Jeffery Roesler - Bio

- Ph.D. (1998) in CEE at University of Illinois
- University of California-Berkeley
  - Post-doctoral researcher (1998-2000)
- University of Illinois Urbana-Champaign (2000-present)
  - Professor; Associate Head & Dir. of Graduate Studies and Research (2014-present)
- President, Int'l Society of Concrete Pavement (2016-2020)
- Research area interests:
  - ➢Passive road sensing for AV, Concrete pavement design and analysis, Concrete fatigue/fracture, Fiber-reinforced concrete, Urban Heat Island, Photocatalytic concrete, Internal Curing, Non-contact ultrasonics for concrete construction, Recycled materials for concrete, Roller compacted concrete, foamed cellular concrete

Effect of Dowels and Tie bars on Premature Cracking in JPCP

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National Concrete Consortium Fall 2020

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  - Illinois Department of Transportation thru Illinois Center for Transportation
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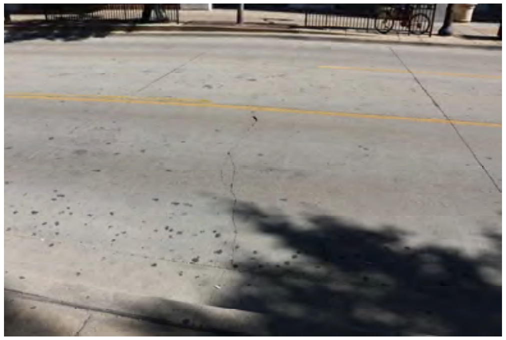
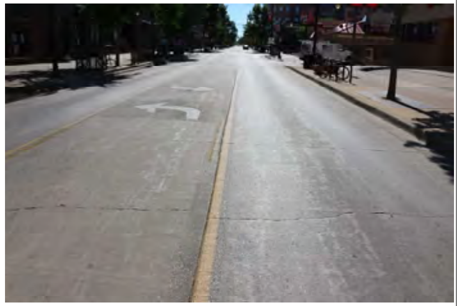
  - Chair of Technical Review Panel
- UIUC Researchers:
  - Roberto Montemayor, Prakhar Gupta, Dr. John DeSantis

Problem Statement

- Premature Cracking in Urban Concrete Pavements
  - <1 year after construction (earliest observed)
  - Between 1-5 years after construction
- Why is this occurring?
  - Construction?
  - Design?
  - Excessive restraint?

Green Street (4th to Wright)



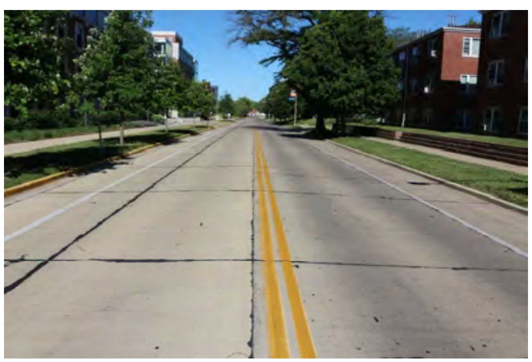


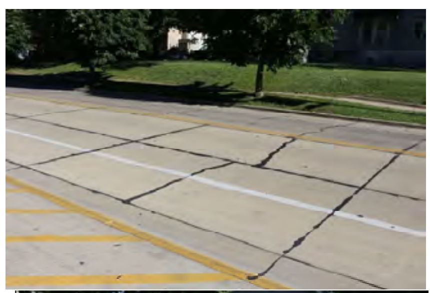
Champaign, IL

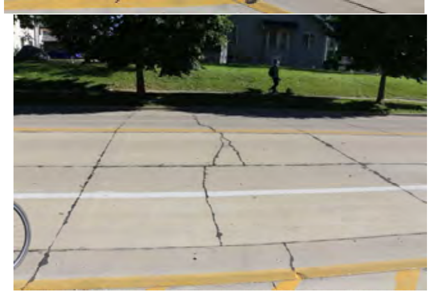
Gregory Drive (Oak to 1st)

Champaign, IL

Gregory Drive (1st-4th St)

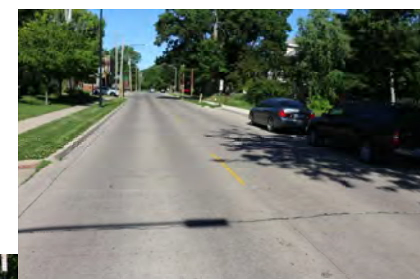


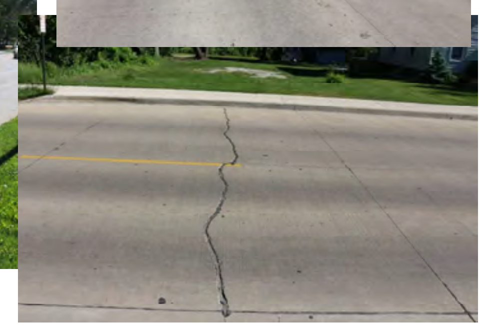




Champaign, IL

Springfield Avenue





Urbana, IL

Summary of Initial Observations of Distress Extent

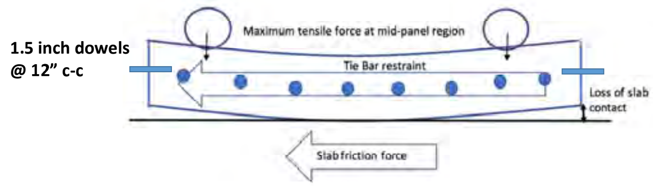
- Initial sites within Champaign-Urbana, IL

Inspection	Age (Years)	No. of Lanes	Slab Thickness (in.)	Joint Spacing (ft)	Panel Width (ft)	Trans. Crack (%)
Green St.	7	3	9	15	11, 10, 11	**37.5**
Stadium Dr.	13	4	10	10	8, 8, 8, 8	**0**
1st Street	1	3	10	15	10.5, 9.5, 6	**0**
Springfield Ave	9	2	8.5	12	11, 11	**11**
Gregory (Oak-1st)	4	2	8.5	15	18, 14.5	**4.3**
Gregory (1st-4th)	1-2	4	~8.5	15	18, 14.5	**>10***
S. 4th St.	1	4	8.5	14	11, 9.5	**0**
John St.	10	4	8.5	14	7.5, 7.5, 7.5, 7.5	**0**
Logan St.	8	2 (4)	8	15 and 10	4, 11, 11, 4	**25**

*Estimated
-Transverse and Longitudinal reinforcement had consistent spacing and depth

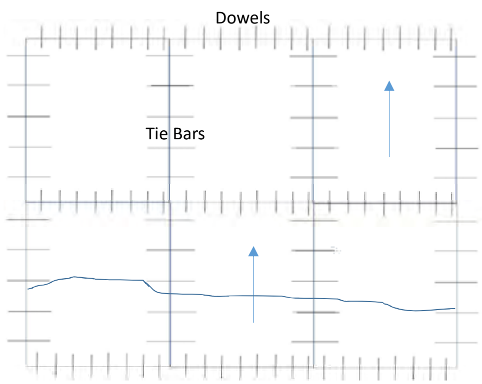
Primary Cracking Hypothesis

- Axial tensile stresses caused by excessive reinforcement in longitudinal & transverse joints that restrain thermal expansion / contraction.
- Tied C&G + doweled transverse joint offer high restraint versus low friction subbase (granular)



Initial Hypothesis

- Transverse cracking due to high restraints from tie bar / dowels (?)
- High restraint lead to stress development due to concrete shrinkage (temp+moisture)
- Re-assess reinforcement design standards
  - Reducing bar diameter?
- ***Need to confirm hypothesis in other cities***



Restraint System: higher steel reinforcement than need for base friction or ME tie bar design

Construction Survey

- Visual assessment of construction in C-U in Summer 2018 (M-Core project).

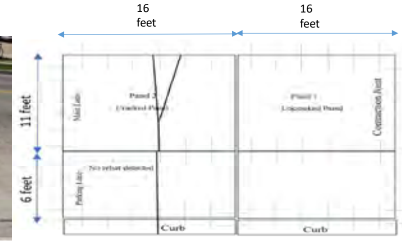
IDOT Research Project Objective

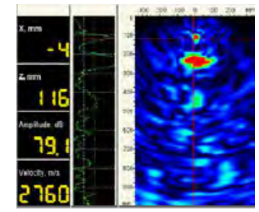
- TASK 1 – **Review of Extent of Premature Cracking of Urban JPCP**
  - Is this a problem locally?
- TASK 2 – **Select Field Survey of Urban JPCP in Illinois**
  - Occurring throughout the state? Other states?
- TASK 3 – **Development of Premature Cracking Mechanisms**
  - What is the source of distress?
    - Initial hypothesis: steel reinforcement overdesigned (excessive restraint)?
    - Slab geometry, sawcutting, friction of base layer, etc.?
  - How to resolve?

Field Evaluation – Multiple districts in Illinois

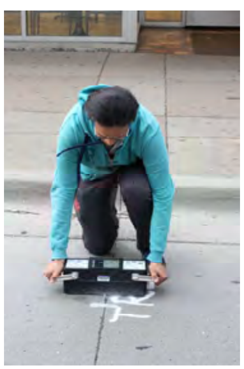
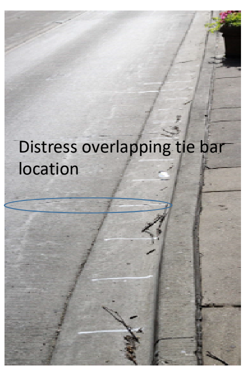
VISUAL
- ➢Lane config.
- ➢Slab geometry
- ➢Distress

ULTRASONIC
- ➢Thickness
- ➢Joint details
  - ➢Tie Bars
  - ➢Dowels
  - ➢Spacing

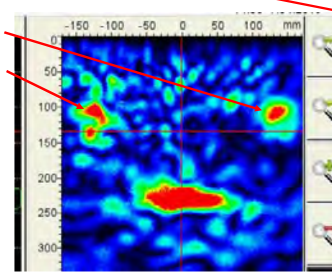
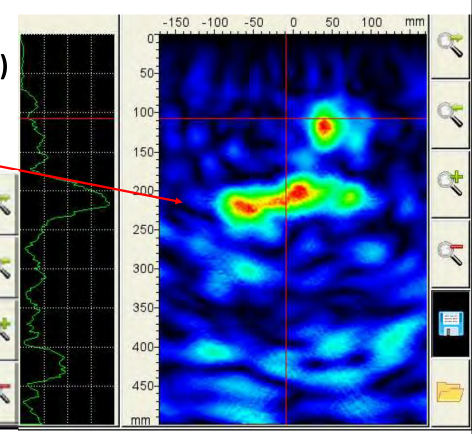



MIRA Ultrasonic Testing

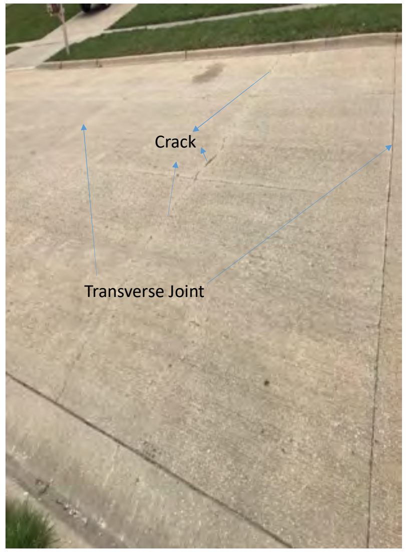




Field Evaluation Tool

ULTRASONIC TESTING SYSTEM (MIRA)
- ➢Thickness
- ➢Tie Bars
- ➢Dowels
- ➢Spacing

District 5 - Chatham Lane



Bloomington, IL

District 8 (East St. Louis)

Mid-Panel Cracks

30 ft Panels

4-5 years old

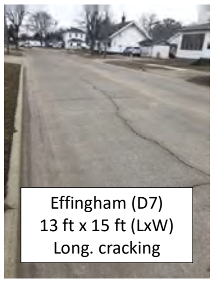
Survey Summary (May 2020 Update) - State of Illinois			
District	**Survey towns/areas**	**Premature Transverse Cracking**	**Observations**
District 1	Joliet, Naperville, Shaumburg, Aurora, Des Plaines, Crystal Lake.	No	9-10” slabs in good shape
District 2	Galena	No	Longitudinal cracks on 14ft median lane
District 3	Oswego, Yorkville, Dwight, Morris, Utica	No	9-10” Slabs in good shape. The only crack founded was at an entrance of a school.
District 4	Peoria, Dunlap, Morton.	No	9-10” slabs in good shape Cracks were present only in utilities
District 5	Champaign, Urbana, Rantoul, Mahomet, Bloomington, Normal.	Yes	Significant amount of roads showing premature cracks
District 6	Springfield	--	Low amount of concrete roads
District 7	Effingham	Yes for long panels	Long panels ~30ft
District 8	Granite city, Madison, East St Louis, Maryville	Yes for long panels (30ft)	8” roads in good shape (Only cracks at curb) Only long panels showed premature cracks.
District 9	*Carbondale*	--	*Pending*

Updated Hypothesis of Premature Cracking

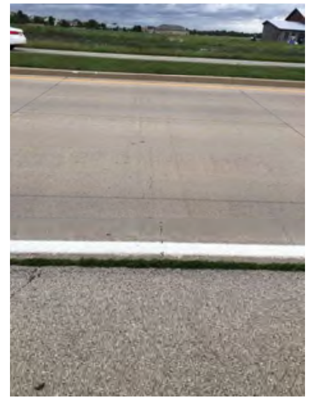
- Dowel/Tie Bar interaction (Excessive Restraint during contraction)
  - Dowel bars 1.5” diameter 12” spacing
  - Tie bar spacing # 6 bar @ 24”
    - Non-uniform restraint
  - Slab thickness 8” to 9”
  - Curb and gutter sections (plate w/ hole effect)
  - No grease on dowels?
- Low base layer friction (no resistance to contraction)
- Rapid temperatures drop (>40°F)
- Non-activated contraction joints (Sawcutting)
- *Concrete mixture proportions/constituents (Not a factor)*
- Excessive curling – (unlikely)

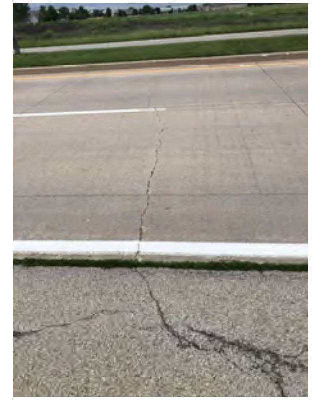
Slab Geometry - Summary

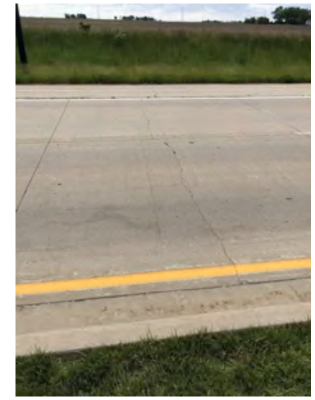
- More cracking prevalent in non-traditional geometries
  - 14 ft width slabs resulting in longitudinal cracking
  - Slab lengths > 15 ft resulting in transverse cracking



Curtis Road – Champaign, IL

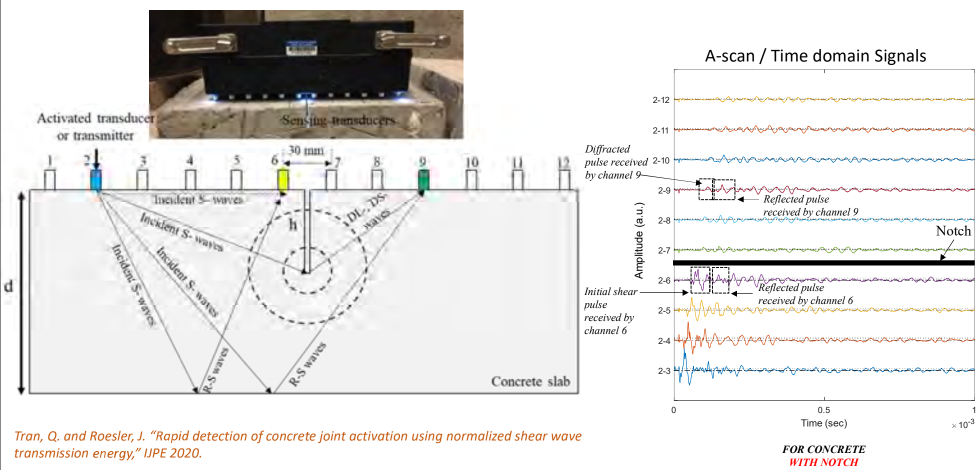






Photos 2020

Sawcut Timing - Ultrasonic Evaluation of Joint Cracks

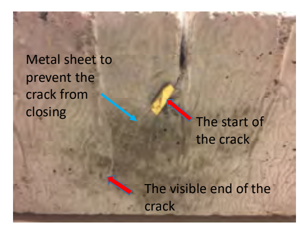


Tran, Q. and Roesler, J. "Rapid detection of concrete joint activation using normalized shear wave transmission energy," IJPE 2020.

Sawcut Timing - Ultrasonic Evaluation of Joint Cracks

Test setup

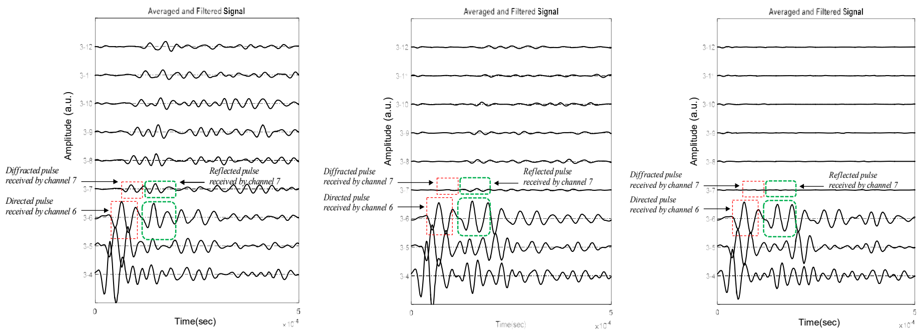
No crack



Partial crack

Full crack

Sawcut Timing - Ultrasonic Evaluation of Joint Cracks

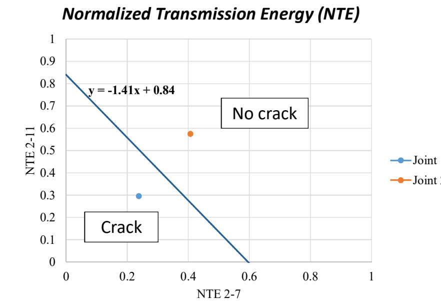


NO crack   **PARTIAL** crack   **FULL** CRACK

Tran, Q., Roesler, J., "Rapid detection of concrete joint activation using normalized shear wave transmission energy," Int'l Jrnl Pav't Eng (IJPE) 2020.

Sawcut Timing - Ultrasonic Evaluation of Joint Cracks

- Healey St. (Champaign, IL)
  - Surveyed 2019
  - Constructed 2017
  - PCC = 8"
  - 13'x13' panels
  - Dowels/tie bars included
  - 50% panels cracked (trans. cracking)



- *Some Urban Concrete Pavement cracks are related to non-activated joints*

Normalize the energy by the 6th receiver's energy

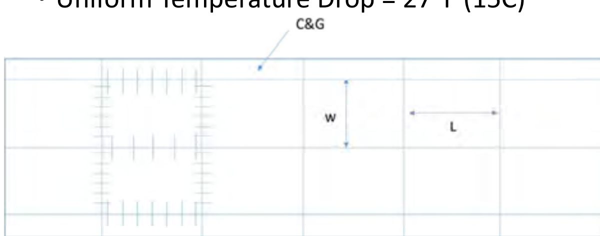
$$Normalized\ energy = \frac{Energy\ of\ sensor_i}{Energy\ of\ sensor_6}$$

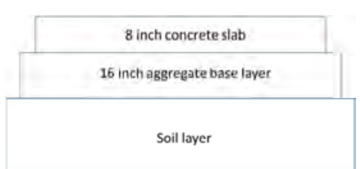
where:
i : receiver No. from 7 to 12

3D Analysis of Urban JPCP w/ C&G - Friction

- 2-lane road (15 ft x 11 ft) w/ C&G (15 ft x 2 ft)
- Dowels & tie bars (Modeled as springs)
- Slab base-friction coefficient (initially)
- Uniform Temperature Drop = 27°F (15C)

Friction coefficient	Max. Stress @ bottom of PCC mid-panel (psi)
1	6.70
10	35.68
100	115.89
infinite	174.20





Dowel Bar Restraint: NCHRP 637 Findings

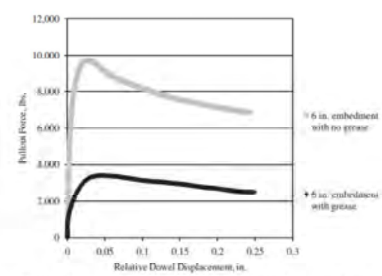


Figure 3.5. The effect of greasing dowels on pullout force versus displacement.

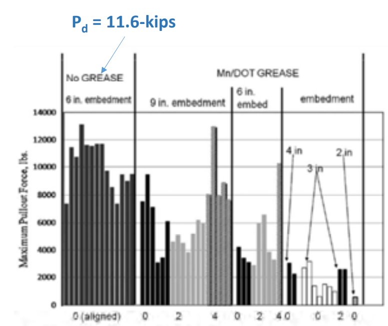


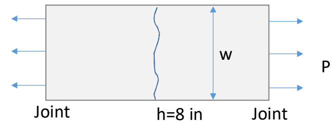
Figure 3.7. Distribution of maximum pullout forces for greased and ungreased dowels with varying degrees of misalignment.

What is pull-out force for 9-in embedment & no grease?

Khazanovich, Hoegh, Snyder (2009)

Dowel Bar Restraint: Calculations of Slab Forces

- What is the force required to crack @ mid-slab, which is the same force needed to restrain joints from relieving stresses (zero deformations)
- Force (P) = w*12*thickness (h)*f_t
- f_t=400 psi; width=11 ft; thickness=8 inch
- P = 11ft*12 inch/ft*8in*400 psi = *422.4 kips*
- P_{adj} = 4.22.4k/2.7 = **156k** (over 11 dowels or $P_d \geq 14$k)



Tie bar acts as a plate w/hole

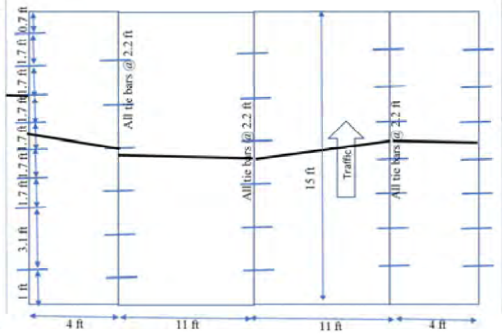
a/d=0.1
K=2.7 to 3

- Dowelled joint must resist 156-kips to crack 8-in slab!
  - P=**10k**/dowel*11 dowels=**110-kips** (6-in)
  - P=**15k**/dowel*11 dowels=165-kips (9-in)

Tie bar assessment

PANEL 1 (Cracked Panel)	
Tie bar spacing	Varied, 0.52 m (1.7 ft) to 0.67 m (2.2 ft)
Length of Tie bar	0.55 m (1.8 ft)
Misaligned Tie Bars	No
Dowel Bar Spacing	0.30 m (1.0 ft) consistent
Dowel Bar Length	0.45 m (18 in.)
Misaligned Dowel Bar	No

Logan Street (Champaign, IL)



Tie bar assessment

- Not primary cause of cracking
- Contributes to crack development and propagation

Midwest State Practice

- State highway agencies predominantly use No.5 steel diameter tie bars, with several No. 4 and ~10 states use No. 6 option (ACPA 2009)

State	Size	Length (in.)	Spacing (in.)	Epoxy coated or other comment	Pullout Load (?)
Illinois	No. 6	30	30	District Dependent	11,000 lbs.
Wisconsin	No. 4	24	24 in. two-lane 30 in. multilane	Yes, but can bend	None
Indiana	No. 5 <= 9 in. No. 6 d > 9 in.	36	36	Yes, can bend	None referenced
Kentucky	No. 5	30	20	Yes. Allows hooks for long. Const.	9000 lbs. hook bolts only
Missouri	No. 5 <=10 in. No. 6 > 10 in.	30 40	30 30	Yes, but can bend. Allows hooks.	None referenced
Iowa	No. 5 >= 8 in.	36	30 in. 15 in. for lanes total > 52 ft. for 10 in. pav't (Spec.)	Yes, but can bend	None referenced

Recommended Tie Bar Guidance

Malella et al. 2009. "A Mechanistic-Empirical Tie Bar Design Approach for Concrete Pavements," *ACPA, Skokie, IL*

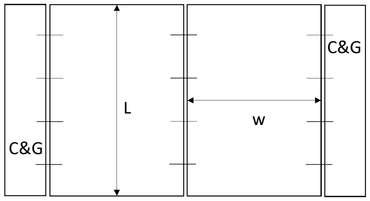
- Design is function of:
  - Base type (frictional characteristics)
  - # of adjacent tied lanes and lane width

Table B-1. Tie bar design for two tied 12-ft lanes on a 6-in unbound base.

Total Equivalent Free Strain, Microstrain	Tie Bar Size Designation	Tie Bar Spacing, in	Tie Bar Length, in	Steel Grade
500	#4	45	24	40
550	#4/#5	45	24	60/40
600	#4/#5	45	24	60/40
650	#4/#5	45	24	60/40
700	#4/#5	45	24	60/40
750	#4/#5	45	24	60/40
800	#4/#5	45	24	60/40

M-E Tie Bar Design: Overview

-no longitudinal restraint
-no load transfer consideration



- Objectives:
  - Ensure joint integrity
  - Reduce excessive ***lateral*** restraint
- M-E Design Process (from Mallela et al., 2009)
  1. Obtain design inputs
  2. Estimate design thermal loading
  3. Compute drying shrinkage strain
  4. Determine equivalent free strain
  5. Determine tie bar design parameters from tables

These steps are automated with the online tie bar designer.

M-E Tie Bar Designer: Design Criteria

- Maximum/critical joint opening
- Excessive steel yielding
  - Joint opening limited to a critical value computed for each tie bar size and embedment length

Online M-E Tie Bar Designer Inputs: Example

- State: Illinois
- Location: Champaign
- Cement type: Type I
- Cementitious materials content: 600 lb/yd^3
- Coefficient of thermal expansion: 5.5 με/ºF
- Pavement thickness: 8"
- Lane configuration: Two tied 12' lanes
- Subbase type/thickness: Unstabilized – 6"
- Month of construction: July
- Curing procedure: Curing compound

Online Tie Bar Designer: Example Results

Gives automatic tie bar options

- Gives the equivalent amount of steel per foot needed for each grade of steel
- Allows for alternate designs

Online Tie Bar Designer: Results vary with Concrete Pavement Inputs

Subbase Type – Thickness	Two Tied 12’ Lanes	Two Tied 14’ Lanes
Asphalt Treated Subbase – 6”	#6 @ 36” (Gr. 60) – 24” Length*	#6 @ 36” (Gr. 60) – 24” Length*
Cement Treated Subbase – 6”	#6 @ 36” (Gr. 60) – 24” Length*	#6 @ 36” (Gr. 60) – 24” Length*
Unstabilized (Granular) Subbase – 6”	#5 @ 45” (Gr. 40) – 24” Length* #4 @ 45” (Gr. 60) – 24” Length*	#5 @ 45” (Gr. 40) – 24” Length* #4 @ 45” (Gr. 60) – 24” Length*

*Identical results for 6”-10” thick pavements (not necessarily limited to this range)

Updated Concrete Slab Details – IDOT (2018)

- Slab geometry - joint spacing = 12 ft (h<10-inch) & 15ft (h≥10-inch)
- Review new tie bar guidelines (2018)
  - Construction Joint - #6x30in @ 36-inch spacing
  - Contraction Joint - #6x30in @ 36-inch spacing
  - Previously #6x30 inch @
    - 24 inch (construction joint)
    - 30 inch (contraction joint)
- Review new dowel bar guidelines (2018)
  - Previously 1.5-inch diameter bars for ≥ 8 inch

(2018)

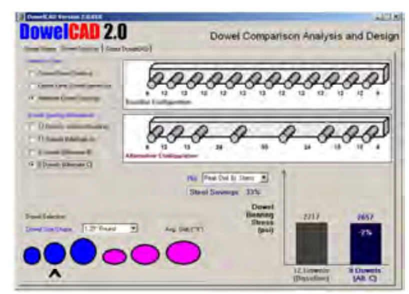
DOWEL BAR TABLE	
PAVEMENT THICKNESS	DOWEL BAR DIAMETER
10 (250) or greater	1½ (38)
8 (200) thru 9.99 (249)	1¼ (32)
Less than 8 (200)	1 (25)

Recommended National Guidance

ACPA Nov. 2008. “Innovative Concrete Pavement Dowel Design Guidelines”

- General guidelines
  - Specific: DowelCAD 2.0

Concrete Design Thickness, in.	Dowel Bar Size, in.
< 8 in. and cracking is predicted cause of failure	Dowels not required
< 8 in. and faulting is predicted cause of failure	1.00 in.
>= 8 in. and < 10 in.	1.25 in.
>= 10 in.	1.50 in.



Premature Cracking Study: Summary

- MIRA ultrasonic testing device helpful for field evaluation
- Premature cracking can develop from multiple mechanisms
  - Slab geometry
  - Transverse joint restraint
    - Dowel greasing and/or misalignment
    - Tie bars can contribute
  - Friction of base layer
  - Non-activated contraction joints
- Dowel greasing is very important!
- Re-evaluate concrete slab design details
  - Slab geometry guidelines
  - ACPA (dowel bar details)
  - Malella et al (2009) report on tie bar details
- ***Final Report out by Dec. 2020***