# Use of HIPERPAV & Maturity Testing for Building Quality Concrete Pavements

Virginia Concrete Conference

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*FHWA / Global Consulting*

# Under the Hood

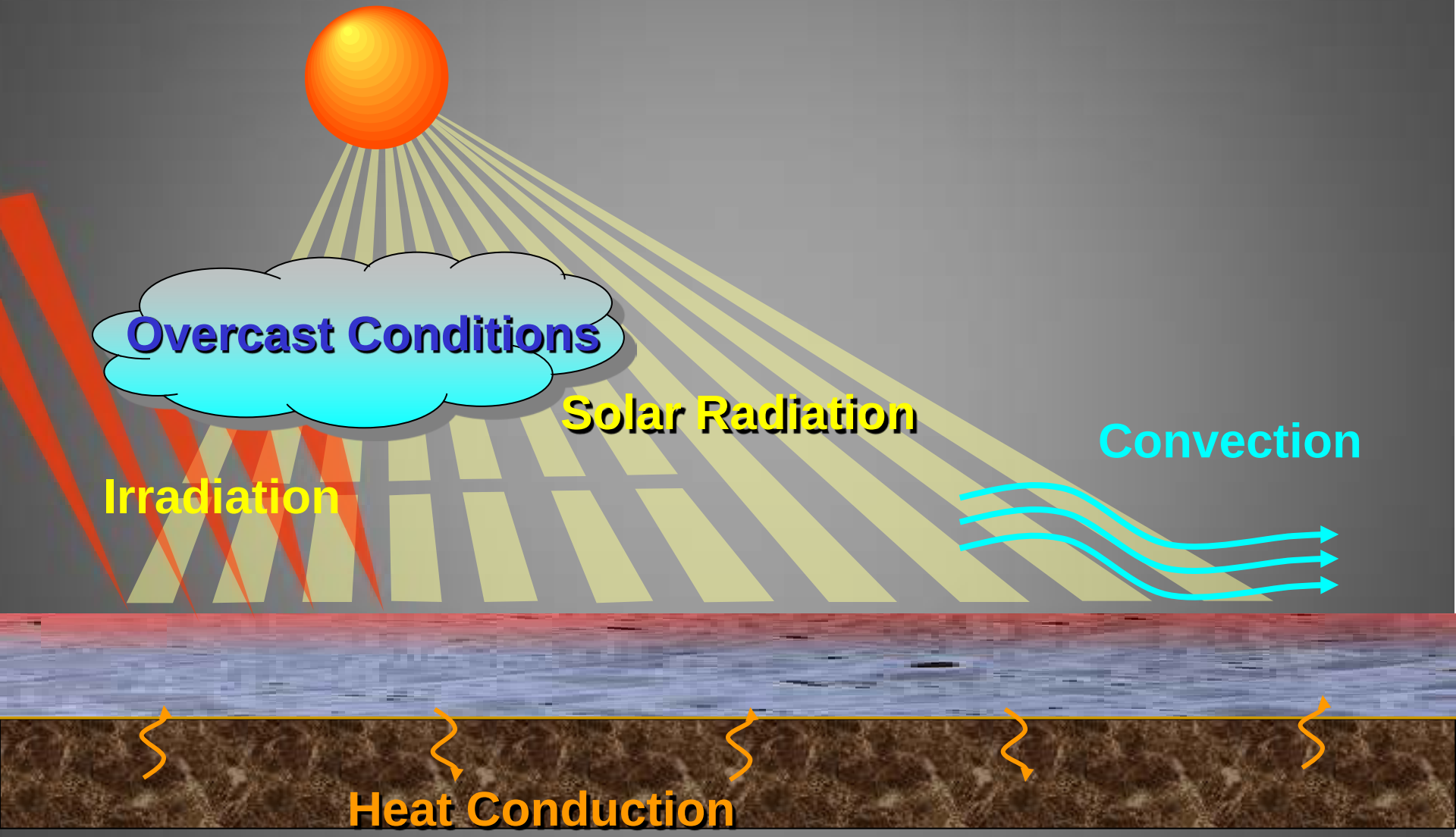
- What does HIPERPAV do?
  - Compares early-age pavement stresses and strengths to determine if cracking is likely
- Why?
  - To help minimize uncontrolled early-age cracking…

# Background

- HIPERPAV uses a Systems Approach to unify several models into one tool that integrates:
  - Design Parameters
  - Material Properties
  - Construction Activities
  - Environmental Conditions

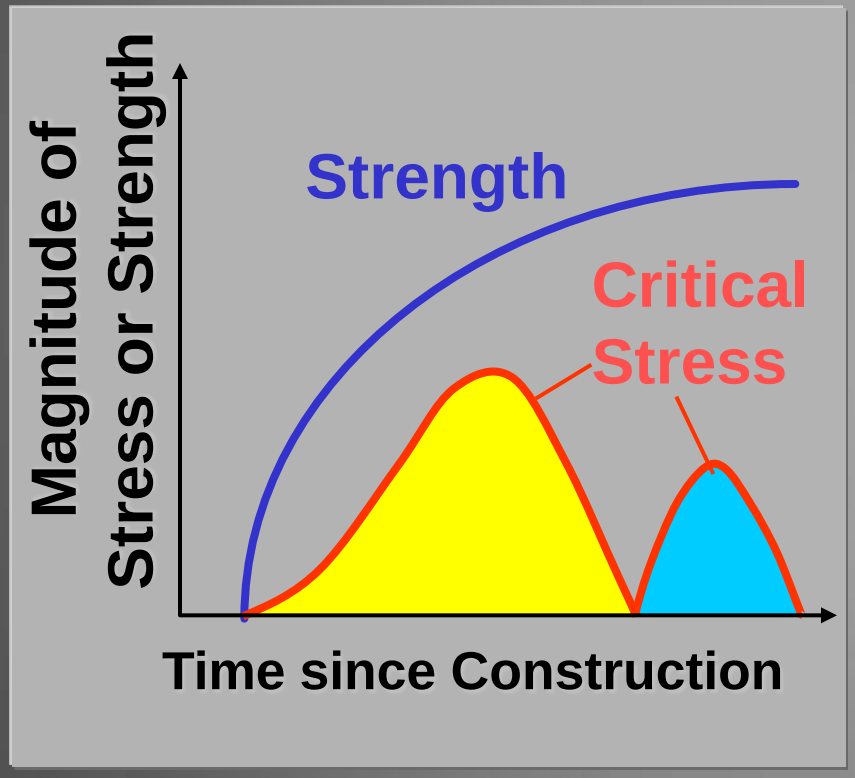
# Environmental Influences

**HIPERPAV**

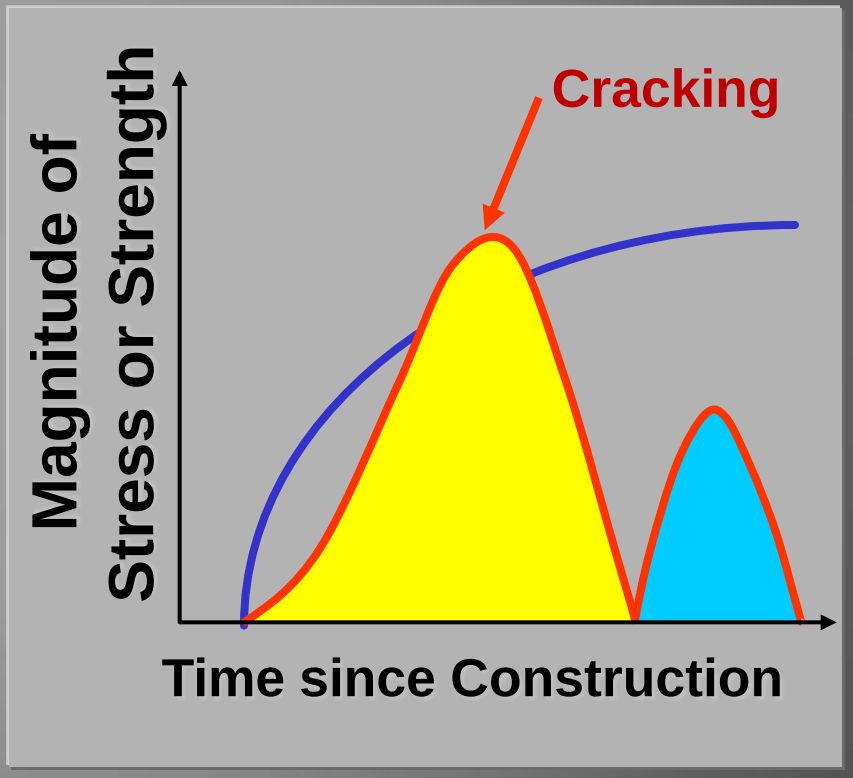



First 72 hours

# Strength and Stress Comparison




Scenario #1




Scenario #2

# Analysis Screen

Scenarios.hp3 * - HIPERPAV 3

File Edit View Strategy Tools Help

Project Info | Strategies

EA JPCP

Analysis - Early-Age JPCP

| Strategy | Status |
|---|---|
| 1 Baseline | Analyzed |
| 2 Cold Front | Analyzed |
| 3 Cold F + cotton | Analyzed |
| 4 Cold F + cott... | Analyzed |

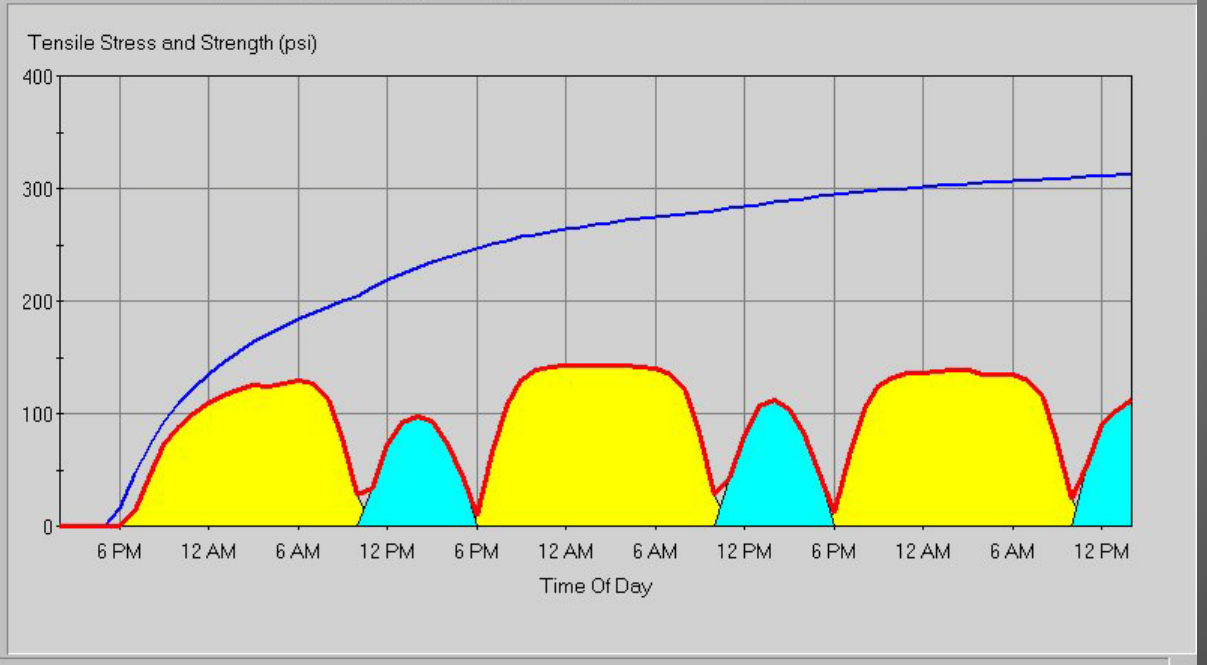
- Strategy Information
- Design
  - Geometry
  - Dowels
  - Slab Support
- Materials and Mix Design
  - Cement
  - PCC Mix
  - PCC Properties
  - Maturity Data
- Construction
- Environment
- **Analysis**
- **Evaporation Rate Analysis**

Display Units (y-axis)
- U.S. Customary (psi)
- Metric (kPa)

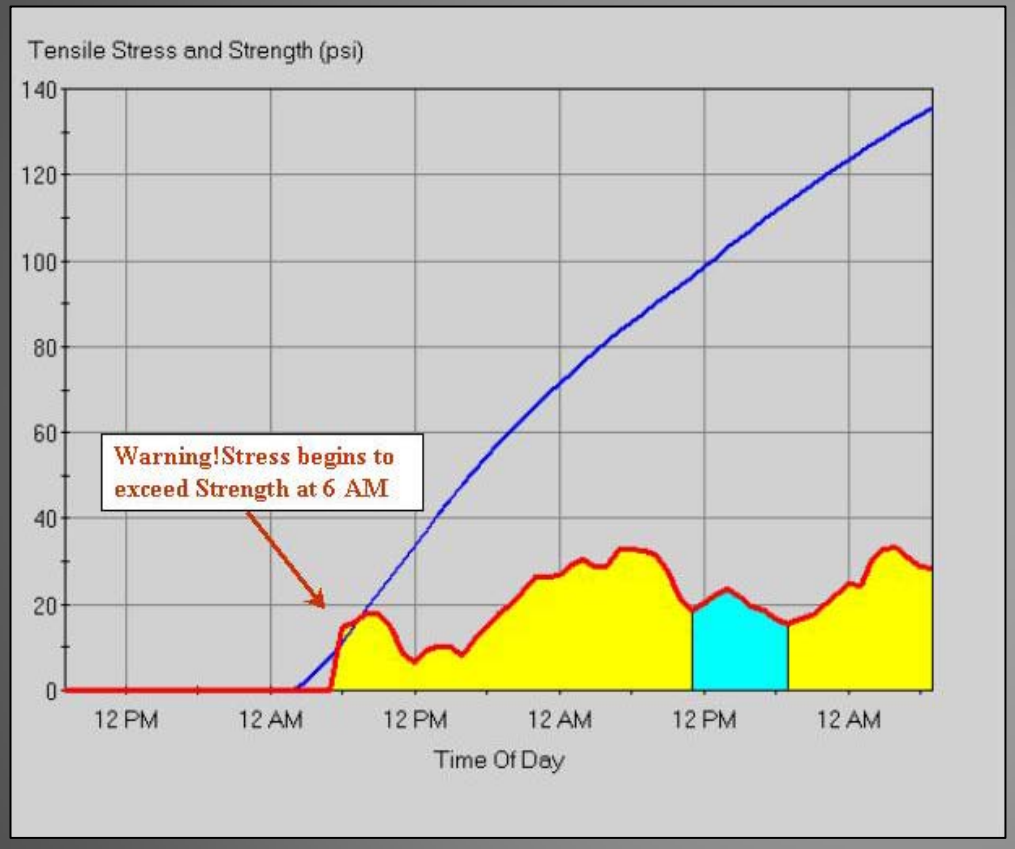
Time Display (x-axis)
- Elapsed Time
- Time of Day

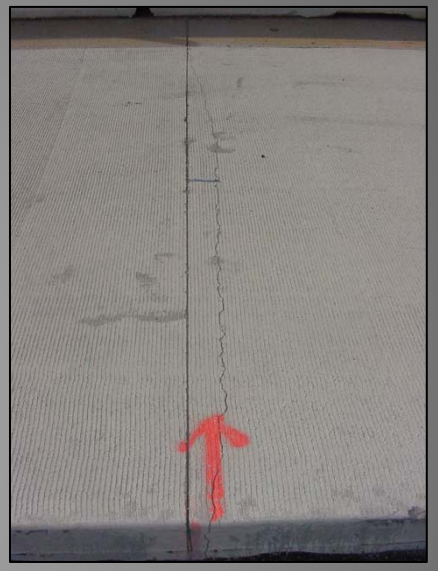
☑ Autoscale
☑ HIPERPAV 2 Chart

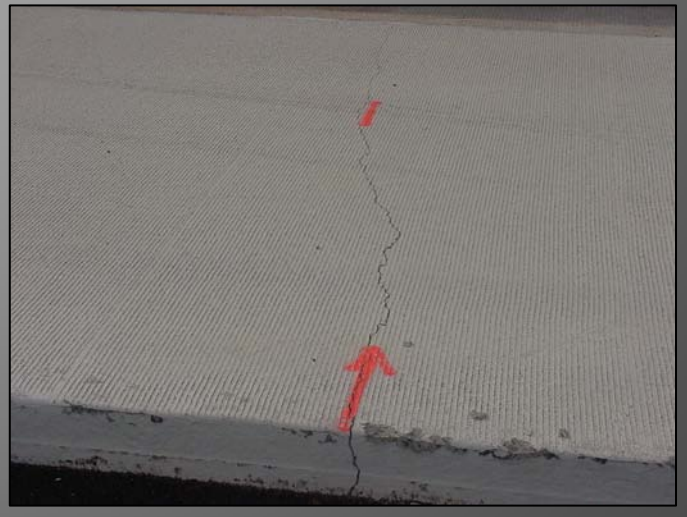
| Hour | Time | PCC Strength | Critical Stress | Critical Stress at Slab Top | Critical Stress at Slab Bottom |
|---|---|---|---|---|---|
| 0 | 2 PM | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 3 PM | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 4 PM | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 5 PM | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 6 PM | 16.6 | 0.0 | 0.0 | 0.0 |
| 5 | 7 PM | 46.4 | 13.5 | 13.5 | 0.0 |
| 6 | 8 PM | 71.7 | 45.9 | 45.9 | 0.0 |
| 7 | 9 PM | 92.0 | 72.4 | 72.4 | 0.0 |
| 8 | 10 PM | 108.9 | 88.5 | 88.5 | 0.0 |
| 9 | 11 PM | 123.1 | 100.2 | 100.2 | 0.0 |



# Risk Analysis



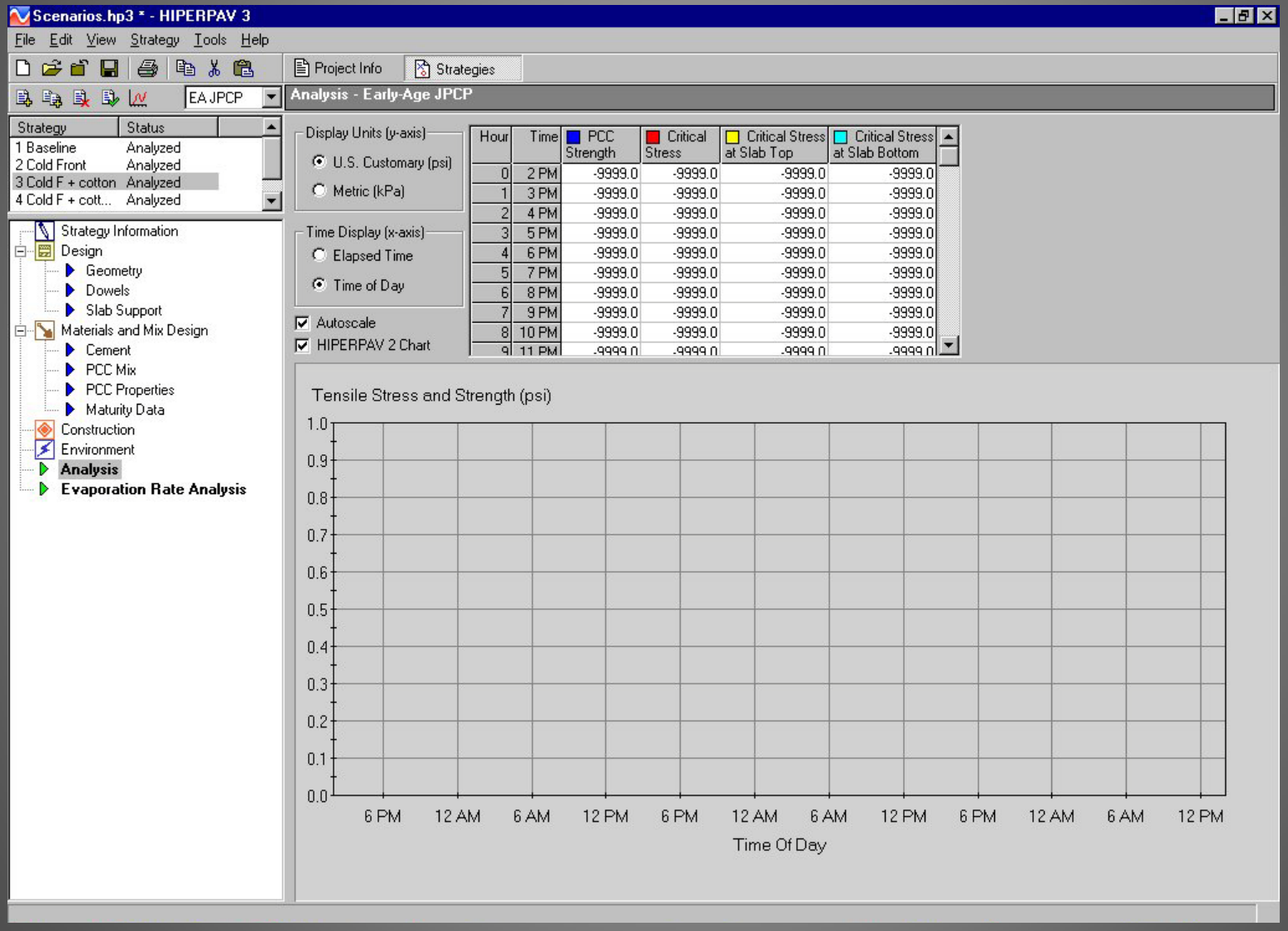





# Baseline Case

- I-35 bypass, Austin TX
- September 2003, mid-day paving
- 10” JPCP with 15’ joint spacing
- Unbound aggregate base
- Concrete Mix:
  - Type I with 18% F-Ash
  - 350psi tensile opening strength
- Early-entry saw with curing compound

# Baseline Case



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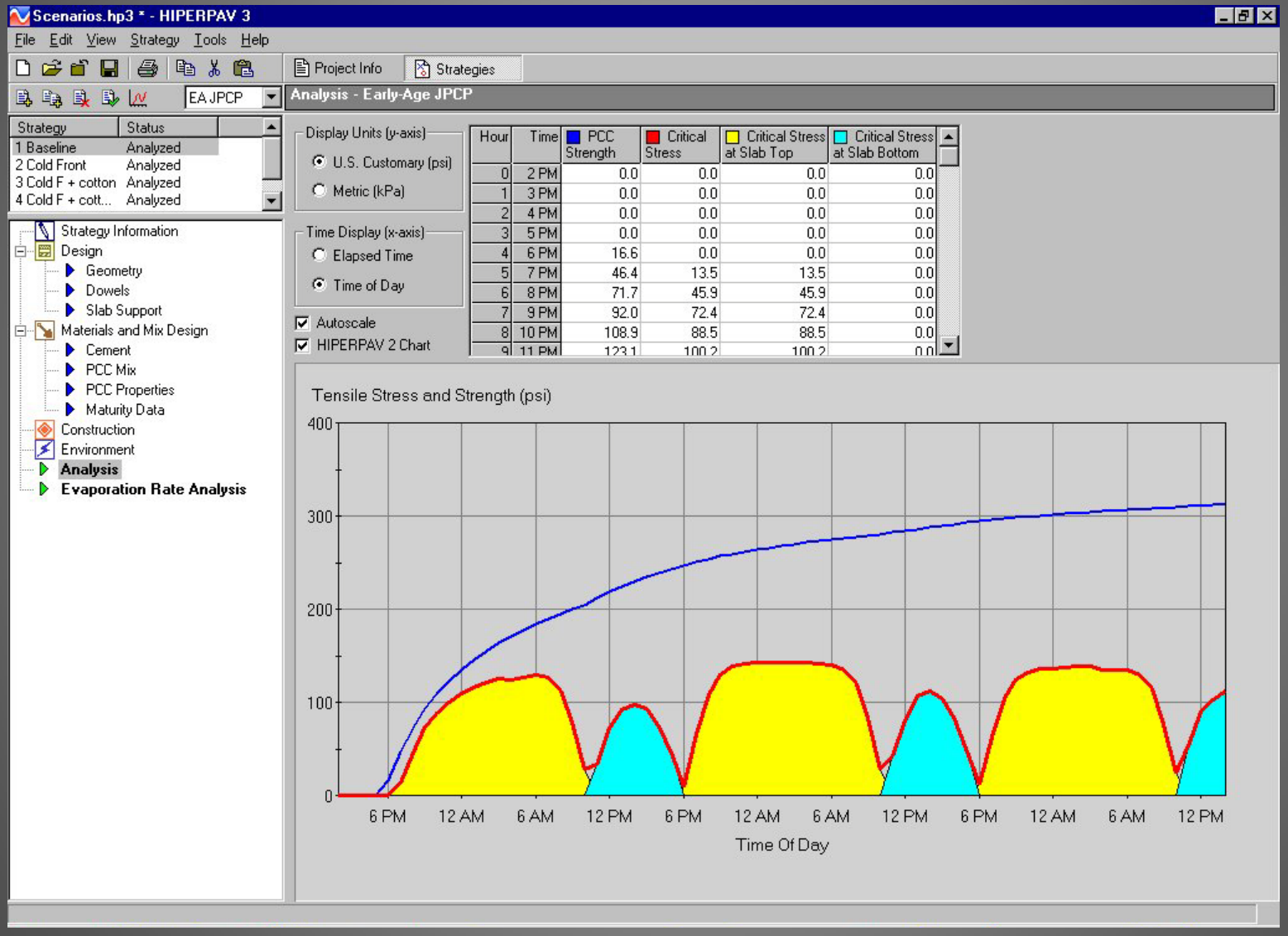
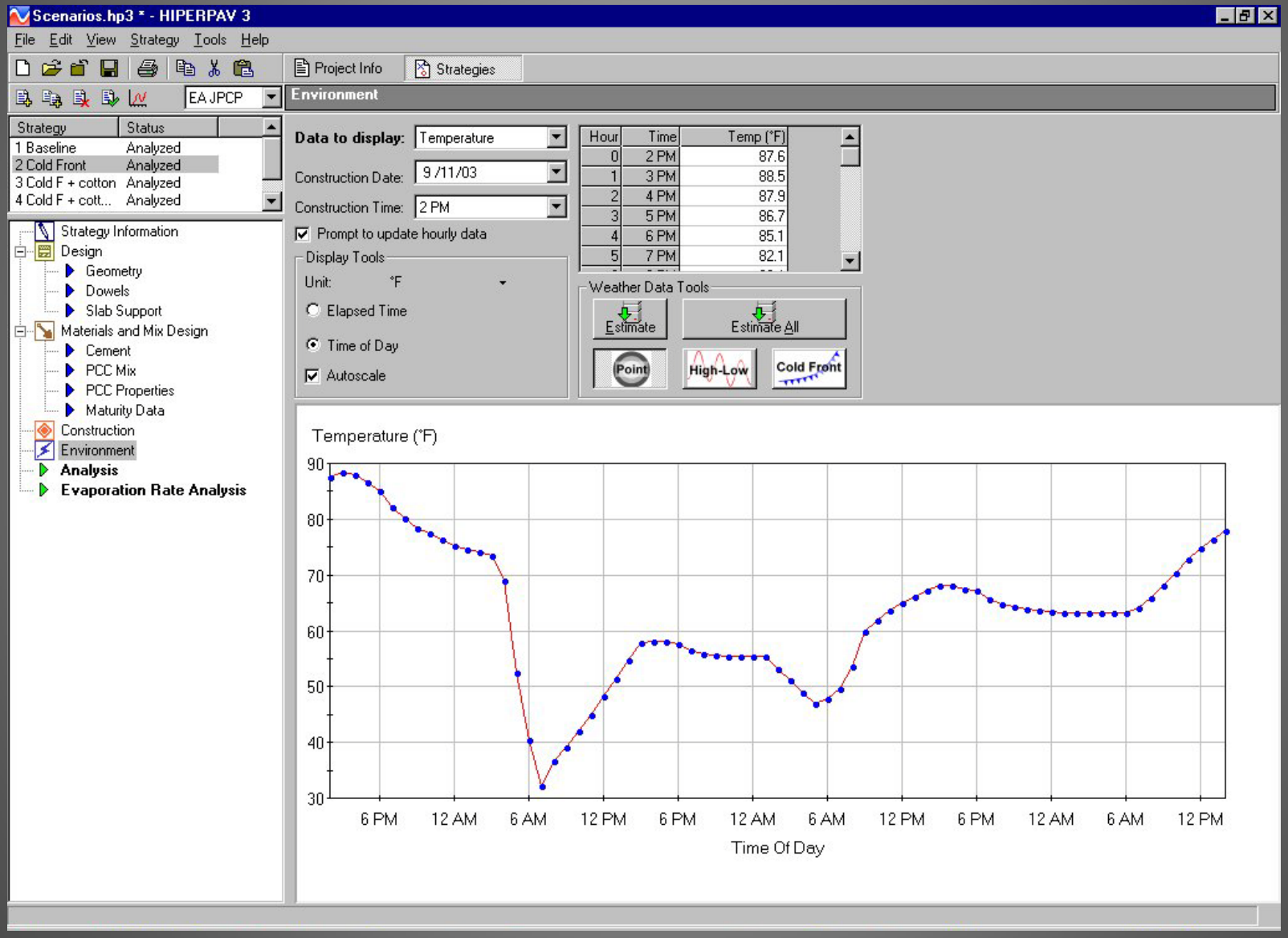


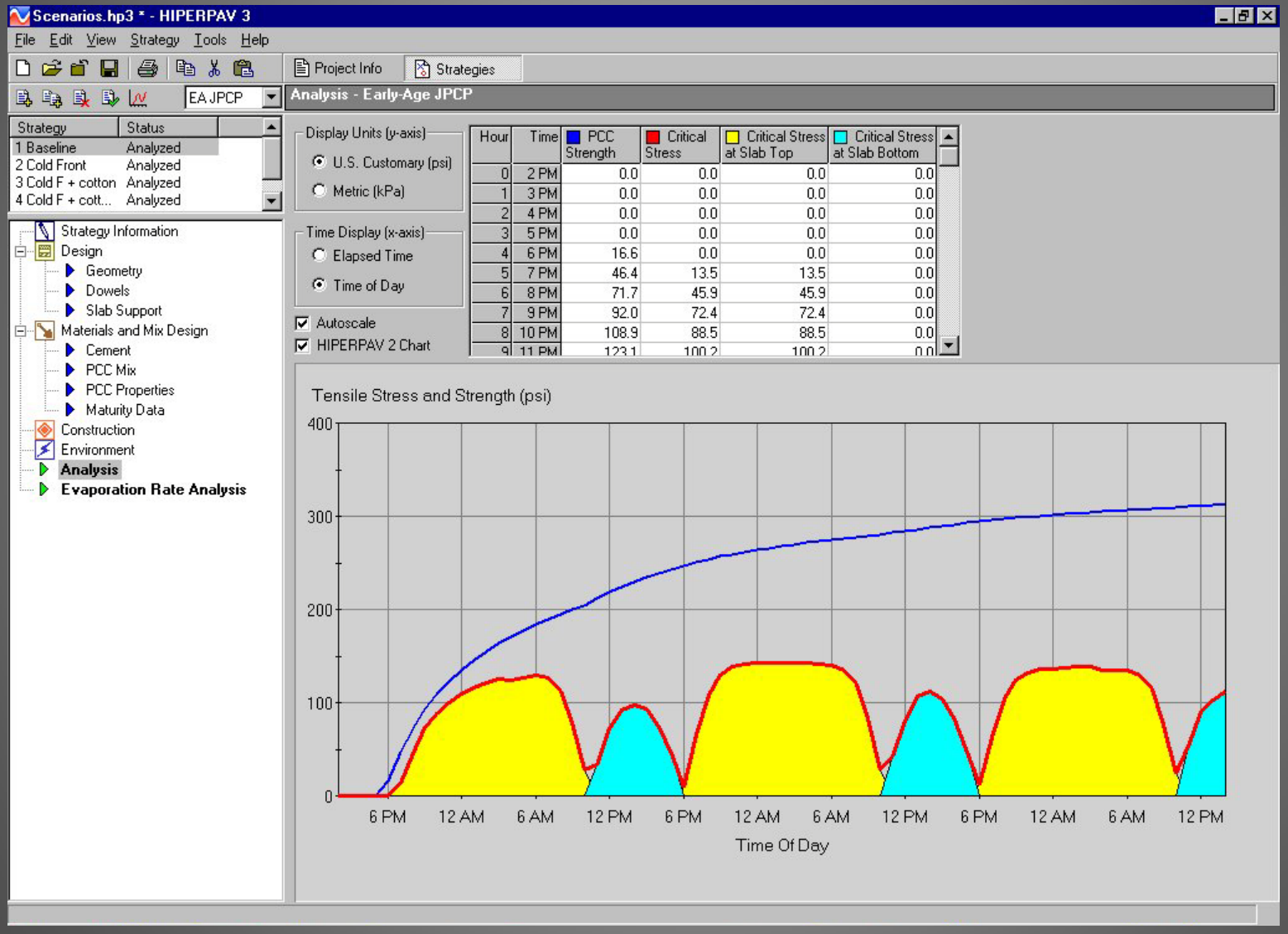
Well, that’s nice…

But, what if the weather is not “ideal”?

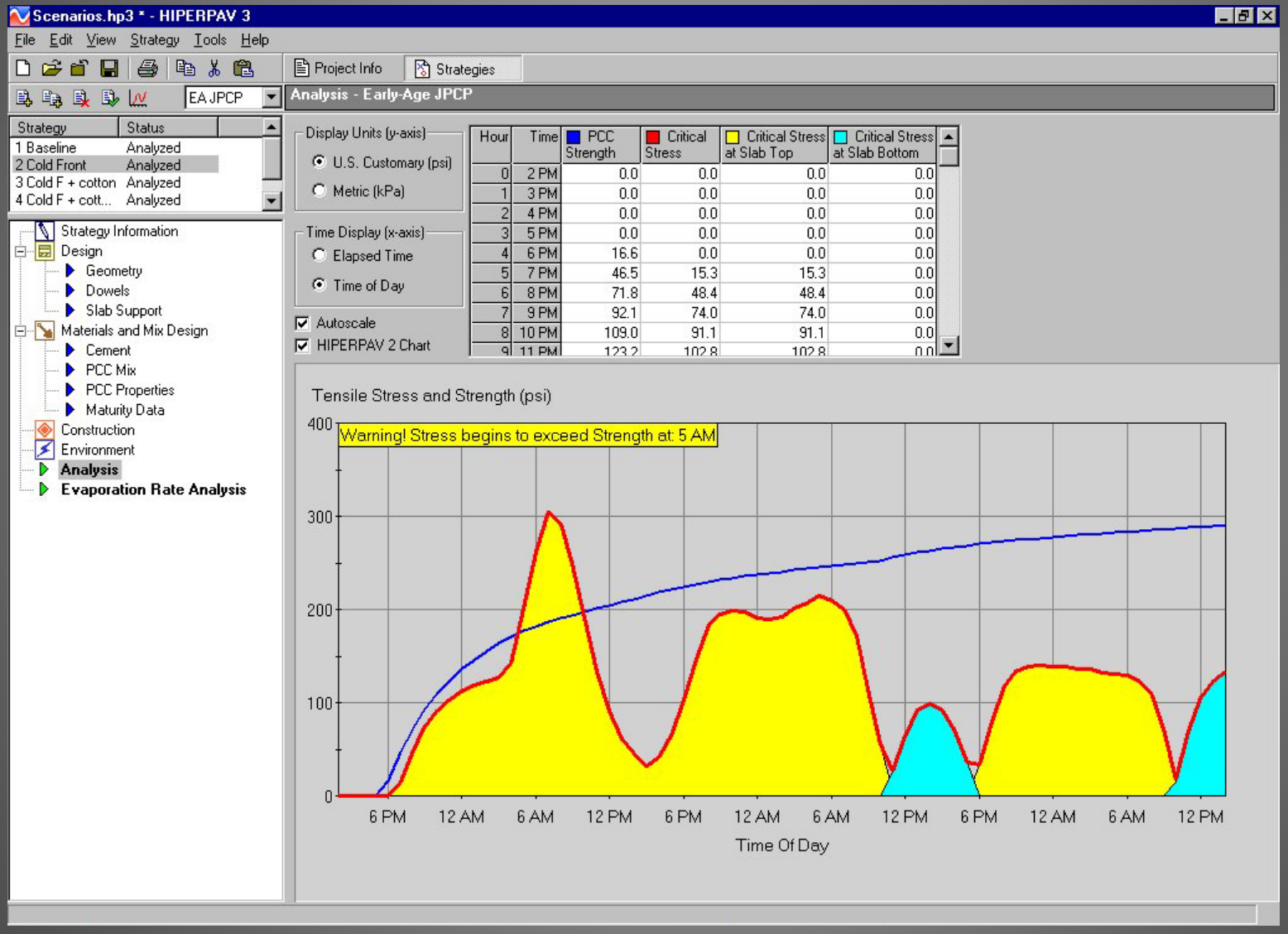
# Cold Front


Scenarios.hp3 * - HIPERPAV 3
File Edit View Strategy Tools Help
Project Info
Strategies
EA JPCP
Environment
Strategy Status
1 Baseline Analyzed
2 Cold Front Analyzed
3 Cold F + cotton Analyzed
4 Cold F + cott... Analyzed
Strategy Information
Design
Geometry
Dowels
Slab Support
Materials and Mix Design
Cement
PCC Mix
PCC Properties
Maturity Data
Construction
Environment
Analysis
Evaporation Rate Analysis
Data to display: Temperature
Construction Date: 9 /11/03
Construction Time: 2 PM
Prompt to update hourly data
Display Tools
Unit: °F
Elapsed Time
Time of Day
Autoscale
Hour Time Temp (°F)
0 2 PM 87.6
1 3 PM 88.5
2 4 PM 87.9
3 5 PM 86.7
4 6 PM 85.1
5 7 PM 82.1
Weather Data Tools
Estimate
Estimate All
Point
High-Low
Cold Front
Temperature (°F)
90
80
70
60
50
40
30
6 PM
12 AM
6 AM
12 PM
6 PM
12 AM
6 AM
12 PM
6 PM
12 AM
6 AM
12 PM
Time Of Day

# Baseline Case



# Cold Front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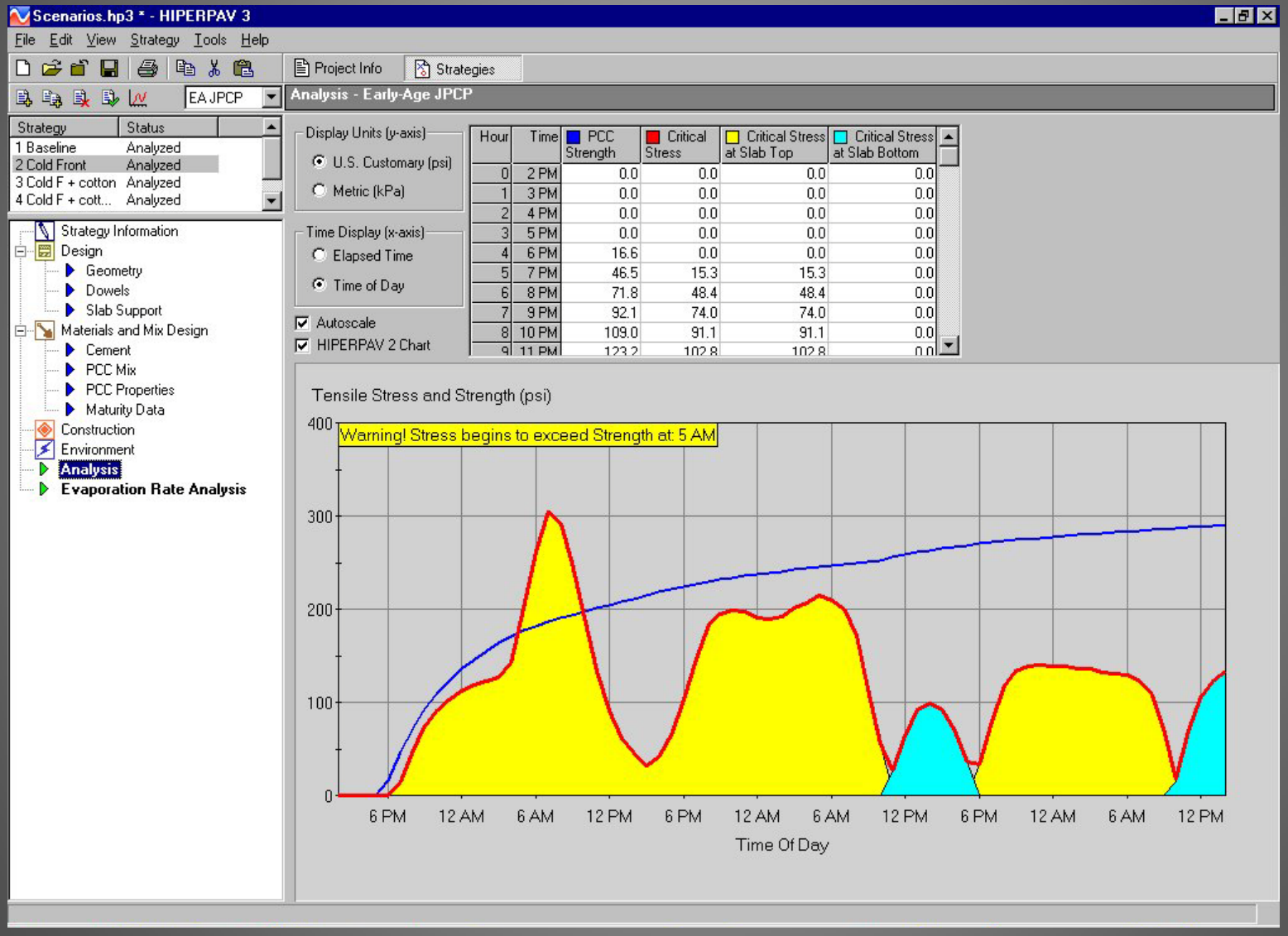
U.S. Customary (psi)
Metric (kPa)
Time Display (x-axis)
Elapsed Time
Time of Day
Autoscale
HIPERPAV 2 Chart
Hour Time PCC Strength Critical Stress Critical Stress at Slab Top Critical Stress at Slab Bottom
0 2 PM 0.0 0.0 0.0 0.0
1 3 PM 0.0 0.0 0.0 0.0
2 4 PM 0.0 0.0 0.0 0.0
3 5 PM 0.0 0.0 0.0 0.0
4 6 PM 16.6 0.0 0.0 0.0
5 7 PM 46.5 15.3 15.3 0.0
6 8 PM 71.8 48.4 48.4 0.0
7 9 PM 92.1 74.0 74.0 0.0
8 10 PM 109.0 91.1 91.1 0.0
9 11 PM 123.2 102.8 102.8 0.0
Tensile Stress and Strength (psi)
Warning! Stress begins to exceed Strength at: 5 AM
400
300
200
100
0
6 PM 12 AM 6 AM 12 PM 6 PM 12 AM 6 AM 12 PM 6 PM 12 AM 6 AM 12 PM
Time Of Day

What Now?

Maybe some Polyethylene Sheeting or Blankets?

# Cold Front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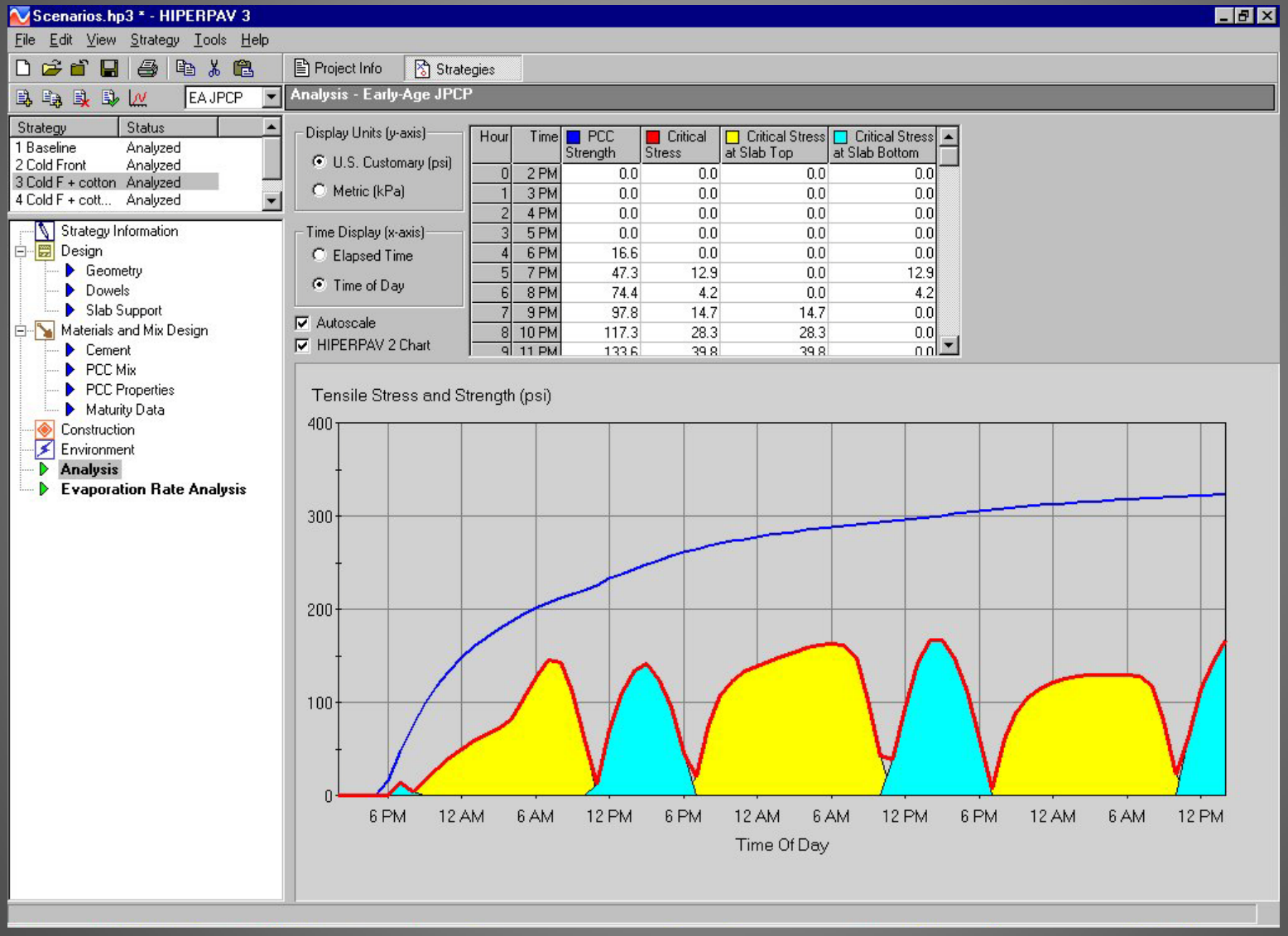
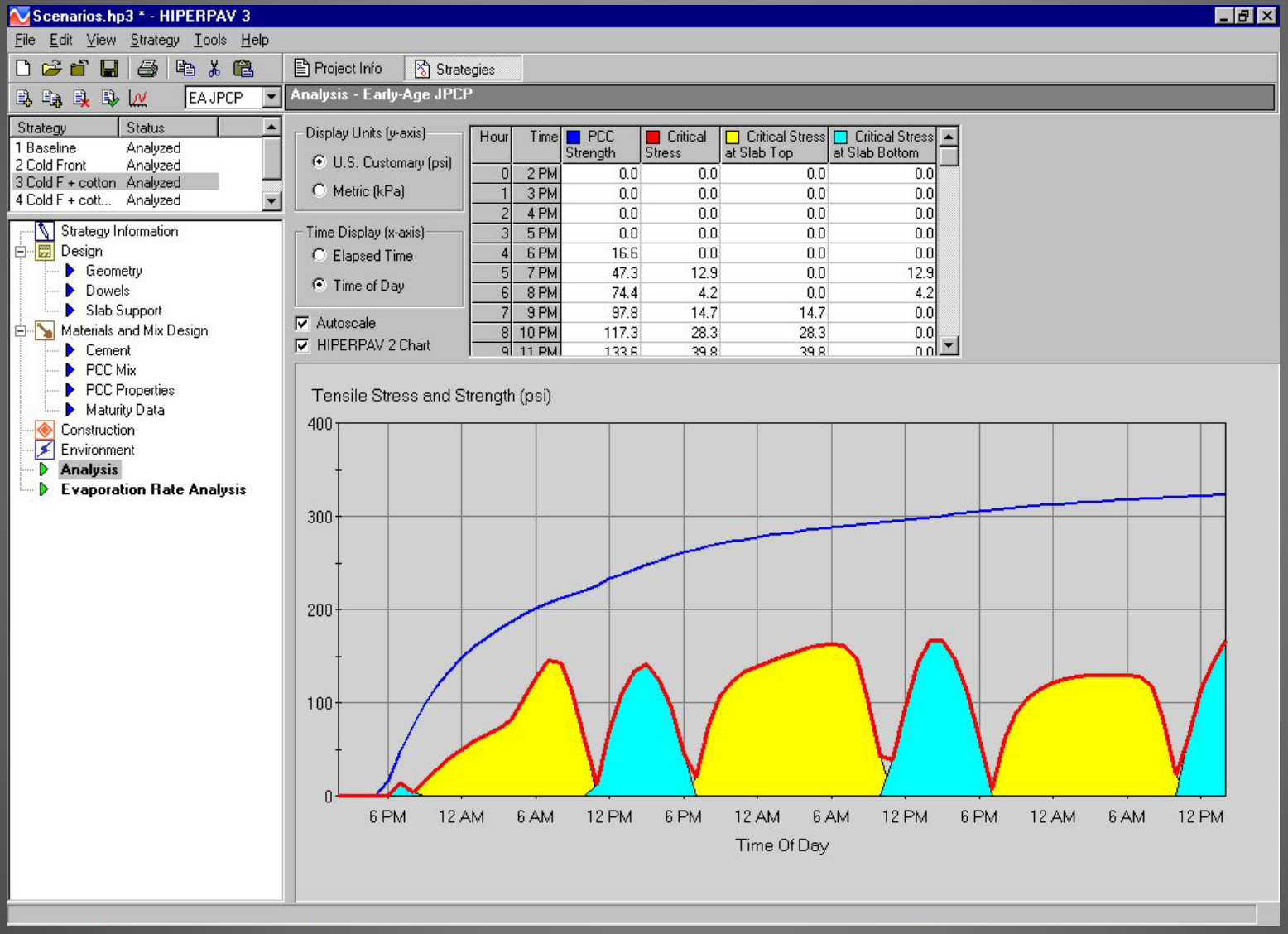
Warning! Stress begins to exceed Strength at: 5 AM
400
300
200
100
0
6 PM 12 AM 6 AM 12 PM 6 PM 12 AM 6 AM 12 PM 6 PM 12 AM 6 AM 12 PM
Time Of Day

# Cold Front + Blankets

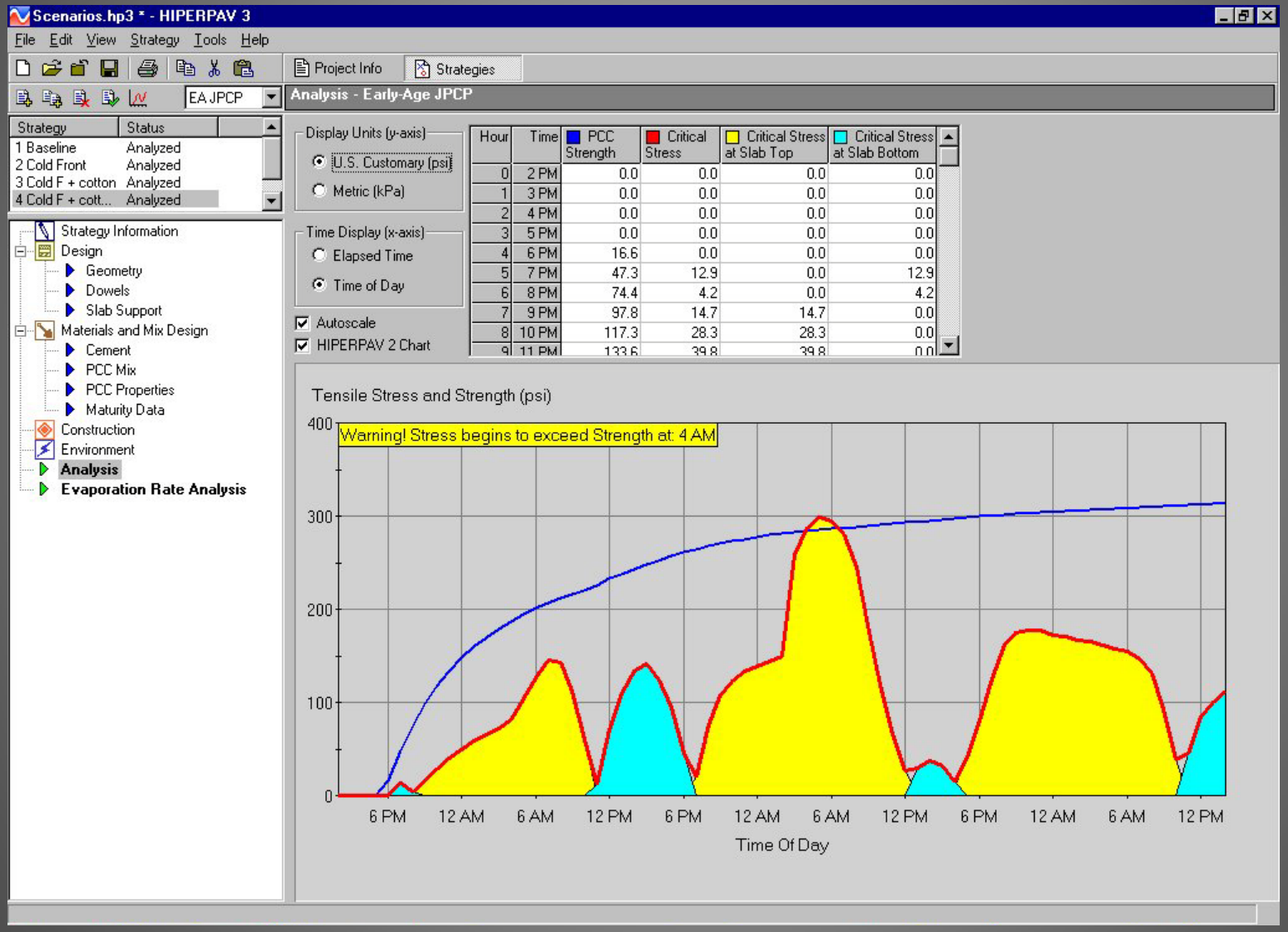


# What happens if I have to open to traffic in 36 Hours?

# Cold Front + Blankets



# Cold Front + 36 hours of Blankets




(Blankets removed at 36 hours)

Is there another way?

What about a
Fast-Track Mix?

# Cold Front

Scenarios.hp3 * - HIPERPAV 3

File Edit View Strategy Tools Help

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Display Units (y-axis)
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- ( ) Metric (kPa)

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- ( ) Elapsed Time
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[x] Autoscale
[x] HIPERPAV 2 Chart

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| 3 | 5 PM | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 6 PM | 16.6 | 0.0 | 0.0 | 0.0 |
| 5 | 7 PM | 46.5 | 15.3 | 15.3 | 0.0 |
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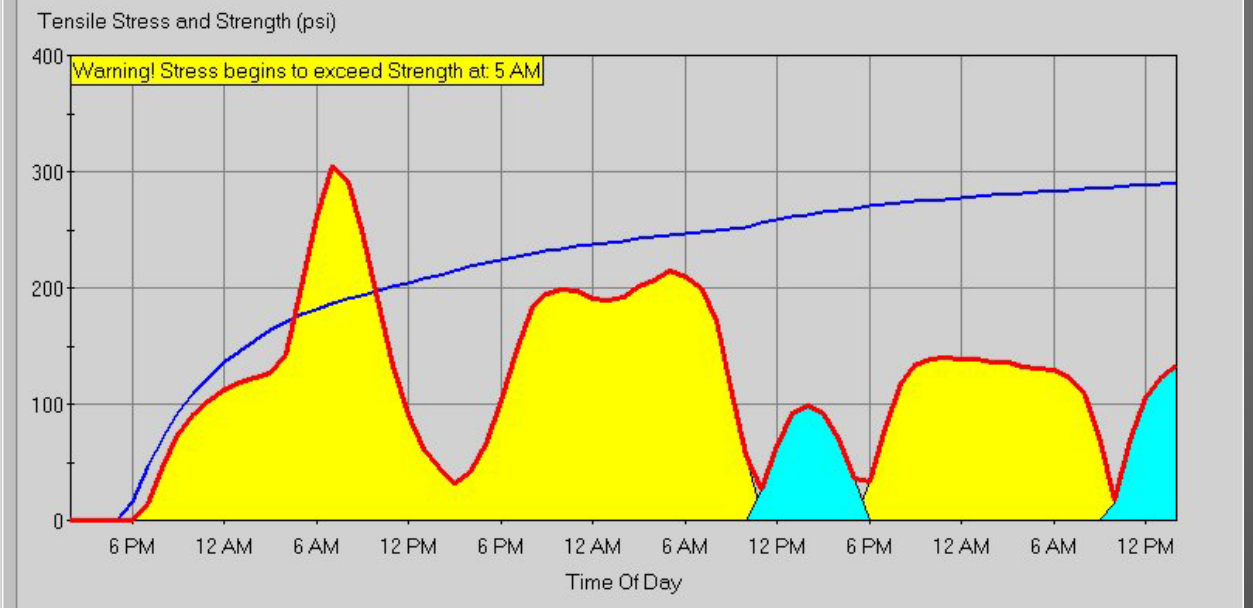
| 7 | 9 PM | 92.1 | 74.0 | 74.0 | 0.0 |
| 8 | 10 PM | 109.0 | 91.1 | 91.1 | 0.0 |
| 9 | 11 PM | 123.2 | 102.8 | 102.8 | 0.0 |



# Cold Front + Fast Track Mix

Scenarios.hp3 * - HIPERPAV 3

File Edit View Strategy Tools Help

Project Info | Strategies

EA JPCP

Analysis - Early-Age JPCP

| Strategy | Status |
|---|---|
| 2 Cold Front | Analyzed |
| 3 Cold F + cotton | Analyzed |
| 4 Cold F + cott... | Analyzed |
| 5 Fast Track Mix | Analyzed |

- Strategy Information
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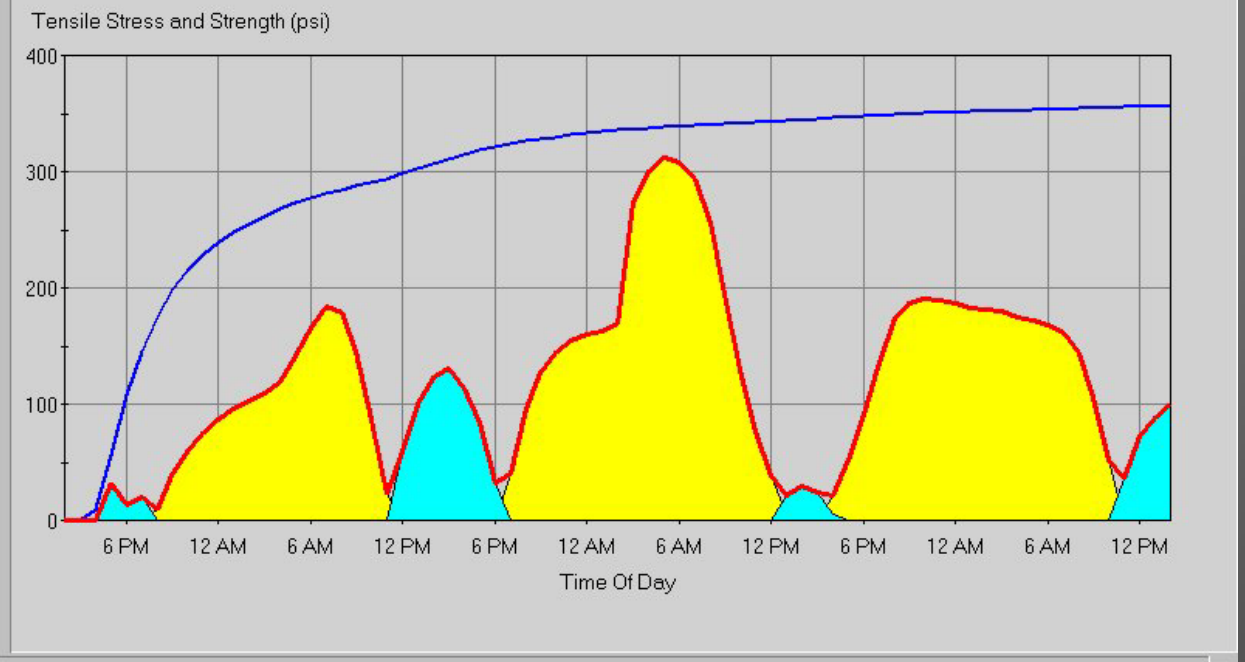
Display Units (y-axis)
- (•) U.S. Customary (psi)
- ( ) Metric (kPa)

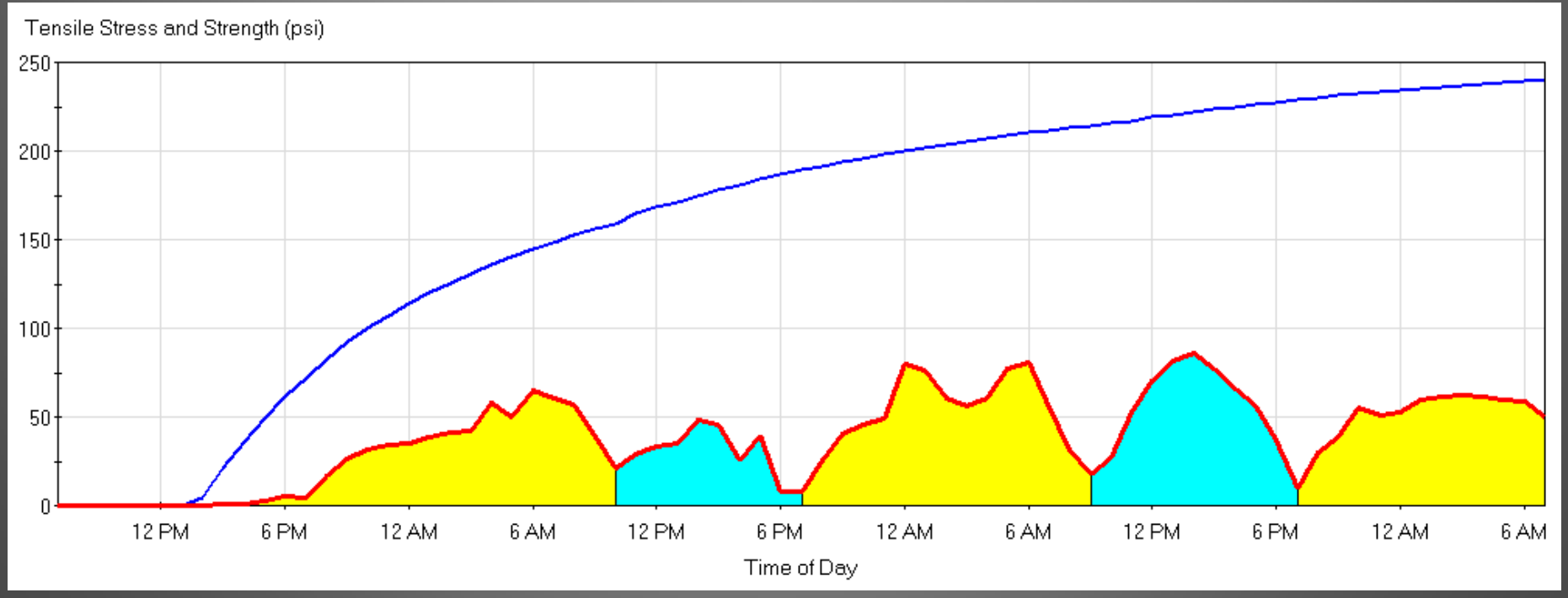
Time Display (x-axis)
- ( ) Elapsed Time
- (•) Time of Day

[x] Autoscale
[x] HIPERPAV 2 Chart

| Hour | Time | PCC Strength | Critical Stress | Critical Stress at Slab Top | Critical Stress at Slab Bottom |
|---|---|---|---|---|---|
| 0 | 2 PM | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 3 PM | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 4 PM | 9.2 | 0.0 | 0.0 | 0.0 |
| 3 | 5 PM | 56.7 | 31.9 | 0.0 | 31.9 |
| 4 | 6 PM | 108.1 | 13.3 | 0.0 | 13.3 |
| 5 | 7 PM | 145.7 | 20.1 | 0.0 | 20.1 |
| 6 | 8 PM | 174.0 | 8.9 | 8.9 | 0.0 |
| 7 | 9 PM | 197.1 | 38.8 | 38.8 | 0.0 |
| 8 | 10 PM | 214.1 | 58.7 | 58.7 | 0.0 |
| 9 | 11 PM | 227.6 | 74.9 | 74.9 | 0.0 |



# ROUTE 58 – Unbonded Section



# What are typical uses?

- Predict responses in cold and hot weather paving
- Predict potential strength gain for tight closures and opening to traffic
- Determine optimal mix characteristics
- Determine effects of design parameters on stress development
  - Joint spacing, thickness, base type
- Forensic studies – crack development

# State DOT Implementation

Ohio DOT

- Since 2005 included in specifications

Wisconsin DOT

- Since 2007 included in special provisions for numerous projects
- Customized software for WI materials

CALTRANS

- Include in updated specifications for 2010

Delaware DOT

- Since 2011 included in specifications

# Maturity Method

# Background

- What is the maturity method?
  - Non destructive means to estimate **in-place** strength of concrete
  - Strength is evaluated as a function of **TIME** and **TEMPERAPTURE**
  - For a given mixture, concretes of the same maturity have the same strength

# Maturity Method

- The concept of maturity is actually pretty simple.
- More heat = More strength.
- More time = More strength.
- The Maturity Method simply combines both time and temperature into an index value

# Maturity Index

Calculate the **Maturity Index** by either:

- **Nurse-Saul function**
  - Maturity index - temperature-time factor (TTF)
  - Simple math
- **Arrhenius equation**
  - Maturity index - equivalent age ($t_e$)
  - More complex math

# Maturity Method

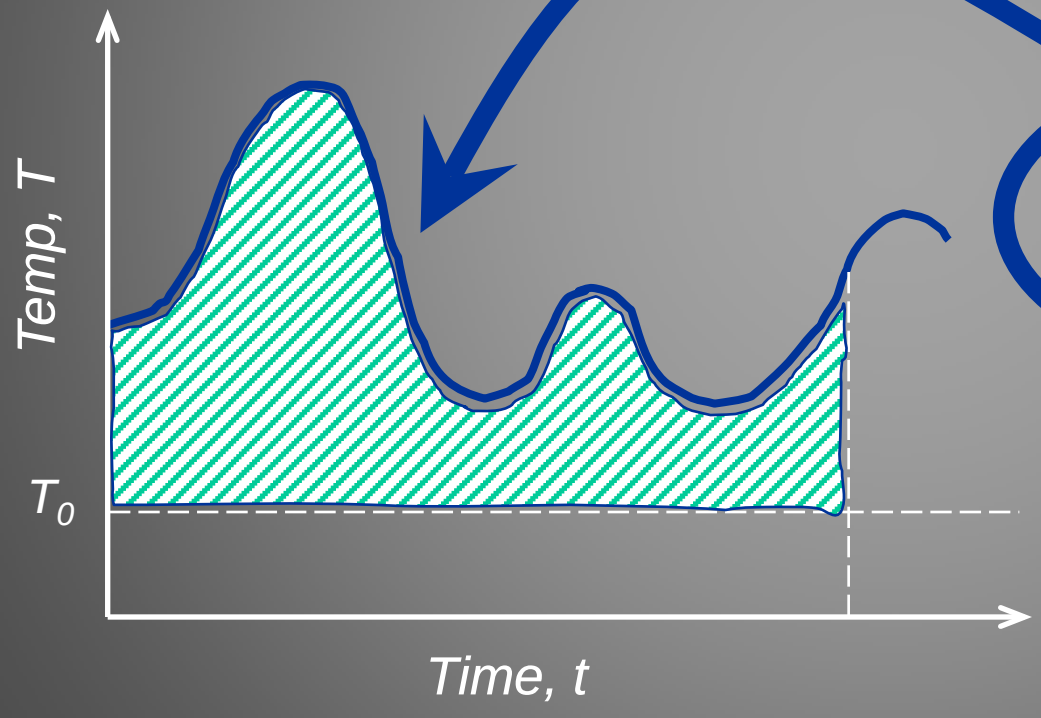
- Nurse-Saul function
  - Maturity is a function of the product of curing time and concrete temperature

$$M = \sum_{0}^{t} (T_c - T_o) \cdot \Delta t$$

  - Saul also introduced the “Maturity Rule”
  - Samples of the same mix at the same maturity has approximately the same strength whatever combination of time and temperature go to make up that maturity

# Maturity Method

## Nurse-Saul Function

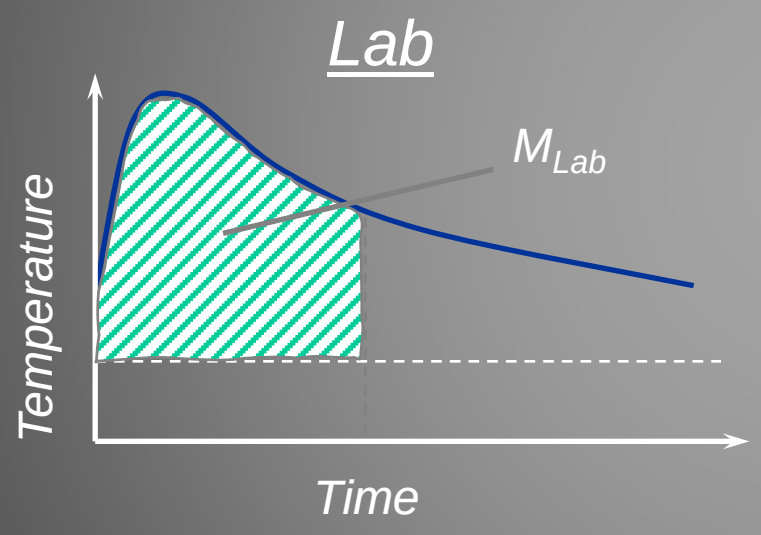


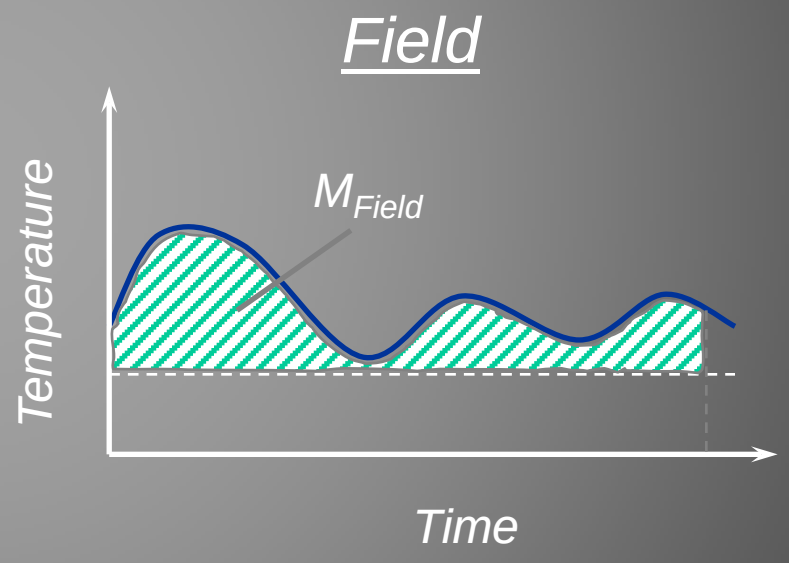

$$M = {}_{o}\Sigma^{t} (T-T_o)\Delta t$$

# Maturity Method

Nurse-Saul Function (cont.)

What does this mean?




When $M_{field} = M_{lab}$ , the two concretes are of the same strength...

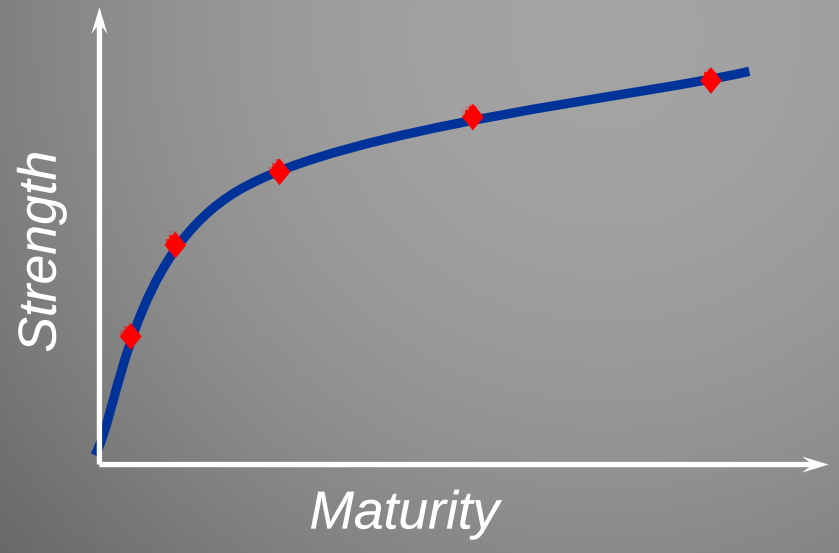
# Maturity Method

**Two Step Process:**

1. Develop strength-maturity curve in the laboratory (this can be done in field too)
2. Measure time & temperature (maturity) in the field and estimate strength

# Maturity Method

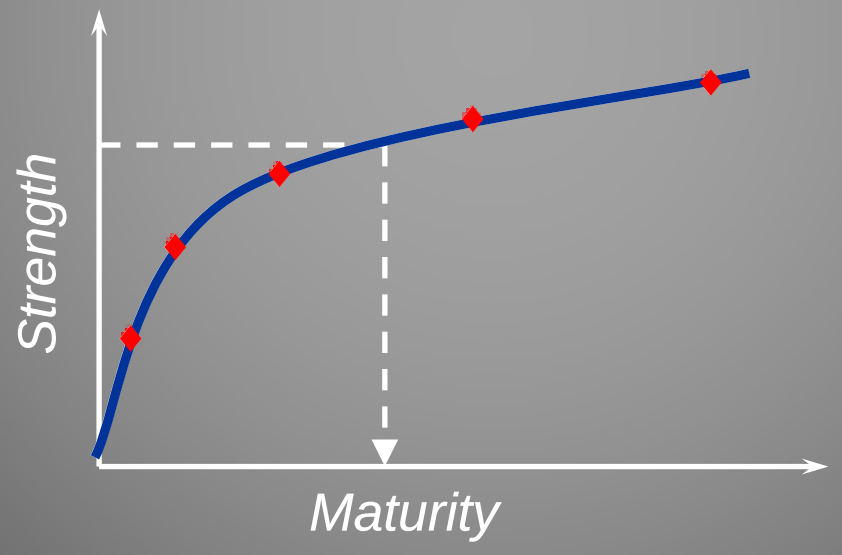
1. Relate strength to maturity
   - Cast cylinders in lab, and instrument them
   - Break cylinders, and record maturity



   - Build the “maturity curve”

# Maturity Method

1. Relate strength to maturity (cont.)
   - Determine maturity value that corresponds with strength of interest…



# Maturity Method

2. Measure in-place maturity to <u>estimate</u> strength

- As soon as possible after concrete placement, instrument in-place concrete

# Maturity Method

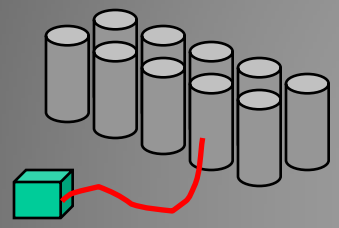
2. Measure in-place maturity to <u>estimate</u> strength

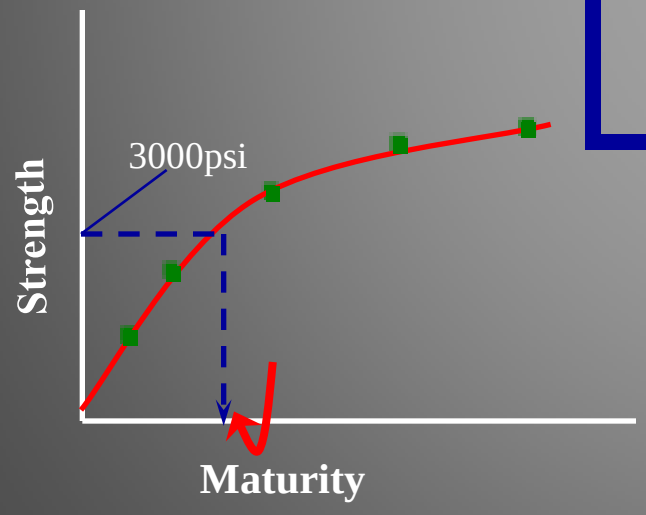
- Monitor maturity until it reaches the value corresponding to the strength of interest

- For critical operations, verify in-place strength (NDT, companion, etc)

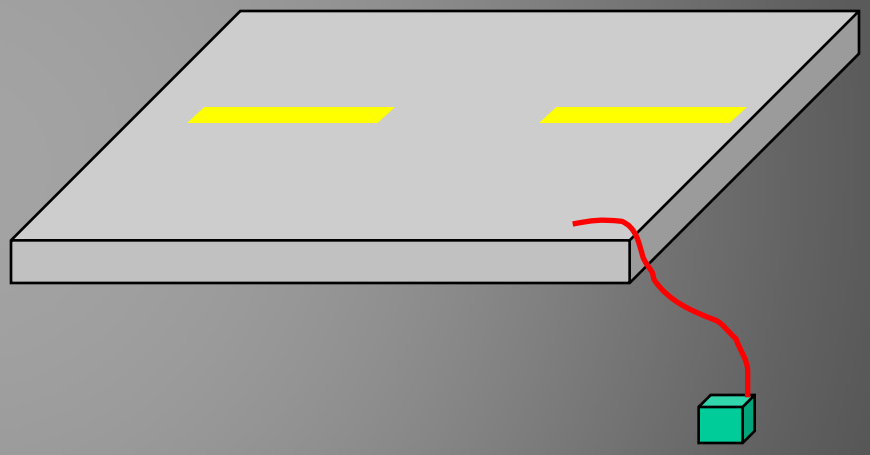
# Maturity Method

## Laboratory Testing






## Field Monitoring



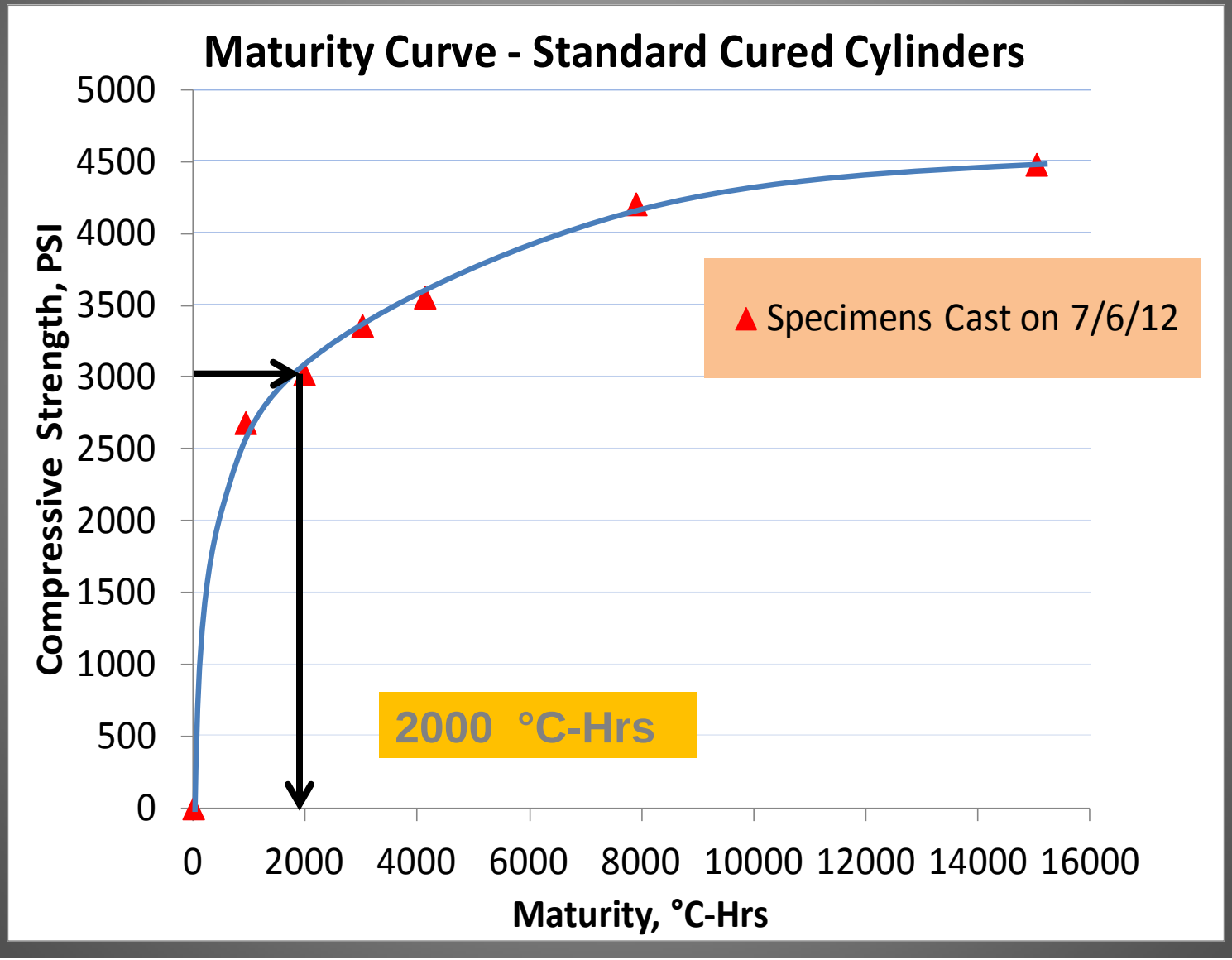
When the maturity reaches this value, we can reliably say that the in-place strength is 3000psi

***(ASTM C 1074)***

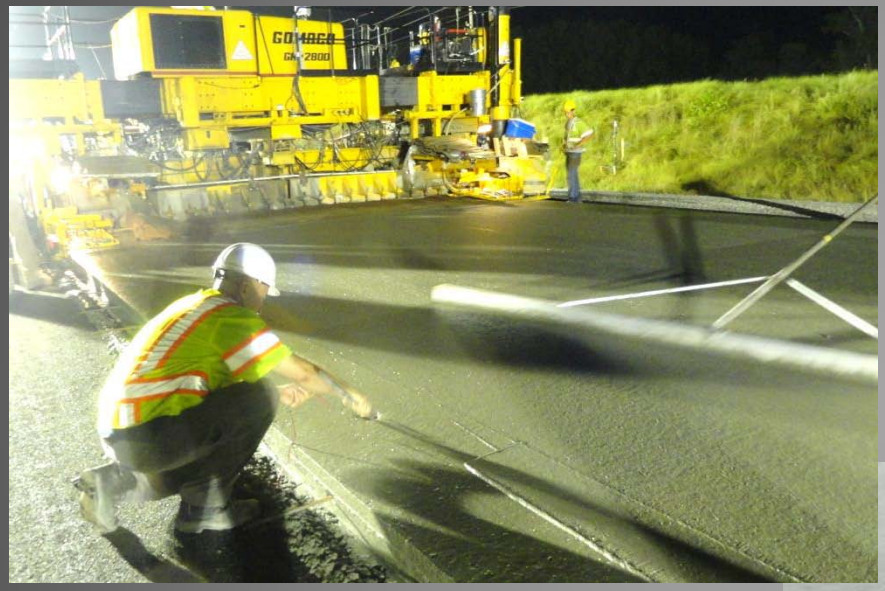
# ROUTE 58

## Laboratory Maturity

# ROUTE 58

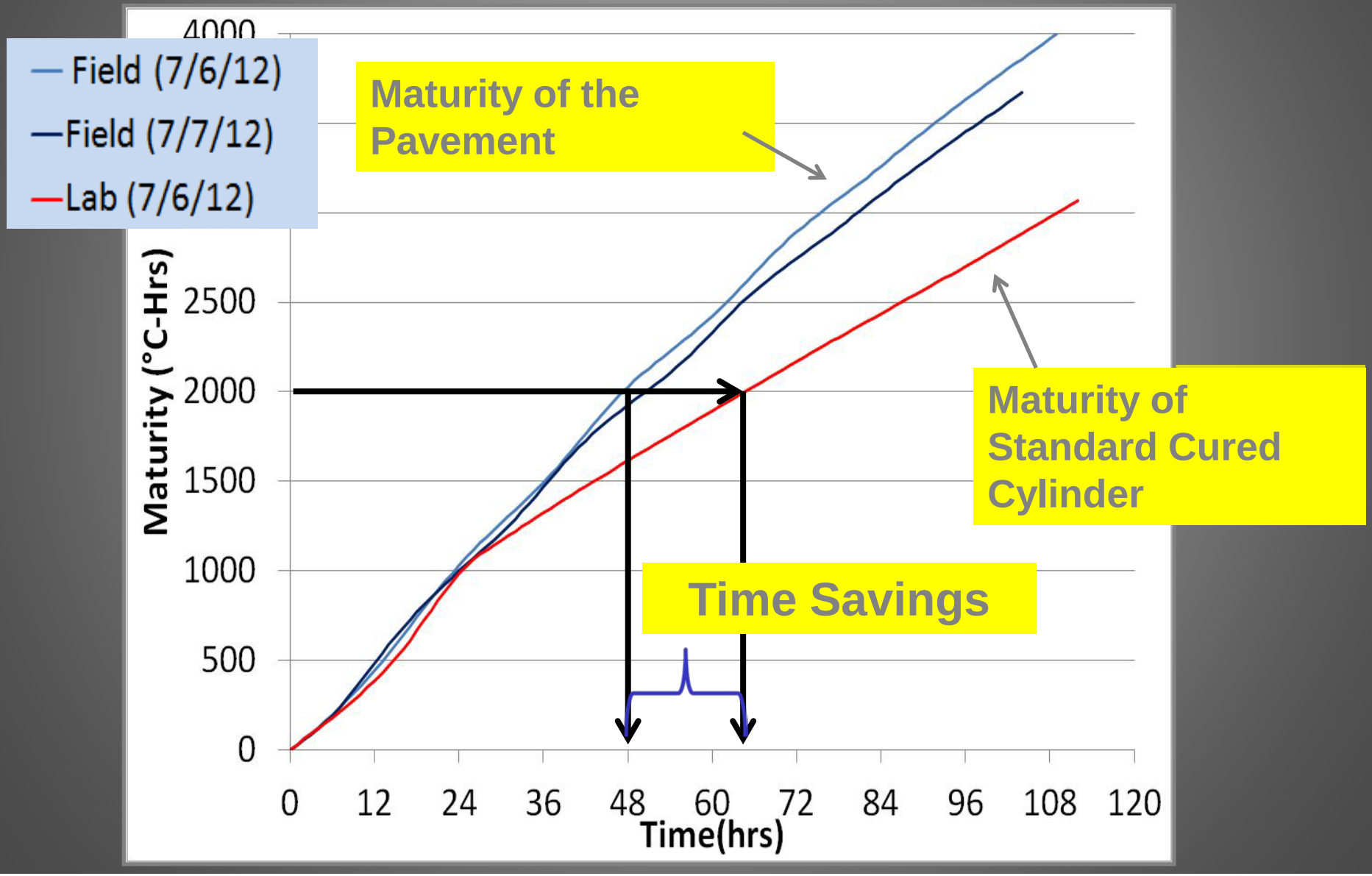

Maturity Curve - Standard Cured Cylinders
Compressive Strength, PSI
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
2000
4000
6000
8000
10000
12000
14000
16000
Maturity, °C-Hrs
Specimens Cast on 7/6/12
2000 °C-Hrs

# ROUTE 58



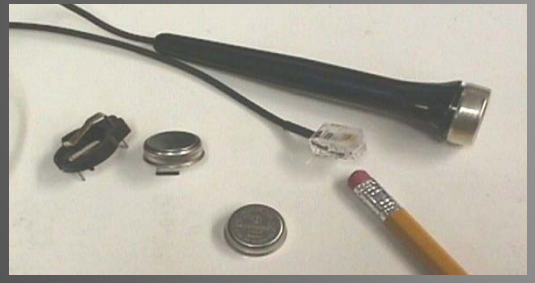
## Field Maturity

# ROUTE 58


Field (7/6/12)
Field (7/7/12)
Lab (7/6/12)
Maturity of the Pavement
Maturity of Standard Cured Cylinder
Time Savings
Maturity (°C-Hrs)
4000
2500
2000
1500
1000
500
0
0
12
24
36
48
60
72
84
96
108
120
Time(hrs)

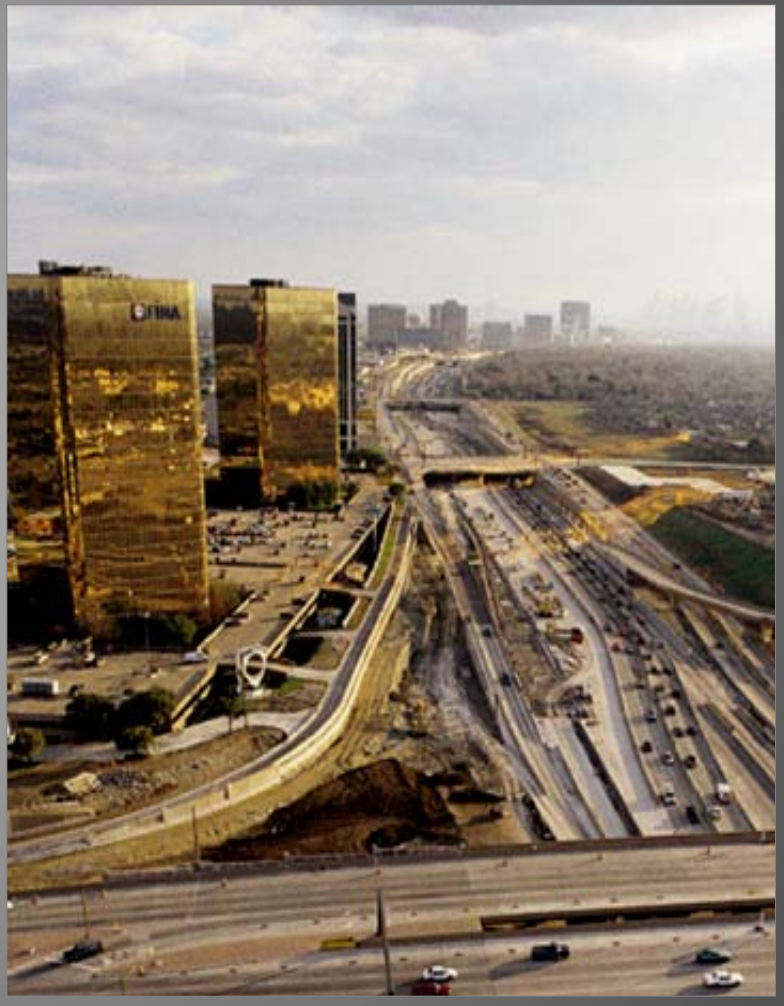
# Maturity Data loggers

- Availability of technology?
  - Wide variety of meters available
  - All record temperature and convert to a maturity value



# Case Study: North Central Expressway (US75), Dallas, TX

- $113M reconstruction
- Maturity implementation reduced pavement opening times from 7 to 4 days
- Maturity reduced bridge opening time from 21 to 8 days
- Traffic detouring time reduced by 60%
- Project opened almost one year ahead of schedule



# Summary

- Maturity has been around for ½ century
- Simple procedure to estimate in-place strength
  - Temperature
  - Time
- Great tool for:
  - Early opening to traffic - speed construction
  - Reducing volume and cost of QC testing
  - Safe removal of shoring and/or protection

# Summary

- Primary cautions:
  - Mixture variability
  - Moist curing (permit hydration)
  - Confirmation strength testing

# Questions

**Download software at:**
**www.hiperpav.com**

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