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MODIFIED PCA STRESS ANALYSIS AND THICKNESS DESIGN PROCEDURES

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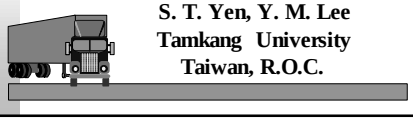
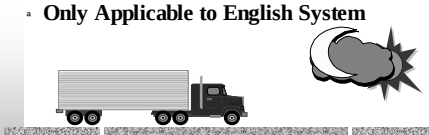


LIMITATIONS OF PCA THICKNESS DESIGN PROCEDURE

- Did NOT Consider Curling Stresses
- Limited to Fixed Gear Configurations
- Only Applicable to English System



OBJECTIVES

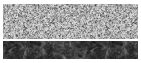
- Modify PCA Stress Analysis & Thickness Design Procedure
- Develop a User-friendly TKUPAV Program for Automatic Stress Calculation & Thickness Design
- Applicable to Metric & English Systems

RESEARCH APPROACH

- Review PCA Thickness Design Procedure
- Effects of Curling & Warping
- Modified PCA Stress Analysis and Thickness Design Procedure
- Development of TKUPAV Program
- Validation of TKUPAV Program
- Conclusions and Recommendations

PCA THICKNESS DESIGN

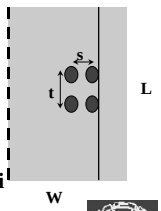
- J-SLAB Program (Edge Stress)
- Equivalent Stress Calculations
- Fatigue Analysis (& Erosion Analysis)
- But Did NOT Consider Curling Stress
- PCAPAV Program



$$D_f = \sum_{i=1}^{m} \frac{n_i}{N_i}$$

PCA Simplifications & Limitations

- Fixed Slab Size:
  L=180 in., W=144 in.
- Fixed Gear Configurations:
  a=4.72 in., t=50 in., s=12 in.
  (Axle Width D=72 in.)
- Fixed Material Properties:
  E=4 Mpsi, «=0.15, AGG=25,000 psi



PCA Equivalent Stress Calculation

$$\sigma_{eq} = \frac{6M_e}{h^2} \bullet f_1 \bullet f_2 \bullet f_3 \bullet f_4$$

$M_e = f(\alpha, k)$ (in English System)

SA/NS , TA/NS , SA/WS , TA/WS

PCA Fatigue Analysis

$$\begin{cases} \log N_f = 11.737 - 12.077 \times SR & SR \geq 0.55 \\ N_f = \left(\dfrac{4.2577}{SR - 0.4325}\right)^{3.268} & 0.45 < SR < 0.55 \\ N_f = \text{Unlimited} & SR \leq 0.45 \end{cases}$$

$SR = \sigma / S_c$, N_f = Allowable Load Repetitions

EFFECTS OF CURLING & WARPING

- Thermal Curling Stress (Positive αT => Additional Stress)
- Moisture Warping Stress (Negative αM => Stress Reduction) (But Not Easy to Measure)
- Suggest to Include the Effect of Positive αT

MODIFIED PCA STRESS ANALYSIS & THICKNESS DESIGN PROCEDURES

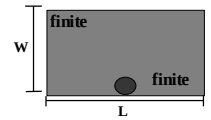
- ILLI-SLAB F.E. Program
- Identification of Mechanistic Variables (Dimensionless)
- Development of Stress Prediction Models
- Modified Equivalent Stress Calculation
- Modified PCA Fatigue Analysis & Thickness Design Procedures

ILLI-SLAB Program

- Originally Developed by Tabatabaie , 1977
- Continuously Revised by Wong, Conroyd, Ioannides , 1980-1985
- Included Curling Analysis by Korovesis, 1986-1989
- Re-Compiled by Lee, 1995 (Microsoft FORTRAN PowerStation)

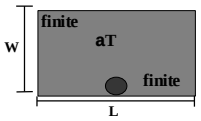
Identification of Mechanistic Variables (Loading Only)

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



Identification of Mechanistic Variables (Loading + Curling)

$$\frac{\sigma}{E}, \frac{\alpha h}{a^2}, \frac{qh}{k a^2} = f\left(\frac{a}{a}, \Delta T, \frac{L}{a}, \frac{W}{a}, \frac{\mu h^2}{k a^2}, \frac{Ph}{k a^4}\right)$$



Development of Stress Prediction Models

- Factorial F.E. Runs Based on the Dimensionless Mechanistic Variables
- Two-Step Modeling Approach
  - Projection Pursuit Regression (PPR)
  - Piece-wise Linear Regression
- S-PLUS Statistical Package
- Lee & Darter (TRR 1449)

Modified Equivalent Stress Calculation (I)

$$\sigma_{eq} = \left(\sigma_W \cdot R_1 \cdot R_2 \cdot R_3 \cdot R_4 \cdot R_5 + R_T \cdot \sigma_C\right) \cdot f_3 \cdot f_4$$

Modified Equivalent Stress Calculation (II)

$$\sigma_W = \frac{P}{h^2} \times f_1\left(\frac{a}{a}\right)$$

$$\sigma_C = \frac{1}{2} E \alpha \Delta T \times f_2\left(\frac{W}{a}\right)$$

$R_1 \sim R_5, R_T$ = Prediction Models

Modified Fatigue Analysis & Thickness Design Procedures

- Calculate Expected Load Repetitions (ni)
- Calculate Modified Equivalent Stress (σ_{eq}) (1) Loading Only; (2)Loading + Curling ($\Delta T>0$)
- Calculate Stress Ratio (σ_{eq}/Sc) & Determine Max. Allowable Load Repetitions (Ni)
- Check Cumulated Fatigue Damage p=(ni/Ni) < 100%
- Repeat Previous Steps, If Necessary

DEVELOPMENT OF TKUPAV PROGRAM

- Using Visual Basic Program (Ver. 4.0)
- Highly User-Friendly Interfaces
- Basic Features of TKUPAV Program
  - Different Slab Size, Axle Configurations, Material Properties, Temperature Differentials
  - Metric and English Systems
  - English & Chinese Versions

TKUPAV Example Input Screens

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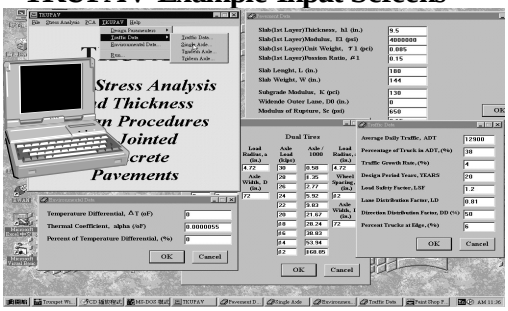
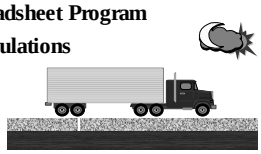


TKUPAV PROGRAM VALIDATION

- Comparing the Results of PCAPAV, TKUPAV, and a Spreadsheet Program
- Equivalent Stress Calculations
  - TKUPAV / PCAPAV
- Fatigue Analysis
  - Loading Only
  - Loading + Day-time Curling

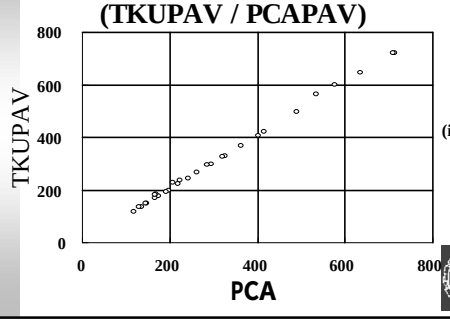


A Case Study for Validation

Single Axle		Tandem Axle	
Load, kips	Axles/1000 Trucks	Load, kips	Axles/1000 Trucks
30	0.58	52	1.96
…	…	…	…
12	168.85	16	124.69

Basic Assumptions: Same as PCA Method

Comparison of Equivalent Stress (TKUPAV / PCAPAV)



Fatigue Analysis for Loading Only

Axle Load	Fatigue (%)	
	PCAPAV	TKUPAV
Single	61.4	70.5
Tandem	2.0	0.9
Sum =	63.4	71.4

Fatigue Analysis for Loading + Day-time Curling

Axle Load	TKUPAV Fatigue (%)		
	90% Load Only	10% Load + Curling	Total
Single	63.4	128.9	192.3
Tandem	0.8	9.8	10.7
Sum =	64.2	138.8	203.0

CONCLUSIONS AND RECOMMENDATIONS (I)

- Modified PCA PEquivalent Stress Calculation & Fatigue Analysis
- Expanded PCA Thickness Design for:
  - Different Slab Size, Axle Configurations, Material Properties, Temperature Differentials
  - Metric and English Systems
- Developed a Highly User-Friendly TKUPAV Program

CONCLUSIONS AND RECOMMENDATIONS (II)

- Illustrated the Effect of Loading + Curling Should be Considered
- Night-time Curling May Be Included, If Desired (Lee & Darter, TRR 1449)
- Further Verifications & Trial Applications
- Other Features of TKUPAV Program: Edge, Corner, Interior Stress Analysis (To Be Published ...)

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THANKS FOR YOUR ATTENTION!

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