Explanation of Top-Down Cracking

Presentation for Northeast Asphalt User/Producer Group 2002 meeting

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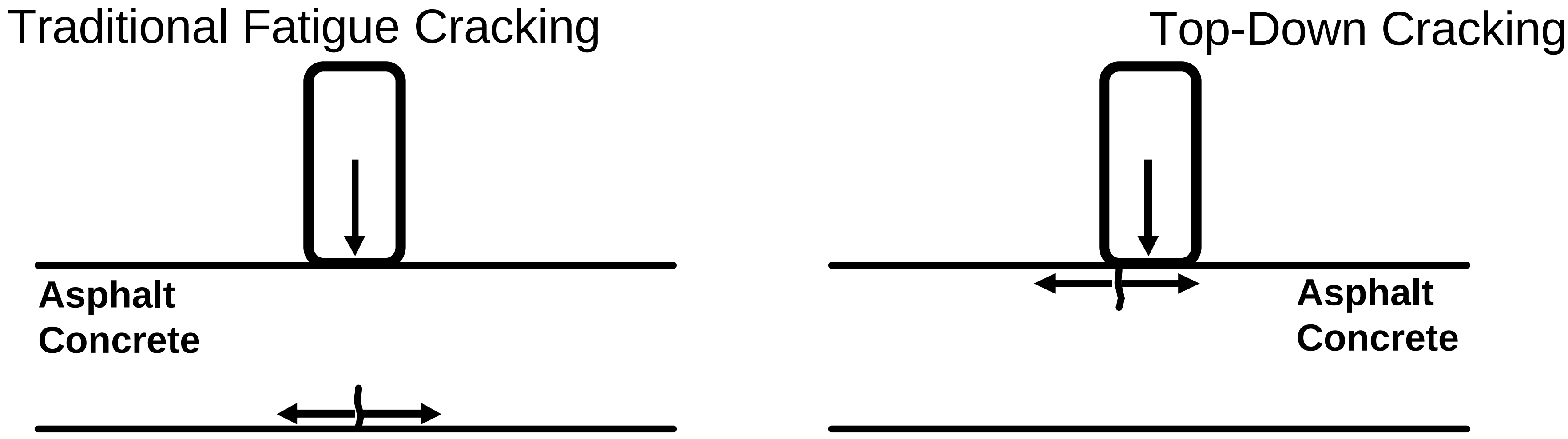
Definition

- Top-Down (Surface-Initiated) Longitudinal Wheel Path Cracking
  - Predominant mode of failure in Florida
  - Prevalent in other parts of US
  - Similar problem reported in Europe & Japan

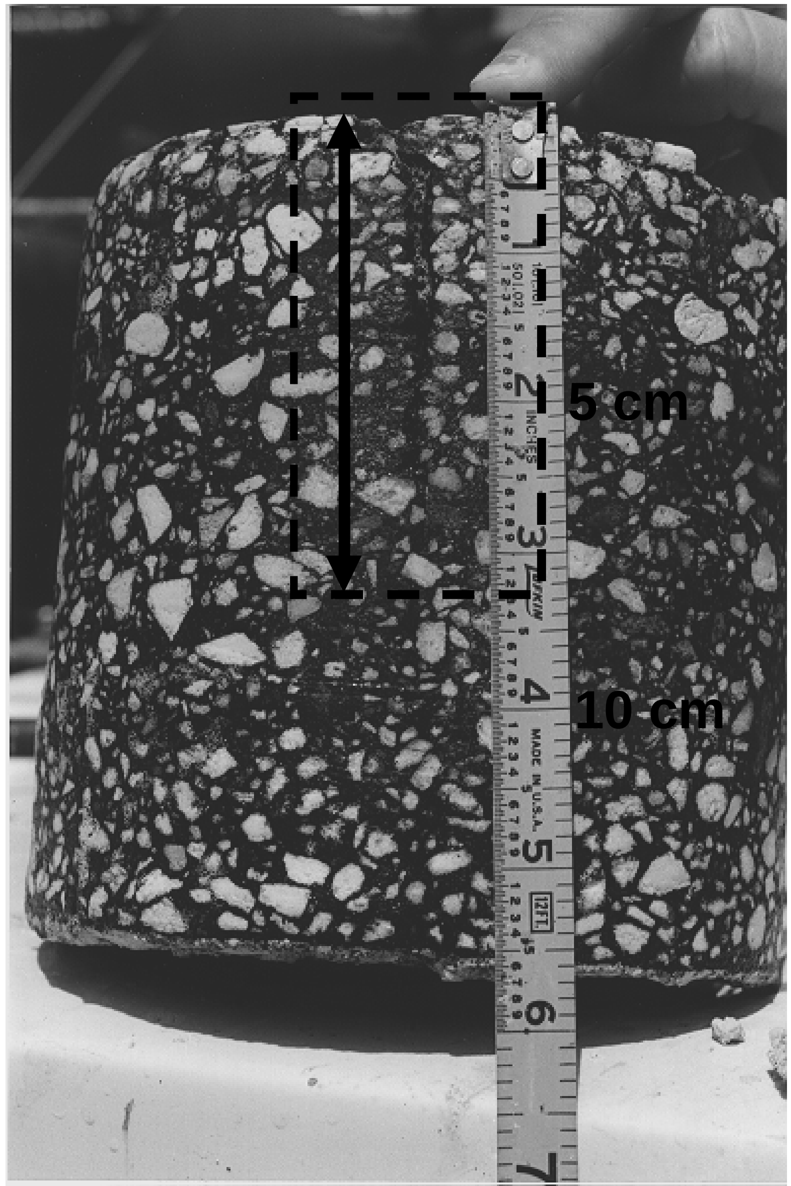


Cracking in Florida’s Highways

- Increased Appearance of Longitudinal Wheel Path Cracking in Major Highways
    - Pavements aged 5 to 25 years

- Florida DOT Project 352
    - Commenced in 1996, second phase started 1999
    - Sought to define initiation, identify propagation mechanism
    - Cores & trenched sections extracted for visual inspection of cracks

Cored Section from FL Highway



I-75 in North Florida

US-1 near Key Largo, Florida


Centered
in Truck
Wheel Path

Other States

- Cracking Observed in Other States

  - Rowe et al. identified top-down cracking in New Jersey, Pennsylvania, and Indiana

    - I-287 in NJ

- Minnesota MnROAD mainline test road

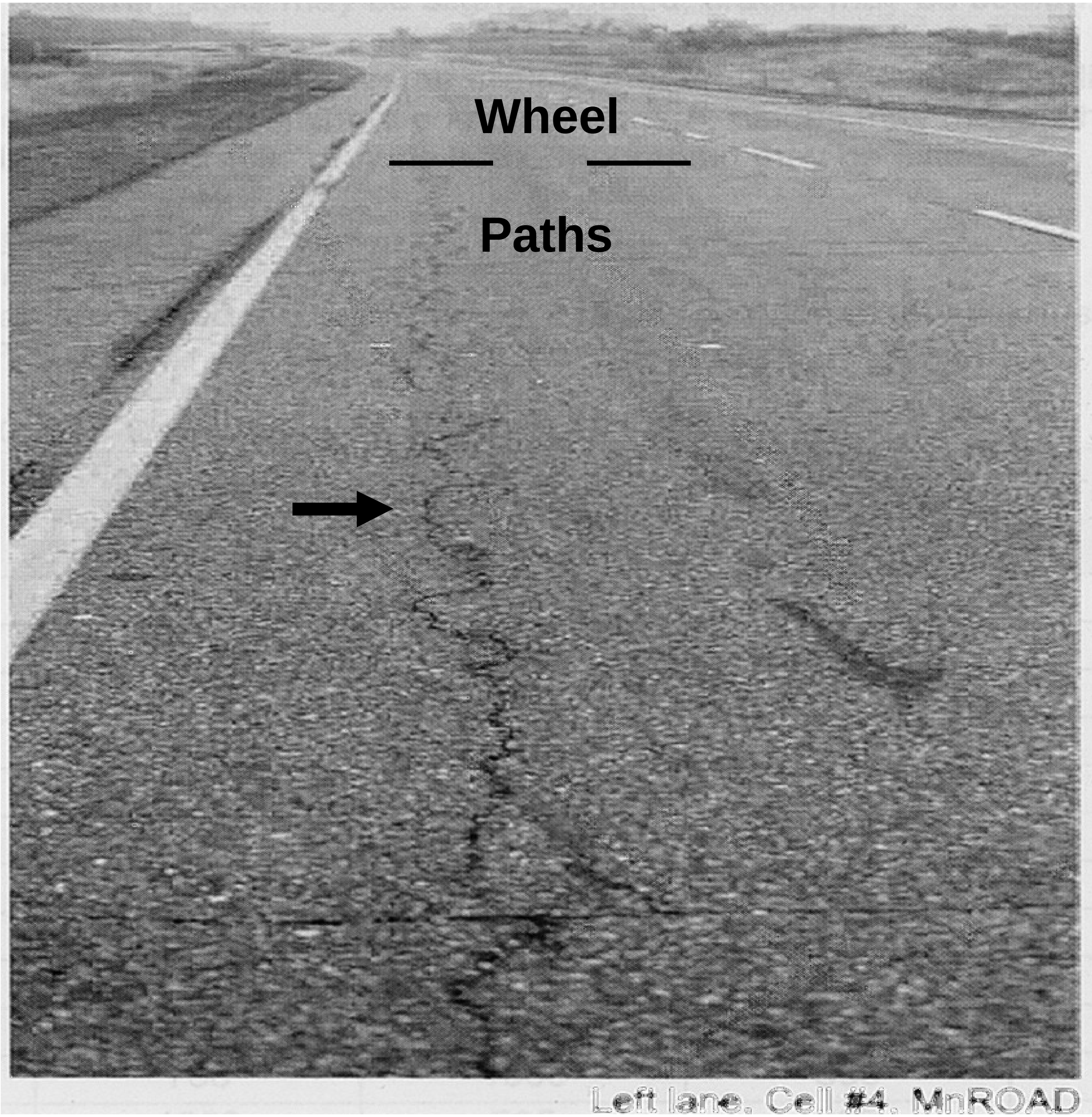
  - Cracks located in wheel path & do not propagate through entire layer

  - First appeared after 3 years of traffic

- Similar problem recorded in Texas

US-77 Highway in Texas

MnROAD



Around the World

- Europe

  United Kingdom – widespread cracking, research cited cracks fail in tension

  Netherlands

  - Analyzed cracks using distortion energy approach

- Japan

  Similar pattern to cracking found in US

  Noted that cracks stop on part of pavement under overpasses

  - Reported longitudinal cracks as high temperature phenomenon

Japan

Identification of Potential Causes

Non-Uniform Vertical Loading (Tire Rigidity)

Interlayer Slippage or Delamination

☞ **Realistic Load Spectra** **Load Position & Magnitude**
Truck Tire Contact Stress Pattern

☞ **Thermal Stresses**

☞ **Stiffness Gradients Within Asphalt Concrete Layer**
Induced by non-uniform temperatures throughout depth

Selection of Analysis Tools

BISAR - cannot physically model cracks

RIGID - predicted no tension near surface

TC Model - predicted tensile thermal stresses near surface, but for critical condition

☞ Finite Element Model – can model cracks & predict pavement's global and crack tip response

Theory for Prediction

Elastic Layer	Allows no discontinuities or flaws
Distortion Energy	Predicts highest $?_t$ @ bottom of AC
☞ Fracture Mechanics	Linear elastic, modified 2-dimensional model

Purpose of Research:

To formulate explanation for cracking mechanism

Parametric Study: Full Depth Asphalt Concrete

Pavement Structure ? AC & Base thickness

Layer Stiffness ? AC & Base E

Loading ? Magnitude, tire type, position in lane

Crack Properties ? Initial crack length assumed from IDT test samples

Temperature ? Induced stiffness gradients, thermal stress

Analytical Design Setup

Structure

- 2 AC thickness – 10 cm, 20 cm
- 2 AC stiffness – 5500 MPa, 8300 MPa
- 2 Base stiffness – 140 MPa, 300 MPa
- 5 Crack lengths – 6.25 to 37.5 mm, + one continuum case

Loading

- 6 Wander positions – wide rib over crack to 63 cm away

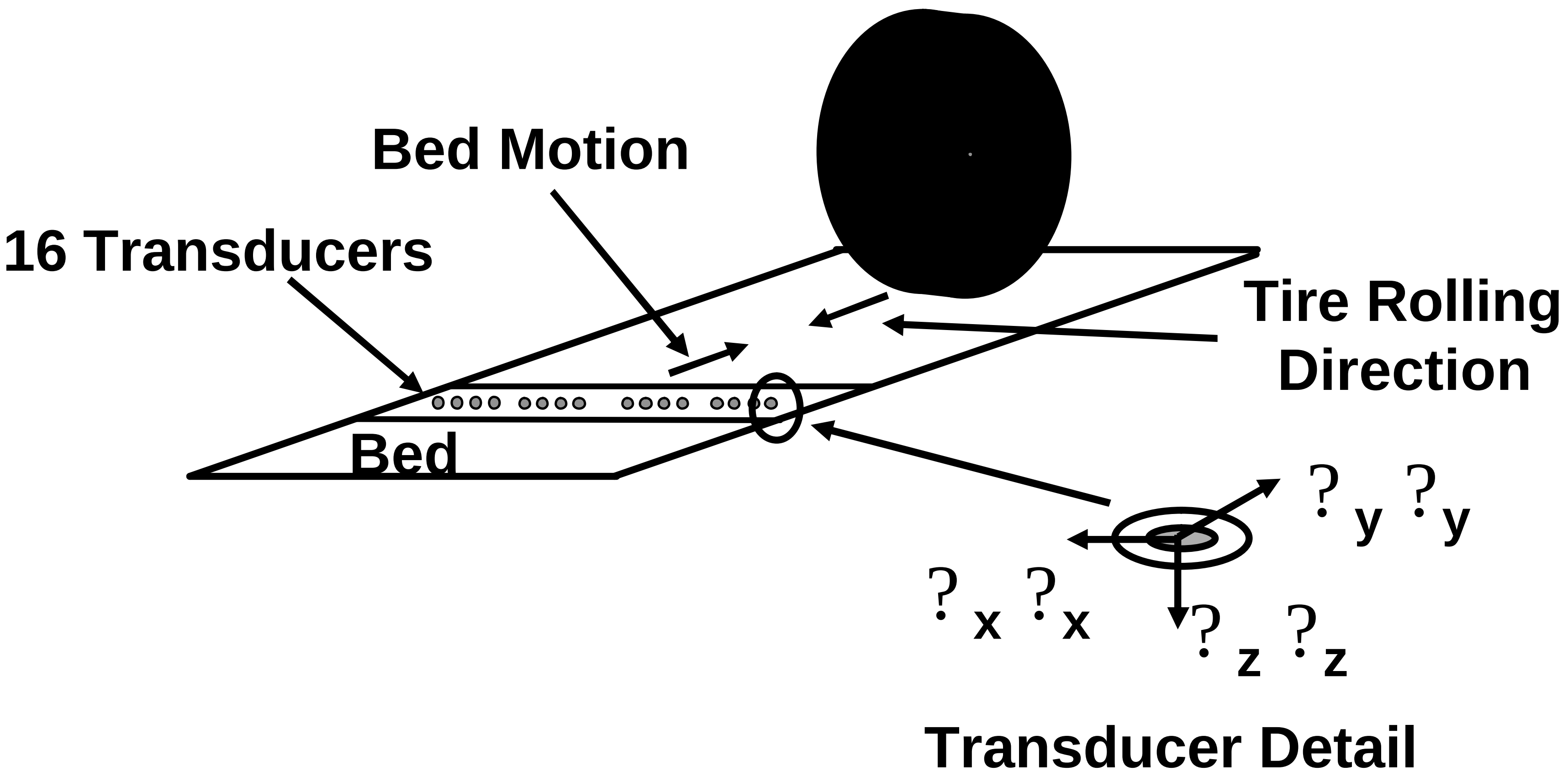
Temperature

- 4 AC temperature-induced stiffness gradient cases
- 3 Depths in AC to calculate effect of thermal stresses

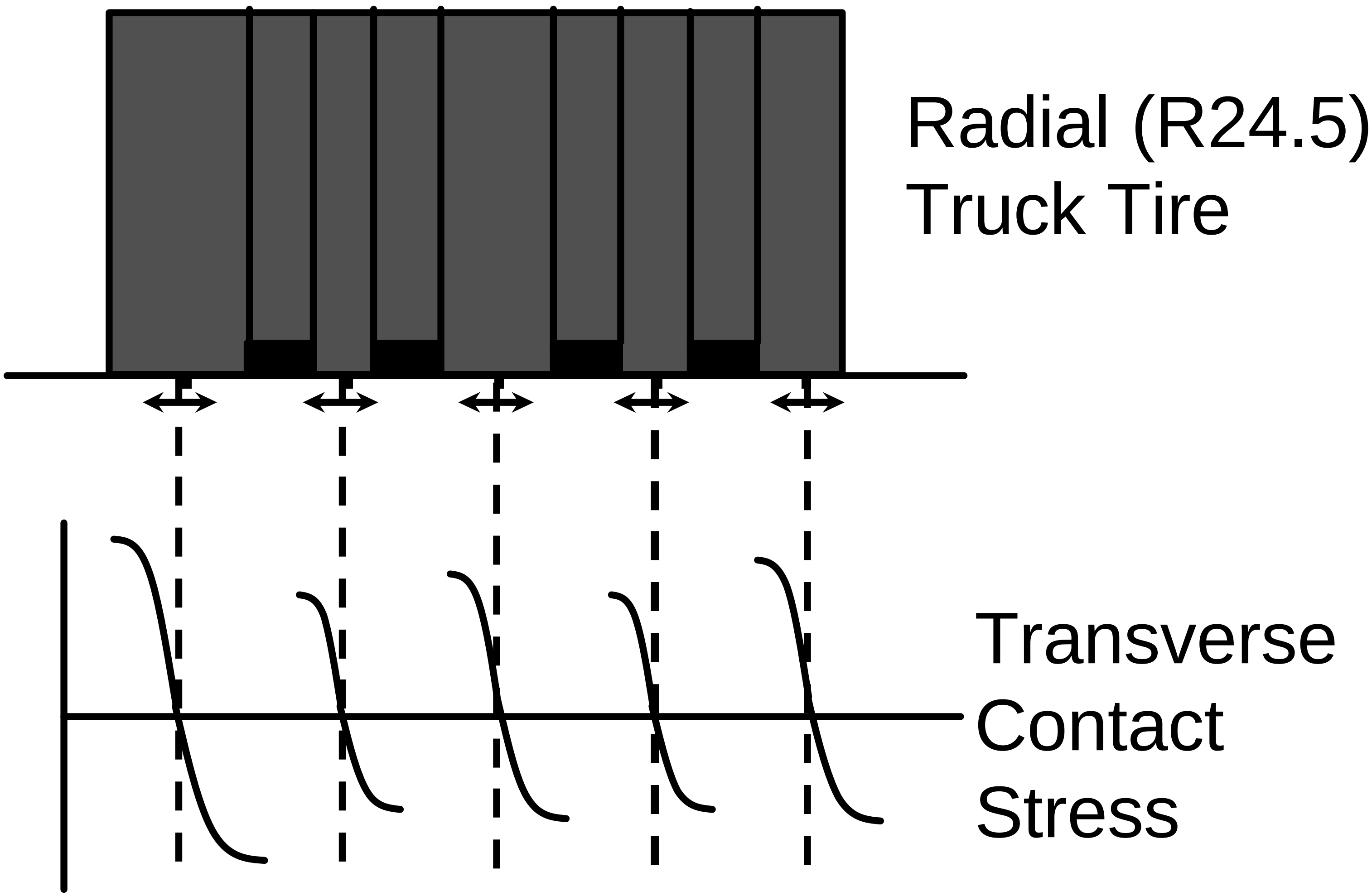
All other variables constant

Measured Tire-Pavement Interface Stresses

(Smithers Scientific Services, Inc.)



Transverse Contact Stresses



Summary of Results

Use of Wide-Based (Supersingle) Radial Tires ? = Pavement Damage ?

- Wheel path cracking & instability rutting

Realistic Measured Tire Contact Stress Distributions Must Be Considered in Design

How Does Crack Grow Below the Top 1-cm of Surface?

Analytical Studies Predicted Top-Down Cracks
Are Primarily Driven By Tension Not Shear

Summary of Results

Design Must Involve:

Pavement Must Be Modeled With A Crack

Load Spectra (Magnitude and Wander) Is Critical

– ESAL Concept Useless For This Problem

Damage (Crack Growth) Develops Under Critical Conditions – Need An Appropriate Crack Growth Model

Temperature Effects Must Be Evaluated

– Gradients Result in Significant Increase in Stress Intensity at the Crack Tip

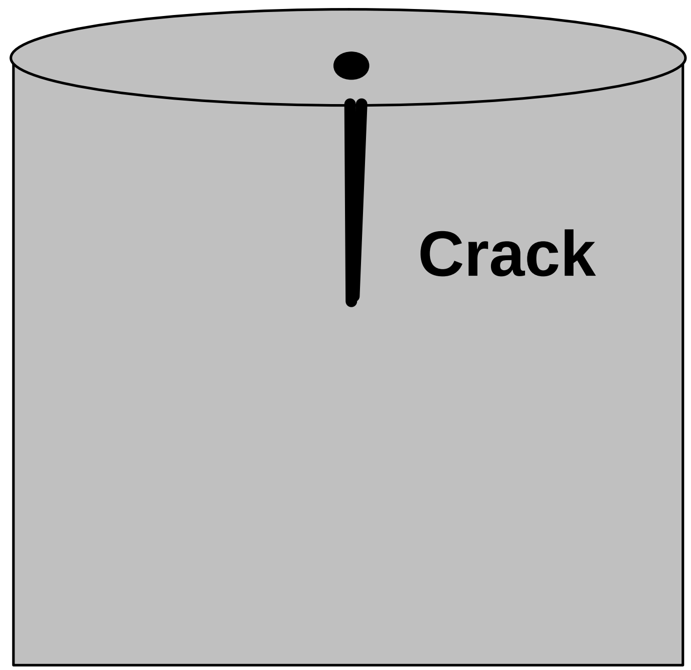
Direction of Crack Growth

Short cracks

-**Pure tension either from rib load or pavement bending**

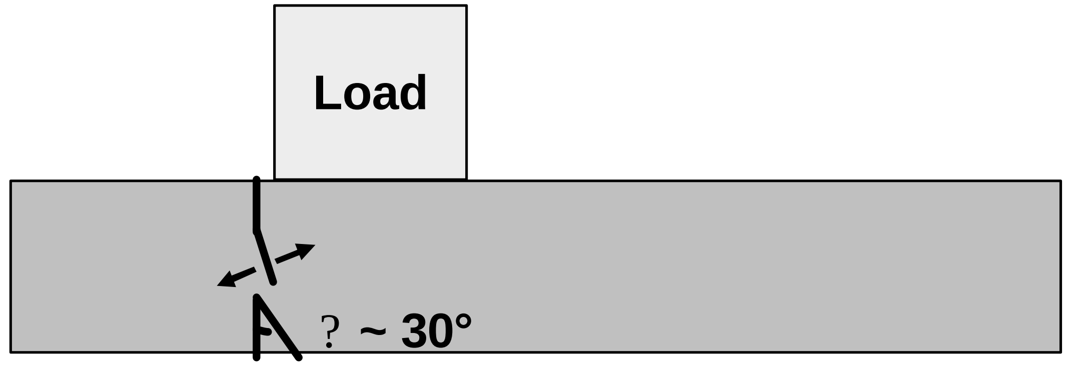
- Grow straight down

CORED SECTION



Cored Section from FL Highway

Direction of Crack Growth

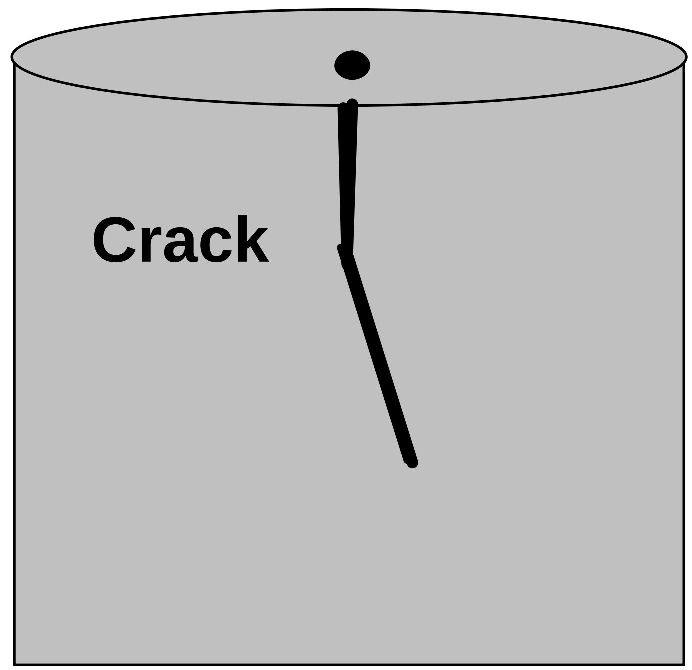


Intermediate or long cracks

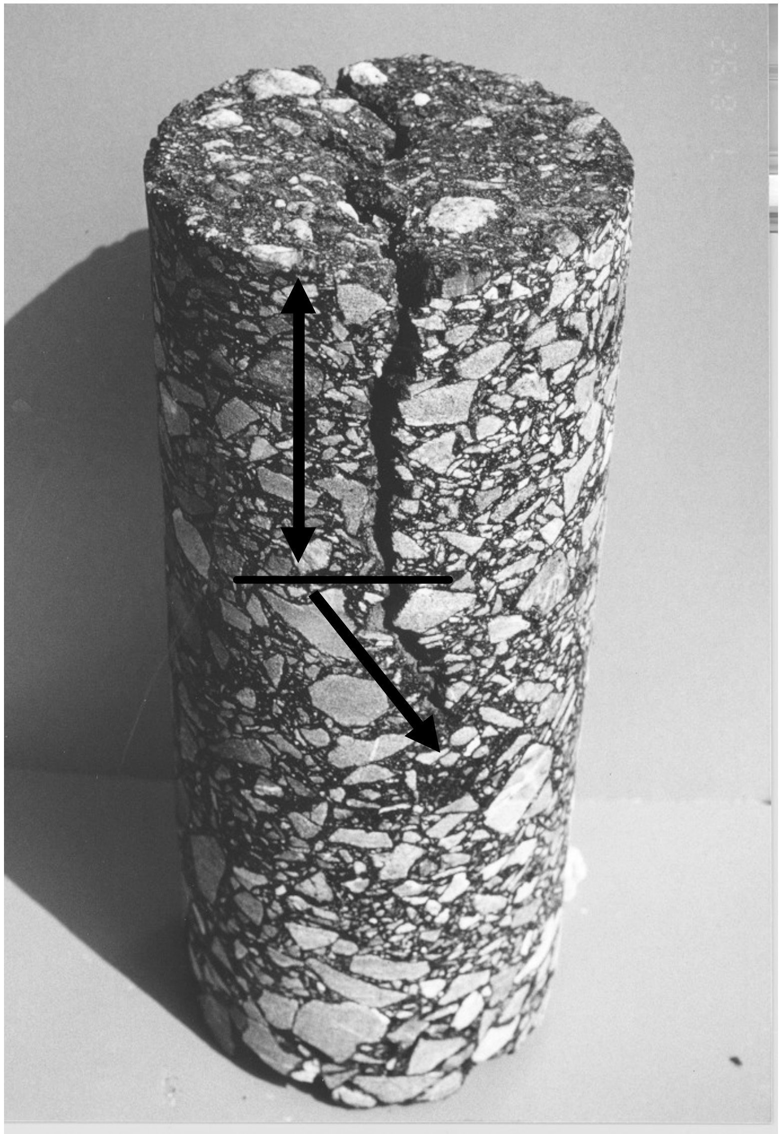
-**Combined tension from rib load, pavement bending, and/or tension at bottom of AC**

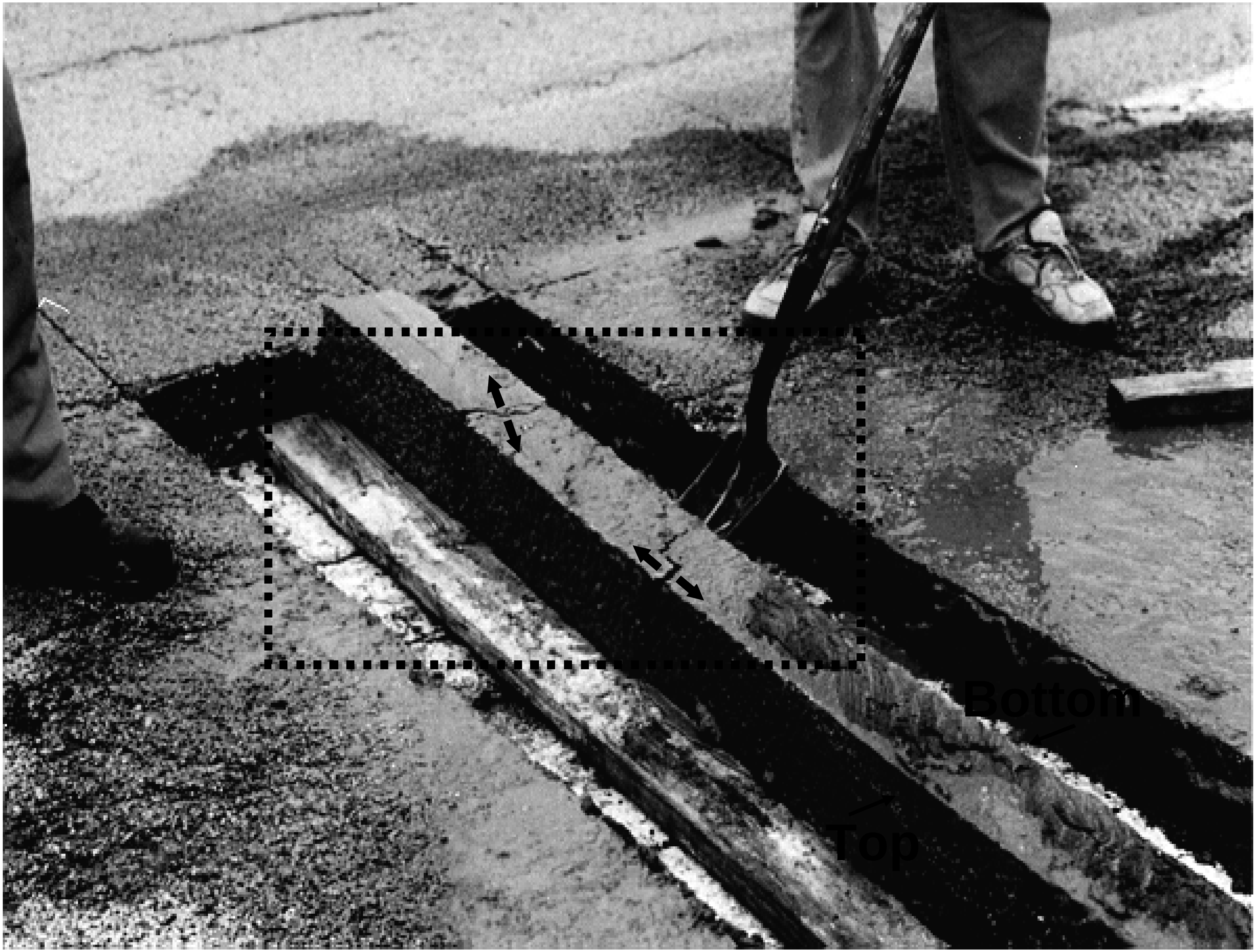
-**Grow at angle of around 30° in toward load**

CORED SECTION



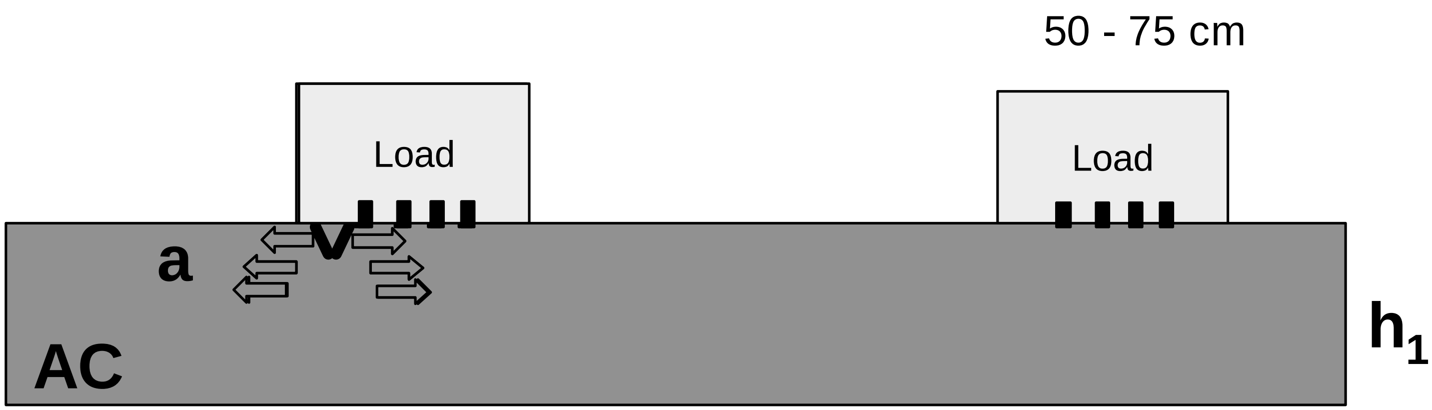
Cored Section from Highway in Japan




Bottom
Top

Concept of Crack Growth Rate

Short Cracks, a = 6.25 - 12.5 mm

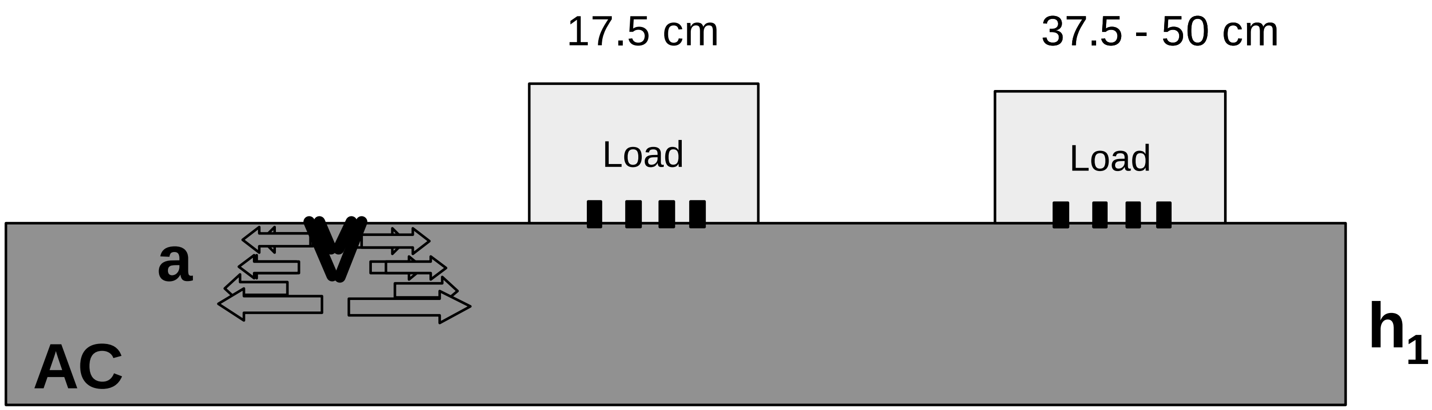


Significant tension induced - loading concentrated mostly in wheel path

✍ Fast cracking rate

Concept of Crack Growth Rate
"Time of Low Crack-Growth Activity"

Intermediate Cracks, a = 12.5 - 25 mm



Stress redistributions occur

Requires more load repetitions for crack growth ✍ Cracking rate slows down considerably

Concept of Crack Growth Rate

Long Cracks, a = 25 - 37.5 mm

Requires more load repetitions to drive crack since load position less common

✍ Cracking rate slow, but begins to speed up as crack length increases

Potential Solutions

<u>Improved Mixture Design</u>

- Maximize Fracture Resistance of Mixtures

- Improved Gradation & Mix Volumetrics

- Appropriate Mixture Design Parameters (e.g. Fracture Energy)

- Modifiers

Potential Solutions

Specialized Thin Surface Layers

Apply Highly Modified, Low Stiffness/Stress Relief, High Strain Tolerance Surface Layer

Interaction With Tire Manufacturers & Researchers

Watch for Major Changes in Tire Technology & Assess Resulting Influence on Pavement Performance

Other Investigation

- Evaluate AC overlay on concrete pavements & other pavement structures
  - ✍Pre-solve several cases to identify most critical conditions for crack growth
  - ✍Load on crowned surface vs. flat plane
- Experimental validation of material properties
  - ✍Mixture testing
    - ✍ **Unmodified vs. modified binder**
    - ✍ **Unaged vs. aged binder**
    - ✍ **Differential aging in bituminous layer**

Other Investigation

- True 3-dimensional model of mechanism
  - ✍Is it necessary?
- Viscoelastic analysis including pavement temperature gradient
  - ✍Other methods for predicting crack growth

Other Investigation

- Top-down in wheel path versus in other locations in lanes
  - **Visual observations & results from non-destructive testing recorded in database (PMS)**

  - **Helps provide clues to initially identify cause of damage**
    - **Truck load-related, stiffness gradients?**
    - **Paver-related, segregated areas?**
    - **Construction-related, poorly compacted joints?**
    - **Combination?**

- Cracks start <u>at</u> surface or <u>near</u> surface in upper part of top layer?

Top-down Cracking

Not in wheel path

Construction-related?

Different cause for initiation?

Same mechanism for crack growth?

Conclusions

- Cracks propagate in tension
- Load wander and tire characteristics must be considered
- Temperature-induced gradients in AC result in higher tension
- Describing cracking pattern may yield clues on how cracks initiate and develop