Pennoni Associates Inc.

- Consulting Engineers

Eighth Annual

PENNSYLVANIA CONCRETE CONFERENCE

Holiday Inn, Grantville, Pennsylvania

January 31, 2007

PRESENTATION OUTLINE

- Concrete Maturity Testing
  (what it is and how it is done)
- Past Accomplishment
  (over last year)
- Future Implementation
  (what's next)

Concrete Maturity Testing (CMT)

- What is Concrete Maturity?

Concrete Maturity is an expression that represents the influence of Temperature on the Rate of Strength Development or Strength Gain.

Concrete Maturity Testing (CMT)

- When is CMT more Beneficial?

When it is impractical to obtain cylinder results such as at night when road needs to be opened.

Concrete Maturity Testing (CMT)

- ASTM C1074:
  - Available Apparatus
  - The three Steps of CMT:
    - Calibration
    - Estimation
    - Verification
- Benefits of CMT

Concrete Maturity Testing (CMT)

- 1950: Nurse & Saul described TTF
- 1987: CMT became an ASTM Standard Practice (ASTM C 1074)
- ASTM C 1074 Provides a Procedure for Estimating Concrete Strength using Maturity Method.

Concrete Maturity Testing (CMT)

- Maturity is expressed in two functions:
  - Temperature-Time Factor (TTF)
  - Equivalent Age at a T_s (EA)

Concrete Maturity Testing (CMT)

- The difference between the two functions TTF and EA is as follows:
  - TTF assumes that the rate of strength development is a linear function of temperature.

Concrete Maturity Testing (CMT)

- The difference between the two functions TTF and EA is as follows:
  - EA assumes that the rate of strength gain varies exponentially with concrete temperature.

Concrete Maturity Testing (CMT)

- Computing TTF: (Nurse-Saul formula)
  - TTF (°C-hours) = $\Sigma(T_a - T_0)\Delta t$

    where Ta is the average temperature (°C) during time interval Δt (hours).

    and where T_0 is the Datum Temperature at which it is assumed that concrete ceases to gain strength -10°C (14°F) unless a more accurate value is determined by testing.

Concrete Maturity Testing (CMT)

- Computing EA: (Arrhenius formula)
  - EA (days or hours) = $\Sigma e^{-Q(1/Ta - 1/Ts)}\Delta t$

    where Q is the activation energy (°K),
    where Ta is the average temperature during time interval Δt,
    and where T_S is the Specified Temperature

Concrete Maturity Testing (CMT)

- Available Apparatus (fall in 3 categories)
  - Multi-Channel Data Acquisition
  - Embedded Sacrificial Loggers
  - Embedded Re-usable Probes (Wireless)

Concrete Maturity Testing (CMT)

- Multi-Channel Data Acquisition

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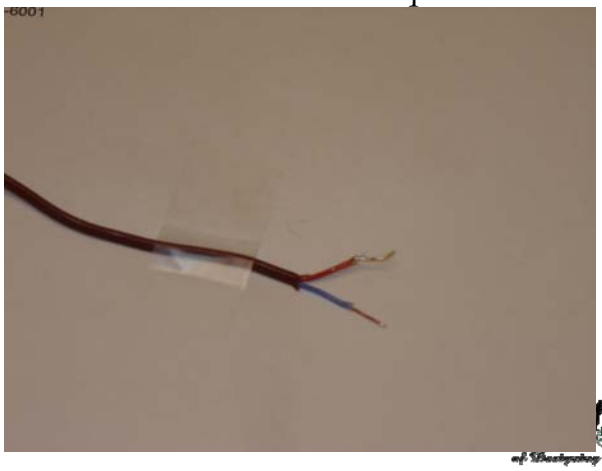
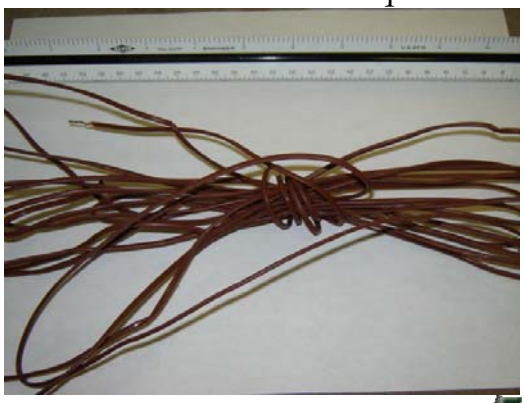
- Multi-Channel Data Acquisition



Concrete Maturity Testing (CMT

- Multi-Channel Data Acquisition



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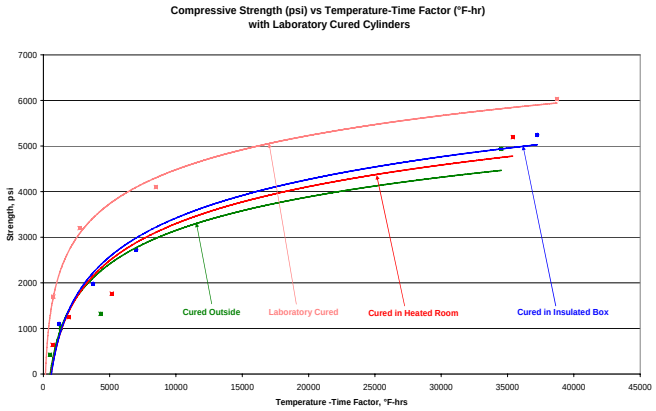

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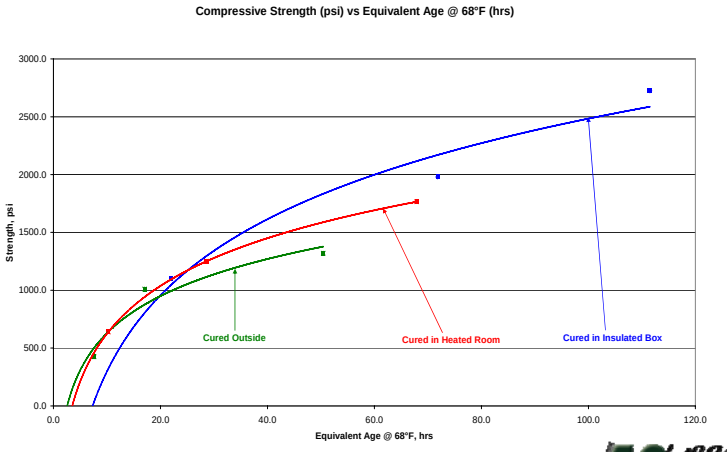

Concrete Maturity Testing (CMT)

- Multi-Channel Data Acquisition Advantages:
  - View Real-Time Data On-Screen
  - Multi-Location Simultaneous Monitoring
  - Mostly Re-Usable Wiring

Concrete Maturity Testing (CMT)

- Multi-Channel Data Acquisition Disadvantages:
  - Labor Intensive & Time Consuming Set-up (only if a large number of channels is required)
  - Leave Logger & Lap Top on-Site
  - Does not Compute TTF or EA

Concrete Maturity Testing (CMT)

- Multi-Channel Data Acquisition Approximate Cost (Least Expensive)
  - Data Acquisition Unit $4,500 (one-time)
  - 1000 lf of Thermocouple Wire $500.00
  - Thermocouple Plugs $2.50/each (one time)

Concrete Maturity Testing (CMT)

- Embedded Sacrificial Loggers:

Concrete Maturity Testing (CMT)

- Embedded Sacrificial Loggers:

Concrete Maturity Testing (CMT)

- Embedded Sacrificial Loggers Advantages:
  - Easy Installation
  - Computes TTF & EA
  - Hand Held Reader (No lap top necessary)

Concrete Maturity Testing (CMT)

- Embedded Sacrificial Loggers Disadvantages:
  - Sacrificial
  - No Centralized Output (go to each logger)
  - Downloading Data to PC (Additional Step)

Concrete Maturity Testing (CMT)

- Embedded Sacrificial Loggers Approximate Cost
  - Loggers $44/each (sacrificial)
  - Kit including Reader & Software $9,000

Concrete Maturity Testing (CMT)

- Embedded Re-Usable Probes (Wireless):

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Concrete Maturity Testing (CMT)

- Embedded Re-Usable Probes (Wireless): Advantages:
  - Easy Installation
  - Computes EA (& TTF indirectly)
  - Wireless Technology
    - "Hyperterminal" (switch between units)
    - "Remote Desktop" (connect to networked computer)
  - Re-Usable Probes

Concrete Maturity Testing (CMT)

- Embedded Re-Usable Probes (Wireless): Disadvantages:
  - No Continuous Read-Out
  - Stop Meters & Re-launch (for each output)
  - Separate Wireless Units

Concrete Maturity Testing (CMT)

- Embedded Re-Usable Probes (Wireless): Approximate Cost
  - Re-Usable Probes $20/each
  - Meter $500/each
  - Wireless Unit $650 /each
  - Kit $9,000
    (10 meters, 1wireless, 30 probes)

Concrete Maturity Testing (CMT)

- Embedded Re-Usable Probes (Wireless): Suggested Improvements
  - Embed the Wireless Technology into the meter itself, so that one sender may communicate with an unlimited number of meters (combining two units into one).

Concrete Maturity Testing (CMT)

- Embedded Re-Usable Probes (Wireless): Suggested Improvements
  - Continuous Screen Read-Out and Logging /Recording data, thus reducing the need for….

Concrete Maturity Testing (CMT)

- Embedded Re-Usable Probes (Wireless): Suggested Improvements
  - Stopping Meters, Saving Data, Re-Launching, therefore precluding the possibility of forgetting to re-launch the meter and also reduce the merging of data files.

Concrete Maturity Testing (CMT)

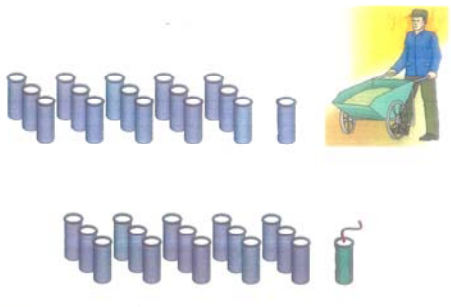
- Embedded Re-Usable Probes (Wireless): Suggested Improvements
  - Adding the TTF calculations feature to be graphically displayed by the software.

Concrete Maturity Testing (CMT)

- Calibration (First Step)
  - Prepare 16 Cylinders at Batch Plant Preferably (5 sets of three, 1 instrumented)
  - Embed 2 Sensors in one Cylinder (half way down the cylinder)

Concrete Maturity Testing (CMT)

- Calibration (First Step)



Concrete Maturity Testing (CMT)

- Calibration (First Step)

Concrete Maturity Testing (CMT)

- Calibration (First Step)
  - Cure Cylinders in Water Bath

    Two important factors to keep in mind:

    1) maintain cylinders at a constant temperature

    2) simulate the temperature of structural element to the extent possible

Concrete Maturity Testing (CMT)

- Calibration (First Step)

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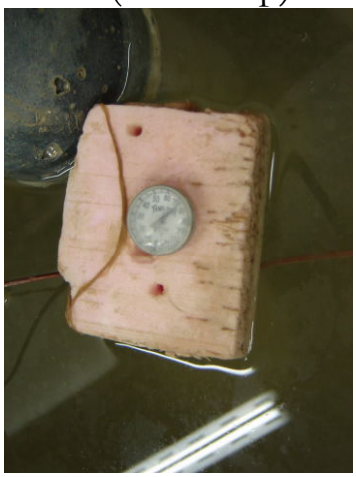

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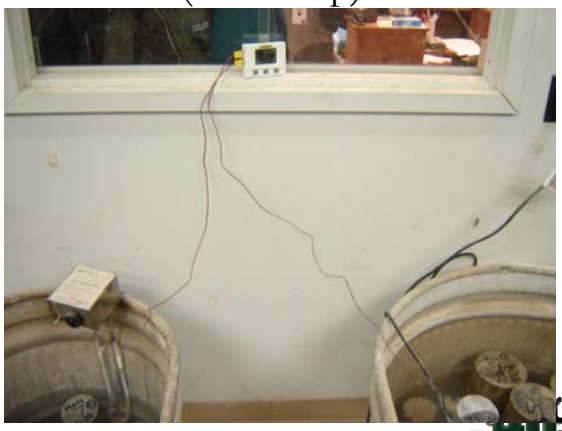


Concrete Maturity Testing (CMT)

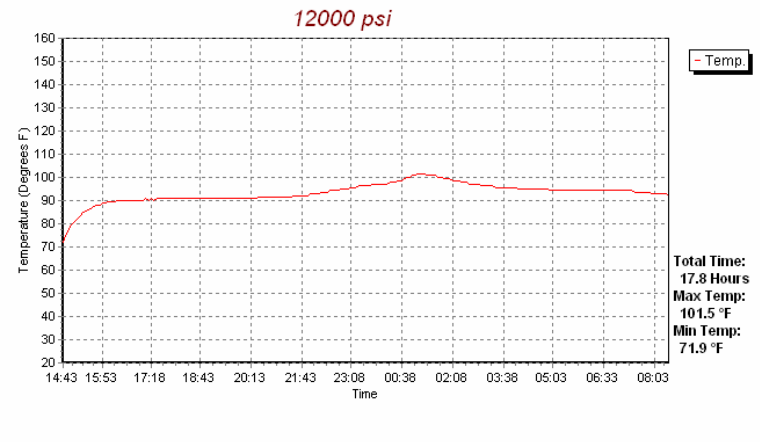
- Calibration (First Step)
  - Perform Compressive Strength Testing on two Cylinders at five appropriate test ages (with two tests before target age and two tests after target age)
  - If results range is greater than 10% of the average of two results, test third cylinder

Concrete Maturity Testing (CMT)

- Calibration (First Step)
  - Download Temperature History from both sensors in cylinder at each test age
  - A Graph of Compressive Strength versus Maturity Index is Obtained.

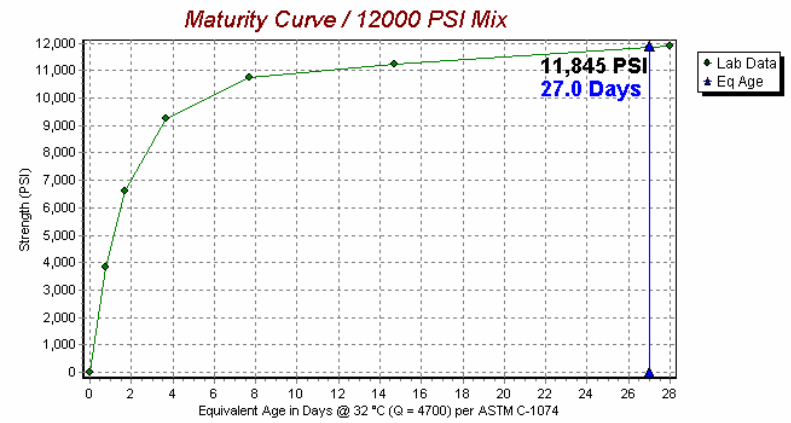
Concrete Maturity Testing (CMT)

- Temperature History



Concrete Maturity Testing (CMT)

- Maturity Curve



Concrete Maturity Testing (CMT)

- Estimation (Second Step)
  - Embed Sensors into the Fresh Concrete at various critical locations
  - Download Temperature History of Sensors at various desired ages.

Concrete Maturity Testing (CMT)

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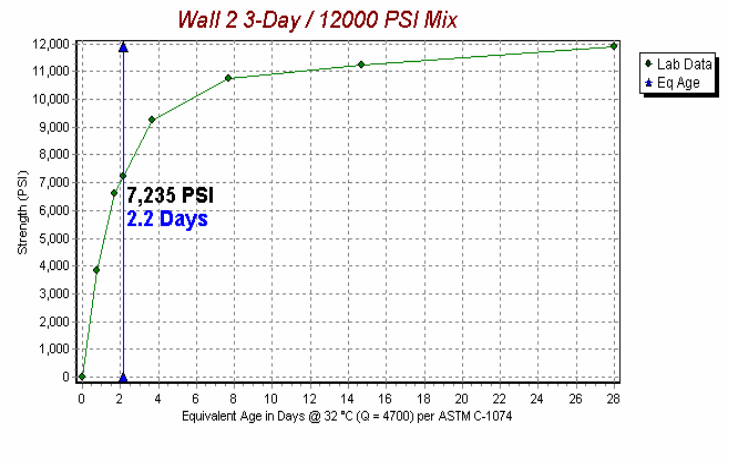
- Estimation (Second Step)
  - Using the Software, Obtain an Estimated Concrete Strength from the Recorded Temperature History and the Established Calibration Curve.
  - Initially Compare the Estimated Strength to Actual Cylinder Results.

Concrete Maturity Testing (CMT)

- Estimation Curve



Concrete Maturity Testing (CMT)

- Verification (Third Step)
  - Prepare One Additional Cylinder along with the Regular Number of Cylinders used for the project.
  - Instrument the Additional Cylinder with two Sensors (as in the calibration stage).

Concrete Maturity Testing (CMT)

- Verification (Third Step)
  - Cure the Additional Cylinder in the same way as the rest of the Cylinders.
  - Download the Temperature History of the Instrumented Cylinder.

Concrete Maturity Testing (CMT)

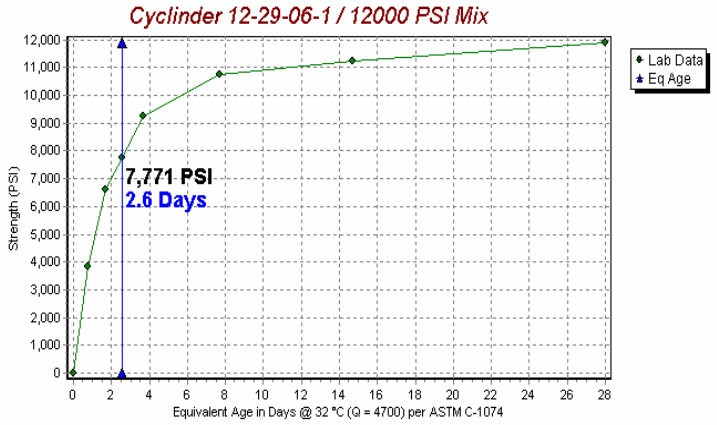
- Verification (Third Step)
  - Using the Software, Obtain an Estimated Concrete Strength from the Recorded Temperature History and the Established Calibration Curve.
  - Test a companion Cylinder at the same age and Compare Actual Results to Estimated.

Concrete Maturity Testing (CMT)

- Verification (Third Step)
  - Verify that Estimated Test Results are Within ± 10% of Actual Test Results.
  - It is preferable that the Estimated Strength is 10% less than Actual Strength (shows that estimated strength is conservative).

Concrete Maturity Testing (CMT)

- Verification Curve



Concrete Maturity Testing (CMT)

- BENEFITS:
  - Opening Roadways to Traffic
  - Termination of Cold Weather Protection
  - Removal of Formwork & Re-shoring
  - Post-Tensioning

Past Accomplishment

- "White Paper":
  - Proposed CMT developed by PAI entitled: "Proposed Outline for Use of Concrete Maturity Method for PADOT Pavement Projects"
  - Letter of invitation to Industry Representatives to Discuss CMT

Past Accomplishment

- December 1, 2006 Meeting with Industry Representatives, Objective:
  - To bring paving industry representatives together with PADOT personnel and consultants to discuss issues, experiences, and concerns regarding the use of the CMM and obtain their guidance regarding next steps in the process of adopting and implementing this technology.

Past Accomplishment

- December 1, 2006 Meeting with Industry Representatives, Discussion:
  - Mixed Results from PADOT Districts
  - PTM versus ASTM
  - Write CMM specifications
  - Developing a Statewide Special Provision
  - Perform Pilot Studies
  - Conduct a Survey of PADOT Districts & Other States

Past Accomplishment

- December 1, 2006 Meeting with Industry Representatives, Outcome:
  - To conduct a survey of all PADOT districts as well as other States using the CMT to gather more information specifically documenting benefits and cost savings and summarize findings in a report
  - To Review and Discuss Report and Consider next steps

Past Accomplishment

- December 1, 2006 Meeting with Industry Representatives, Follow-up:
  - A survey questionnaire was developed by PAI and was reviewed by PADOT and other interested parties.
  - The survey questionnaire was sent to all eleven PADOT Districts and Five other States: OH, NY, MI, IL, IO.

Current Activities

- Received some responses from PADOT Districts and other States.
- Still waiting on remaining responses
- A summary Report has been started collating all the data received to date.

Future Implementation

- After survey questionnaires and data have been received, we will finalize summary report.
- In light of the received data, we will review the existing Special Provision on "Maturity Meter System" and propose modifications.

Future Implementation

- Set-up a meeting with Industry Representatives to review and discuss survey summary report and to consider proposed modifications of the existing Special Provision.
- Determine whether a CMM specification should be written.

Future Implementation

- Consider impact on other specifications and documents if CMM specifications are written.
- Determine whether a PTM should be written to address PADOT nuances not covered in ASTM C1074.

Future Implementation

- Explore the possibility of performing Pilot Testing on specific projects within one or two PADOT Districts.

Concrete Maturity Testing (CMT)

Any Questions?