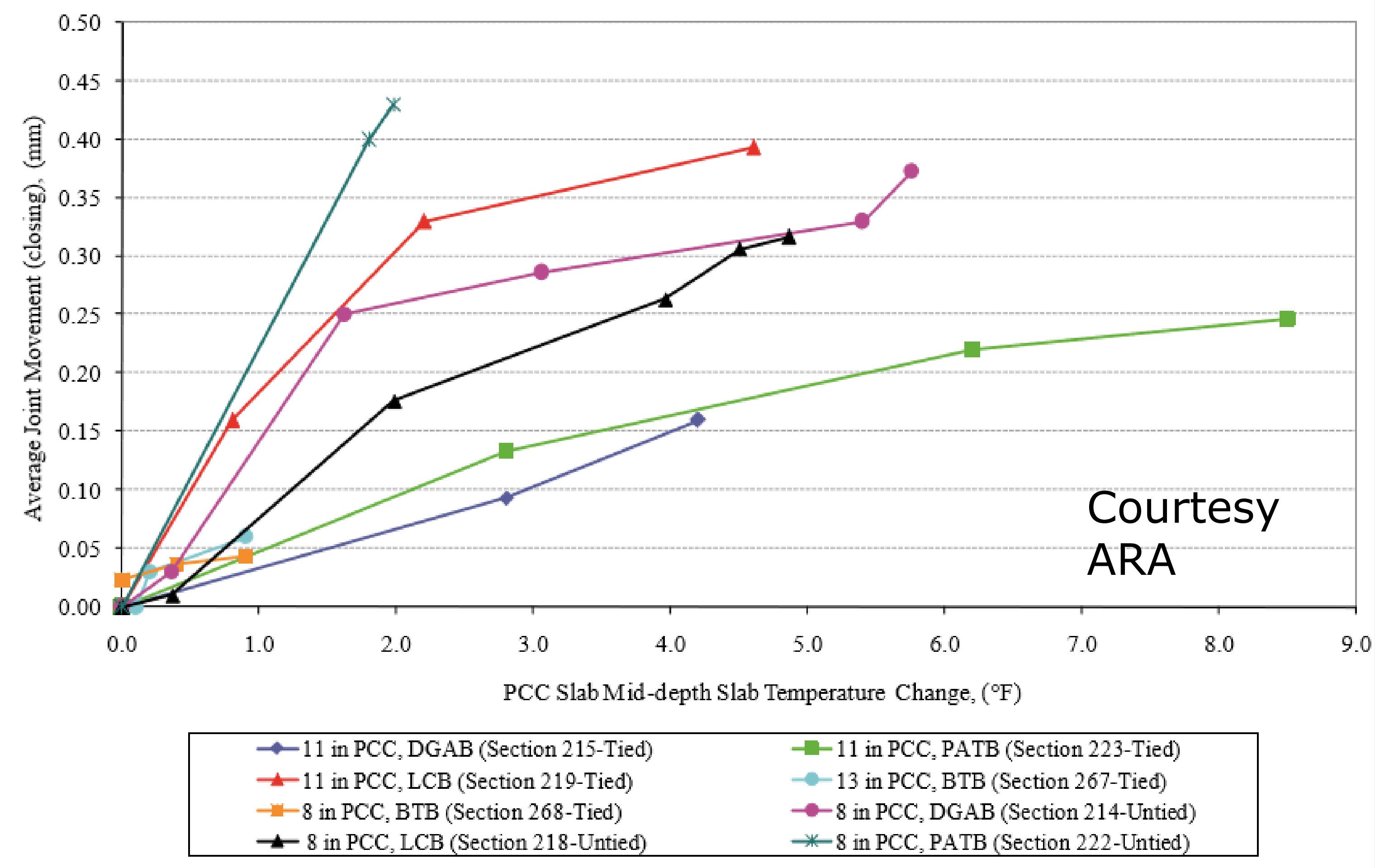
Field Investigation (Arizona SPS-2)
PCCP Temperature Vs Load Transfer



Field Investigation (Arizona SPS-2)
PCCP Temperature Vs Joint Movement



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ARA M-E Tie Bar Design Procedure

- ISLAB2005 Used With a Two-Layered System Consisting of PCCP with Tied Joints and a Base Layer Resting on a Winkler Foundation
- Two Slab Dimensions Used:
  - Standard Section: 15 x 12 feet
  - Widened Lane Section: 15 x 14 feet
- Concrete Drying Shrinkage and Temperature Drop used to Define the Environmentally-induced Loading

M-E Sensitivity Analysis

- Base Modulus More Important than Concrete Slab-base Interface Friction
- Joint Opening (and tie steel stress) Increases with Increasing Base Thickness and Base Modulus
- Higher Steel Contents Needed for Stiffer Bases
- PCCP Slab Thickness Does Not Have a Significant Effect on Either Joint Opening or Tensile Stresses in Tie Bars
- Increasing Lane Width and Number of Tied Lanes will Increase Opening of Longitudinal Joints

Comparison Between AASHTO and M-E Approach

- Two locations- Las Vegas and Chicago
- When Two – Three Lanes Tied Together
  - Little Difference for Unbound Bases
  - For Stabilized Bases, M-E Approach Requires Significantly More Steel
- When More than Three Lanes Tied Together
  - M-E Required Less Steel for Unbound Bases
  - Stabilized Bases Little Difference
- M-E Approach Insensitive to Thickness While AASHTO Increases Steel Content

Mechanistic-Empirical Tie Bar Designer

LOCATION DETAILS

State: Select State...

Location: Select City...

CONCRETE MATERIAL DETAILS

Cement Type: Select Cement Type...

Cementitious Materials Content (lb/yd³):

Coefficient of Thermal Expansion (10⁻⁶/ºF):

CONCRETE PAVEMENT STRUCTURE DETAILS

Concrete Pavement Thickness (in.):

Lane Configuration: Select Lane Configuration...

Subbase Type/Thickness: Select Subbase Type/Thickness...

CONSTRUCTION DETAILS

Month of Construction: Select Month of Construction...

Curing Procedure: Select Curing Procedure...

Submit | Save Inputs

Select Cement Type...

Cement type is required

- Type I
- Type I/II
- Type II
- Type III

Select Lane Configuration...

- Two Tied 12-ft Lanes
- 12-ft Lane Tied to a 14-ft Lane
- Two Tied 14-ft Lanes
- Three Tied 12-ft Lanes
- Four Tied 12-ft Lanes

Select Subbase Type/Thickness...

- Asphalt Treated Subbase (ATB) - 6 in.
- Cement Treated Permeable Subbase - 6 in.
- Cement Treated Subbase (CTB) - 6 in.
- Lean Concrete Subbase (LCB) - 6 in.
- Soil Cement Subbase - 6 in.
- Unstabilized (Granular) Subbase - 6 in.

Select Month of Construction...

Select Curing Procedure...

- Curing Compound
- Wet Burlap

Example Problem

LOCATION DETAILS

State:	Arizona
Location:	Phoenix

CONCRETE MATERIAL DETAILS

Cement Type:	Type I/II
Cementitious Materials Content (lb/yd³):	550.0
Coefficient of Thermal Expansion (10^{-6}/ºF):	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

Submit | Save Inputs

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The Solution

CALCULATED DESIGN

Total Free Strain:	700	Rounded up from 698.04	
Tie Bar Size:	#6	**Tie Bar Spacing*:**	36
Tie Bar Length:	24	**Steel Grade:**	60

THE LONGITUDINAL JOINT IN THIS DESIGN CONTAINS 0.147 IN.^{2} OF STEEL PER FOOT; THIS VALUE MAY BE USED TO DETERMINE EQUIVALENT DESIGNS FOR ALTERNATE TIE BAR SIZES.

* The provided tie bar spacing shown is a maximum value. A slightly shorter tie bar spacing may be neccessary, depending on slab length and the required distance between tie bars and dowel bars at transverse joints.

NOTE: The original research investigating the impact of cement type on ultimate shrinkage did not consider a Type I/II cement; because you have selected Type I/II cement, the cement type factor used in the calculation of ultimate shrinkage is assumed to be 1.0, comparable to that of Type I cement. See page 53 of "A Mechanistic-Empirical Tie Bar Design Approach for Concrete Pavements" for more details on the ultimate shrinkage calculation.

SPS-2 Findings

Shoulder

Subgrade Construction

Travel Lane

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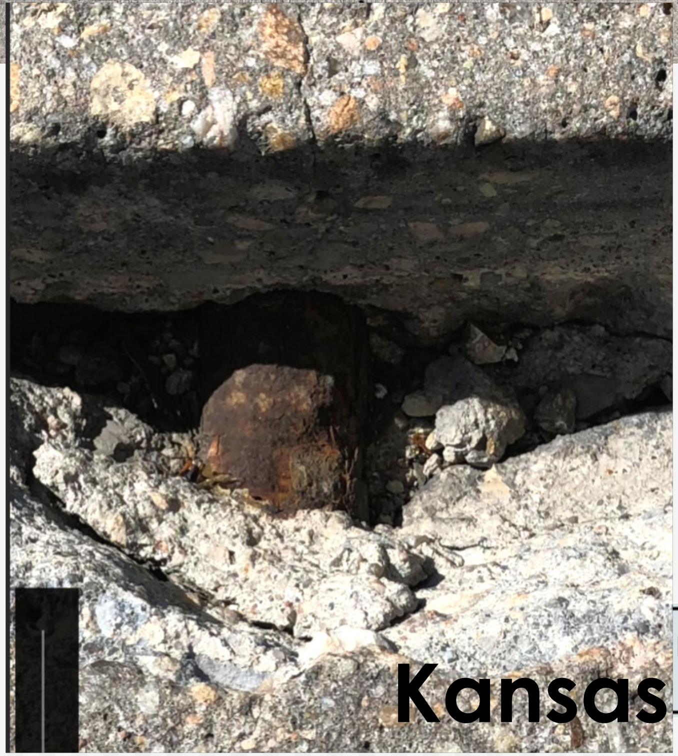
SPS-2 Findings

Lane Width

SPS-2 Findings



Cracking Over Dowels

8” PCCP

What Do You Do With Untied Joints or Longitudinal Cracks

Repair It

Repair: Cross-Stitching

- First Attempted by Army Corp of Engineers in 1971 on Military Airfield
  - Research concluded that stitching among the most viable techniques to strengthen longitudinal joints
- First Highway Application in 1985 on I-70, Utah
  - Applied to 9” JPCP – approx 1800’
  - After Over 30 yrs, repairs performed well overall, preventing lane separation and minimizing settlement of the slabs

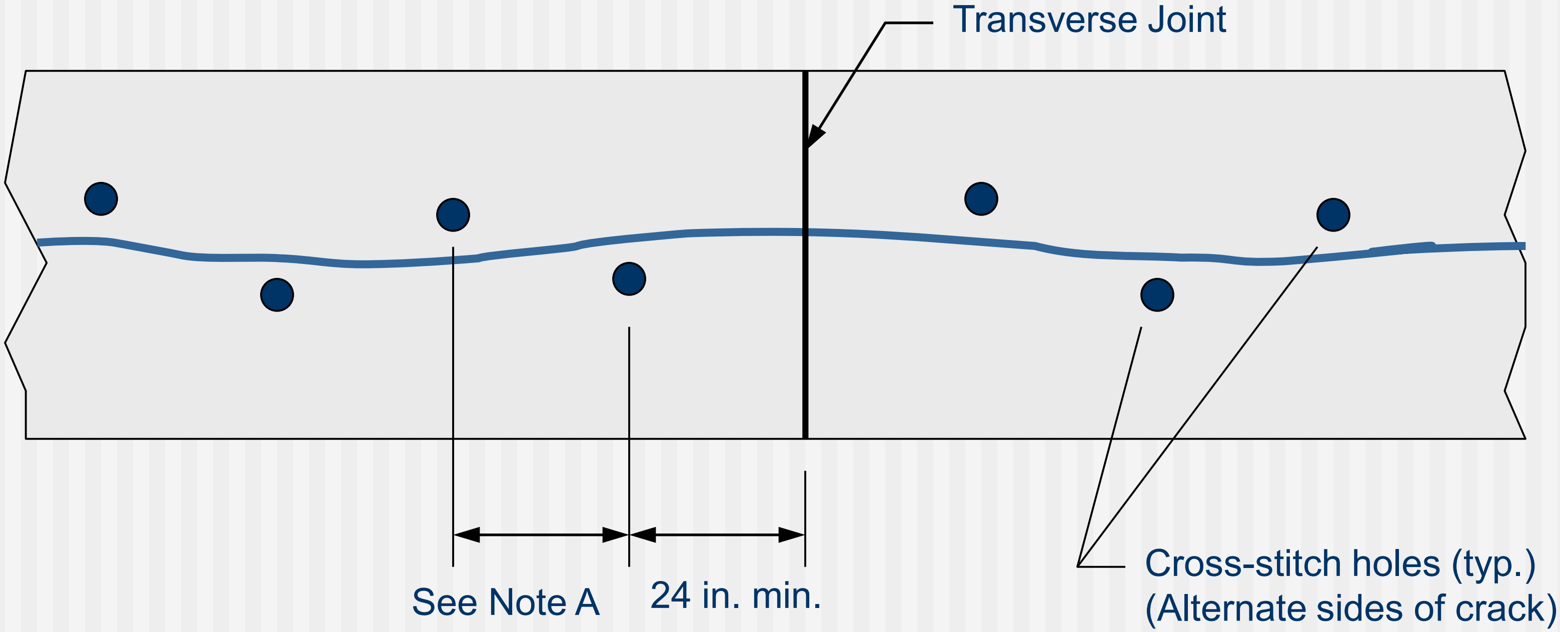
Cross Stitching Techniques

- Bar diameter dependent on slab thickness and facility type
- Bars are spaced 24 - 36 in. dependent on slab thickness and facility type
- Alternate bars on either side of crack or joint

Cross Stitching Techniques

- Drill holes at 35 degrees for slabs less than 12 in. thick
- Drill holes at 45 degrees for slabs 12 in. thick or greater
- DO NOT drill through bottom of slab

Top View



Note A: *Distance between holes is 24 in. for heavy traffic; 36 in. for light traffic*
Note B: *Determine distance from longitudinal crack to hole based on slab thickness T and drill angle. Slabs less than 12 inches thick require a 35° insertion angle.*

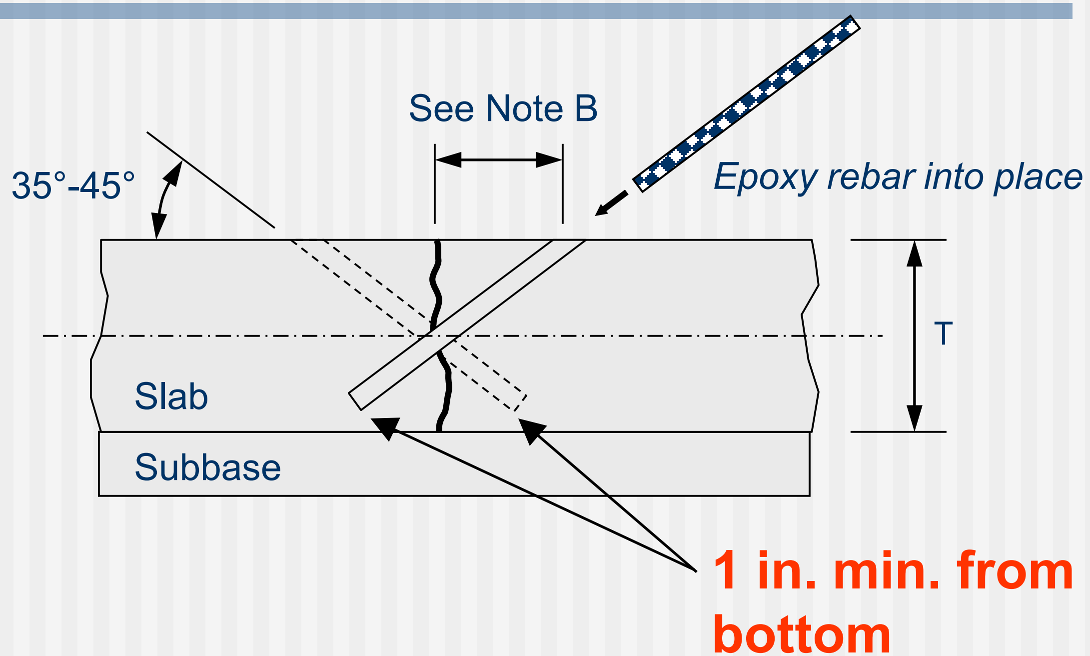
Cross Stitching Steps

- Drill Holes
- Inject Epoxy into Holes
- Insert Tiebar into Hole
- Remove Excess Epoxy
- Finish Flush with Surrounding Pavement Surface

Drilling Holes

- Drill holes using frame-mounted hydraulic drill
- Intersect crack or joint at mid-depth
- Select drill diameter no more than 0.375 in. larger than the tiebar diameter
- Bar length should allow at least 1 in. from top and bottom of pavement

Cross-Section View



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Recommended Tiebar Lengths and Locations

Slab Thickness	Dist. From Joint or Crack	Drilled depth	Length of Bar
8.0”	5.7”	11.9”	9.8”
9.0”	6.5”	13.5”	11.5”
10.0”	7.0”	14.0”	12.5”
11.0”	8.0”	16.0”	13.0”
12.0”	8.5”	17.5”	14.0”
13.0”	9.5”	20.0”	16.0”
14.0”	10.0”	21.0”	18.0”

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Inject Epoxy

- Inject epoxy into hole – DO NOT POUR
- Allow some volume for bar to occupy hole

Insert Tiebar

- Insert bars into hole with twisting motion
- Make sure bar is fully inserted
- Remove excess epoxy and finish flush with pavement surface

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Summary

- A New Methodology for Design of Longitudinal Joints in Concrete Pavements Placed on different Types of Bases
  - The M-E Approach Considers Environmentally-Induced Strains as an Input to Tie Bar Design
  - Better for Situations When Multiple Lanes and Shoulders are Tied Together
  - Evaluated Several Combinations of Pavement Cross-Section, Concrete Materials, Slab-base Friction, steel-concrete interface, and longitudinal joint factors

Bonus Question

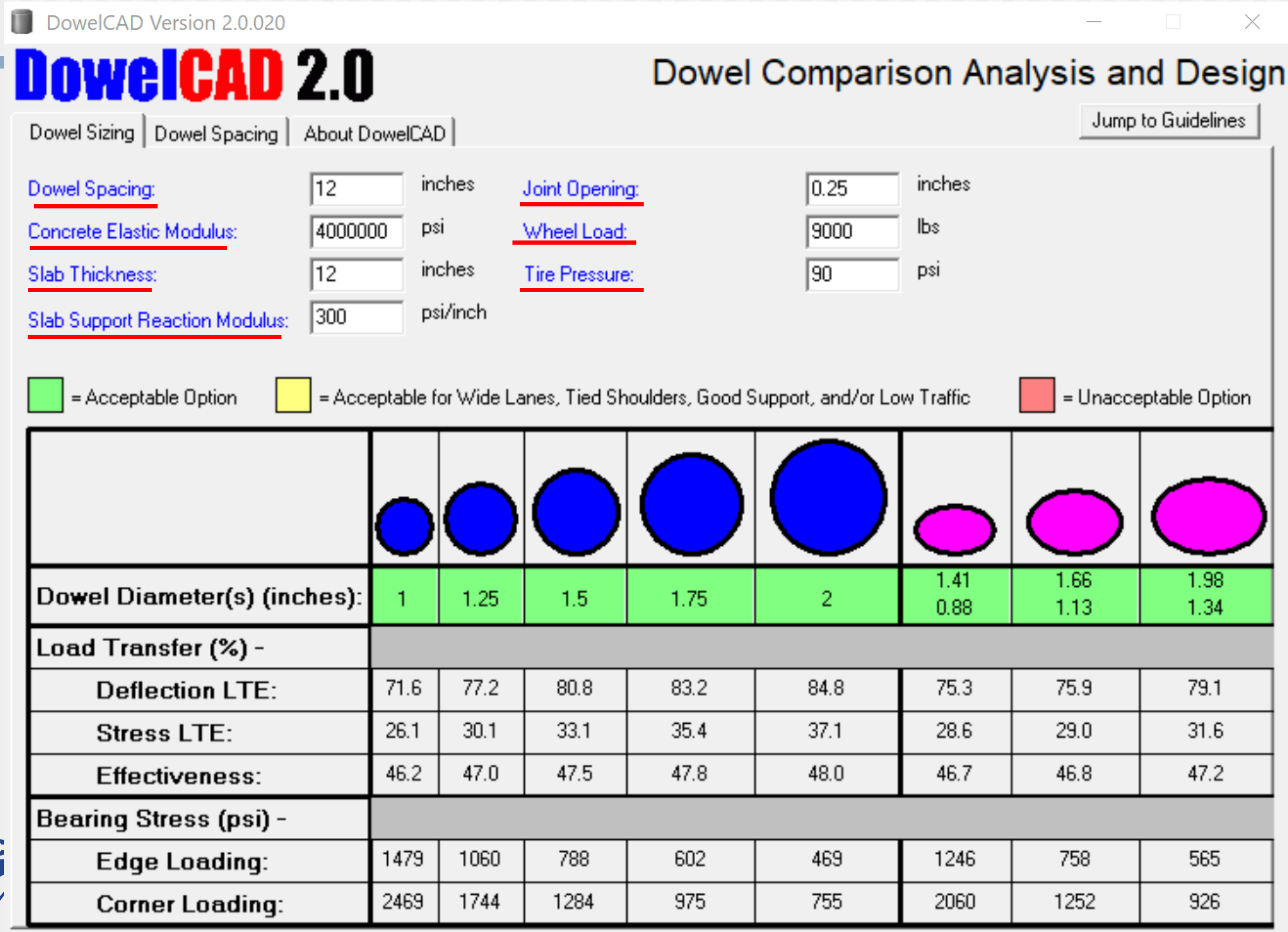
How Many Lanes Can Be Tied Together?

What About Dowel Optimization

ACPA to the Rescue

DowelCAD 2.0

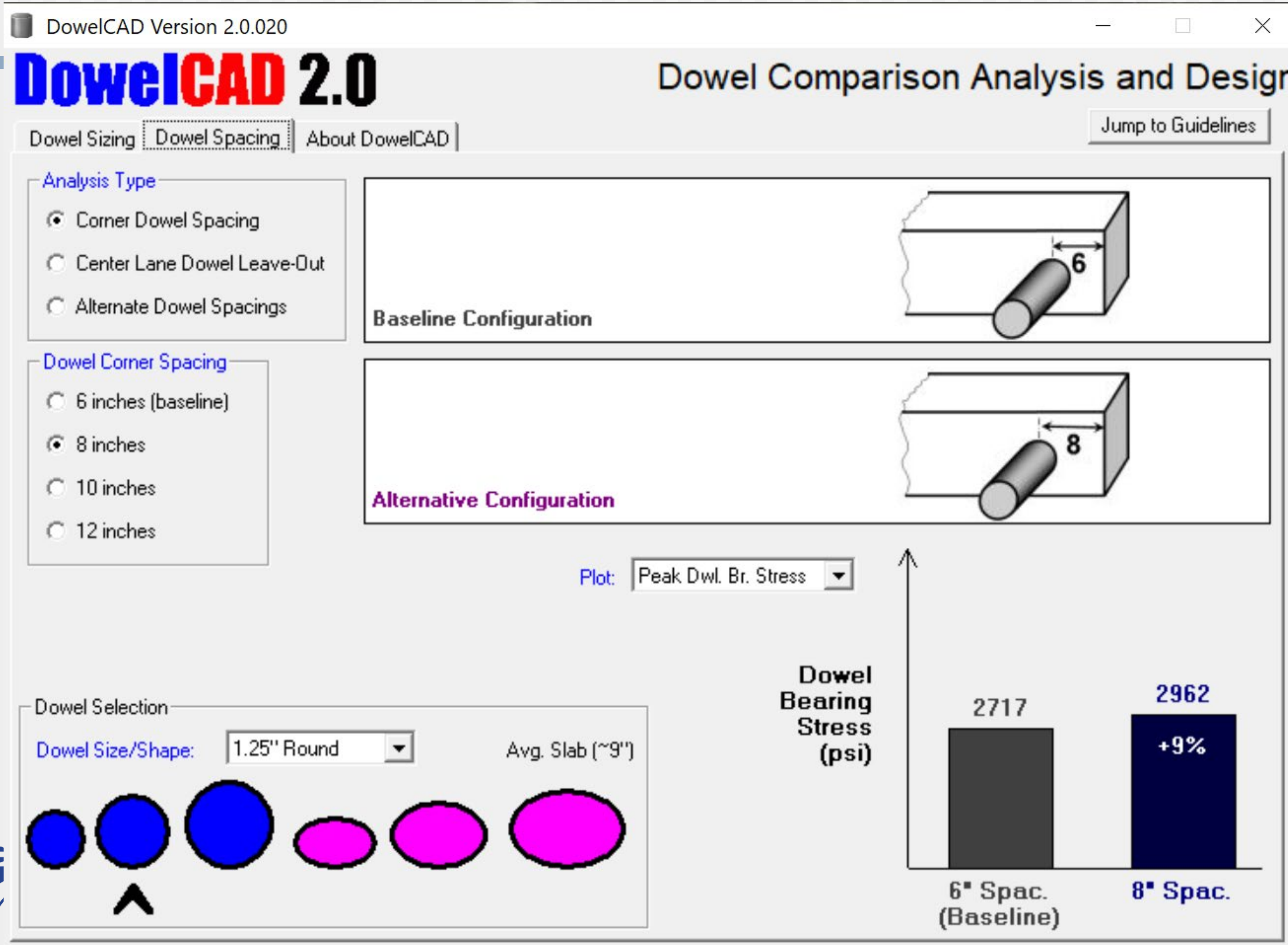
http://www.acpa.org/dowelcad/



Dowel Diameter(s) (inches):	1	1.25	1.5	1.75	2	1.41 0.88	1.66 1.13	1.98 1.34
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

http://www.acpa.org/dowelcad/

DowelCAD 2.0



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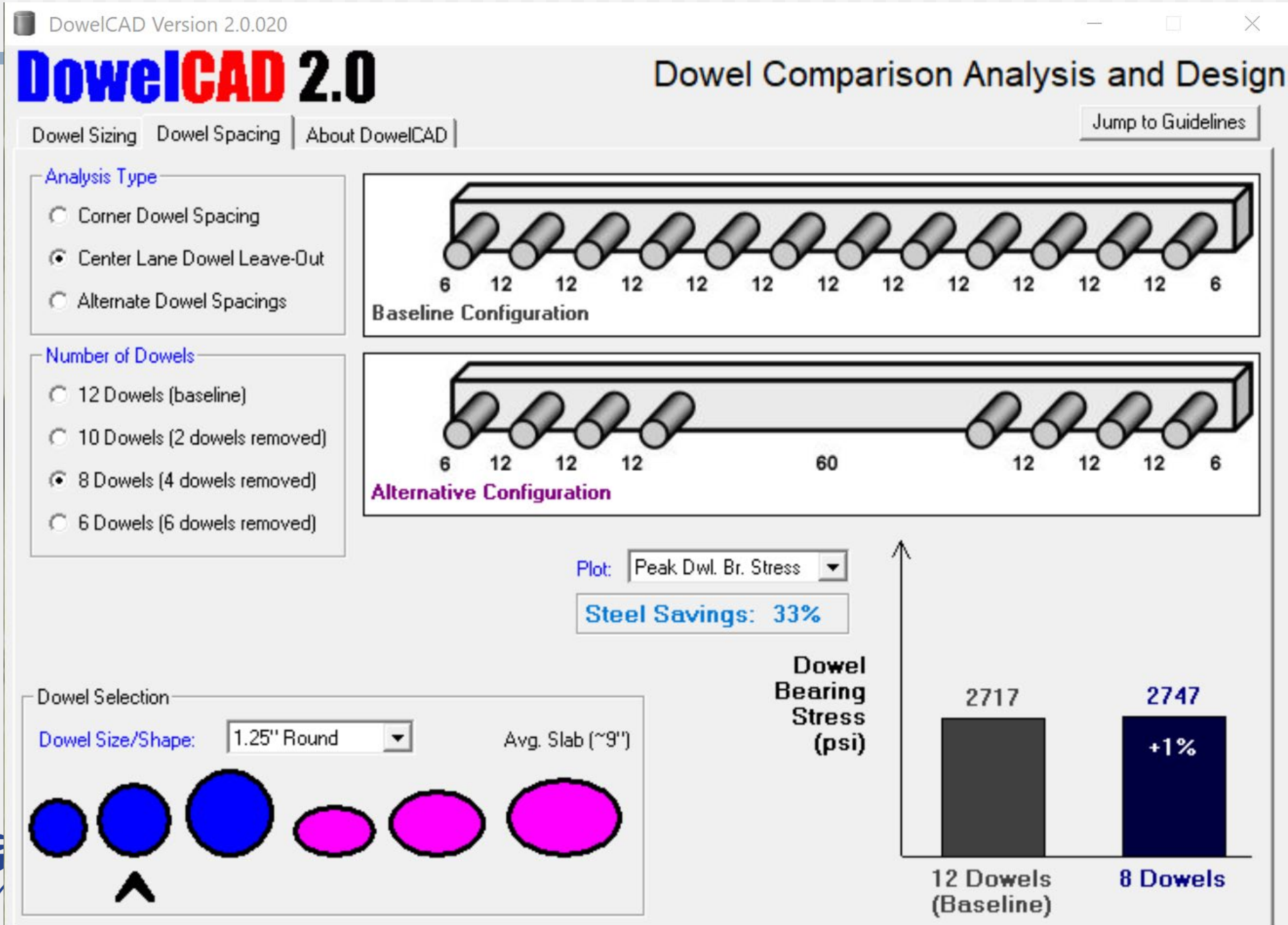

Questions?

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