Modeling and Mitigation of Thermal-Induced Reflective Cracking in Asphalt Concrete Overlay

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INTRODUCTION

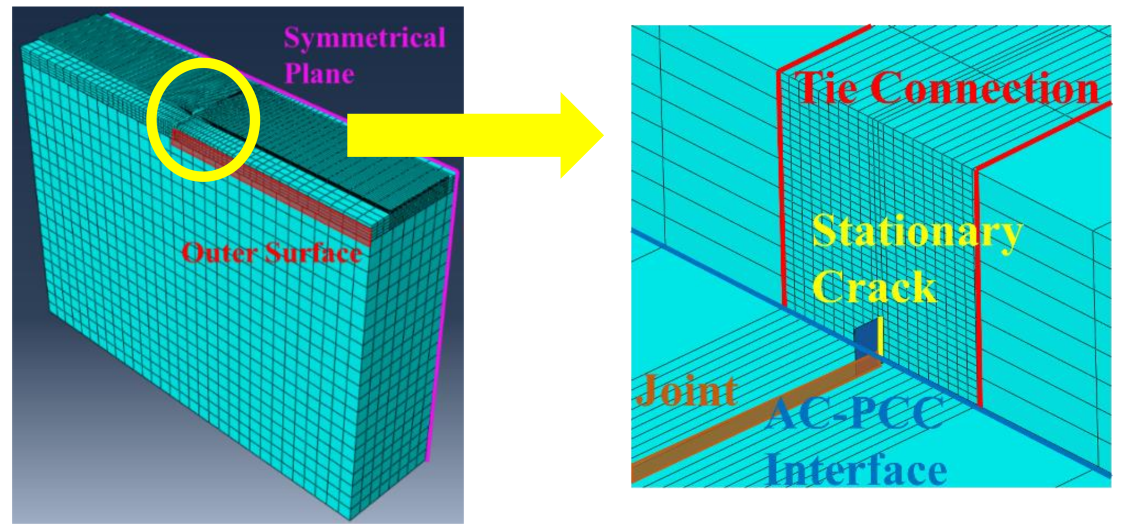
- Asphalt concrete (AC) overlay is an efficient and effective method to rehabilitate deteriorated rigid pavements and restore structural capacity
- The diurnal and seasonal temperature cycles generate contraction and curling effect in the underlying concrete slabs, tearing apart AC overlay gradually
- Reflective cracking belongs to the category of fatigue cracking, which can be studied by fatigue model methods and mechanistic methods
- Commonly used mitigation strategies including increasing overlay thickness, stress-absorbing interlayer, geosynthetic etc.

OBJECTIVE

- Developing finite element (FE) models to simulate thermal-induced reflective cracking in asphalt concrete overlay
- Predicting crack initiation and propagation by stress-based fatigue model and Paris' law
- Analyzing the effectiveness of two mitigation methods, increasing overlay thickness and applying stress-absorbing interlayer

METHODOLOGY

- FE models for pavement responses
  - Displacement-controlling loading model
  - Real thermal loading model



- Cracking Initiation:

$$N_f = \left(\frac{S_v}{\sigma}\right)^n$$ Stress-Based Fatigue Model

Derived from low-temperature and low-frequency bending fatigue tests (Lv et al, 2017)

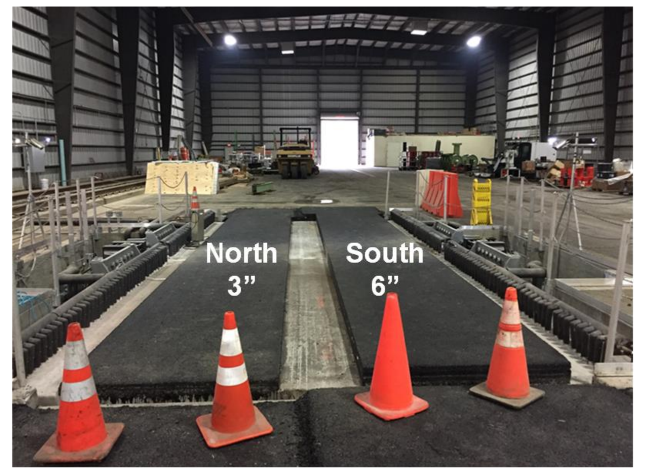
- Cracking Propagation:

$$\frac{da}{dN} = A \cdot (\Delta J)^n$$ Modified Paris' law

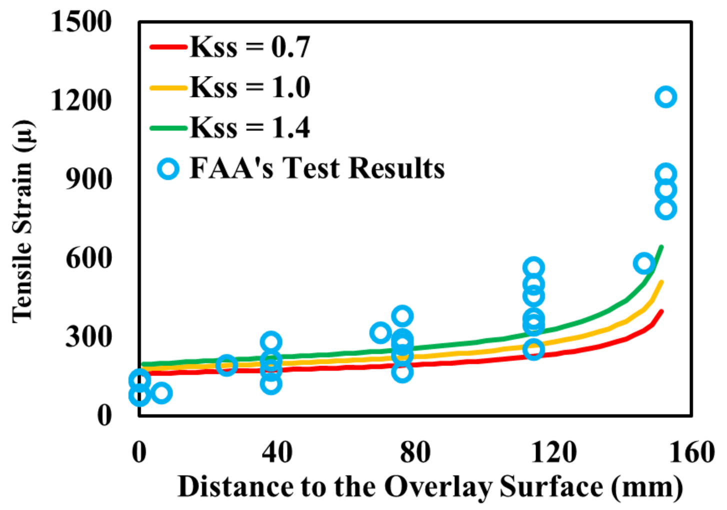
A and n are derived from material properties and loading frequency

MODEL CALIBRATION AND VALIDATION

- The derived displacement-controlled models were calibrated and validated with field test at NAPTF
- Temperature-Effect Simulation System (TESS):
  - AC overlay, concrete slabs, subgrade
  - Overlay thickness: 3-inch and 6-inch
  - Loading: displacement-controlled slab movement
- Tensile strains along depths were used to calibrate overlay-slab interface contact stiffness:

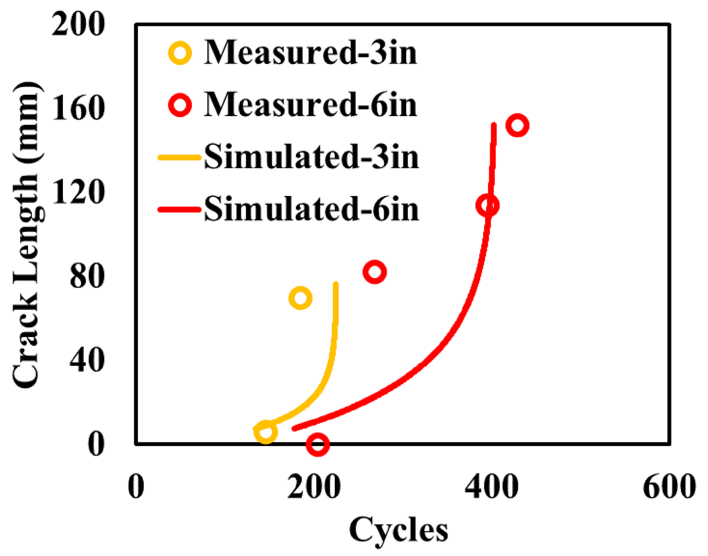


NAPTF section (Yin, 2017)



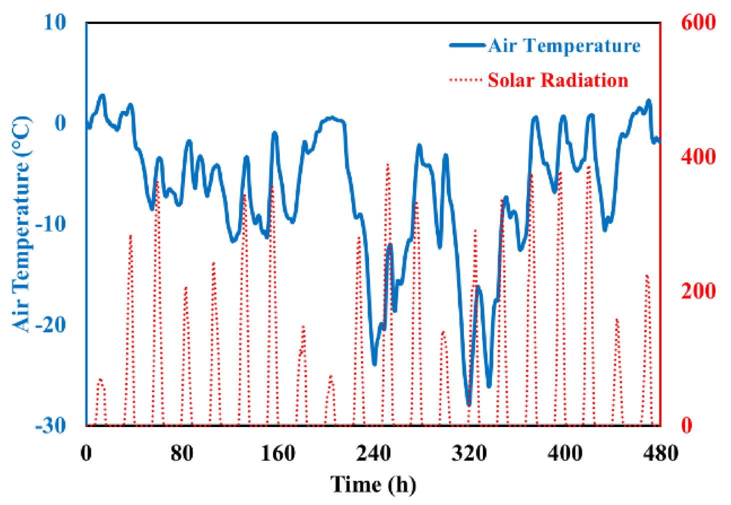
Tensile strain along depth

- The proposed model can roughly catch the trend of thermal-induced reflective cracking
- The perfect match is meaningless because of the uncertainty of fatigue process

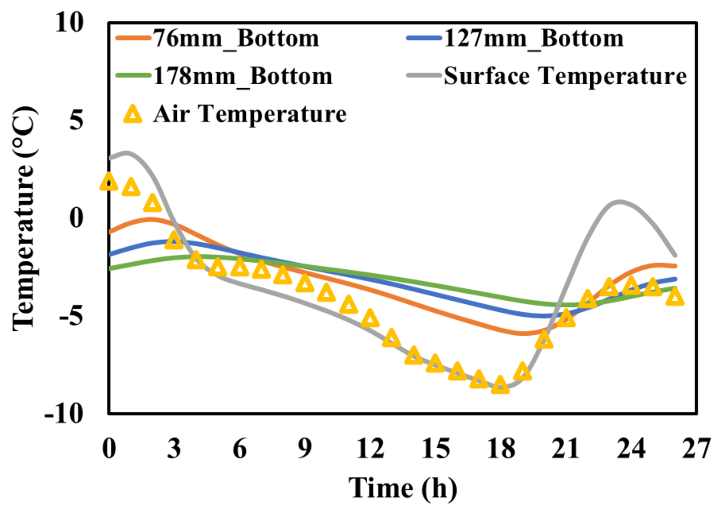


ANALYSIS OF CRACKING MITIGATION

- The derived real thermal loading model were used to analyze temperature effect and mitigation strategies
- Pavement temperature predicted from climate data
- Cooling Process: -4.1°C to -11.7°C in 14 hours

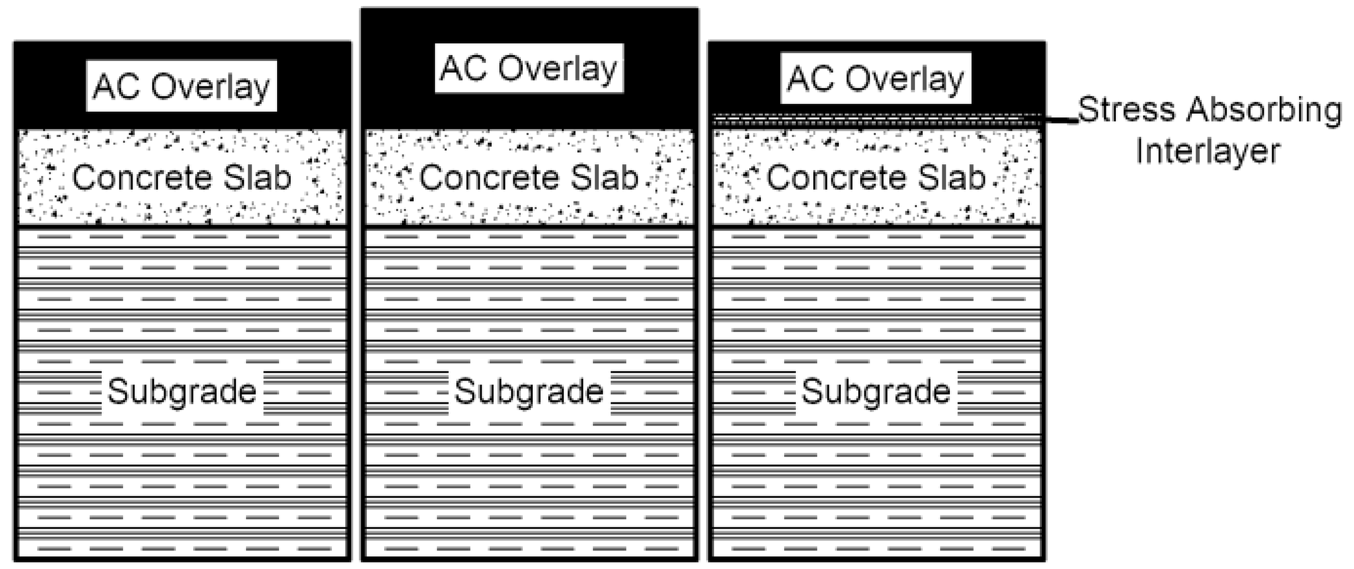


Climate inputs

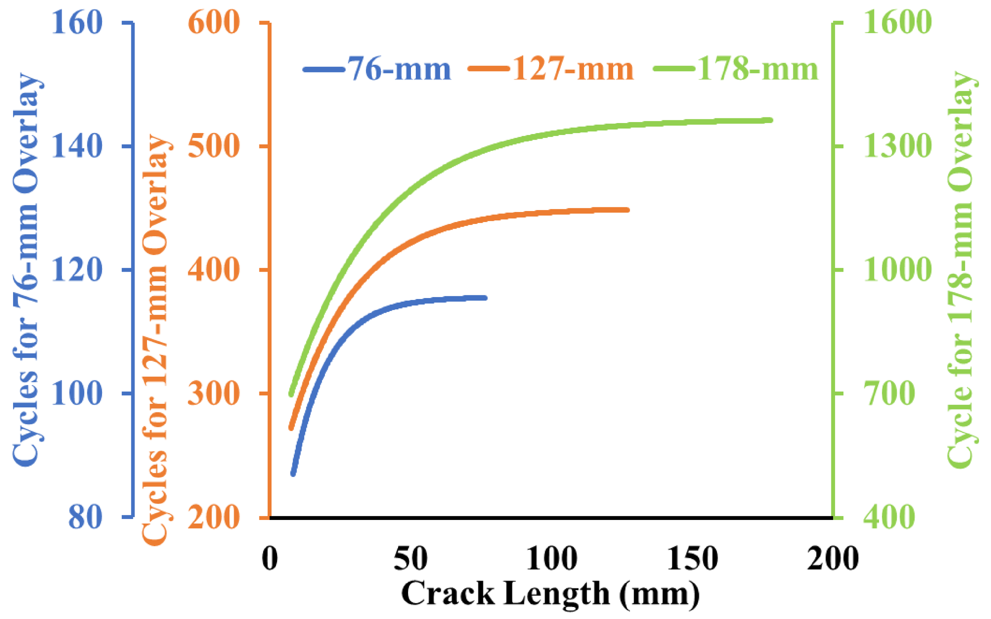


Pavement temperature

- Two mitigation strategies were considered:
  - Increasing overlay thickness (3in vs 5in vs 7in)
  - Stress-absorbing interlayer (1in at overlay bottom)

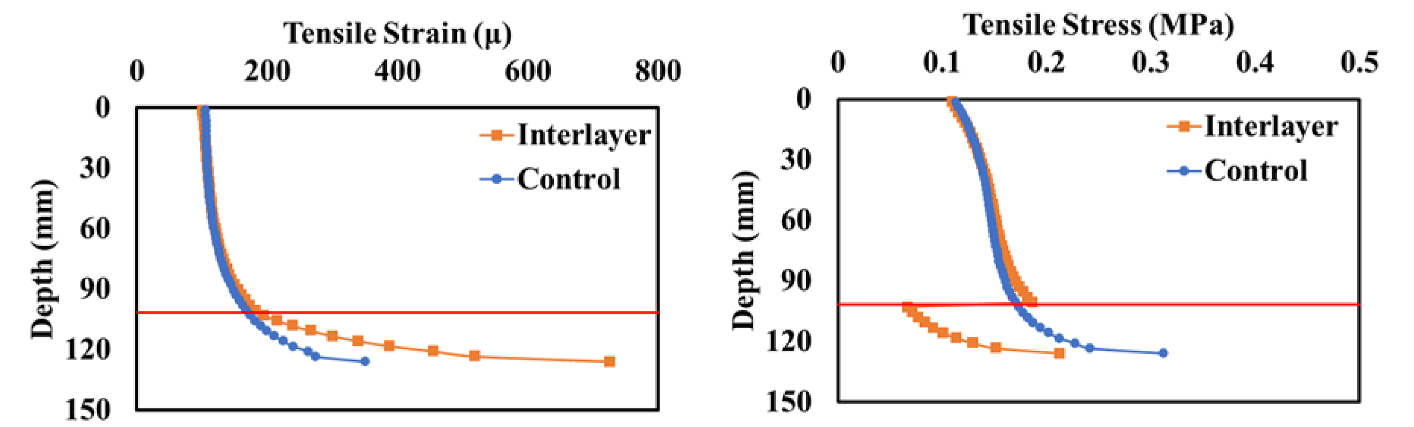


- When the thickness increases from 3-inch to 5-inch, the total cycles become 2.9 times of before.
- If the thickness increases from 5-inch to 7-inch, the total crack cycles become 2 times of before.

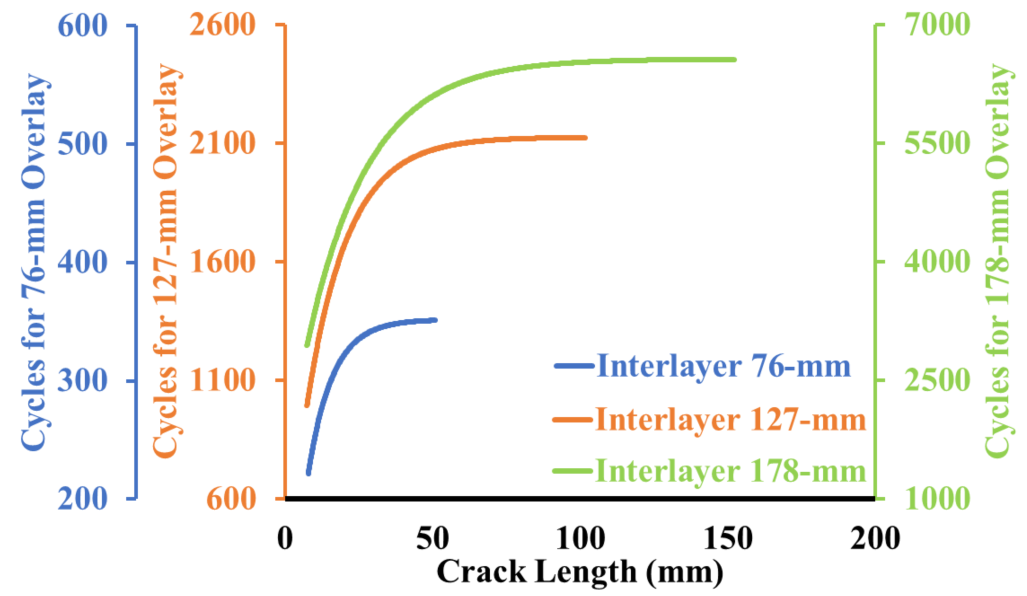


Reflective cracking cycles for control sections

- The tensile strain in interlayer is larger than the counterpart in control section, but it does not generate cracks due to higher fracture energy
- The critical stress at overlay bottom is reduced with the employment of interlayer



- For interlayer sections, the total cycle numbers that cracks reflect to the pavement surface are several times larger than those in control sections.
- For 5-inch AC overlay, increasing 2-inch overlay only gains 913 more thermal cycles, but applies 1-inch interlayer would bring 1669 more cycles.



Reflective cracking cycles for interlayer sections

Conclusions

- The developed model is feasible to capture the trend of thermal-induced reflective cracking
- Increasing overlay thickness alters the pavement temperature and further extends the crack initiation and propagation cycles, but shows less effective for thicker overlay
- Applying stress-absorbing interlayer reduces the stress concentration and alleviates the reflective cracking. Thicker overlay gains more benefits from applying interlayer