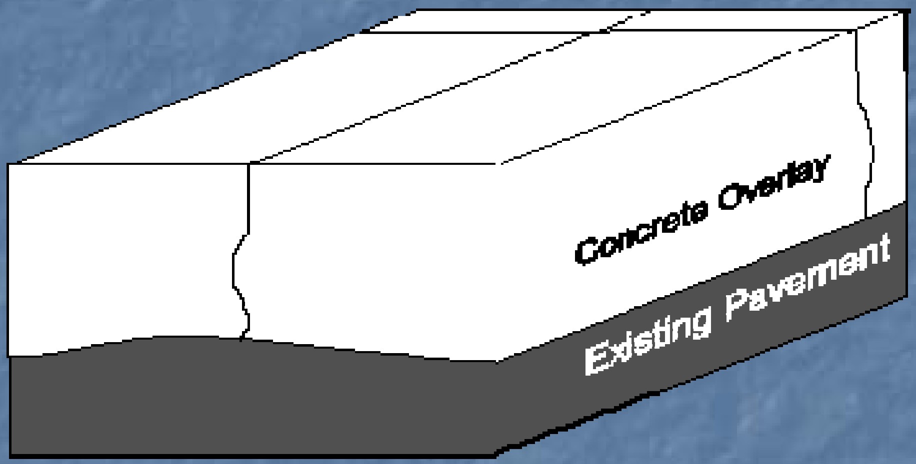
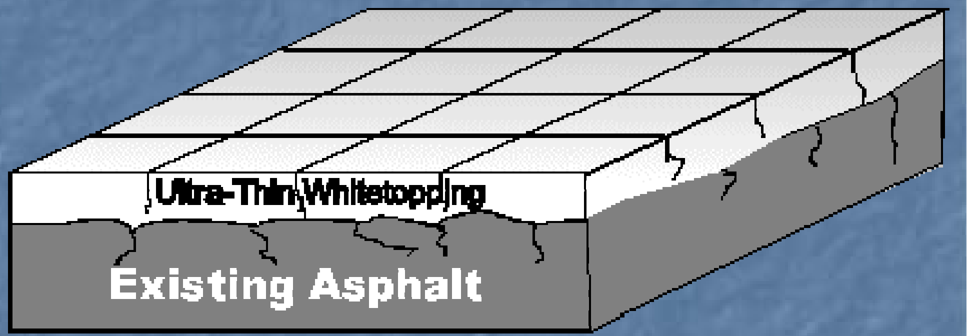
Applications, Design & Construction of Ultra-thin Whitetopping

Dr. Julie M. Vandenbossche, P.E.
- University of Pittsburgh-

Whitetopping



Conventional
(no bond)



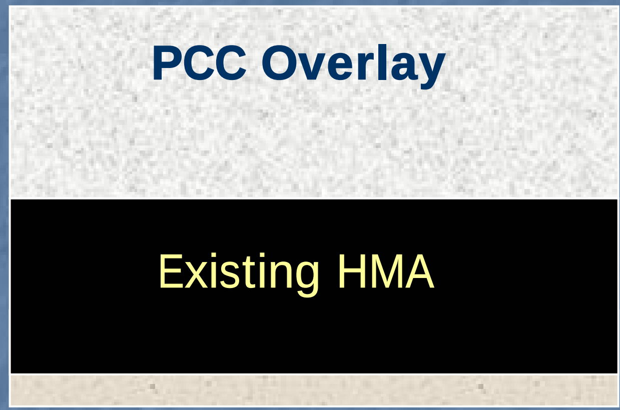
Ultra-thin
(bond is key!)

Definitions

Bond is not required

Thin Whitetopping
(TWT)

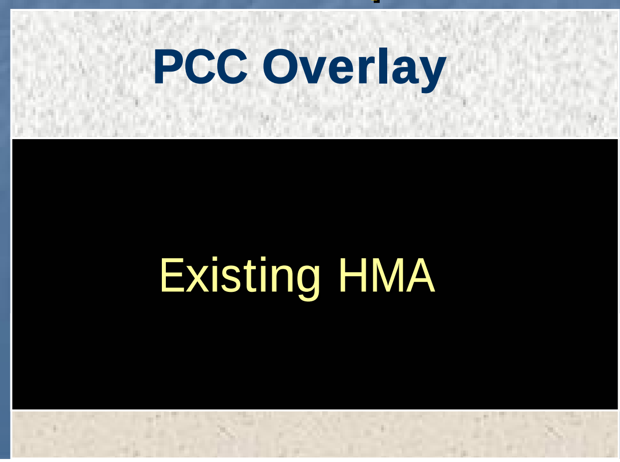
> 100 to 200 mm



Bond *is* required

Ultra-Thin Whitetopping
(UTW)

50 to 100 mm



Definitions

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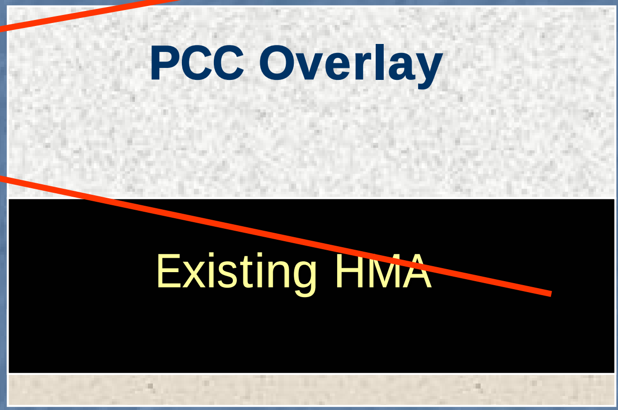
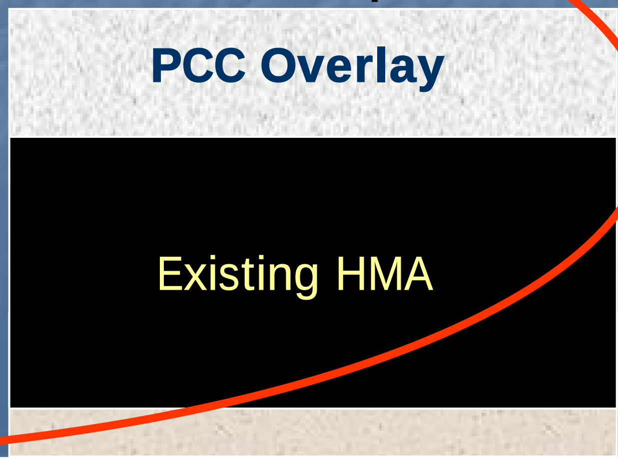


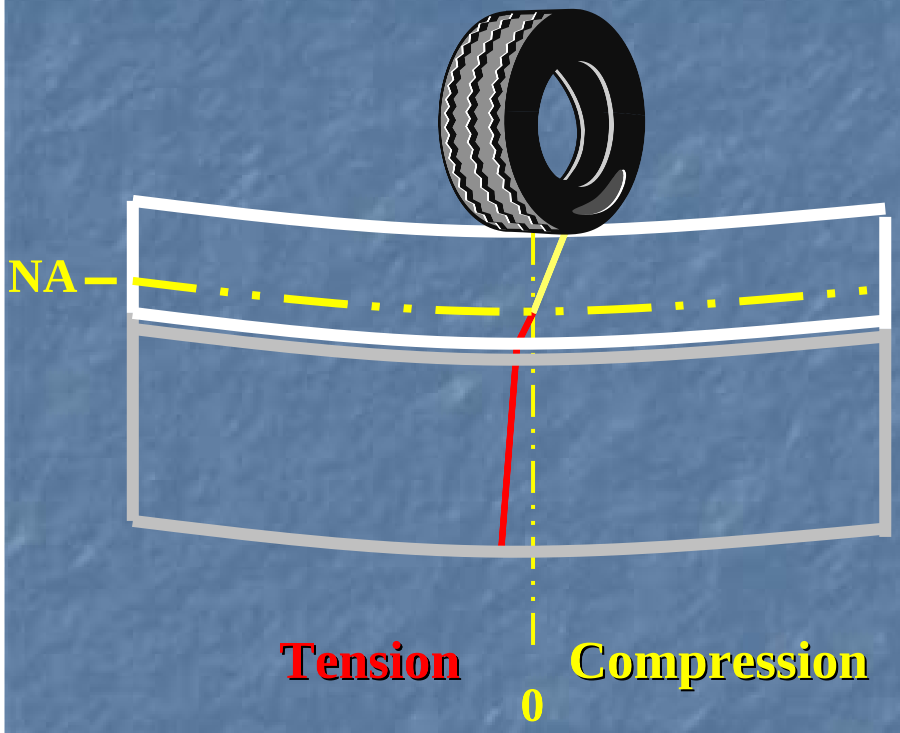
Bond *is* required

Ultra-Thin Whitetopping (UTW)

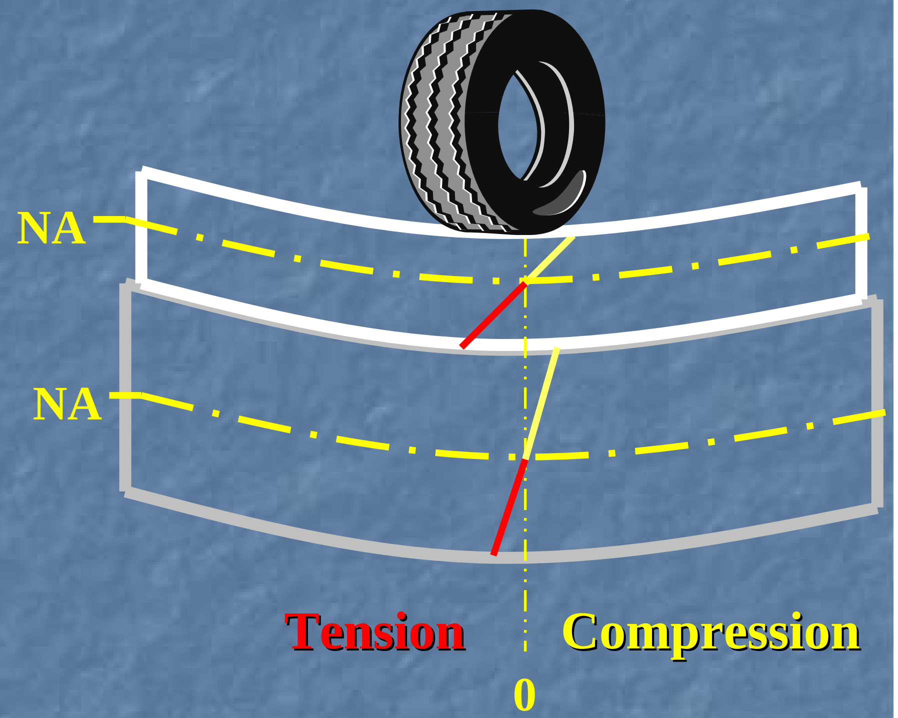
50 to 100 mm



How does UTW work?

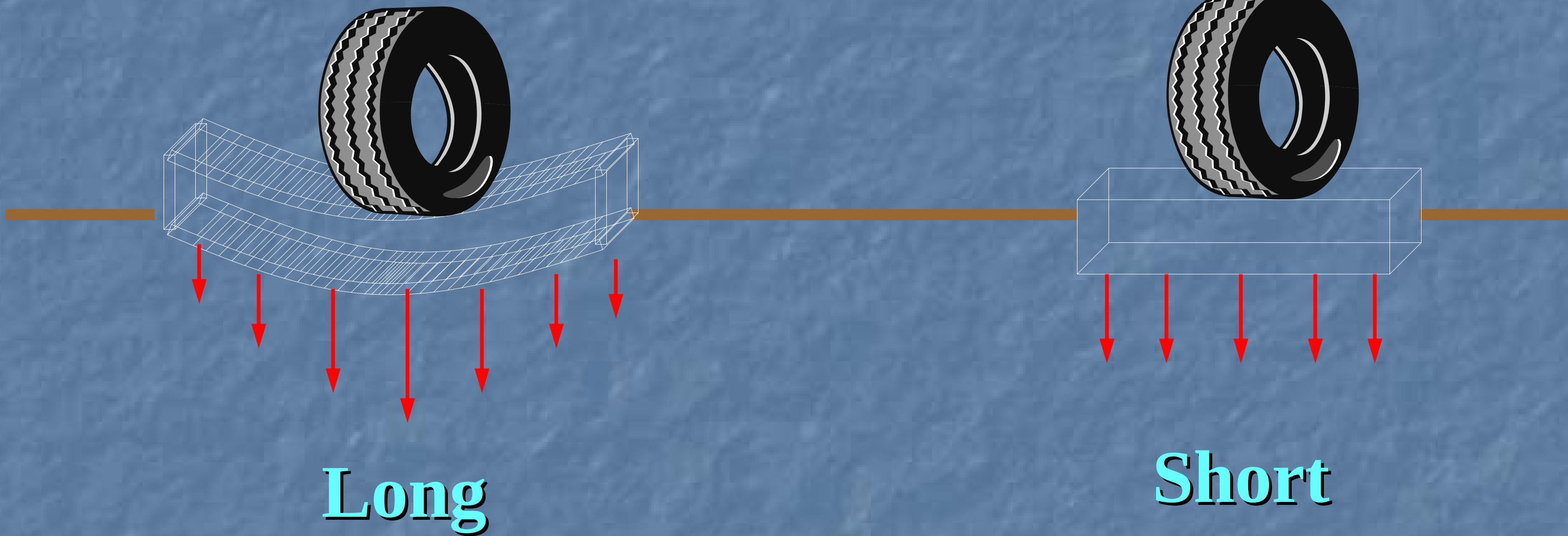


Bonded



Unbonded

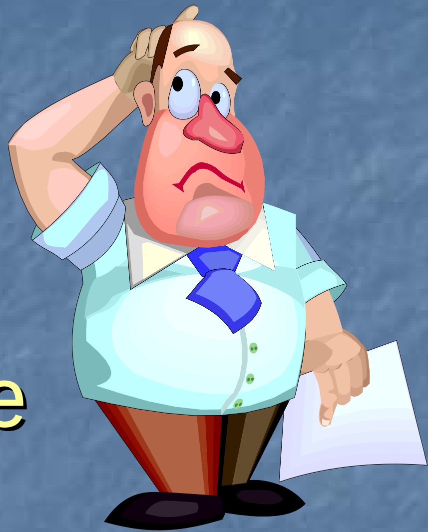
How does UTW work?

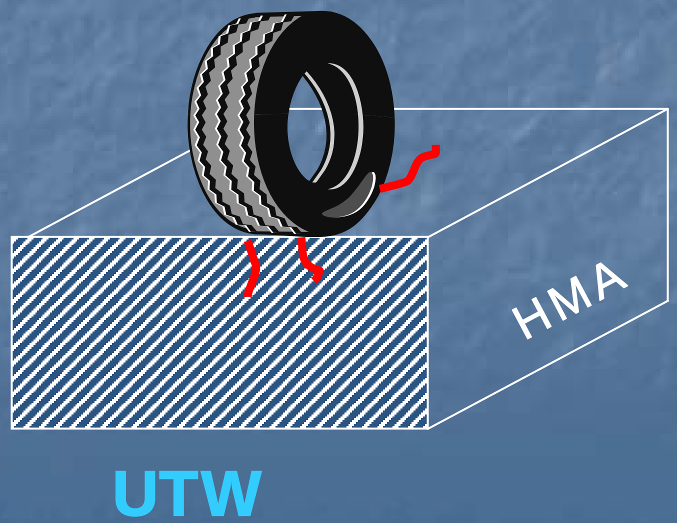


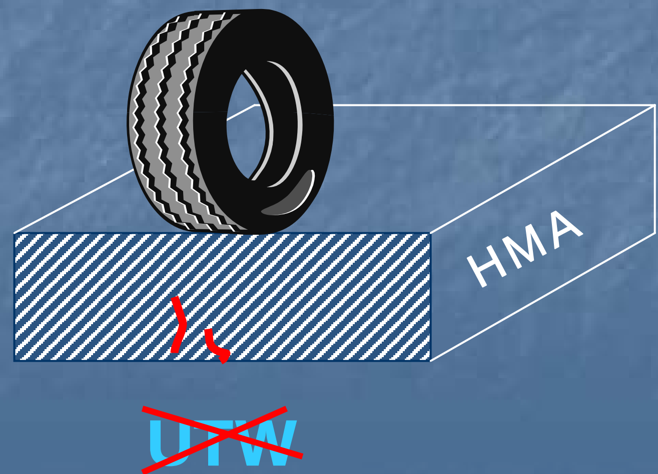
Joint Spacing

When to consider UTW

- HMA thickness $\geq$ 75 mm
- No stripping/raveling
- No excessive bottom-up fatigue cracking



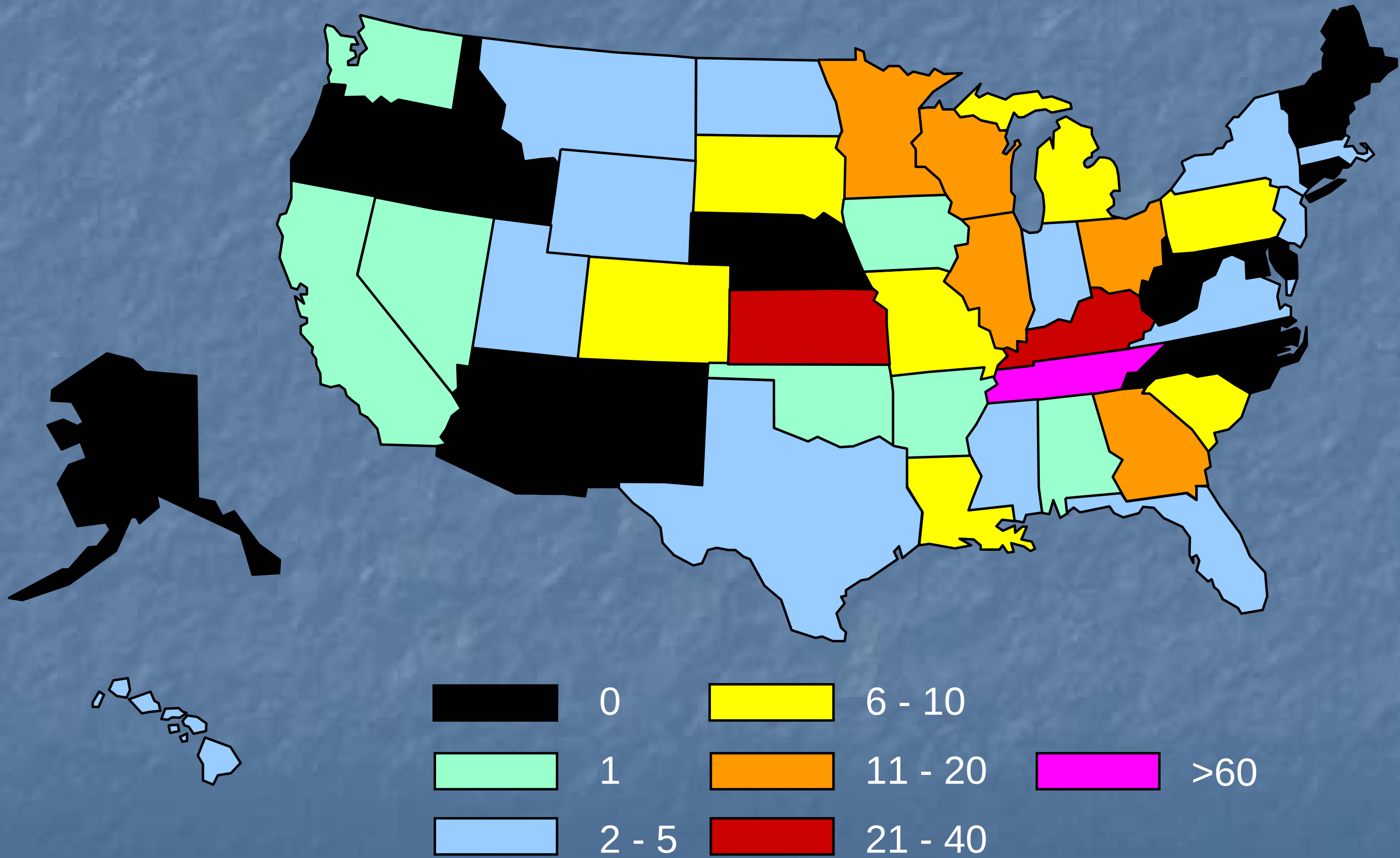




Keys to UTW Performance

- Adequate (HMA and soil) support layers
- PCC-HMA bond (essential)
- Slab size / joint spacing
- Concrete material selection
- Design Inputs
  - Traffic, layer thickness, climate, etc.

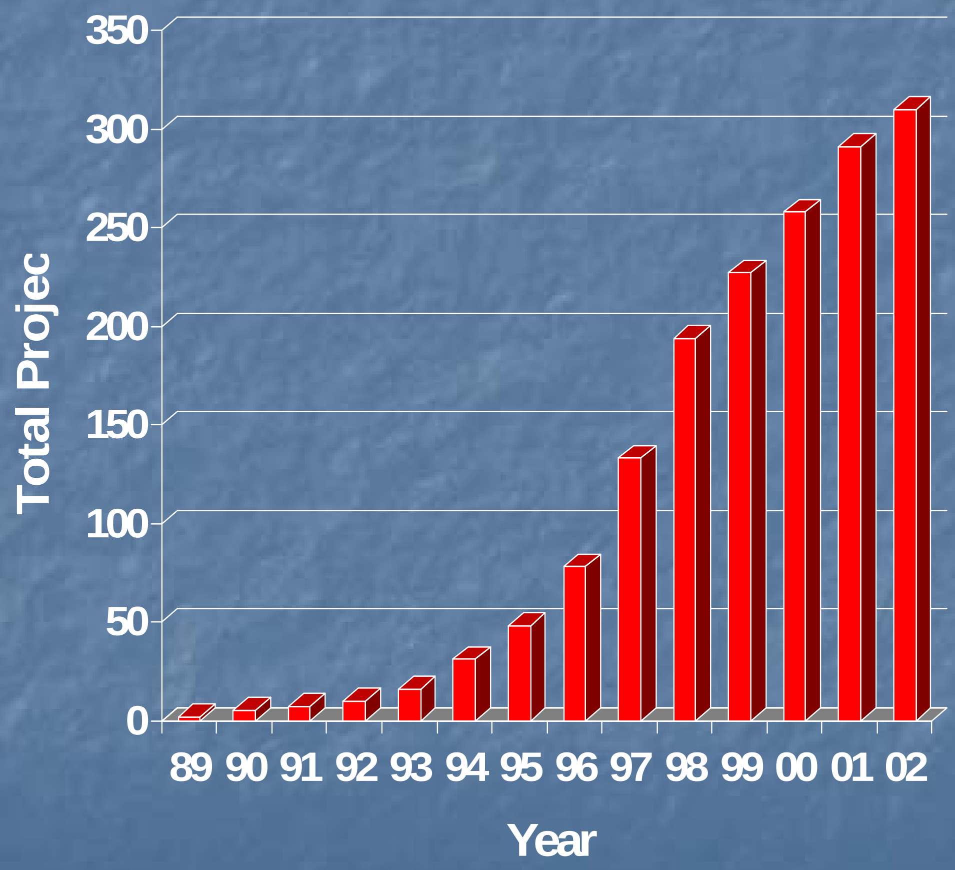
UTW Use by State - 2002



Jerry Voight - ACPA

Ultra-Thin Whitetopping

Since 1990, over 300 UTW projects have been constructed



Ultra-Thin Whitetopping

Since 1990 about 1 million SY placed – It is not experimental anymore

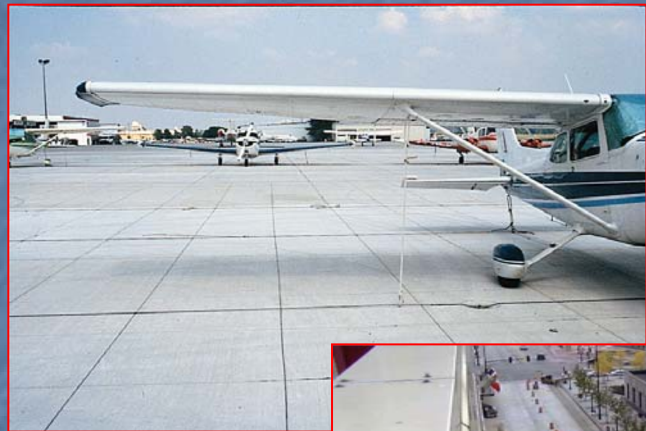
Over 835,000 m^2

Jerry Voight - ACPA

Appropriate applications

Applications for UTW

- Streets
- Intersections
- Bus pads
- GA airports
- Parking lots

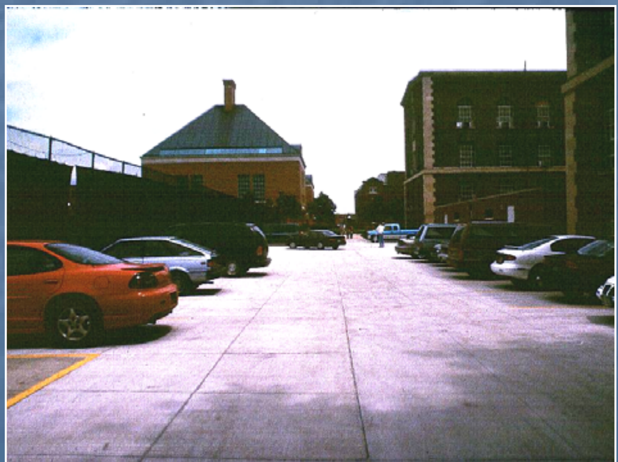


Stopping Areas...

Chicago Bus Stops

- Building more than 1000 concrete bus stops (approximately 30 x 3 m)
- Cobblestone/asphalt base costly to remove
- Thickness constrained from 90 to 140 mm
- Increase strength
- Use structural fibers

UTW Commercial Projects



Lancaster, PA
Rt 30 & 896

R. Riley

Whitetopping - Advantages

Structural

- Improved structural capacity
- Low maintenance
- Reacts structurally as if on strong base course
- Concrete slabs bridge problems asphalt cannot

Randy Riley

Whitetopping - Advantages

Construction

- Can place on pavement in poor condition.
  - Little or no pre-overlay repair needed.
- Avoid reconstruction problems.
  - Minimal rain delays.
  - Maintain traffic on existing surface.

Randy Riley

Whitetopping - Advantages

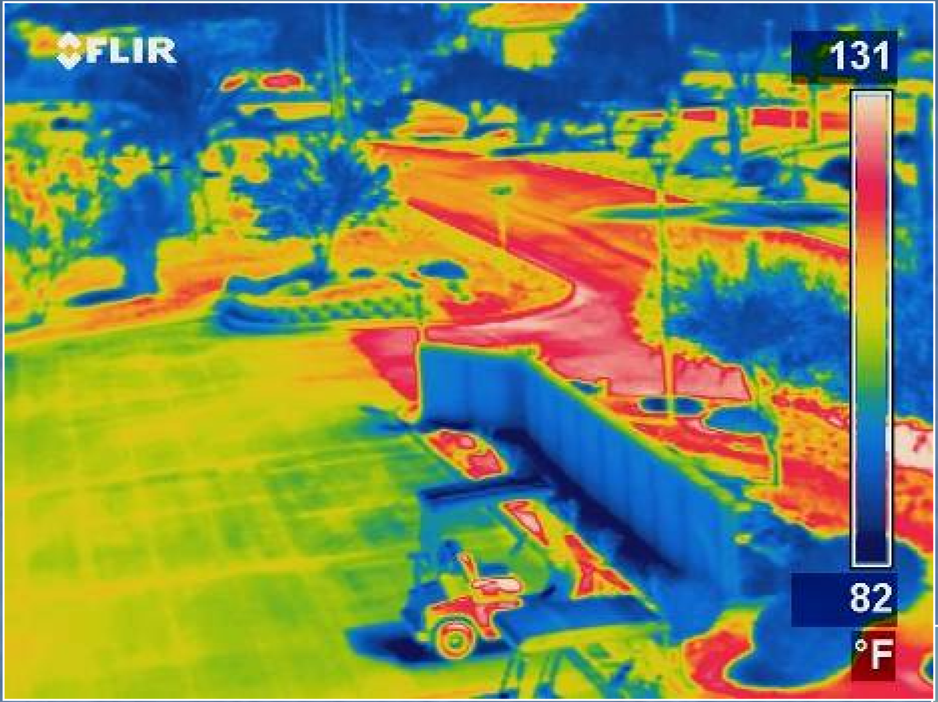
Safer

- Visibility
- Decreased stopping distances
- Non-rutting
- Less work zone reconstruction
  - *less accidents*

Concrete

Asphalt

Randy Riley

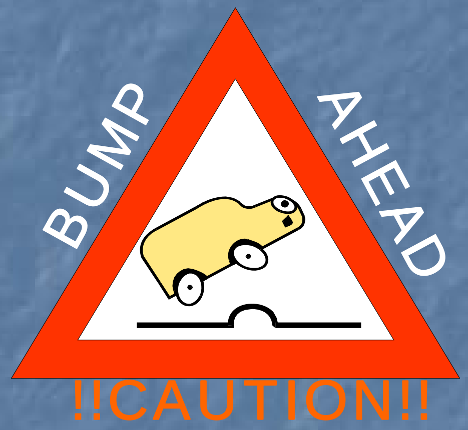


Albedo & Heat Island

Rio Verde, AZ

After Riley

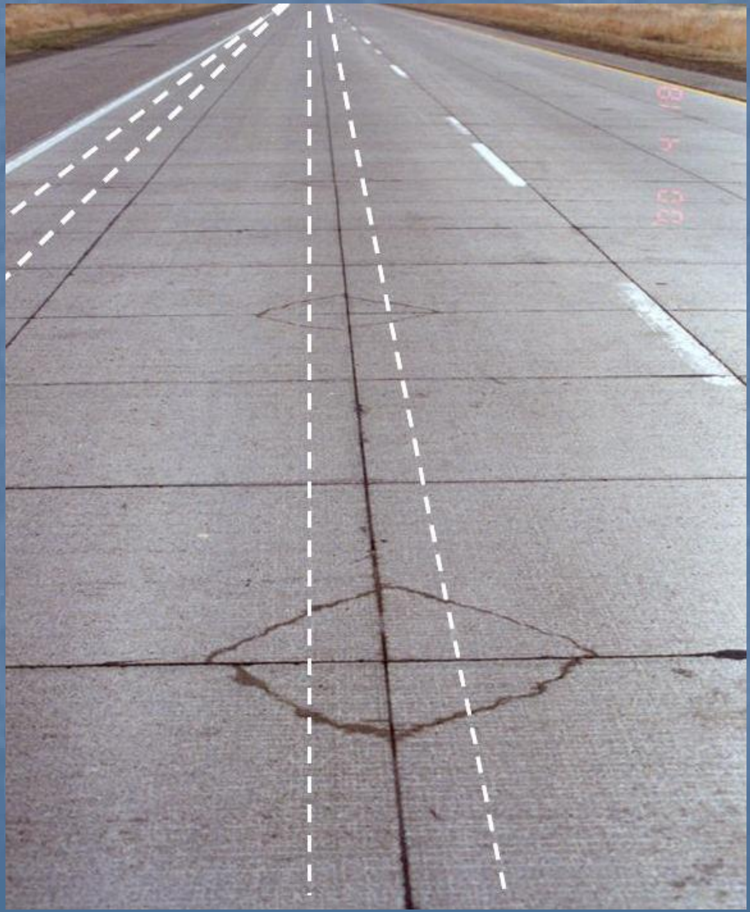
Typical Distresses



Typical Distresses

Transverse Cracking

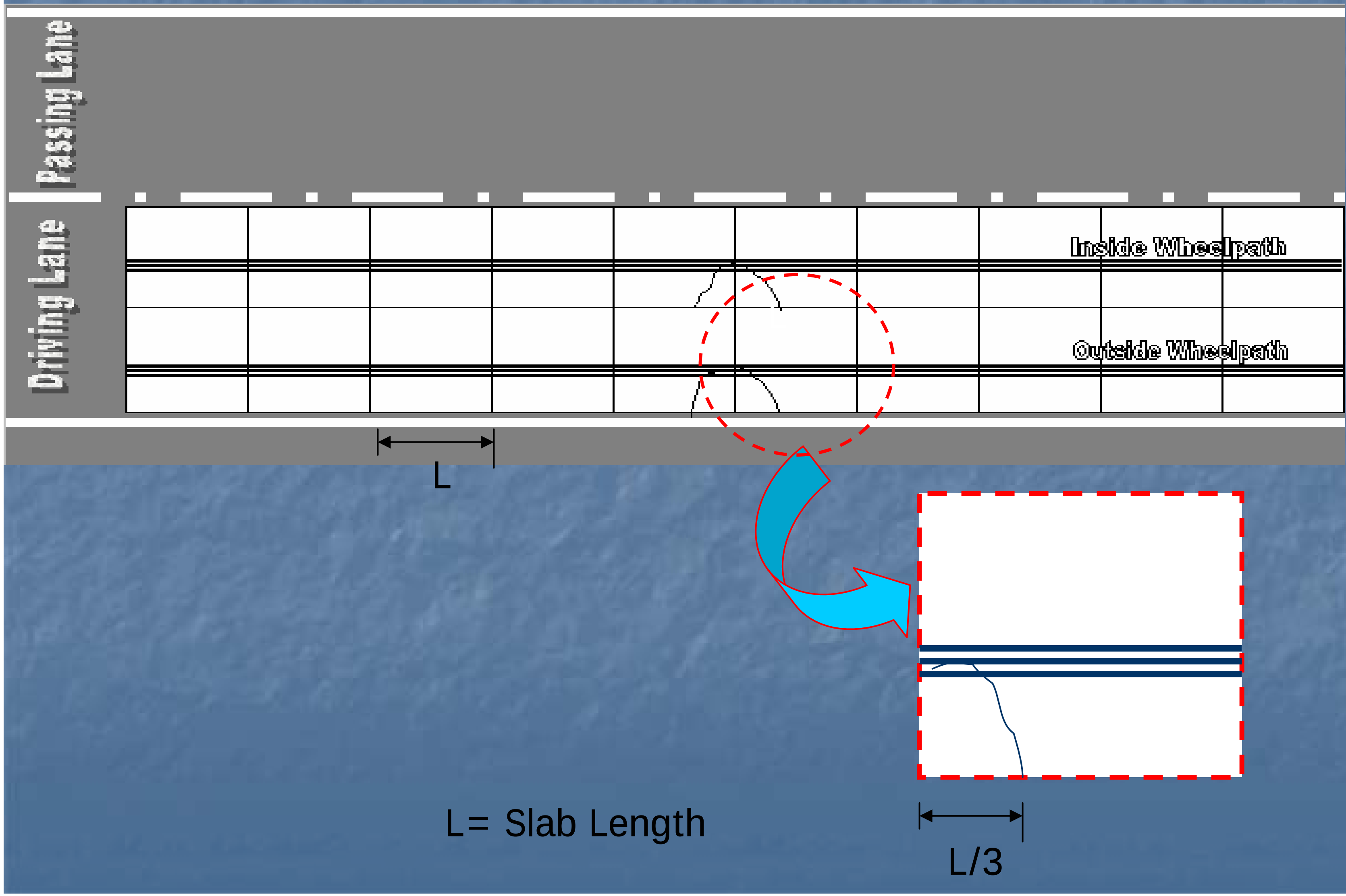
Corner Breaks & Transverse Cracking



Corner Breaks

Typical Distresses

(1.5 ft x 1.8 m Panels)



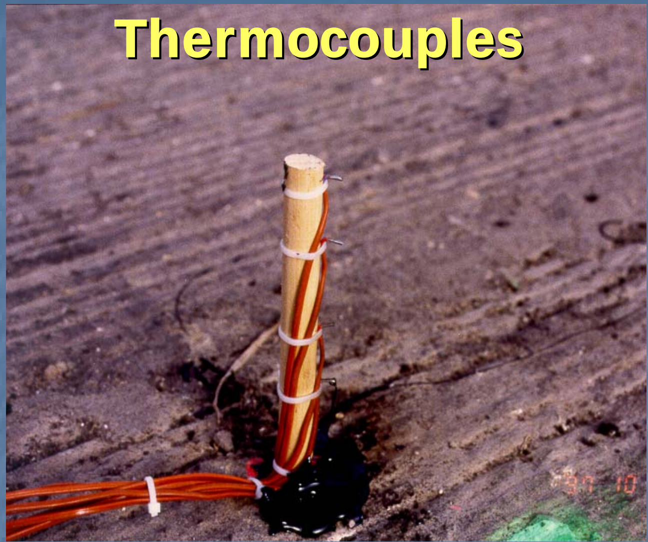
L= Slab Length

Findings from instrumented UTW

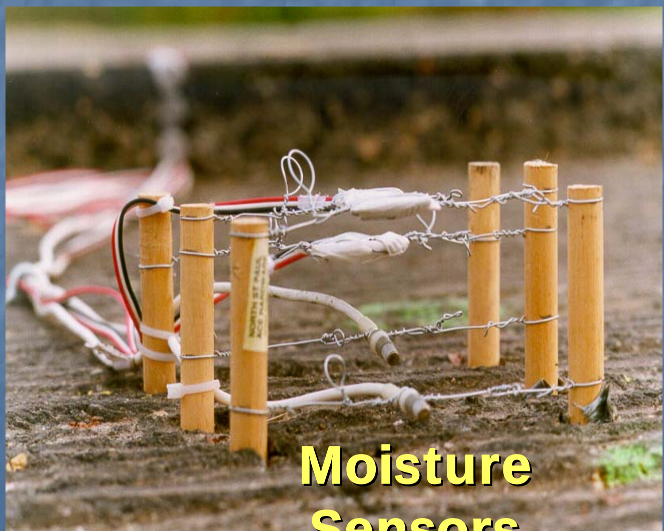
Minnesota Test Sections

- 102 mm - 1.2 m x 1.2 m Panels (polypropylene fibers)
- 76 mm - 1.2 m x 1.2 m Panels (polypropylene fibers)
- 76 mm - 1.5 m x 1.8 m Panels (polyolefin fibers)
- 152 mm - 1.5 m x 1.8 m Panels (polypropylene fibers)
- 152 mm - 3 m x 3.7 m Panels (polypropylene fibers)
- 152 mm - 3 m x 3.7 m Panels (polypropylene fibers & dowels)

Sensor Installations Prior to Paving



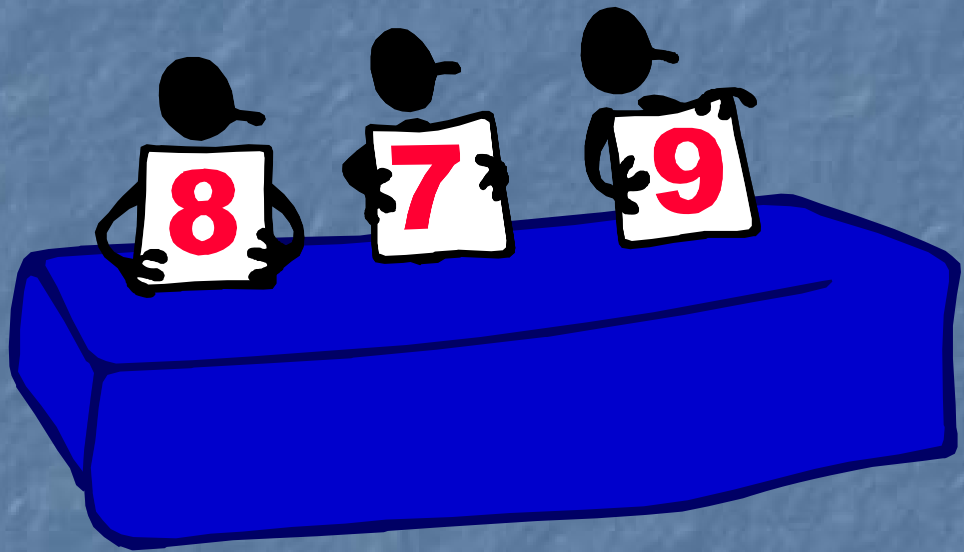
Thermocouples



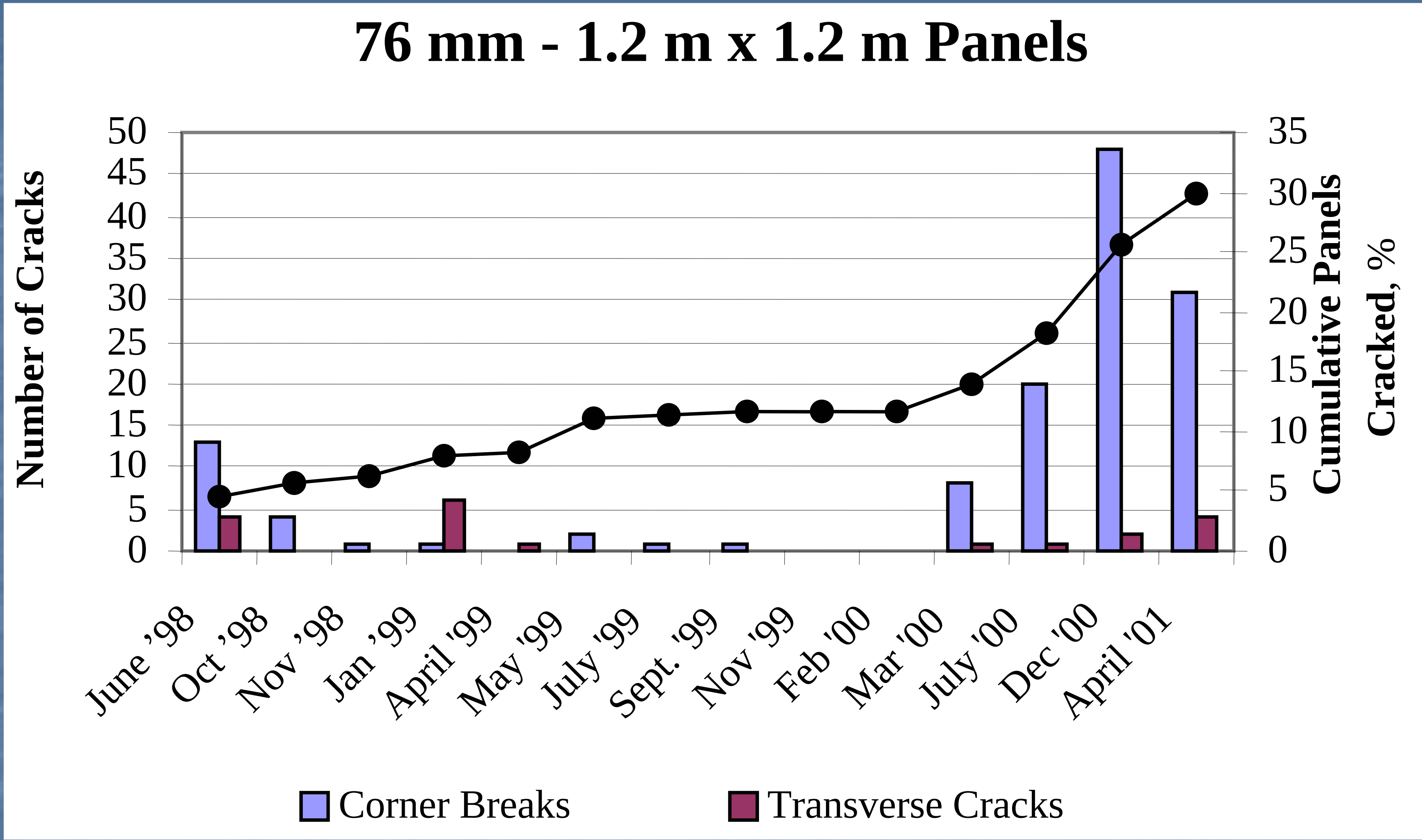
Moisture Sensors

Static Strain Sensors

Performance after 4 years

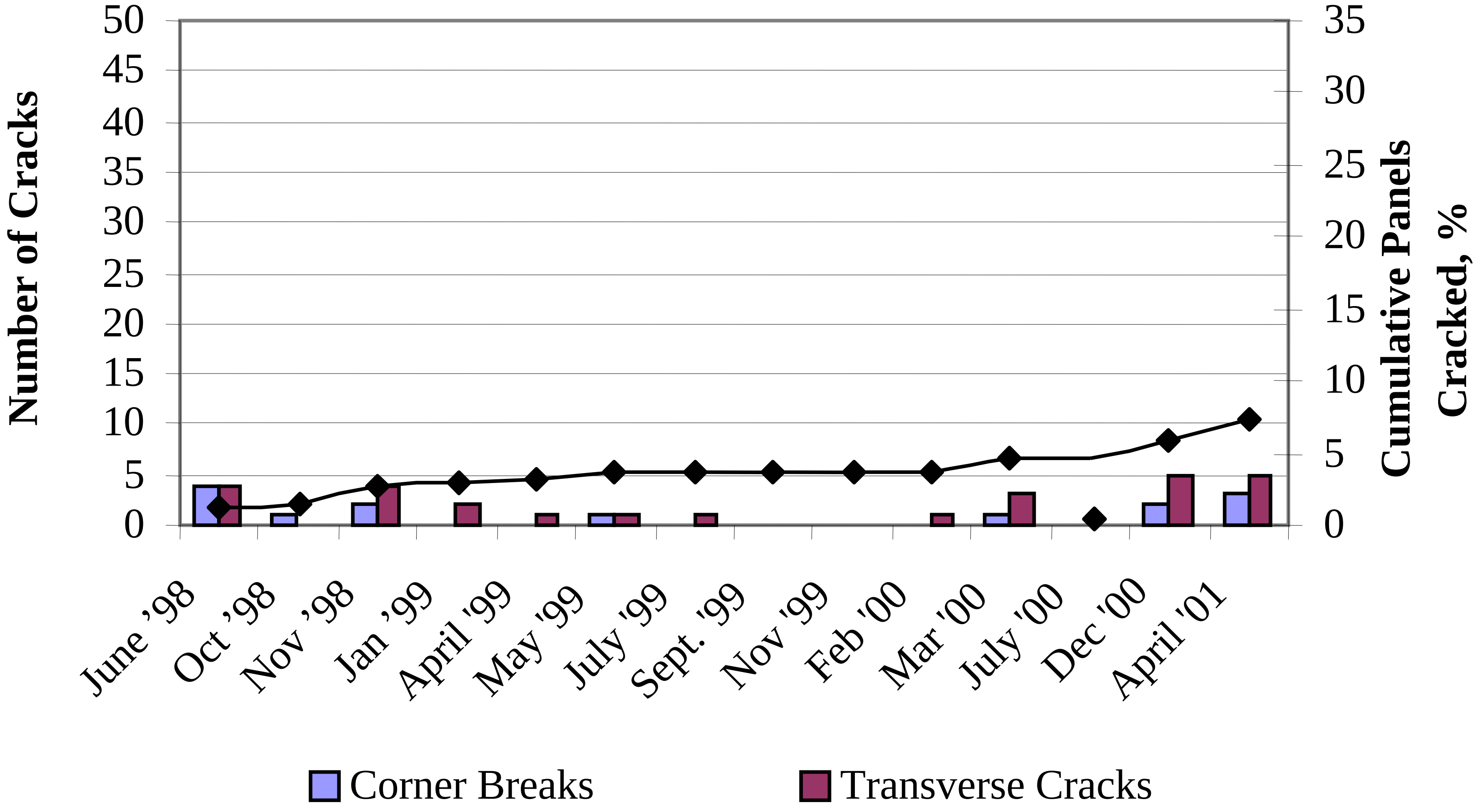


Interstate highway with 25,000 ADT, 12-13% trucks

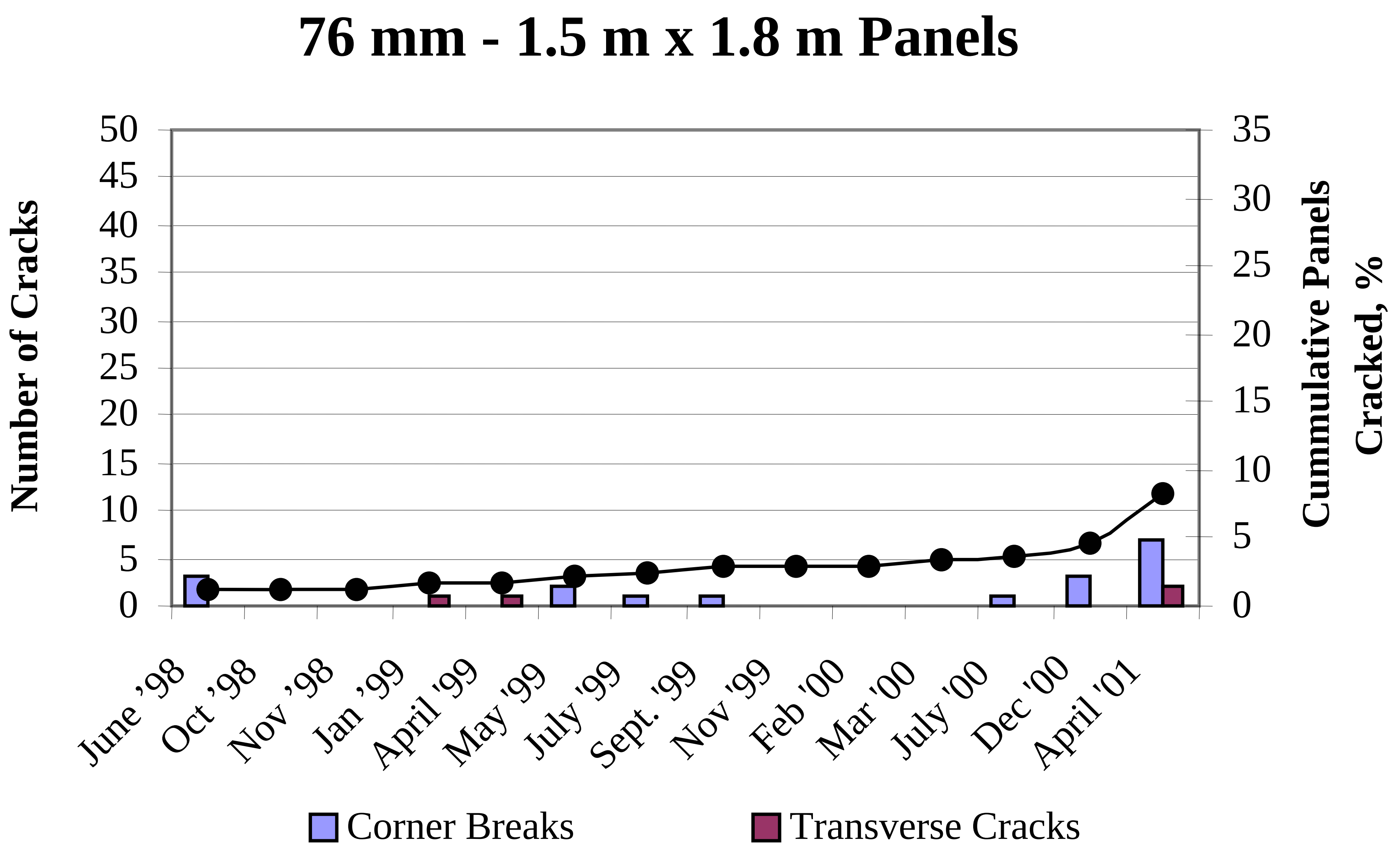


83 % of the distress occurred in the driving lane.

102 mm - 1.2 m x 1.2 m Panels



73 % of the distress occurred in the driving lane.



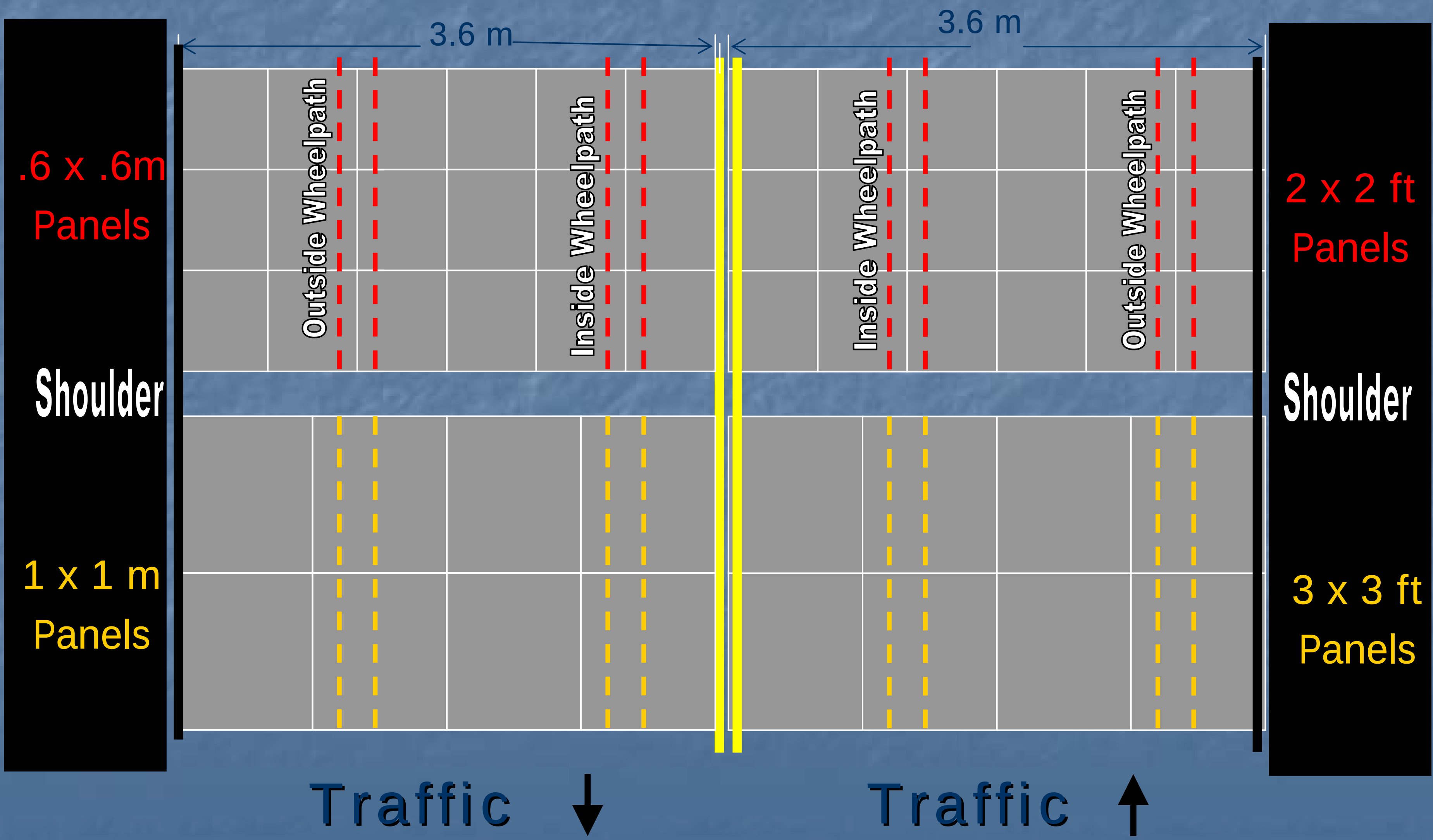
75 % of the distress occurred in the driving lane.

Whitetopping Crack Summary

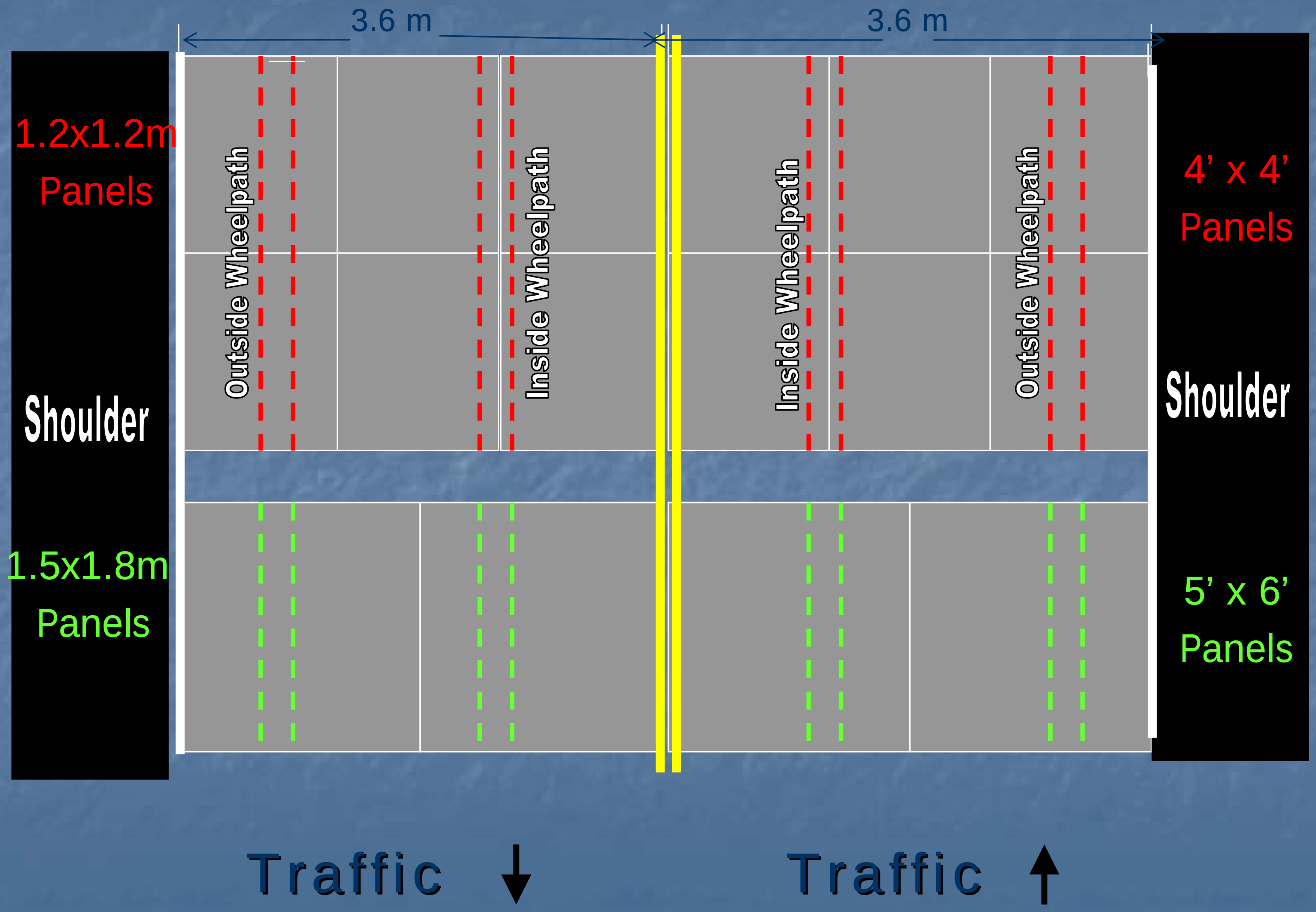
Cell	Panels Cracked (%)	Corner Cracks	Trans. Cracks	Long. Cracks
102- 1.2x1.2m	7	14	27	0
76- 1.2x1.2m	40	165	19	0
76- 1.2x1.2m *	8	18	4	0
152- 1.2x1.2m	0	0	0	0

***All transverse cracks in 78 mm 1.2 x 1.2m section are reflective cracks.**

Longitudinal Joint Layout

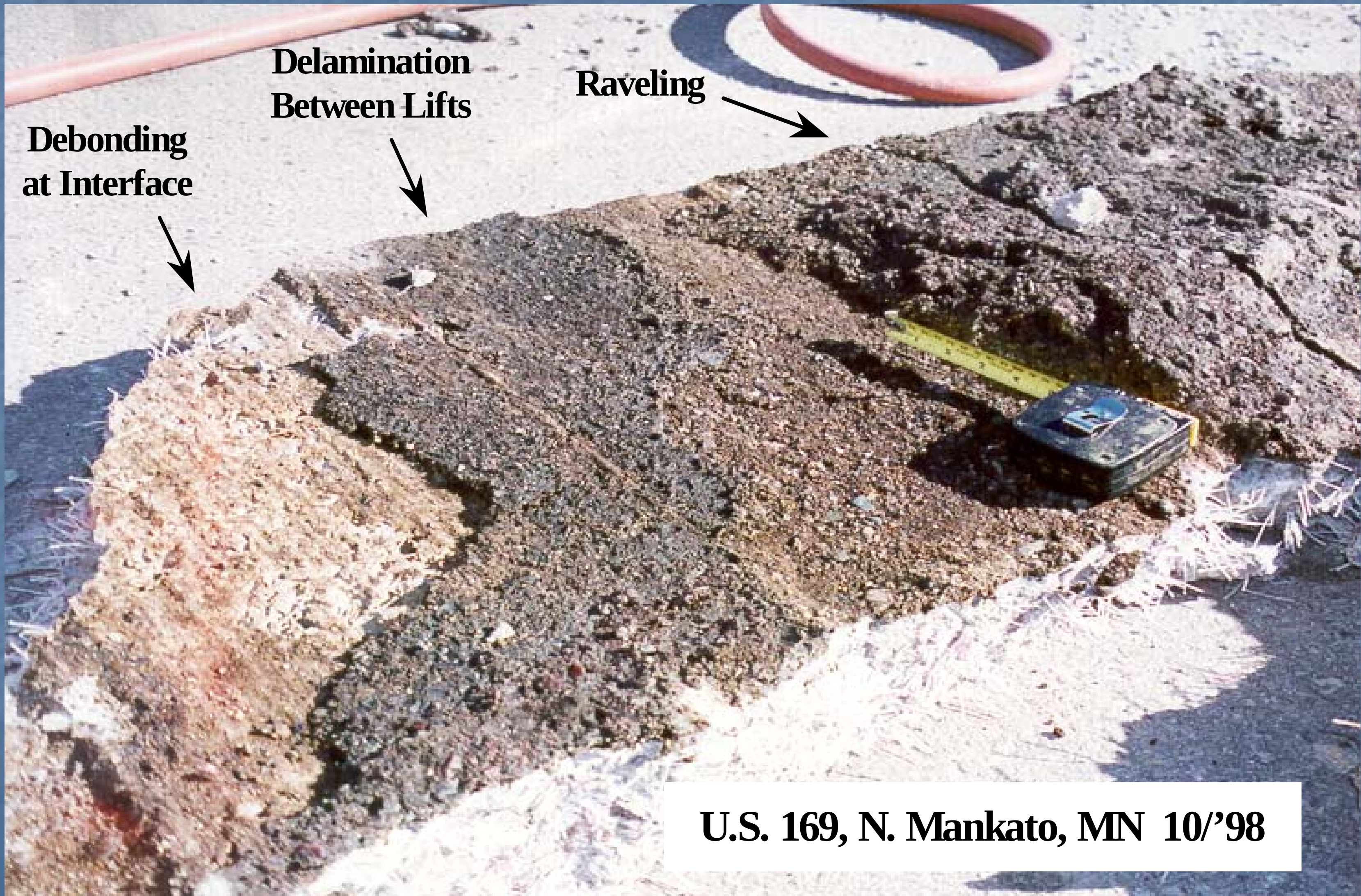


Longitudinal Joint Layout




U.S. -169, N. Mankato, MN (10/’98)

Debonding



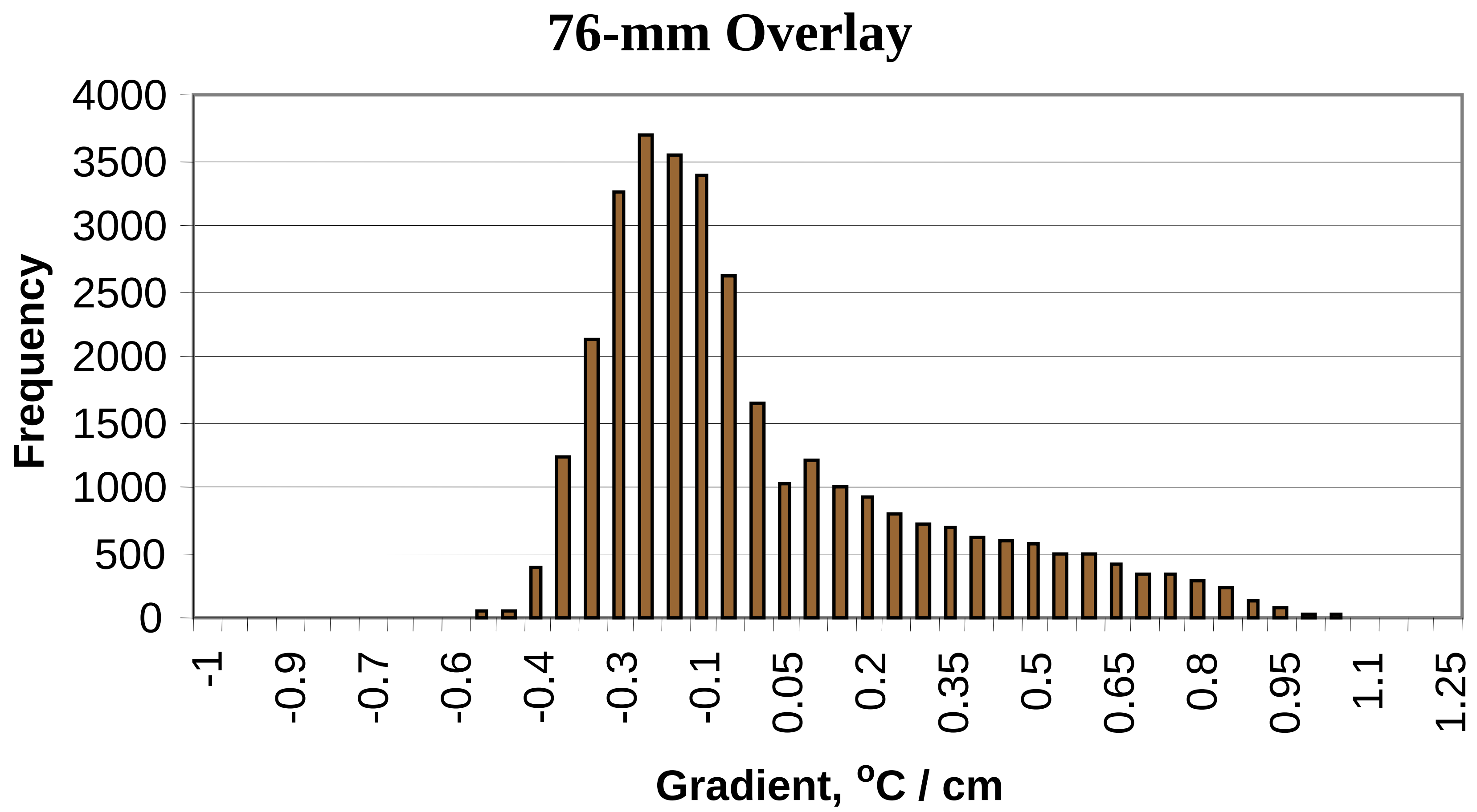
Delamination Between Lifts
Raveling
Debonding at Interface
U.S. 169, N. Mankato, MN 10/'98

Debonding

Delamination
Between Lifts
Raveling
Debonding
at Interface
SP208 near
Sao Paulo
U.S. 169, N. Mankato, MN 10/'98

Temperature effects

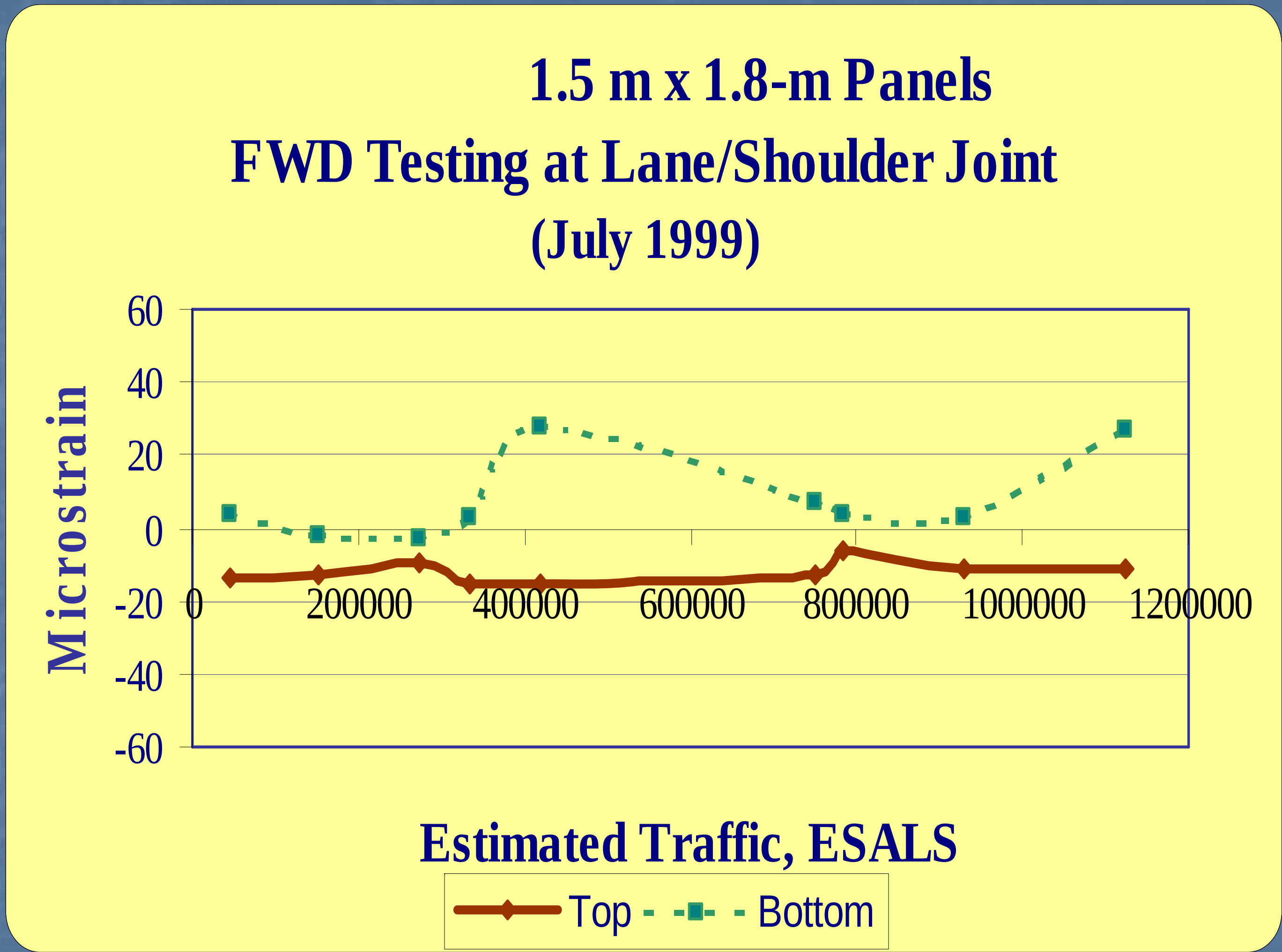
Temperature Characterization (Thermocouple Data)



Temperature Characterization (Thermocouple Data)

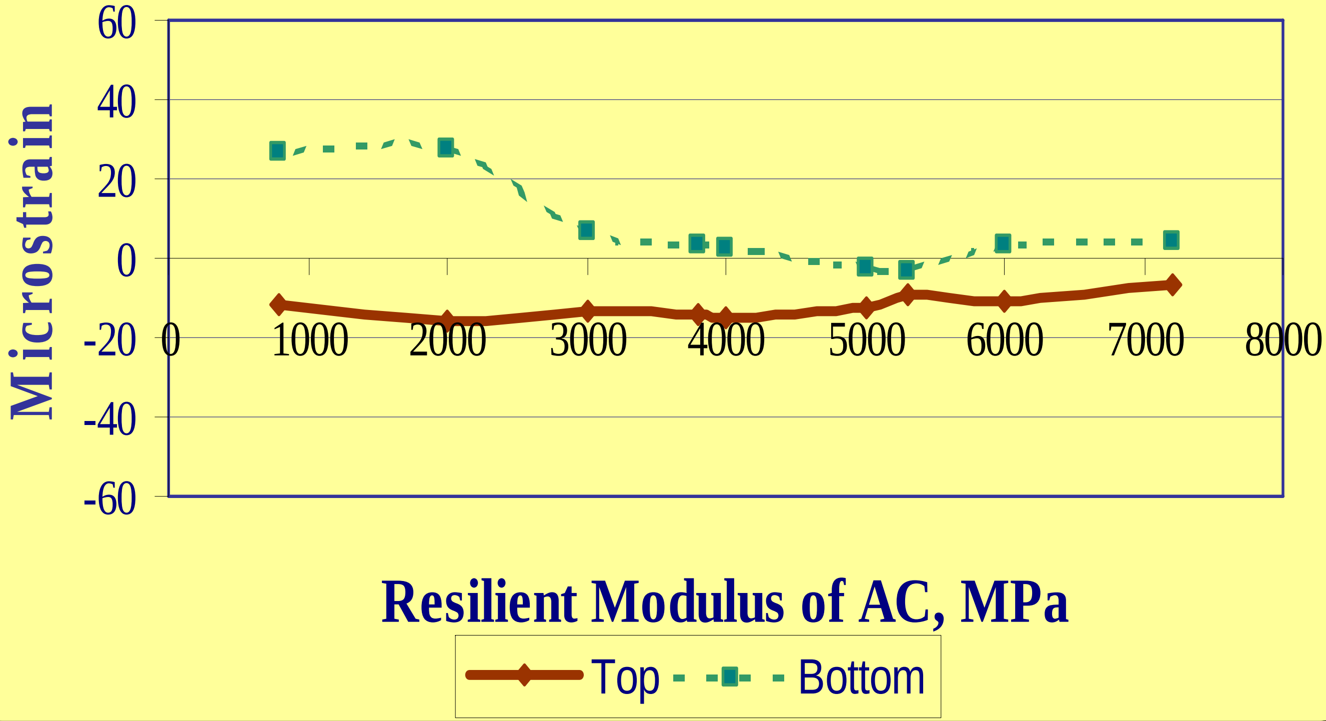
Overlay Thickness	Temperature Gradients, °C/cm		
	Max. Negative	Max. Positive	95% of the Time
76 mm	-0.82	+1.23	-0.40 to +0.80
102 mm	-0.61	+0.81	-0.35 to +0.60
152 mm	-0.63	+0.96	-0.25 to +0.45

The mean gradient is approximately - 0.2 °C/cm for all three overlays.

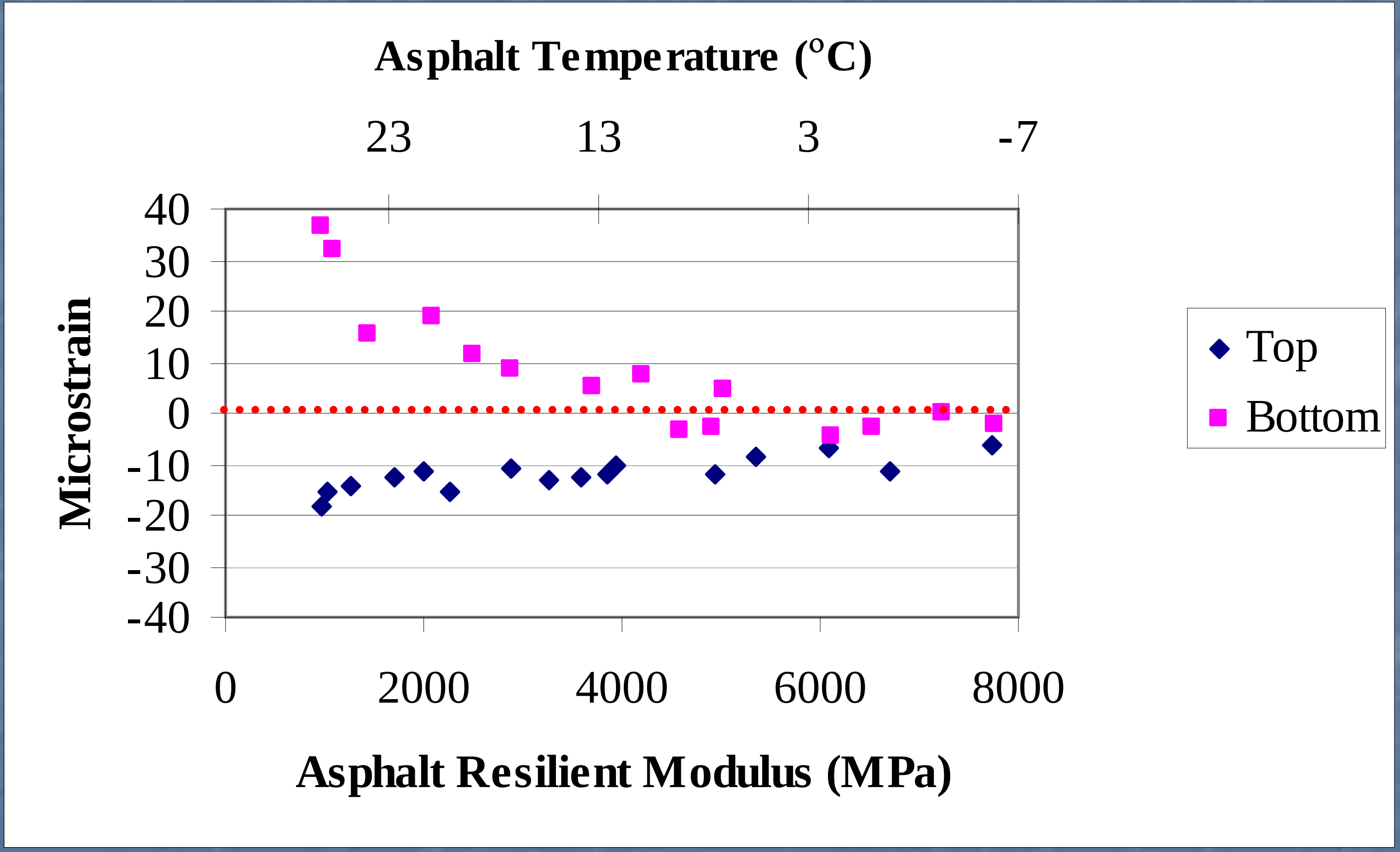


1.5 m x 1.8-m Panels
FWD Testing at Lane/Shoulder Joint
(July 1999)
Microstrain
60
40
20
0
-20
-40
-60
0
200000
400000
600000
800000
1000000
1200000
Estimated Traffic, ESALS
Top
Bottom

1.5 m x 1.8-m Panels
FWD Testing at Lane/Shoulder Joint
(July 1999)



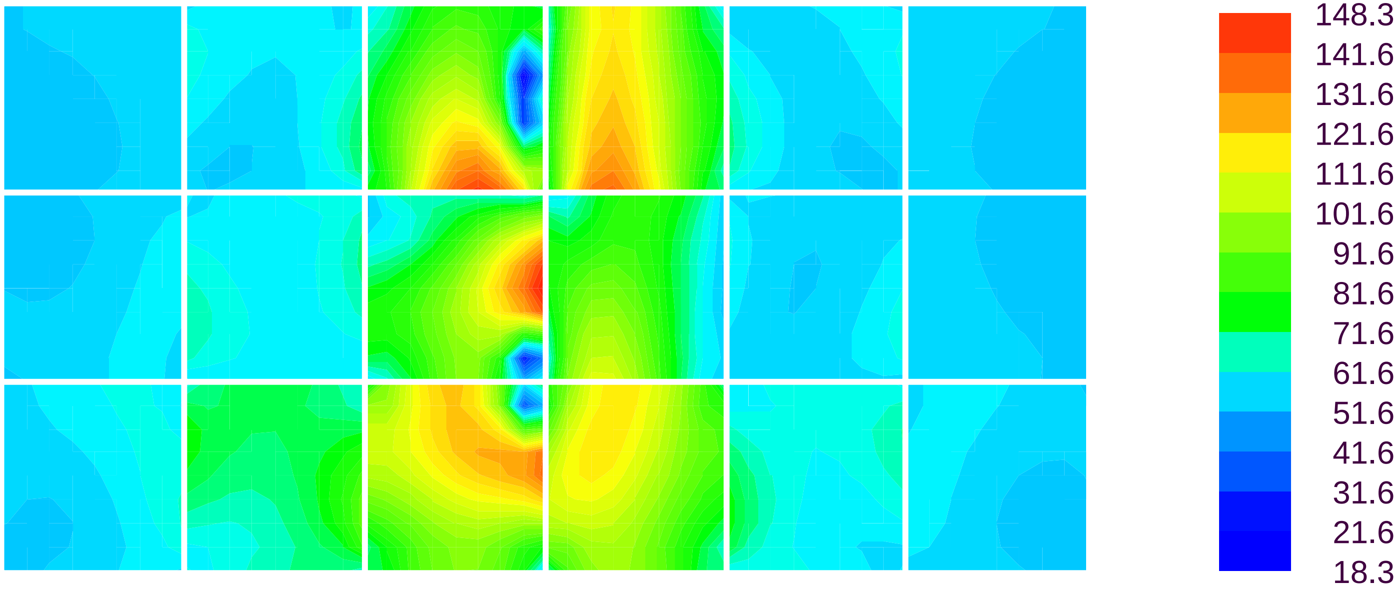
Temperature and applied load



40 kN FWD load in wheelpath for 76 mm 1.52-m x 1.83-m panels

ISLAB 2000 FEM

Principal Stresses



Modeling Assumptions:

76-mm 1,2 x 1.2m Panels
Fully bonded
0.80 ^{o}C/cm gradient
356 kN Tandem axle load

1. **HMA temp. greatly influences stress (strains)**
2. **Temperature gradients have little influence on stress (strains)**

Lessons learned ?

- Must obtain a good bond
- Initial condition of existing HMA
- HMA layer must have adequate structure
- Evaluate original structure (depth of HMA layers, condition of HMA...)
- Fibers help keep cracks tight
- Joint layout

Designing UTW

UTW Design

Joint Spacing

1. 12 to 18 times pavement thickness
2. Keep longitudinal joints out of wheelpath

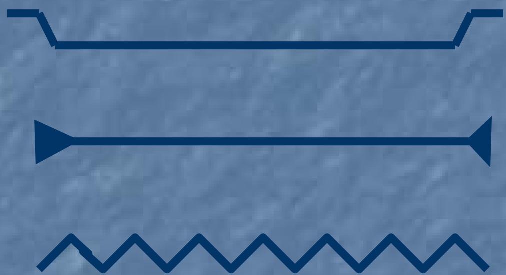
UTW Design

Concrete mixture design.....

- Typical Higher Cement Content
  - Fast track type construction
- Low Water / Cement Ratio
- Synthetic Fibers
- Durable, Quick Opening to Traffic

Macro vs Micro Fibers

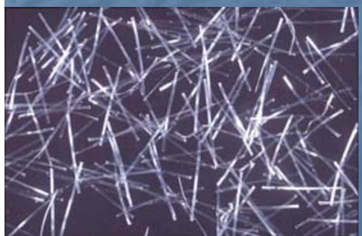
Macro-Fibers

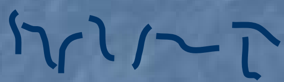


Diameters: 0.2 to 0.8 mm
(0.008 - 0.03")

Materials: Steel, Synthetic

Micro-Fibers



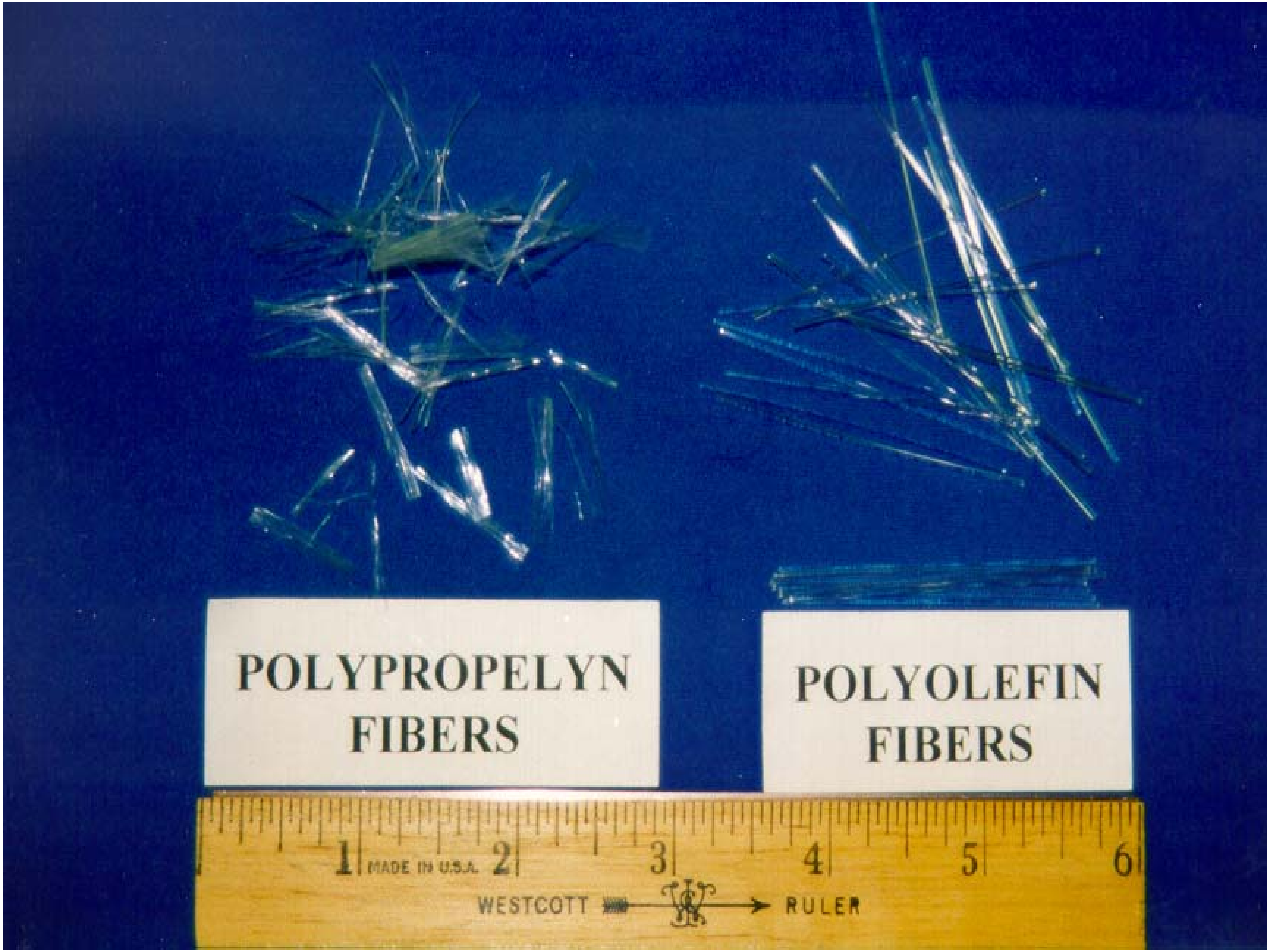


Diameters: < 0.1 mm
(< 0.004")

Materials: Polypropylene, Steel, Carbon, ...

Typically a 20% increase in the cost of the mix.

Adapted from Jeff Roesler


POLYPROPELYN
FIBERS
POLYOLEFIN
FIBERS
1 MADE IN U.S.A. 2 3 4 5 6
WESTCOTT RULER

UTW Design

Sample mix designs…

	Polypropylene	Polyolefin
w/c	0.38	0.41
Cement (kg/m^3)	386	386
Fly Ash (kg/m^3)	0	0
FA (kg/m^3)	1285	762
CA (kg/m^3)	1773	1052
Fibers (kg/m^3)	2	15

UTW Design

HMA condition assessment ..

- Values chosen for design:
  - Poor (${E_{AC}}$ = 700 MPa)
    - fatigue cracked, old
  - Fair (${E_{AC}}$ = 2,500 MPa) ←
  - Good (${E_{AC}}$ = 4,000 MPa)
    - rutting, no structural damage

UTW Design Equations

Effective radius of relative stiffness...

$$l_e = \left(\frac{I_e}{(1-0.15^2)*k} \right)^{0.25}$$

$$NA = \frac{\frac{(E_c t_{PCC}{}^2)}{2} + E_b t_{BIT} \left(t_{PCC} + t_{BIT}/2 \right)}{E_c t_{PCC} + E_b t_{BIT}}$$

$$I_e = (Eh\text{^}3/12)e = \frac{(E_c t_{PCC}{}^3)}{12} + E_c t_{PCC} (NA - \frac{t_{PCC}}{2})^2 + \frac{(E_b t_{BIT}{}^3)}{12} + E_b t_{BIT} (t_{PCC} - NA + \frac{t_{BIT}}{2})^2$$

UTW Design Equations

Determining total stress...

$$\log(\sigma_{18}) = 5.025 - 0.465\log(k) + 0.686\log(L/l_e) - 1.291\log(l_e)$$

Based on 2-D Finite element with 36% stress increase (partial bond)

$$\sigma_T = 28.037 - 3.496(CTE * \Delta T) - 18.382(L/l_e)$$

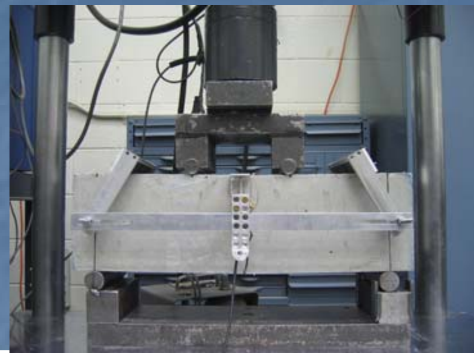
$$\sigma_{Total} = \sigma_{18} + \sigma_T$$

Superposition assumes slab and HMA remain in contact

UTW Design Equations

PCC strength characterization...

ASTM C1609-07



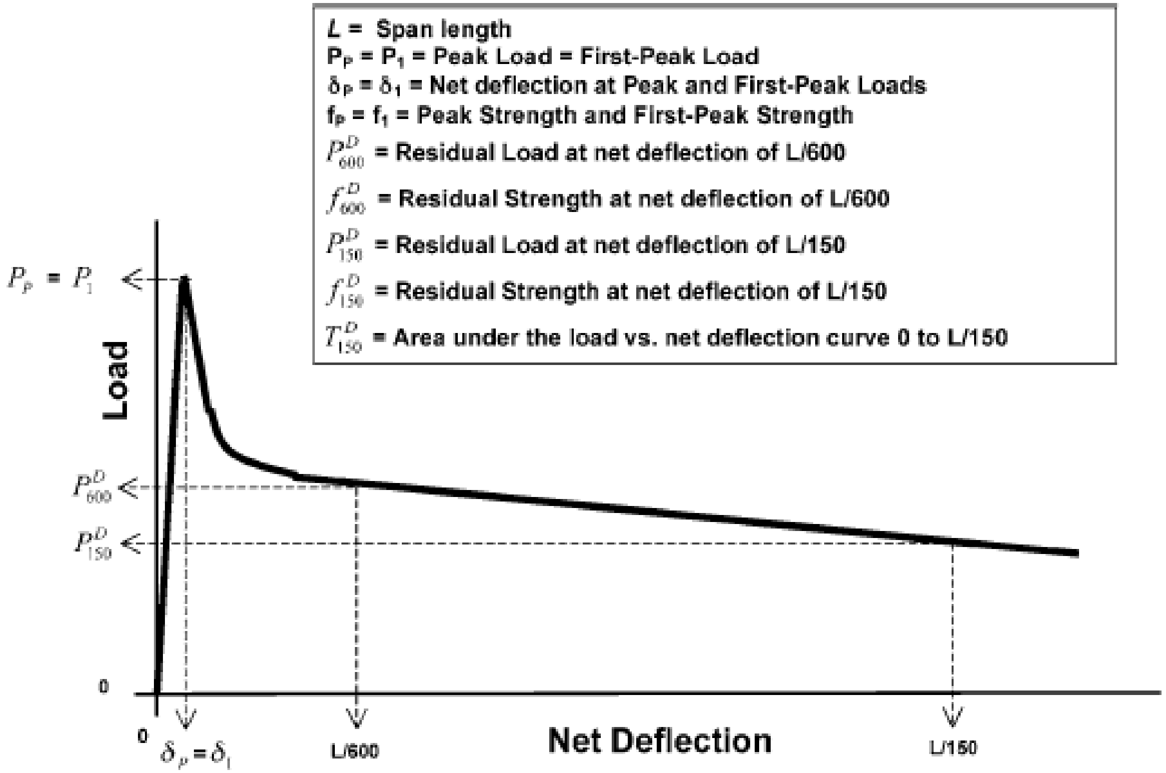


FIG. 3 Example of Parameter Calculations for First-Peak Load Equal to Peak Load (Not to Scale)

Beams: 150x150x530mm

Span: 450mm

L/150 = 3 mm

$$MOR = \frac{P_1 L}{bd^2}$$

$$f_{150}^{150} = \frac{P_{150}^{150} L}{bd^2}$$

$$R_{150}^{150} = \frac{f_{150}^{150}}{MOR} * 100$$

UTW Design Equations

Stress Ratio...

$$R_{150}^{150} = \frac{f_{150}^{150}}{MOR} * 100$$ (ASTM C1609-07)

R_{150} values = 20%

$$\text{Stress Ratio (SR)} = \frac{\sigma_{Total}}{(1+R_{150}) * MOR}$$

UTW Design Equations

Fatigue ...

$$R^* = 1 - \frac{(1 - R) * P_{cr}}{0.5}$$

$$\log N_{PCC} = \left[- \frac{SR_{total}^{-10.24} \log(R^*)}{0.0112} \right]^{0.217}$$

UTW Design Procedure

http://www.pavement.com/pavtech/tech/utwcalc/main.asp

UTW Design

- Traffic
  - Category A – Low truck volume
  - Category B – Medium truck volume
- *Average* Flexural Strength
  - Third-point loading (ASTM C78)
- Composite k-value of all layers below HMA

UTW Design

- Composite k-value of all layers below HMA

Subgrade		Combined thickness of base and subbase, in. (mm)		
Soil	k, pci (MPa/m)	4 (100)	8 (200)	12 (300)
Poor	75 (20)	90 (24)	120 (32)	150 (41)
Fair	100 (27)	118 (32)	152 (41)	186 (51)
Good	150 (41)	168 (46)	208 (56)	250 (68)
Excellent	200 (54)	217 (59)	260 (71)	310 (84)

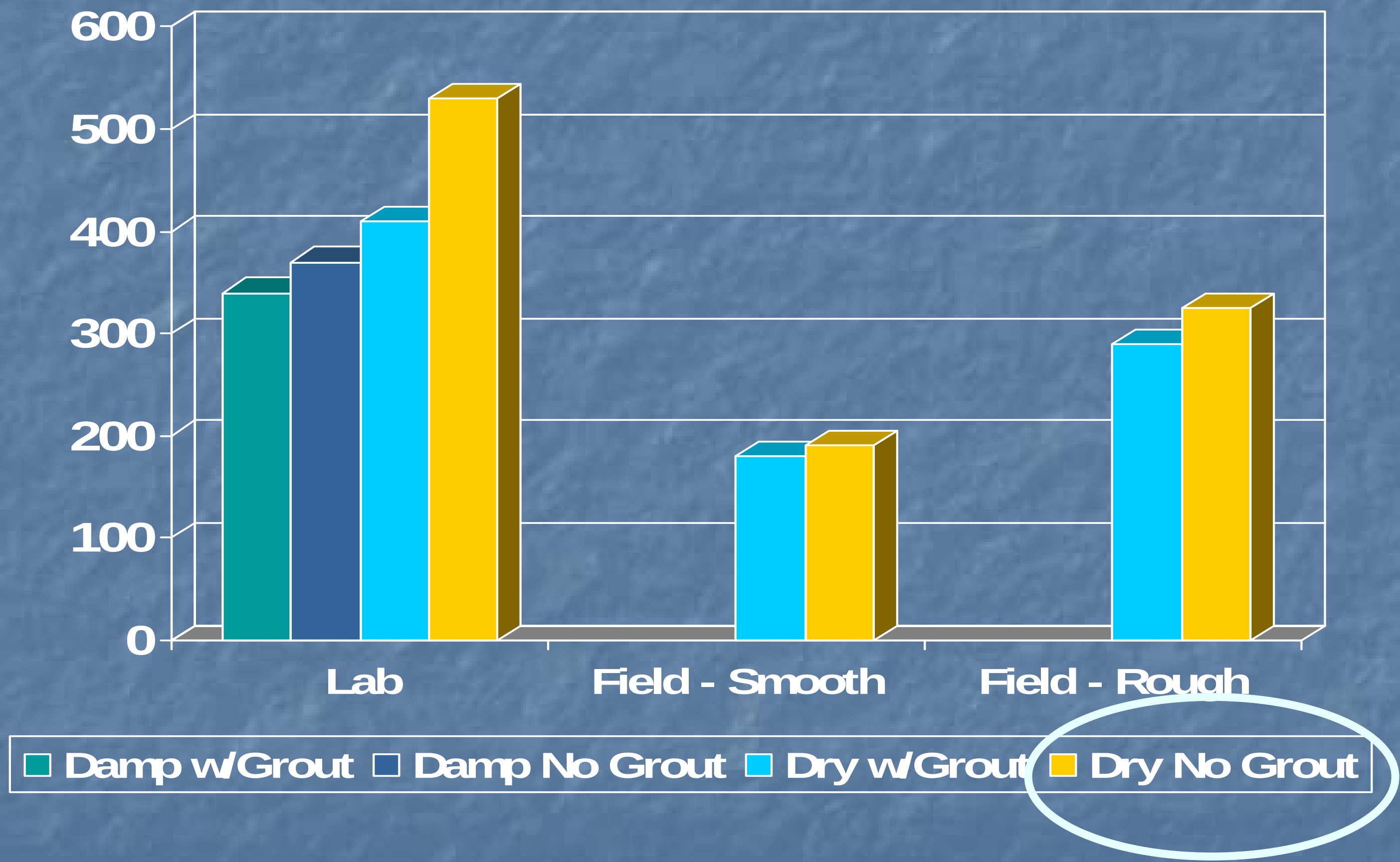
Construction

UTW Construction

- Milling
  - Use when rutting > 25mm
  - Removes between 25 and 76mm
    - Can shave off top of ruts
- Used with inlays
  - Limited vertical clearances
  - Single lane replacement
  - Runway keelways

Randy Riley

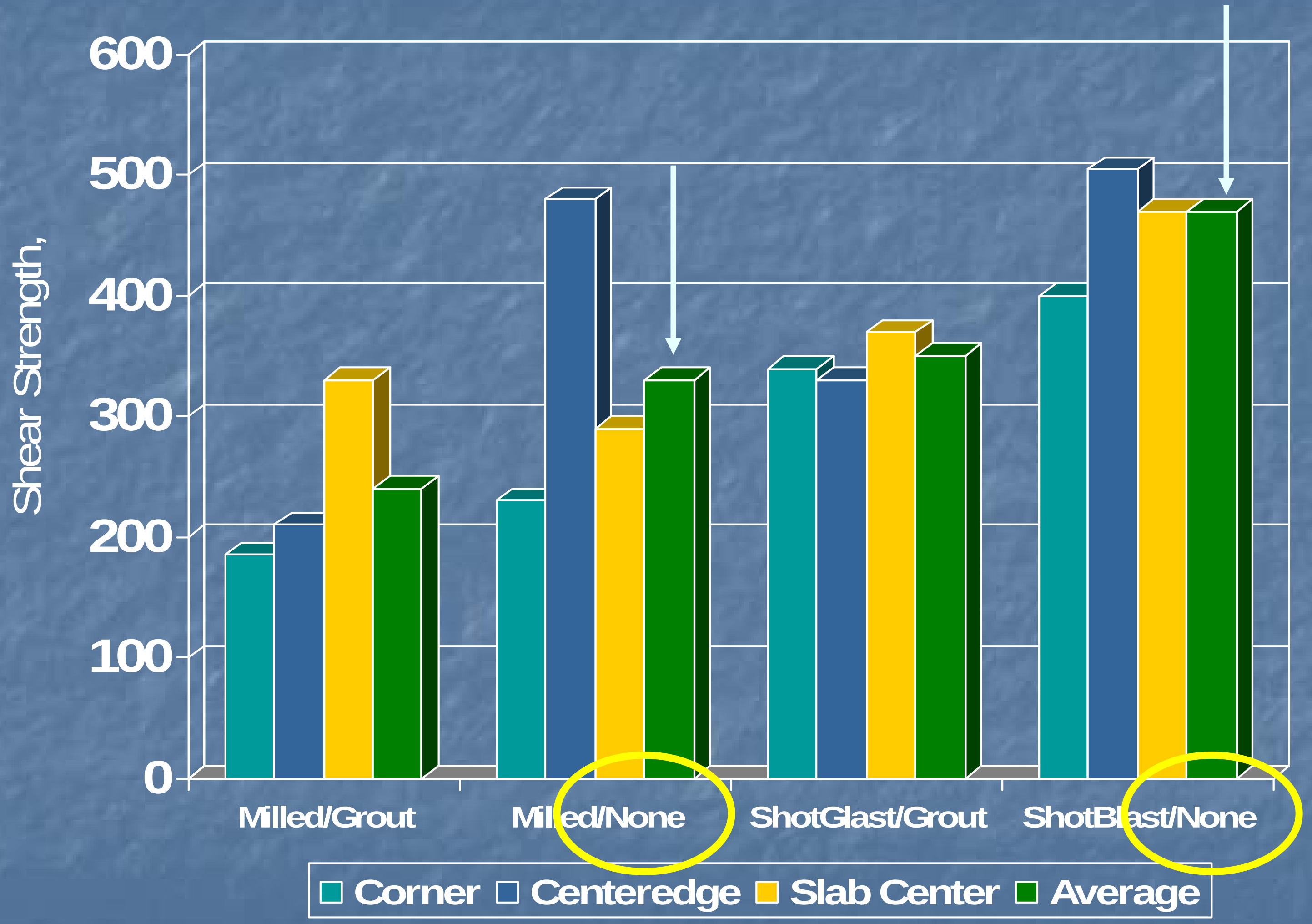
Bonded Concrete Overlays
Grout or No Grout?



Ref. “Resurfacing and Patching Concrete Pavement with Bonded Concrete”, Highway Research Board, Volume 35, 1956

Randy Riley

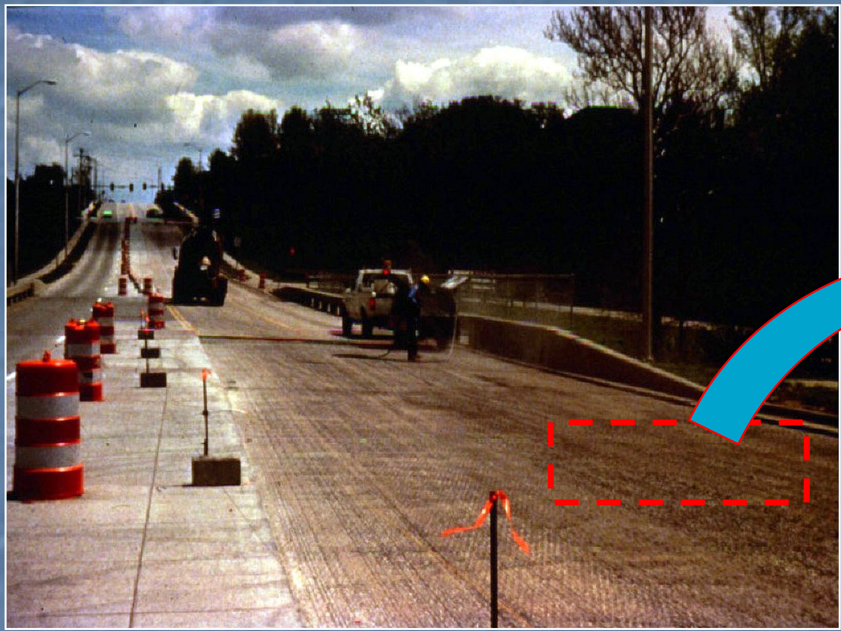
Mill? Blast ? Grout?



Ref. Unpublished Research, David Whitney, Department of Civil Engineering, University of Texas at Austin

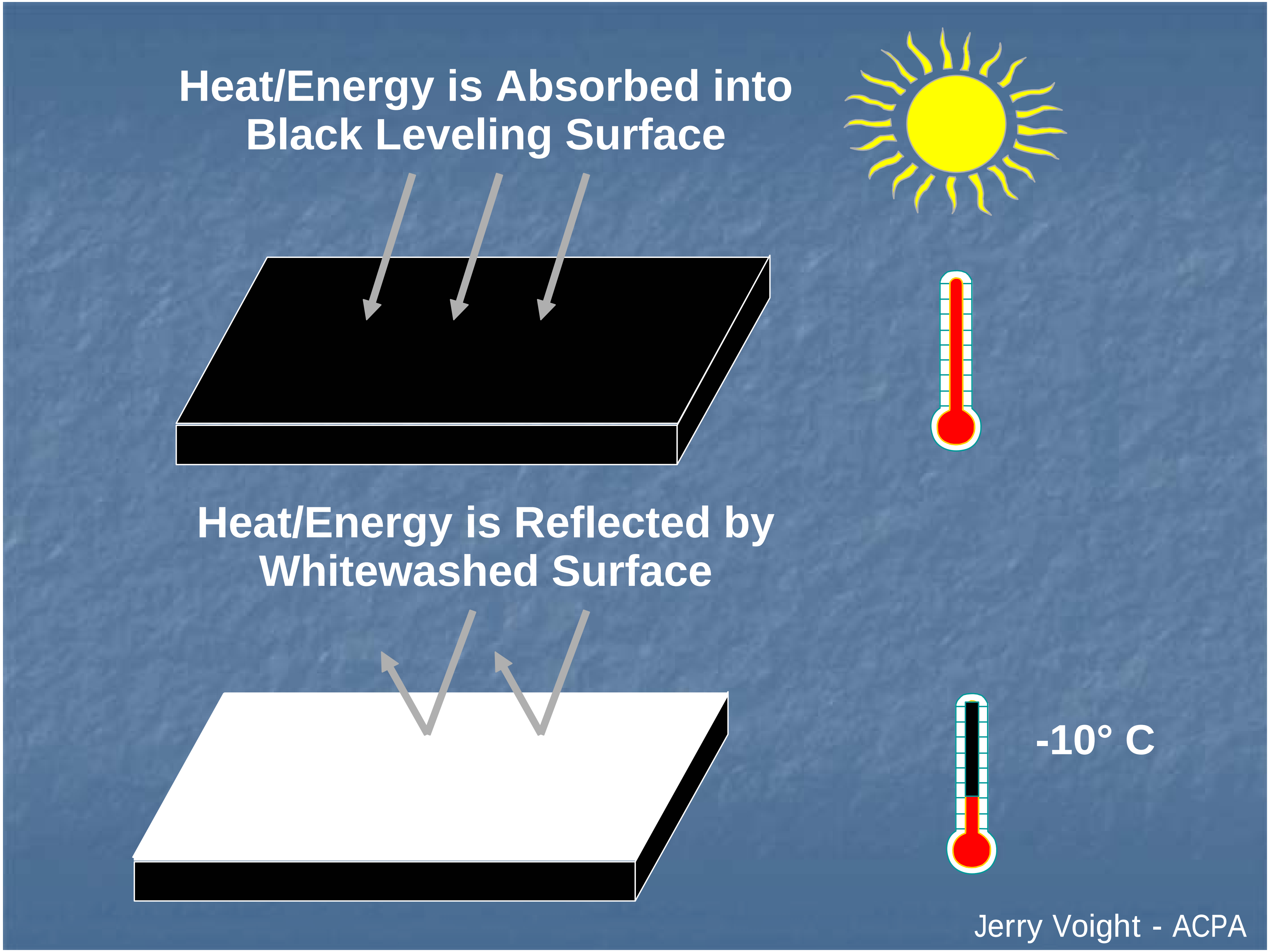
Randy Riley

Surface Preparation



- Clean surface
  - Sweeper
  - Compressed air

Adapted from Randy Riley


Heat/Energy is Absorbed into Black Leveling Surface
Heat/Energy is Reflected by Whitewashed Surface
-10° C
Jerry Voight - ACPA

Paving

- Mist surface
- Place concrete
  - Paver
  - Clarey screed

Loss % Varies by Depth

Expected Loss		Adjusted
0% @ 25 cm	=	0.0% @ 75 cm
3% @ 25 cm	=	10% @ 75 cm
5% @ 25 cm	=	16.7% @ 75 cm
8% @ 25 cm	=	26.7% @ 75 cm

UTW Jointing

- Apply curing compound
- Saw joints
- Seal joints (optional)

THANK YOU

ANY QUESTIONS??