Explanation of Top-Down Cracking

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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

Traditional Fatigue Cracking

Top-Down Cracking
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 & trenches sections extracted for visual inspection of cracks
Cored Section from FL Highway
I-75 in North Florida
US-1 near Key Largo, Florida
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
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

arrow 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 $\tau$, @ 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.)

16 Transducers

Bed Motion

Tire Rolling Direction

Transducer Detail
Transverse Contact Stresses

Radial (R24.5) Truck Tire

Transverse Contact Stress
Summary of Results

Use of Wide-Based (Supersingle) Radial Tires $\Rightarrow$ Pavement Damage $\Rightarrow$
- 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
**Short cracks**

-Pure tension either from rib load or pavement bending

- Grow straight down

**CORED SECTION**

**Load**

**Crack**
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 from Highway in Japan
Concept of Crack Growth Rate

*Short Cracks, \( a = 6.25 - 12.5 \text{ mm} \)*

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, $a = 12.5 - 25 \text{ mm}$

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

**Improved Mixture Design**

- 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 at surface or near 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