Top-Down Cracking: Causes and Potential Solutions

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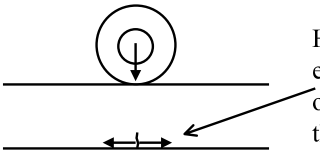
Introduction

Surface-initiated longitudinal wheel path cracking:

- Common mode of failure
- Recently identified
- Mechanisms now better understood
- Occurs primarily under critical conditions
- Existing design methods are inadequate
- Understanding leads to more resistant pavements

Background

- In the Past, Cracking Assumed to Always Start at Bottom of AC Layer (Structure has a Strong Effect)



Have evaluated effects of factors on response at this location

CRACKING IN WHEEL PATHS

CORE EXTRACTED FROM FIELD

Objectives

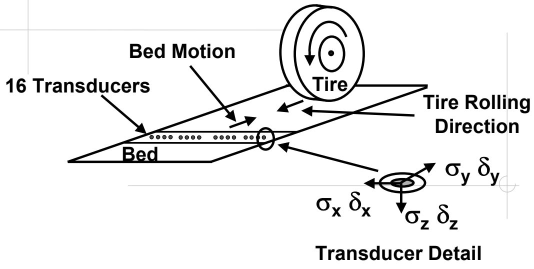
- To Summarize Findings Related to Top-Down Cracking
  - Mechanisms for Initiation and Propagation
  - Key Factors Dominating the Mechanisms
  - Implications for Mitigation and Design (improved guidelines for mixture and pavement design)

Pavement Surface Stresses

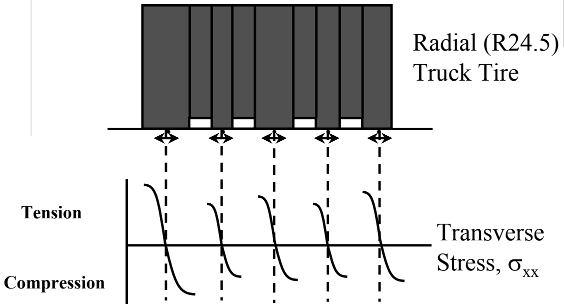
- Tire-Pavement Interface Stresses
  - Including lateral stresses
- Thermal Stresses
- Pavement Structure Effects
  - Layer Stiffness and Thickness

Measured Tire-Pavement Interface Stresses

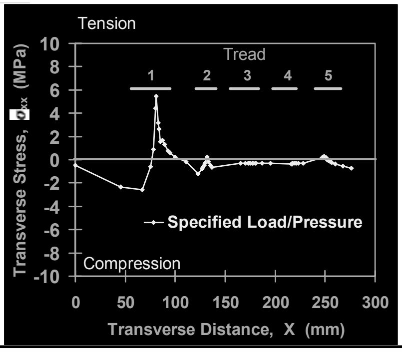
(Smithers Scientific Services, Inc.)



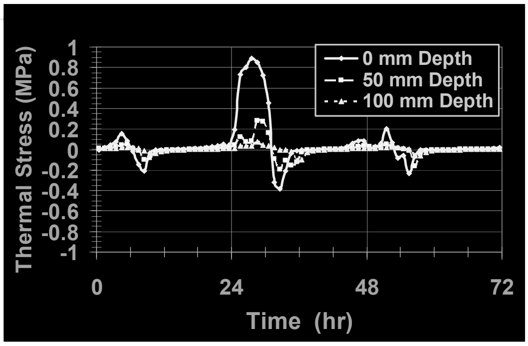
Transverse Contact Stresses



Transverse Surface Stress Distribution



Thermal Stress



Findings for Crack Initiation

- Primary Contributors to Surface-Initiated Longitudinal Wheel Path Cracking
  - Transverse contact stresses induced by radial truck tires
  - Thermal stresses
  - Age-Hardening near surface

Propagation of Top-Down Cracks

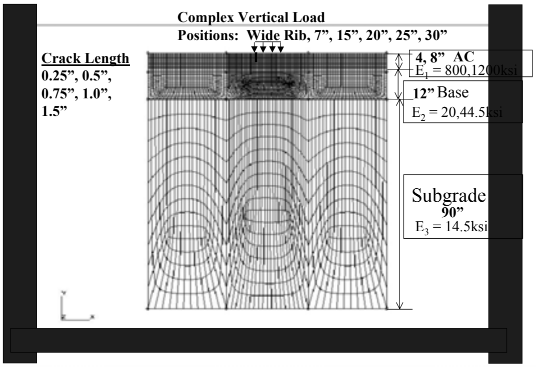
◈Surface Contact Stresses (Tire or Thermal) Cannot Explain Propagation of Top-Down Cracks

- Continued work to identify mechanisms and factors controlling propagation

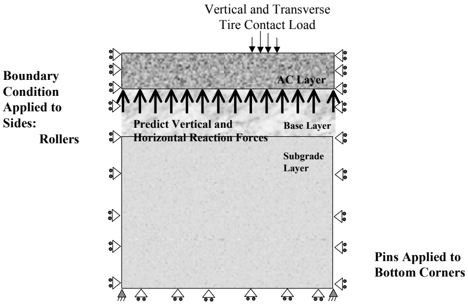
RANGE OF FACTORS

- Load Spectra
  - Positioning with respect to crack
  - Realistic tire contact stresses (vertical and lateral)
- Cracks and Discontinuities
  - Crack depth
- Asphalt Pavement Thickness
  - Interstate highway pavements – thick/stiff
- Surface and Base Layer Stiffness
- Stiffness Gradients Induced in Asphalt Layer
  - Daily temperature and environmental fluctuations

STRUCTURAL PARAMETERS

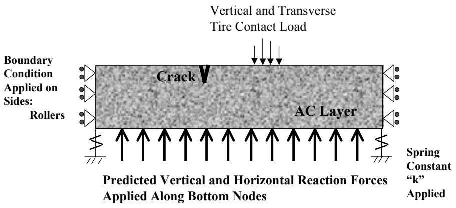


MODELING SYSTEM – STEP 1



MODELING SYSTEM – STEP 2

Model geometry of crack & increase mesh refinement



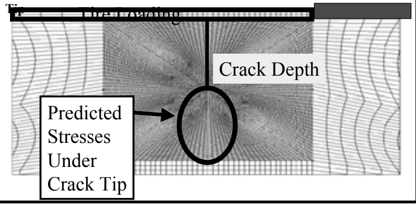
USE OF FRACTURE MECHANICS

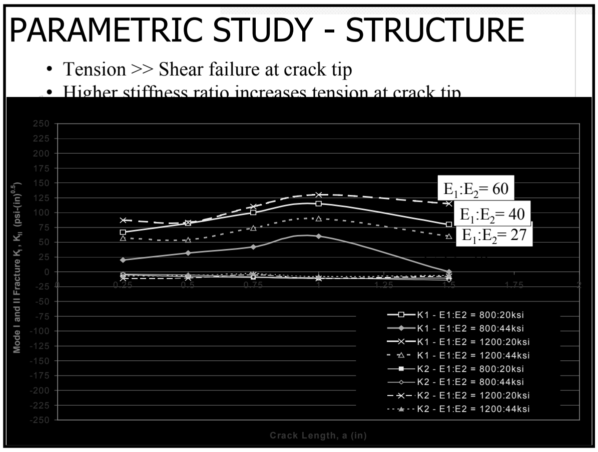
Mode I Stress Intensity Factor, $K_I \approx \lim_{r \to 0} \sigma_{xx} * (2\pi r)^{1/2}$

Mode II Stress Intensity Factor, $K_{II} \approx \lim_{r \to 0} \tau_{yx} * (2\pi r)^{1/2}$

Fracture Energy Release Rate, $J = (K_I^2 + K_{II}^2) * \frac{1-\nu^2}{E}$

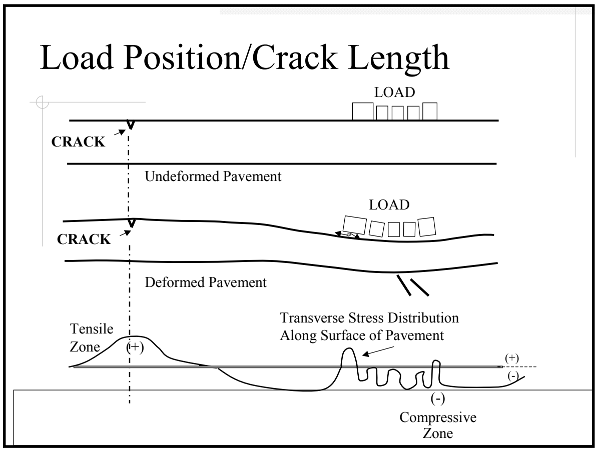
Provides local description of crack tip region



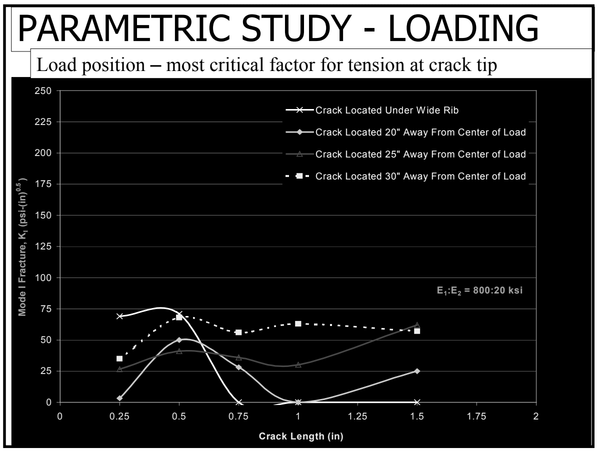


PARAMETRIC STUDY - STRUCTURE

- Tension >> Shear failure at crack tip
- Higher stiffness ratio increases tension at crack tip



Load Position/Crack Length



PARAMETRIC STUDY - LOADING

Load position – most critical factor for tension at crack tip

STIFFNESS GRADIENTS

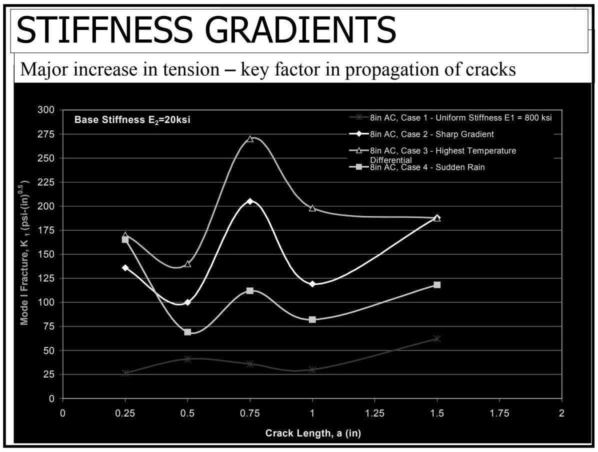
Temperature differentials, age-hardening, sudden rains induce sub-layers of variable stiffness within asphalt concrete

Case 1: Uniform temperature distribution (i.e., no stiffness gradient) mean pavement temperature computed at 1/3-depth when temperature conditions = warm

Case 2: Sharpest temperature gradient near surface - temperatures at 7 PM represent this condition

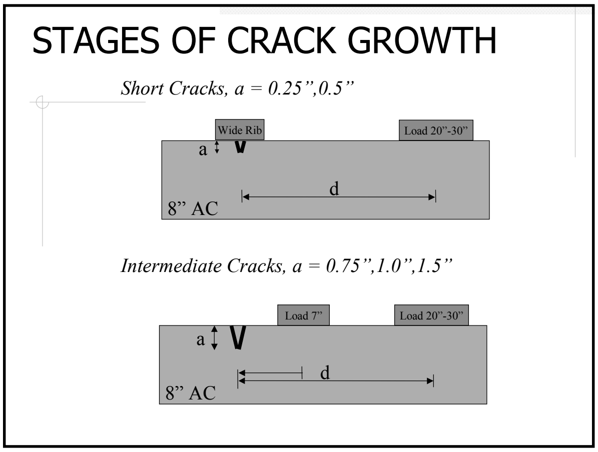
Case 3: Highest temperature differential between surface & bottom of asphalt concrete layer - temperatures at 5 AM represent this condition

Case 4: Rapid cooling near the surface represent case of sudden rain showers



STIFFNESS GRADIENTS

Major increase in tension – key factor in propagation of cracks



STAGES OF CRACK GROWTH

Short Cracks, a = 0.25”,0.5”

Intermediate Cracks, a = 0.75”,1.0”,1.5”

MPLICATION OF LOAD SPECTRA

Load Wander & Magnitude Instrumental in Mechanism

- Critical position not always directly in wheel path on top of crack
  - Depends on crack length, pavement structure, type of stiffness gradient
  - Need to determine how many loads induce tension @ crack tip

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Key Findings

◈Top-Down Cracks Develop Even in Thick Pavements (Previous Field Studies)

◈Mechanisms Cannot be Captured Without Considering

- Realistic Contact Stresses
- Temperature Gradients
- Load Wander
- Presence of Cracks (Fracture Mechanics)

Most Recent Field Test Sections

5 pairs of poor and good performing sections throughout Florida

•Location:

◈Performance:

SR 16-4C

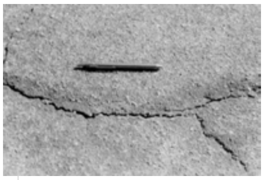
SR 16-6U

US 19-1U

US 19-2C

TPK 1U

TPK 2C

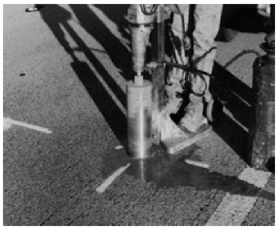


NW 39-1C

NW 39-2U

Sampling

- Coring



Section	WP	BWP	Total
SR 16-4C	3	4	7
SR 16-6U	4	4	8
US 19-1U	18	18	36
US 19-2C	18	18	36
SR 375-1U	12	0	12
SR 375-2C	12	0	12
TPK-1U	12	12	24
TPK-2C	8	12	20
NW 39-1C	18	18	36
NW 39-2U	18	18	36
		Total	227

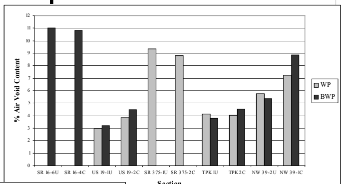
- Sample selection: closest to average BSG
- Crack depth:

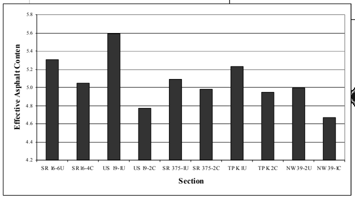
Crack Depth (in)	Rating
< 1/2	10
1/2 - 1	8
1 - 1 1/2	6
1 1/2 - 2	4
2 - 3	2
> 3	0

Section	Performance Rating
SR 16 - 4C	0
SR 16 - 6U	6
US 19 - 1U	10
US 19 - 2C	0
SR 375 - 1U	10
SR 375 - 2C	2
TPK 1U	10
TPK 2C	2
NW 39 - 1C	0
NW 39 - 2U	10

Volumetric Properties

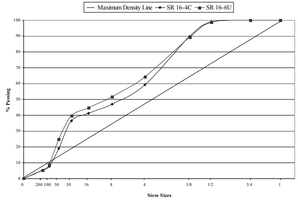
- Air Void Content





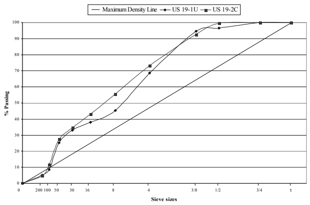
- Effective Asphalt Content

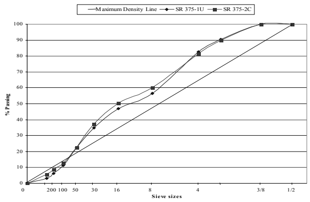
- Aggregate Gradation



SR 16

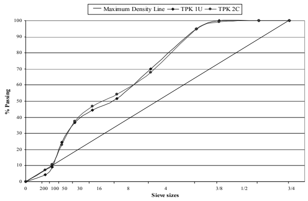
US 19



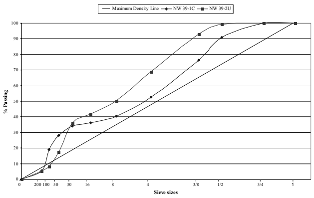


SR 375

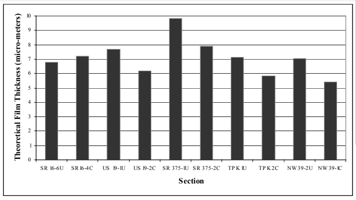
TPK

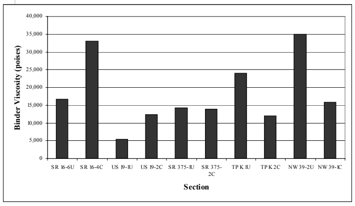


NW 39



◆ Theoretical Film Thickness

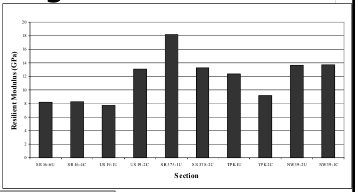


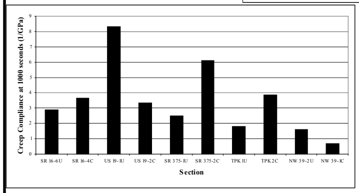


◆ Binder Viscosity

Mixture Testing

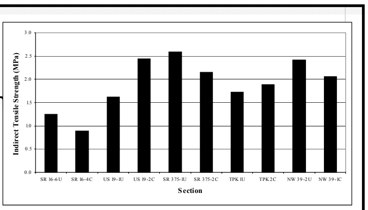
◆ Resilient Modulus

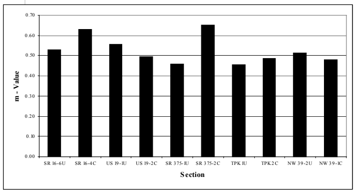




◆ Creep Compliance

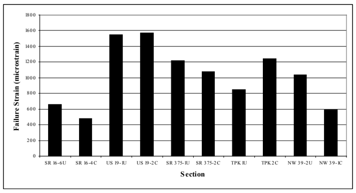
◆ Tensile Strength

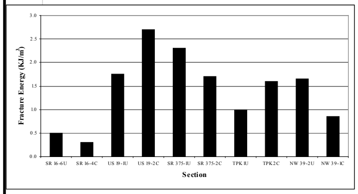




◆ m-value

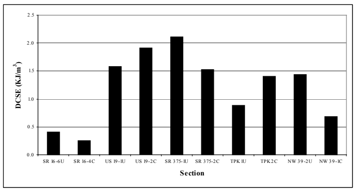
◆ Failure Strain





◆ Fracture Energy

- DCSE



FWD Analysis

- Geometry

Section	Friction Course	AC	Base	Sub-base
SR 16-4C	0.6	3.0	6.7	12.0
SR 16-6U	0.6	3.0	6.7	12.0
US 19-1U	0.5	9.0	8.0	12.0
US 19-2C	0.5	7.0	8.5	12.0
SR 375-1U	0.6	6.3	7.5	12.0
SR 375-2C	0.6	6.3	7.5	12.0
TPK-1U	0.5	7.0	12.0	12.0
TPK-2C	0.5	6.1	12.0	12.0
NW 39-1C	0.8	4.0	12.5	12.0
NW 39-2U	1.0	3.3	12.5	12.0

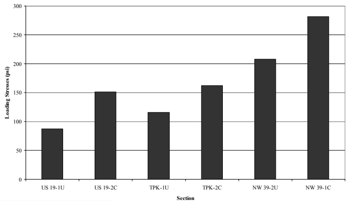
◈Pavement Structure

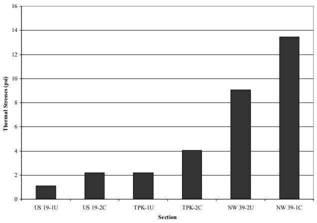
Section	AC	Base	Sub-base	Sub-grade
US 19-1U	550	51	37	24
US 19-2C	1,000	37	22	28
TPK-1U	800	97	39	17
TPK-2C	900	34	19	24
NW 39-1C	1,500	28	71	28
NW 39-2U	1,500	63	58	30

Section	E1/E2
US 19-1U	11
US 19-2C	27
TPK-1U	8
TPK-2C	26
NW 39-1C	52
NW 39-2U	24

◈Loading stresses

Design load: 9000 lbs



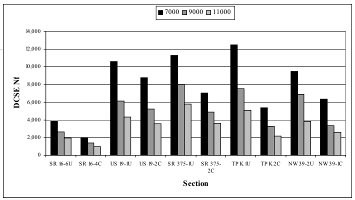


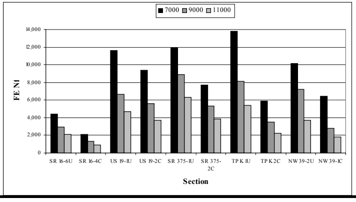
◈Thermal Stresses

Cooling rate: 10ºC/hr

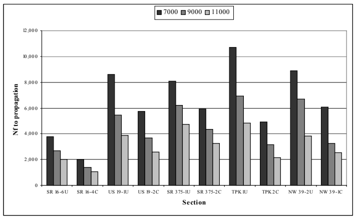
Crack Growth Model

◈Initiation





- Propagation



Individual Analysis of the Sections

◈SR 16: high air voids, high m-value, low FE
possible effect of friction course

◈US 19: stiffness overwhelmed FE, low AC content and film thickness

◈SR 375: low FE, high m-value, high air voids

- TPK: low base stiffness, high m-value, low film thickness
- NW 39: high E_1/E_2 ratio, low compliance, low tensile strength, low FE, possible effect of friction course

Summary of Findings

- Structure has effects on surface-initiated cracking
- Load + Thermal stresses plays significant role
- High MR + Low Compliance / Load and thermal σ
- UF Cracking model properly explained performance differences
- No single property will assure adequate mixture performance. Need of conditions and model

Key Findings (Continued)

- Design Approach Using Averaged Pavement and Load Conditions Inadequate
  - Critical Conditions Must Be Identified
- Mitigation Should be Addressed Primarily Through
  - More Crack-Resistant Surface Materials
  - Use of Less Damaging Tires

Implications for Design

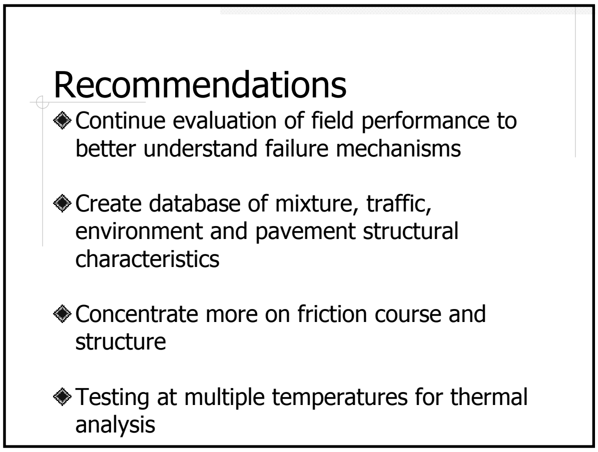
- Focus on Improving Surface Materials
- Dialogue With Tire Designers
- Pavement Design/Management
  - Realistic contact stresses
  - Load spectra (magnitude and position)
  - Temperature gradients
  - Cracks/discontinuities (fracture mechanics)

Potential Solutions

- Improved Mixture Design
  - Maximize Fracture Resistance of Mixtures
  - Improved Gradation/Volumetrics
  - Appropriate Mixture Design Parameters (e.g. Fracture Energy)
  - Modifiers
- Specialized Thin Surface Layers
  - Highly Modified, Low Stiffness/Stress Relief, High Strain Tolerance

Conclusions

- Stiffness and Compliance should be limited
- Thermal stresses should be considered in structural design
- More attention should be paid to the effect and design of friction courses
- It is critical to identify appropriate design conditions to evaluate performance using the parameters from the laboratory
- UF cracking model adequately represents cracking mechanisms



Recommendations

- Continue evaluation of field performance to better understand failure mechanisms
- Create database of mixture, traffic, environment and pavement structural characteristics
- Concentrate more on friction course and structure
- Testing at multiple temperatures for thermal analysis