The Numerator –
From Westergaard to ISLAB: Why Finite Element Modeling Matters for Concrete Pavements

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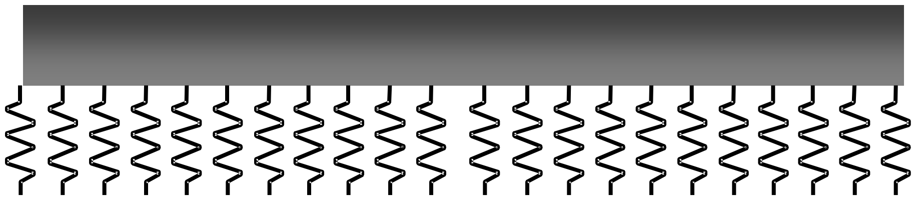
Outline

- Westergaard model & solutions
- Limitations
- Evolution of FE programs
- ISLAB2000 capabilities
- Demonstration of results
- Why ISLAB is preferred

Westergaard Model

- PCC layer: a plate
- Subgrade : Winkler foundation



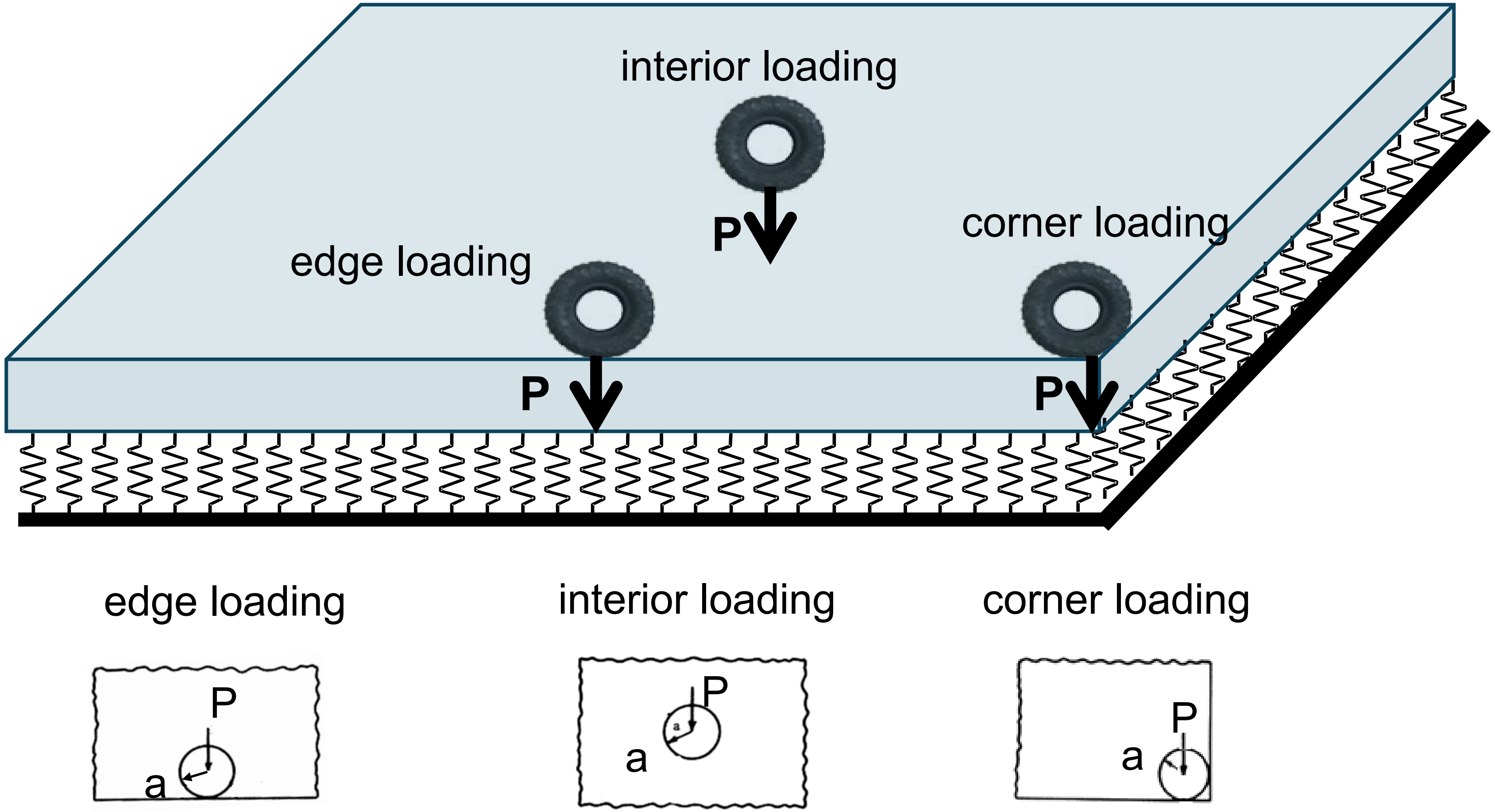
H_{PCC}, E_{PCC}, μ_{PCC}
k

$$D\nabla^4 w(x,y) + k\,w(x,y) = p(x,y)$$

$$D = \frac{E_{PCC}\,h^3_{PCC}}{12(1-\mu^2_{PCC})}$$

- Scale: radius of relative stiffness $\ell = \sqrt[4]{\frac{D}{k}}$

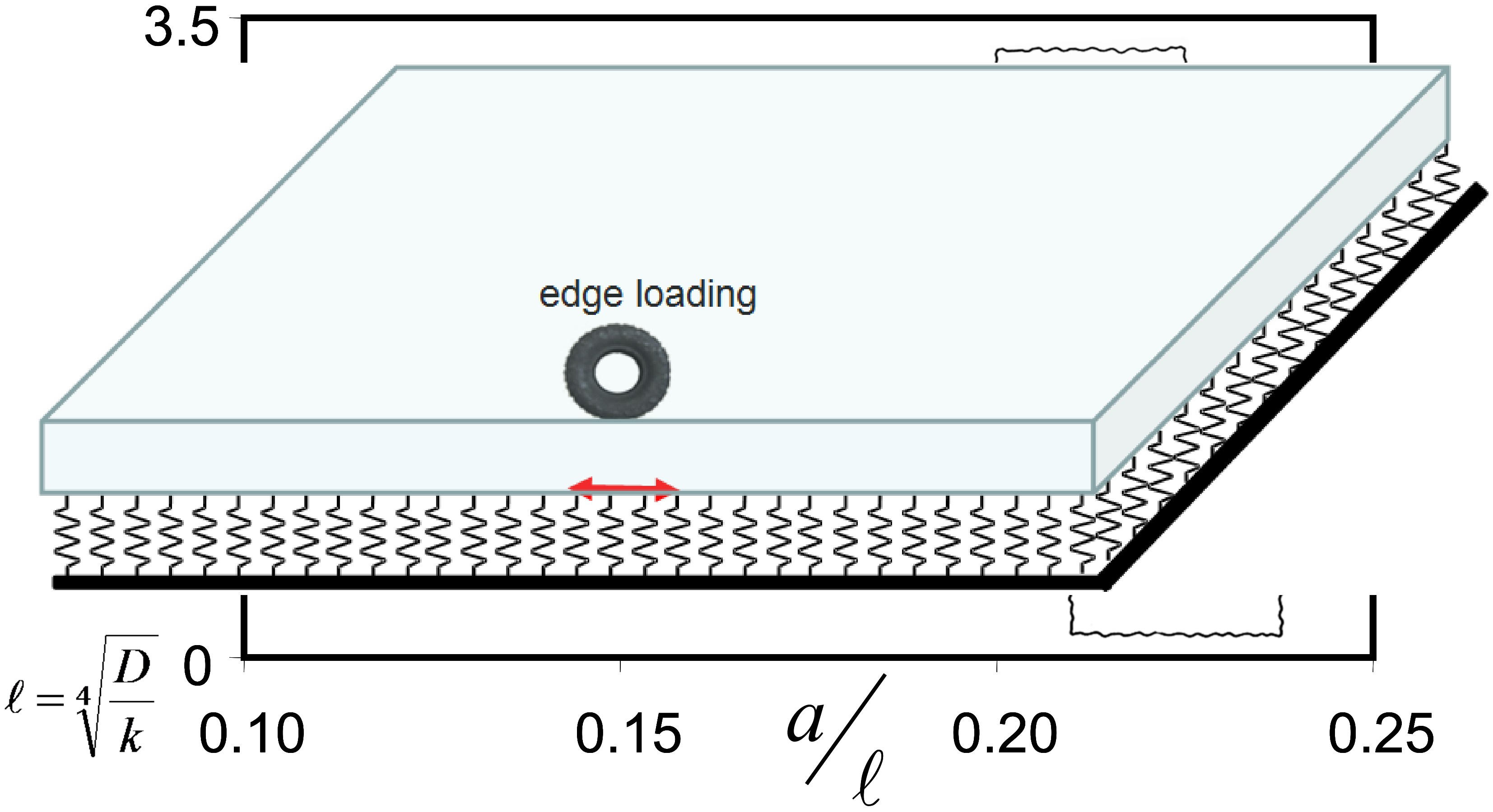
Westergaard's Solutions



a= wheel footprint radius, P = wheel load

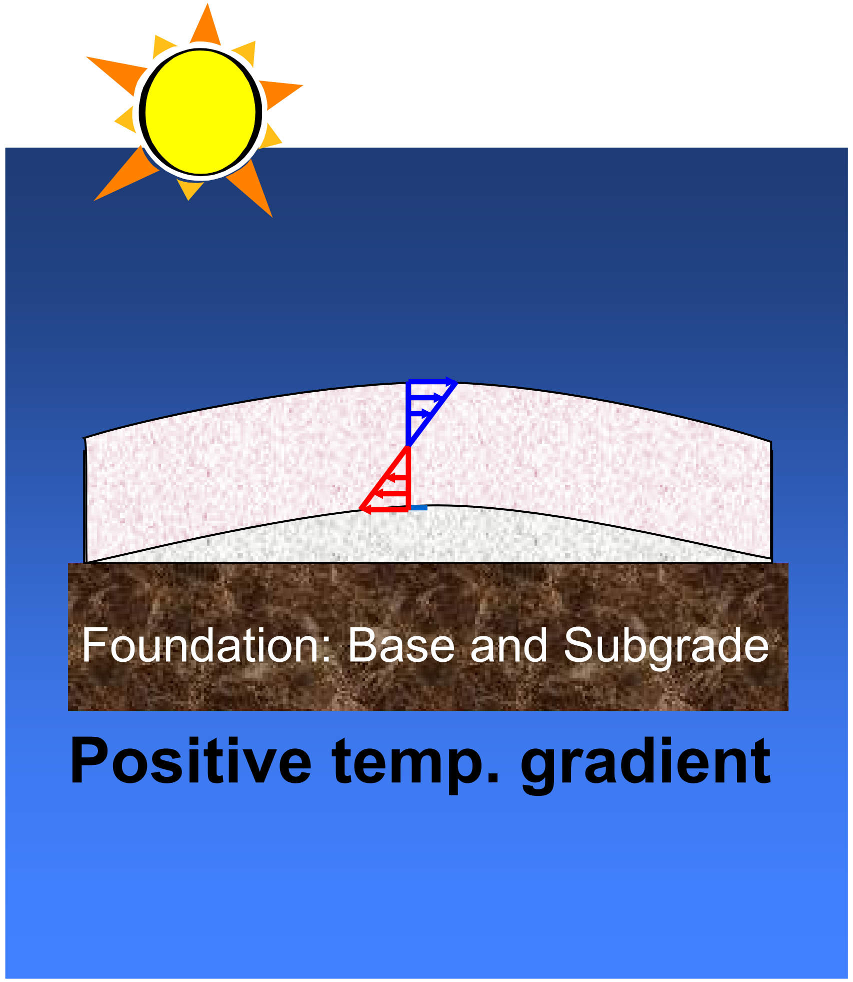
Westergaard's Solutions

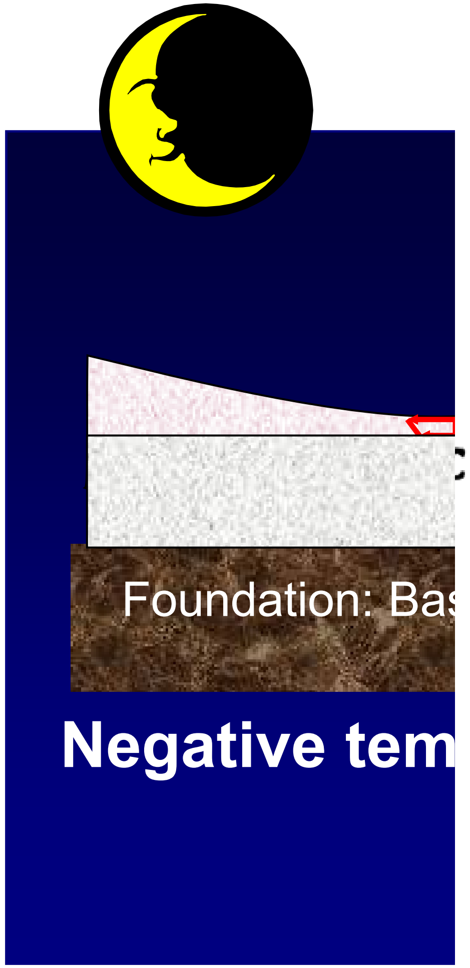
Maximum Plate Tensile Stresses

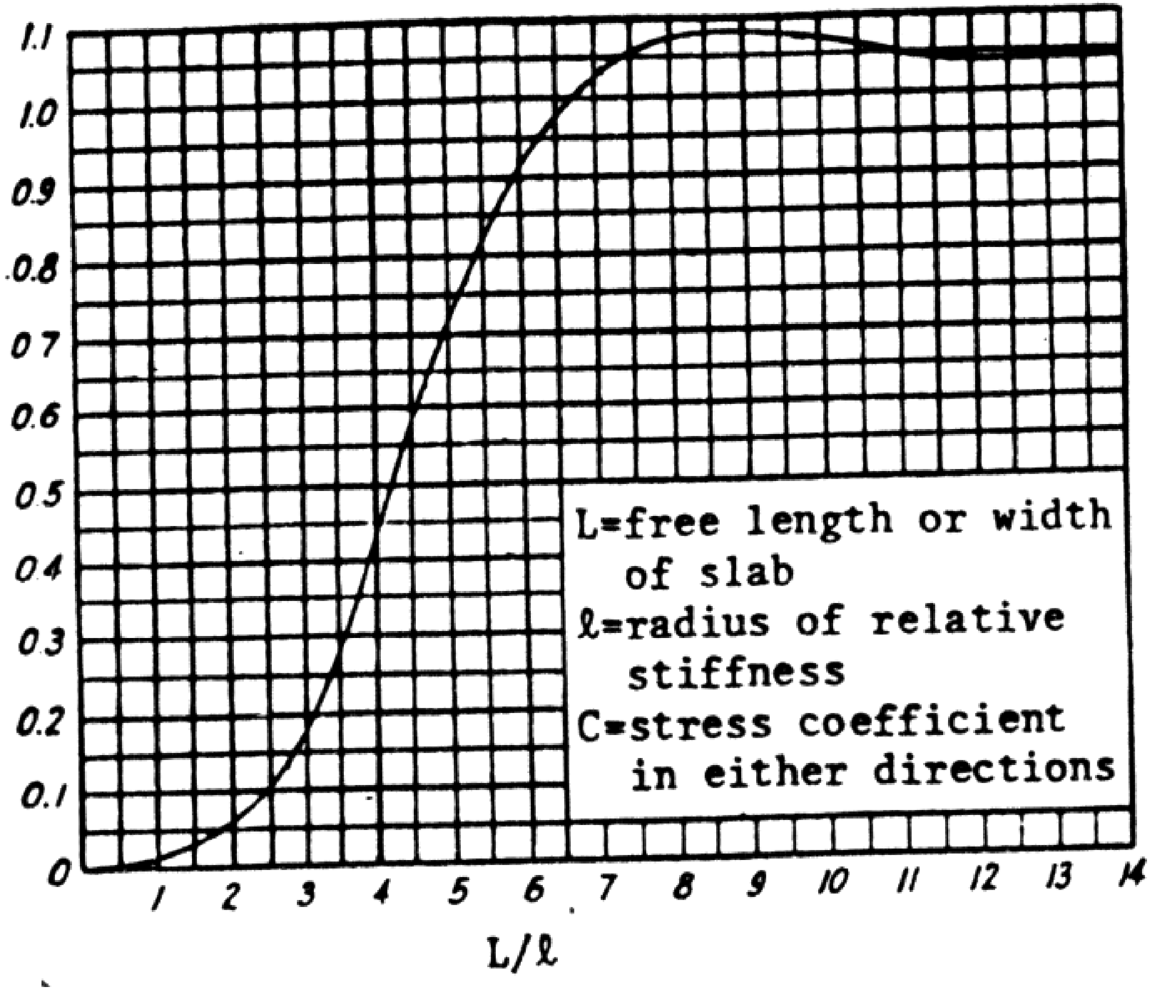


a= wheel footprint radius; P=wheel load; h = plate thickness

Curling and Warping







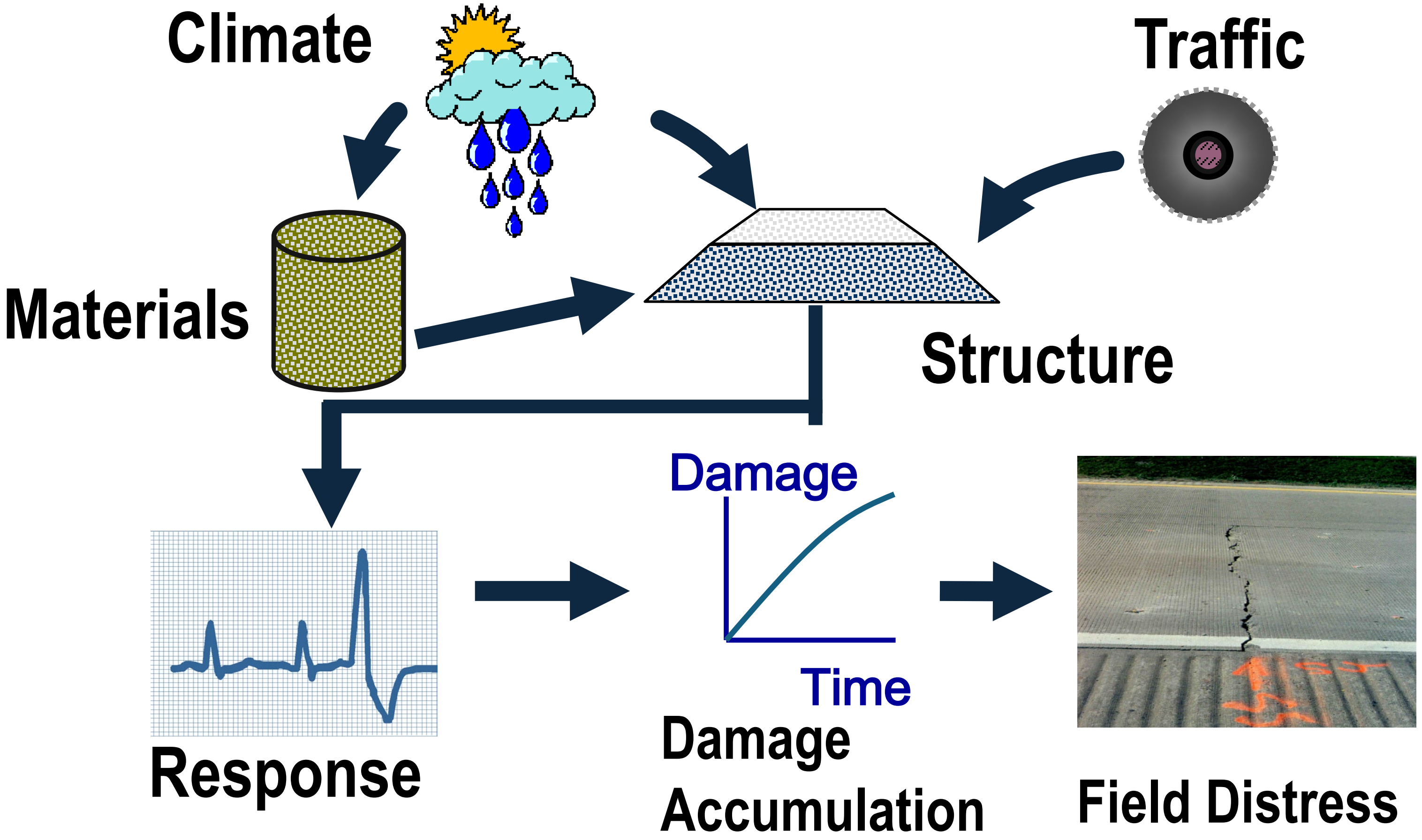
Limitations of Westergaard's Solutions

- Single slab
  - no joints
- Infinite/semi -infinite in horizontal direction
  - no slab size effect
- Single layer slab
- Full contact of the plate with the foundation
  - no separation
- Single wheel
  - no axle loads

Finite Element Programs

- KenSlab (Huang 1973), JSLAB (Tayabji 1977), EverFE (1999)
- ILLISLAB
  - Tabatabai and Barenberg (1978) – multiple slabs, base layer, doweled joints
  - Ioannides (1985) – Pasternak and elastic half-space foundations
  - Korovesis (1989) – slab curling, separation from subgrade
  - Khazanovich (1994) – nonlinear temperature distribution, separation between slab and base
  - Roesler and Khazanovich (1997) – fracture mechanics-based modeling of partial depth cracks
- ISLAB2000 (Khazanovich et al. 2000)

NCHRP 1-37A Project: Development of a MEPDG (1997 -2004)



Dr. Mike Darter
Professor (emeritus)
University of Illinois
Founder of ERES
Consulting, Inc.
NCHRP 1-37A Rigid
Pavements Group Leader

ISLAB2000 became an important mechanistic engine underlying the rigid-pavement analysis framework developed for MEPDG.

(NCHRP 2004, AASHTO 2008)

ISLAB2000

Suite of three programs:

- ISLAB2000Pre – a user-friendly preprocessor for development of ISLAB2000 finite element models
- ISLAB2000 – a computational engine performing the finite element analysis
- ISLAB2000Post – a tool for visualization of the ISLAB2000 analysis results

ISLAB2000Pre

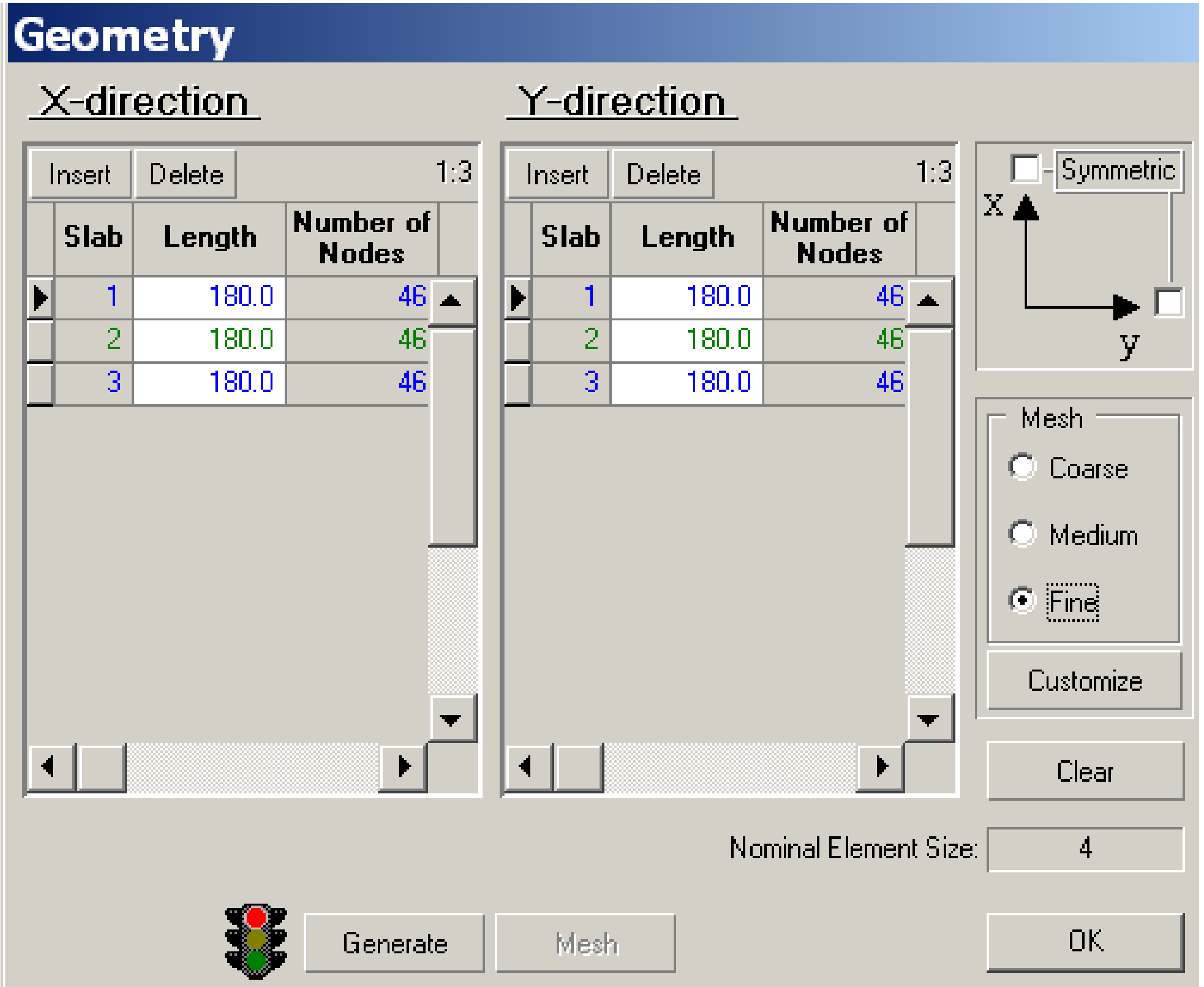
- Define pavement geometry
- Provide characteristics of the pavement layers
- Provide subgrade properties
- Provide characteristics of joints
- Define the axle load
- Provide temperature distribution through the slab thickness

ISLAB2000Pre

- Geometry: Multiple slabs in both direction. Simple rules to generate mesh.
- Pavement structure: multiple layers, bonded and unbonded, possible separation between layers
- Subgrade: Winkler foundation, Pasternak, Kerr
- Load: multiple rectangular footprints
- Joints: Aggregate interlock; dowels, partial depth cracks
- Curling and Warping: Linear, Quadratic, and Piecewise Linear

Pavement Geometry

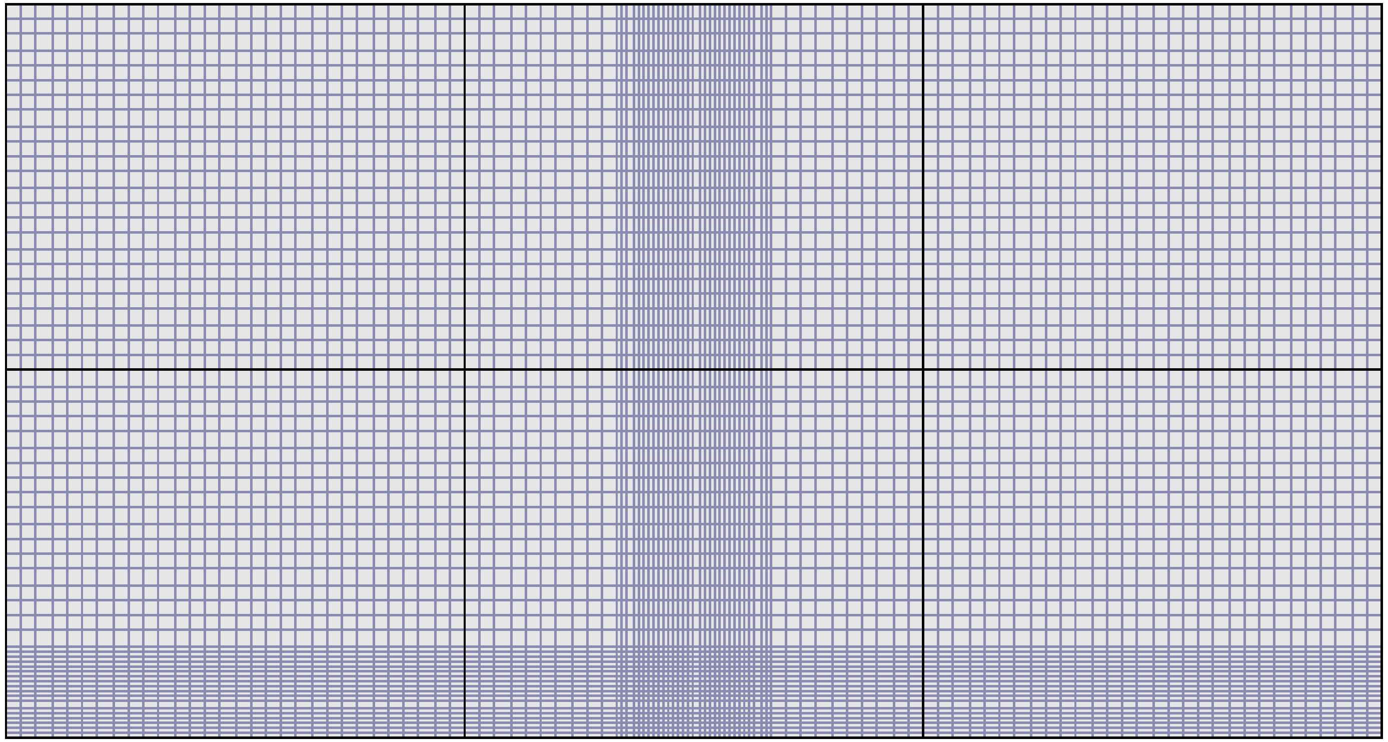
- Number of slabs in each direction and their lengths and widths
- Coordinates of nodes of the finite element mesh



Mesh Size Effect

- Coarse mesh (larger elements)
  - Faster solution
  - Smaller output files
  - Less accurate solution

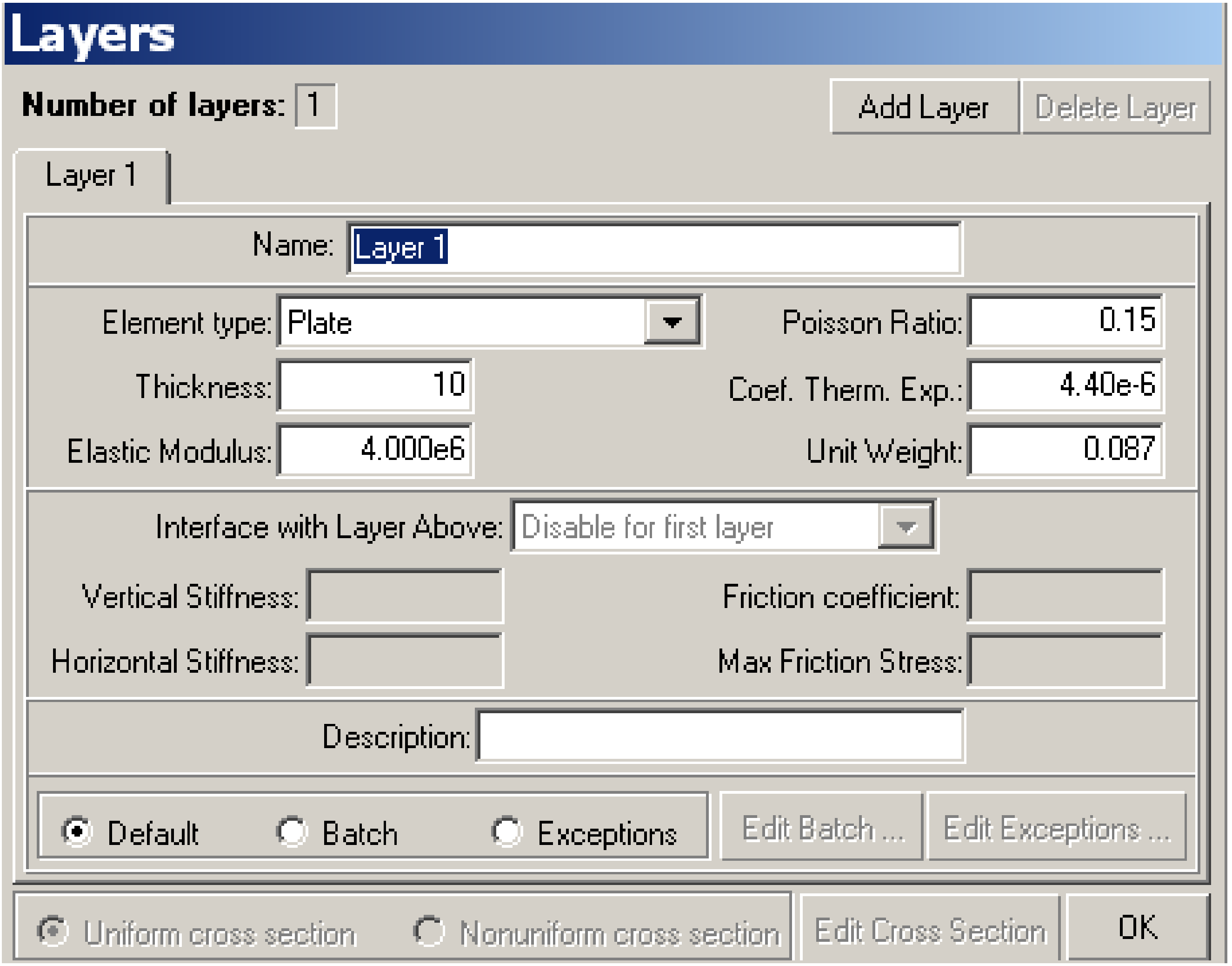
- Finer mesh
  - Slower solution
  - Larger output files
  - More accurate solution



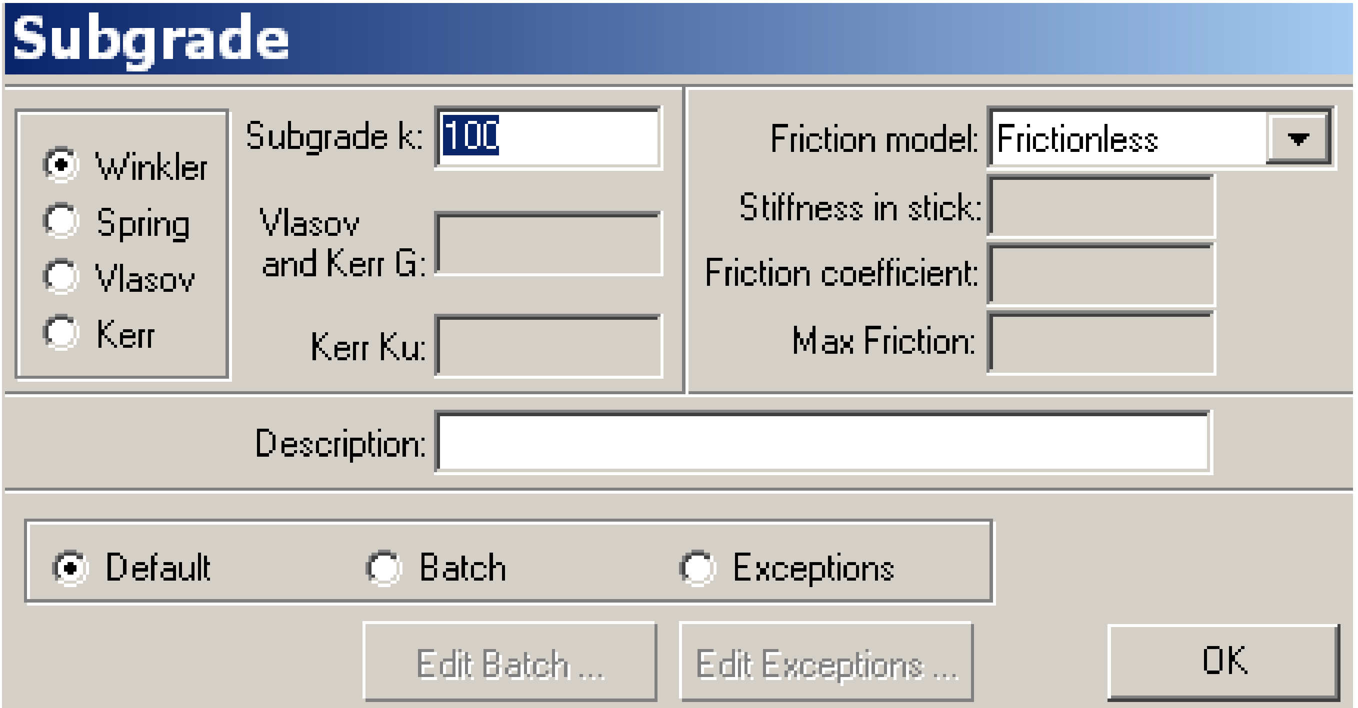
Mesh refinement is not simply about "more elements = better.”

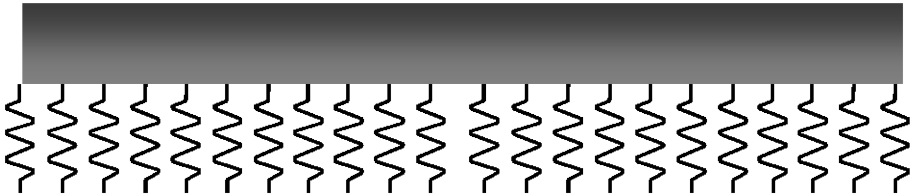
Modeling of Constructed Layers

- Thickness
- Modulus of elasticity
- Poisson’s ratio
- Coefficient of thermal expansion
- Unit weight



Subgrade Modeling in ISLAB2000





k

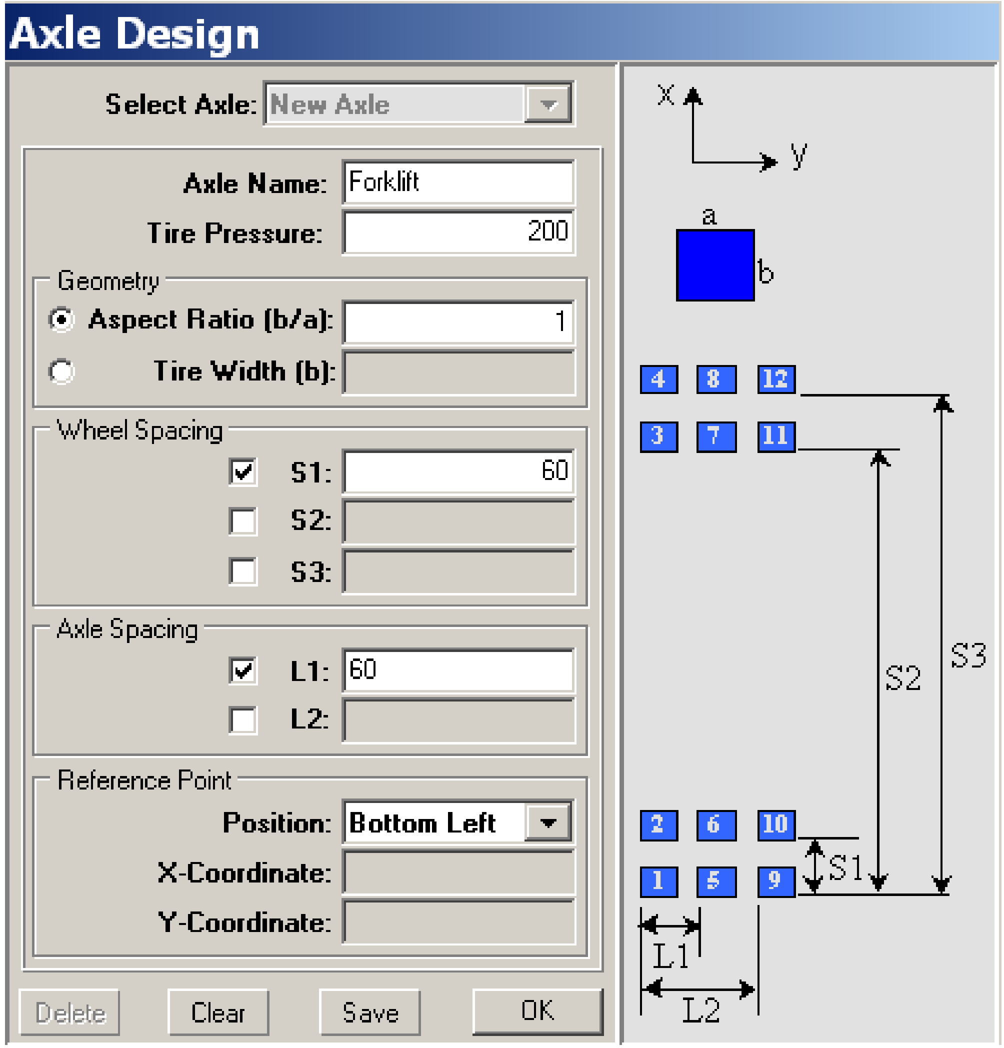
Tensionless foundation

k=pressure/deflection

Modeling of Surface Loads

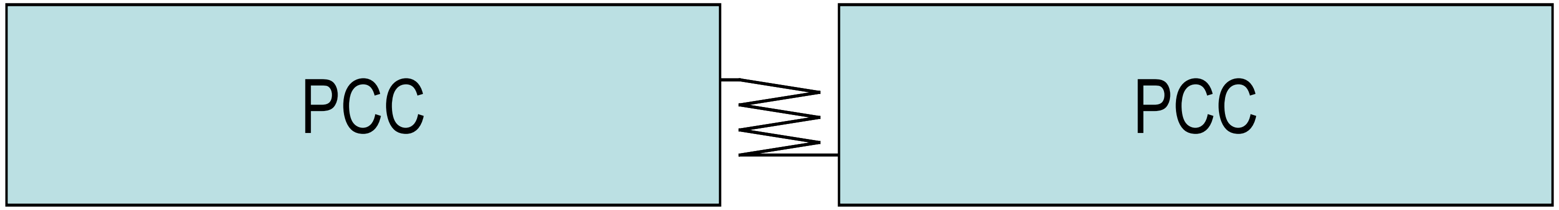
- Rectangular footprint
- Aspect ratio
- Number of wheels/footprints
- Tire pressure
- Wheel spacing

- Axle coordinates
- Axle weight

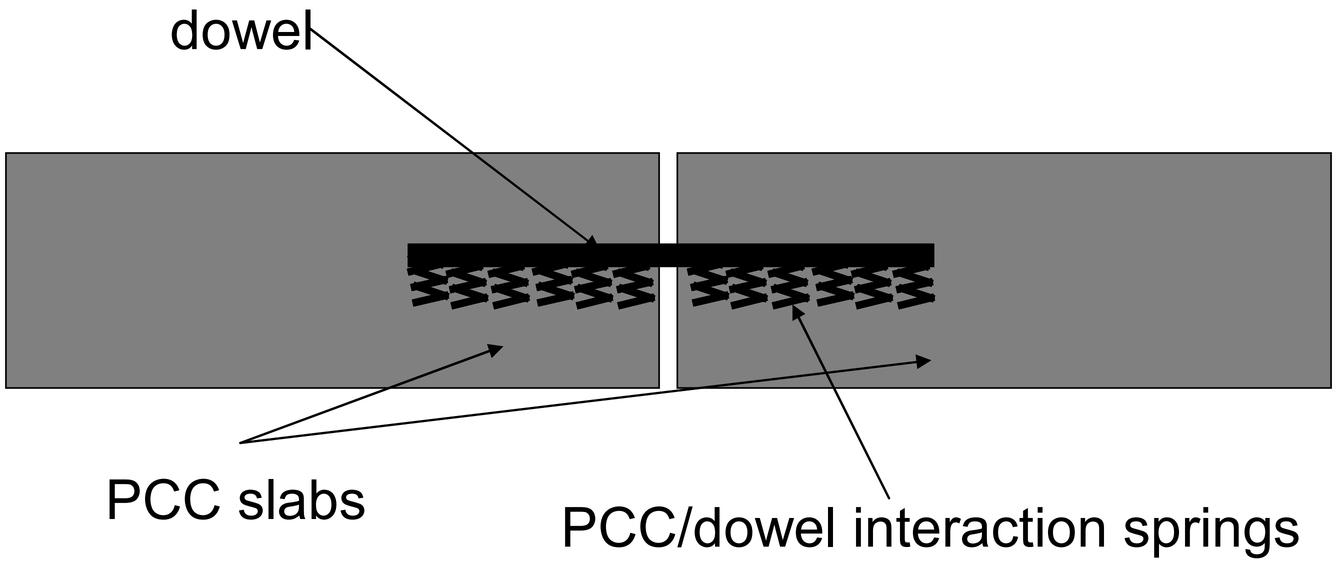


Modeling of Joints

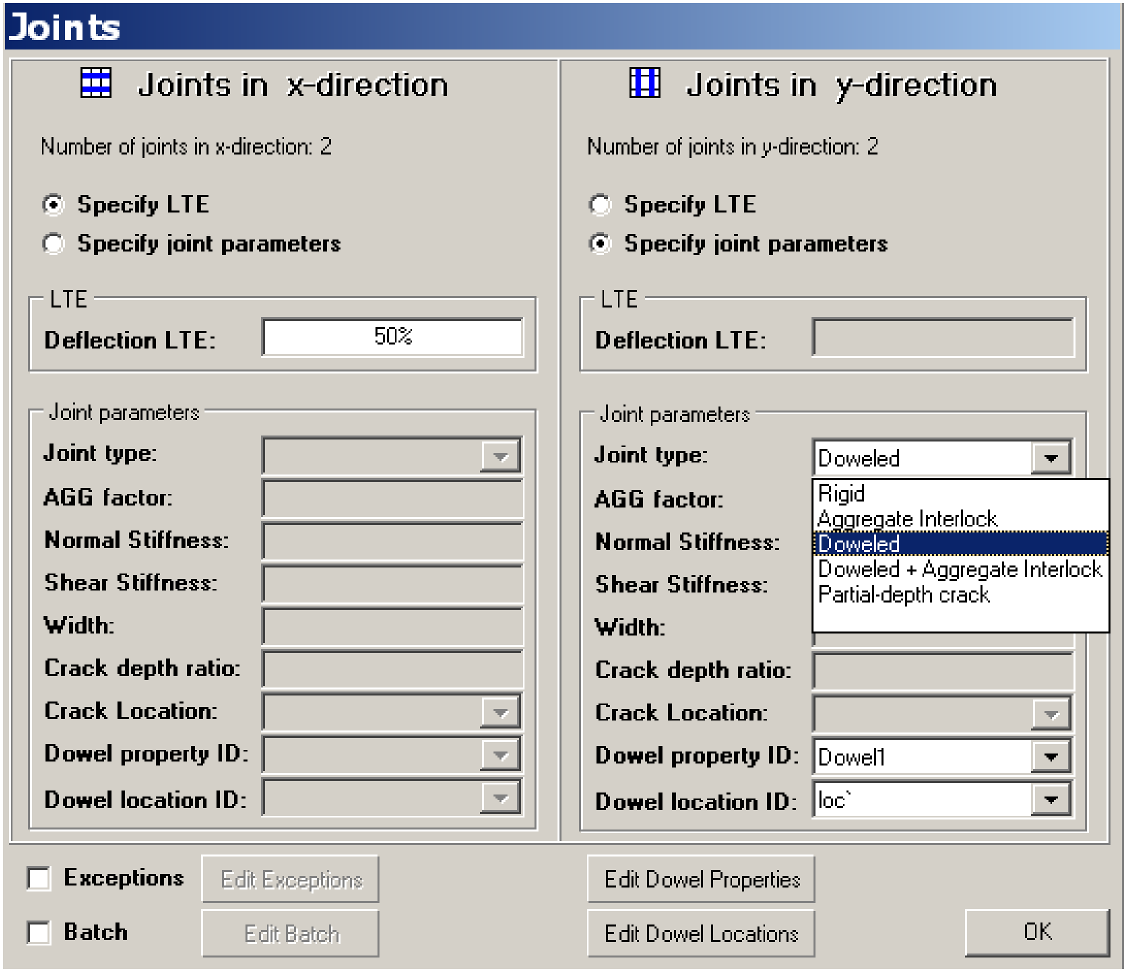
- Aggregate interlock load transfer

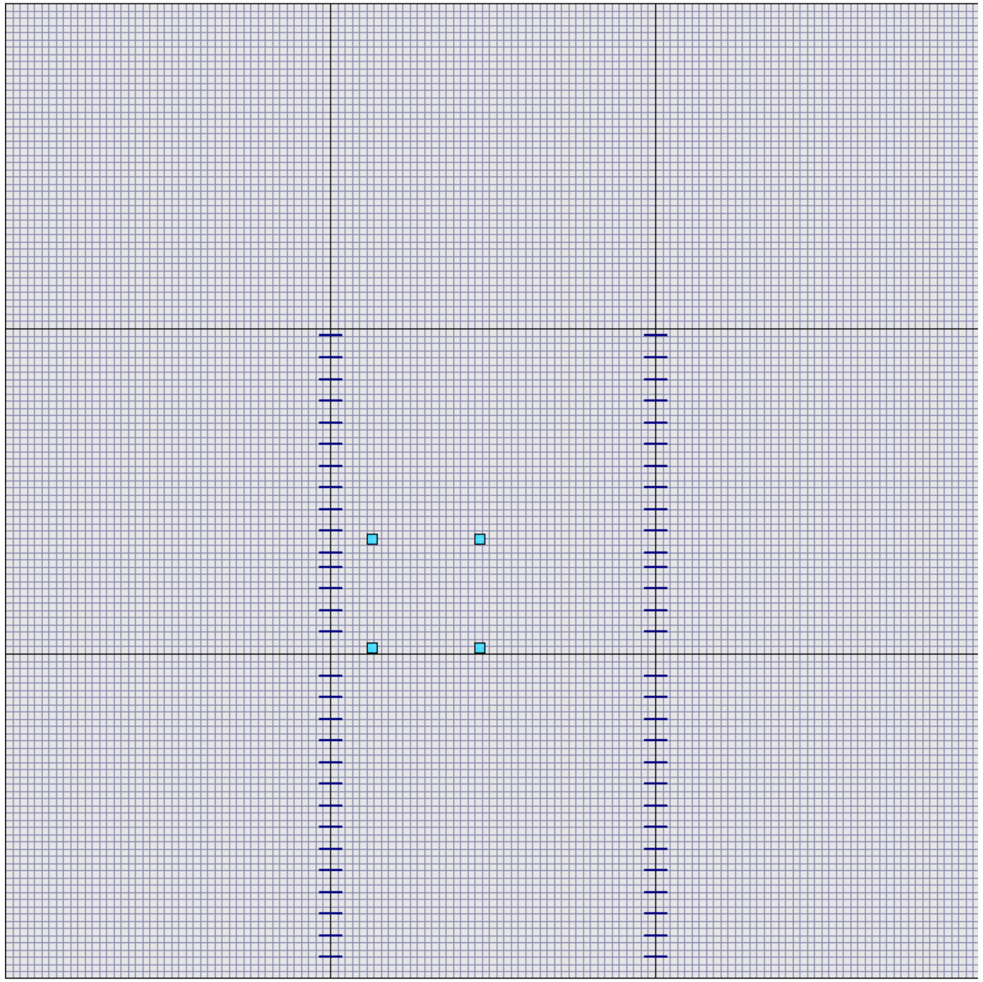


- Dowel load transfer

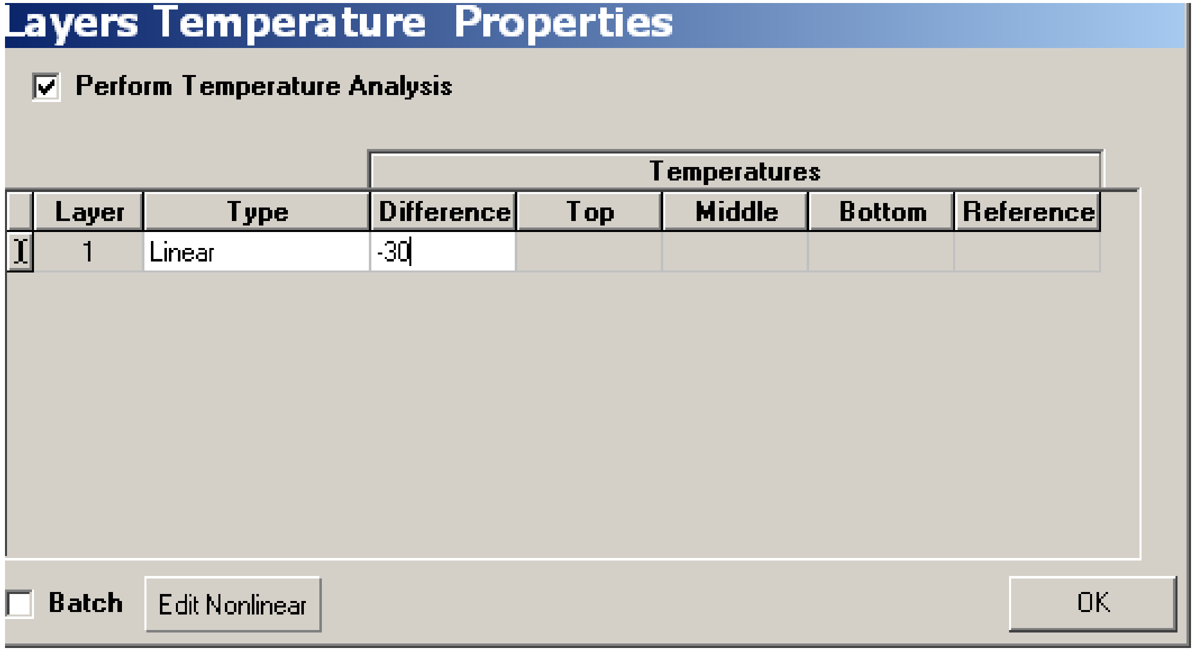


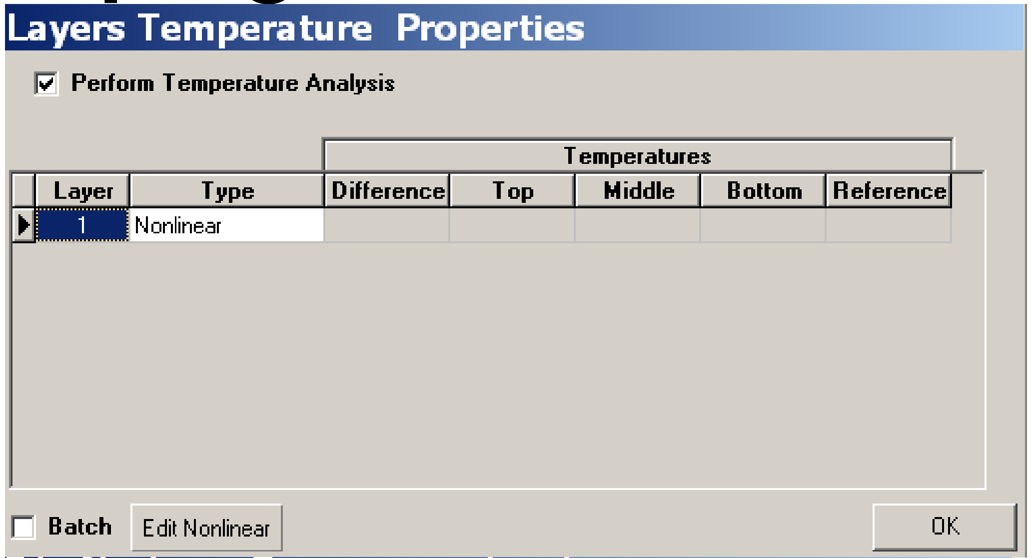
Modeling of Joints

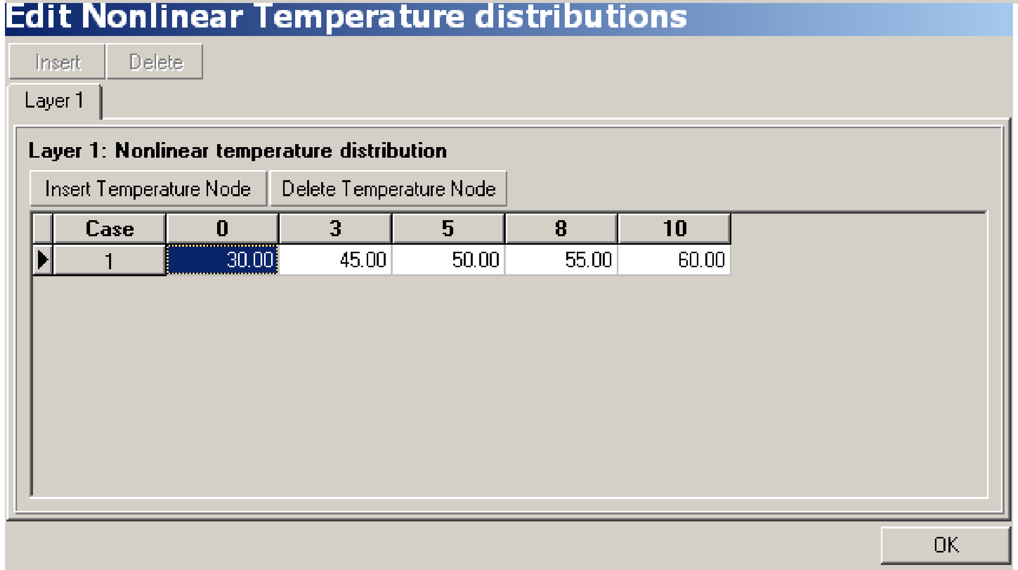




Modeling of Curling and Warping



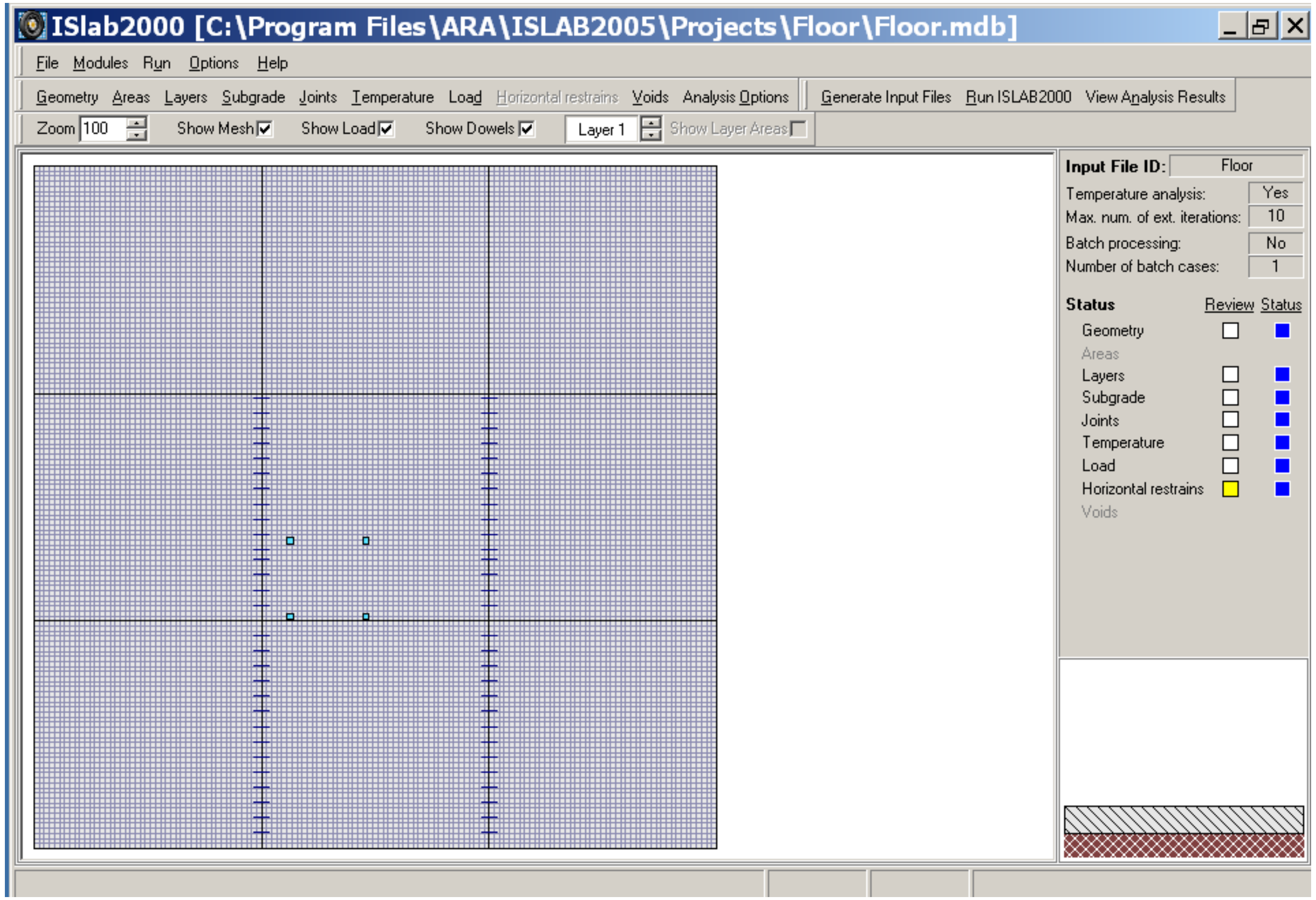




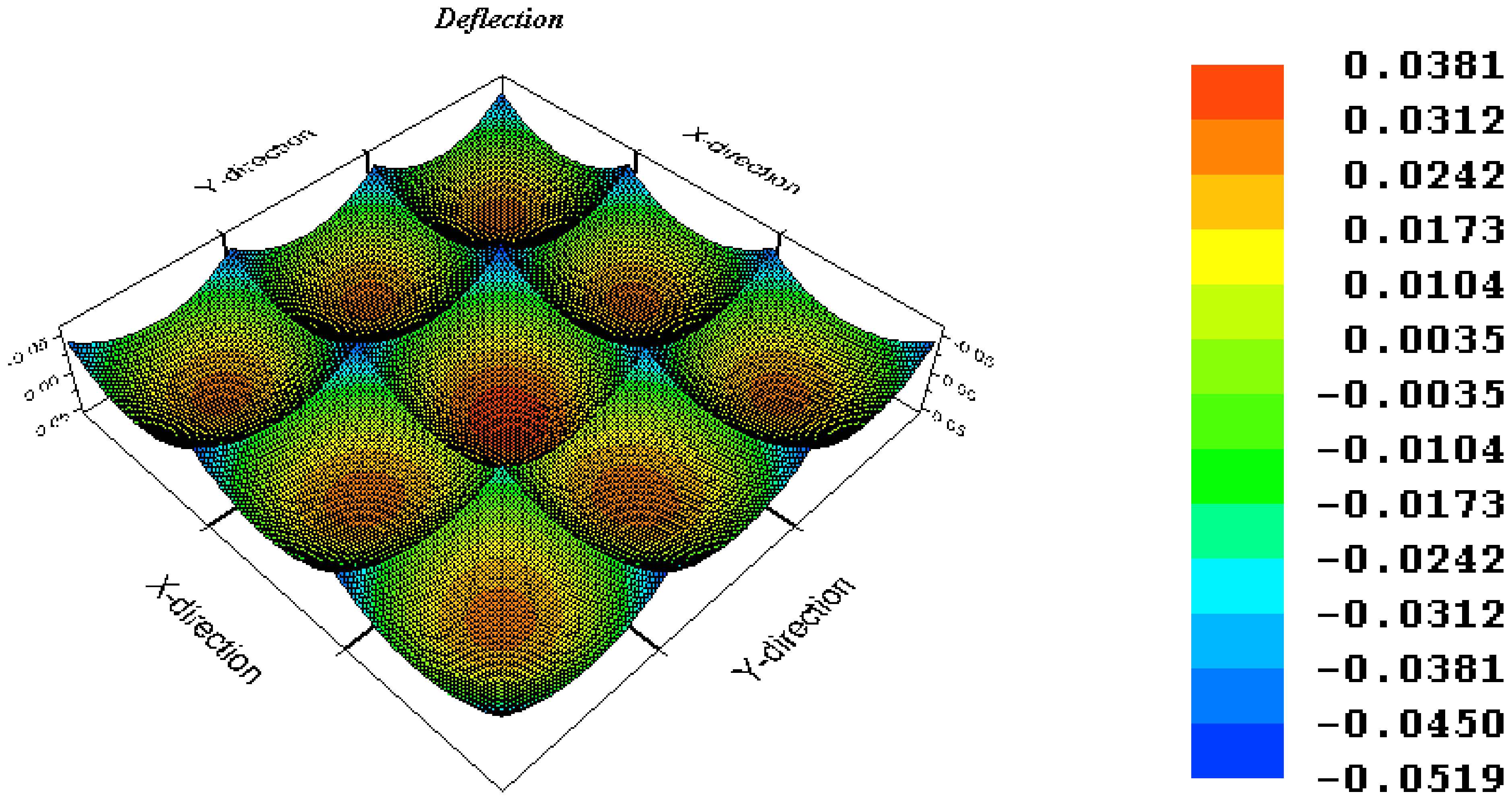
THE SLAB DESIGNER.

ISLAB2000 Analysis Process

- Create model using ISLAB2000Prep
- Run ISLAB2000 analysis
- View results using ISLAB2000Post

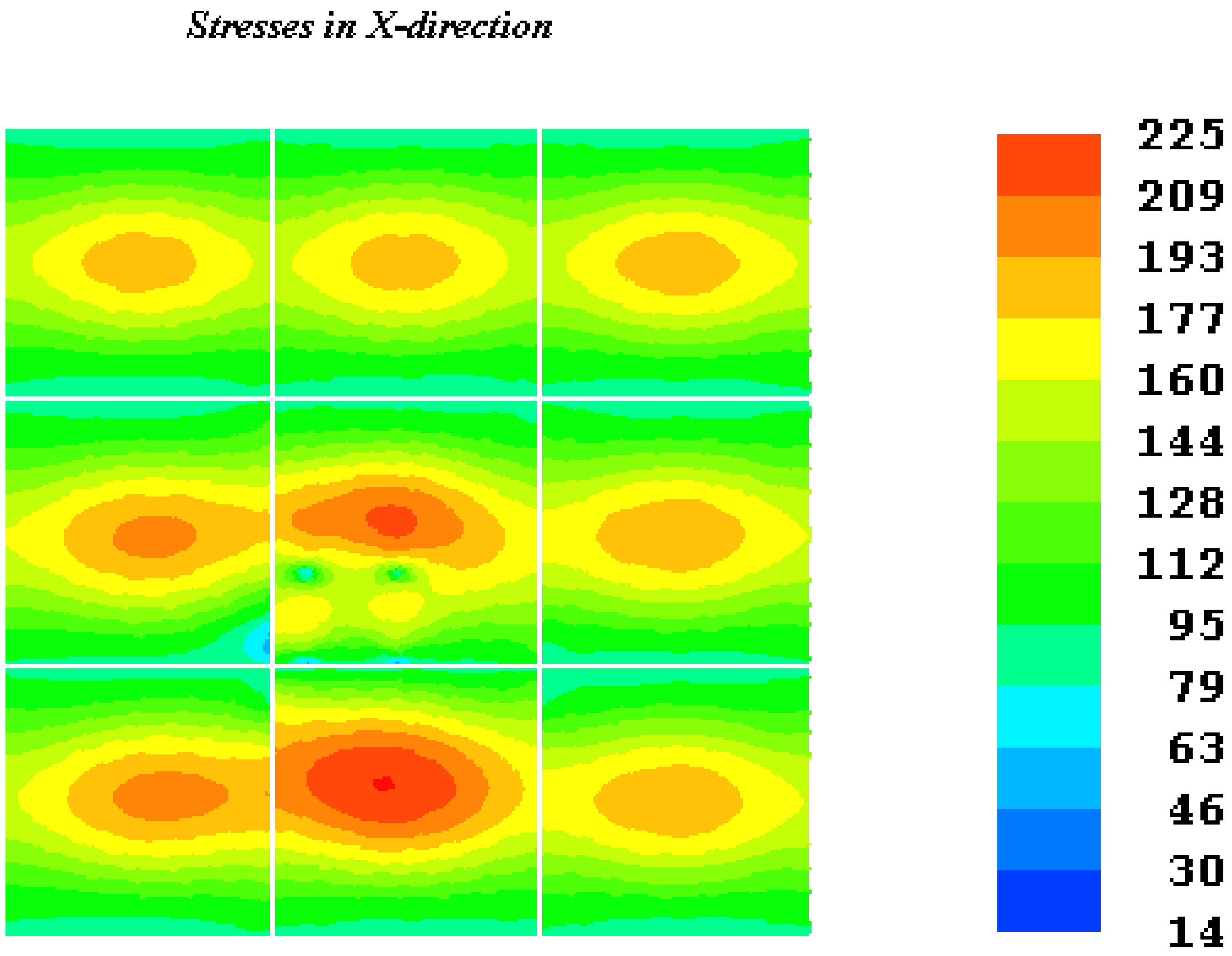


ISLAB2000 Slab Deflections



Westergaard: 0.005 -0.02 in

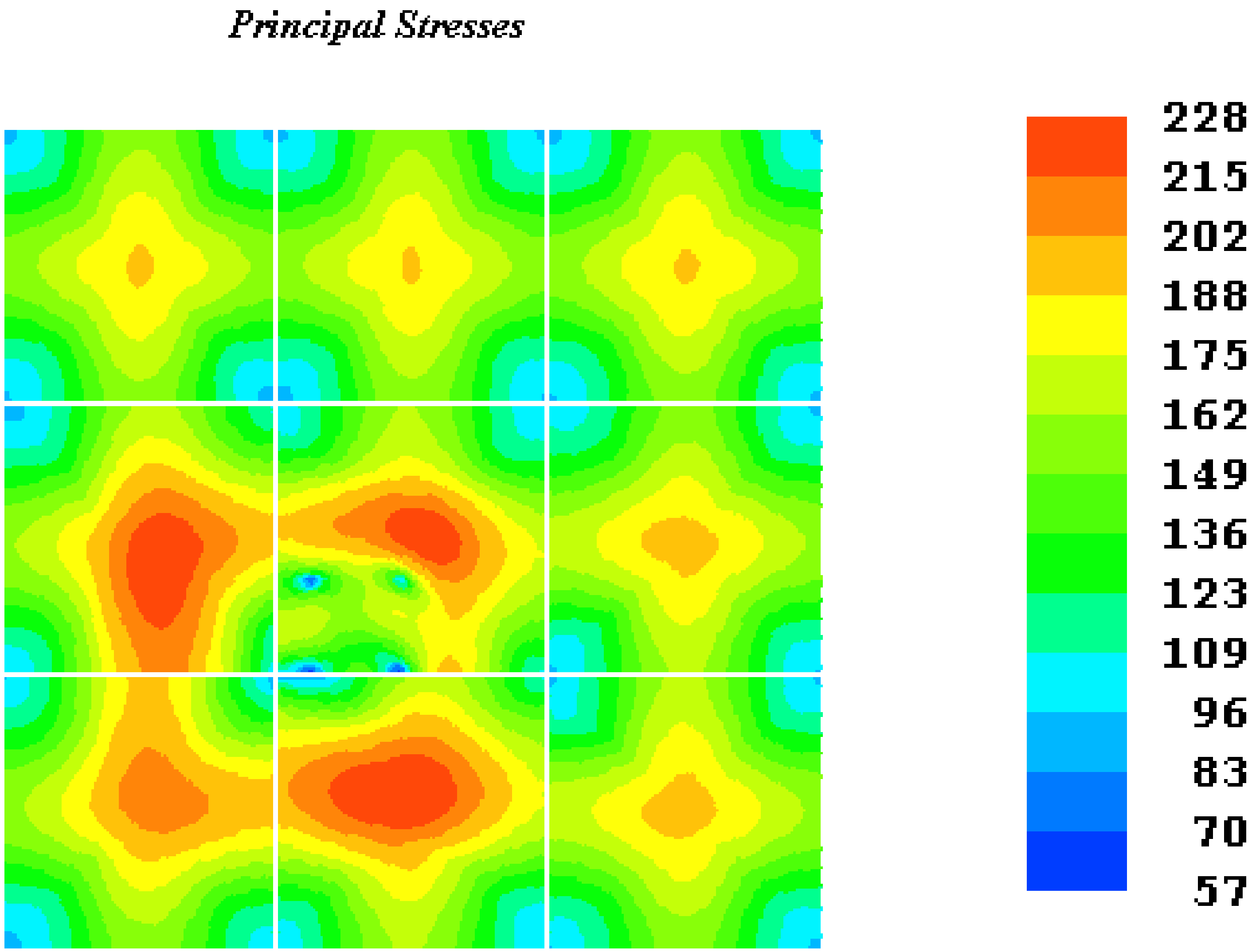
ISLAB2000 Slab Top Surface Normal Stresses



Westergaard: 270 - 660 psi

THE SLAB DESIGNER.

ISLAB2000 Slab Top Surface Principal Stresses



Why ISLAB is well suited for concrete pavement analysis

- Westergaard solutions are elegant but limited by strong idealizations (single infinite slab, full contact, single wheel, linear temperature, no joints)
- These idealizations can cause significant stress errors under real jointed, multi-axle, and curling conditions
- ISLAB removes the limitations: multi-slab systems, realistic joints, layer separation, multi-axle loads, and nonlinear temperature
- ISLAB was used for the MEPDG development, it supplies the mechanistic accuracy modern design and analysis require
- Use Westergaard for quick estimates; use ISLAB for virtually all real jointed concrete pavement work

Key Takeaways : The question is not whether a model is simple or complex: it is whether its assumptions are consistent with the pavement we are trying to understand.

Thank You

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