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## CORNER LOADING AND CURLING STRESS ANALYSIS OF CONCRETE PAVEMENTS

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## RESEARCH APPROACH

- Closed-Form Solutions / F. E. Model
- Characteristics of Corner Stresses
- Results of Actual Field Measurements
- Identification of Mechanistic Variables (Dimensionless)
- Corner Stress Prediction Models
- Validation of Stress Predictions



## I. CLOSED-FORM SOLUTIONS / ILLI-SLAB F. E. MODEL

• Westergaard/ Bradbury

• Corner Loading

• Thermal Curling

• Loading Plus Curling

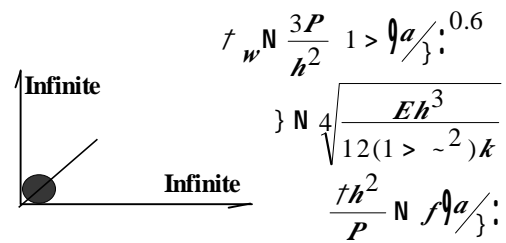
• ILLI-SLAB F. E. Model

• Dimensional Analysis

• Identification of Mechanistic Variables



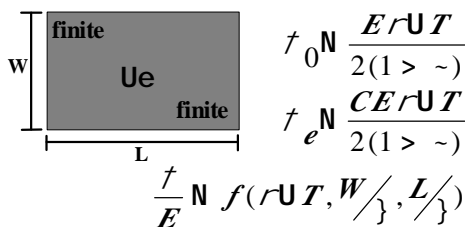
## Corner Loading



Critical Location:  $X_1 \approx 2.38\sqrt{a}$



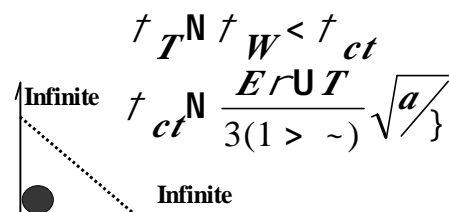
## Thermal Curling



No explicit solutions for corner stress



## Loading Plus Thermal Curling

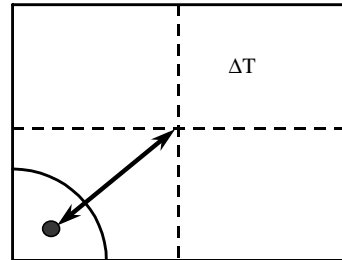


## II. CHARACTERISTICS OF CORNER STRESSES

- o Loading Only
- o Curling Only
- u Large Loading + Small Curling
- a Small Loading + Large Curling
- r Medium Loading + Medium Curling
- e Max. Combined Stress Location



## CRITICAL STRESS LOCATION



(Corner Loading Plus Curling)

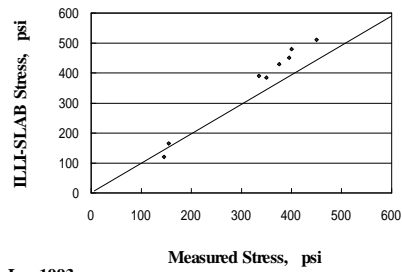


## III. RESULTS OF ACTUAL FIELD MEASUREMENTS

- IAASHO Road Test
  - o Edge Stress (Loading + Curling)
- dTaiwan a Second Northern Highway
  - o Corner Stress (Loading + Curling)
- o Compared to ILLI-SLAB Results
- o Validated Its Applicability



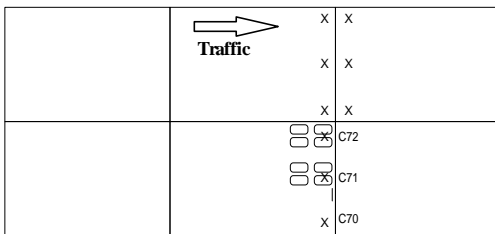
### AASHO Road Test



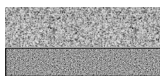
REF: Lee 1993



### Taiwan a Second Northern Highway



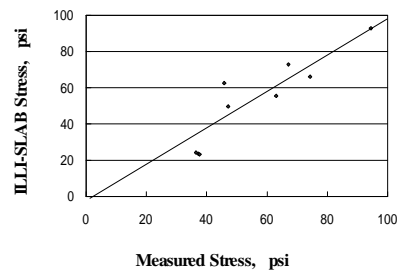
10 PCC  
6 CCB



Unbonded



### Taiwan a Second Northern Highway

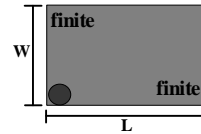


#### IV. IDENTIFICATION OF MECHANISTIC VARIABLES

HLLI-SLAB Model & Dimensional Analysis  
 Loading Only, Curling Only,  
 Loading + Curling  
 All Dimensionless Variables



#### Corner Loading

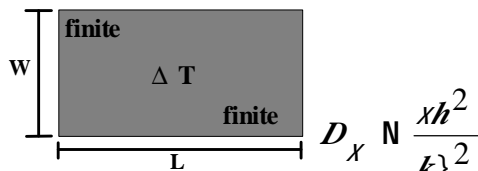


HLLI-SLAB Model:  
 Minor Principal (Tensile)  
 Stress on the Top of the Slab

$$\frac{t h^2}{P} N f \left\{ \frac{a}{\}, \frac{W}{\}, \frac{L}{\} \right\}$$



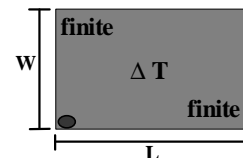
#### Thermal Curling



$$\frac{t}{E} N f \left\{ \frac{\Delta T}{\}, \frac{W}{\}, \frac{L}{\}, D_x \right\}$$



#### Loading Plus Thermal Curling



$$D_x = \frac{\alpha h^2}{k^2}$$

$$D_P = \frac{P h}{k^4}$$

$$\frac{t}{E} = f \left\{ \frac{\Delta T}{\}, \frac{a}{\}, \frac{W}{\}, \frac{L}{\}, D_x, D_P \right\}$$



#### V. DEVELOPMENT OF CORNER STRESS PREDICTION MODELS

Based on Dimensionless Variables Identified  
 Factorial F. E. Runs  
 Two-Step Modeling Approach (Lee & Darter, 1994):

Projection Pursuit Regression  
 Piece-wise Linear Regression



#### Case I : Loading Only

$$R N \frac{t}{w} i(\text{Case I})$$

$$N=84, R^2=0.98, SEE=0.0081$$

$$0.05 \leq \frac{a}{\} \leq 0.3, 2 \leq \frac{L}{\} \leq 7,$$

$$\frac{W}{\} N \frac{L}{\}$$



**Case II : Loading Plus Curling, UT=0**

$$R N \frac{f_i(\text{Case II})}{f_w}$$

$N=108, R^2=0.962, SEE=0.0096$   
 $0.05 \leq a \leq 0.3, 0.2 \leq L \leq 15,$   
 $W \leq N \leq L, 1 \leq D_x \leq 10^5 \leq 10,$   
 $2 \leq D_P \leq 10^5 \leq 130$



**Case III : Loading Plus Curling, UT<0**

$$R N \frac{f_i(\text{Case III})}{f_o} > f_i(\text{Case II})$$

$N=432, R^2=0.951, SEE=0.09$   
 $0.05 \leq a \leq 0.3, 0.2 \leq L \leq 15,$   
 $1 \leq D_x \leq 10^5 \leq 10, 2 \leq D_P \leq 10^5 \leq 130,$   
 $5.5 \leq r \leq 10^5, W \leq N \leq L$



**VI. VALIDATION**

**In-Field Testing Data**

AASHO Road Test

Taiwan - Second Northern Highway

Totally Different Sets of F.E. Runs

Based on a Wide Range of Input Parameters :

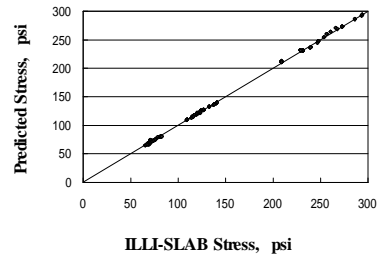
E, k, h, L, UT

Case I, Case II, Case III

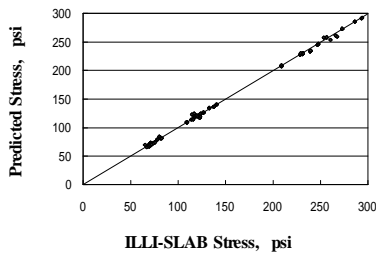
A Numerical Example



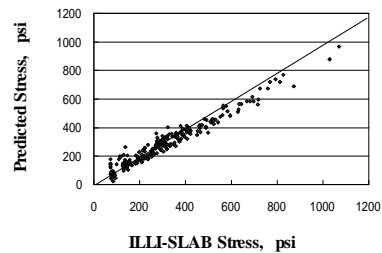
**Case I: Loading Only**



**Case II: Loading + Curling, UT=0**



**Case III: Loading + Curling, UT<0**



### A Numerical Example

*Pavement Slab:*

$E=3 \text{ Mpsi}$ ,  $k=400 \text{ pci}$ ,  $L=W=141 \text{ in.}$ ,

$h=9.97 \text{ in.}$ ,  $\chi=0.224 \text{ pci}$ ,  $\sim NA?BF$

Load:  $P=7,624 \text{ lbs}$ ,  $A=10 \times 10 \text{ in.}^2$

*Curling:*  $UeN>BA \cdot F$ ,  $a=5.5E-06 / \cdot F$

→ } N 28.21 in., a / } N 0.2, L / } N W / } N 5,  
 $D_x \text{ N } 7E > 05$ ,  $D_p \text{ N } 30E > 05$



### The Proposed Calculation Process

1. Loading Only: Case I

$$\dagger_w \times R1 = 122.3 \times 1.062 = 129.9 \text{ psi}$$

(ILLI-SLAB 129.1 psi)

2. Loading Plus Curling: Case II & III

$$\dagger_w \times R2 + \dagger_o \times R3 = 122.3 \times 1.0541 < 197.1$$

$$\times 0.139 = 142.4 \text{ psi}$$

(ILLI-SLAB 147.5 psi)



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