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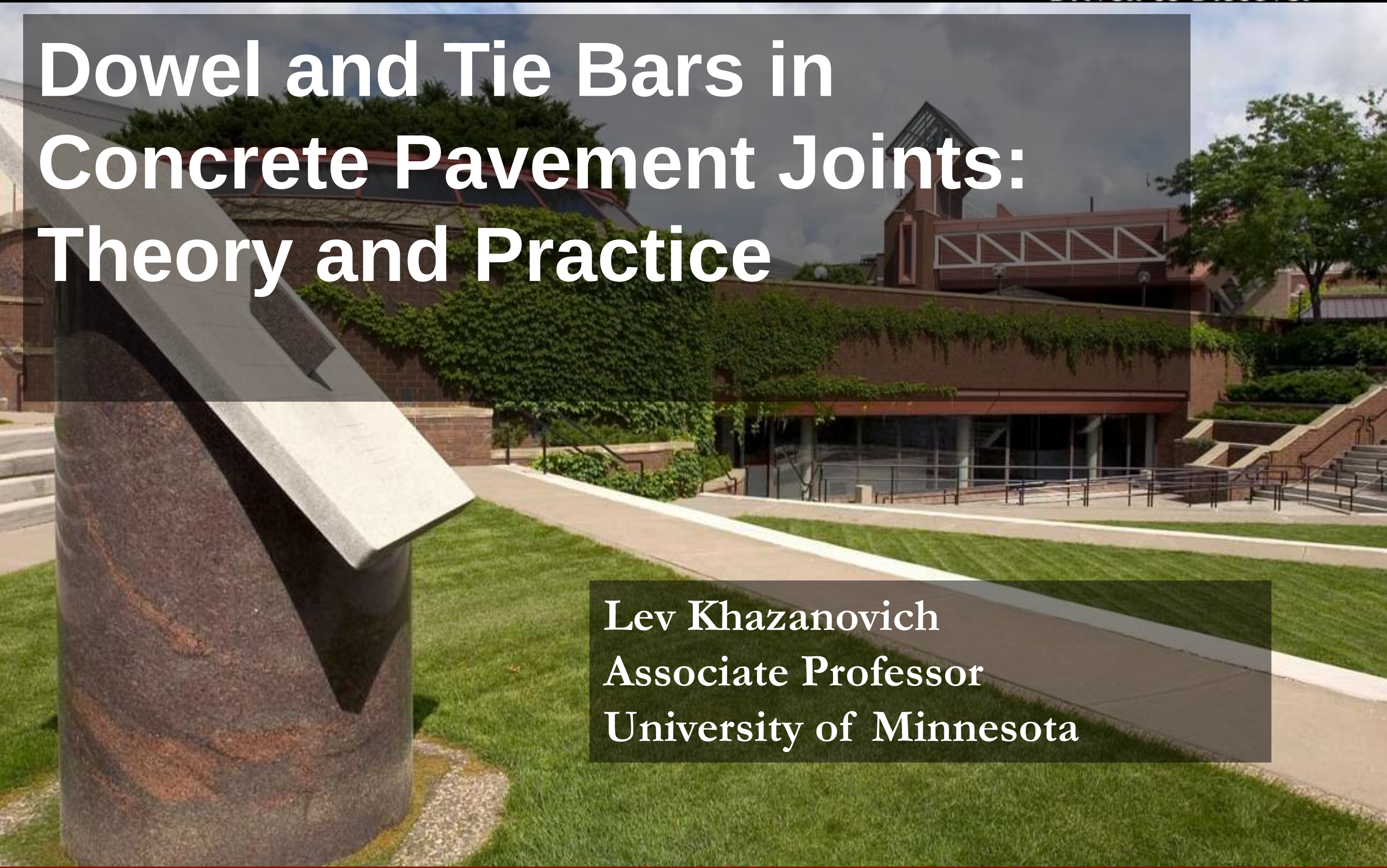

Dowel and Tie Bars in Concrete Pavement Joints: Theory and Practice

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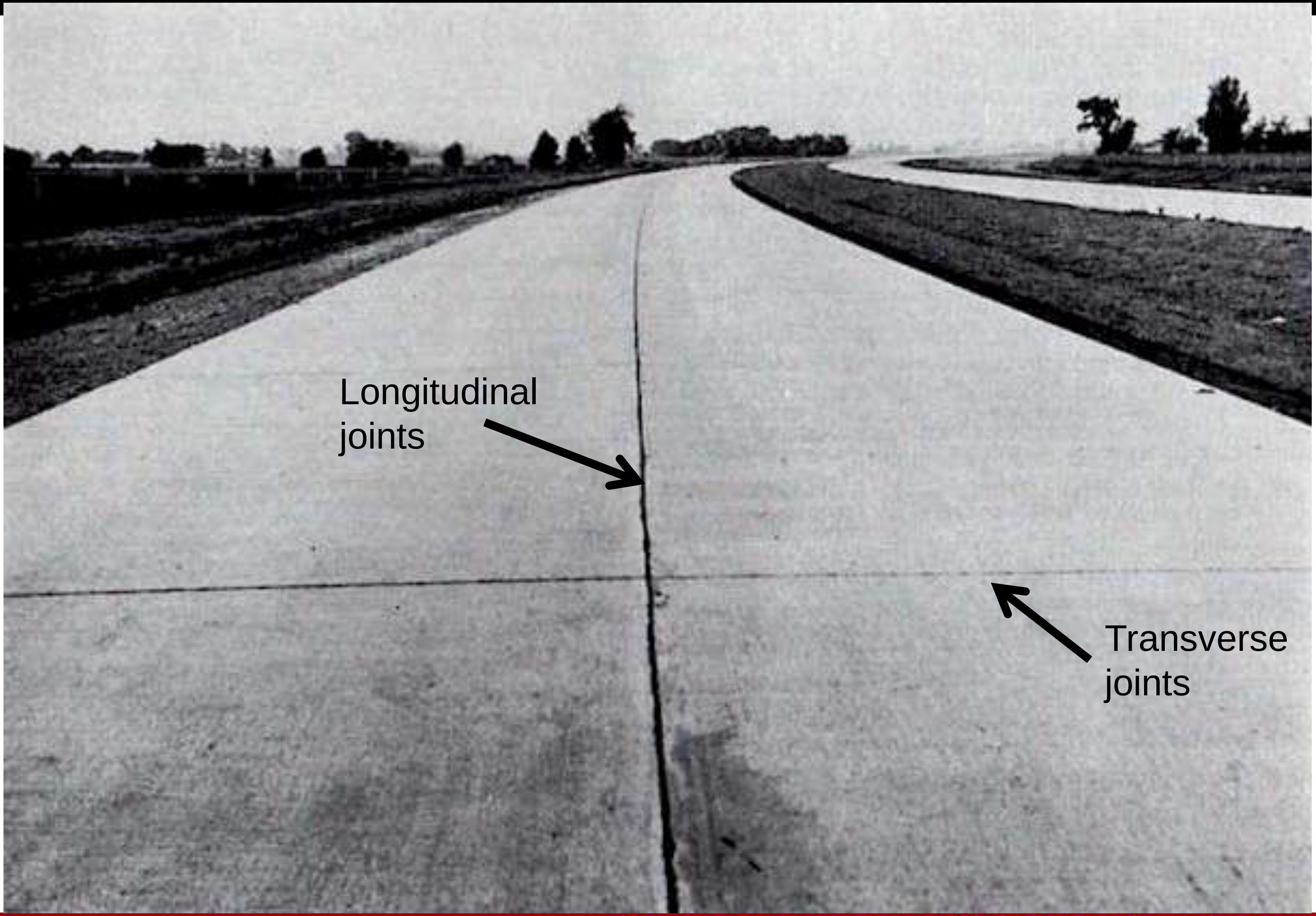
November 2, 2011
2nd International Conference on Best Practices for Concrete Pavements

Department of Civil Engineering

Presentation Outline

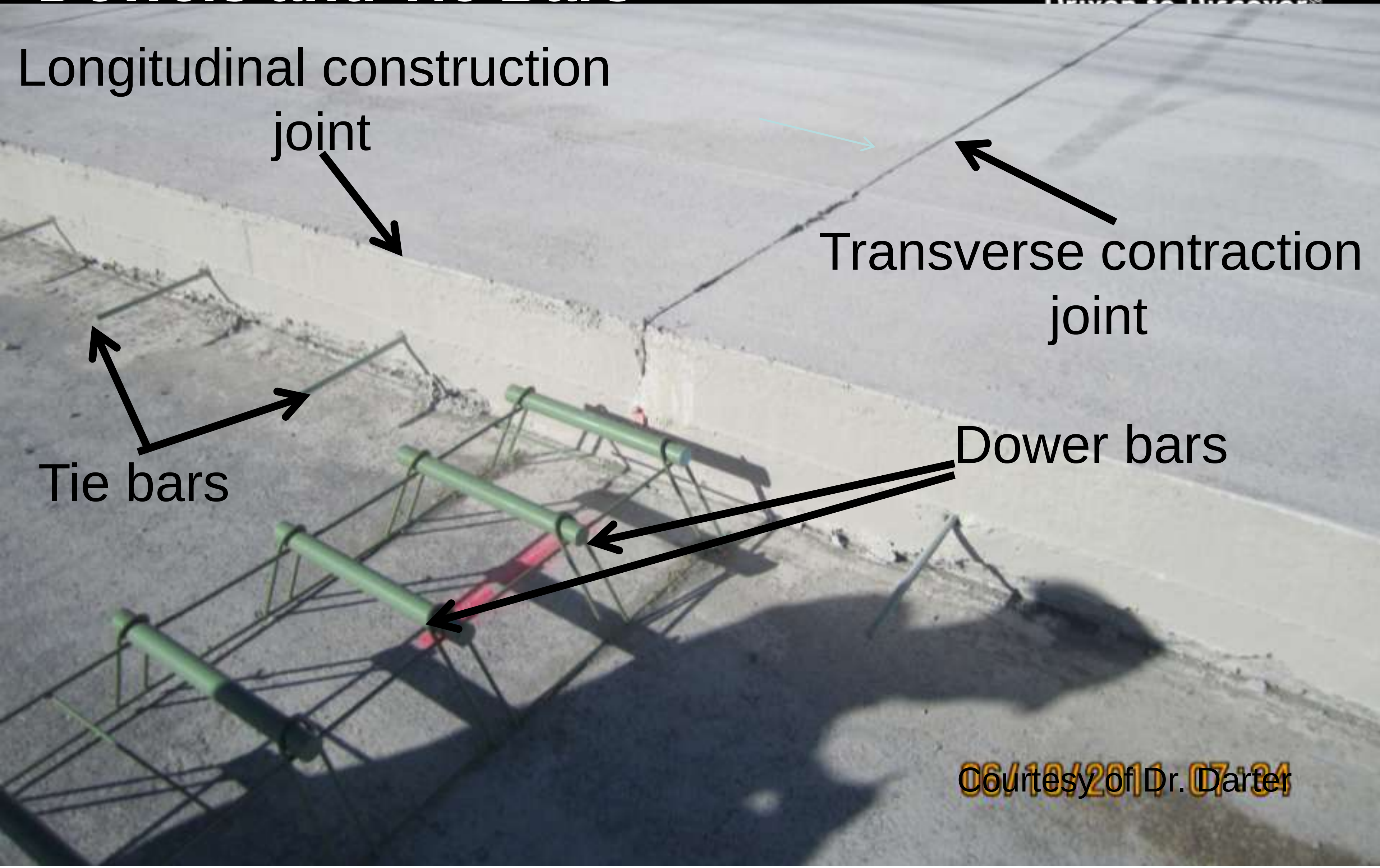
- **Introduction**
  - **Pavement joints, dowels, and tie bars**
- Benefits of dowel and tie bars
- Dowel and tie bar design
- Construction
- Summary


Longitudinal
joints
Transverse
joints

- 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



Presentation Outline

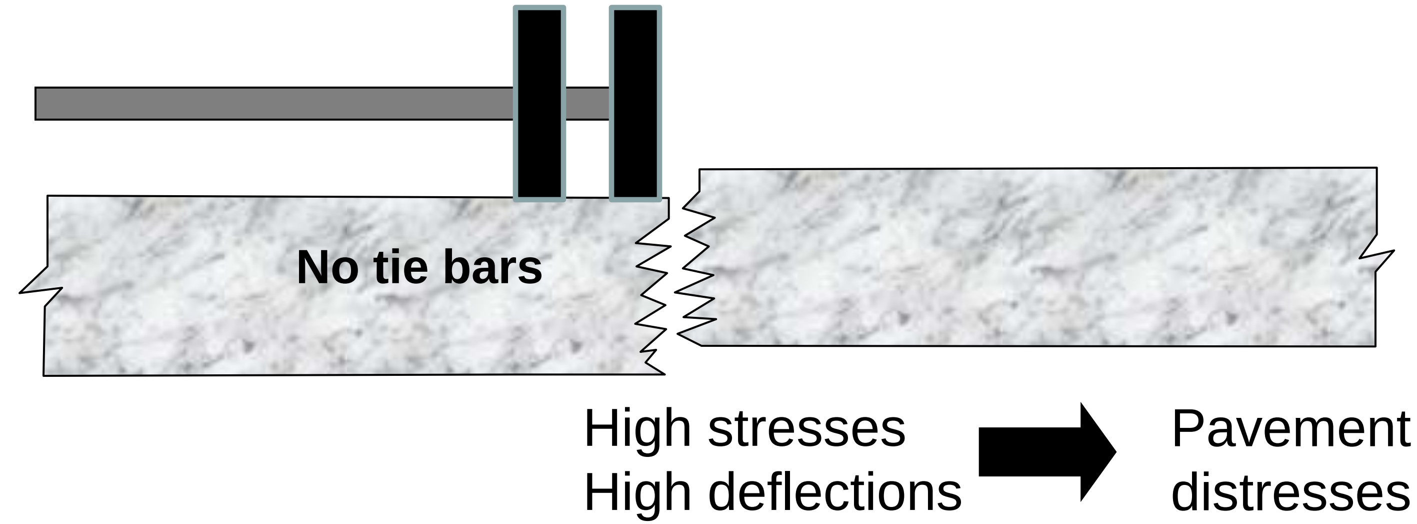
- Introduction
- **Benefits of dowel and tie bars**
  - **Theory**
    - **Mechanism of load transfer**
    - **Effect on deflections and stresses**
    - **Effect on performance**
  - **Practice**
  - **Cost**
- Dowel and tie bar design
- Construction
- Summary

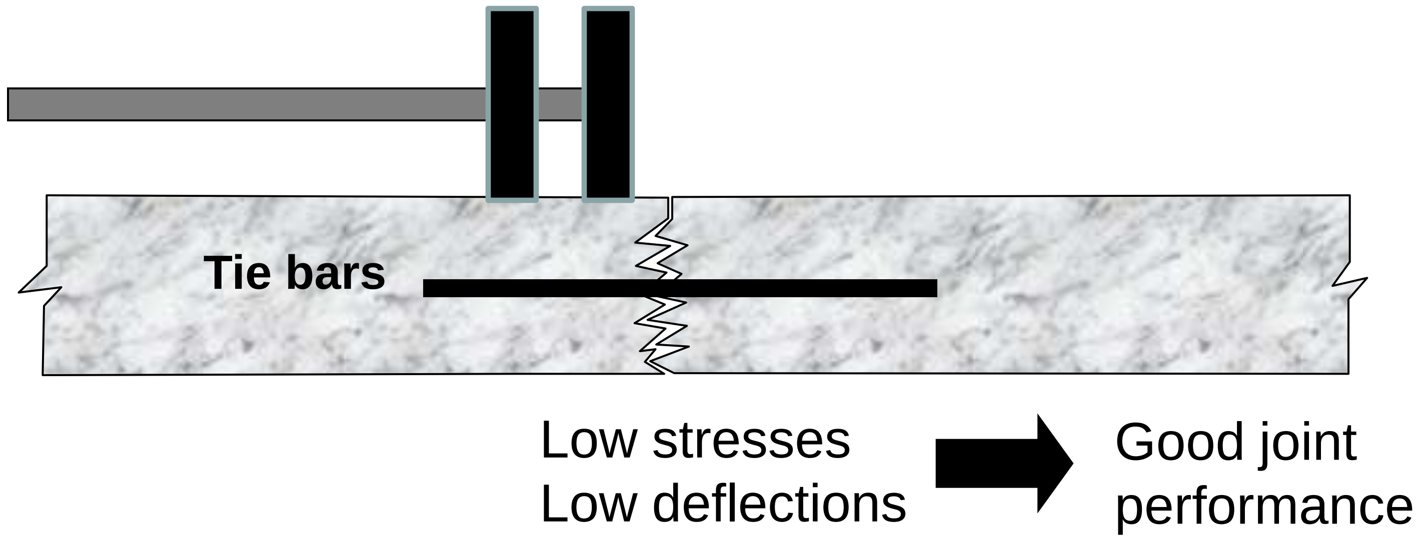
Why do we need tie bars?

None or inadequate tie bar design

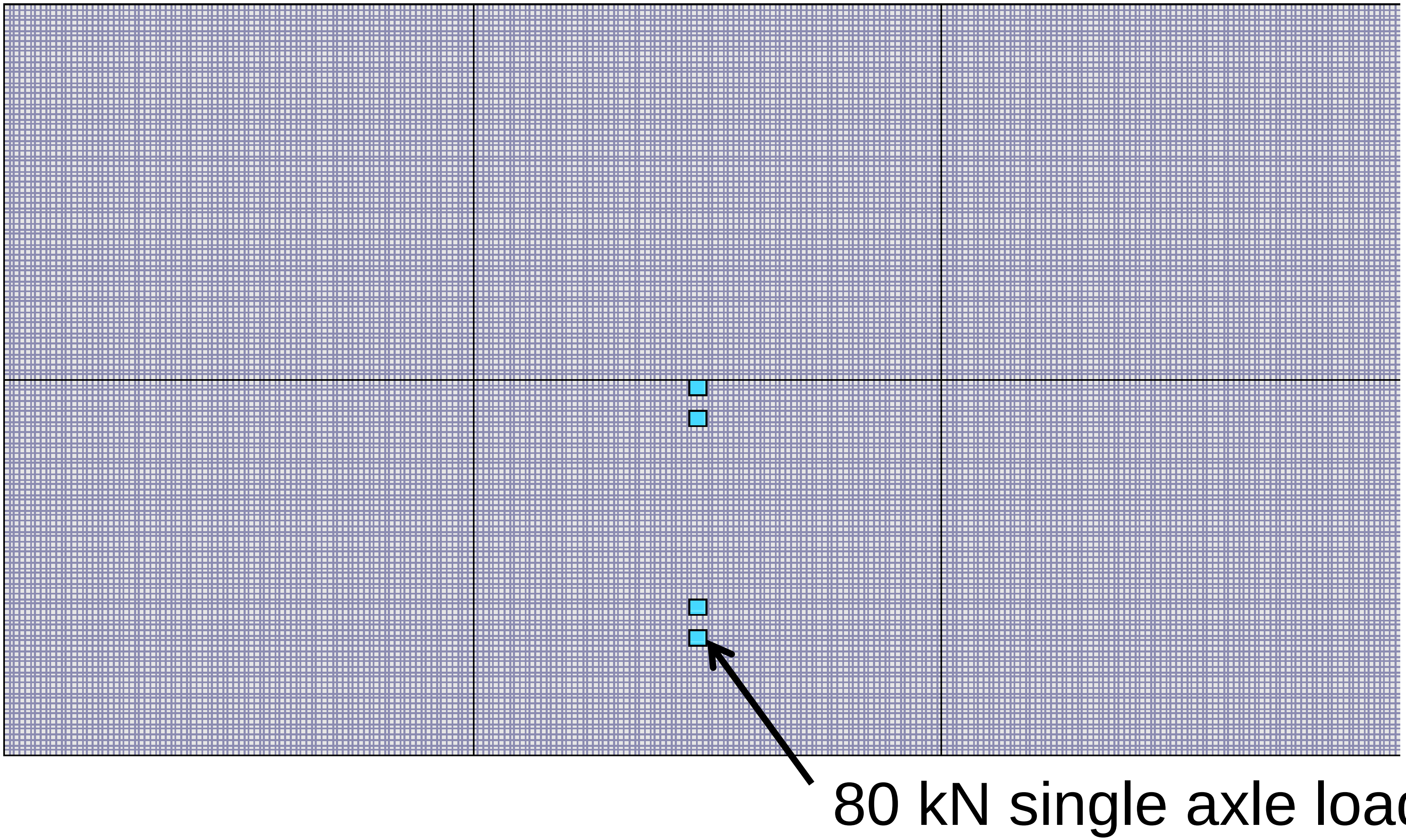
Lane separation

Effect of tie bars on pavement responses





ISLAB2000 Finite Element Model



Deflections without Tie Bars

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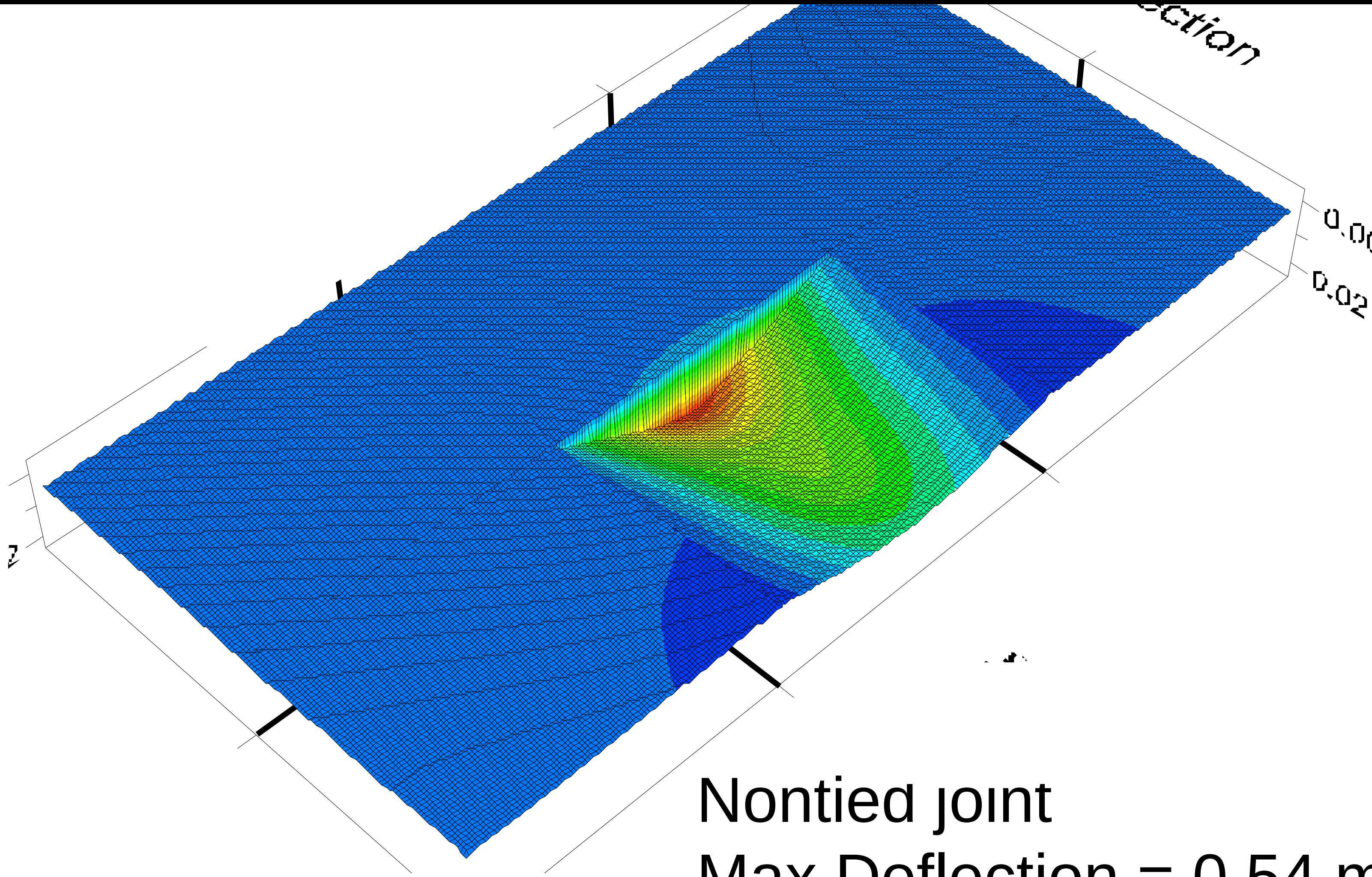
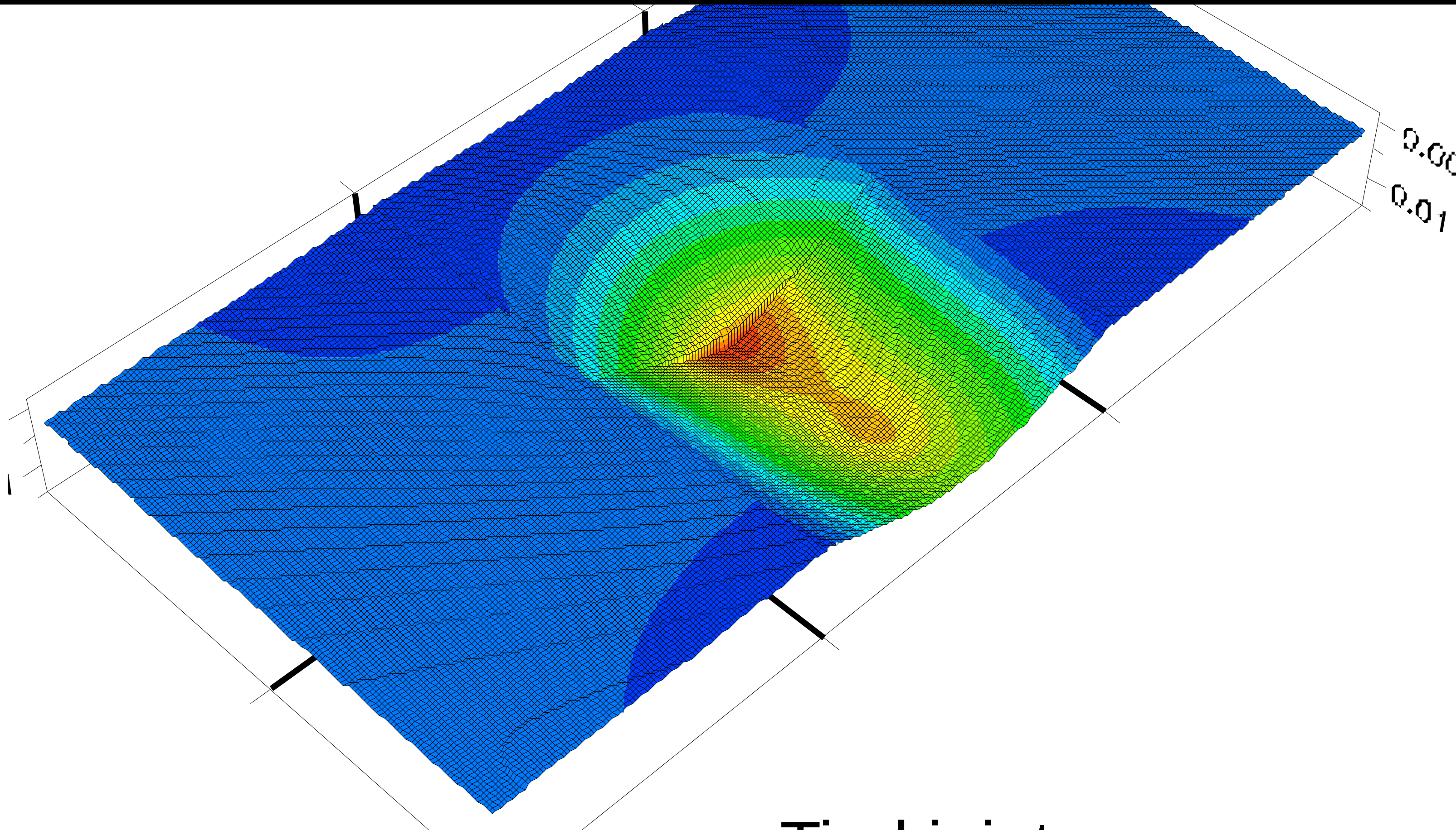


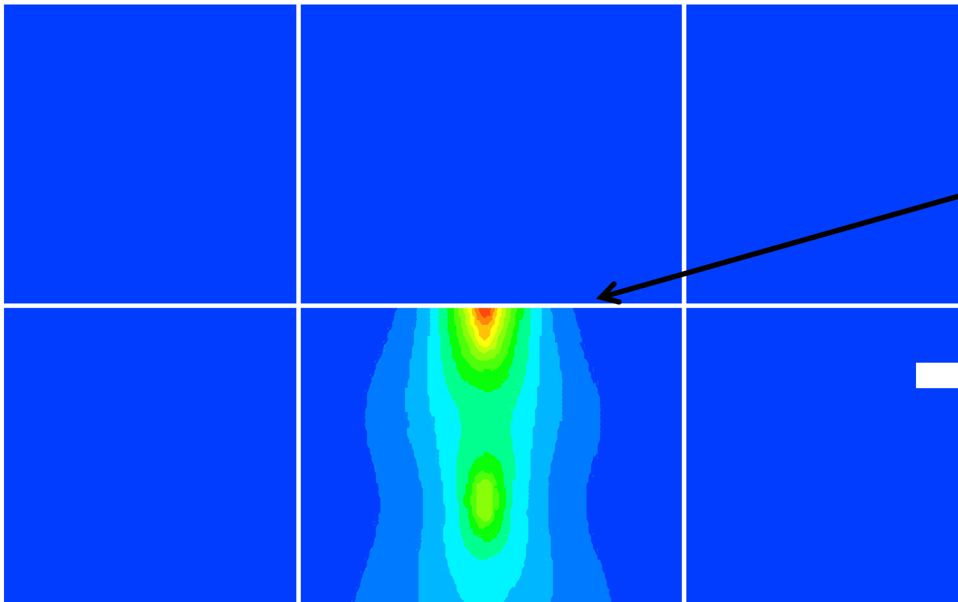
Nontied joint
Max Deflection = 0.54 mm

Deflections with Tie Bars

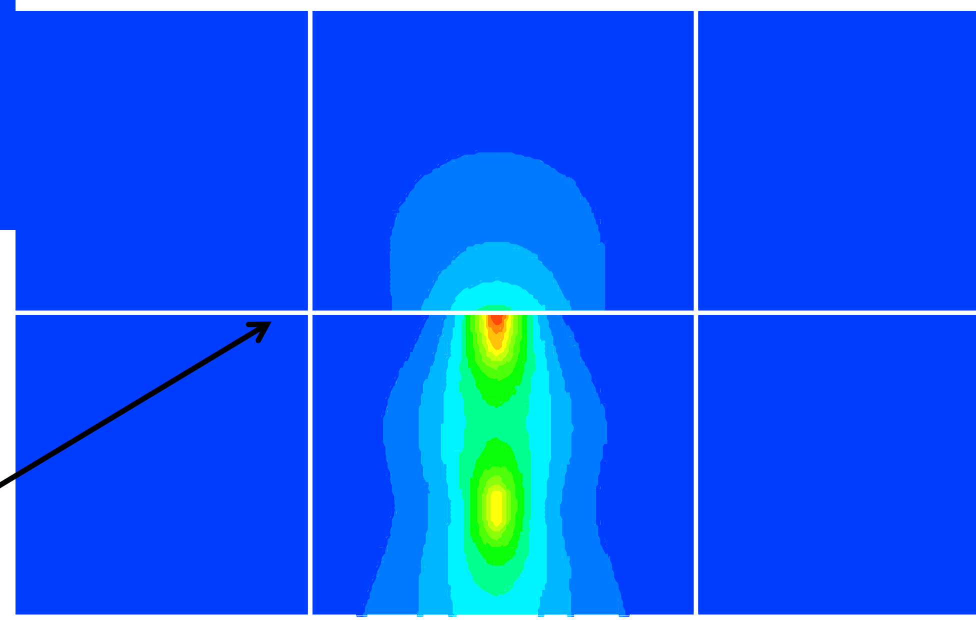


Tied joint
Max Deflection = 0.33 mm

Principal Stresses at the Slab Bottom



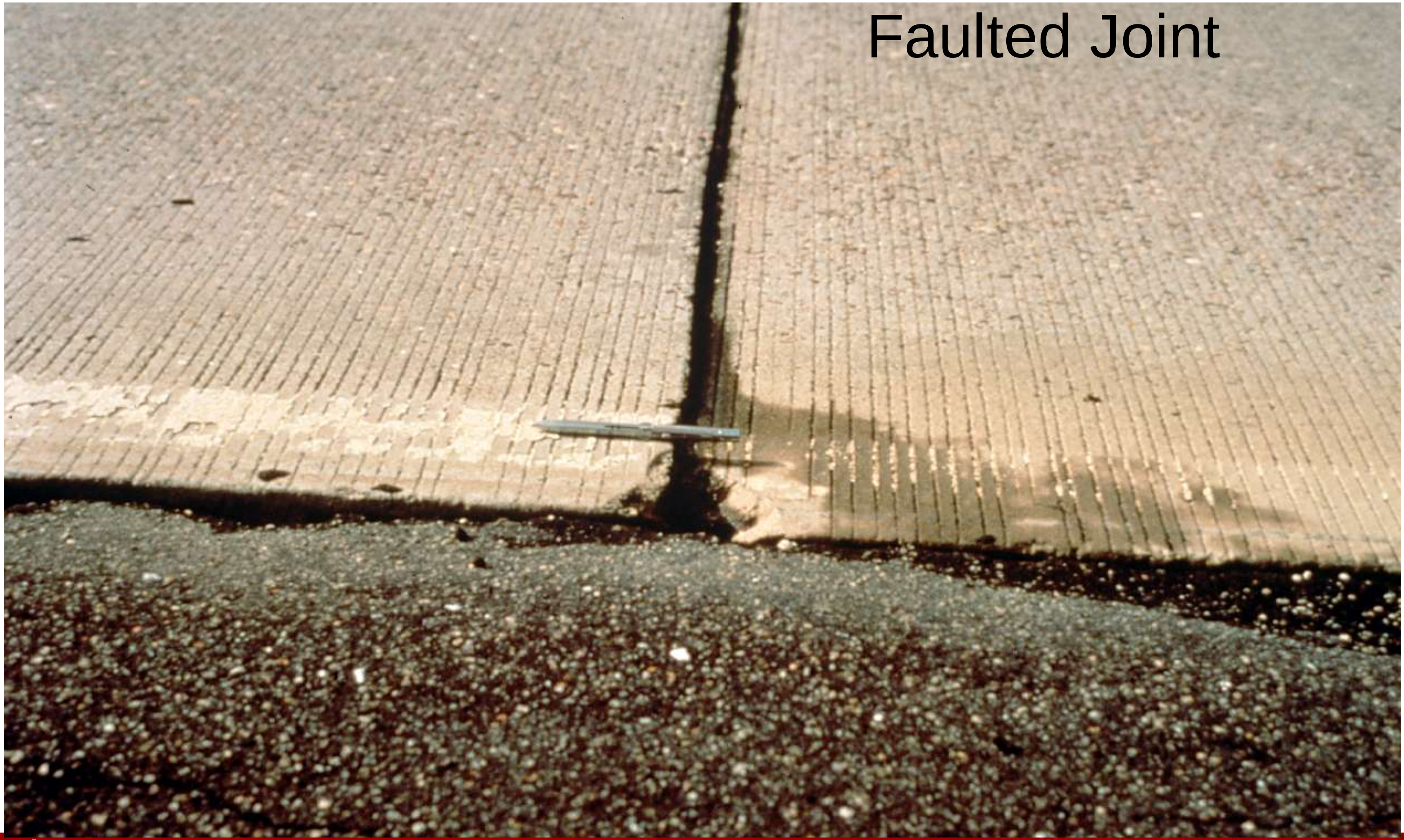
Nontied joint
Max Stress = 2051 kPa



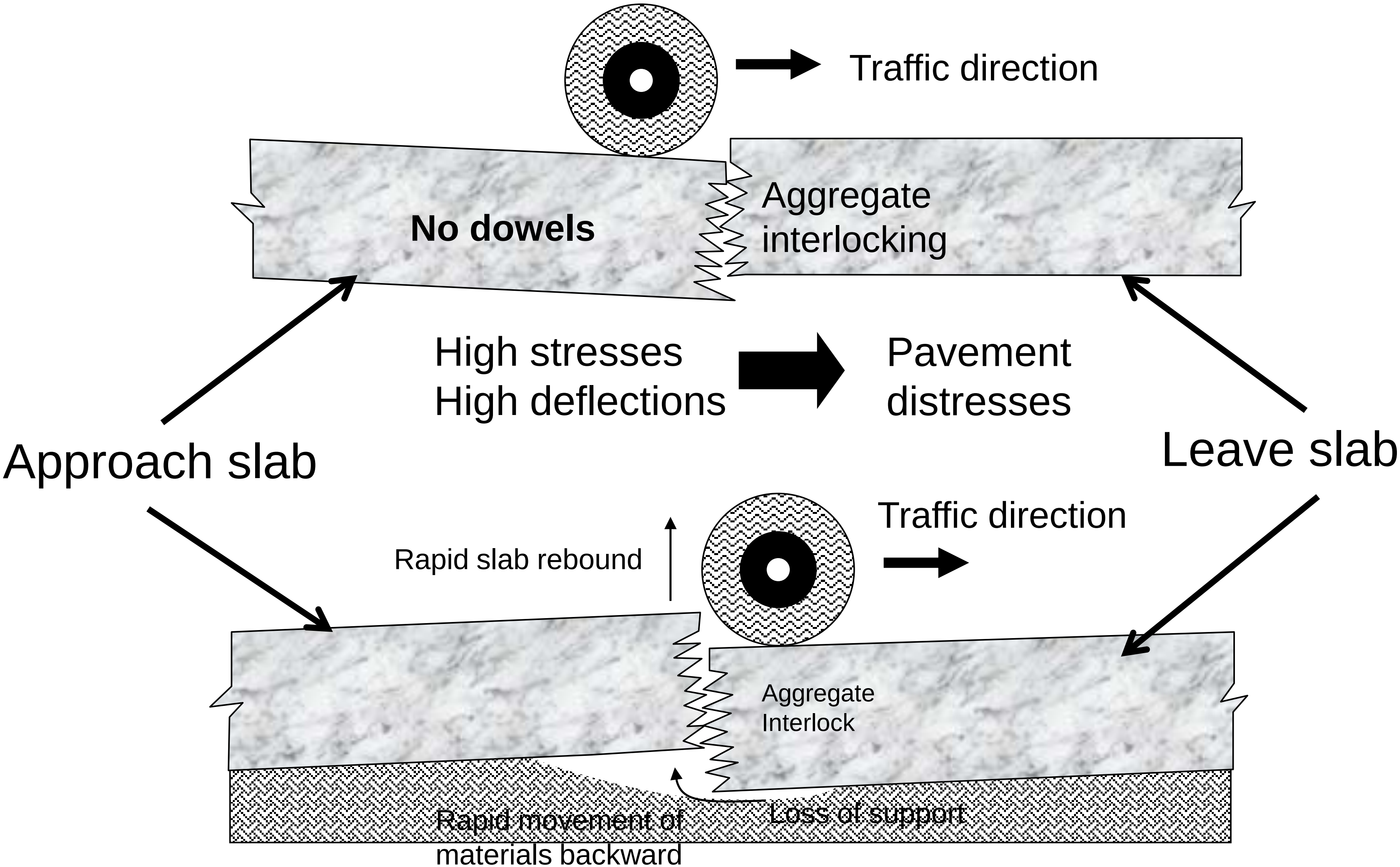
Tied joint
Max Stress = 1603 kPa

Why do we need dowels?

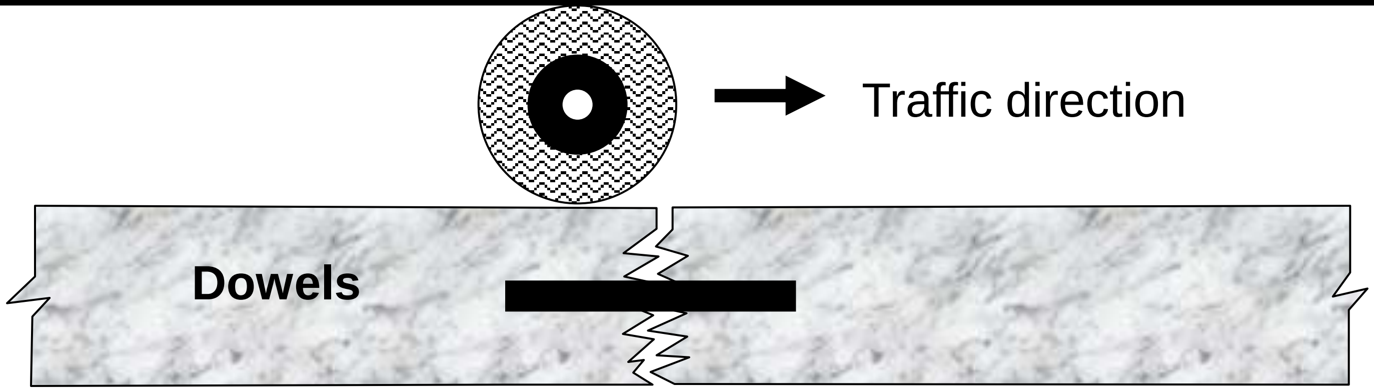
None or inadequate dowel bar design



Effect of dowels on pavement responses

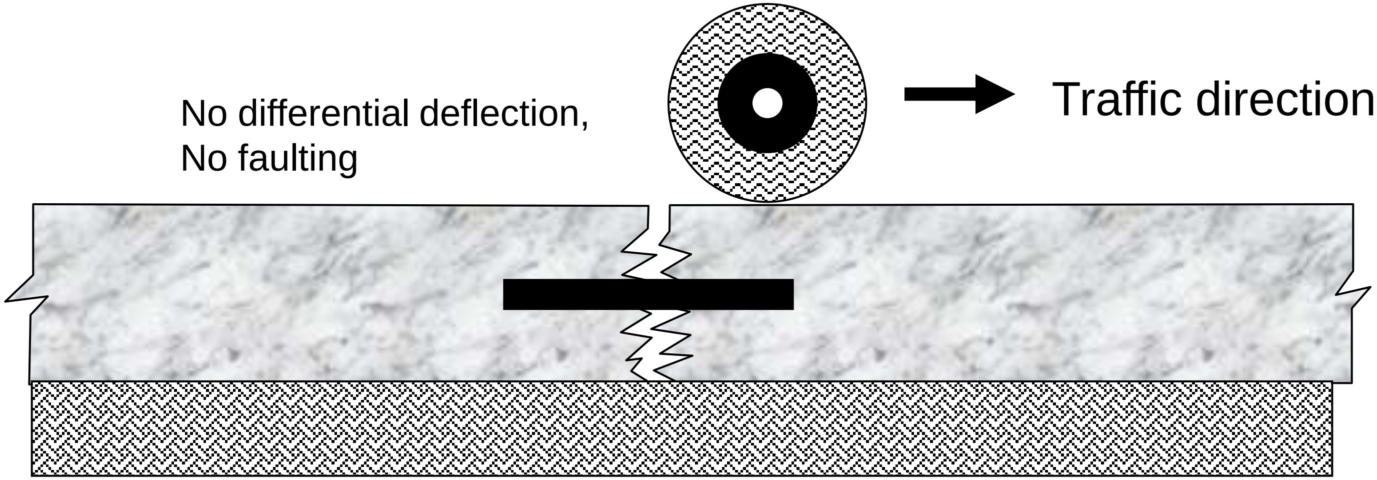


Effect of dowels on pavement responses

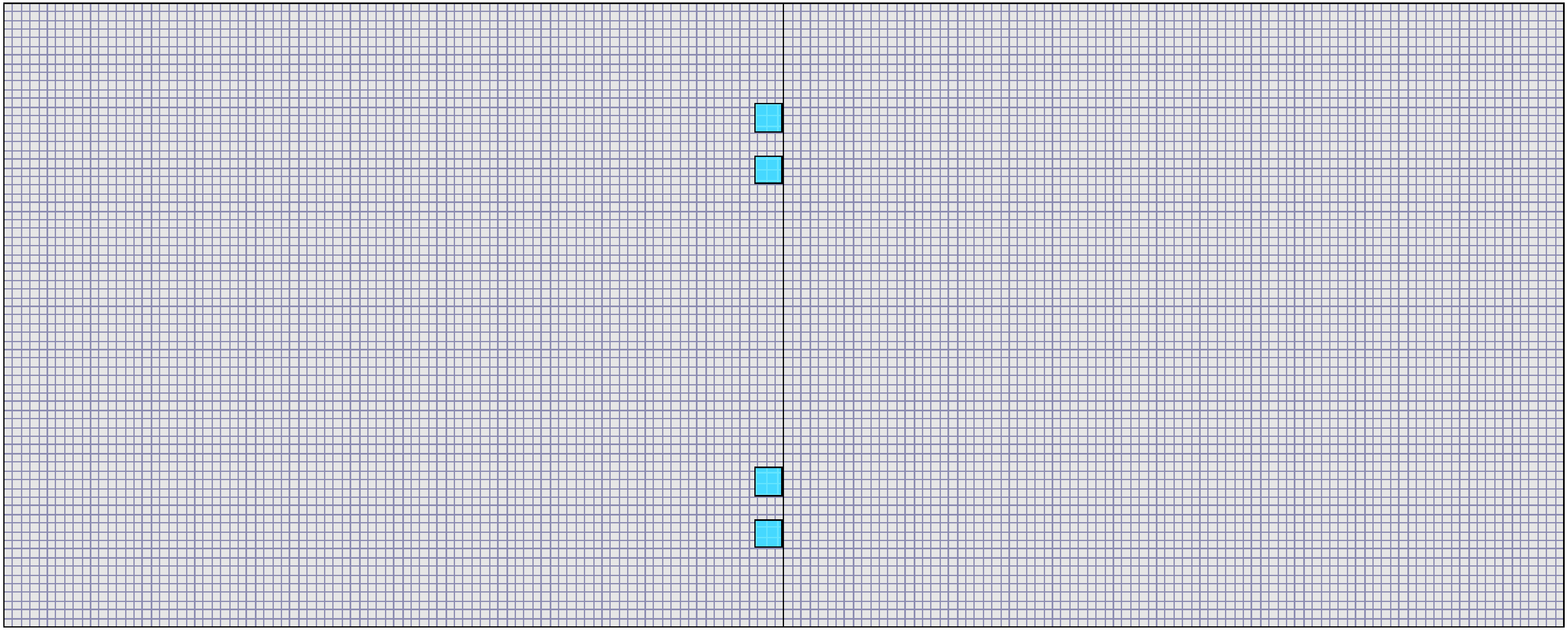


Low stresses
Low deflections

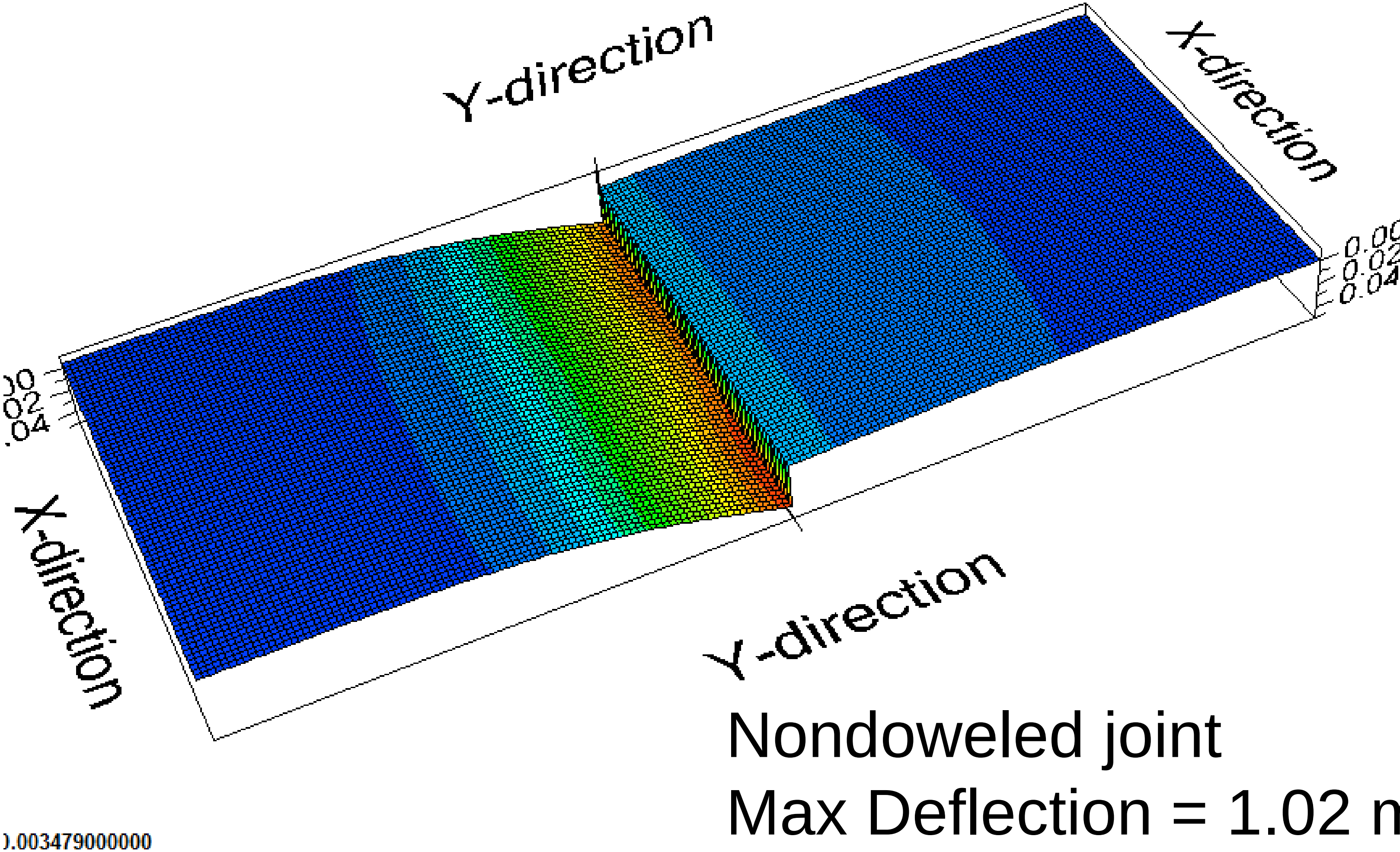
Good joint performance



ISLAB2000

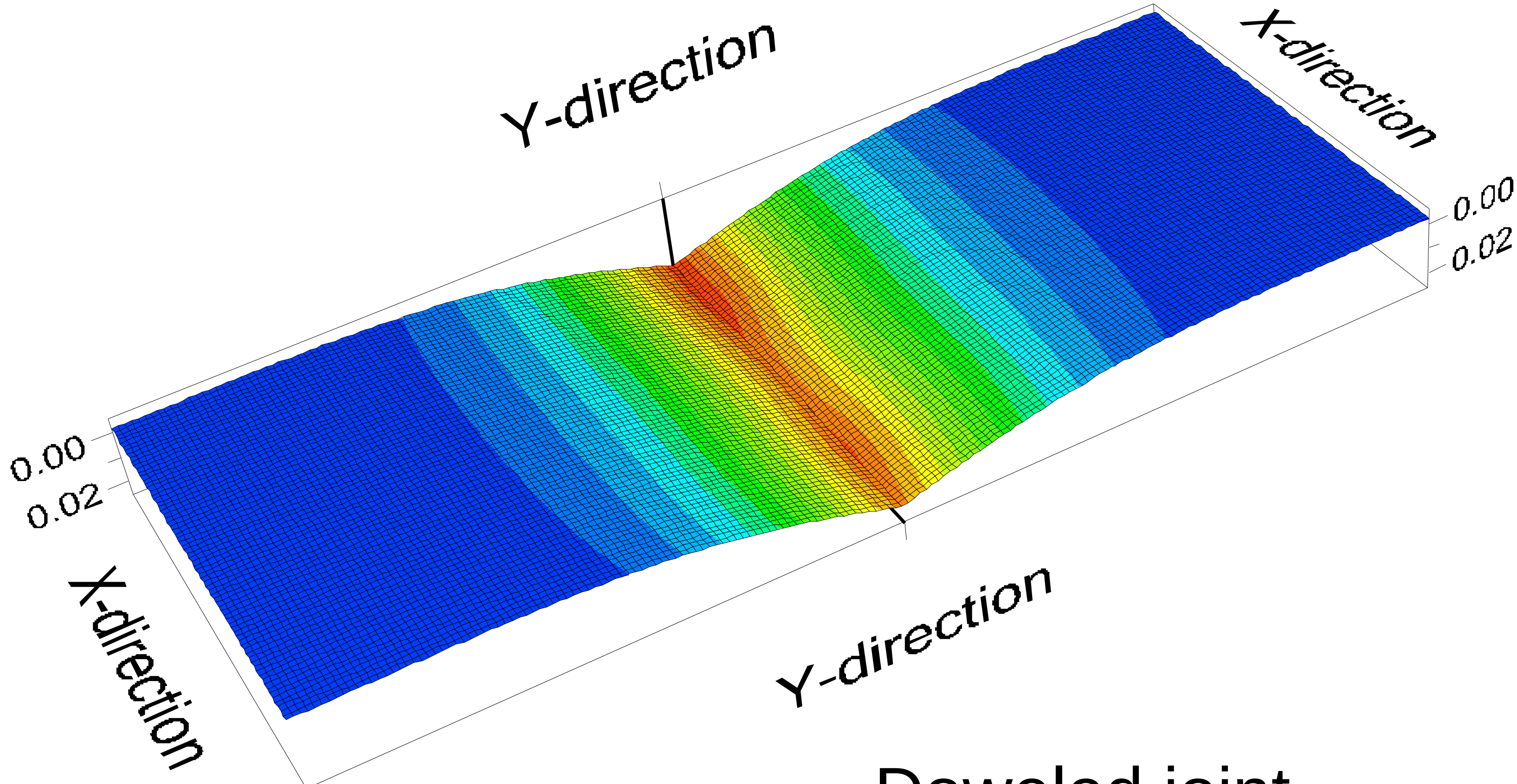


Effect of Dowels on Deflections



Nondoweled joint
Max Deflection = 1.02 mm

Effect of Dowels on Deflections



Doweled joint
Max Deflection = 0.6 mm

Effect of Dowels on Stresses

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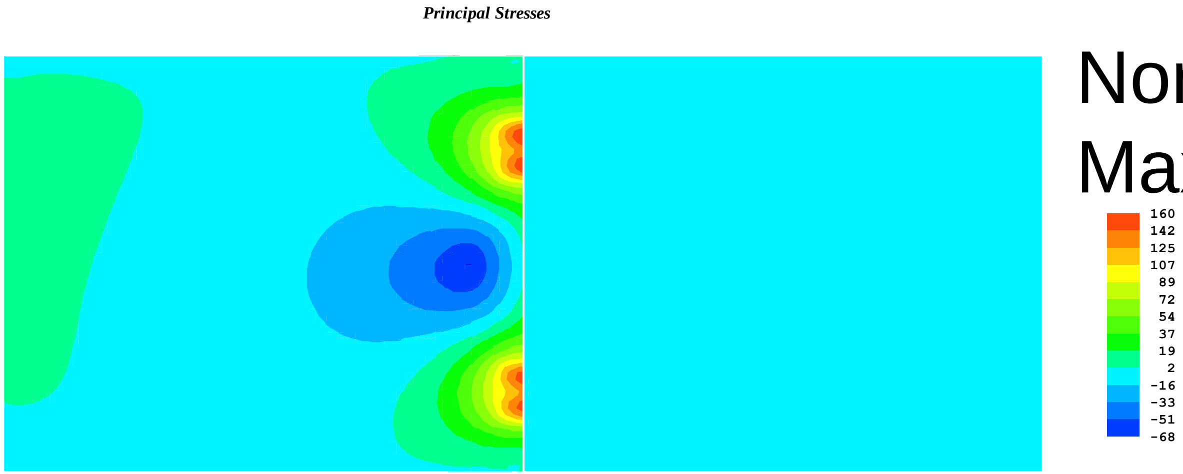
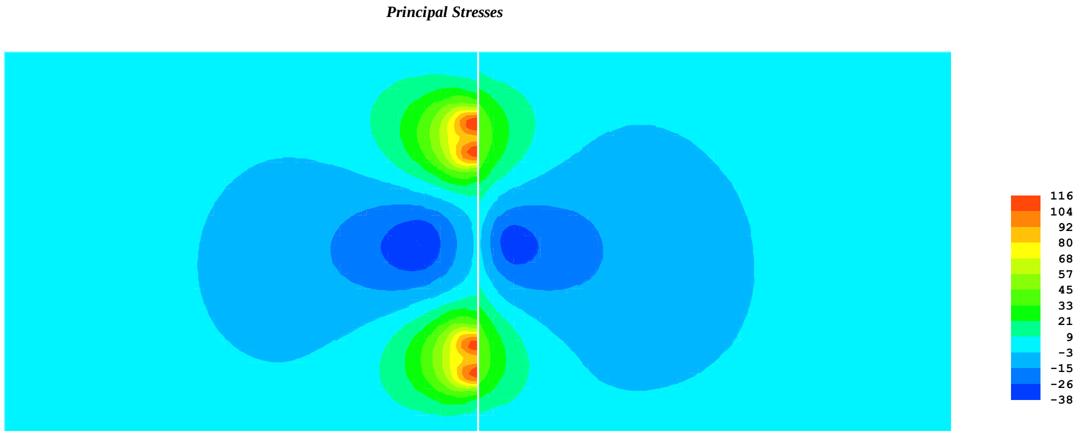
Principal Stresses at the Slab Bottom



Nondoweled joint
Max Stress = 1120 kPa

Doweled joint
Max Stress = 812 kPa

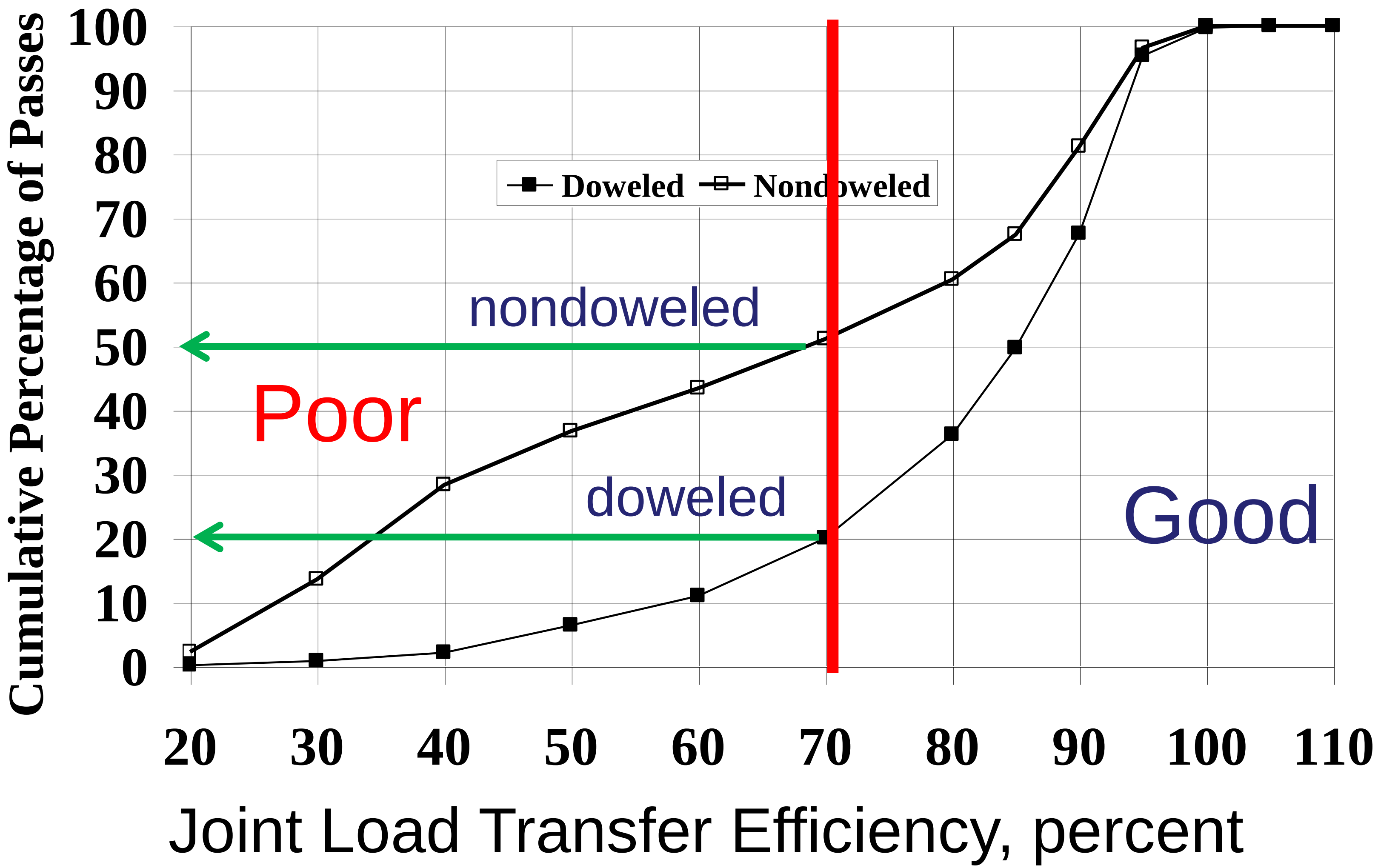


Federal Highway Administration Long Term Pavement Performance Studies

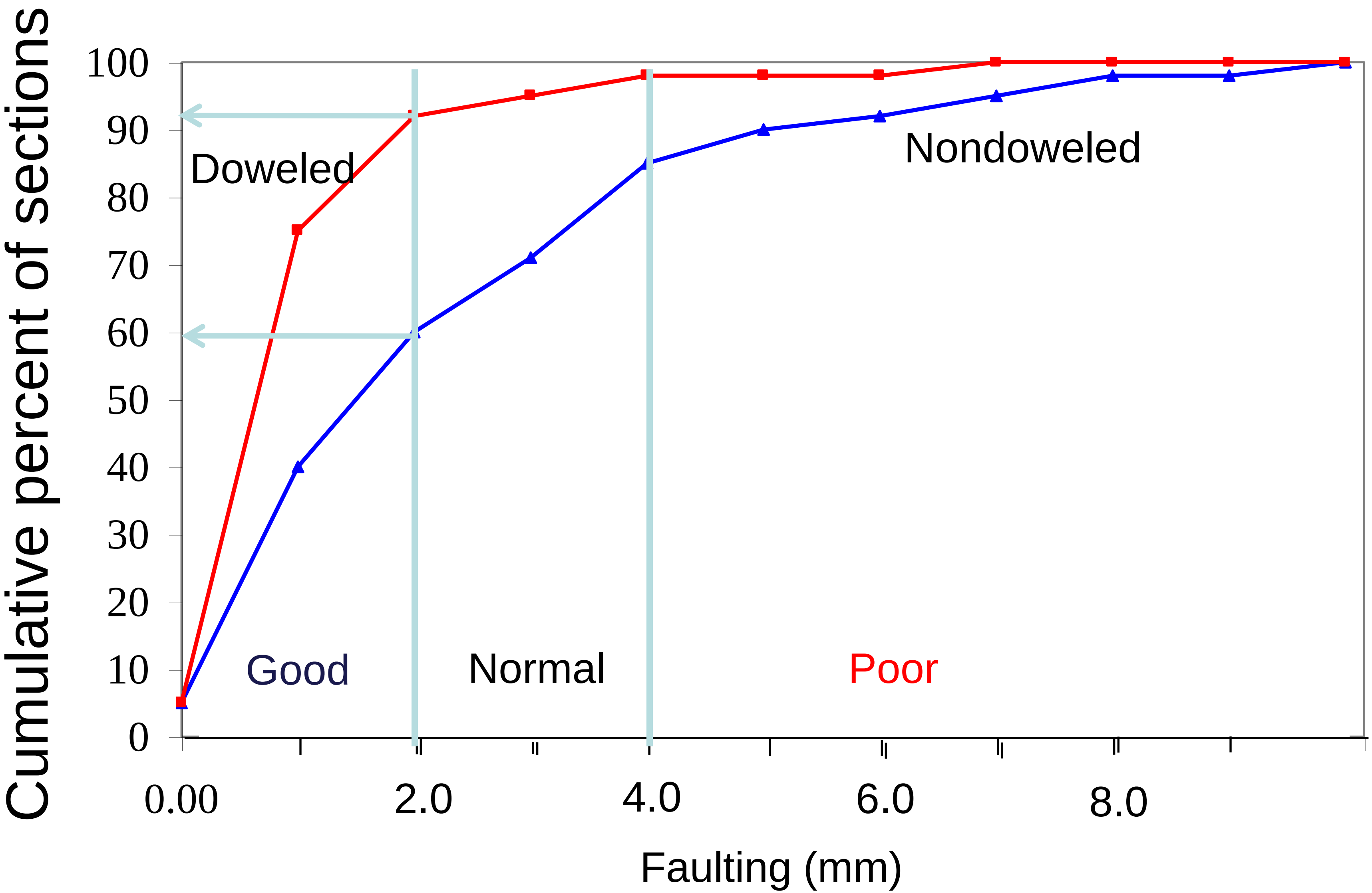
1. **Evaluation of Joint and Crack Load Transfer** (Khazanovich and Gotlif 2002)
2. **Common Characteristics of Good and Poorly Performing PCC Pavements (**Khazanovich et al. 1997)

Almost 150 pavement sections located throughout USA

Effect on Load Transfer Efficiency



Effect of Dowels on Faulting



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

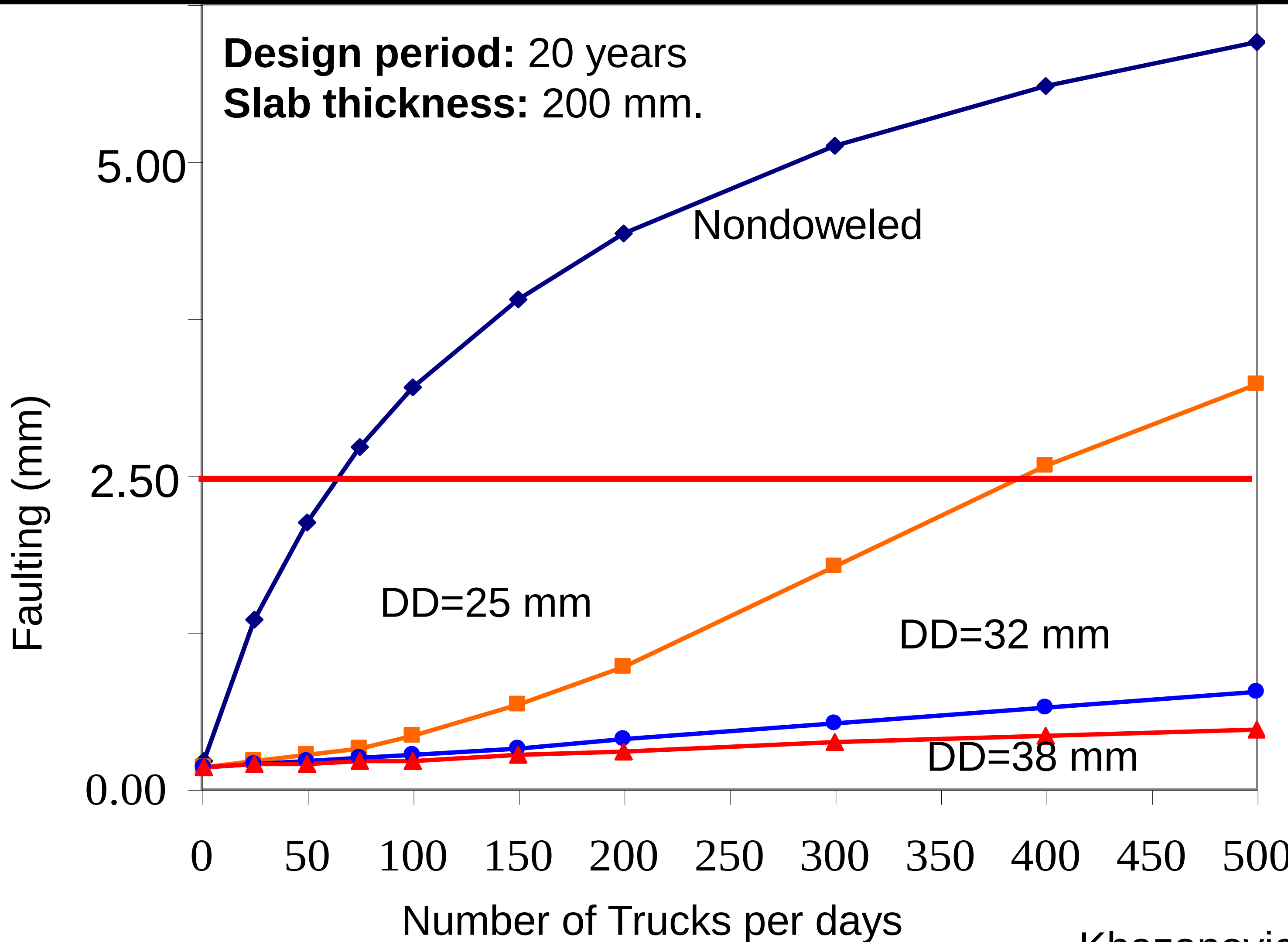
25 mm

USA

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

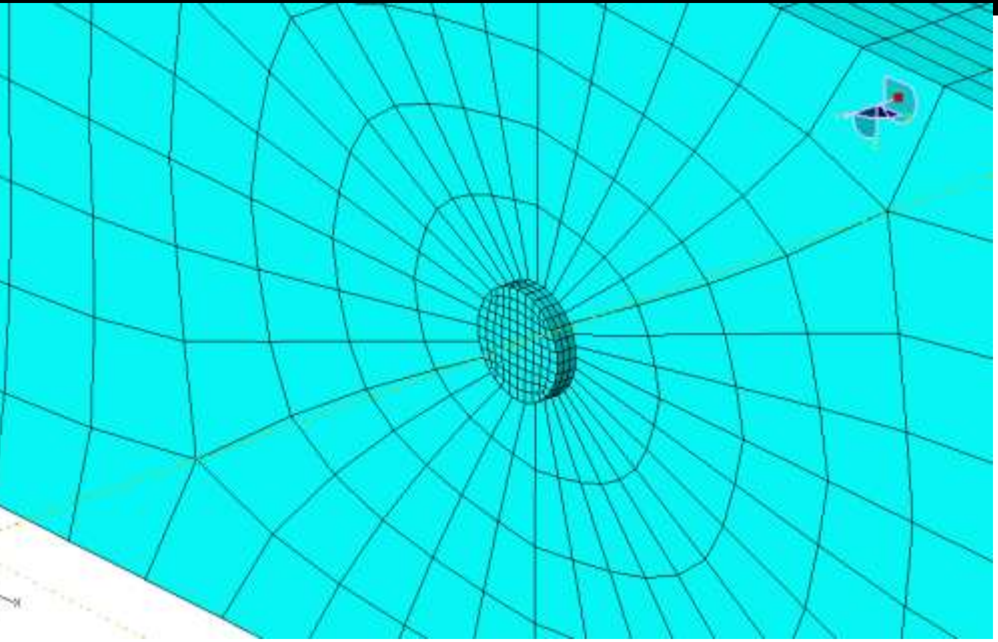
MEPDG – based on the maximum allowed faulting

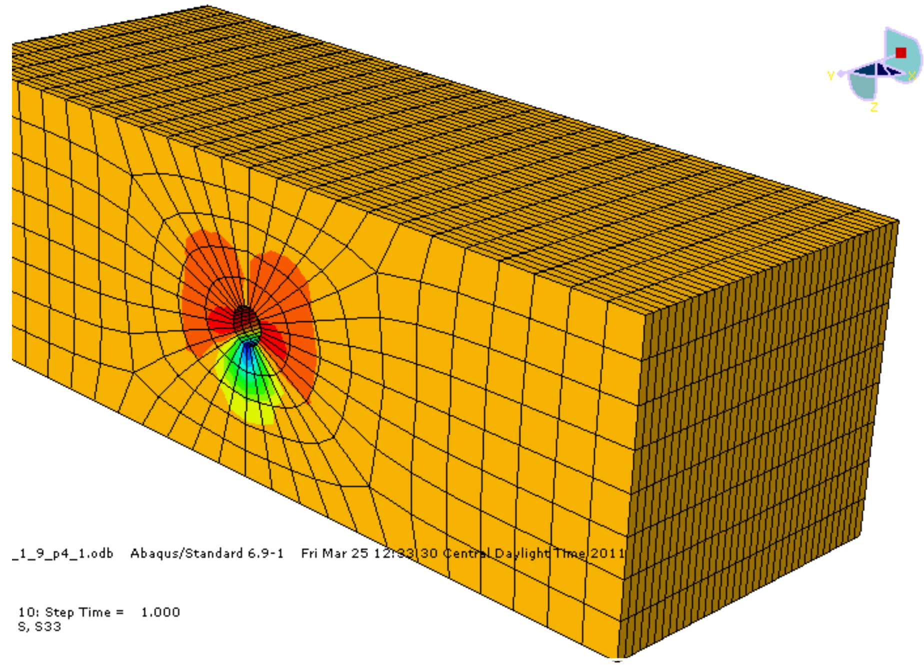
Effect of Dowel Diameter on Faulting



Khazanovich et al. 2004

Effect of Dowels Diameter on Bearing Stresses





Dowel Diameter, mm	Concrete Bearing Stress, MPa
25	17.3
32	12.7
38	9.3

Dowel Length and Spacing

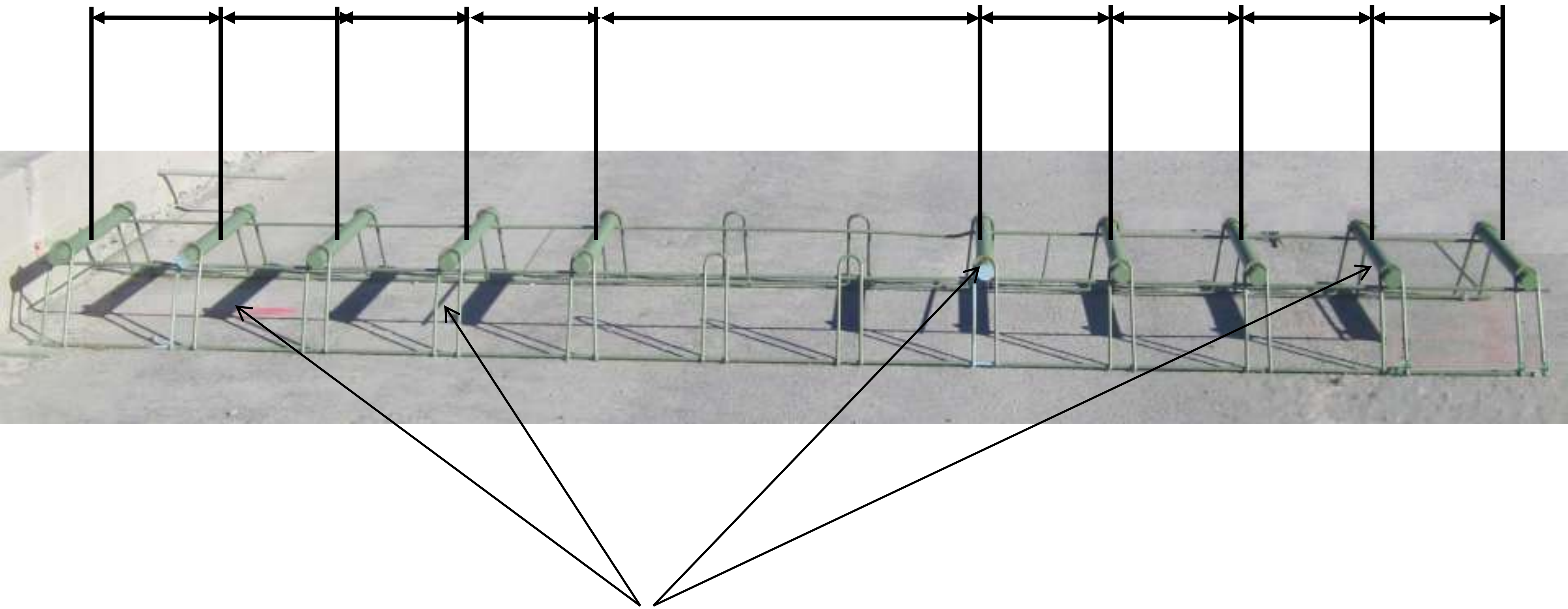
- Dowel length

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



Dowels in the wheel paths only

Tie bar Diameter

- Tie bar diameter

Austria:	14 mm
Germany:	20 mm
USA:	12.5 and 16 mm

Tie Bar Length and Spacing

- 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

FHWA Tie Bar Spacing

Bar diameter: 12.5 mm
Steel yield strength: 280 MPA

PCC thickness (mm)	Distance to free edge (mm)			
	3000	3600	4800	7200
225	650	550	400	275
250	600	500	400	250
275	550	450	350	225
300	500	400	325	225

FHWA Tie Bar Spacing

Bar diameter: 16 mm
Steel yield strength: 280 MPa)

PCC thickness (mm)	Distance to free edge (mm)			
	3000	3600	4800	7200
225	1050	875	650	425
250	950	775	600	400
275	850	725	525	350
300	775	650	500	325

Presentation Outline

- Introduction
- Benefits of dowel and tie bars
- Dowel and tie bar design
- **Construction**
  - **Installation**
  - **Common problems**
  - **Evaluation**
  - **Fixing**
- Summary

Installation

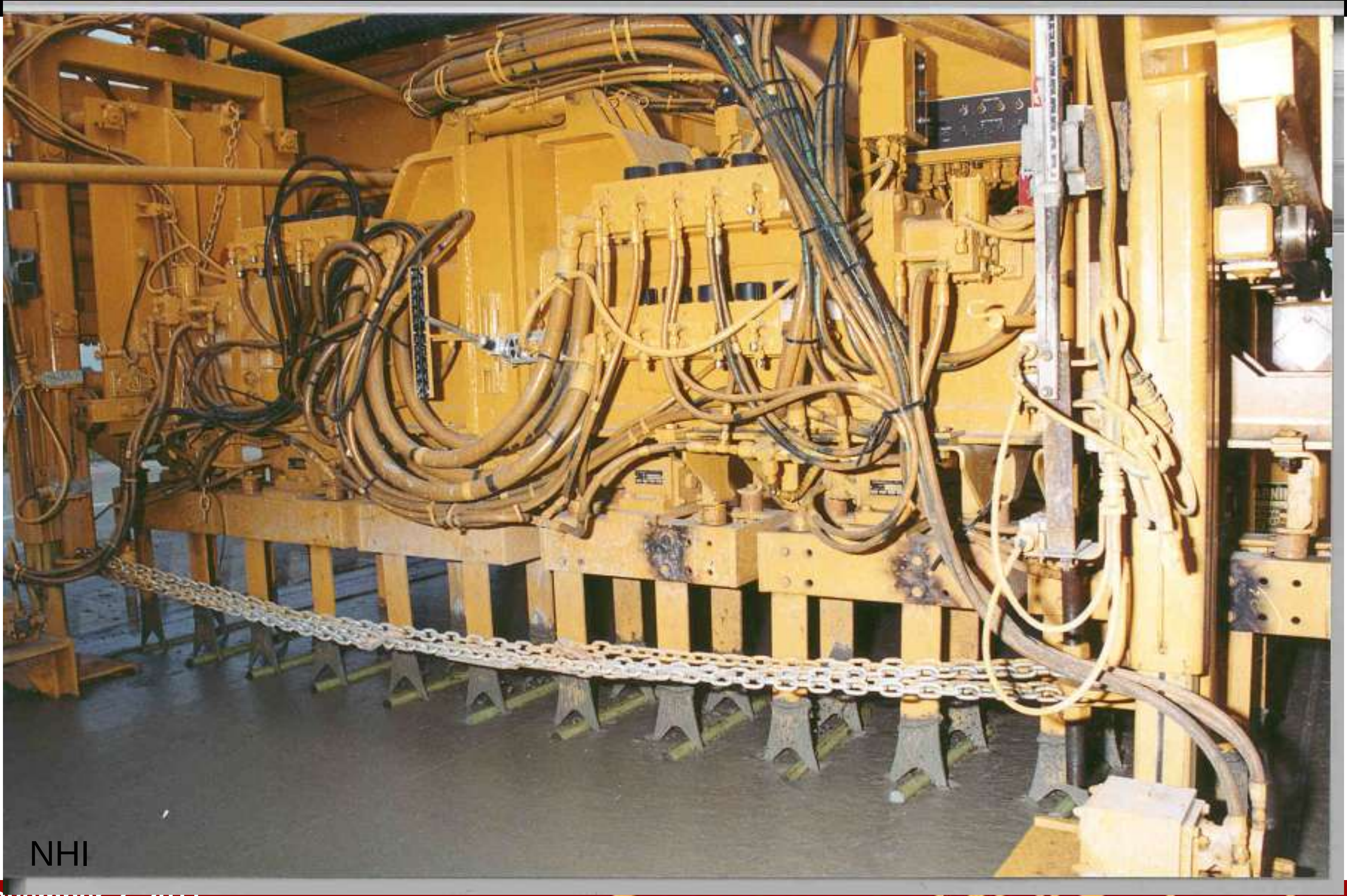
- Dower bars
  - Dowel baskets
  - Dowel bar inserter (DBI)

  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

Dowel Bar Inserter



Tie Bar Installation

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

e

Vertical Position Problem

Cracking occurred near the joint the next morning

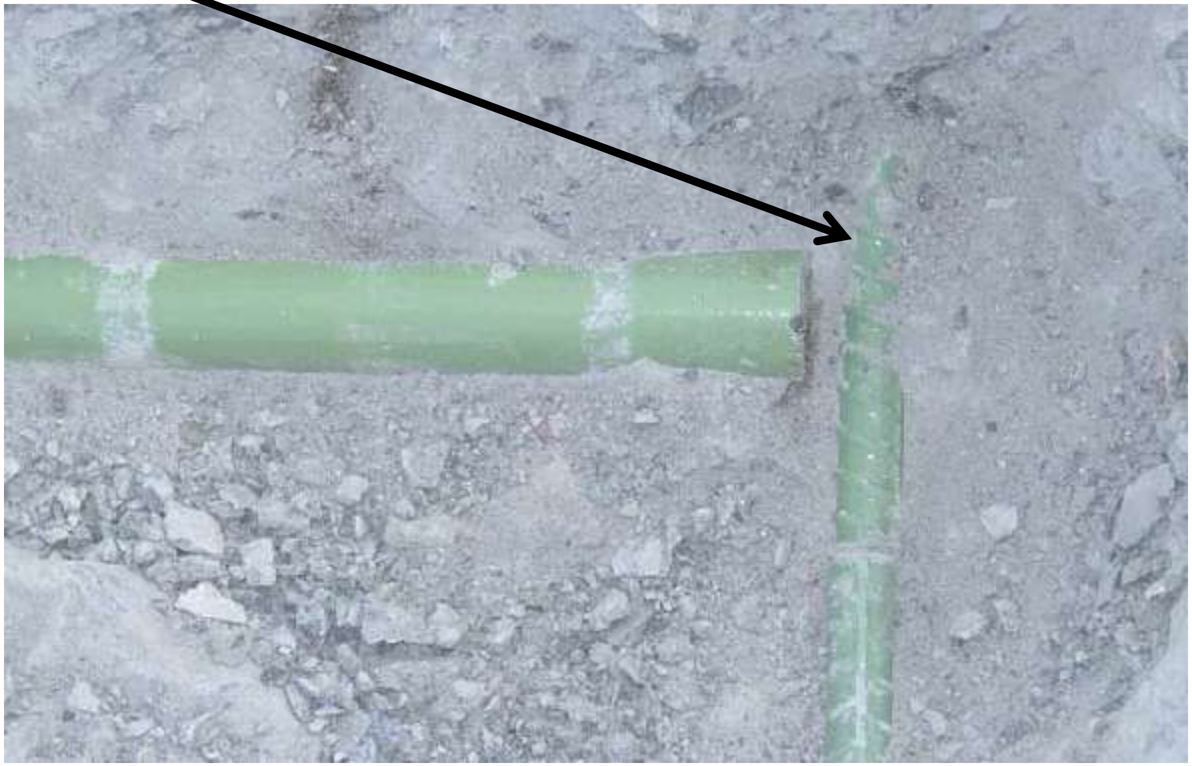
Common Problems

Common Problems

Common Problems

Common Problems

The tie is too close to the dowel



Poor Consolidation of Concrete

Entrapped air

Dowel bar

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

-

NDT for Bar Placement

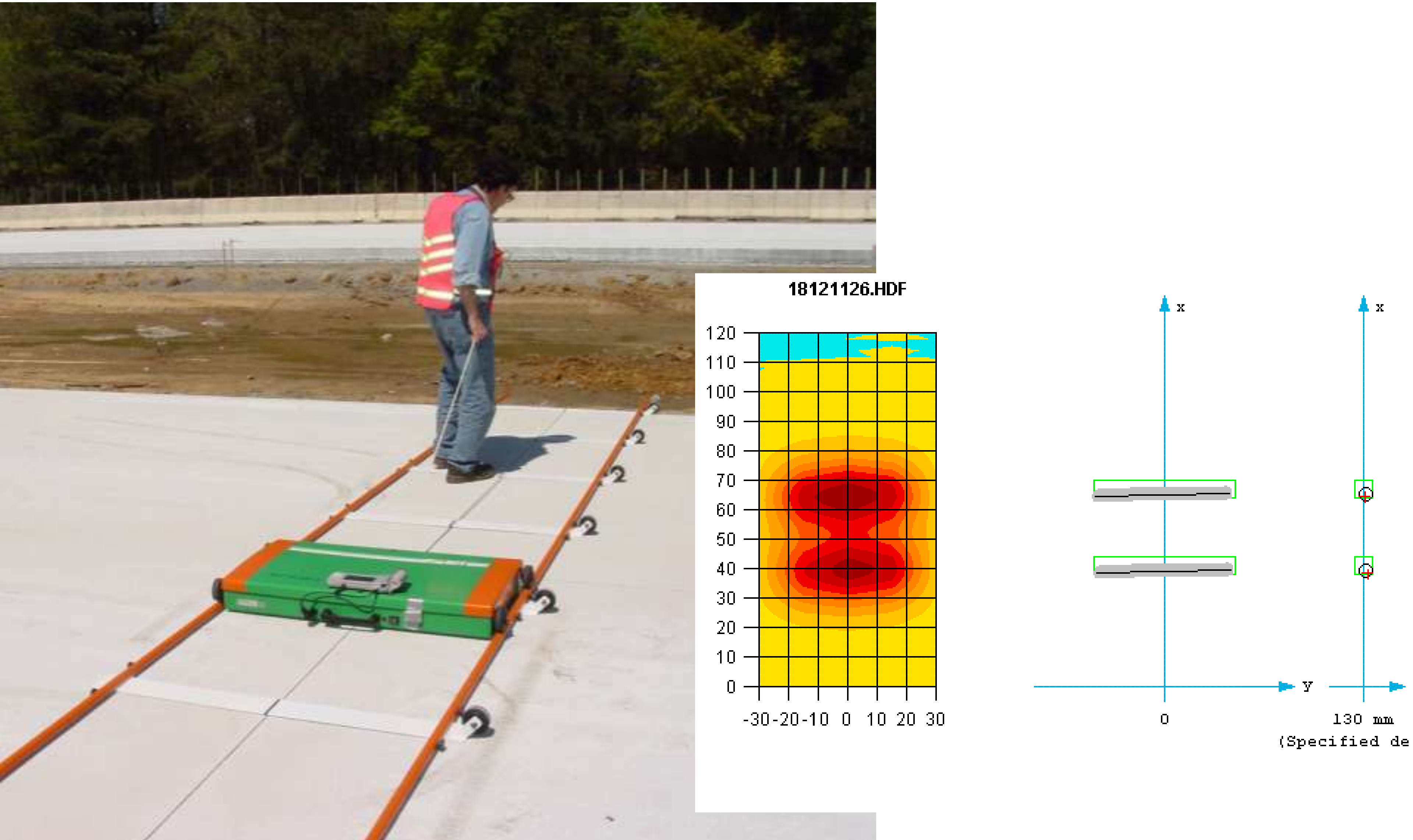
Non-destructive Methods for Bar Location

- Magnetic (MIT SCAN)
- Ground-penetrating radar (GPR)
- Ultrasound tomography

MIT SCAN

- 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

MIT SCAN


18121126.HDF
120
110
100
90
80
70
60
50
40
30
20
10
0
-30 -20 -10 0 10 20 30
x
x
y
0
130 mm
(Specified de

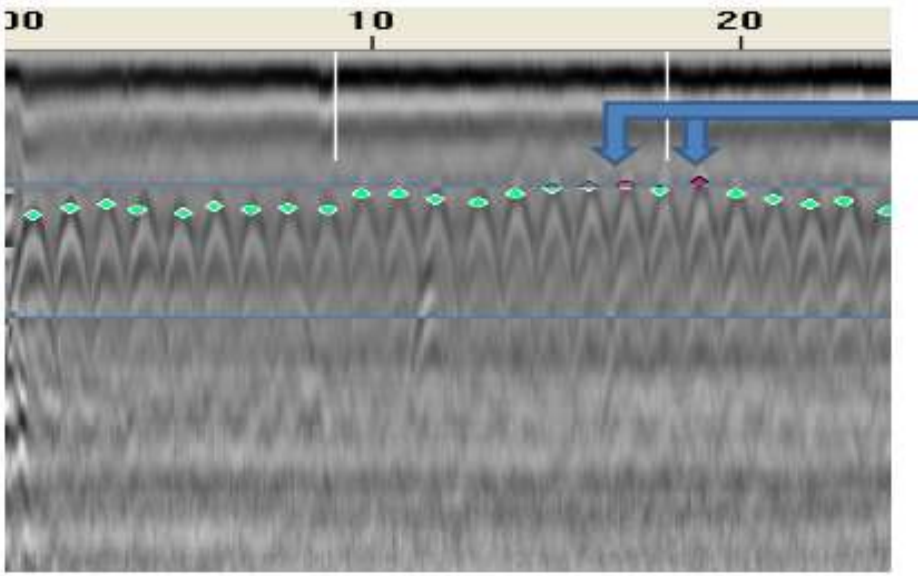
Ground-Penetrating Radar (GPR)

Advantages

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

Disadvantages

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

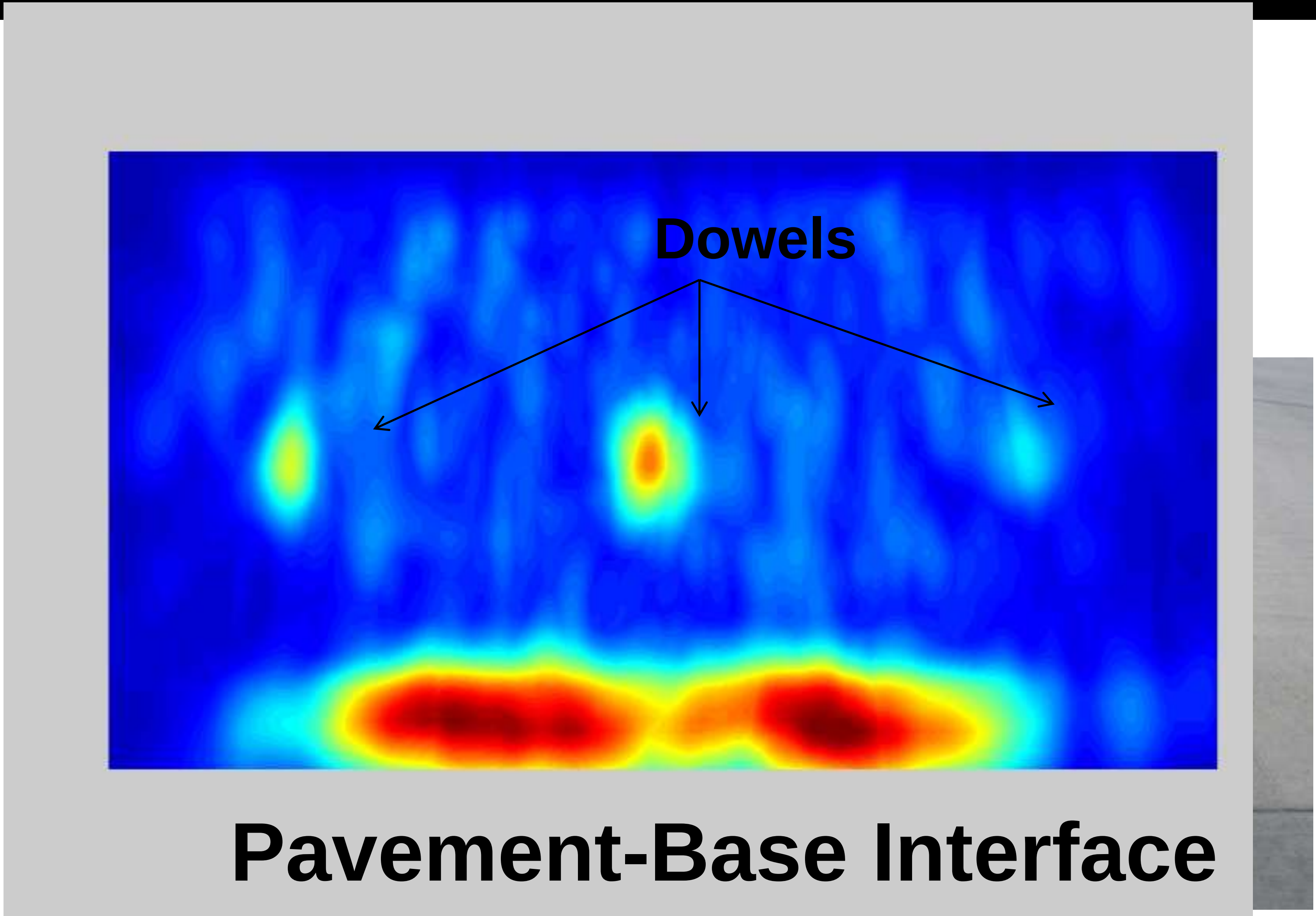


Rister and Graves 2011

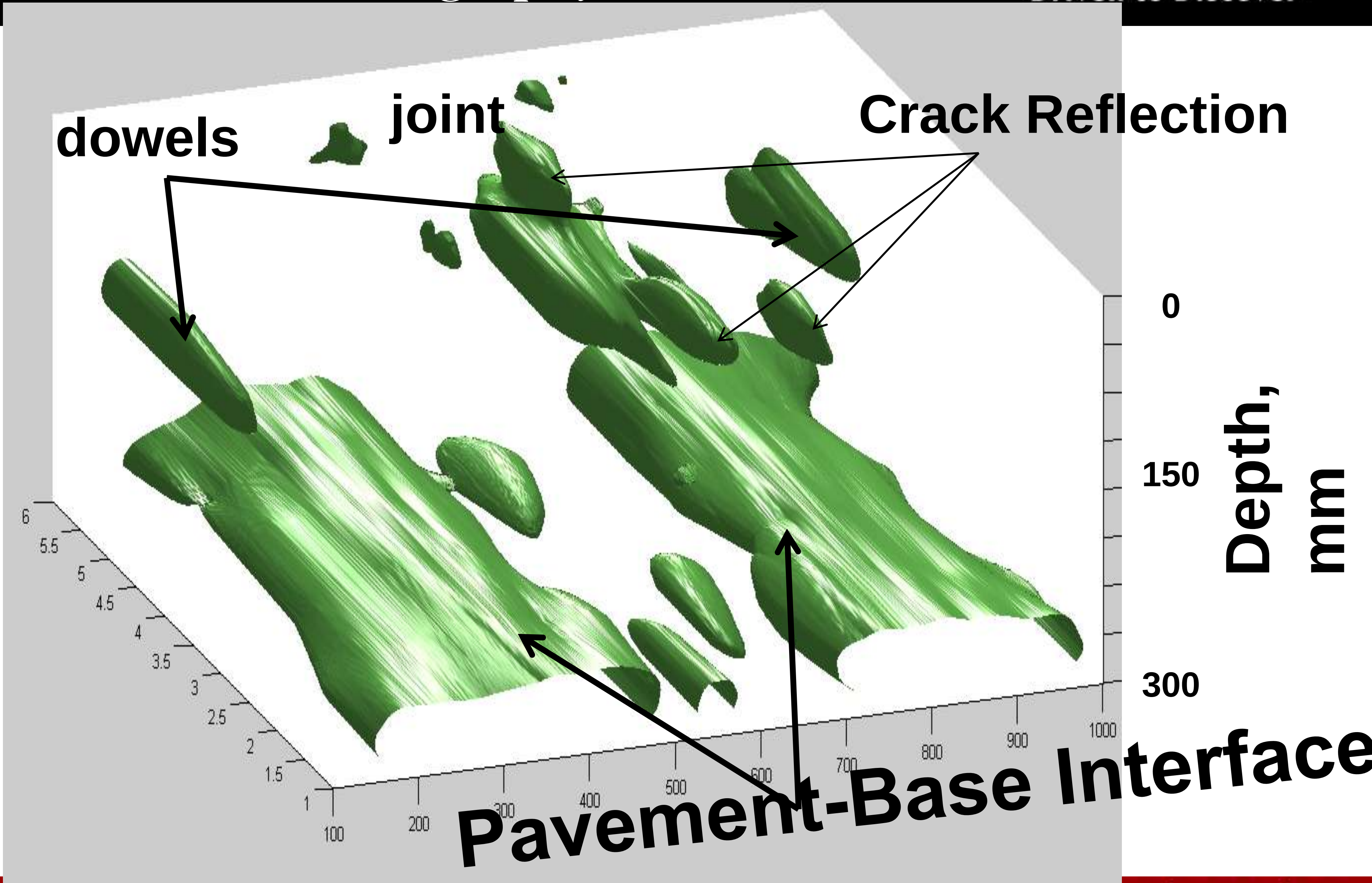
Ultrasound Tomography

Advantages
- Determines not only bar position but also condition of concrete around dowel/tie bar

Disadvantages
- Relatively slow


Dowels
Pavement-Base Interface

Ultrasound Tomography



Alignment Tolerances

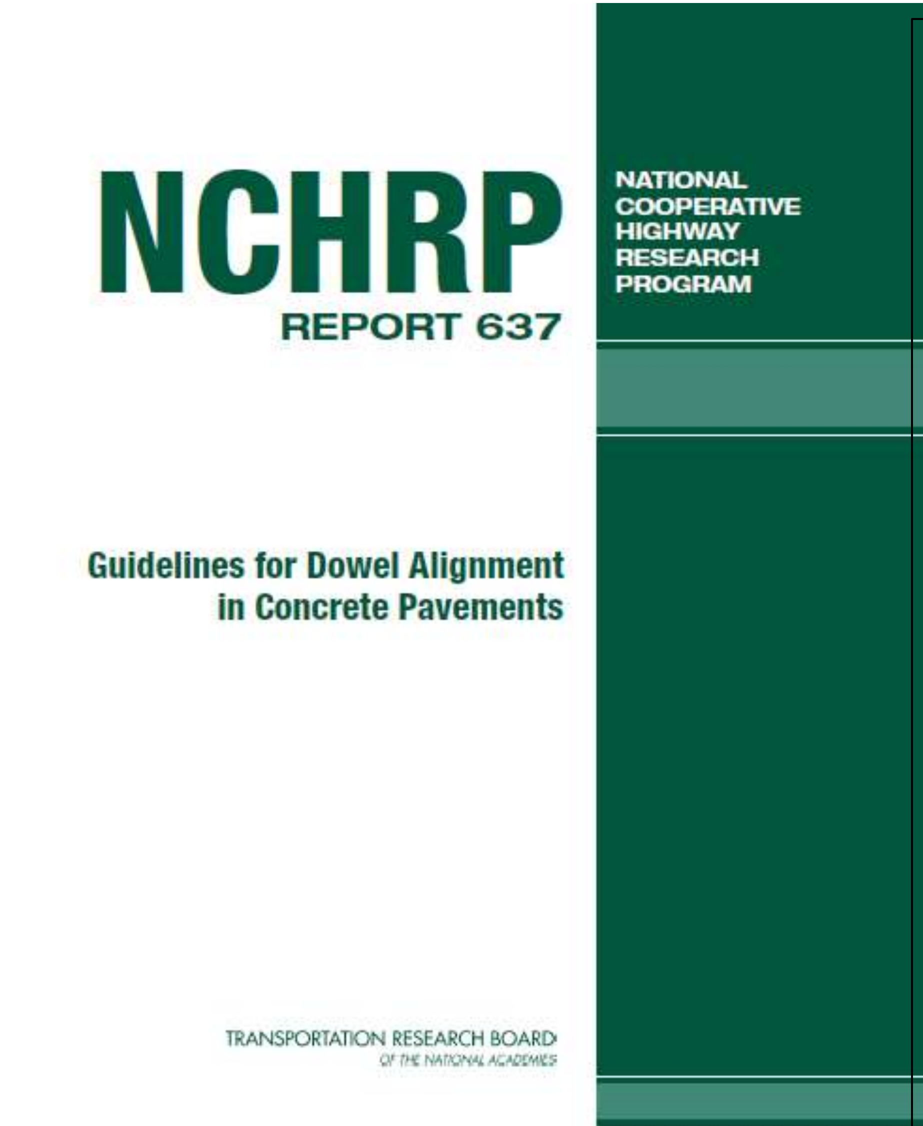
Washington DOT tolerances for tie bars

- 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

Alignment Tolerances



NCHRP 10-69 Study
University of Minnesota (Prime Contractor)

Lev Khazanovich
Kyle Hoegh
Mark Snyder

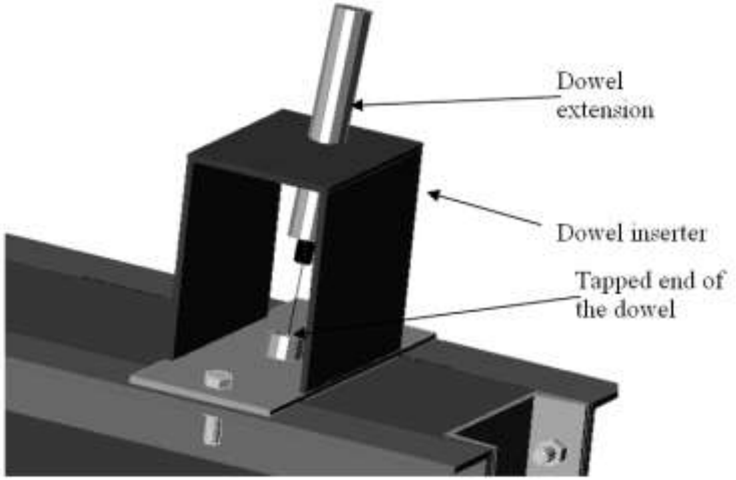
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_637.pdf

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.

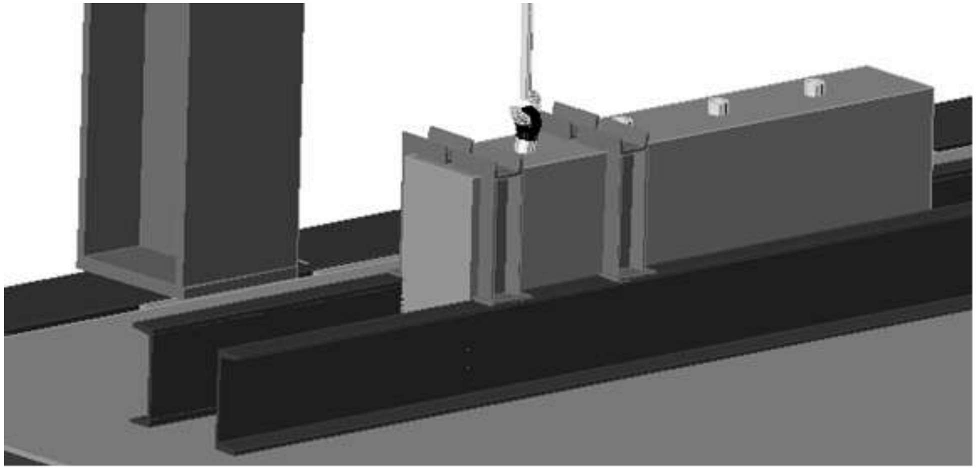
Laboratory Testing

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

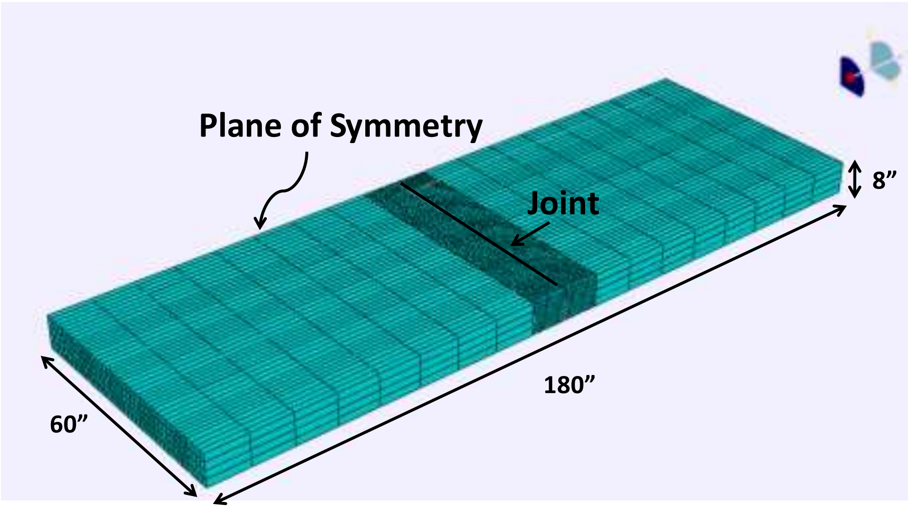


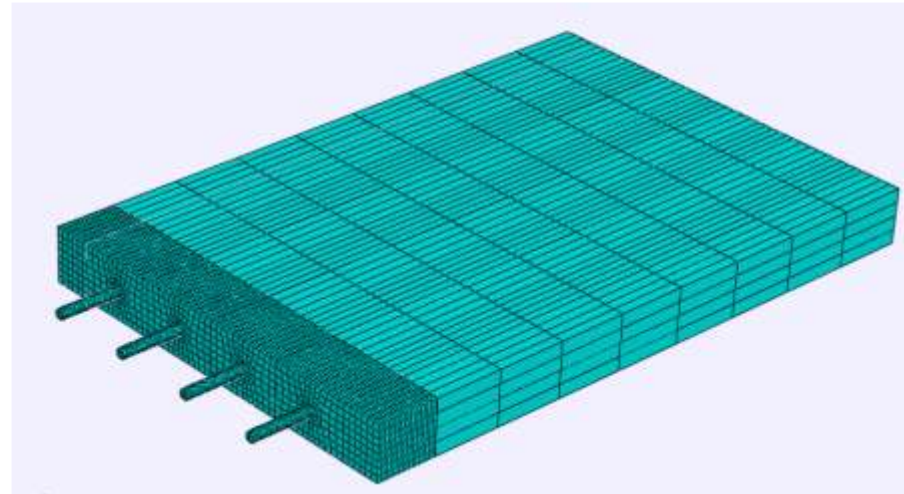
Shear Test

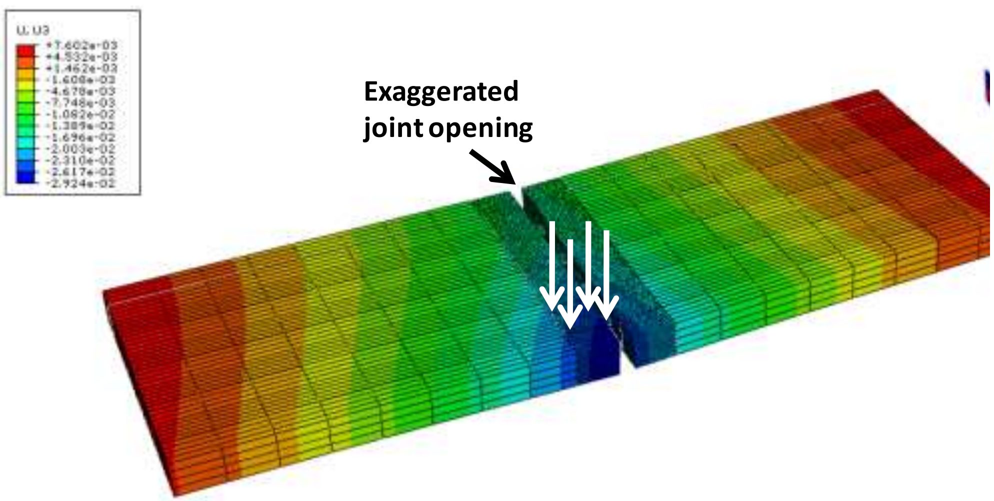
Pullout Test

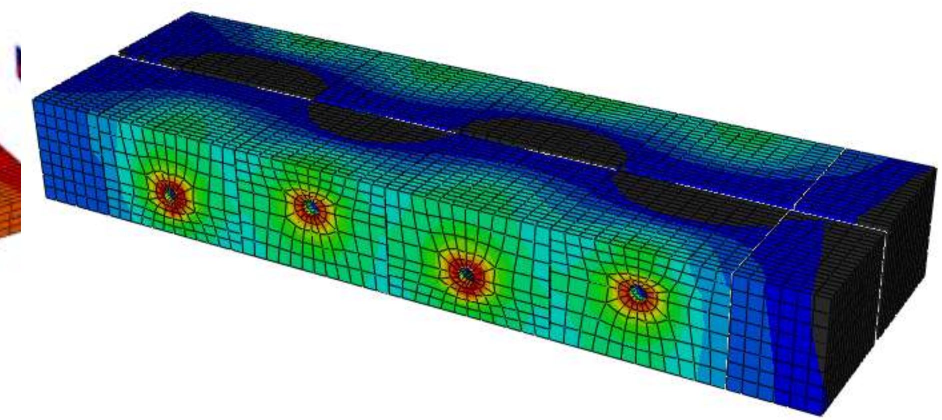


Analytical Modeling









- Dowel greasing is very important!
- Dowel alignment

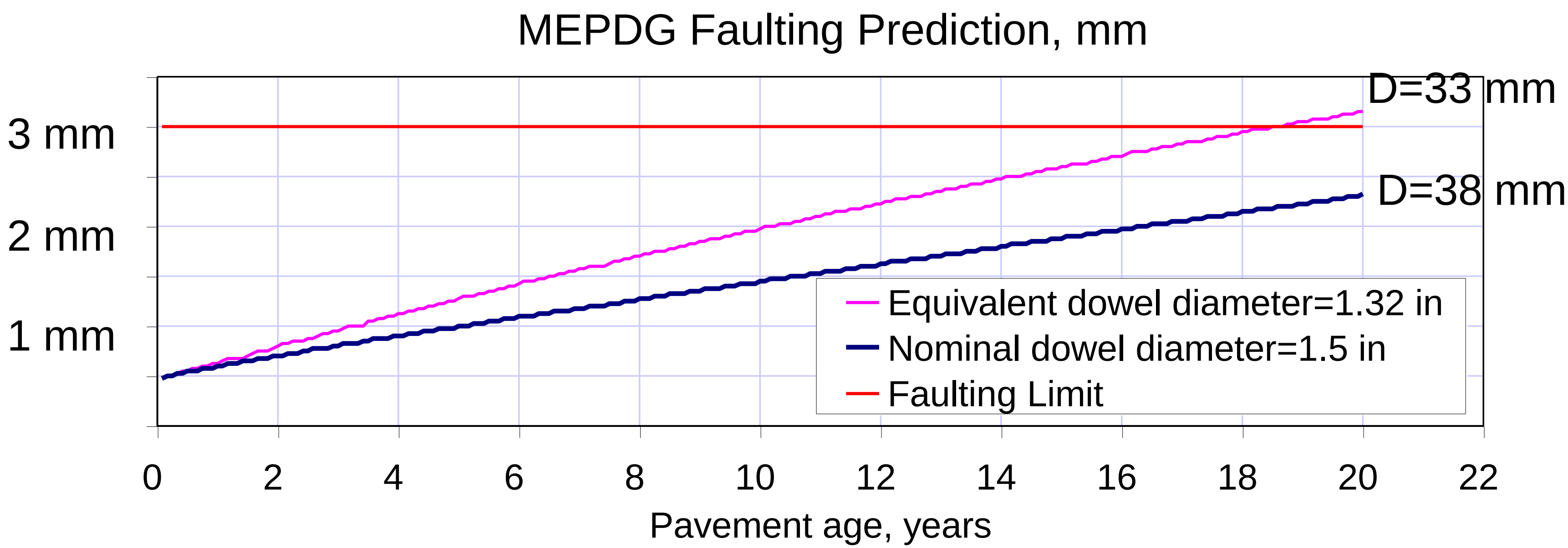
	Good	**Bad**
Vertical position	Mid-depth +/- 13 mm	Concrete cover <50 mm Concrete cover < saw cut depth
Embedment length	>175 mm	< 50 mm
Rotation	< 25 mm/450 mm	> 75 / 450 mm

- 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 12.5 mm
d_0 = nominal dowel diameter



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

Summary

- 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