Updates on Cracking Models and Transfer Functions in ME Design

Kevin Hall and Nam Tran

Overview

- Types of cracking predicted by ME Design
- Model forms and enhancements (made and planned)

Cracking Models & Transfer Functions

Bottom-up cracking

Top-down cracking

Transverse cracking

Reflection cracking

Mixture Properties for Cracking Models

Types of Cracks	Mixture Properties
Bottom-Up	• Fatigue strength from flexural beam fatigue test
Top-Down	• Fatigue strength from flexural beam fatigue test
Transverse (Thermal)	• Indirect tensile strength • Indirect tensile creep compliance
Reflection	• None (regression equation)

Bottom-Up Alligator Cracking

Bottom-Up Cracking Prediction

Steps	Mixture Properties
Allowable load applications	$N_{f-AC} = k_{f1}(C)(C_H)(\beta_{f1})(\varepsilon_t)^{k_{f2}\beta_{f2}}(E_{AC})^{k_{f3}\beta_{f3}}$
Cumulative damage index	$DI = \sum(\Delta DI)_{j,m,l,p,T} = \sum\left(\frac{n}{N_{f-AC}}\right)_{j,m,l,p,T}$
%Lane area of cracking	$FC_{bottom} = \left(\frac{C_4}{1+e^{(C_1*C_1'+C_2*C_2'*log(D_k*100))}}\right) * \left(\frac{1}{60}\right)$
Notes	• No changes or enhancements and none planned for the short-term

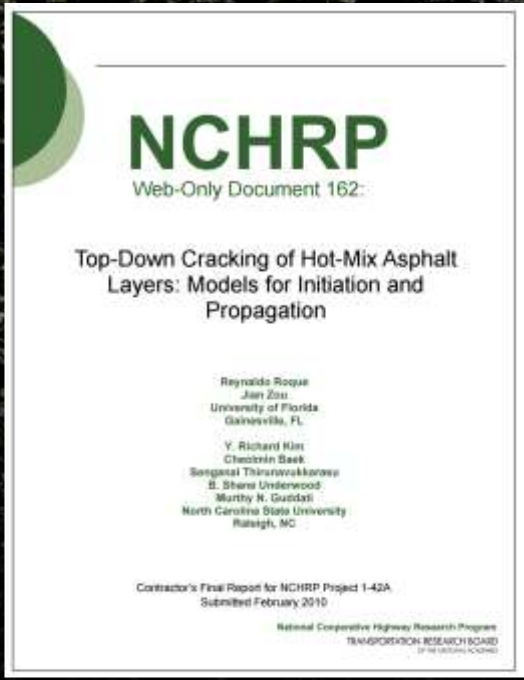
Top-Down Longitudinal Cracking

Top-Down Cracking Prediction

Steps	Mixture Properties
Allowable load applications	Same as bottom-up (assumes cracks initiate at the surface)
Cumulative damage index	Same as bottom-up
Length of longitudinal crack (ft/mi)	$FC_{top} = \left(\frac{C_4}{1+e^{\left(C_1 - C_2 * log\left(D_{top}\right)\right)}} \right) * 10.56$

Top-Down: Planned Enhancements

- ISSUE:
  - MEPDG Manual of Practice recommends the length of top-down cracking predicted by Pavement ME Design not be used to make revisions to the design.


NCHRP
Web-Only Document 162:

Top-Down Cracking of Hot-Mix Asphalt Layers: Models for Initiation and Propagation

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Contractor's Final Report for NCHRP Project 1-42A
Submitted February 2010

National Cooperative Highway Research Program
TRANSPORTATION RESEARCH BOARD

NCHRP 1-42A (Kim & Roque)

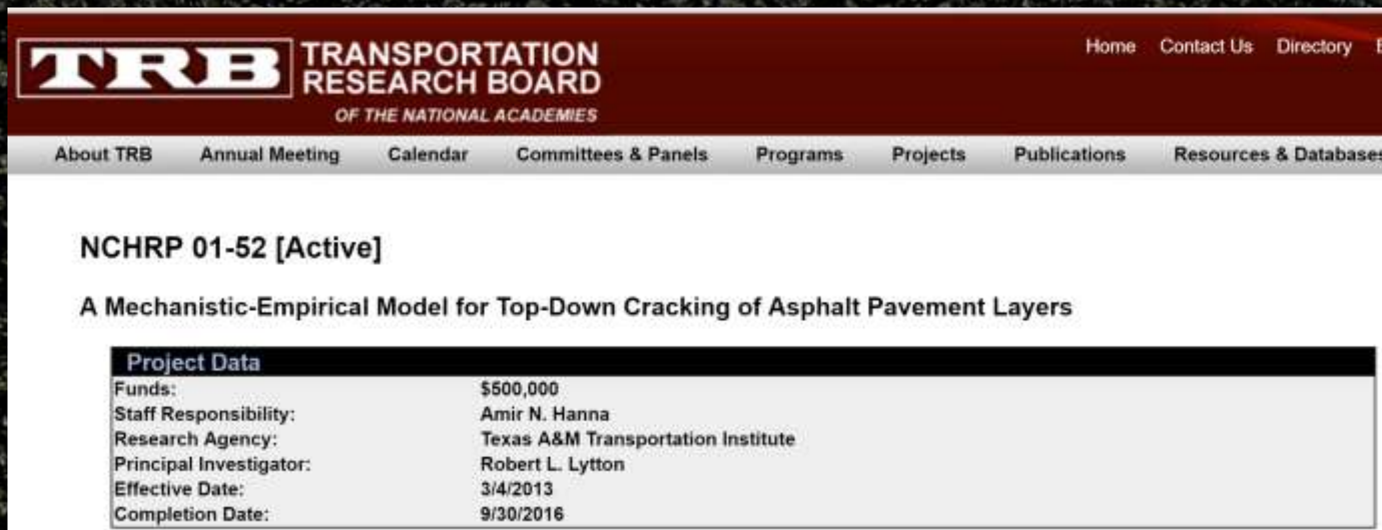
2 Primary Models:

1. VECD-based crack initiation model
(time and location of crack initiation)

2. HMA-FM-based crack growth model
(predict propagation of cracks over time)

Framework for approach…

Top-Down: Planned Enhancements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NCHRP 01-52 [Active]

A Mechanistic-Empirical Model for Top-Down Cracking of Asphalt Pavement Layers

Project Data	
Funds:	$500,000
Staff Responsibility:	Amir N. Hanna
Research Agency:	Texas A&M Transportation Institute
Principal Investigator:	Robert L. Lytton
Effective Date:	3/4/2013
Completion Date:	9/30/2016

- Targeting a fracture mechanics approach, similar to approach used for:
  - ME based transverse cracking (low temperature) model
  - ME based reflection cracking model

Transverse Thermal Cracking

Transverse Cracking

Steps	Mixture Properties
Stress intensity factor	$K = \sigma_{tip}(0.45 + 1.99(C_o)^{0.56})$
Change in crack depth	$\Delta C = A(\Delta K)^n$
A & n parameters	From indirect tensile creep-compliance and strength
Amount of thermal cracking (ft/mi)	$TC = \beta_{tl} N \left[\frac{1}{\sigma_d} log\left(\frac{C_d}{H_{HMA}}\right)\right]$

Transverse Cracking

- Current AASHTO software predicts transverse cracks only caused by low temperature events.
- Multiple local calibration projects, summary of results:
  - Transverse cracks exhibited in warmer climates
  - MEPDG will not predict transverse cracking without a significantly high local calibration factor of the transfer function
- Mechanism of transverse cracks in warm climates questioned for predicting transverse cracks:
  - AASHTO white paper prepared, but no action taken to date

Reflection Cracking

Reflection Cracking: v2.1 and Earlier

- Version 2.1 and earlier versions:
  - Prediction of reflection cracks was based on an empirical regression equation and only applicable to load-related cracks.

$$RC = \frac{100}{1 + e^{a+bt}}$$

Where:
RC = percentage of cracks reflected
t = time (yr)
$a = 3.5 + 0.75\ h_{ac}$
$b = -0.688584 - 3.37302\ h_{ac}^{-0.915469}$
h_{ac} = HMA overlay thickness (in)

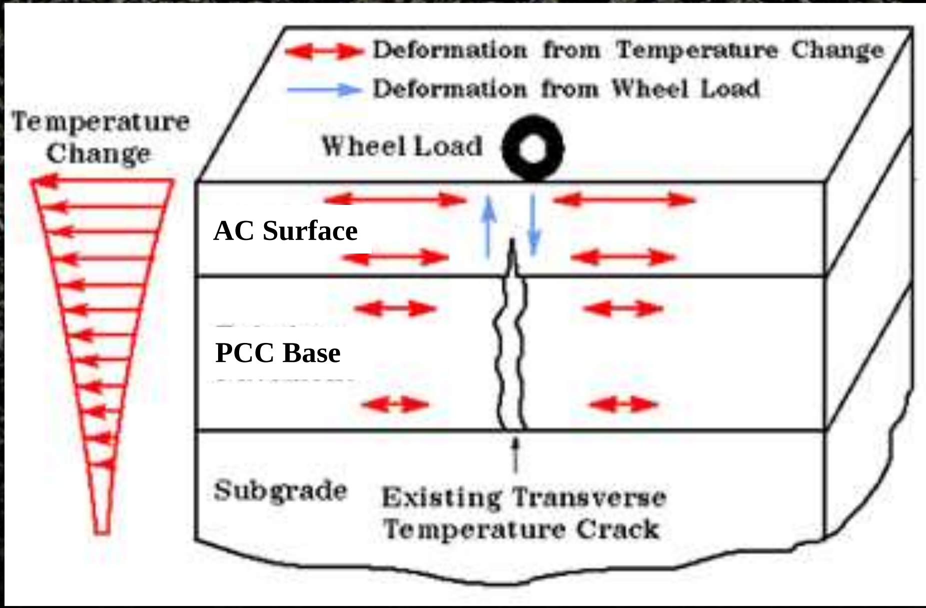
Reflection Cracking: v2.2 Enhancement

(Developed from NCHRP 1-41, Lytton)

- Integrated the ME based fracture mechanics model in the software for predicting reflection cracks.
- Applicable to load and non-load related cracks of flexible, semi-rigid, intact PCC, and fractured PCC pavements.
- Key features include:
  - Traffic impact
  - Temperature profile computed using ICM
  - AC mix and binder properties and thermal stress computation done using existing ME Design approach
  - Utilization of ME Design AC material properties A, n
  - Adapting procedure for cracking for the longitudinal and transverse directions (i.e., for alligator cracking)

Reflection Cracking Mechanisms

1	Differential vertical deflections across joints & cracks.	Traffic Induced	Crack initiates & propagates in shear.
2	Bending or increased tensile strains above joints & cracks.	Traffic Induced	Crack initiates in tension & propagates in tension & shear.
3	Thermal expansion & contraction of joints & cracks.	Thermal Induced	Crack initiates & propagates in tension.



Thermally Induced Reflective Cracking

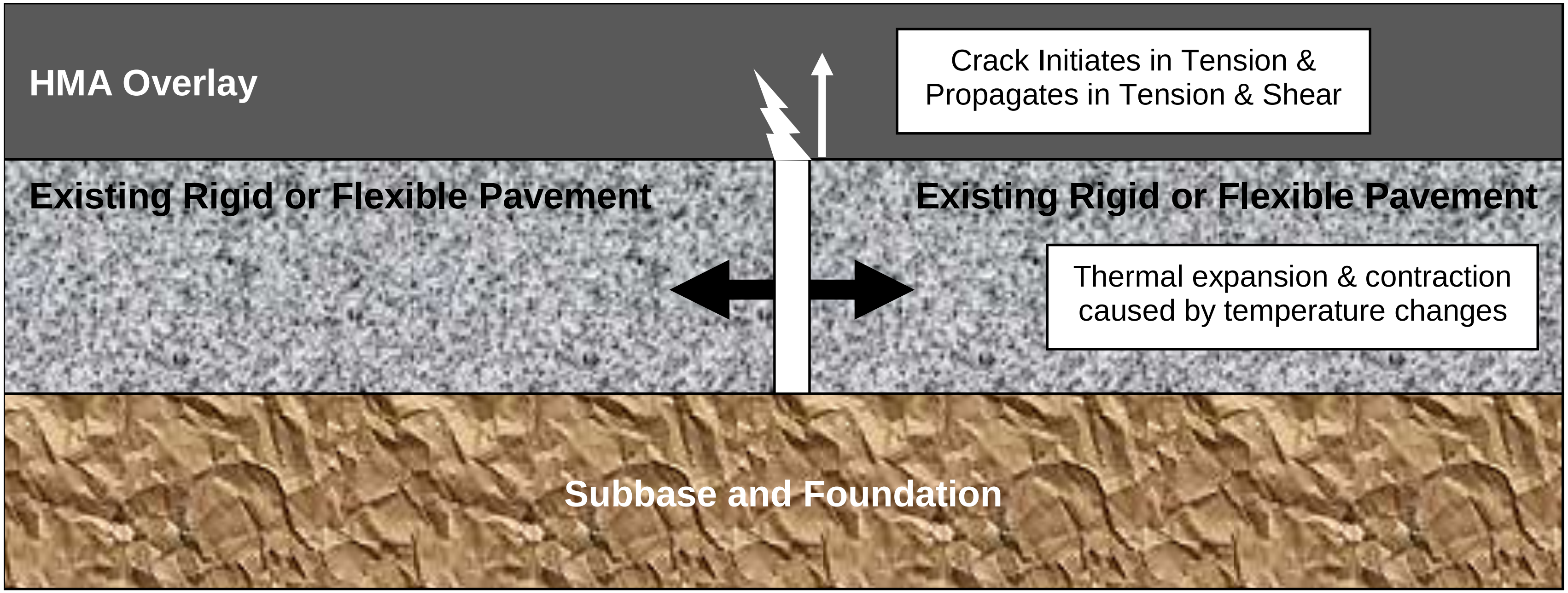
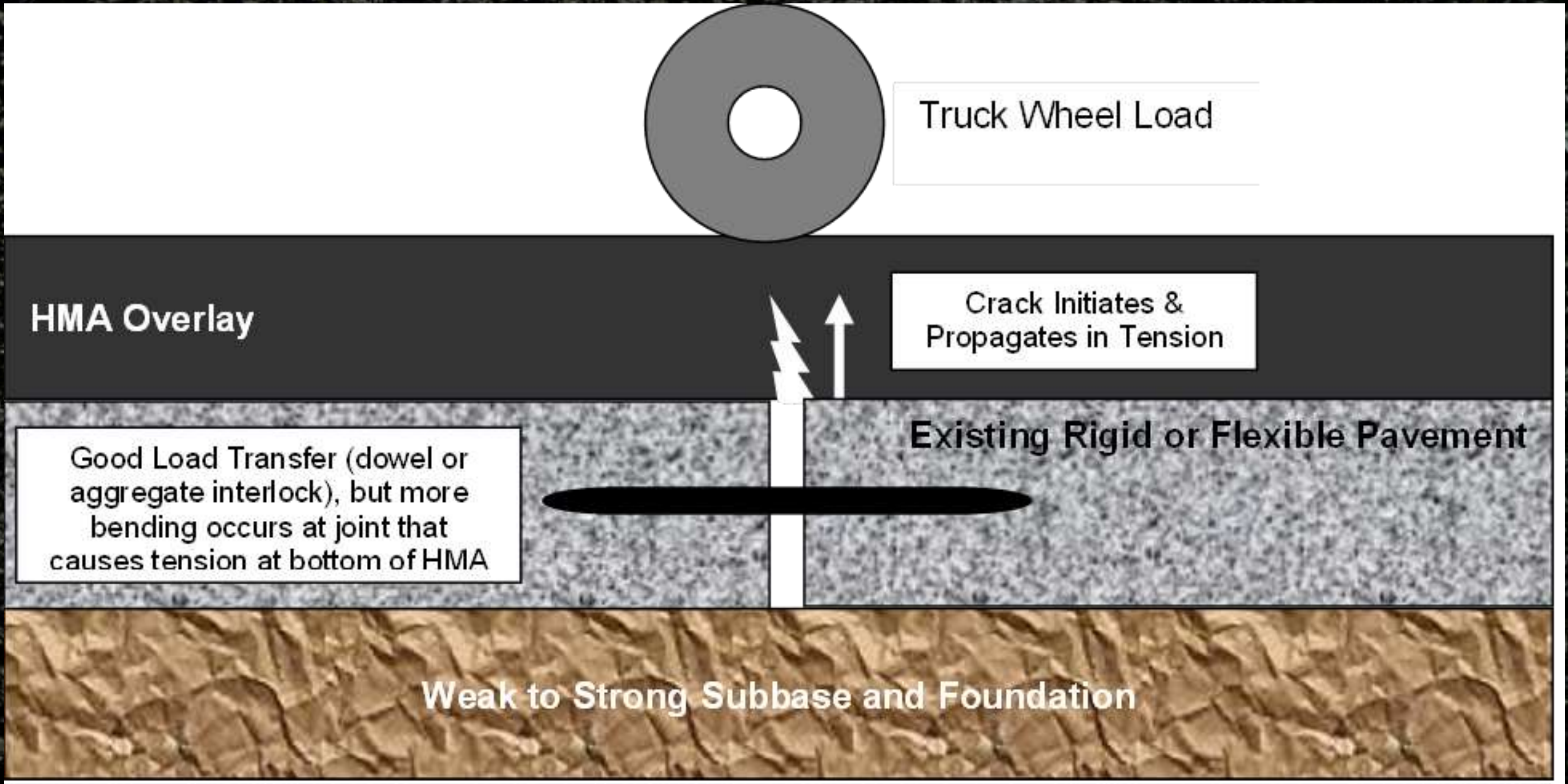


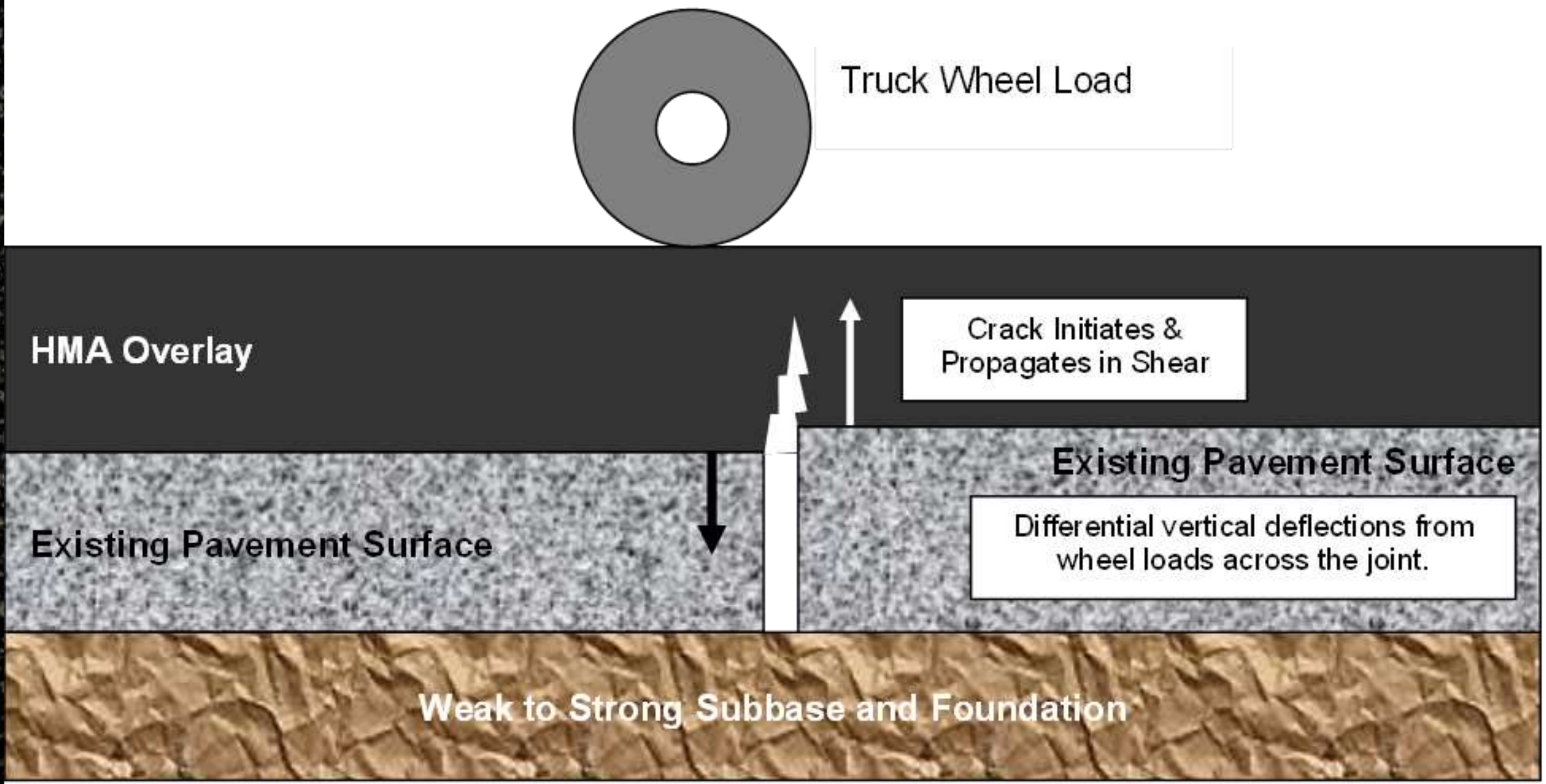
Figure 5.6b. Mechanisms of Thermally Induced Reflective Cracks of HMA Overlays

Bending Response Mechanism



Bending Response Mechanism

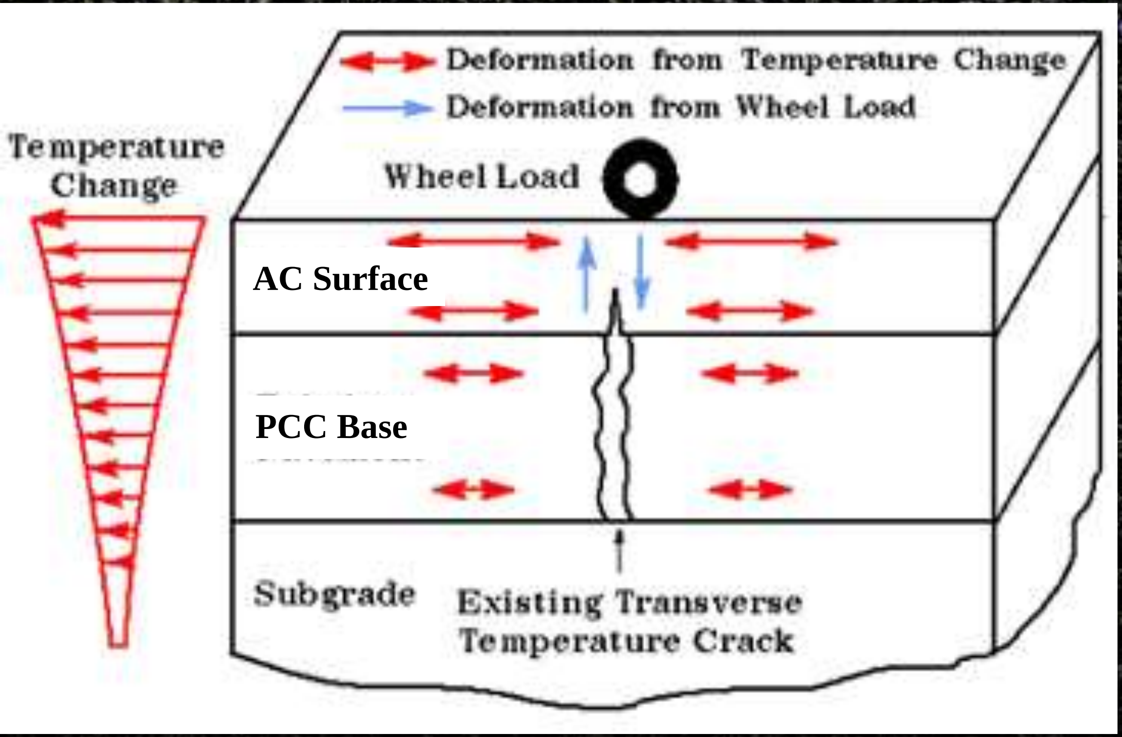
Share Response Mechanism



Shear Response Mechanism

Reflection Cracking - Observations

- From calibration, shear is significantly more critical than for the bending and tensile mechanisms.



Reflection Cracking Prediction Process

Define layer properties subjected to bending, shear & thermal stresses.

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Generate stress intensity factors for specific rehabilitation strategy.

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Characterize existing transverse cracks and fatigue cracks.

→

Calculate damage increments & crack propagation from three mechanisms.

↓

Predict total transverse & fatigue cracks.

MEPDG Cracking: Summary

Cracking Designation	Status
Bottom-Up	• No changes or enhancements; none planned for the short-term
Top-Down	• No changes to date; changes anticipated (NCHRP 1-52)
Transverse (Low Temp)	• No changes to date; need for changes identified (long-term)
Reflection	• Major enhancements in Version 2.2 *(replaced regression with M-E)*

References

- Harold Von Quintus' presentation
- ME Design v2.2 Training Webinar
  - http://me-design.com/MEDesign/Webinars.html
- Phone conversations with Dr. Robert Lytton
- MEPDG: A Manual of Practice, 2nd Ed

Questions?

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