The 75th Annual Meeting of TRB

CORNER STRESS ANALYSIS OF JOINTED CONCRETE PAVEMENTS

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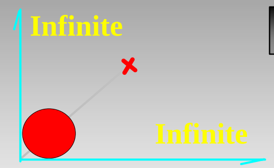
Westergaard's Corner Stress Equation

$X1 = 2.38\sqrt{al}$

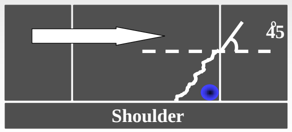
$$l = \sqrt[4]{\frac{E h^3}{12(1-\mu^2)k}}$$

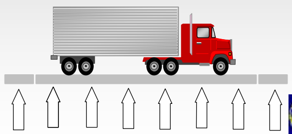


$$\sigma_c = \frac{3P}{h^2}\left[1 - \left(\frac{\sqrt{2}a}{l}\right)^{0.6}\right]$$

OBJECTIVES

- Understand Corner Stress Response under Various Loading Conditions
- Develop Stress Prediction Models
  - Fast, Accurate Computation
  - Mechanistic-Based Design Procedures





RESEARCH APPROACH

- Identify Dominating Mechanistic Variables (Dimensionless)
- Conduct Factorial F.E. Runs (ILLI-SLAB)
- Introduce Adjustment Factors (R)
- Develop Predictive Equations for R (Use Projection Pursuit Regression, PPR)
- Use Various R's and Westergaard Equations to Estimate Corner Stress
- Validation: A Case Study

ILLI-SLAB F.E. Program

- Single or Multiple Slabs
- A Fully Bonded or Unbonded Second Layer
- Load Transfer Conditions
- Thermal Curling
- Concrete Shoulder
- Loss of Subgrade Support

Dominating Mechanistic Variables

- Finite Size
- Wheel, Axle Spacing
- Widened Outer Lane
- Tied Concrete Shoulder
- Second Layer

a/l +

- L/l, W/l
- s/l, t/l
- Do/l
- AGG/kl
- $(h_{efft}/h_1)^2$

$$\frac{\sigma h^2}{P}, \frac{\delta k l^2}{P}, \frac{q l^2}{P} = f\left(\frac{a}{l}, \frac{L}{l}, \frac{W}{l}, \frac{s}{l}, \frac{t}{l}, \frac{D_0}{l}, \frac{AGG}{kl}, \left(\frac{h_{efft}}{h_1}\right)^2\right)$$

Projection Pursuit Regression

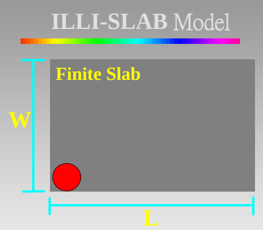
- Introduced by Friedman and Stuetzle, 1981
- Use Local Smoothing Techniques
- Projected to Several 2-D Curves
- Model the Response Surface as the Sum of Several Projection Curves

Adjustment Factors

Finite Size	R	a/l, W/l, L/l
Wheel, Axle Spacing	R	a/l, s/l, t/l
Widened Outer Lane	R	a/l, Do/l
Tied Concrete Shoulder	R	a/l, AGG/kl
Second Layer	R	a/l, (hefft/h1)^2

R

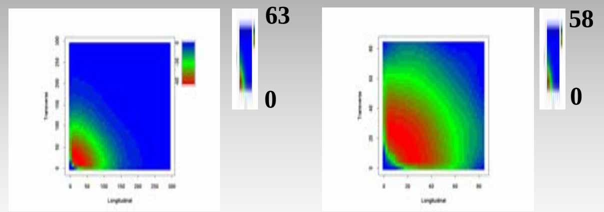
Finite Slab Size Effect



$$\frac{\sigma h^2}{P}, \frac{\delta k l^2}{P}, \frac{q l^2}{P} = f\left(\frac{a}{l}, \frac{L}{l}, \frac{W}{l}\right)$$

ILLI-SLAB Stress = Minor Principal (Tensile) Stress on the Top of Slab Corner

Corner Stress of a Large or Small Slab



L/l=7 **L/l=2**

Prediction Model - A Single Wheel Load

- **Factorial F.E. Runs**

a / l : 0.05, 0.1, 0.2, 0.3
L / l : 2, 3, 4, 5, 6, 7
W / l : 2, 3, 4, 5, 6, 7
($L / l \geq W / l$)
Total of 84 runs

$$R = \frac{\sigma_i}{\sigma_w}$$

- **Statistics:**

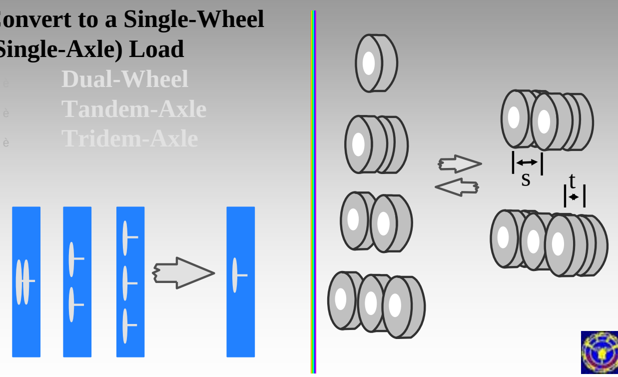
N = 84, R^2 = 0.980
SEE = 0.0081, CV = 0.79%

- **Limits:**

$0.05 \leq a/l \leq 0.3$
$2 \leq L/l \leq 7$
$W/l \leq L/l$

Effect of Wheel and Axle Spacing

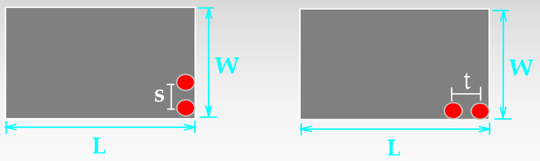
- **Convert to a Single-Wheel (Single-Axle) Load**
  - **Dual-Wheel**
  - **Tandem-Axle**
  - **Tridem-Axle**



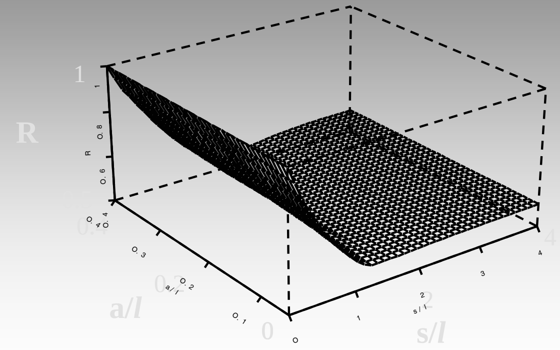
Dual-Wheel / Tandem-Axle Load

- a/l = 0.05,0.1,0.2,0.3,0.4
- s/l = 0 ~ 4.0 by 0.2 step
- $W/l = L/l$ = 10

$$R = \frac{\sigma_s}{\sigma_{s=0}}$$



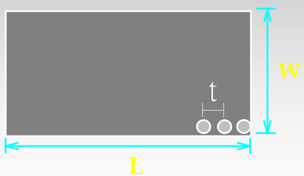
Dual-Wheel/Tandem-Axle Effect (R)



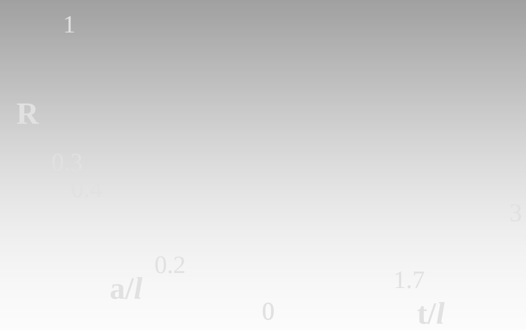
Tridem-Axle Load

- a/l = 0.05,0.1,0.2,0.3,0.4
- t/l = 0 ~ 4.0 by 0.2 step
- $W/l = L/l$ = 10

$$R = \frac{\sigma_t}{\sigma_{t=0}}$$



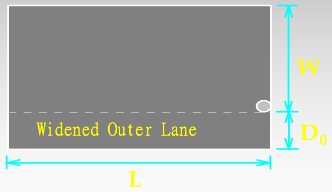
Tridem-Axle Effect (R)



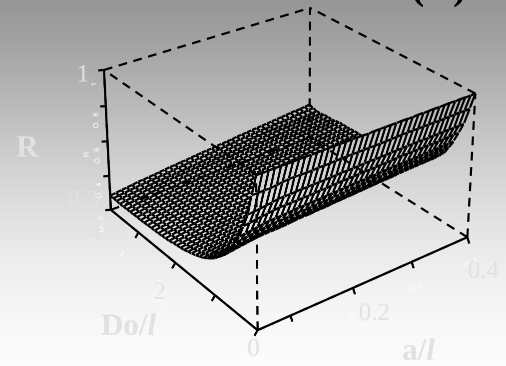
A Widened Outer Lane

- a/l = 0.05,0.1,0.2,0.3,0.4
- D_0/l = 0 ~ 4.0 by 0.2 step

$$R = \frac{\sigma_D}{\sigma_{D=0}}$$



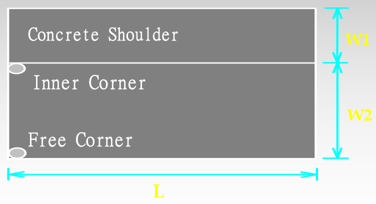
Widened Outer Lane Effect (R)



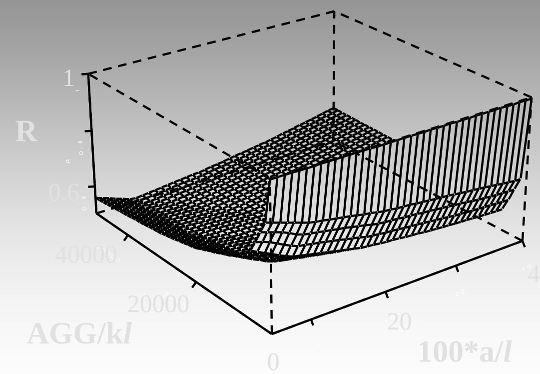
A Concrete Shoulder

- a/l = 0.05, 0.1, 0.2, 0.3, 0.4
- AGG/kl = 0, 5, 50, 500, 5000, 10000, 00

$$R = \frac{\sigma_{AGG}}{\sigma_{AGG=0}}$$



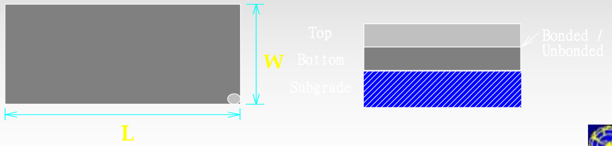
Concrete Shoulder Effect (R)



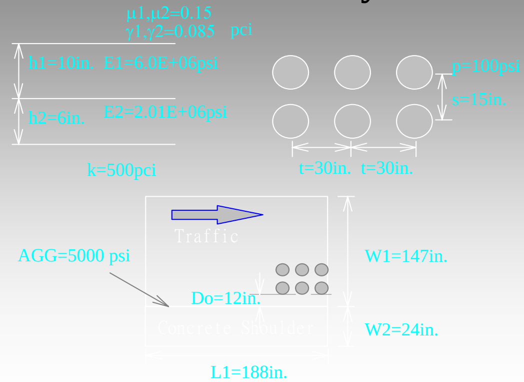
A Second Layer (Unbonded)

- a/l=0.05,0.1,0.2,0.3,0.4
- (hefft/h1)^2=1 ~ 2.0 by 0.1 step

$$h_{efft} = \left[h_1^2 + h_2^2 \left(\frac{E_2 h_2}{E_1 h_1} \right) \right]^{0.5}$$



Validation: A Case Study



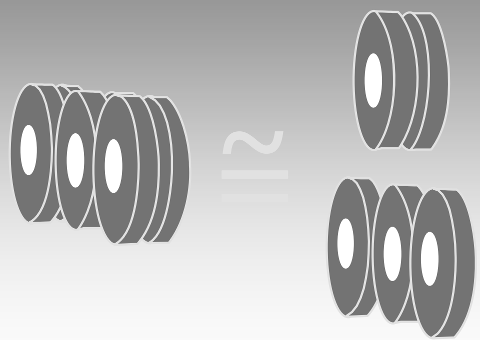
The Proposed Calculation Process

Finite Size	R=1.03	*a/l,W/l,L/l*
Gear Config.	R=0.30	*a/l,s/l,t/l*
Widen Outer Lane	R=0.67	*a/l,Do/l*
Concrete Shoulder	R=0.97	*a/l,AGG/kl*
Second Layer	R=0.94	*a/l,(hefft/h1)^2*

Westergaard 810 psi X **R=0.188** = **153 psi**

(ILLI-SLAB 145 psi)

Gear Configurations



Conclusions

- Analyzed Various Loading Conditions on JCP Corner
  - Finite Slab Size Effect
  - Different Gear Config. (Dual, Tandem, Tridem)
  - A Widened Outer Lane
  - A Concrete Shoulder
  - A Second Layer
- Corner Stress Adjustment Factors (Stress Reduction)

Recommendations

- Further Validations with In-field Testing Data
- Lab. Model Testing Based on the Dominating Variables Identified
- Effects of Adjacent Slabs (Doweled/Nondoweled), Thermal Curling
- User-Friendly Computer Program for Instant Stress Calculations
- Effects of Dynamic Loading, Nonlinear Material Properties

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