2nd International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control

Parameter Study of Load Transfer and Curling Effects on Rigid Pavement Deflections

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Problem Statements

- Extensive re-backcalculation analysis of LTPP test sections indicated extremely difficulties in interpreting in situ rigid pavements deflection data exist
- ➔Probably due to temperature curling, moisture warping and loss of subgrade support
- ➔Objectives: study the effects of adjacent slabs and temperature curling on rigid pavement deflections

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Research Approach

- Literature Review
  - Various backcalculation analyses
  - Theoretical closed-form equations, FE solutions
- Modification and Validation of FE Program
- Effects of Temperature Curling
  - Additional controlling dimensionless variables
- Effects of Adjacent Slabs
- Deflection Databases & Adjustment Factors
- On-going Development & Future Directions

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Various Backcalculation Analyses

- **AREA Concept**
- **Closed-form Procedures**
  - **ILLI-BACK (Ioannides 1989, 1990)**
  - **NUS-BACK (Li, Fwa, 1997, 1998)**
- **Regression Models**
  - **Hall (1991); AASHTO (1993)**
- **Modified Deflection Ratio Procedures**
  - **Lee (1997,1998)**
- **Extensive Re-backcalculation Analysis of LTPP GPS Test Sections (1997)**

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Closed-Form Deflection Equations

- Losberg (1960)
  - Dense Liquid & Elastic Solid Foundations
- Maximum Deflections
  - Winkler Foundation
    - Interior, Edge, and Corner (Westergaard)
  - Elastic Solid Foundation
    - Interior (Losberg, 1960)
    - Edge and Corner: regression models (Crovetti, 1994)

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Modification and Verification of F.E. Program

- ILLI-SLAB F.E. Solutions (Korovesis, 1990)
  - Workstation Version ➔ PC Version
  - Microsoft FORTRAN PowerStation Software (1994)
  - Winkler Foundation: L + C Analysis is OK!
- Sheu (1999)
  - Debug Some Syntax Errors
  - Elastic Foundation: L + C Analysis is Possible!
  - Verified Numerically and Graphically Through Extensive Structural Response Investigations

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Parameter Study of Temperature Curling Effect

- Westergaard (1926)
  - Did NOT Explicitly Consider Self-Weight
- ILLI-SLAB (Korovesis, 1990)
  - Include Self-Weight and Loss of Subgrade Support
- Lee & Darter (1994)
  - Two Dimensionless Variables (D_p and D_γ) Identified for L+ C Analysis on Winkler Foundation

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Loading + Curling Analysis on Winkler Foundation

- Concise Structural Response Relationships
  - All Dimensionless Parameters

$$\frac{\sigma}{E}, \frac{\delta h}{\ell^2}, \frac{qh}{k\ell^2} = f\left(\frac{a}{\ell}, \alpha\Delta T, \frac{L}{\ell}, \frac{W}{\ell}, D_\gamma, D_P\right)$$

$$D_\gamma = \frac{\gamma h^2}{k\ell^2}$$

$$D_P = \frac{Ph}{k\ell^4} = 12(1-\mu^2)\frac{P}{Eh^2}$$

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Two Additional Dimensionless Variables Identified for Elastic Foundation

- **Relative Deflection Stiffness due to Slab Self-Weight & Loss of Subgrade Support**

$$D_{\gamma e} = \frac{\gamma h^2}{E_s \ell_e}$$

- **Relative Deflection Stiffness due to External Wheel Load & Loss of Subgrade Support**

$$D_{Pe} = \frac{Ph}{E_s \ell_e^3}$$

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Verification of Dimensionless Variables

- **Self-Weight & Curling**
  - **Numerically Verified (16 ILLI-SLAB Runs)**

$$\frac{\delta h}{\ell_e^2} = f\left(\alpha\Delta T, \frac{L}{\ell_e}, \frac{W}{\ell_e}, D_{\gamma e}\right)$$

- **Loading & Curling**
  - **Numerically Verified (16 ILLI-SLAB Runs)**

$$\frac{\delta h}{\ell_e^2} = f\left(\frac{a}{\ell_e}, \alpha\Delta T, \frac{L}{\ell_e}, \frac{W}{\ell_e}, D_{\gamma e}, D_{Pe}\right)$$

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Loading + Curling Analysis on Elastic Solid Foundation

- **Concise Structural Response Relationships**
  - **All Dimensionless Parameters**

$$\frac{\sigma}{E}, \frac{\delta h}{\ell_e^2}, \frac{qh}{E_s \ell_e} = f\left(\frac{a}{\ell_e}, \alpha\Delta T, \frac{L}{\ell_e}, \frac{W}{\ell_e}, D_{\gamma e}, D_{Pe}\right)$$

$$D_{\gamma e} = \frac{\gamma h^2}{E_s \ell_e}$$

$$D_{Pe} = \frac{Ph}{E_s \ell_e^3}$$

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Parameter Study of Adjacent Slabs Effect

- **Adjacent Slabs Model in ILLI-SLAB**
  - **Only Winkler Foundation Considered**
  - **Doweled & Undoweled: Corner Loading, Transverse & Longitudinal Edge Loading**
- **Dowel-Bar Stiffness Matrix Errors**
  - **Agree with Guo, et al. (1993, 1995)**
  - **Deflection at Loaded Side (δ_L) < Unloaded Side (δ_U)**
- **➔Pure Shear Load Transfer Used in This Study**

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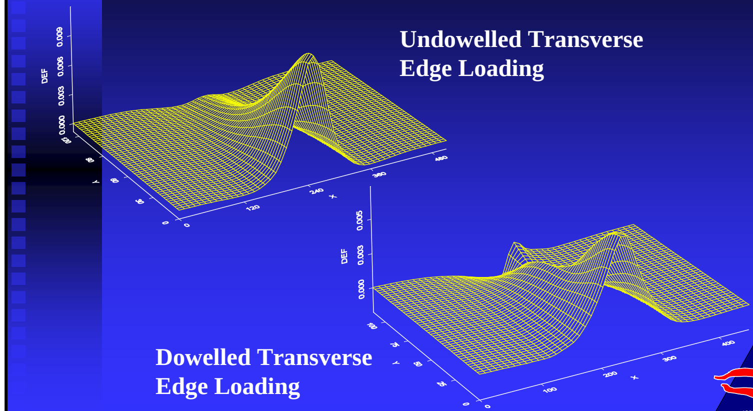
Dowel-Bar Stiffness Matrix Errors



Development of Pavement Deflection Databases

- **Finite Slab Size**

$$R_{LW} = \frac{\delta_i}{\delta_w} = f\left(\frac{a}{\ell}, \frac{L}{\ell}, \frac{W}{\ell}\right) \qquad R_{LW} = \frac{\delta_i}{\delta_{Losberg}} = f\left(\frac{a}{\ell_e}, \frac{L}{\ell_e}, \frac{W}{\ell_e}\right)$$

- **Adjacent Slabs** ← **Factorial F. E. Runs**

$$R_{LTE} = \frac{\delta_m}{\delta_s} = f(LTE_\delta)$$

- **Thermal Curling**

$$R_T = \frac{\delta_{T+P} - \delta_T}{\delta_w} = f\left(\frac{a}{\ell}, \frac{L}{\ell}, \frac{W}{\ell}, \alpha\Delta T, D_\gamma, D_P\right)$$

Adjustment of Adjacent Slabs Effect

- **Load Transfer Efficiency (LTE_δ)**
  - **Backcalculate Joint Stiffness or AGG Factor (Infinite Slab)**

$$LTE_\delta = \frac{\delta_U}{\delta_L} = \frac{1}{0.01 + 0.012\left(\frac{AGG}{k\ell}\right)^{-0.849}}$$

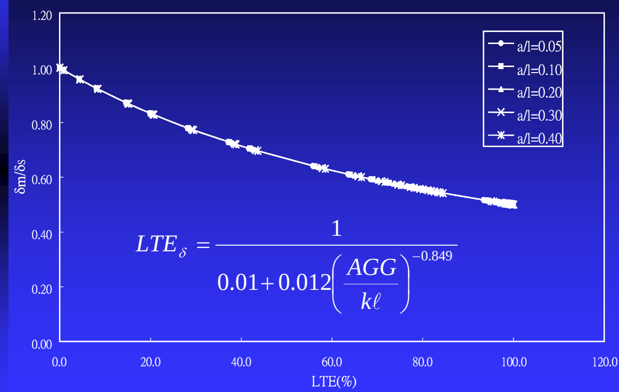
- **Deflection Adjustment Factor (R_{LTE})**

$$R_{LTE} = \frac{\delta_m}{\delta_s} = f(LTE_\delta)$$

$$R_{LTE} = 0.992127 - 0.008069961(LTE_\delta) + 0.00003178733(LTE_\delta)^2$$

  - R_{LTE} is independent of a/ℓ

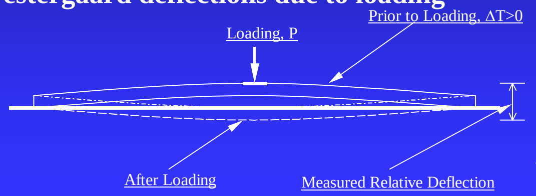
Relationship of R_{LTE} vs. LTE_δ



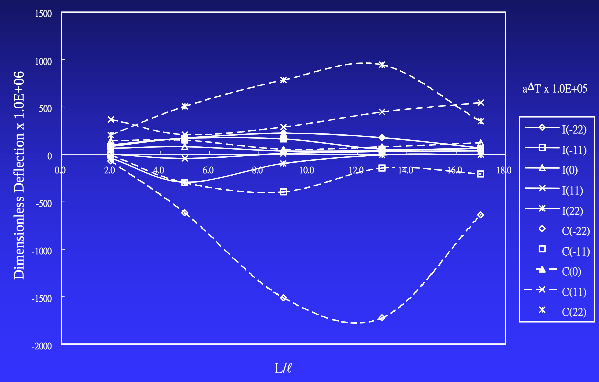
Thermal Curling: Relative Deflections

$$R_T = \frac{\delta_{T+P} - \delta_T}{\delta_w} = f\left(\frac{a}{\ell}, \frac{L}{\ell}, \frac{W}{\ell}, \alpha\Delta T, D_\gamma, D_P\right)$$

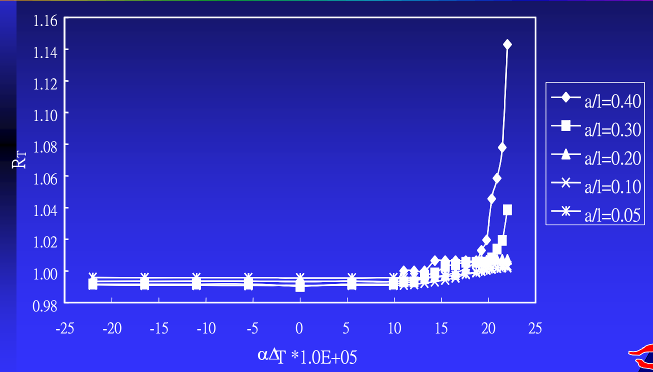
- δ_{T+P} = ILLI-SLAB deflections for loading plus curling
- δ_T = ILLI-SLAB deflections due to thermal curling
- δ_w = Westergaard deflections due to loading



Dimensionless Deflection Due to Loading and Curling



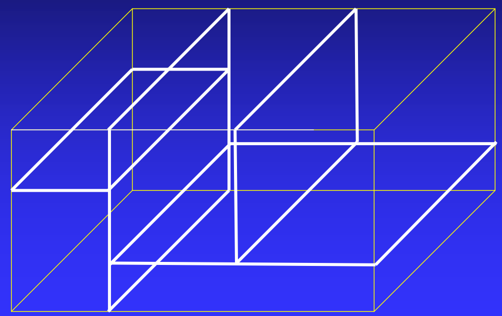
Relative Deflection Adjustment Factor Due to Loading and Curling

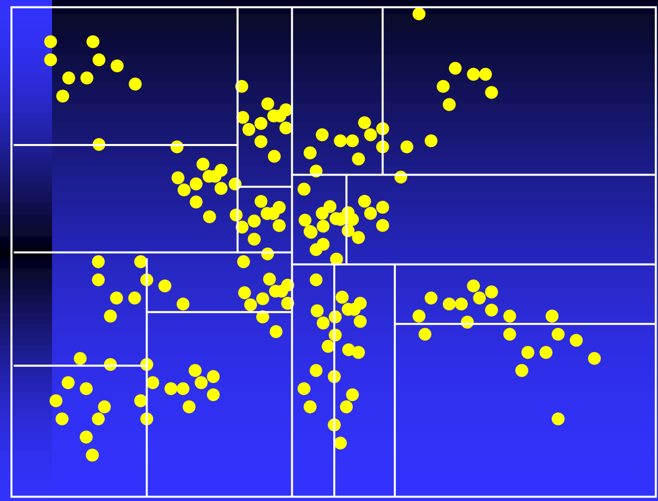


On-going Development of an Integrated Backcalculation Program

- Windows-based TKUBAK Program
  - Valid for a Single Slab and Loading Only
  - Prediction Models (Projection Pursuit Regression)
  - Closed-form Procedures: Closely Simulate ILLI-BACK Backcalculation Program
- Application of Locally-Weighted Regression (LOESS) Technique: S-PLUS Program
  - Cleveland & Devlin (1988), Cleveland & Grosse (1991)
  - Attempt to Increase the Prediction Accuracy

Illustration of Locally-Weighted Regression (LOESS) Technique





Conclusions and Recommendations

- Investigated the Effects of Adjacent Slabs & Thermal Curling on Rigid Pavement Deflections
- Debugged Some Syntax Errors in the F.E. Program
  - Workstation Version → PC Version
  - Elastic Foundation: L + C Analysis is Possible!
  - Verified Numerically and Graphically
- Identified Two Additional Dimensionless Variables ($D_{\gamma e}$ & D_{Pe}) due to L+C for Elastic Foundation
- Parameter Study of Adjacent Slab Effects

Conclusions and Recommendations

  - Dowel-Bar Stiffness Matrix Errors
  - Only Pure Shear Load Transfer Considered
- Deflection Databases & Adjustment Factors
  - Adjacent Slabs Effect
    - Deflection Adjustment Factor (R_{LTE}): R_{LTE} =f(LTE_{δ})
    - R_{LTE} is independent of a/ℓ
  - Loading & Curling Effects
    - Relative Deflection Adjustment Factor (R_T)
- On-going Development of an Integrated Back-calculation Program

THANKS FOR YOUR ATTENTION!

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