Concrete Maturity in India:

Advancing the Indian Concrete Market

How an established technology can improve safety and concrete quality while also saving time, money and energy in concrete construction

Presented by

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Wadeyar Hall
Century Club
K. R. Circle, Bangalore

Willow Island Cooling Tower Collapse

51 Workers were killed when a cooling tower collapsed. It was shown that the primary cause was “green” concrete. In-place strength was lower than test cylinder strength, leading to interest in better in-place strength determinations.

"It has been a week since the chimney collapse at the Bharat Aluminium Company Limited (Balco) thermal power plant in Korba killed 41 workers. Officials believe the use of faulty construction materials caused the collapse."—CNN-IBN

Balco Chimney Collapse, Sept. 2009

Brief History of Maturity Concept

- 1951: Early use of maturity-strength predictor using simple time-and-temperature calculation (Nurse and Saul)
- 1977: Equivalent Age concept proposed by Dutch researchers Freisleben, Hansen and Petersen
- 1987: ASTM adopts first Maturity Standard in US: ASTM C1074: *Standard Practice for Estimating Concrete Strength by the Maturity Method*
- Yes, the maturity method has been around for a LONG TIME!

Maturity Concept Today:

- 1995: First use of the Con-Cure System on a high-rise project in Chicago with great success.
- 1998: Con-Cure Corporation was founded to conduct this testing for contractors as a service.
- 2001: We started selling systems, and developed a detailed training course that we still use today to ensure proper implementation on any project.
- In fact, I am here in India right now because a large and PROGRESSIVE contractor purchased a sophisticated system, and I have come here to conduct training for them.
- *2001-Present: Thousands of maturity meters sold worldwide.*

Maturity Testing: *A New Paradigm.*

In India Today: ⇒ But New Techniques Exist:

The construction industry relies on field-cured cube testing to determine strength of curing concrete.

Using an established ASTM Standard, in-place strength can be determined accurately and instantly.

What is Concrete Maturity Monitoring?

- It is a means of estimating in-place concrete strength using the recorded temperature history of the structure and comparing that history to a strength-time calibration curve created in the laboratory using cubes.
- Maturity is MIX-SPECIFIC, and is also dependent on consistent concrete batching and quality.
- It is completely non-destructive, simple to do, and provides valuable curing history information about the STRUCTURE

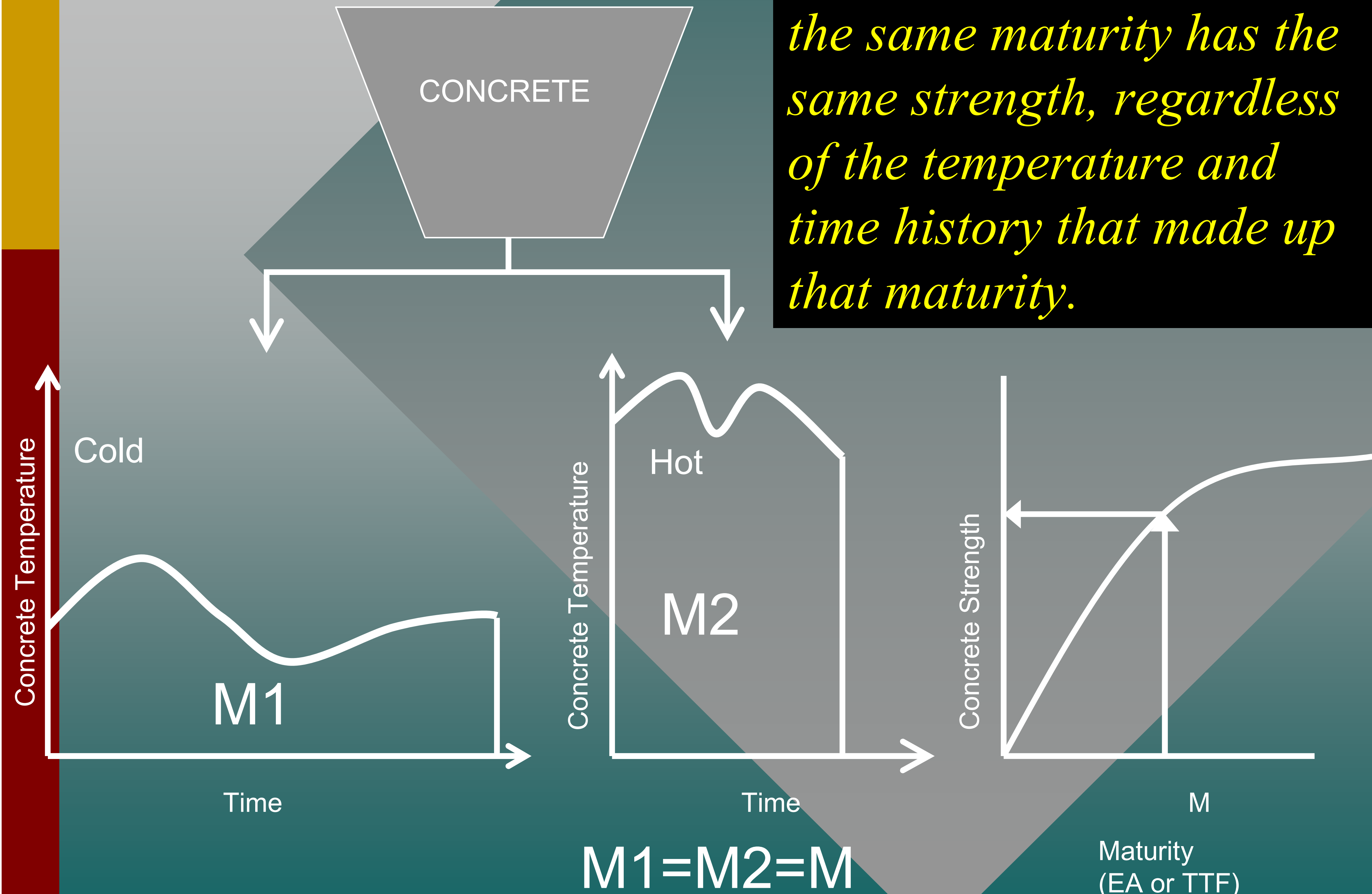
Principle of Maturity Testing

The temperature at which concrete is cured determines the strength of the concrete at any given point in time.

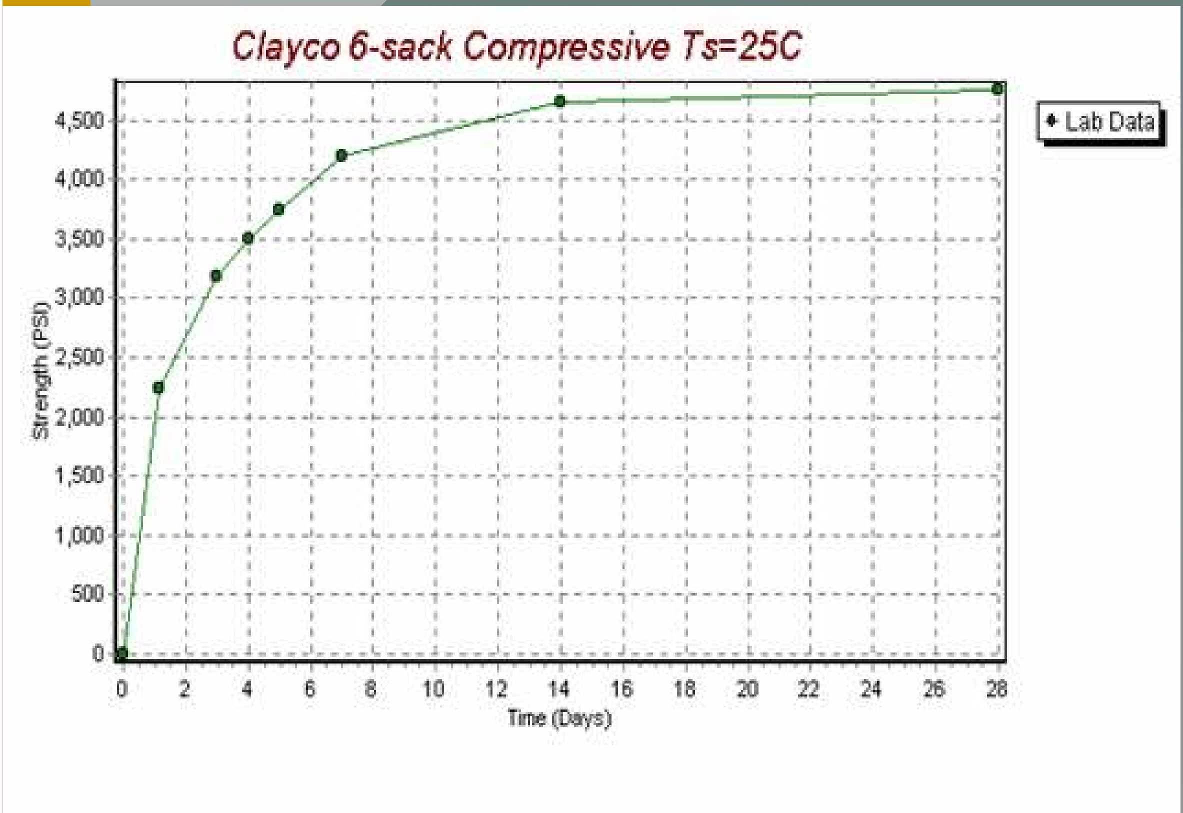
Principle of Maturity Testing

The relationship between the temperature history of a concrete and its strength can be empirically determined, and is called its maturity index.

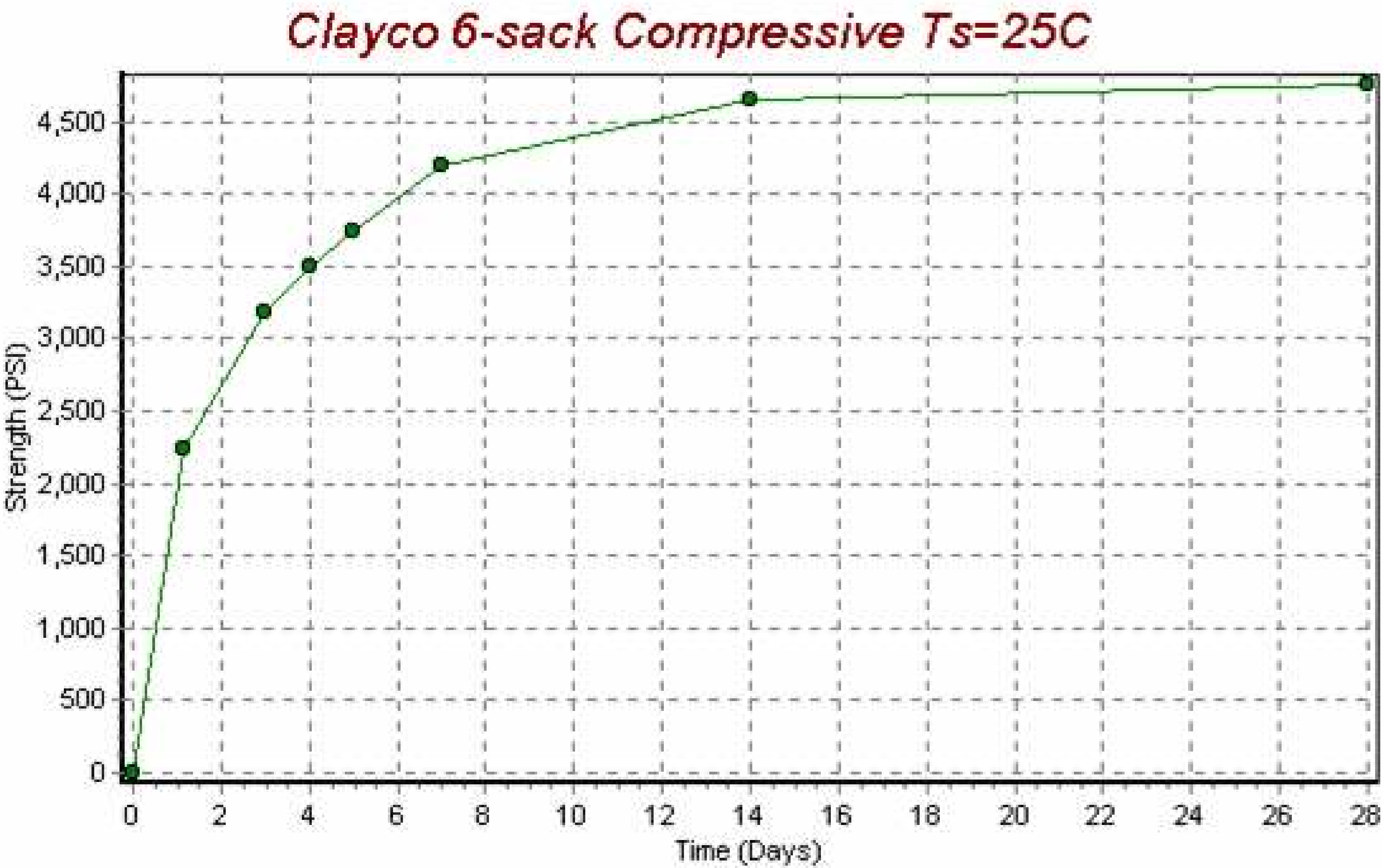
Concrete of a given mix at the same maturity has the same strength, regardless of the temperature and time history that made up that maturity.



4 Steps of Maturity Testing



- Establish Maturity Curve for mix
- Embed sensors & launch maturity meters
- Read meters
- Interpret data


Clayco 6-sack Compressive Ts=25C
Strength (PSI)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Time (Days)

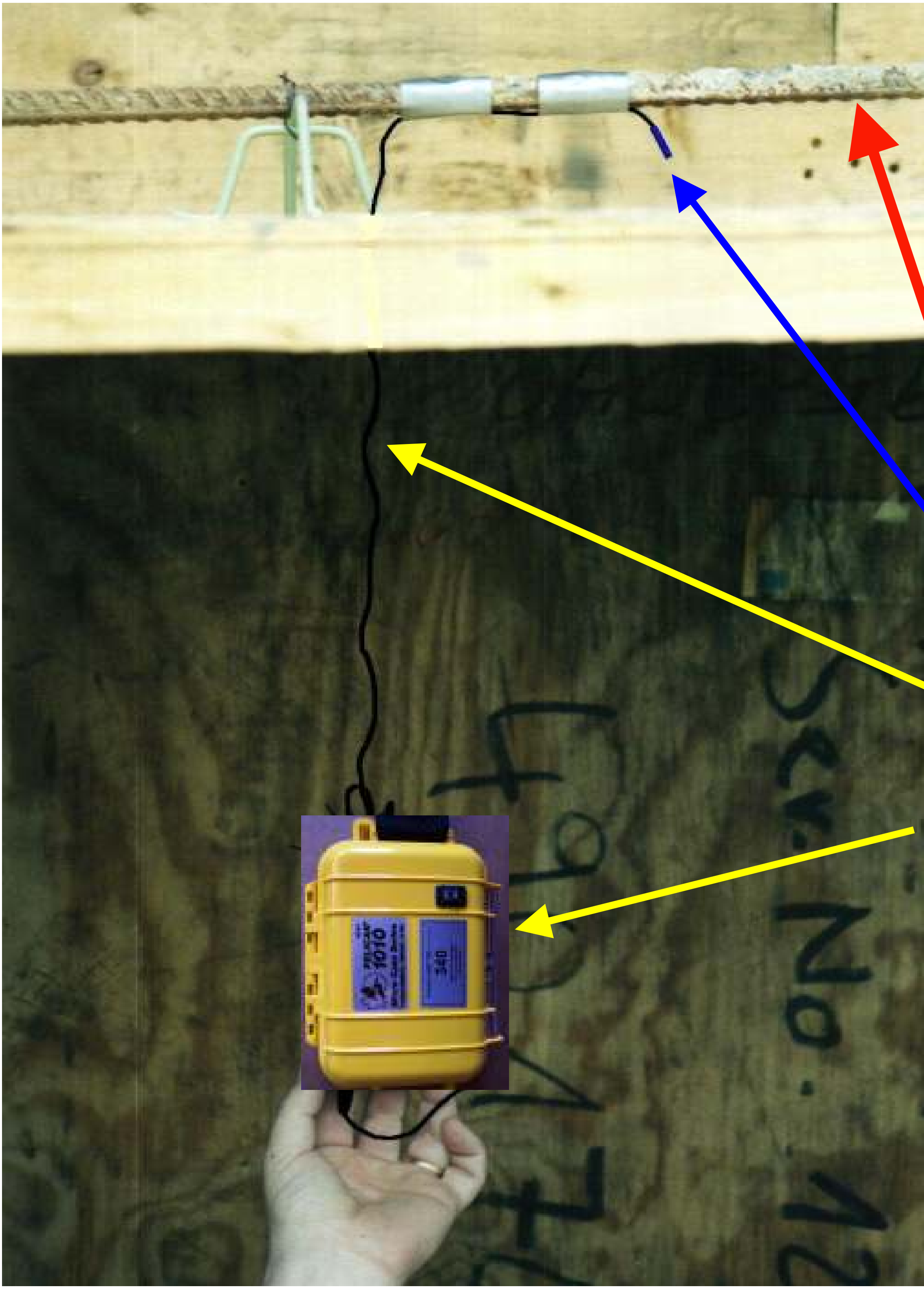
4 Steps of Maturity Testing

- Establish Maturity Curve for mix
- Embed sensors & launch maturity meters
- Read meters
- Interpret data

4 Steps of Maturity Testing

The sensors are placed in the structure by drilling a small hole in the formwork and threading the sensor plug through the hole. The meter is attached below.

- Establish Maturity Curve for mix
- Embed sensors & launch maturity meters
- Read meters
- Interpret data



View showing sensor and meter together, with wire running through formwork.

Rebar

Sensor Tip

Wire

ZoneCure Meter

There is no limit to the number of meters that can be deployed for a given pour.

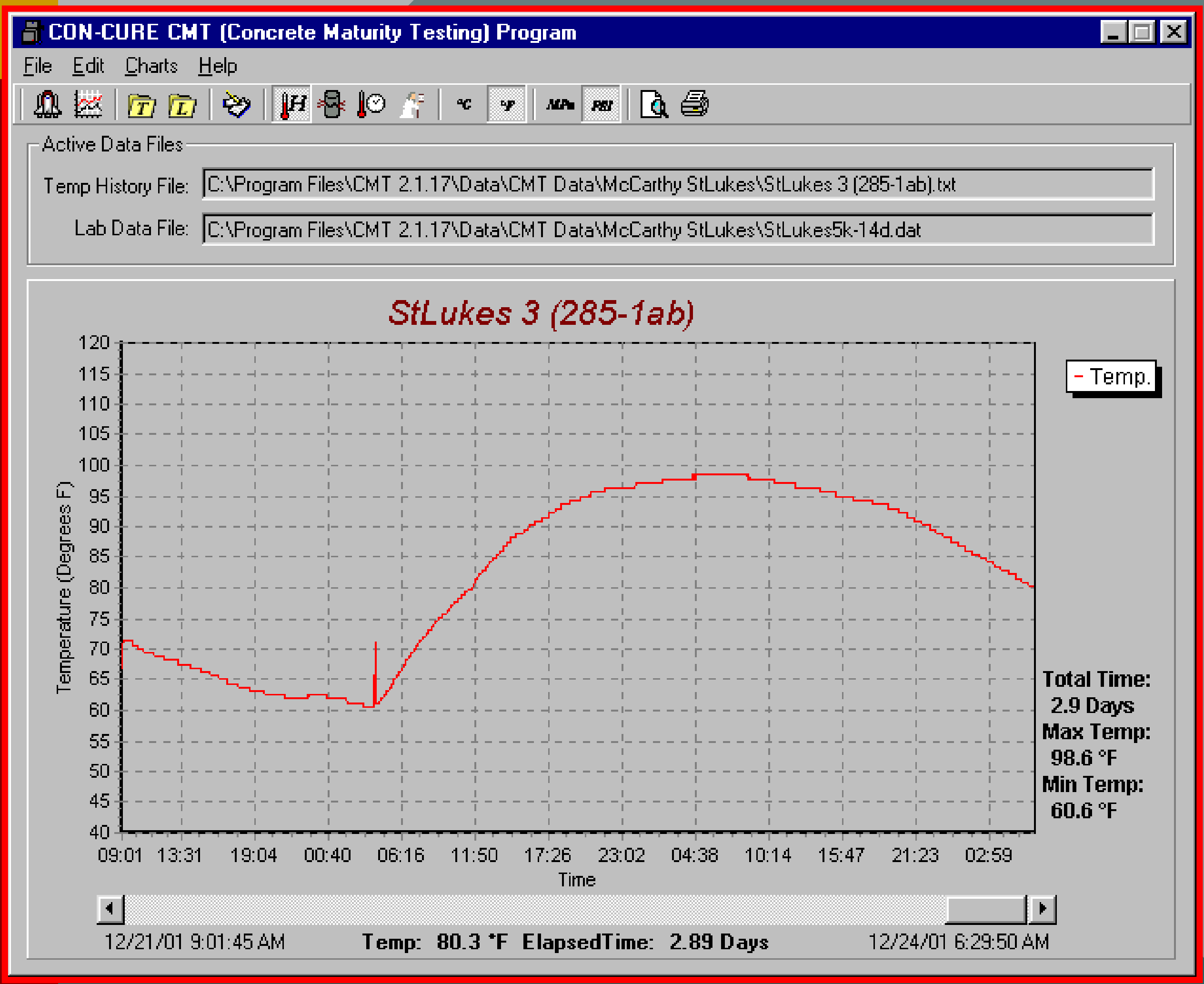
- Maturity Meter at precast concrete plant
- Sensor is merely placed inside the beam
- Concrete strength data is sent wirelessly back to the QC lab and monitored
- As soon as the beam reaches the target strength, it is deshuttered—often much sooner than test samples reach the same strength, saving this customer many hours of curing time per day


1010
372
02/04/2011

We also use the maturity system to monitor and estimate the strength of the SAMPLES, allowing us to validate the maturity calibration effortlessly.

This is also important because changes to the quality of the concrete are spotted within hours, not days or weeks. So simple, and so important for quality.

4 Steps of Maturity Testing



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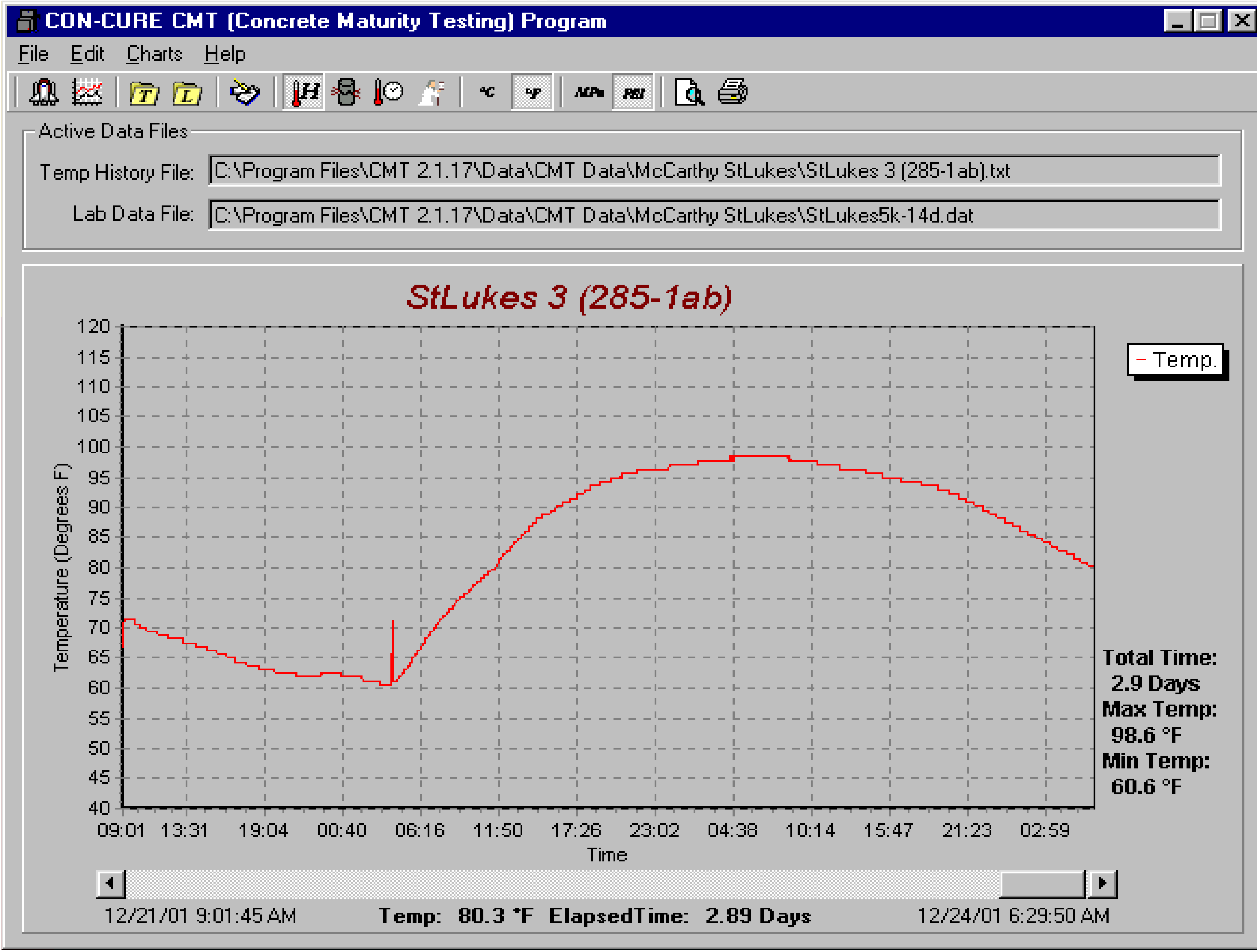
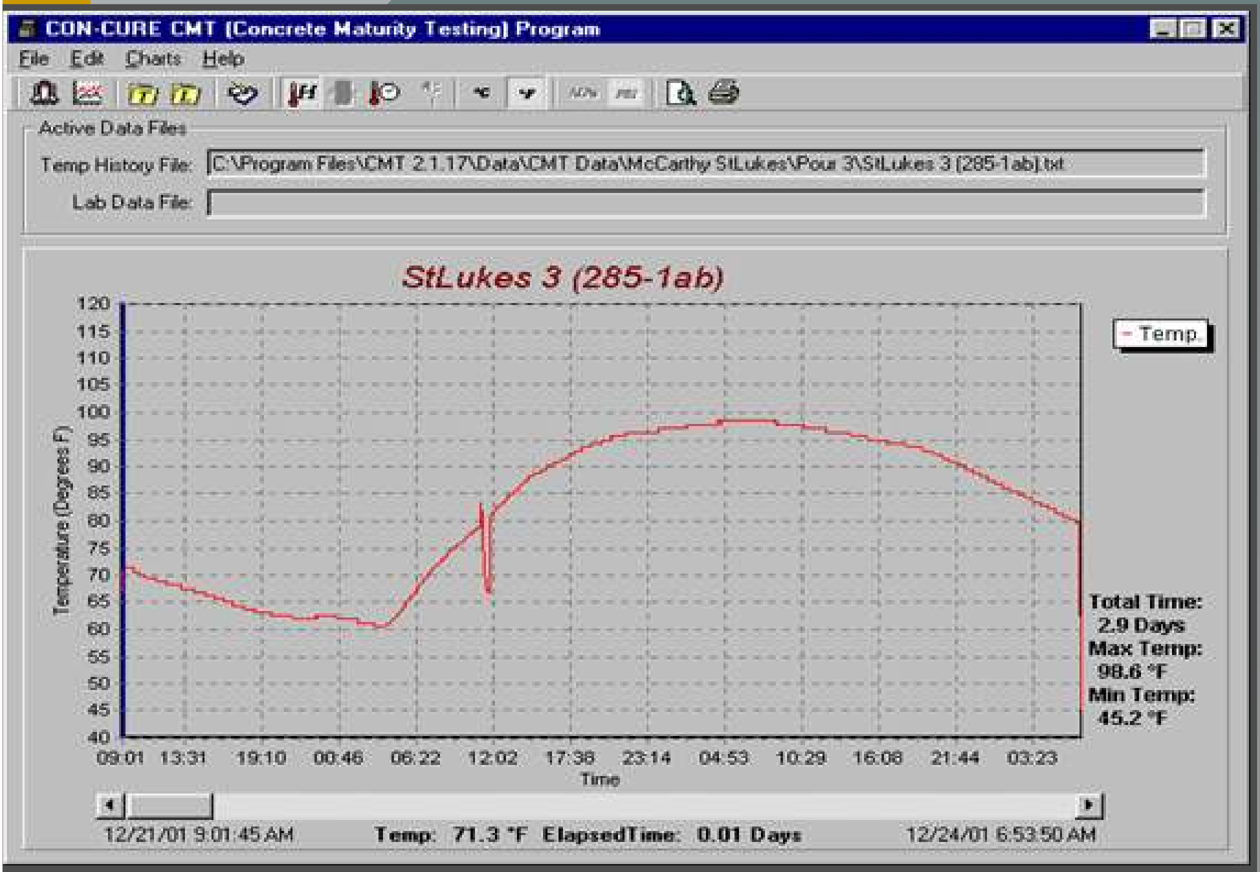

CON-CURE CMT (Concrete Maturity Testing) Program
File
Edit
Charts
Help
Active Data Files
Temp History File:
C:\Program Files\CMT 2.1.17\Data\CMT Data\McCarthy StLukes\StLukes 3 (285-1ab).txt
Lab Data File:
C:\Program Files\CMT 2.1.17\Data\CMT Data\McCarthy StLukes\StLukes5k-14d.dat
StLukes 3 (285-1ab)
Temp.
Temperature (Degrees F)
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
09:01
13:31
19:04
00:40
06:16
11:50
17:26
23:02
04:38
10:14
15:47
21:23
02:59
Time
Total Time:
2.9 Days
Max Temp:
98.6 °F
Min Temp:
60.6 °F
12/21/01 9:01:45 AM
Temp: 80.3 °F ElapsedTime: 2.89 Days
12/24/01 6:29:50 AM

4 Steps of Maturity Testing



- Establish Maturity Curve for mix
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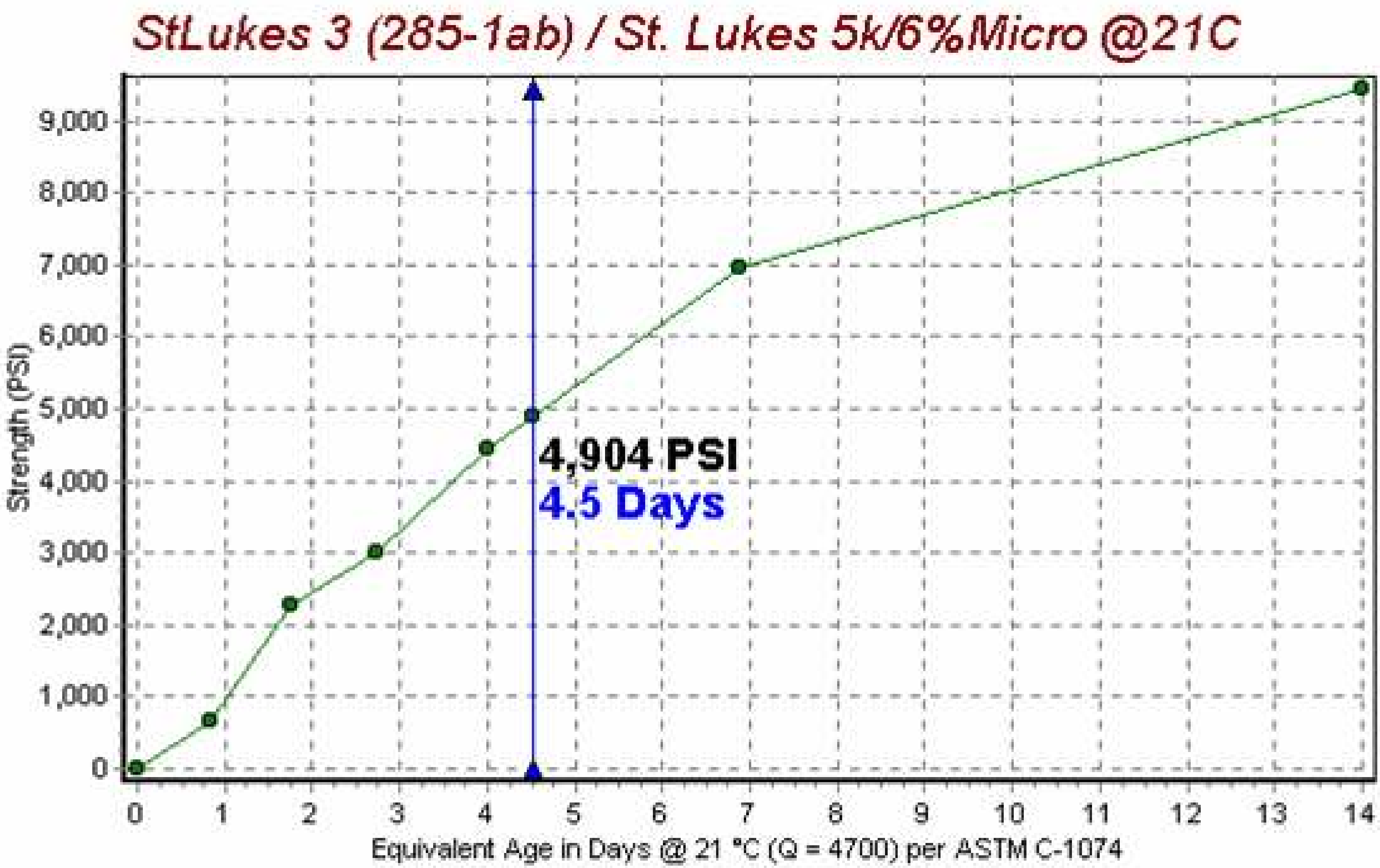


StLukes 3 (285-1ab) / St. Lukes 5k/6%Micro @21C
Strength (PSI)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
4,904 PSI
4.5 Days
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Equivalent Age in Days @ 21 °C (Q = 4700) per ASTM C-1074

Why do Maturity Monitoring?

- Learn in-place strength of concrete at specific locations in a structure without relying on cubes for early-age strengths
- Improve Safety by never deshuttering or stressing post-tensioning tendons too soon
- Improve scheduling on any jobsite by being able to predict strength target times
- Optimize concrete mix designs around in-place strength rather than on cube strength

Some Non-Destructive Concrete Test Methods:

- **Field Cured Cubes** (ASTM C31 & C 39)
- Rebound Hammer* (ASTM C805)
- Penetration Resistance* (ASTM C 803)
- Pullout Strength* (ASTM C 900)
- **Maturity Testing*** (ASTM C 1074)

* require correlation

Field-cured cubes

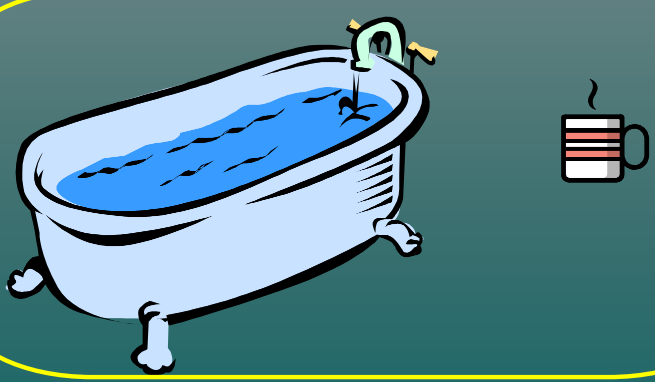
- "Cured same as structure"
- Variable temperature differences
- Conservative strength estimate
- Commonly used - simple & economical

Typically, Underestimate In-place Strength

Comparison: Cubes vs. Reality

Structure =Larger mass
=warmer temps &
better hydration

Test Cubes= smaller mass
= cooler temps



"The Bathtub Test"

Proper quality control is essential...

- Fact: Test samples do not reflect the influence of temperature extremes, weather conditions, critical curing conditions, concrete thickness and any number of other actual job site conditions.
- See Photo, next slide.

•Concrete Cylinders at jobsite.

•Date: March 17 2001, 7:30 a.m.

•Ambient Temperature at the time the photo was taken: 38º F

•Curing conditions of deck: Heated & Covered, with full jacketing.

Estimating In-Situ Strength Development

- Need in-place strength for…
  - – De-shuttering
  - – Application of Post-tensioning
  - – Shore and reshore removal
  - – Rapid Scheduling and Safety

ESPECIALLY IN COLD AND RAINY WEATHER

Early de-shuttering ...

- Speeds up construction
- Requires less form/shoring inventory
- Allows other trades early access
- Sooner completion date
- Increases profits

Contractors need a ...

- Simple
- Economical
- Reliable

method to determine

in-place strength.

The Benefits of Maturity Testing.

De-shutter (and stress PT) Sooner=Project Acceleration.

Waiting times are usually cut dramatically, esp. in the winter. Cubes typically lag far behind the structure.

Extend the construction season.

The Benefits of Maturity Testing.

Save money by assessing cold weather protection to ensure sufficient temperatures for curing without wasted heating.

Can also allow early termination of external heating or thermal protection.

The Benefits of Maturity Testing.

Save money by reducing or eliminating reliance on field-cured test samples.

The High Cost of Waiting:

What does it cost to have a crew waiting on the job for the field-cured samples to achieve the required strength when the slab is already there?

The Benefits of Maturity Testing.

Improve site safety by never de-shuttering or stressing cables too soon

The Benefits of Maturity Testing.

Improve concrete quality by learning the temperature history and strength gain rate of the in-place concrete.

The entire Project team—RMCs, Contractors, Owners and Engineers—become focused on QUALITY rather than lowest possible cost.

Improved consistency and quality of the delivered concrete directly leads to greater safety, faster project completion, lower overall project costs, and less litigation.

The Benefits of Maturity Testing.

– Reduce Costs and improve performance of concrete by optimizing mix designs
  - Lower cement factors, controlled heat of hydration, at lower cost

The Benefits of Maturity Testing.

– Monitor critical areas of a structure.

– Non-destructive, inexpensive and cost-effective.

When Should You Do Maturity Testing?

The Applications:

Applications:

- Post-tensioned structures
- Cold & Hot Weather concreting
- Mass Concrete Projects
- Precast and prestressed concrete

•Parking Garages

•Bridges

•High-rise concrete buildings

Expressed another way:

Any time-sensitive placement where knowing the in-place strength would be beneficial for quality, engineering or economic reasons

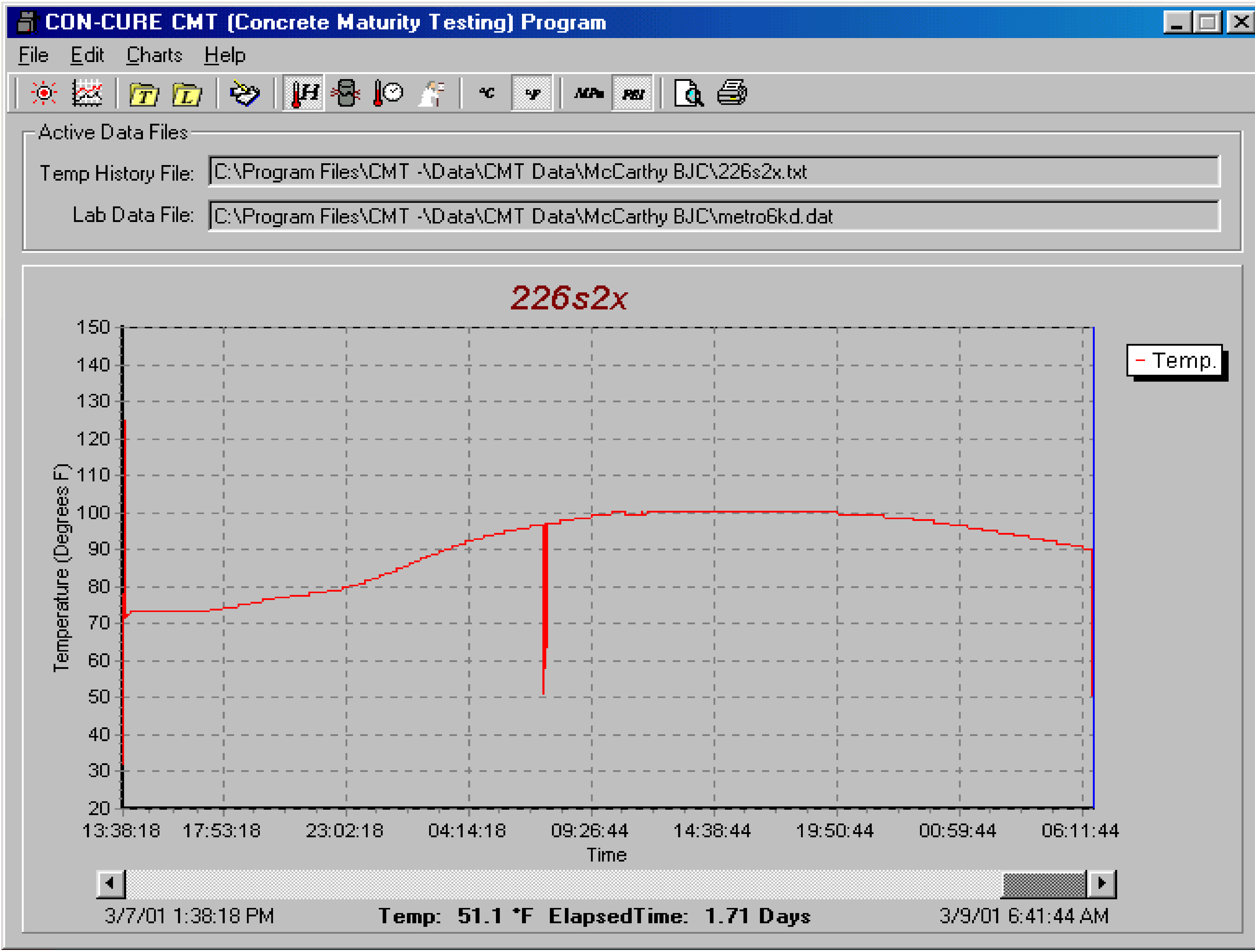
Case Histories: Post-tensioned structures

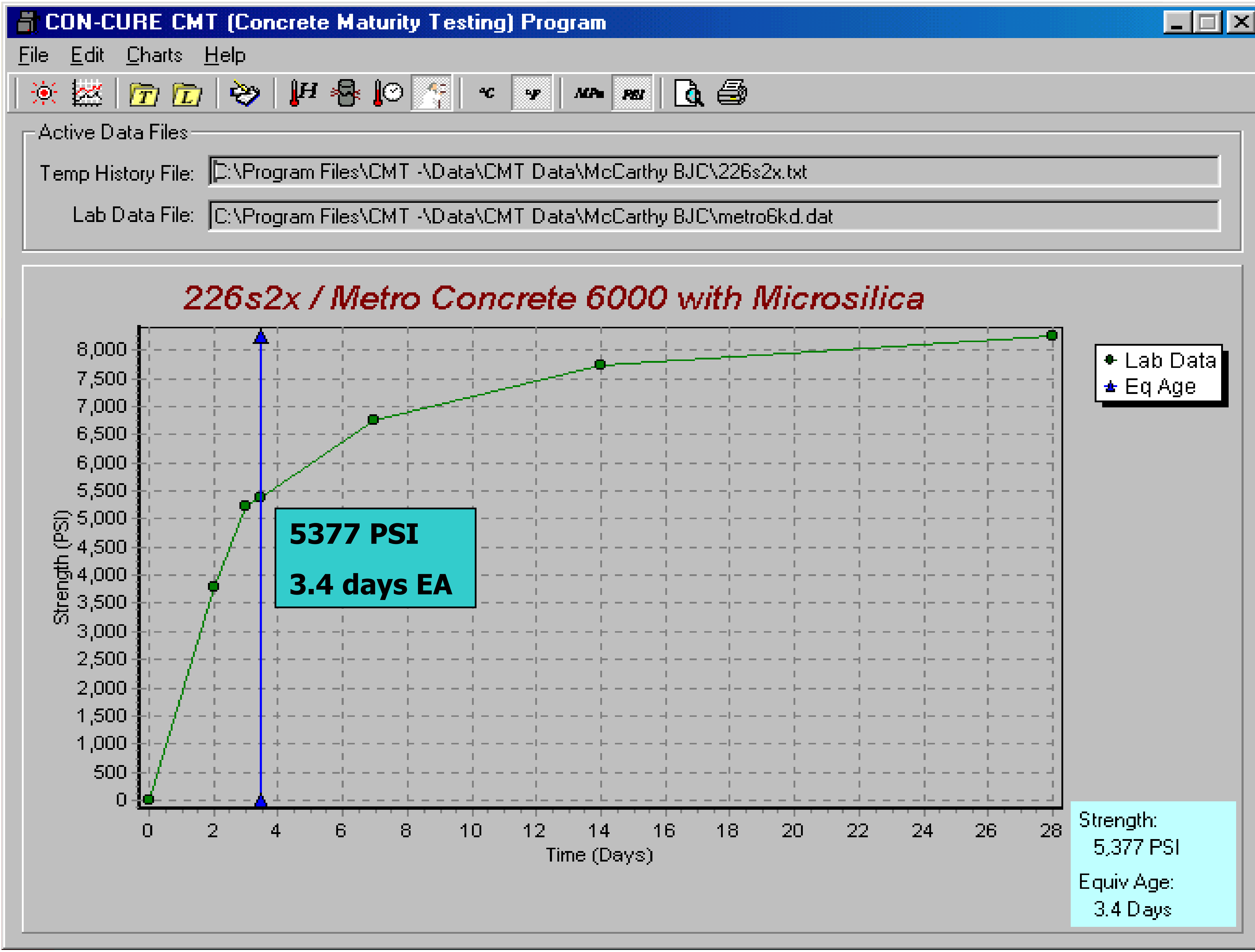
- Parking garages
- Bridges
- High-rise concrete buildings

Parking Garage: Children's Hospital, St. Louis 2000-01

Parking Garage: Children's Hospital, St. Louis 2000-01

- Con-Cure conducted maturity testing for 33 pours at a post-tensioned parking structure in St. Louis during November, December, January, February, March and April.
- Mix: Metro Concrete 6000psi mix with Microsilica and FiberMesh.
- Required strength to begin stessing operations: 3450psi.


CON-CURE CMT (Concrete Maturity Testing) Program
File Edit Charts Help
Active Data Files
Temp History File: C:\Program Files\CMT -\Data\CMT Data\McCarthy BJC\226s2x.txt
Lab Data File: C:\Program Files\CMT -\Data\CMT Data\McCarthy BJC\metro6kd.dat
226s2x
150
140
130
120
110
100
90
80
70
60
50
40
30
20
Temperature (Degrees F)
Temp.
13:38:18
17:53:18
23:02:18
04:14:18
09:26:44
14:38:44
19:50:44
00:59:44
06:11:44
Time
3/7/01 1:38:18 PM
Temp: 51.1 °F ElapsedTime: 1.71 Days
3/9/01 6:41:44 AM


CON-CURE CMT (Concrete Maturity Testing) Program
File Edit Charts Help
Active Data Files
Temp History File: C:\Program Files\CMT -\Data\CMT Data\McCarthy BJC\226s2x.txt
Lab Data File: C:\Program Files\CMT -\Data\CMT Data\McCarthy BJC\metro6kd.dat
226s2x / Metro Concrete 6000 with Microsilica
Strength (PSI)
Time (Days)
5377 PSI
3.4 days EA
Lab Data
Eq Age
Strength:
5,377 PSI
Equiv Age:
3.4 Days

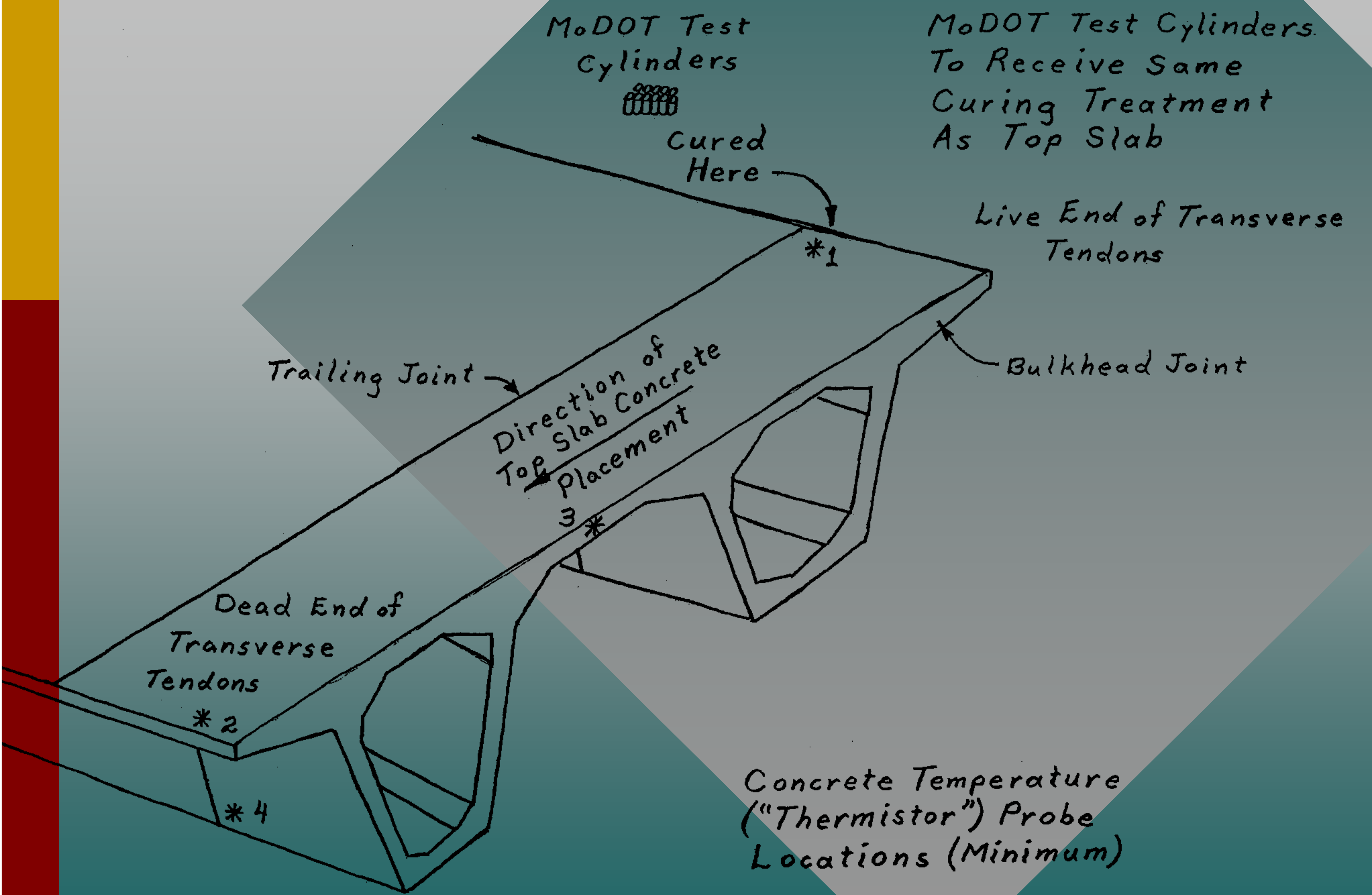
Parking Garage: Children's Hospital, St. Louis 2000-01

- Average in-place age to reach 3450: 27.1 *hours*. Range: 16-48 hours. Ambient temp plays a role in this range. Also, amount of heating has tremendous impact.
- Result:
  - Faster construction because in-place strength higher than field-cured cylinders.
  - Better structure due to less heat being used.
- Saved at least one day for *each pour*, plus tremendous amounts of propane and labor to switch out tanks and for fire watch. Saved more than $5000 in one weekend alone.

Bridges:
Creve Coeur Lake Bridge, St. Louis

Creve Coeur Lake Bridge

- Hundreds of individual post-tensioned segments using a high-early mix.
- Exceptional quality control and testing measures are being used.
- Needed 3500psi to begin stressing PT.
  - No problem achieving this in 12-18h in summer
  - Had trouble achieving this in 24-36h in winter.
- Concerned about cold weather


MoDOT Test Cylinders Cured Here
MoDOT Test Cylinders To Receive Same Curing Treatment As Top Slab
Live End of Transverse Tendons
*1
Trailing Joint
Direction of Top Slab Concrete Placement
Bulkhead Joint
3 *
Dead End of Transverse Tendons
* 2
* 4
Concrete Temperature ("Thermistor") Probe Locations (Minimum)

Creve Coeur Lake Bridge

- MoDOT approved use of maturity testing to track in-place temps and strength gain to determine:
  - Stressing of PT
  - Stripping of travellers (forms)
  - Moving of travellers
  - Loading of structure
  - Cessation of external heating operations

Creve Coeur Lake Bridge

- Using maturity testing allowed the contractor to continue placing concrete even in very cold weather
- Prevented a complete shutdown of the project over the winter months, saving the contractor more than $2,000,000 in costs and liquidated damages
- State gained valuable experience and data to support the use of maturity testing on a wide variety of projects

High-rise concrete buildings: Plaza Residential 30-story tower, Clayton, MO 2001

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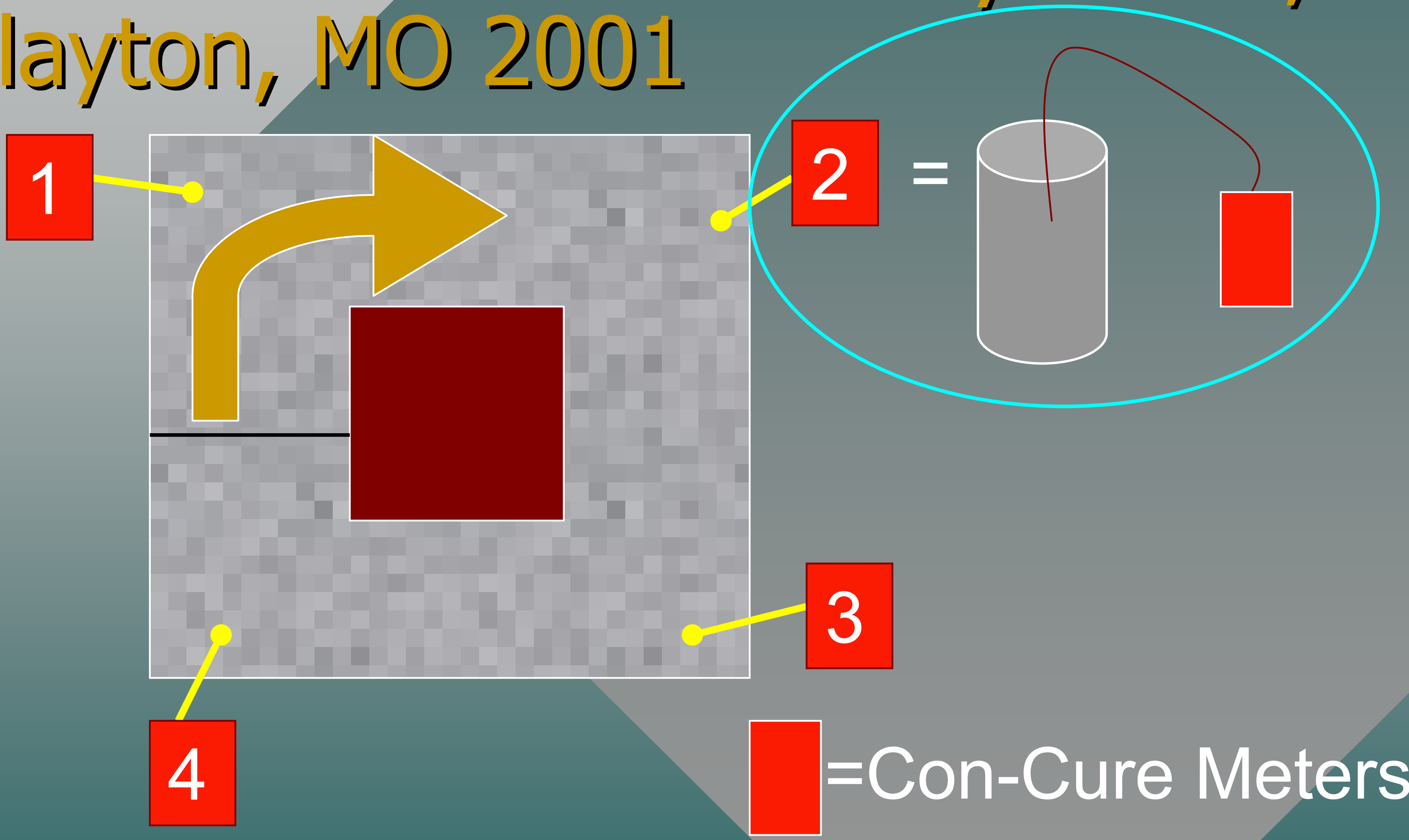
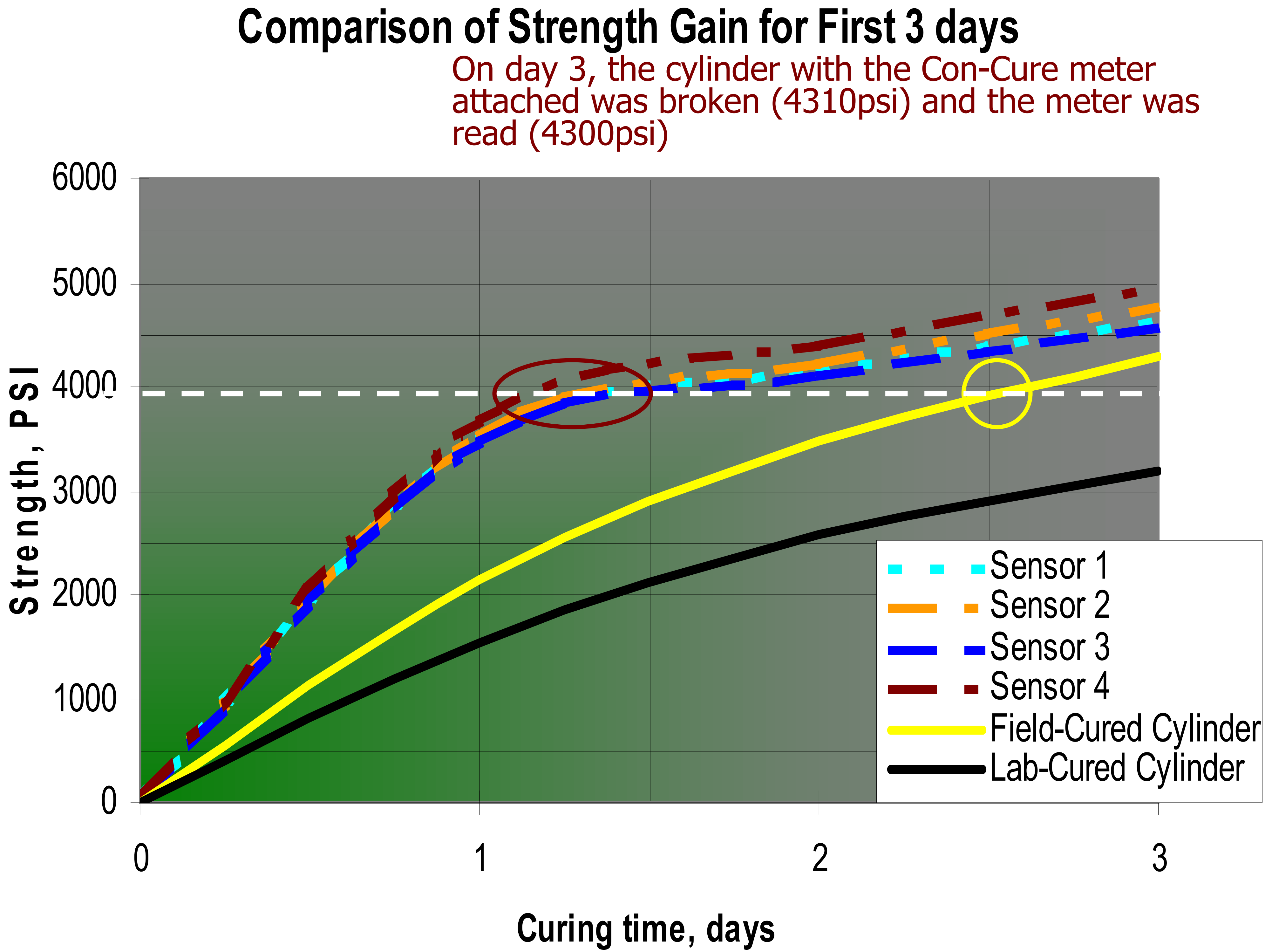


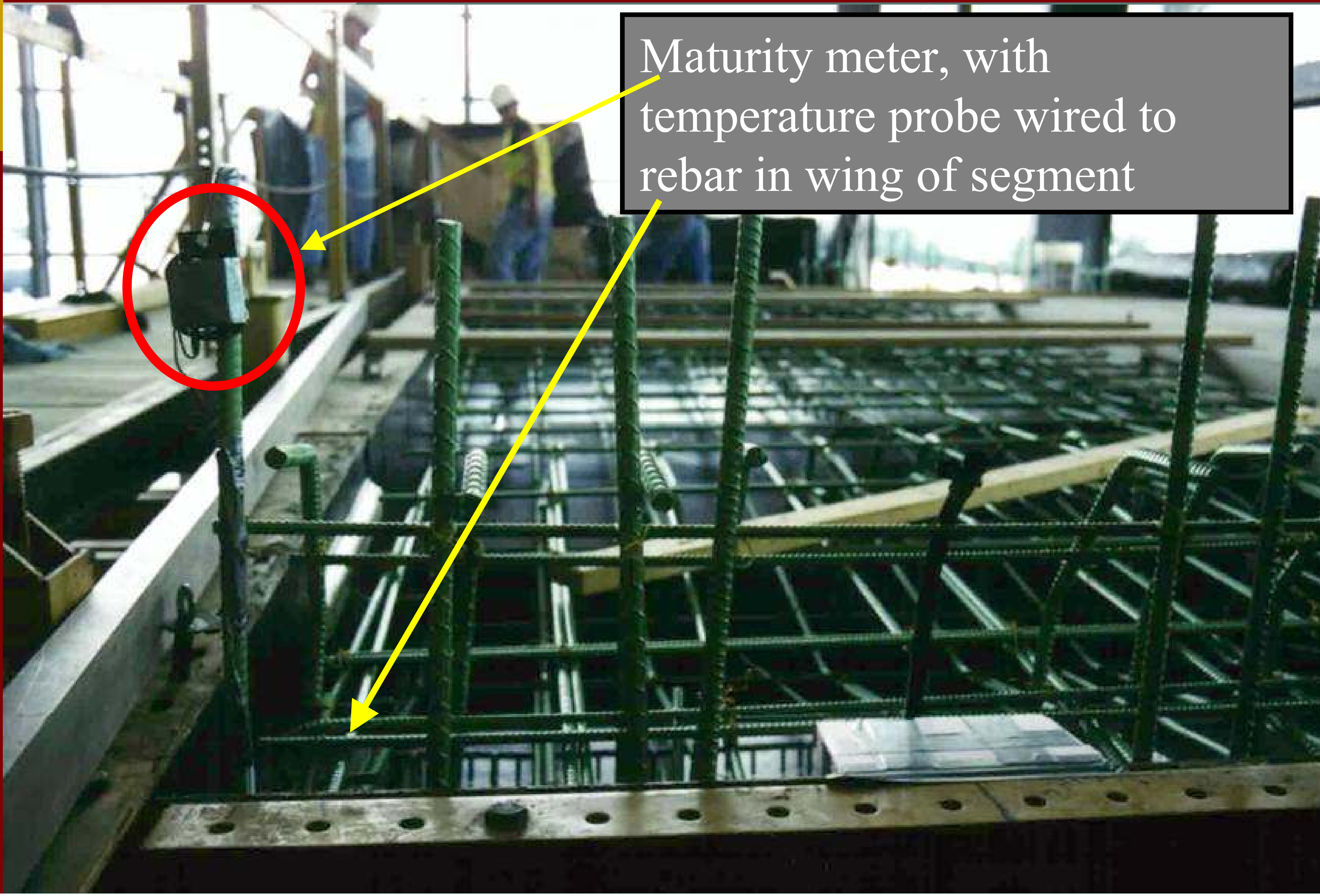
Almost 400 CY of concrete, poured in 6 hours



Comparison of Strength Gain for First 3 days
On day 3, the cylinder with the Con-Cure meter attached was broken (4310psi) and the meter was read (4300psi)
6000
5000
4000
3000
2000
1000
0
Strength, PSI
0
1
2
3
Curing time, days
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Field-Cured Cylinder
Lab-Cured Cylinder

Precast: Bridge Segments

Precast: Bridge Segments



Precast: Bridge Segments

Maumee Crossing Bridge (Toledo, OH):

- Because of well-controlled curing conditions and batching, precast operations lend themselves well to maturity testing.
- Far fewer cylinders need to be taken, saving time, money, space and labor.
- Allowed elimination of reliance on cylinders for determining stripping times, saving an average of 4 hours per segment.
- Heat Sink effect seen in early testing led to improved process and results

Wireless Maturity System Applications:

Precast Concrete Plant

Waco, TX.

An Applications Bulletin from
CON-CURE CORPORATION

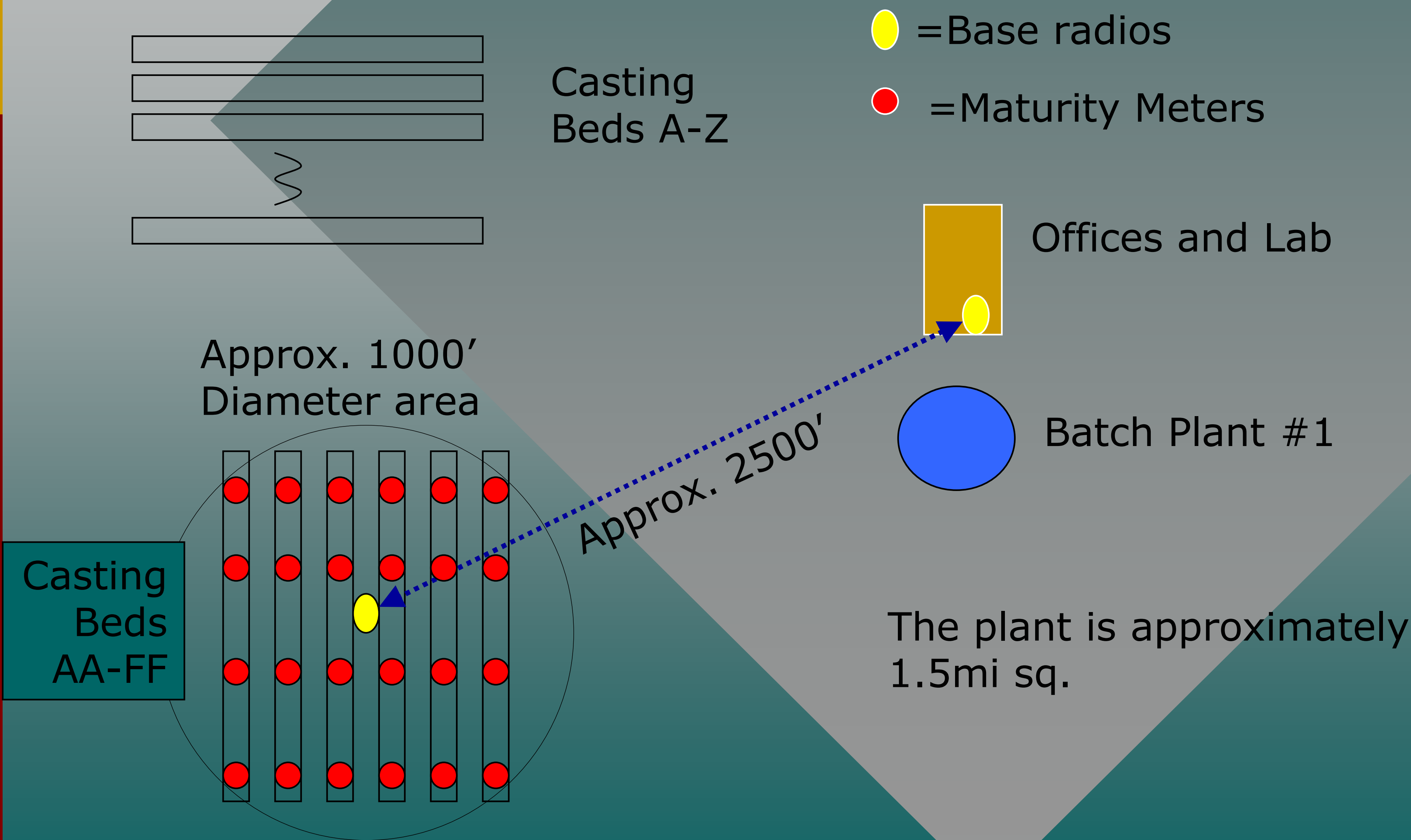
Precast Concrete Plant

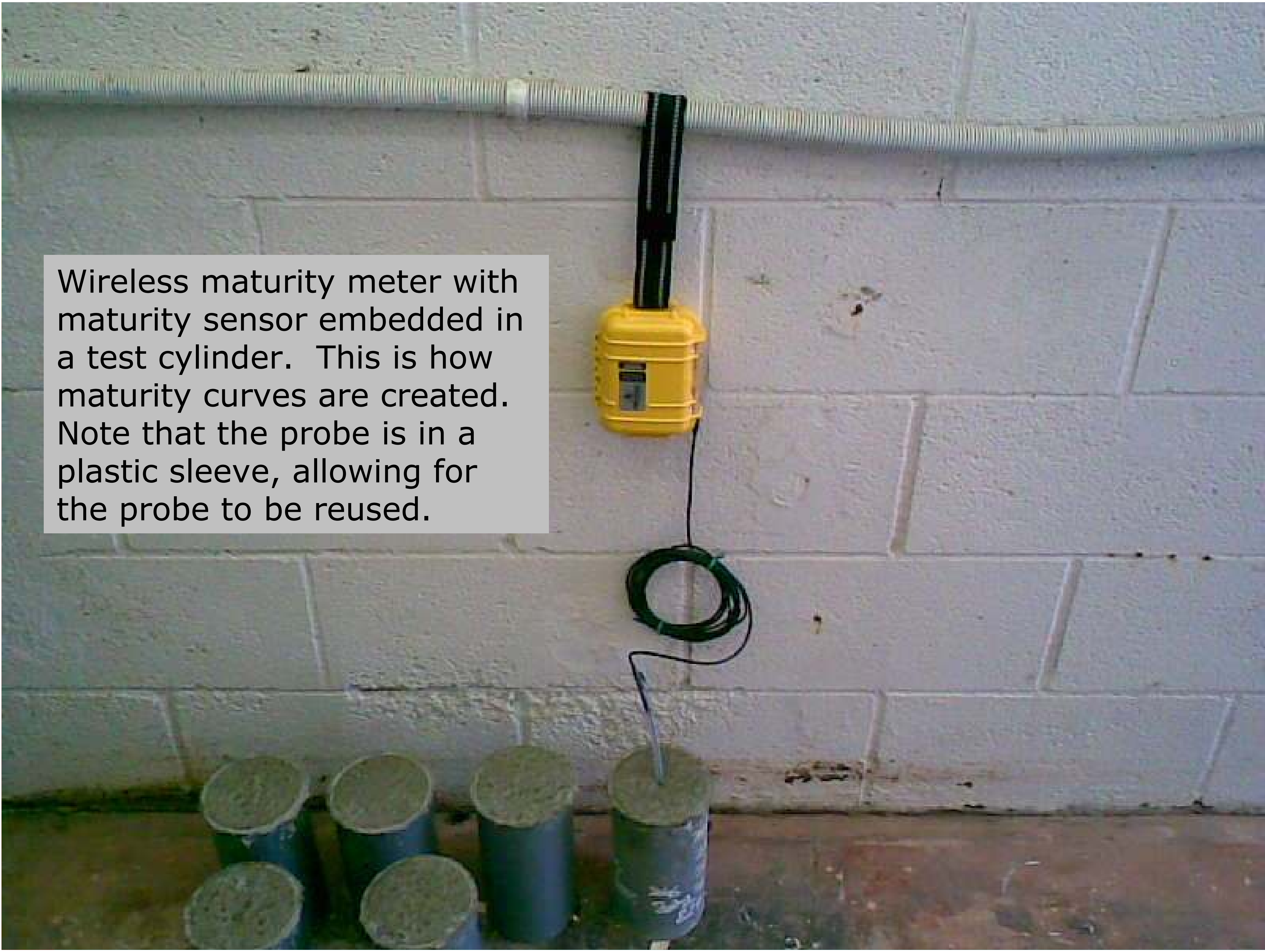
- Prior to implementing the ZoneCure System:
  - Mix designs were created to drive strength in the small 4x8 test cylinders, rather than being optimized to the item being cast.
  - Mix designs were chosen based on the speed at which the casting bed would be required again.
  - One casting per bed per day.

Precast Concrete Plant

- Prior to implementing the ZoneCure System:
  - 700, 800, 900 and even 1000 pounds of pure portland cement was used, with accelerators and retarders to suit requirements.
  - When cylinders fail to reach strength, items are discarded, at very high cost.
  - Very labor intensive operation simply to collect test samples from the sprawling plant in advance of testing.
  - Testing is conducted at any hour of the day or night.

General Plant Layout





Wireless maturity meter with maturity sensor embedded in a test cylinder. This is how maturity curves are created. Note that the probe is in a plastic sleeve, allowing for the probe to be reused.

Wireless Maturity Meter deployed in a beam. Meter is approximately 380 feet from the base node. The laborers shown simply inserted the maturity sensor into the concrete after placement. The sensor immediately begins sending temperature data to the base node, which in turn sends it more than 2000’ to the computer located in the laboratory. The sensor is fully reusable, and the retrieval sleeve is shown in the picture below. The meters do not need to be “launched” or “downloaded.” All operations are fully automatic, with zero interaction on the part of the user.

Another deployed unit. Because this section of the plant gets early shade, both ambient and concrete temperatures are being recorded.

Unit ready to be used on a large pour. The unit is oriented to point towards the base unit for maximum range. This unit was at least 300 feet from the base station, with other meters located in the pathway to form the mesh.

Two units deployed at the end of a long bed. A total of three units are monitoring this piece.

Continuous information is sent to the lab (in the far background beyond the building in the photo) and is evaluated by lab personnel on a routine basis.

The moment the target strength in this piece has been attained, tendons are cut and the piece can be moved and the bed readied for the next pour. With the maturity system, strength and temperature information is always available instantly.

These units are roughly 1800’ from the lab.

After Implementation:

- Real-time test data is transmitted to the lab for instant analysis.
- Predictive tools allow for precise planning of stripping operations, saving labor and time.
- Shorter stripping and tensioning times due to higher strengths in-place. Often up to 40% reduction in curing time.
- Great reduction in wasted technician time collecting field samples.
- New information about excessive cement content, leading to *dramatically* lower raw materials costs.
- More rapid turnover in casting bed availability, possibly allowing two complete castings per day per bed.

CASE HISTORY: Bridge Culvert

- Sorry, this was such a small project I do not have any photos.
- Still, this is as compelling a reason to use maturity testing as any of the others shown here, despite the fact that it was such a small project!

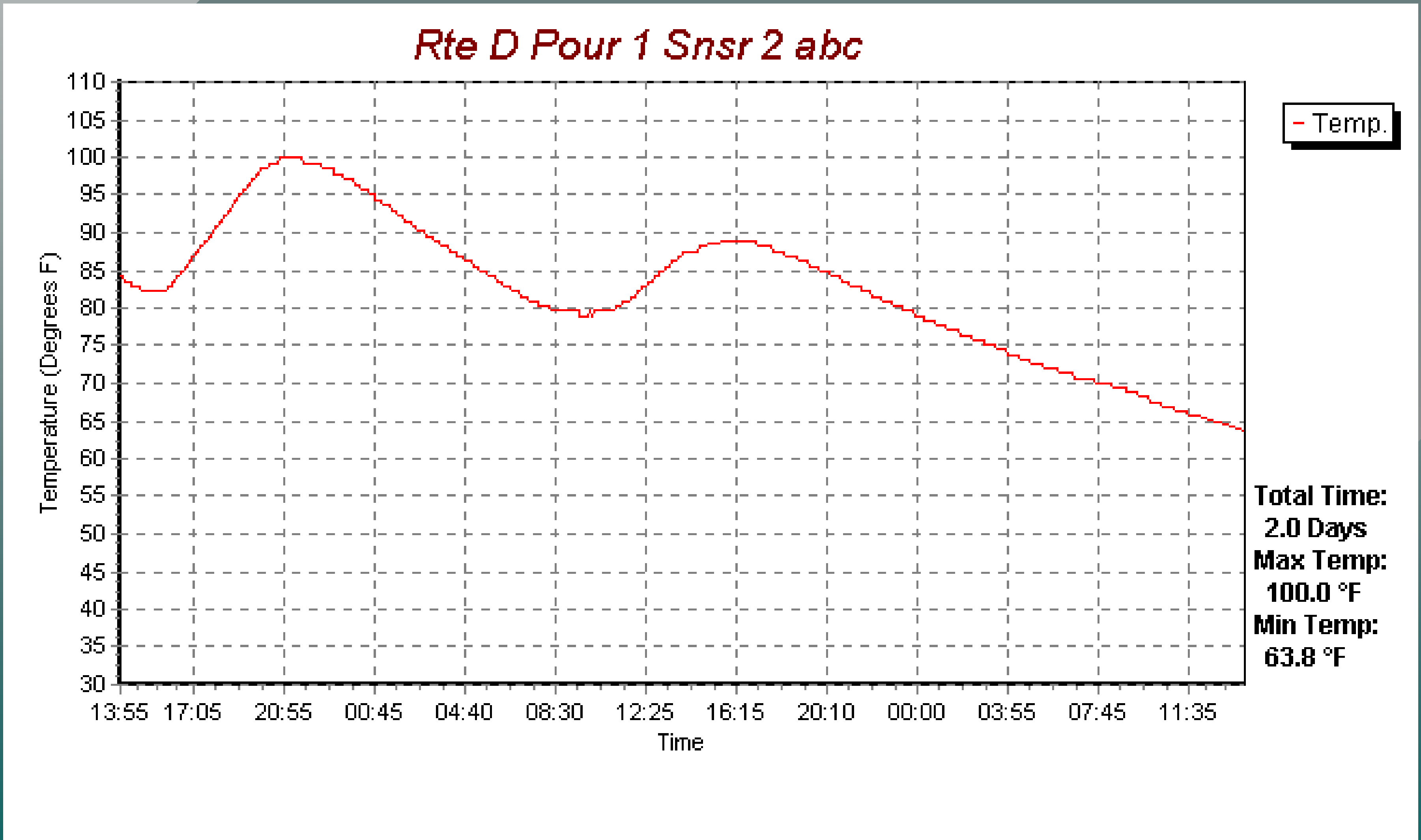
Maturity Testing:

A Stunning Real-World Example and Lessons Learned

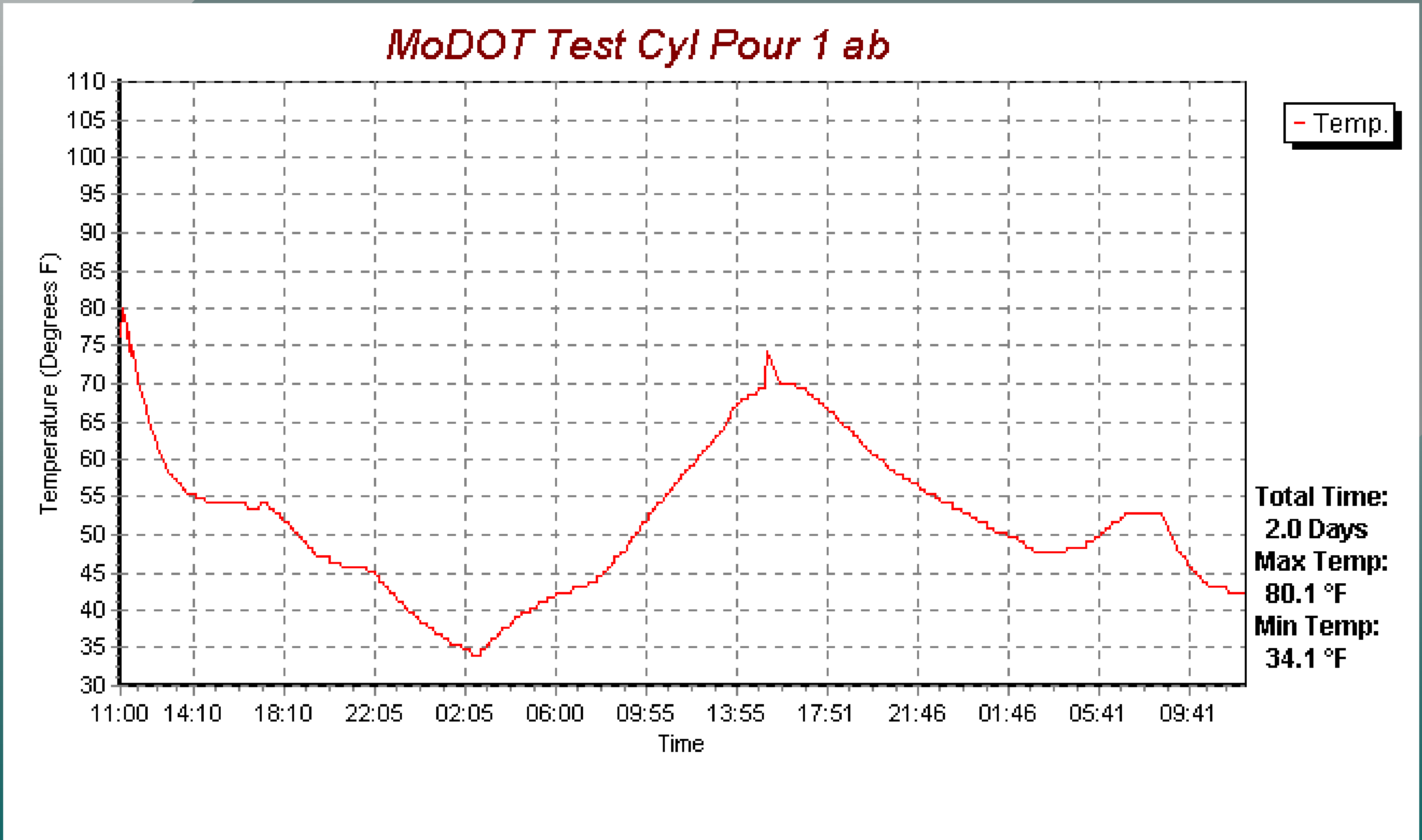
Bridge Culvert, St. Louis MO

- Concrete placed February 2004, ambient temp range: 35F to 50F.
- Three maturity meters per placement.
- Mo. DOT cylinders taken and monitored using maturity meters.
- Comparison between cylinder and in-place strengths/temperatures is startling:

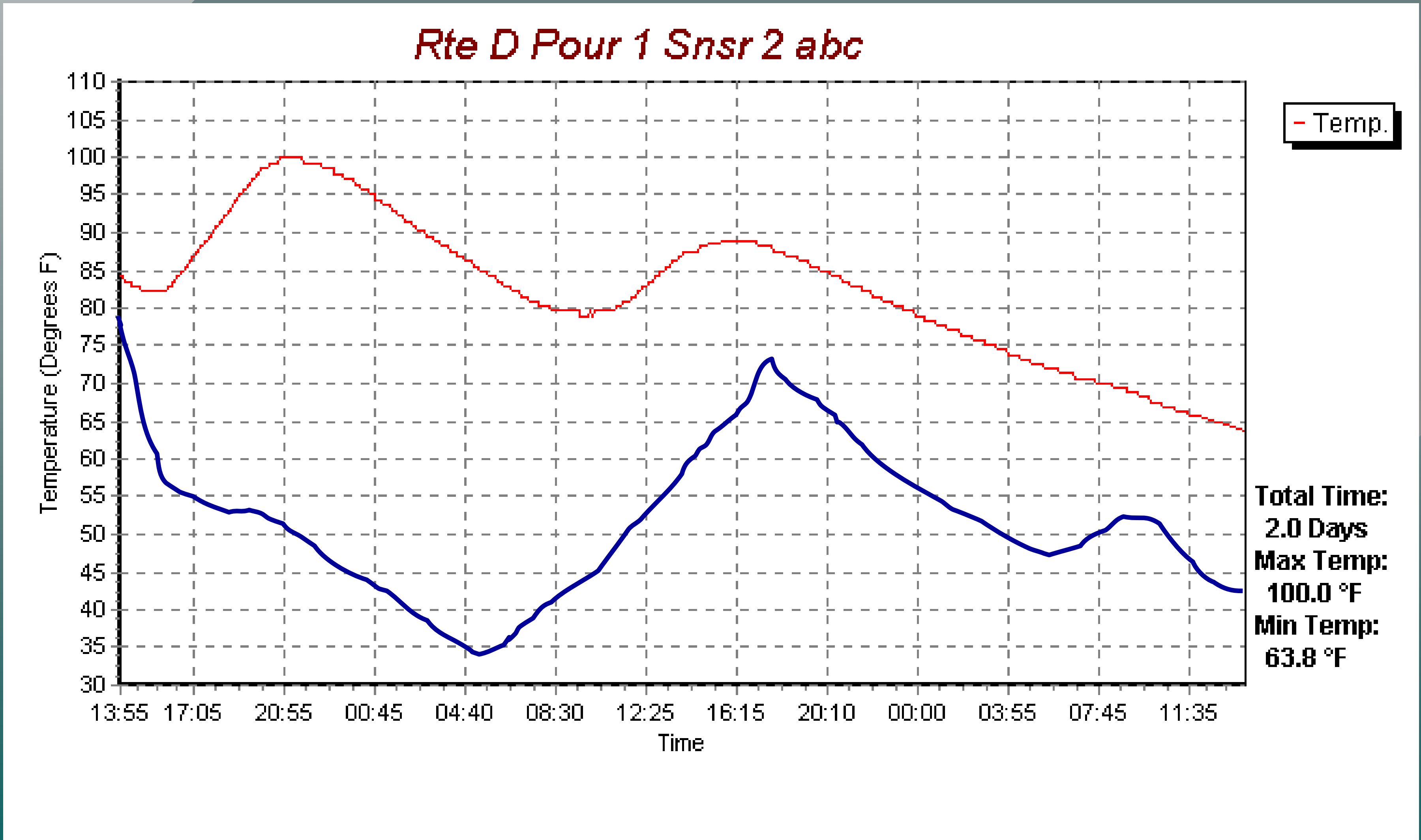
Temperature History Comparison



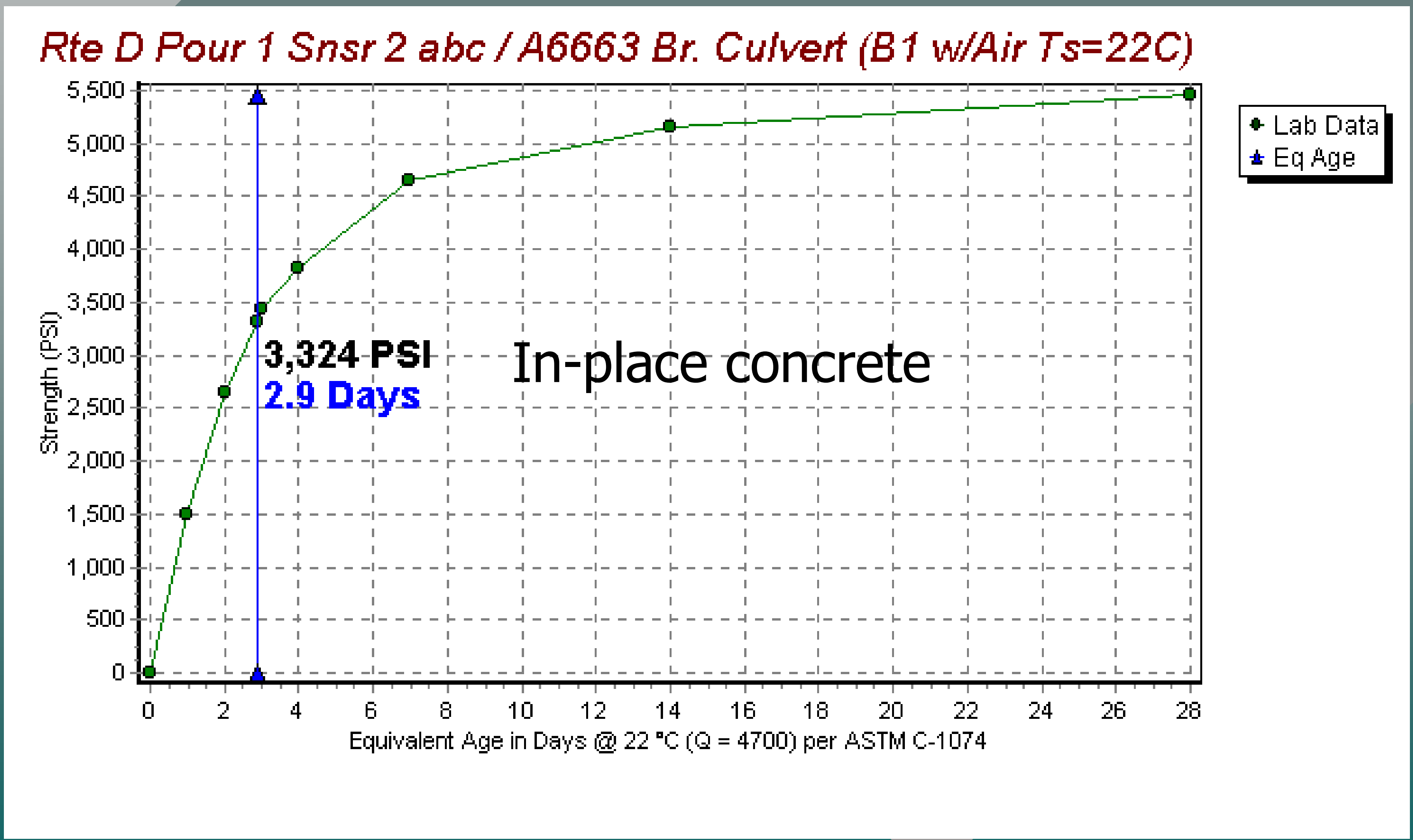
Temperature History Comparison



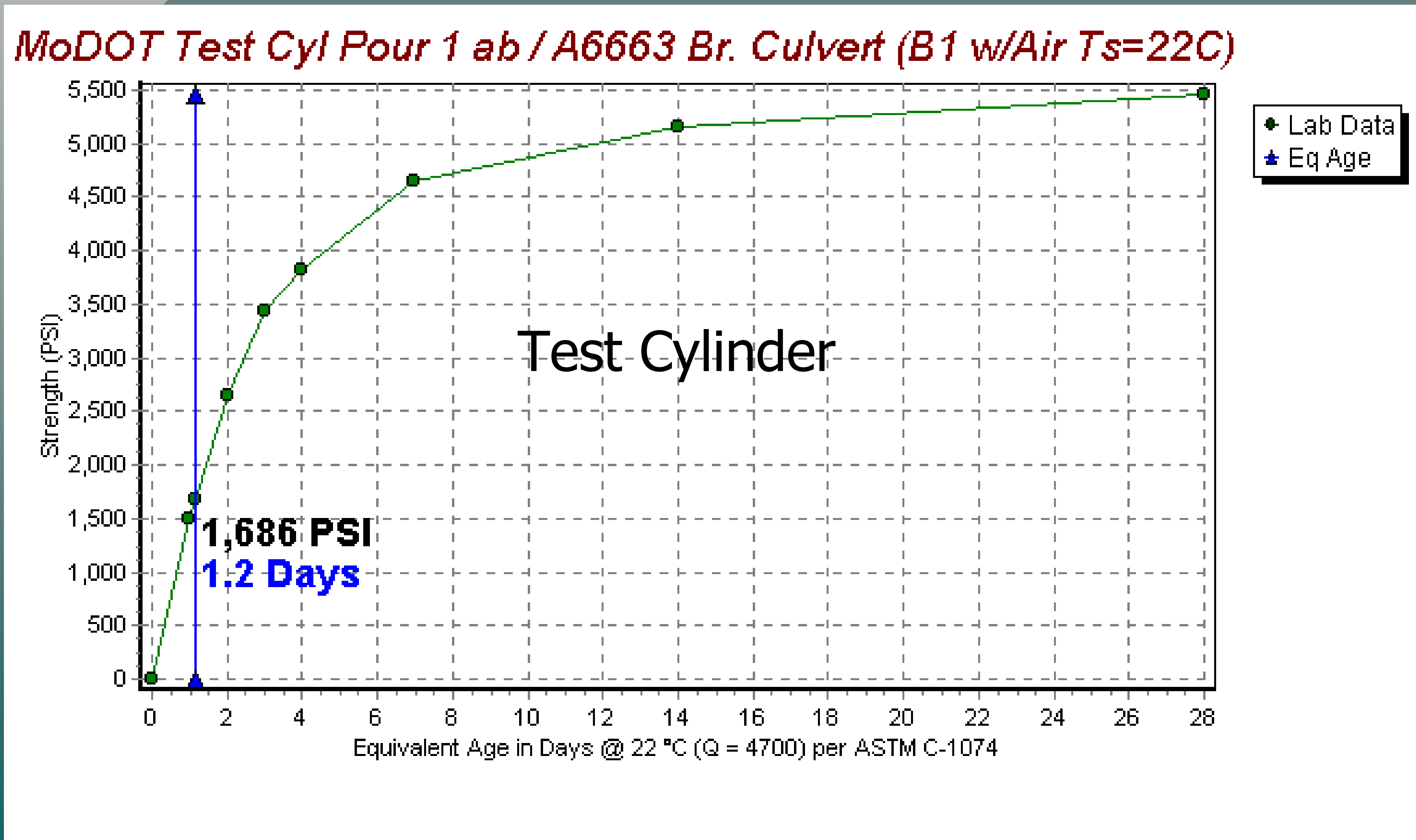
Temperature History Comparison



2-day Strength Comparison



2-day Strength Comparison



Lessons Learned:

- Superior mass of in-place concrete created nearly ideal curing conditions, even without applying external heat (propane). Deck was covered with insulating blanket only. Result: Contractor saved more than $5000 in propane (2 pours).
- Monitoring test cylinders allowed contractor to "ignore" low breaks, speeding construction (early form removal).

Lessons Learned:

- Contractor fully deployed maturity testing on all projects due to extreme value on this job alone.
- Better quality control of test cylinders: Contractor learned firsthand just how far from reality some test cylinders can be. Contractor now ensures cylinders are cured properly.

Lessons Learned:

- Better curing of cylinders led to higher degree of confidence in maturity readings.

Mass Concrete Application: The Lindbergh Tunnel, 2002-3

Thermal differentials must be monitored closely.

- Mass concrete is special case because of risk of severe damage due to excessive heat buildup
- Properly designed concrete mixes can perform well, but need for monitoring is acute

Thermal differentials must be monitored closely.

- Probes are placed in center of mass and at the face. Temperatures are tracked over time.
- Monitoring temps allows earliest cessation of external heating ops
- Maturity can be used to determine safe formwork stripping time

Mix Design Optimization

- With some routine testing, mix designs can be evaluated and optimized for the desired characteristics and reduced costs.
- This contractor saved more than $500,000 by optimizing the mix design.

Maturity Testing has come of age.

- In the US, certain codes (ACI 306 and OSHA) now require the use of maturity testing for many projects. OSHA now requires it for all concrete projects where someone can be injured by a failure.
- ACI has drafted new performance-based criteria for many cold weather placements. Contractors now need to monitor CONCRETE temperature and maturity.

Maturity Testing has come of age.

- Contractors who implement maturity testing now will have an edge when the new specifications are enacted.
- Engineers who familiarize themselves with the uses and limitations of maturity testing will be in good shape to help contractors when this test is required.
- Specify in-place testing for improved understanding of forces creating strength

When I saw this, I immediately saw the parallels in Maturity Monitoring. The "Early Adopters" have benefitted the most, and have moved ahead of their peers in knowledge and scope of understanding of the maturity method. They typically brought Engineers along, kicking and screaming sometimes, but the engineering community is now fully in favor of the use of maturity monitoring. DOTs have jumped at the opportunity to open pavements sooner and with lower costs, but it took them longer to adopt it than contractors. And bringing up the rear is the Precast industry. Ironically, the Precast industry stands to benefit the most from implementing maturity in their plants, from lowering materials costs to streamlining QC procedures. Incremental improvements in Precast lead to very great cost reductions over time.

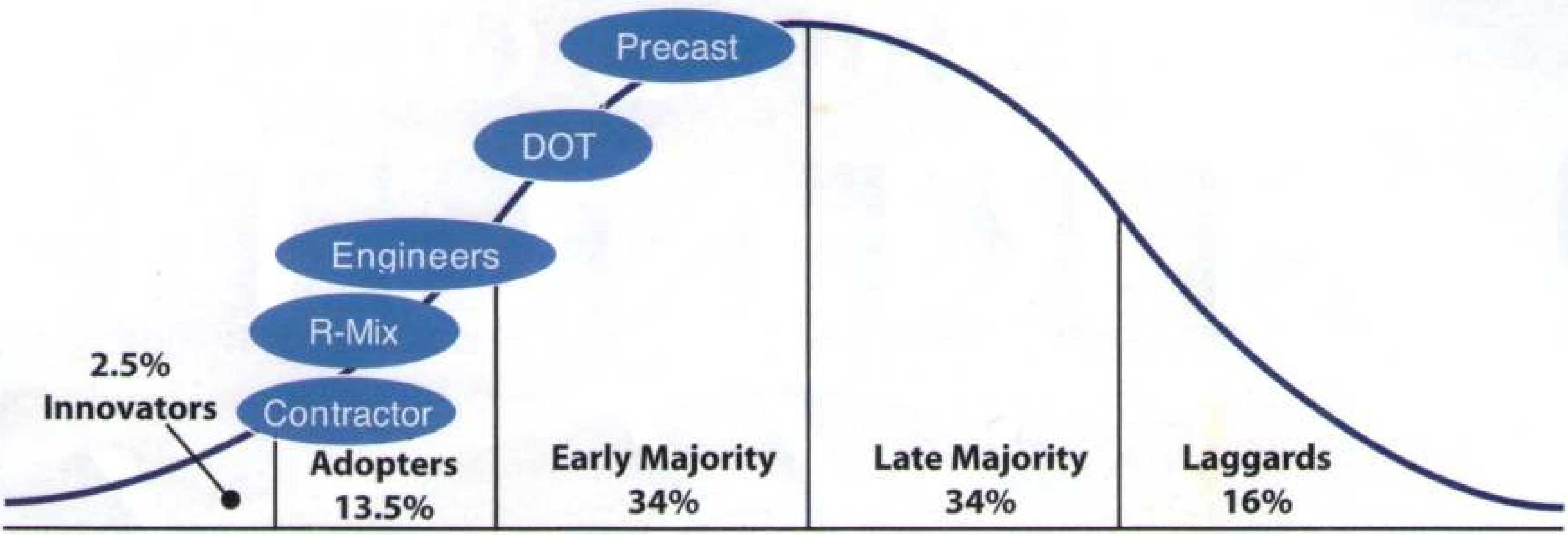


Figure 2. Concrete industry sub-groups and what stage of acceptance of maturity based on the adopter category

Thank you for the opportunity to speak to you today.

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