

# **Elements of Design That Influence Long PCCP Life**

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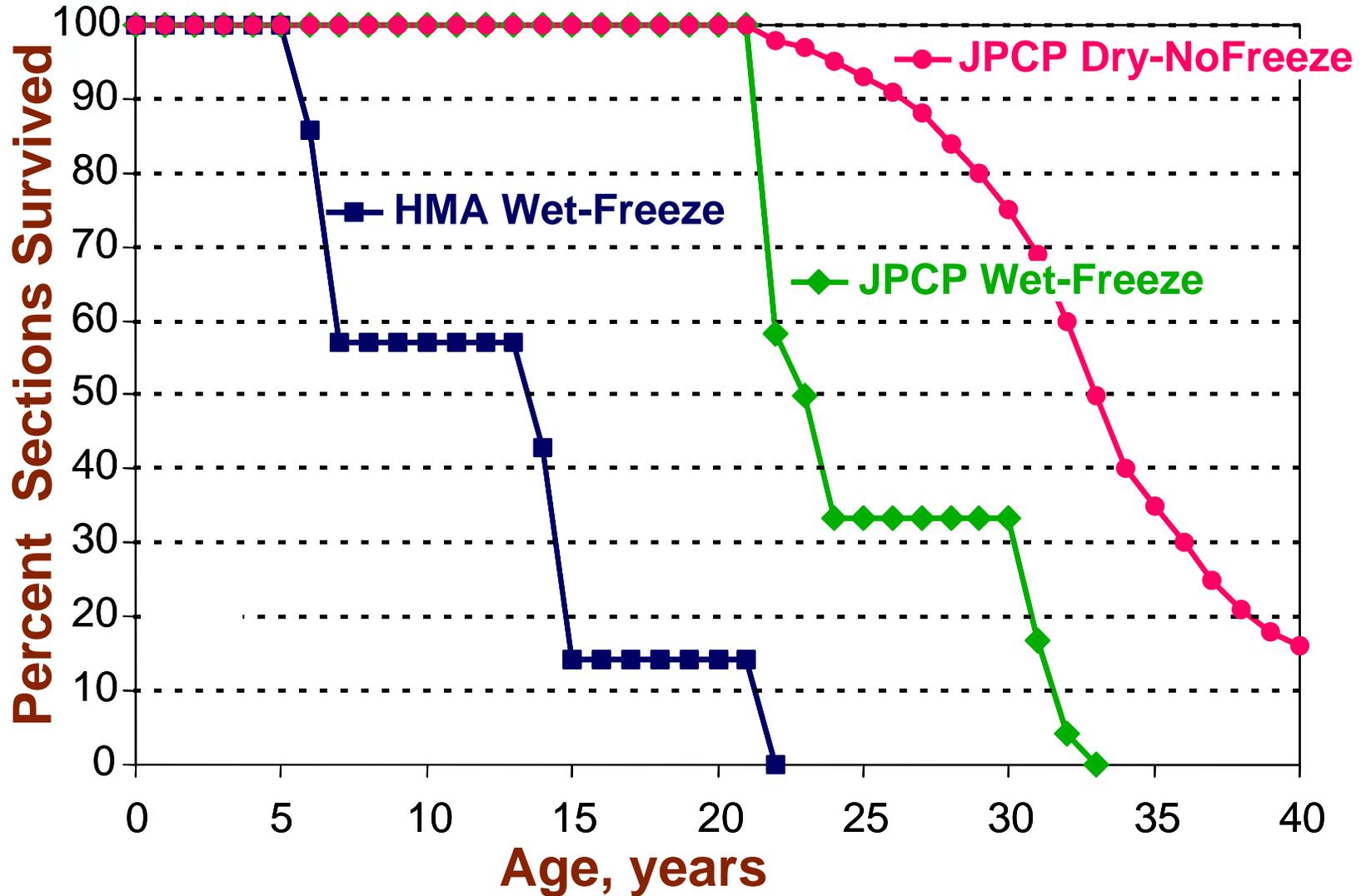
**Caltrans/FHWA/Western States Chapter  
Annual Conference**

**October 18, 20 and 21, 2004**

# Achieving Long-Life Concrete Pavements in California

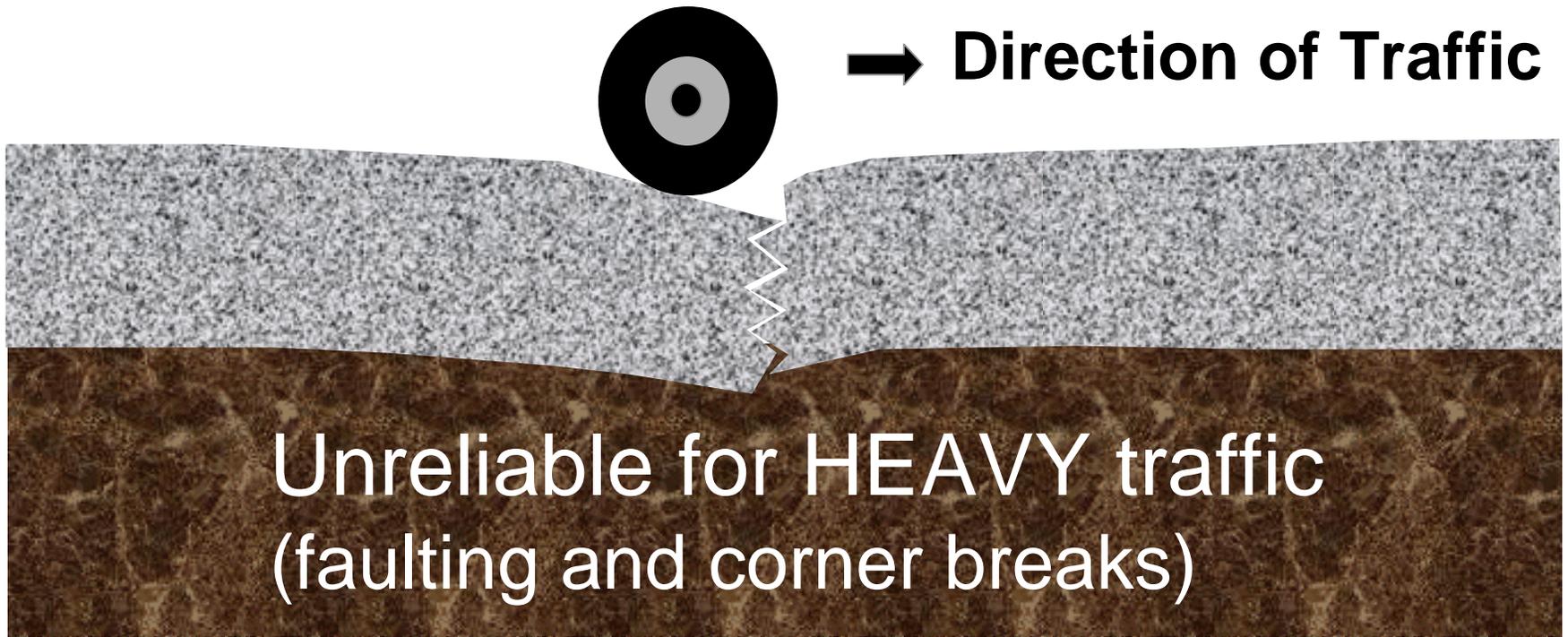
- Four major processes in producing a concrete pavement:
  1. Structural & joint design of the pavement
  2. Concrete materials and mix design
  3. Construction of the pavement
  4. Maintenance
- Long-life: like links in a chain...

# The Past: Survival Curves



# The Past: Relying on Aggregate Interlock Only

- High deflections and stresses





## The Past:

- No dowels
- Built in bathtub
- Erovable base
- **Heavier truck traffic than ever imagined!**

# The Past: Too Long Joint Spacing

## 21 projects in California 1970's construction

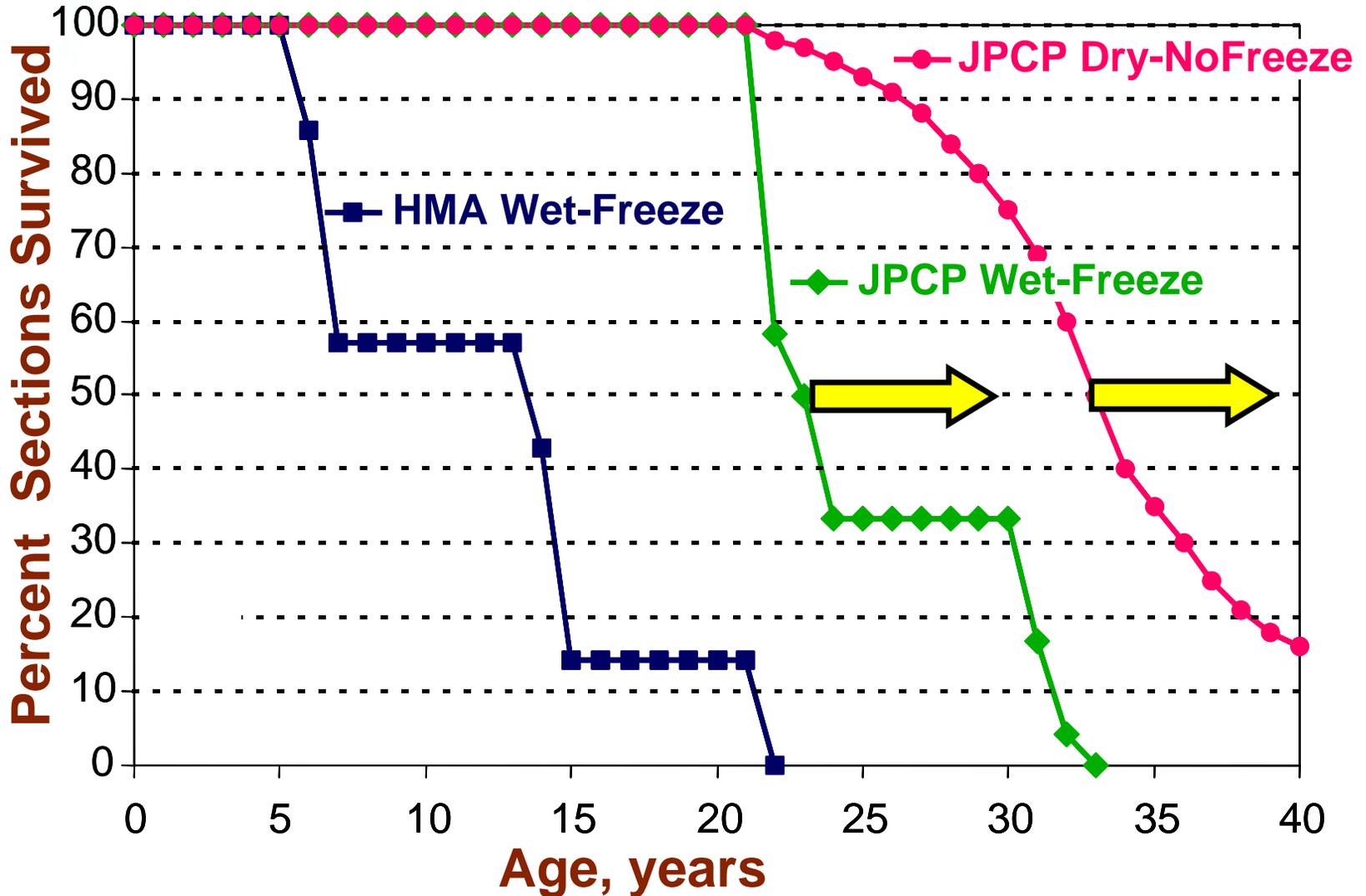
- 3.6 to 4.0-m joint spacing
  - ✓ Mean 10 percent slabs cracked
- 5.5 to 5.8-m joint spacing
  - ✓ Mean 34 percent slabs cracked

# The Past: Durability Problems

## Alkali-Silica Reaction



# The Future: Survival Curves



# Current Improved Technology

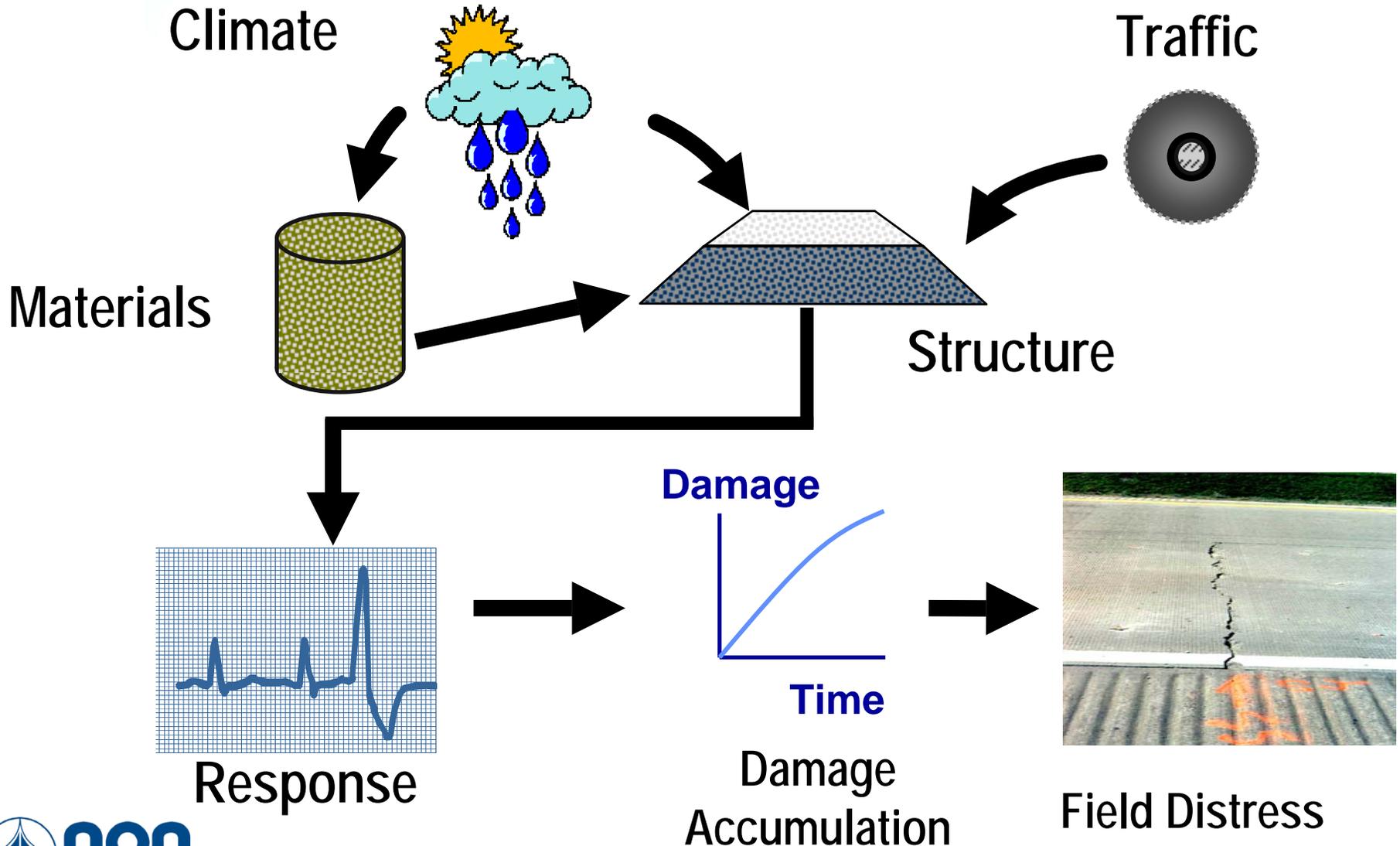
## Mechanistic Design

- Several countries including the US has sponsored the development of a new procedures based on engineering principles

## AASHTO: NCHRP 1-37A

- 6-year (1998-2004) research and development of new concrete pavement design procedure
- Paradigm shift in design of new JPCP & CRCP & Overlays

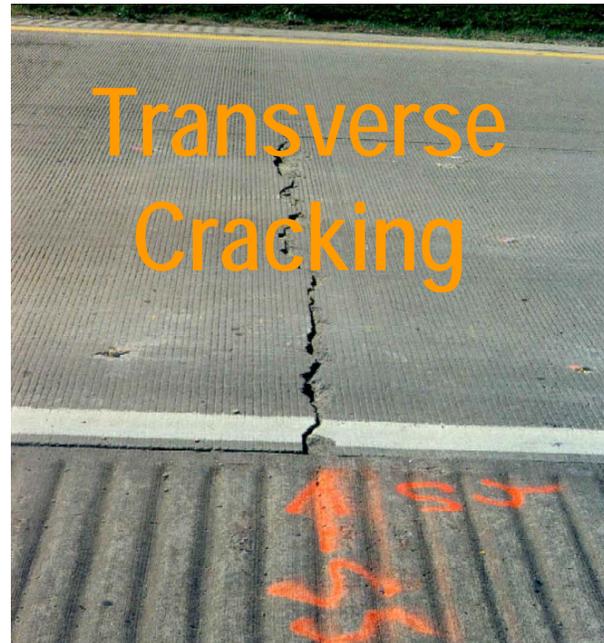
# Mechanistic-Empirical Design



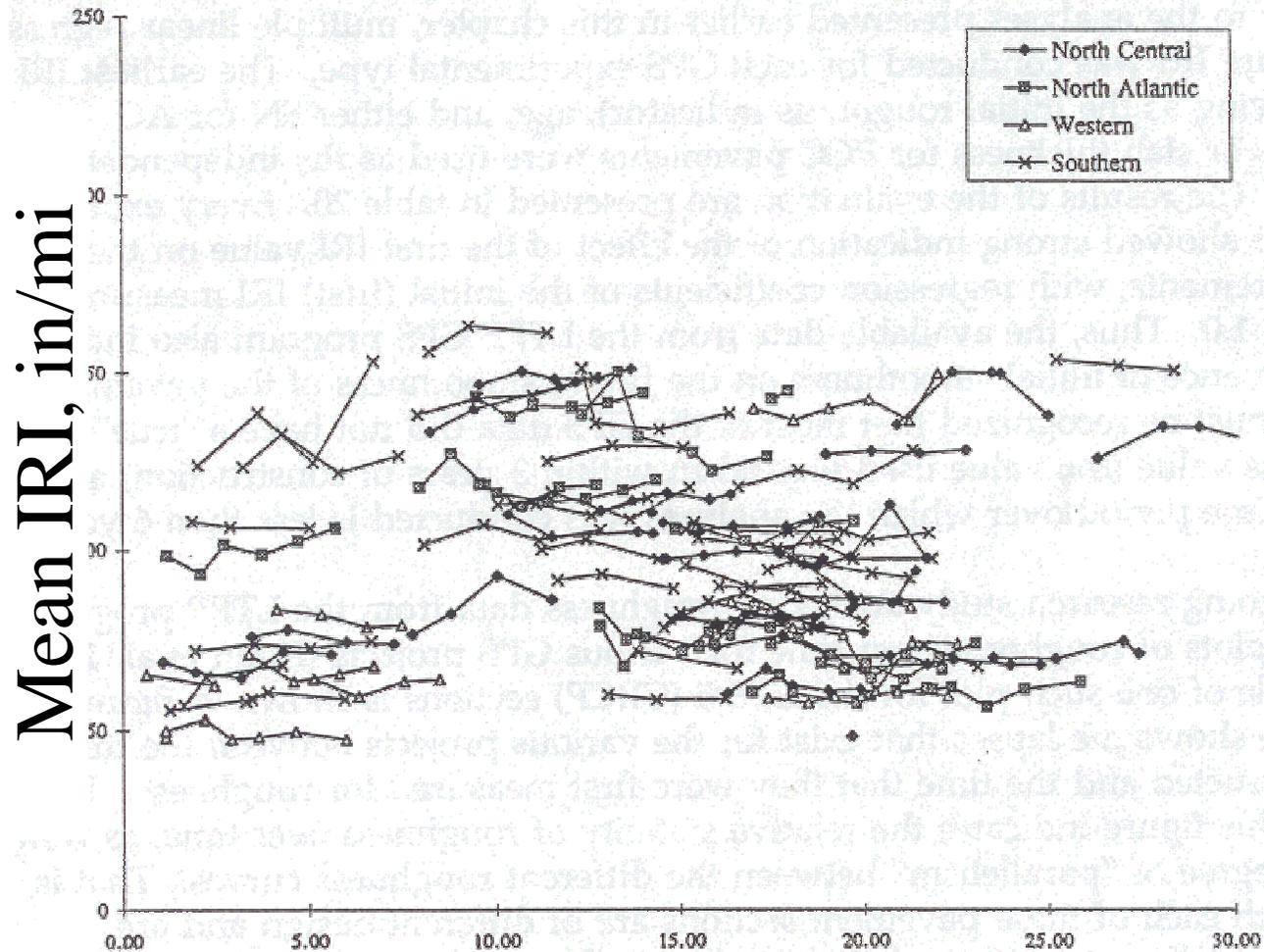
# Design Guide Software



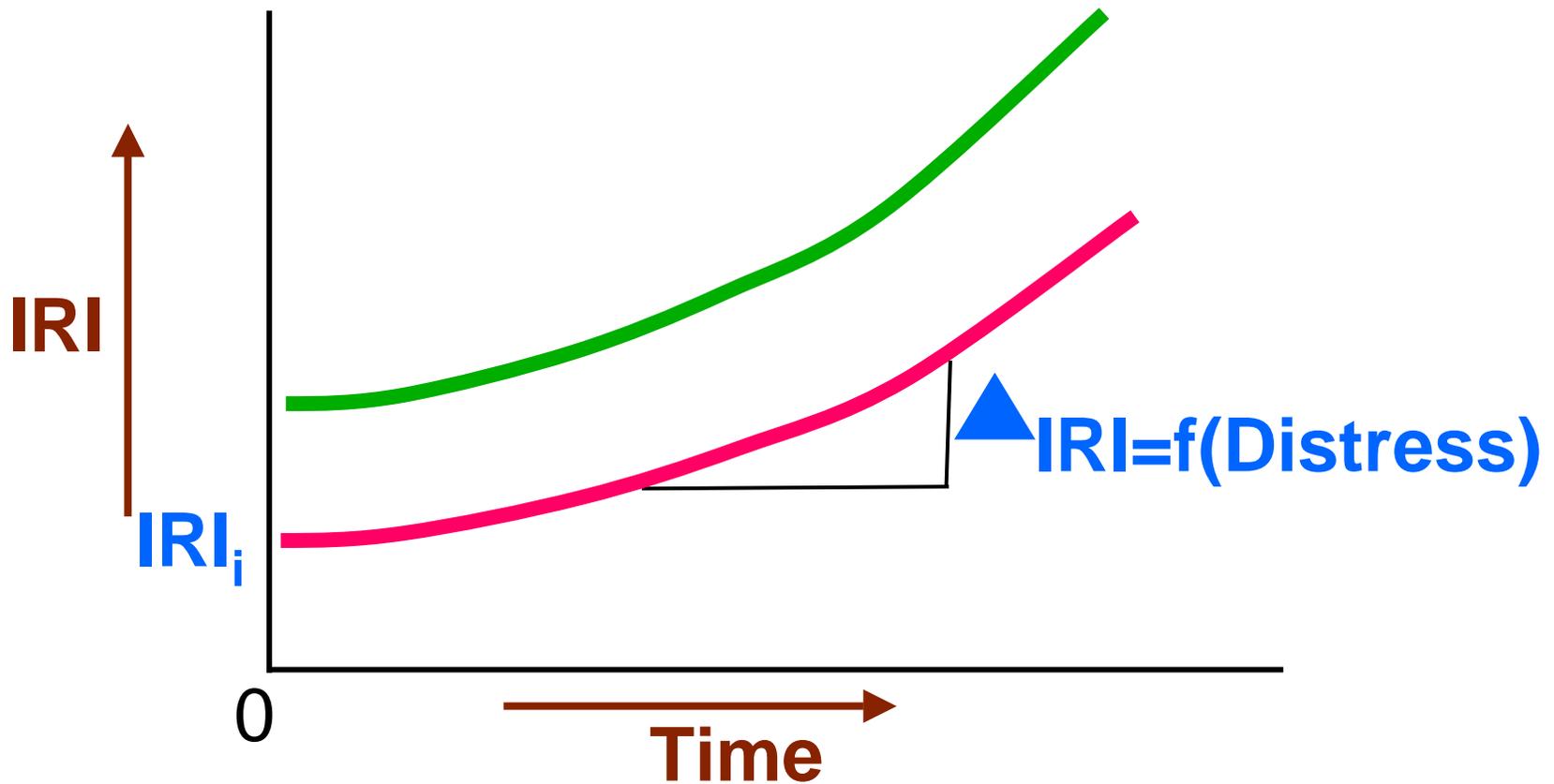
# Design to Prevent Key Distress



# LTPP PCC Smoothness Trends



# Impact of Construction: Initial Smoothness

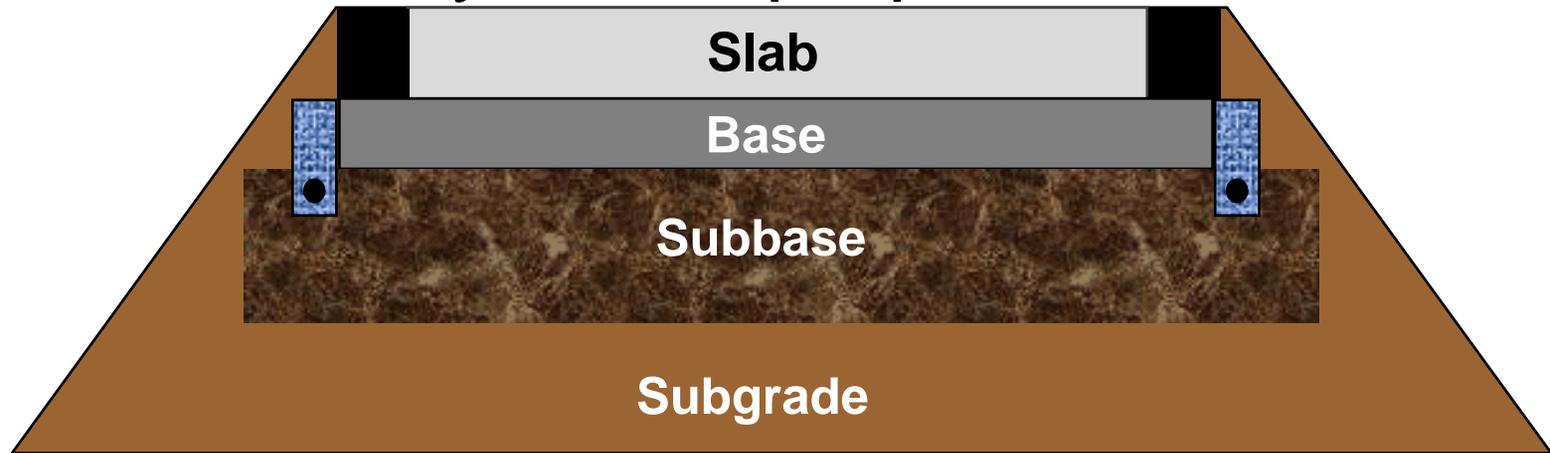


# NCHRP 1-31: Effect of Initial Pavement Smoothness on Pavement Life

- Evaluation of historical pavement performance data from 10 States strongly indicated that **initial smoothness** has a **significant effect on pavement life**.
- **Added pavement life is obtained by achieving a higher level of initial smoothness.**
- Two different analyses used to reach this finding:
  - ✓ Smoothness along many projects (mile by mile): smooth sections stay smooth over life.
  - ✓ Pavement survival analysis in Kentucky & Wisconsin.

# Materials Characterization

- **For Each Layer:** longitudinal edges, elastic modulus, strength, thickness, thermal & hydraulic properties, others ...



# Concrete Slab Characterization

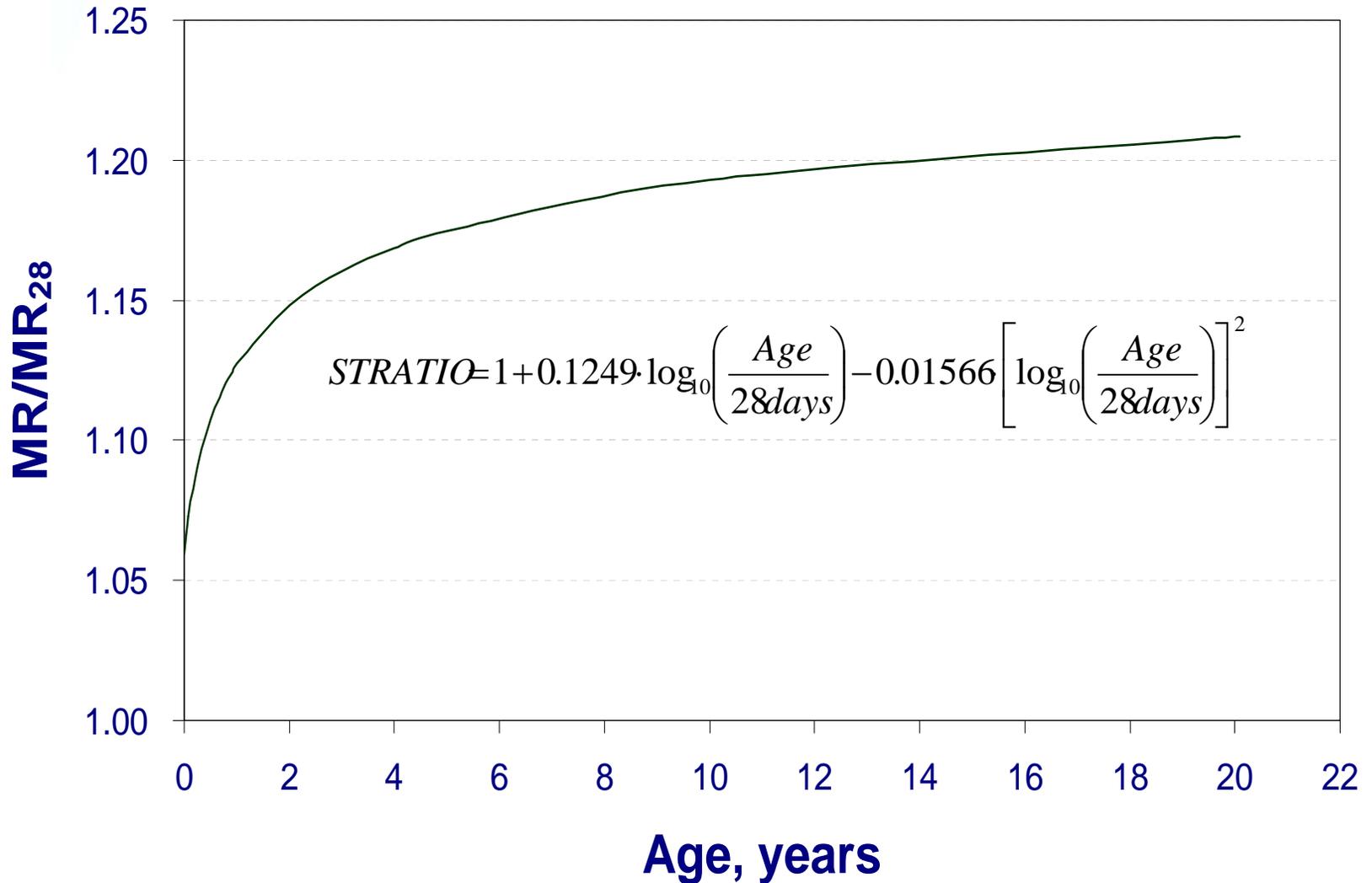
- **Flexural strength (over time)**
- **Modulus of elasticity (over time)**
- **Coefficient of thermal expansion**
- **Permanent curl/warp**
- **Joint spacing**
- **Slab thickness**

# Effects of PCC properties on JPCP Performance--Strength

- Cracking: strength < stress
- California flexural strength at 28-days: 667 psi [585-720]
- PCC strength – the higher the better to reduce cracking, but may be associated with:
  - ✓ Higher shrinkage
  - ✓ Higher modulus of elasticity



# PCC strength gain model

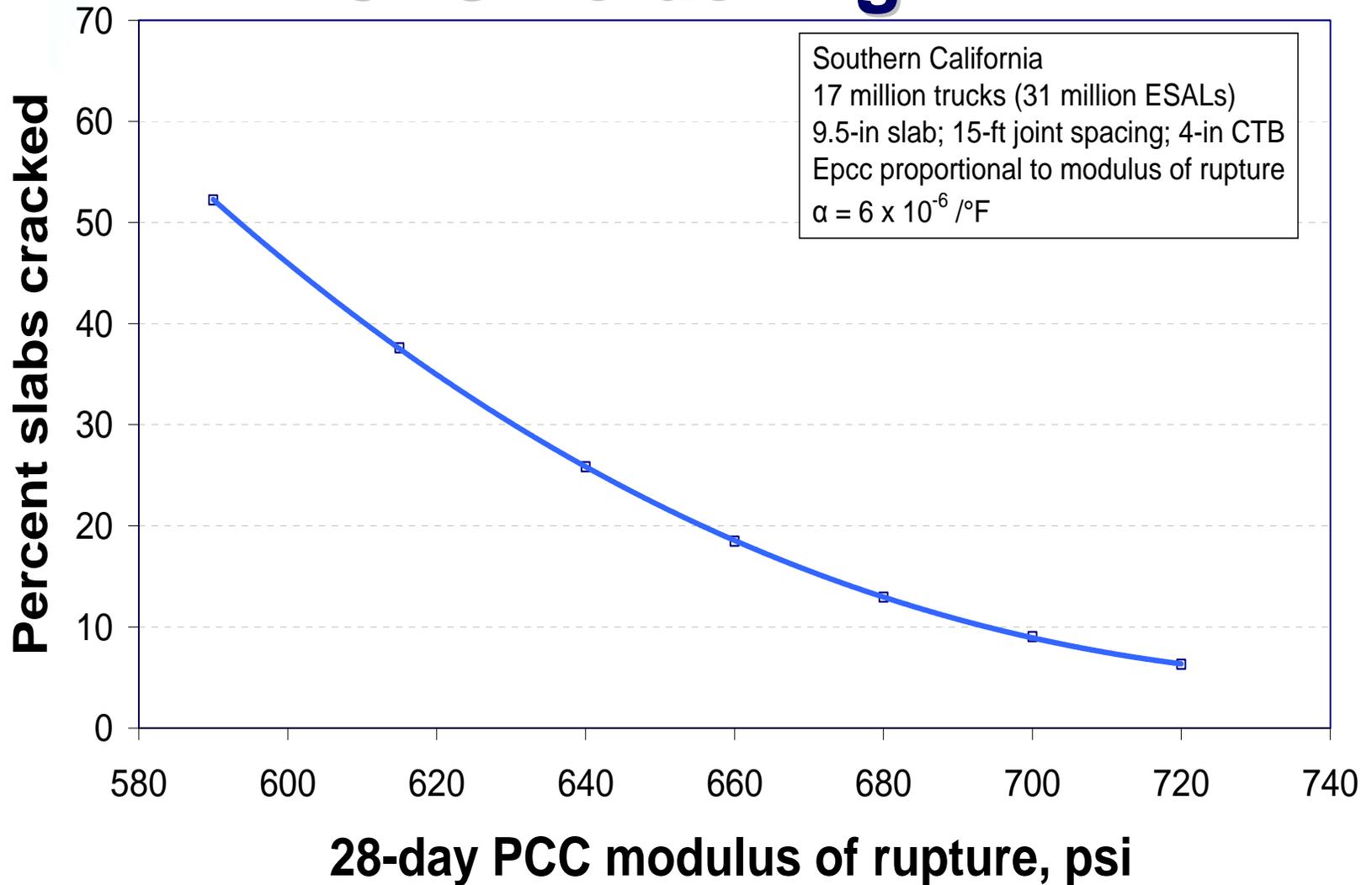


# Effects of PCC properties on JPCP Performance—Modulus of Elasticity, $E_c$

- PCC elastic modulus ( $E_c$ ) – lower is better!
- Cores from California JPCP showed consistently lower  $E_c$ 
  - ✓ 3,325,000 psi CA vs 4,800,000 psi nationally



# Effects of PCC strength on JPCP cracking

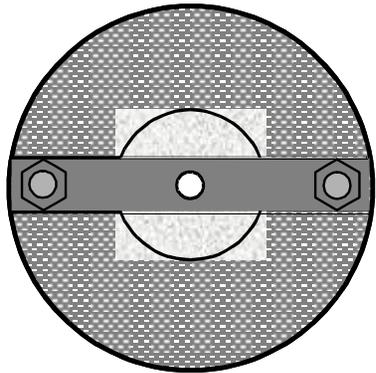


# Effects of PCC properties on JPCP— Thermal Coefficient Expansion

- Thermal coefficient – lower is better!
- California PCC ranged from 5.9 to 6.6 with an average of  $6.15 \text{ E-06}$  per degree F
- Depends mainly on aggregate type
- Test method - AASHTO TP60-00

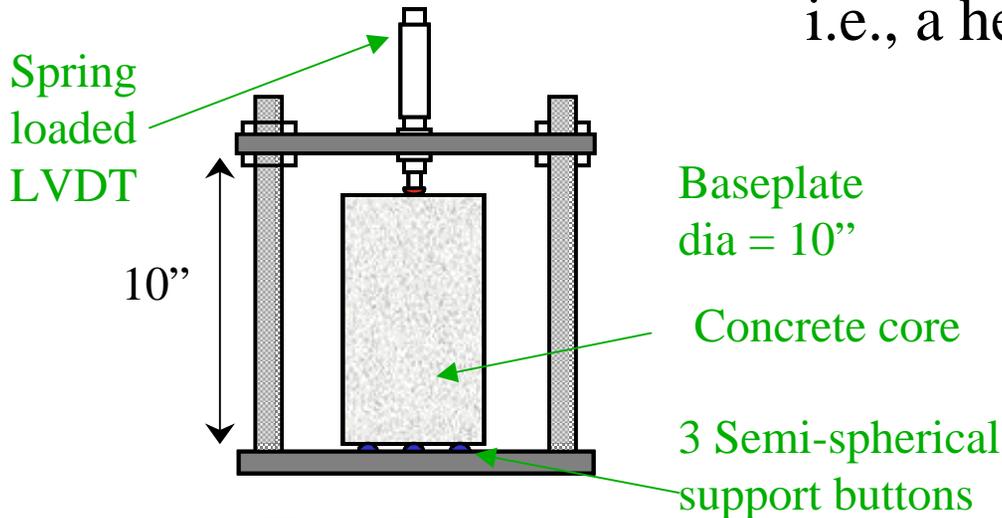


# Concrete CTE – Test Apparatus



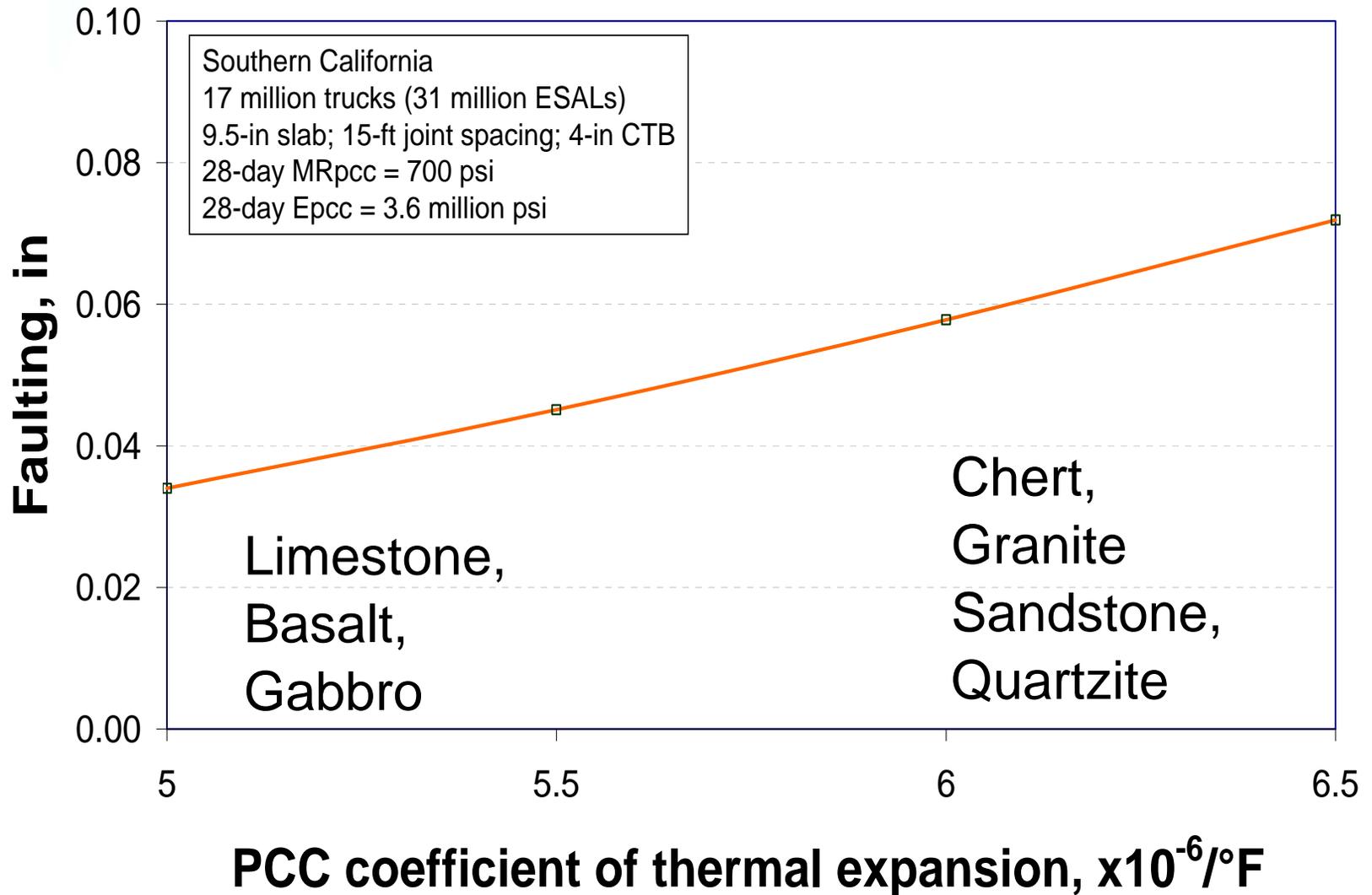
**Top View**

- Test procedure essentially involves measuring change in length of the test specimen at different temperatures
- Length change is measured after expansion and contraction cycles, i.e., a heating and a cooling cycle

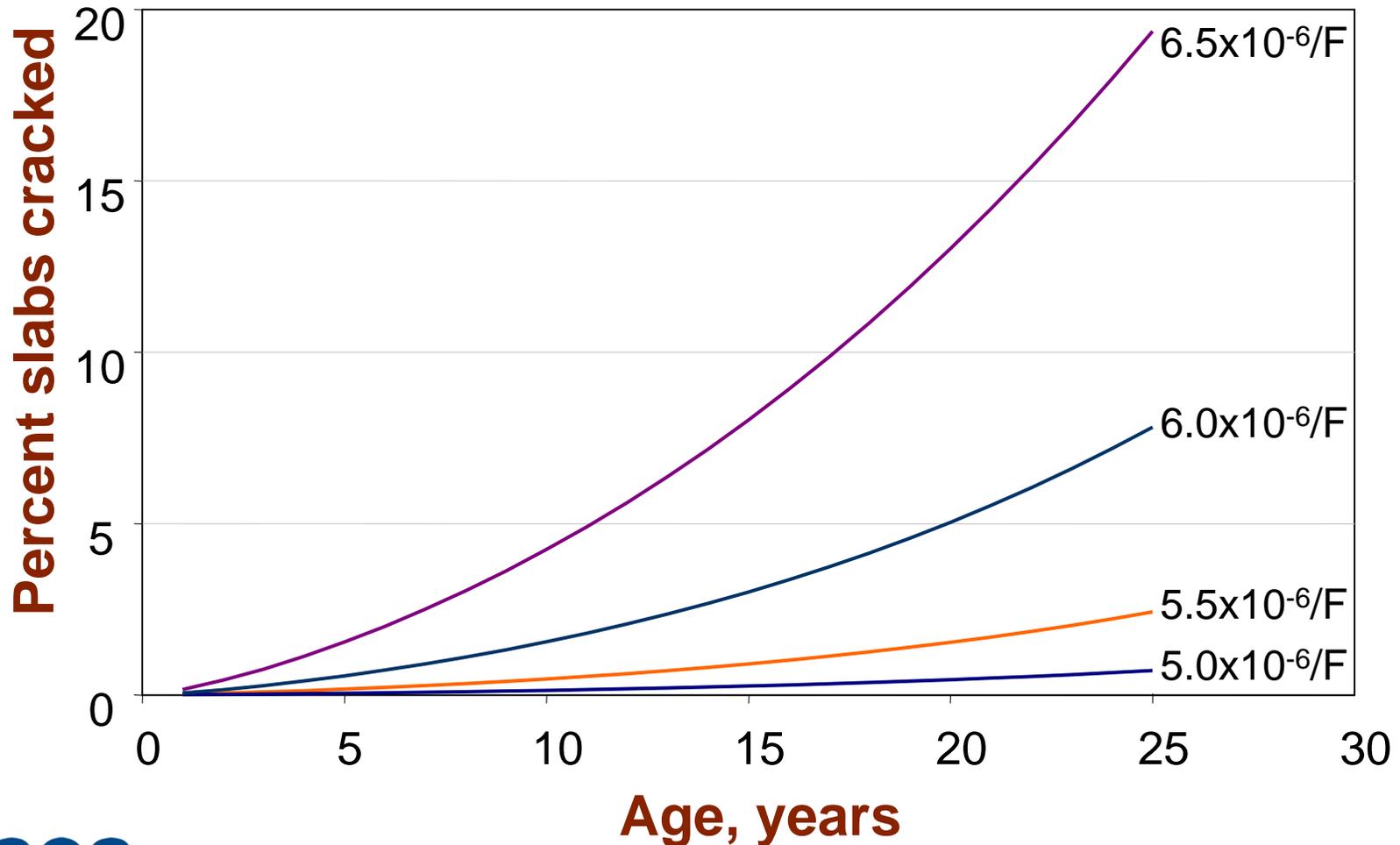


**Test Frame**

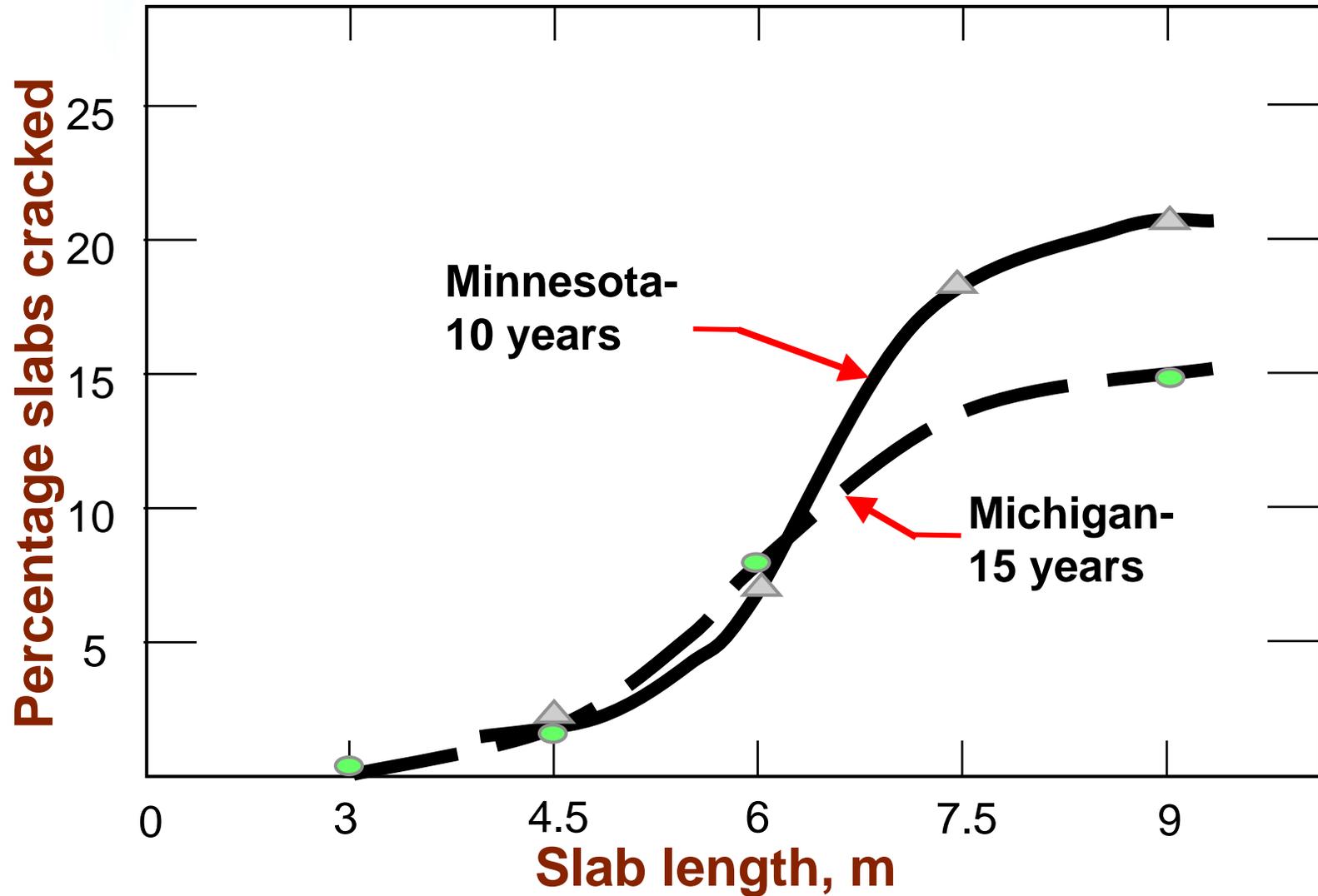
# Effects of PCC Thermal Coefficient



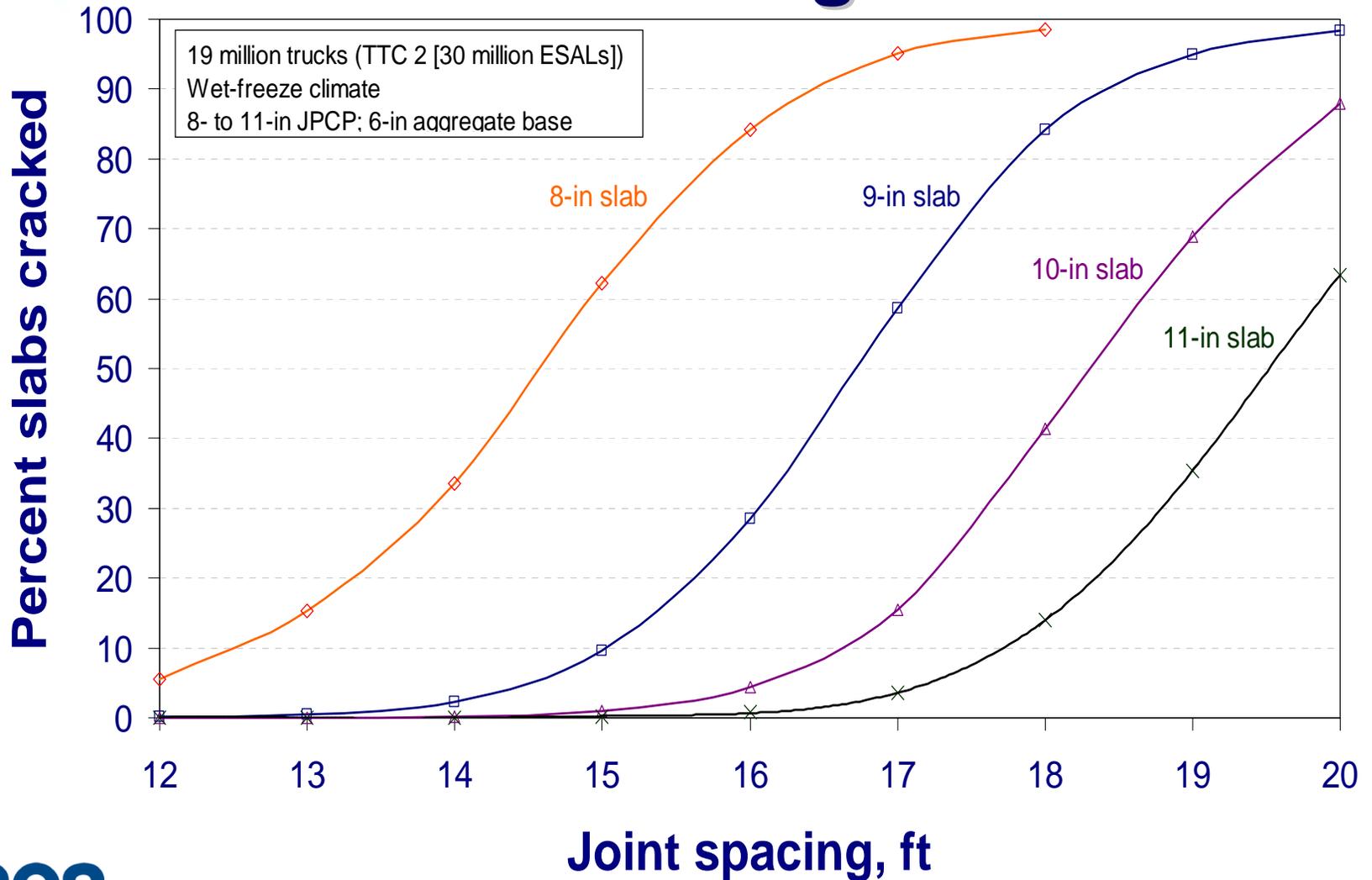
# Concrete Coefficient of Thermal Expansion



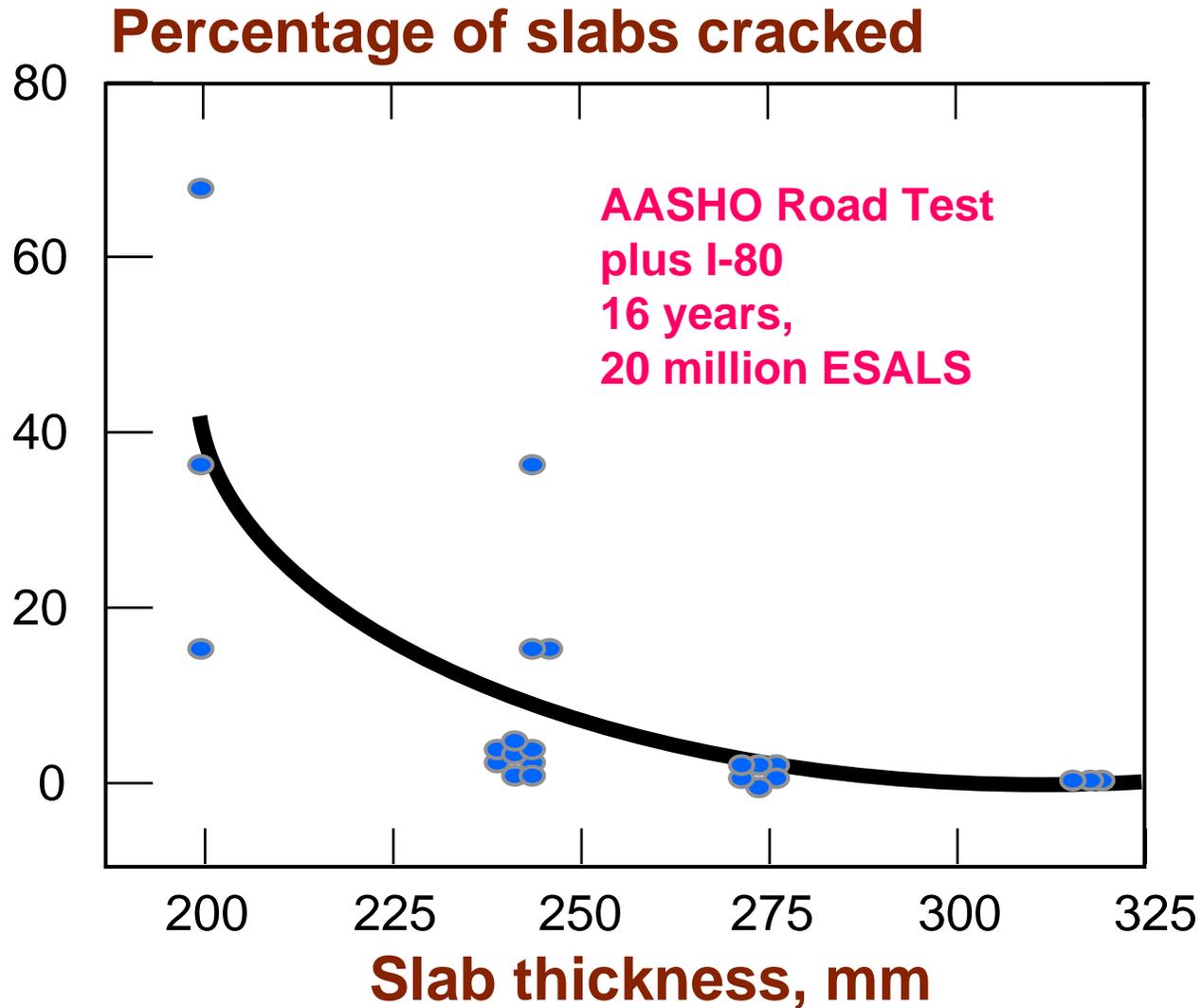
# Slab Length Vs. Cracking



# Slab Thickness & Joint Spacing Vs Cracking

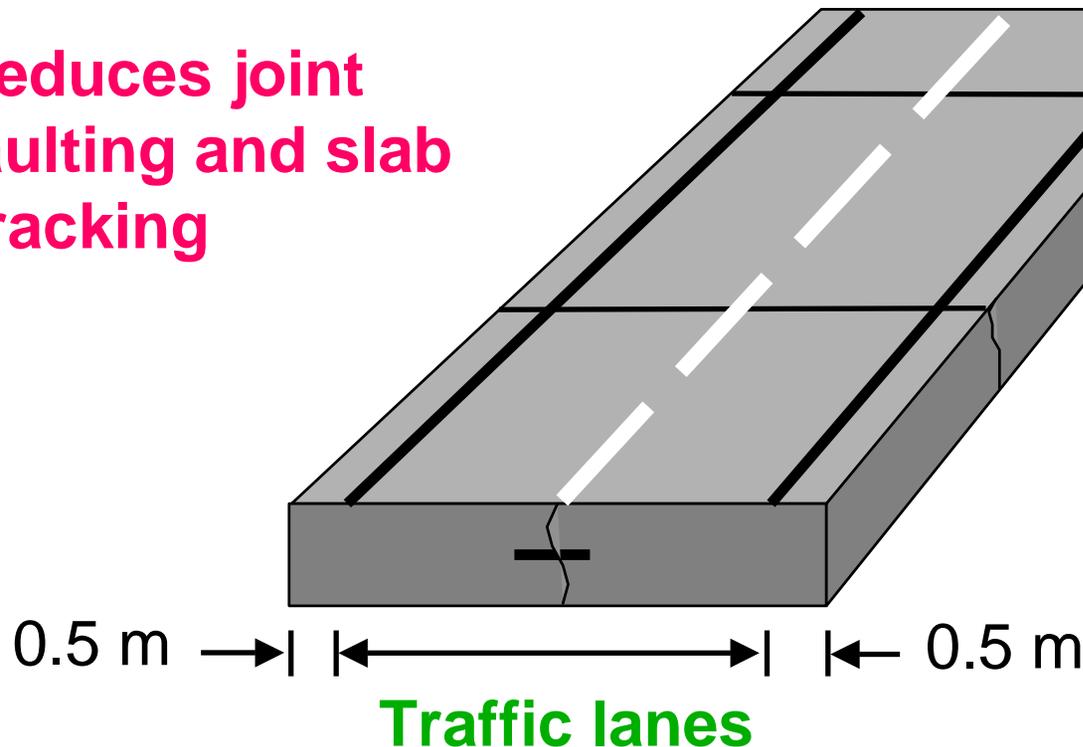


# Slab Thickness Vs. Cracking

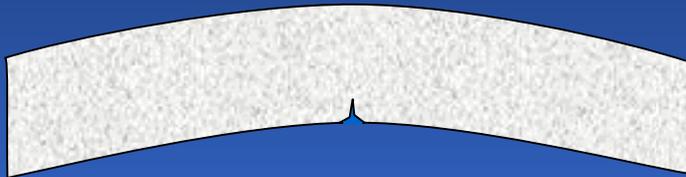


# Widened Slab Design (Cost Effective)

Reduces joint  
faulting and slab  
cracking



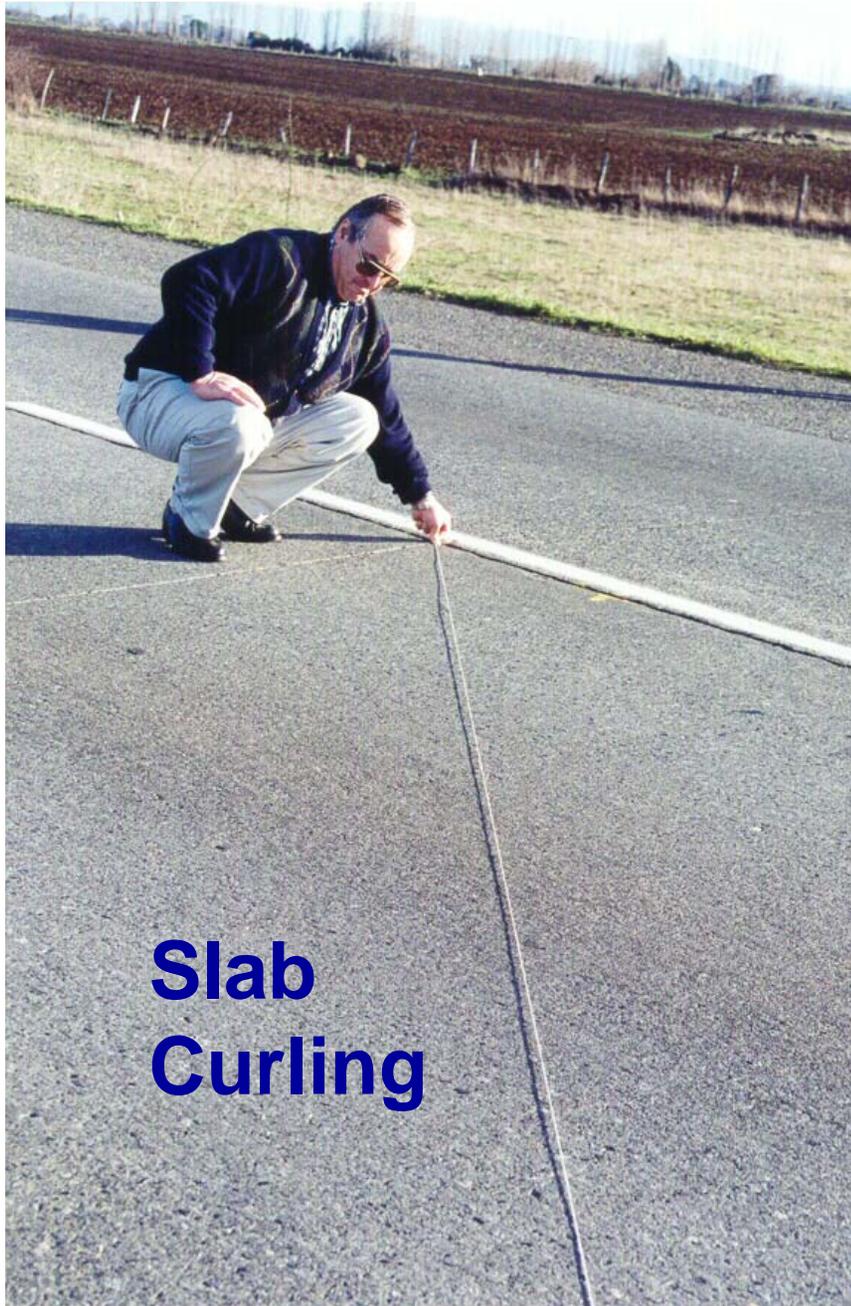
# Climatic Factors Slab Curling/Warping



Positive temp. gradient  
**Bottom Up Cracking**



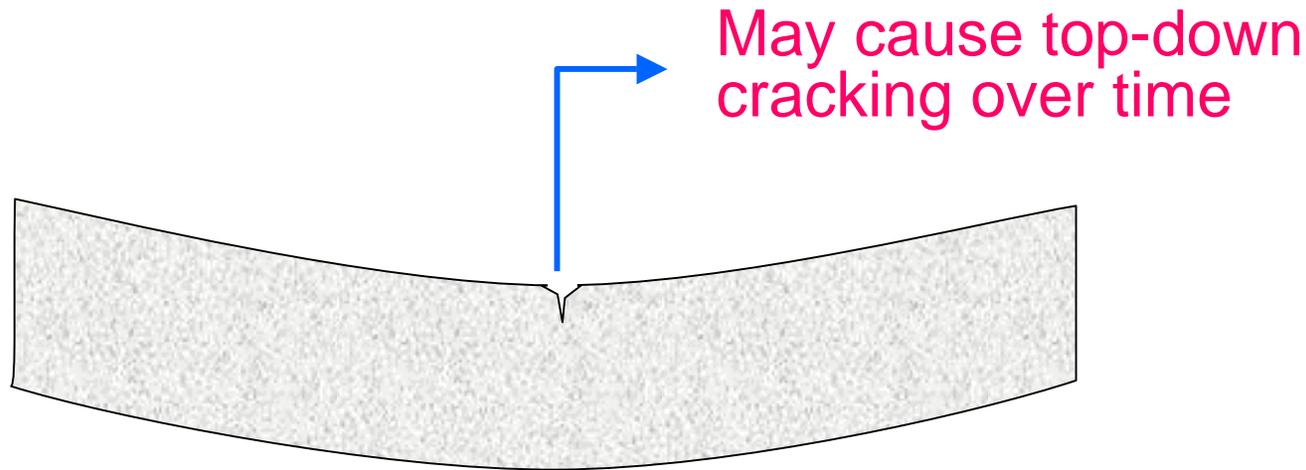
Negative temp. gradient  
& shrinkage of surface  
**Top Down Cracking**



# Slab Curling

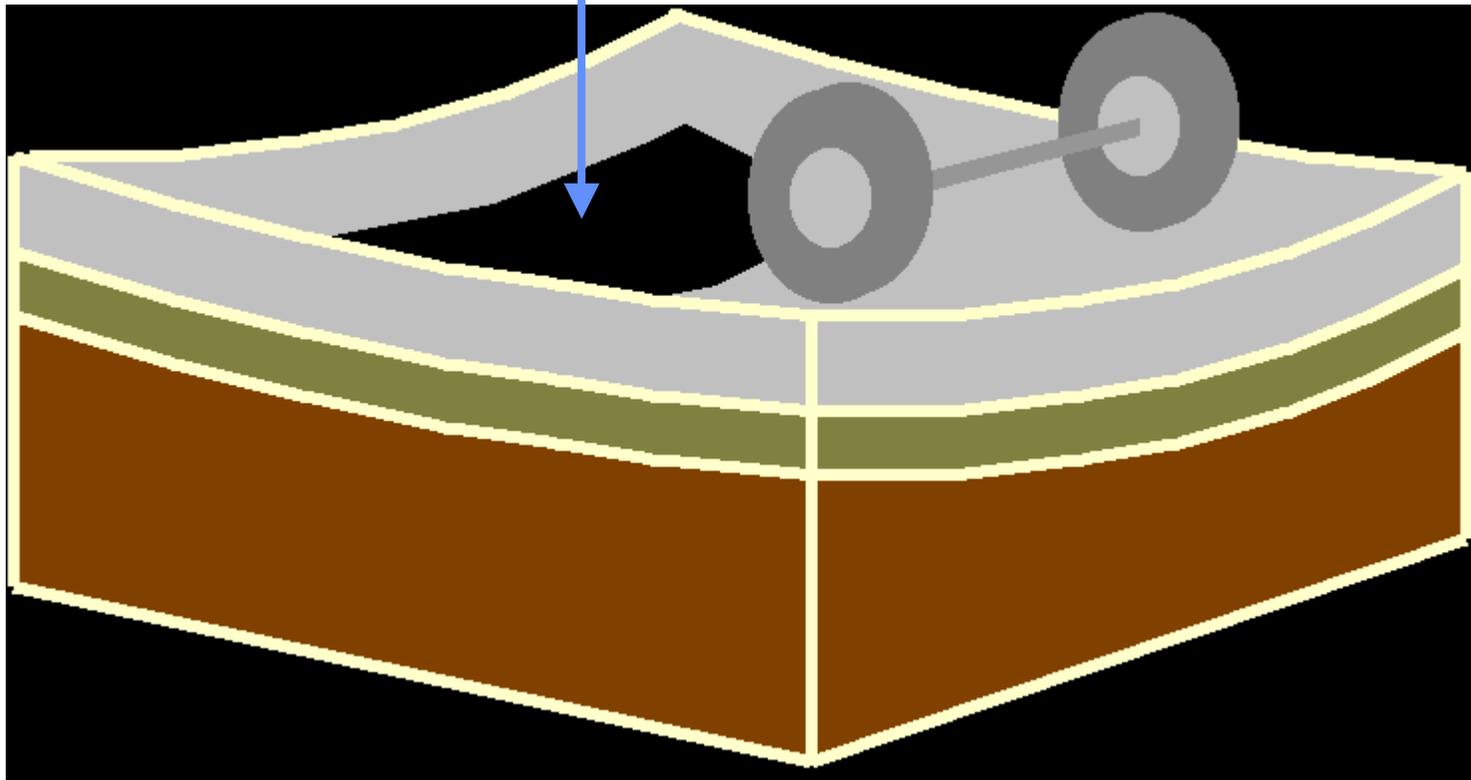
# Construction Curling Problem

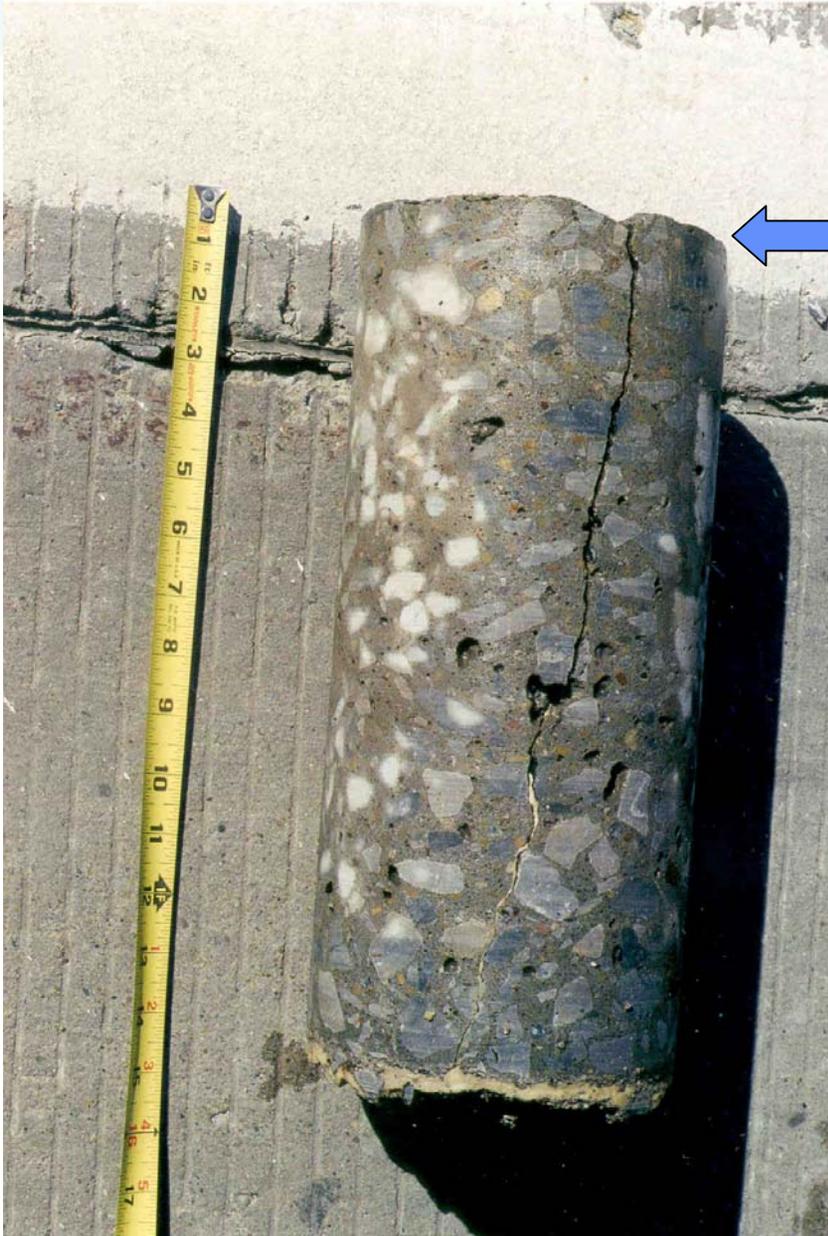
- Sunny, hot morning paving critical
- Negative temperature gradient built into slab results in upward curl over life



# Upward Curl—Top Down Crack

Critical stress region  
at top of slab



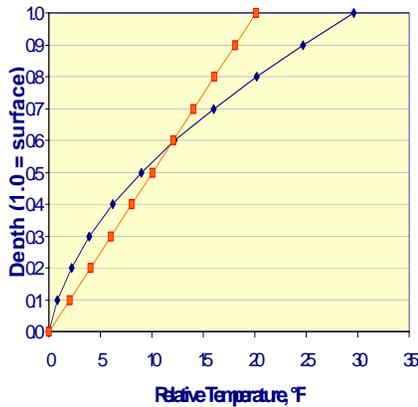


**Top of slab**  
(crack initiation)

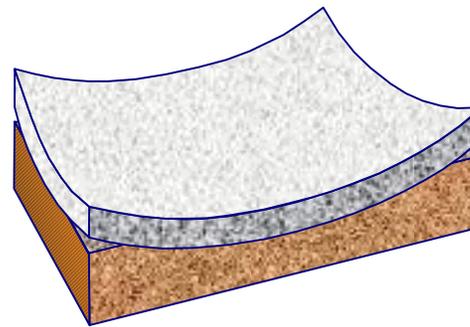
# Now prevent through design & constr.



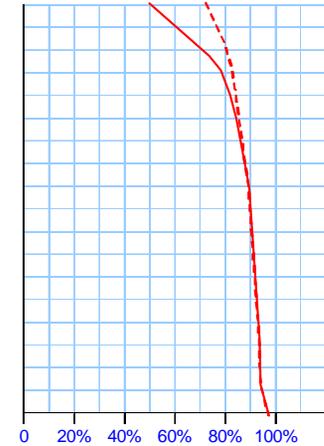
# Components of Curl/Warp Stress (top down cracking risk)



Actual Temperature  
Gradient



Built-in Curling

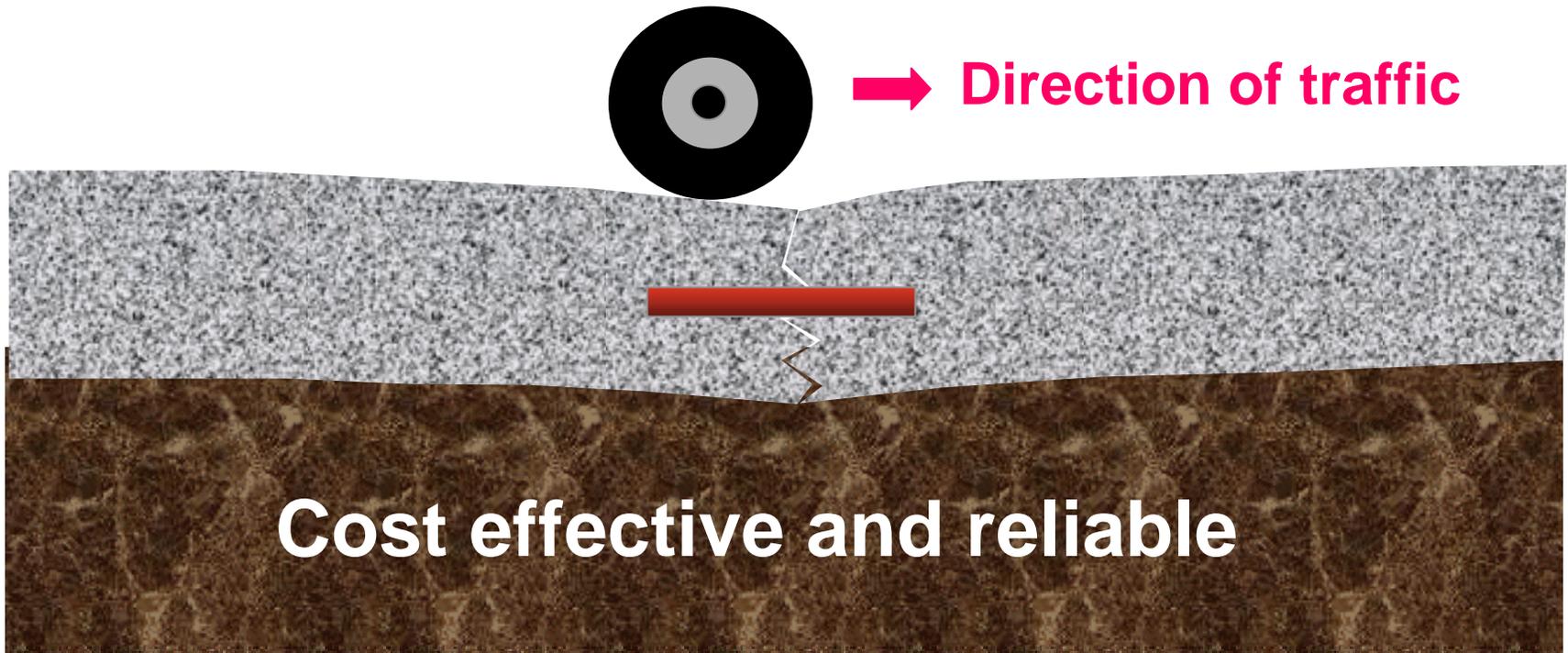


Moisture Gradient

$$\Delta T = \Delta T_{Actual} + \Delta T_{Built-in} + \Delta T_{Shrinkage}$$

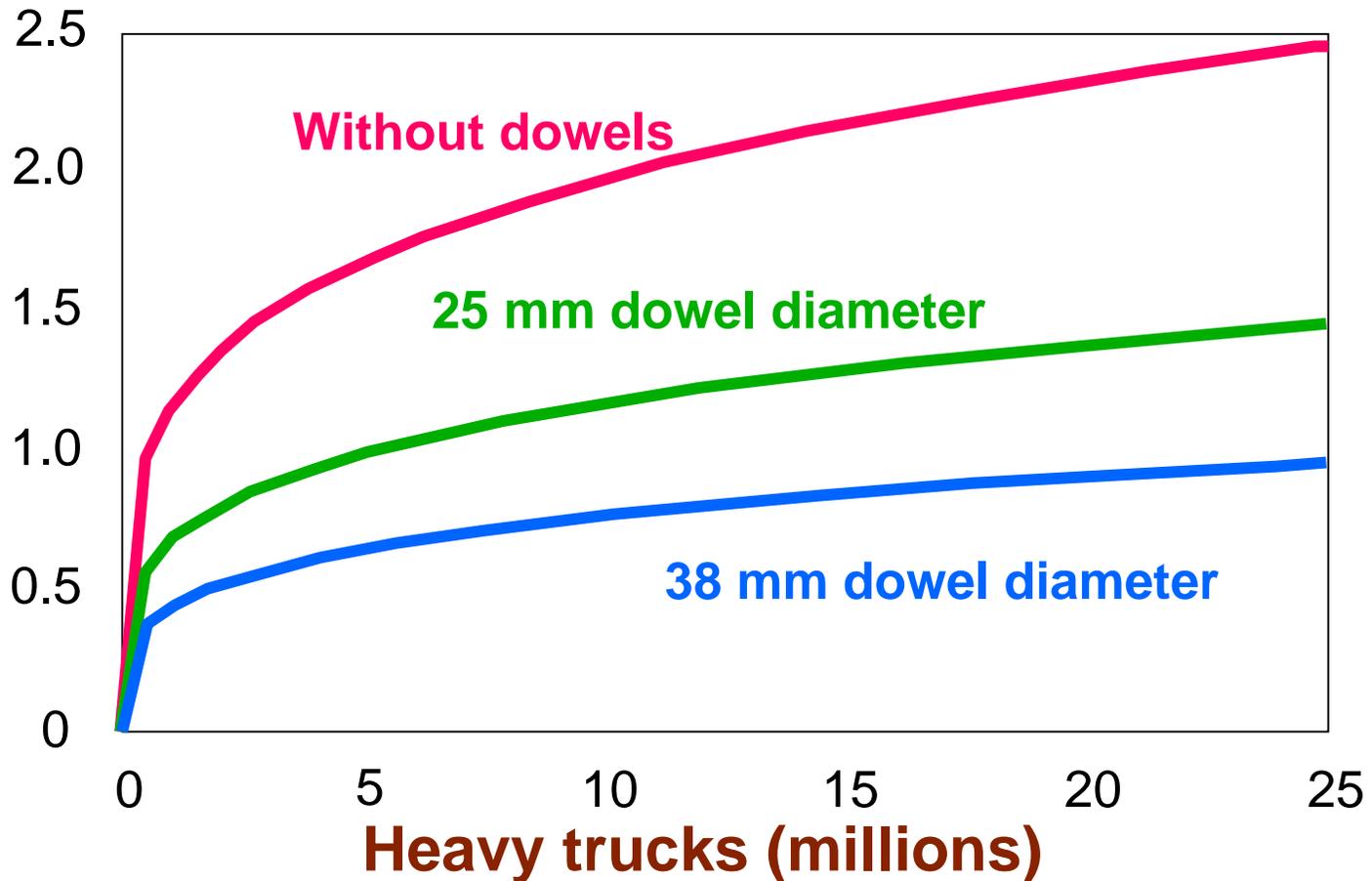
# Joint Load Transfer

- Reduce deflections and stresses



# Joint Performance

## Joint faulting, mm



# Build Concrete Pavement in Your Computer before Building in Field

- Select a trial design
- Obtain inputs, local climate, traffic, soils
- Run Design Guide Software year by year over design life
- Examine performance
- If problems, revise design

# 50-Year Design JPCP Example

- Project Interstate 405 Los Angeles
- Widening of existing 8 to 12-lanes
- ADT 307,000, 5% trucks



# 50-Year Design JPCP — Results Traffic —

- Traffic loadings
  - ✓ Trucks: 126 million/lane/50 years
  - ✓ 4700/day/lane year 1
  - ✓ 9300/day/lane year 50

# 50-Year Design JPCP — Trial Design —

- JPCP slab: 254 mm
- Joint spacing: 4.6 m
- Dowels: 38 mm diameter
- Base: Lean concrete
- Subbase: Aggregate
- Tied concrete shoulder

# 50-Year Design JPCP — Results 250 mm —

- **Joint faulting:** 0.8 mm **ok**
- **Slab cracking:** 11% at 50% Reliability
  - ✓ 25% at 95% Reliability **(too high)**
- **IRI:** 1.41 m/km **ok**

# 50-Year Design JPCP — Results 275 mm —

- **Joint faulting:** 0.7 mm **ok**
- **Slab cracking:** 3.5% at 50% Reliability
  - ✓ 13% at 95% Reliability **ok**
- **IRI:** 1.3 m/km **ok**
- **Acceptable Design**

# The Future?

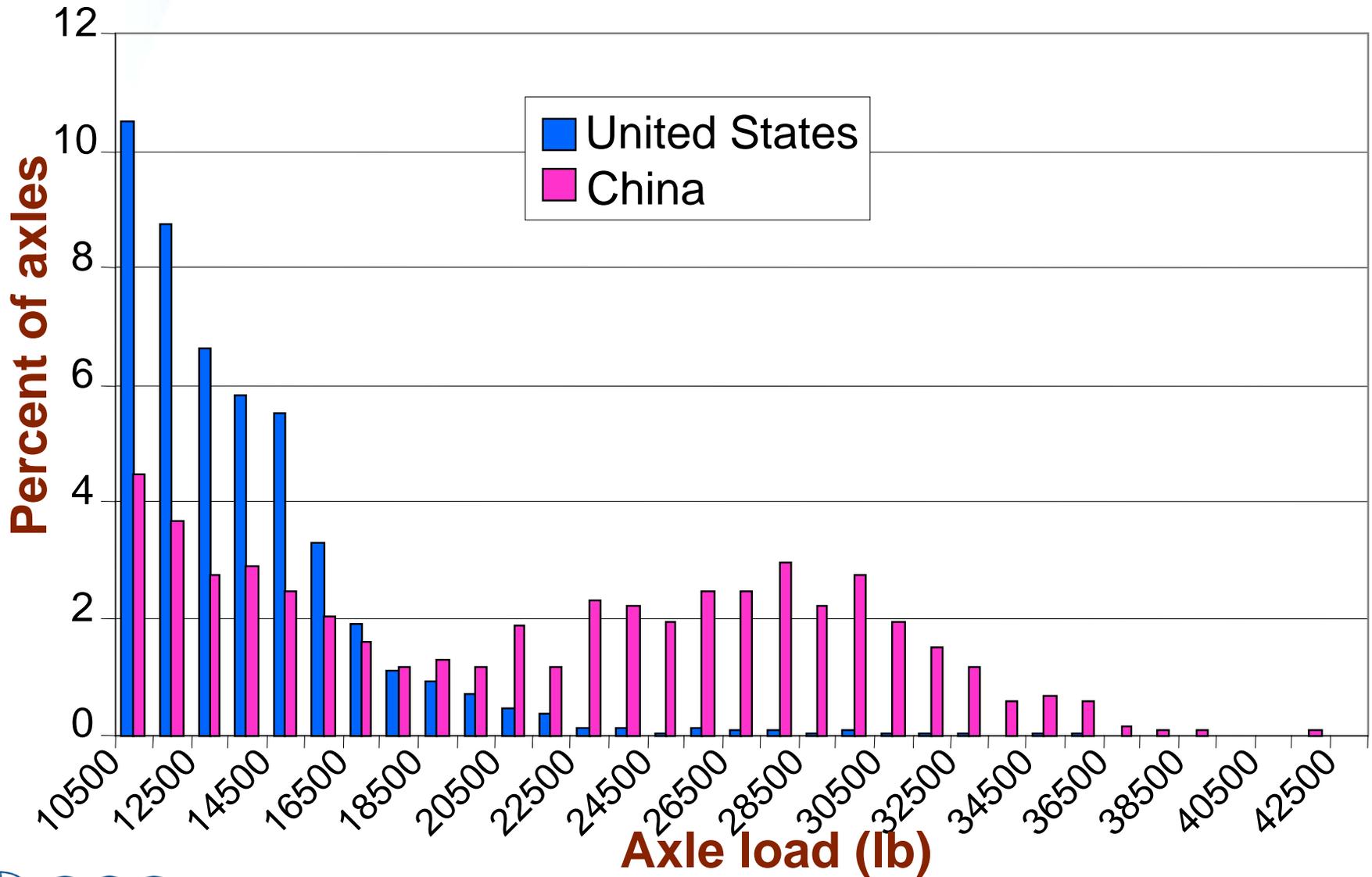


**Challenges down the road**

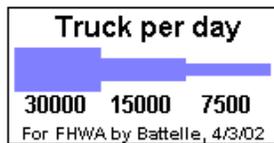
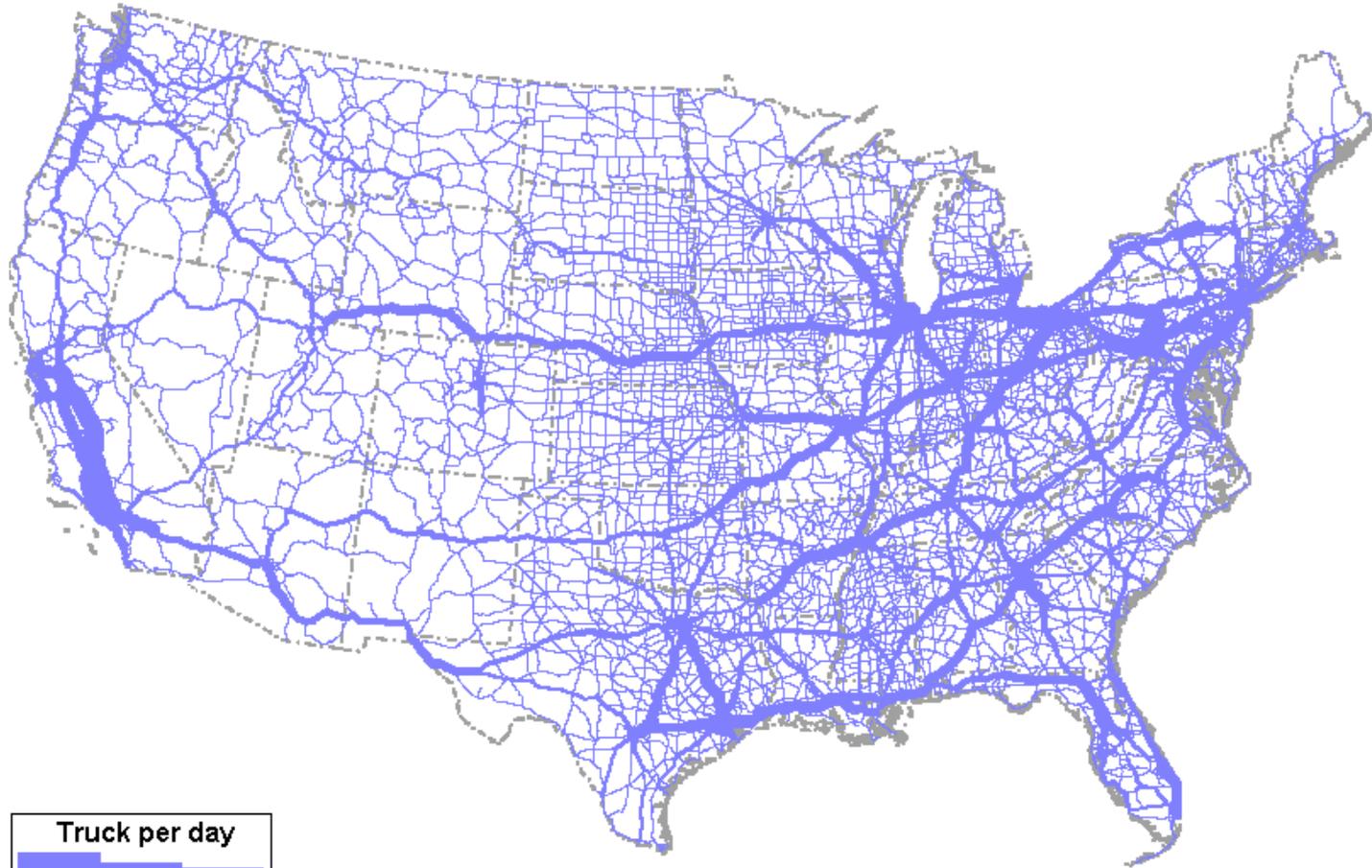


**Traffic Loadings Axle Load Spectra**  
**Single, Tandem, Tridem & Quad**

# The Future: Heavier Axle Loads

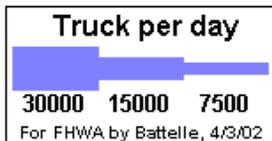
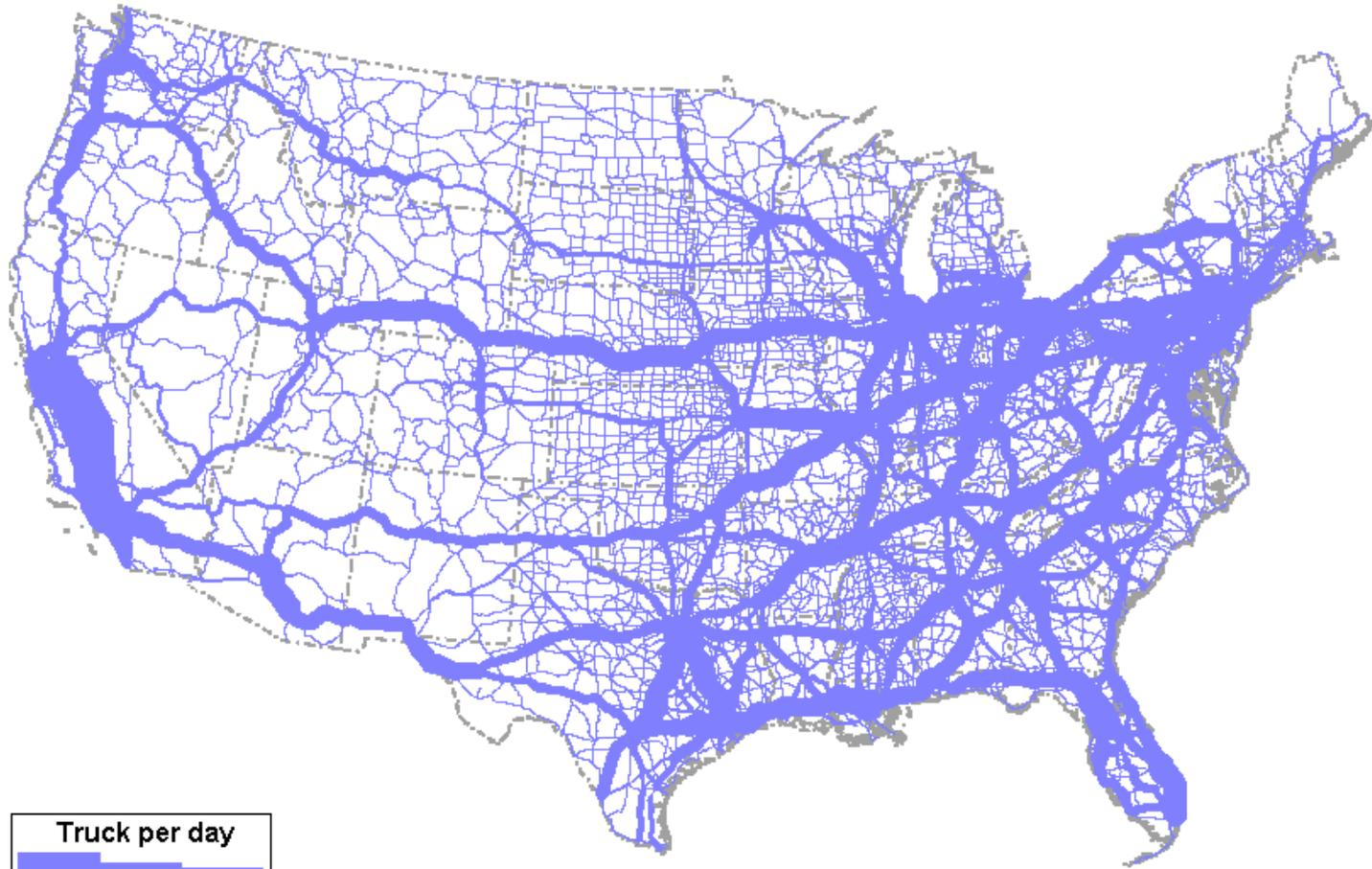


# 1998 Truck Flow



**Battelle**

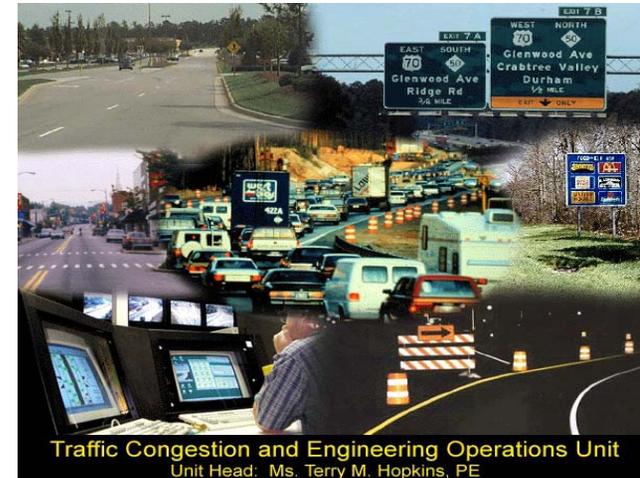
# 2020 Forecast Truck Flow



**Battelle**

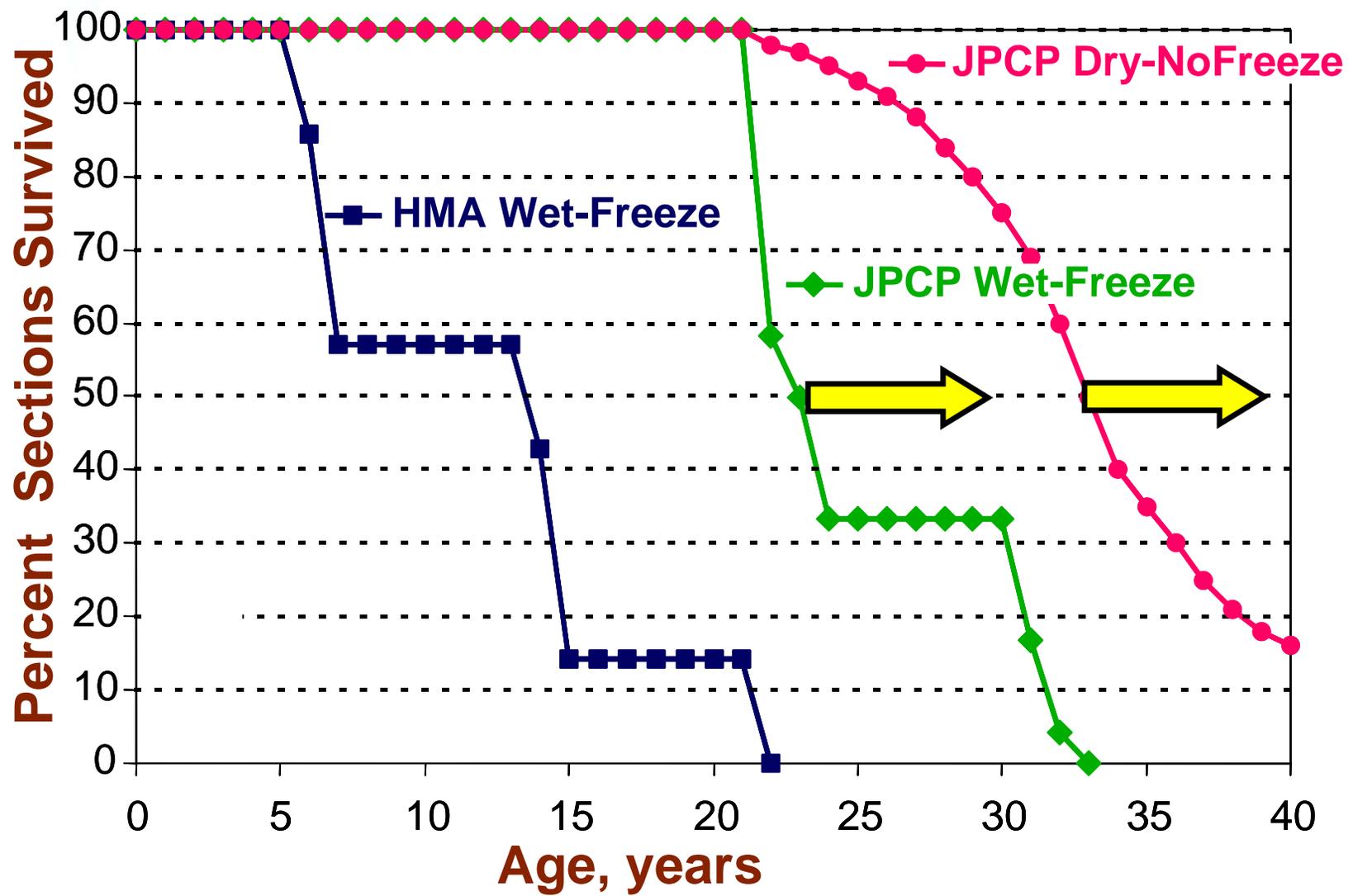
# The Future

- Requirement for no lane closures for many, many years
- Rapid construction and maintenance required



Traffic Congestion and Engineering Operations Unit  
Unit Head: Ms. Terry M. Hopkins, PE

# The Future: Demand Longer Life



# Thank you

Questions? emails welcome 😊  
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