Maturity Meters for Any-Time Strength Measurements

Presented by

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Brief History of the Maturity Method

The "maturity concept" was proposed in the late 1940s and early 1950s as a technique to account for the combined effects of time and temperature on the strength development of a concrete mixture (Nurse 1949; McIntosh 1949; Saul 1951).

Carino and Tank

Specifications

- ✓ **ACI**
  - ✓ 301 Standard Specifications for Structural Concrete (paragraph 2.3.4)
  - ✓ 318 Building Code Requirements for Structural Concrete (paragraph 6.2)

Specifications

- ACI
  - 228.1R In-place Methods of Estimating Concrete Strength (paragraph 2.7)
  - 306 Cold Weather Concreting (paragraph 6.4)

Specifications

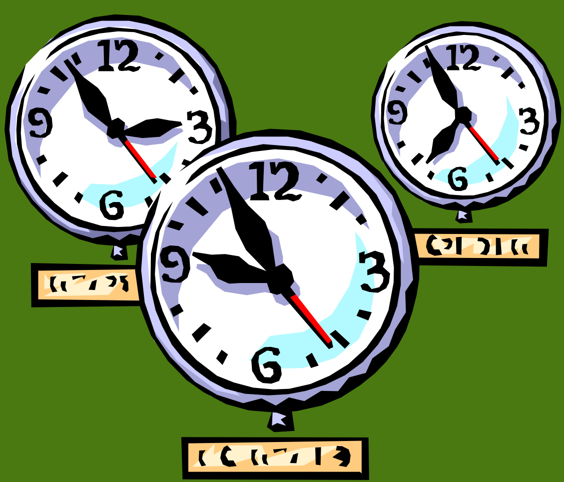
- ✓ **FHWA**
  - ✓ SA-97-105 Guide to Non-destructive Testing of Concrete
- ✓ **ASTM**
  - ✓ C 1074 Practice for Estimating Concrete Strength by the Maturity Method

Used by DOT's

- Texas DOT
- Iowa DOT
- Kentucky DOT
- Florida DOT
- Georgia DOT
- Ohio DOT
- Mississippi DOT
- Nebraska DOT
- Rhode Island DOT
- Tennessee DOT
- Oklahoma DOT
- Minnesota DOT
- Louisiana DOT Approved

Benefits of Using the Maturity Method (to the project)

- Accelerate construction schedules
- Reduce man-hours
- Reduce test specimen cost



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- Remove shoring and re-shoring sooner
- Allows earlier form removal and with confidence that the operation is safe; rented forms can be returned sooner
- Post-tensioning tendons can be stressed earlier
- Open roadways to traffic in less time

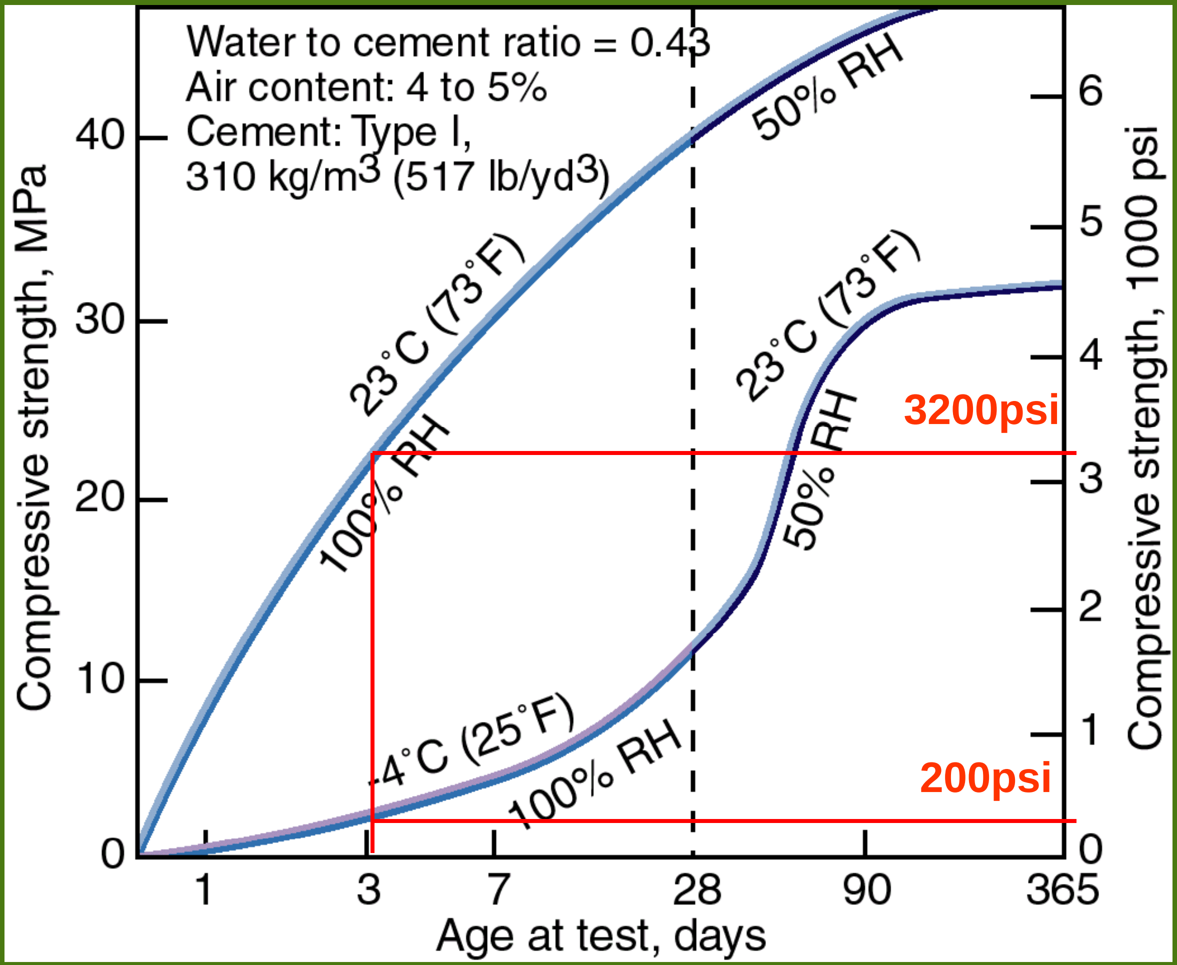
Engineering Benefits of Using the Maturity Method

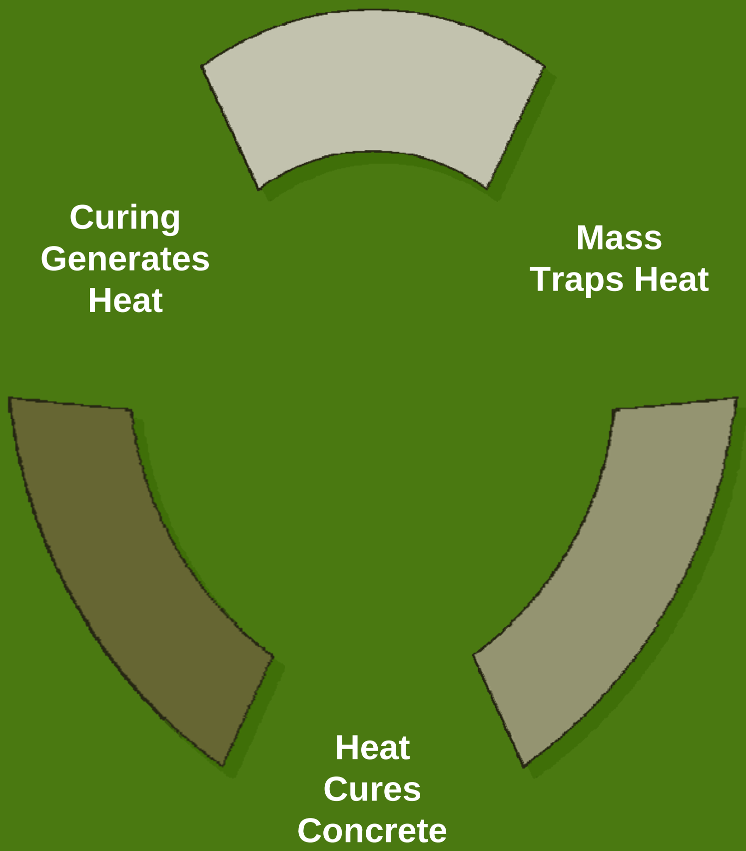
- Provides a better representation of in-place concrete strength gain (compressive or flexural) than laboratory or field cured specimens
- Enables any-time in-place strength measurements
- Enables in-place strength measurements at "lowest strength (youngest concrete)" locations
- Enables in-place strength measurements at "critical stress" locations

Hydration is the chemical reaction between the cement and water in which new compounds with strength producing properties
are formed.

Heat of Hydration is the heat given off during the chemical reaction as the cement hydrates.

Effect of Curing Temperature on Strength Development





Cylinder vs. Placement

Cylinder
- Less Mass
- Less Heat Retention
- Lower Curing Temperature
- Lower Early Strength

Placement
- Greater Mass
- More Heat Retention
- Higher Curing Temperature
- Higher Early Strength

Maturity Rule

"Concrete of the same mix at the same maturity (reckoned in temperature-time) has approximately the same strength whatever combination of temperature and time go to make up that maturity."

A.G.A. Saul, 1951

Maturity Functions

- Temperature-time Factor (Nurse-Saul)

  $M = \Sigma\,(T_a - T_o)\,\Delta t$

- Equivalent age (Arrhenius)

  $t_e = \Sigma e^{-Q}[\,1/T_a - 1/T_s\,]\,\Delta t$

Nurse – Saul Function

(Temperature – time factor)

$$M = \Sigma (T_a - T_o)\, \Delta t$$

M = the temperature – time factor at age t, degree – hours

T_a = average concrete temperature during time interval, Δt

Δt = a time interval, hours

$T_o = 0^\circ$ C

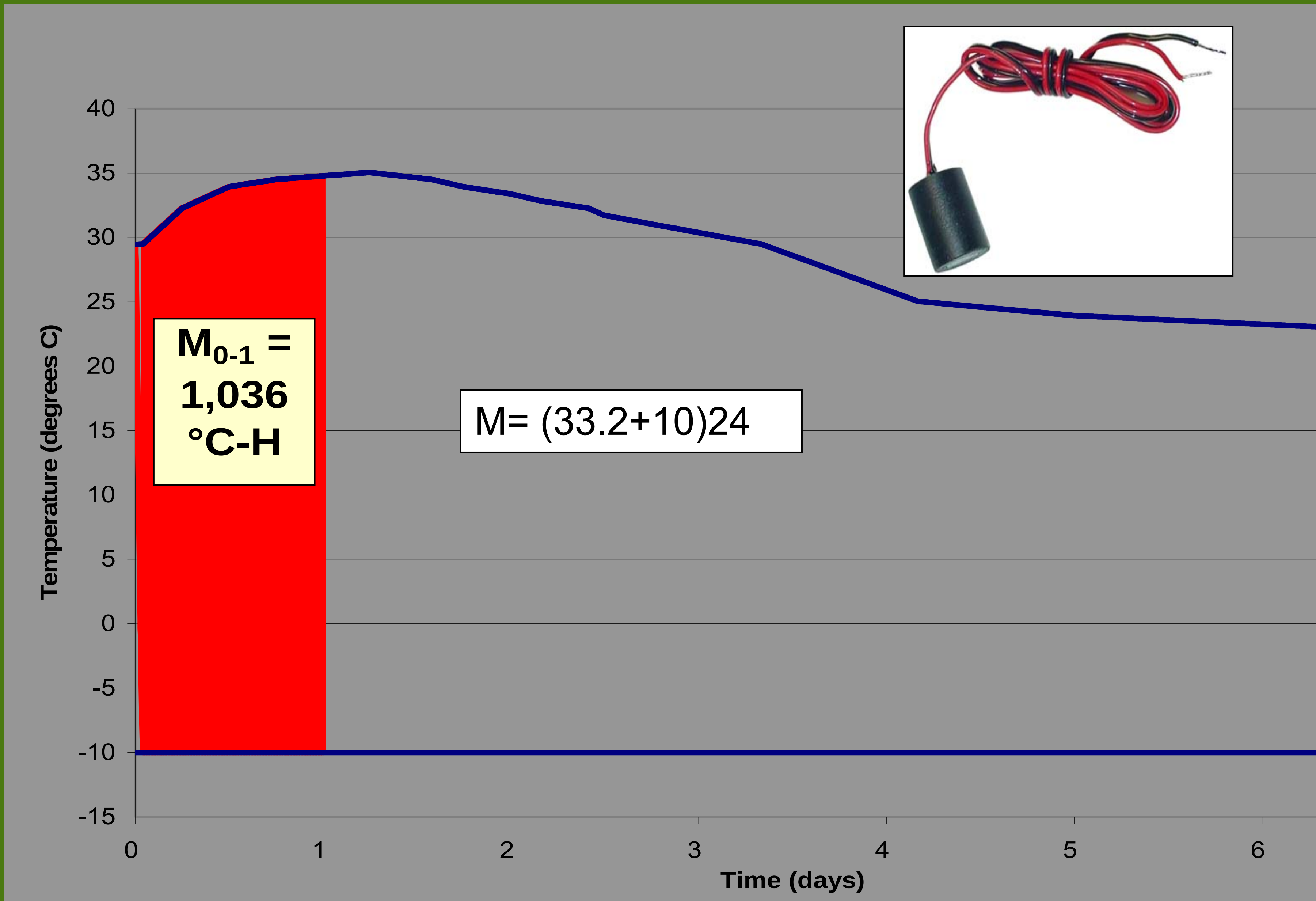
Datum Temperature

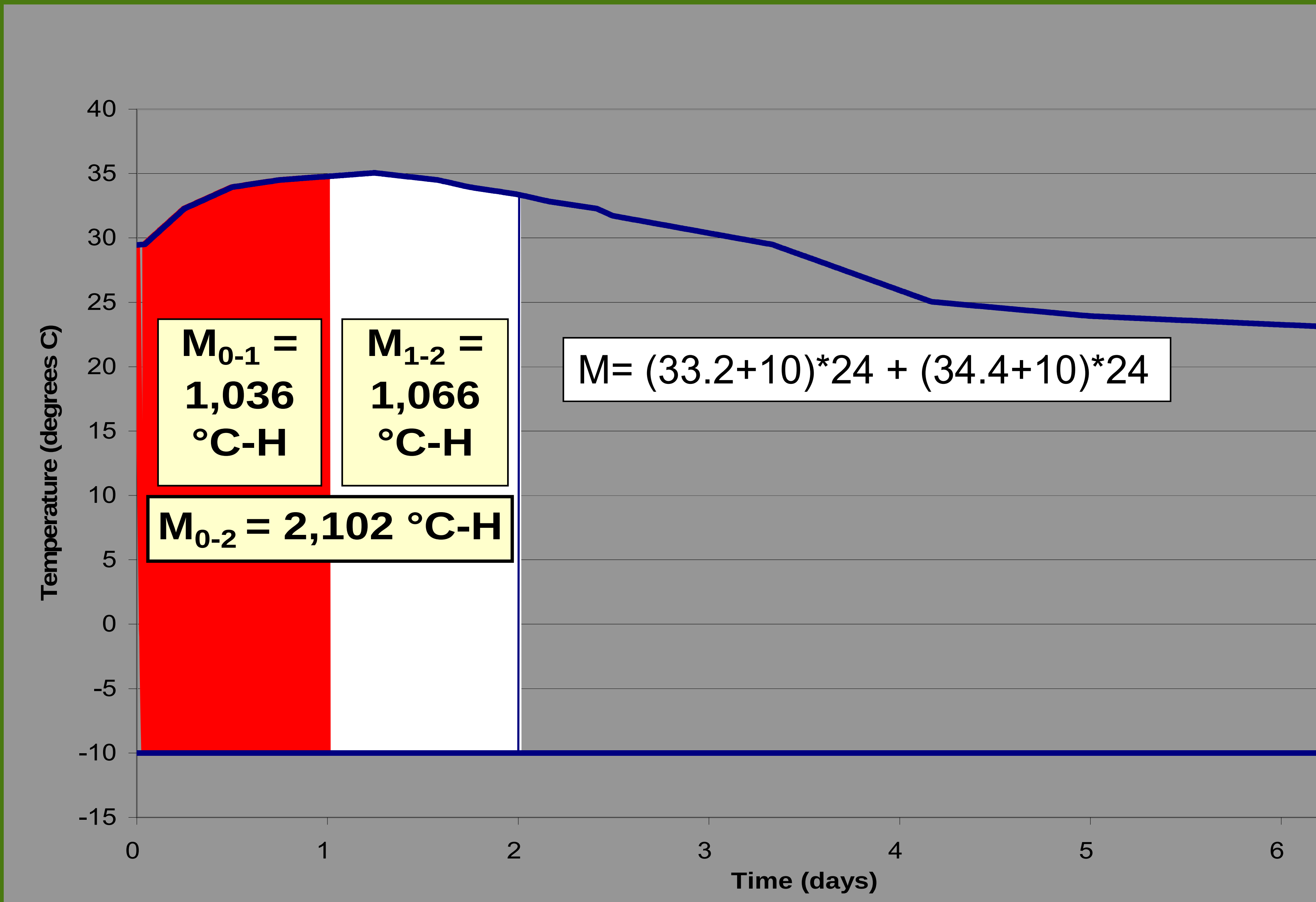
$T_o = 0^\circ C$

Traditionally, the datum temperature has been the temperature below which strength gain ceases, which has been assumed to be about 0°C (32°F)

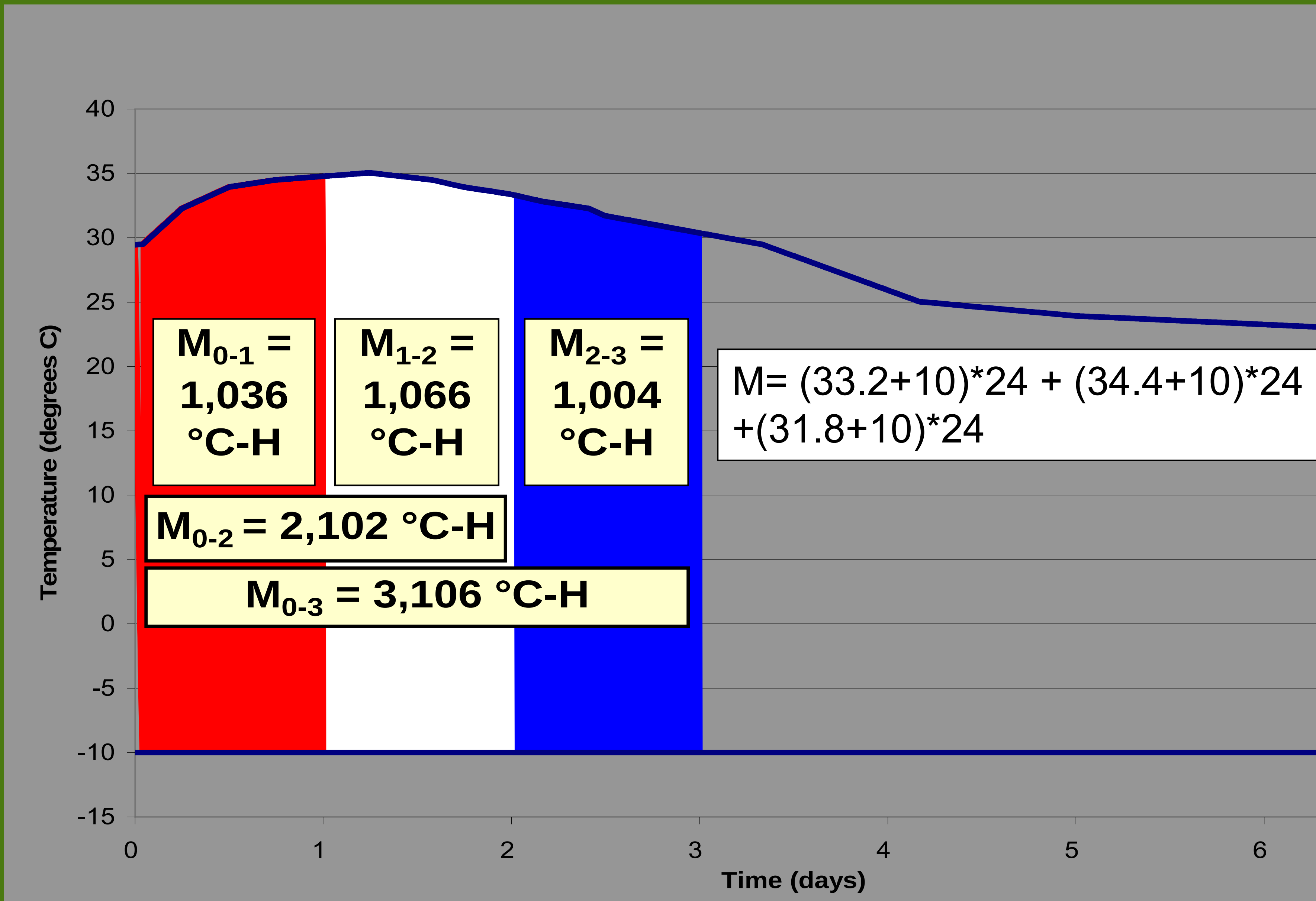
In-Place Concrete Temperature (T_a)

- Ambient conditions
- Types & amounts of cementitious materials
- Admixtures
- Size and shape of the structure
- Formwork & Insulation

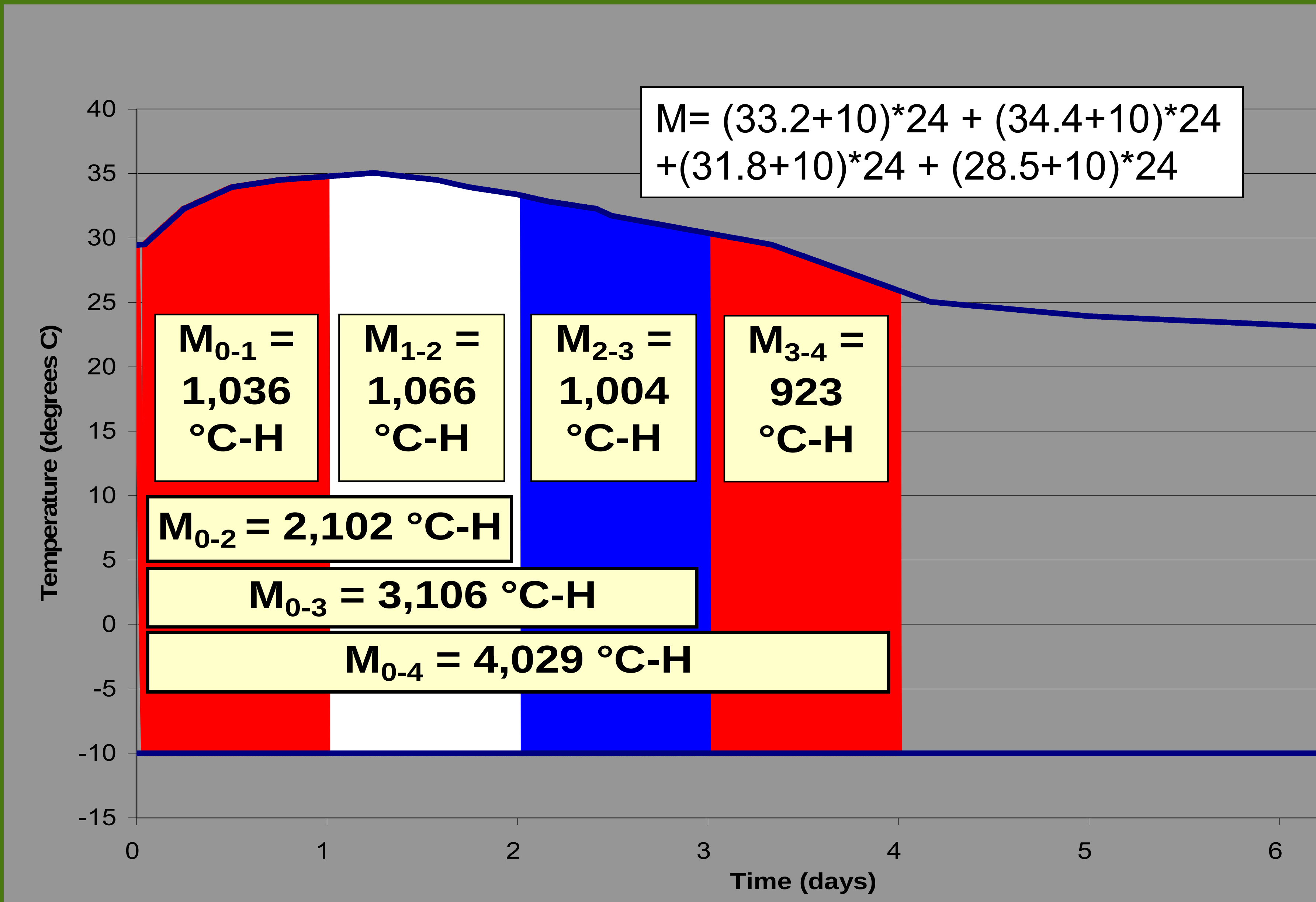

Temperature (degrees C)
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
6
Time (days)
M0-1 = 1,036 °C-H
M= (33.2+10)24



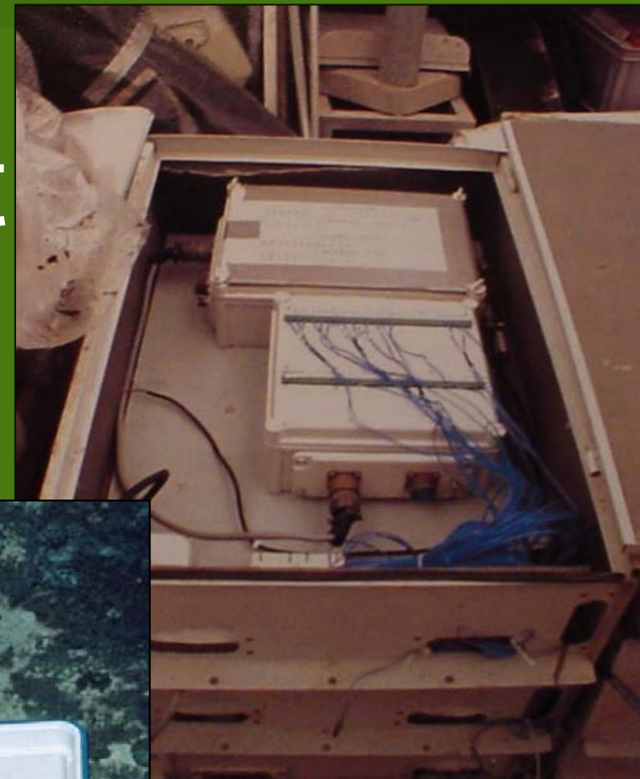
M0-1 = 1,036 °C-H
M1-2 = 1,066 °C-H
M0-2 = 2,102 °C-H
M= (33.2+10)*24 + (34.4+10)*24
Temperature (degrees C)
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
6
Time (days)

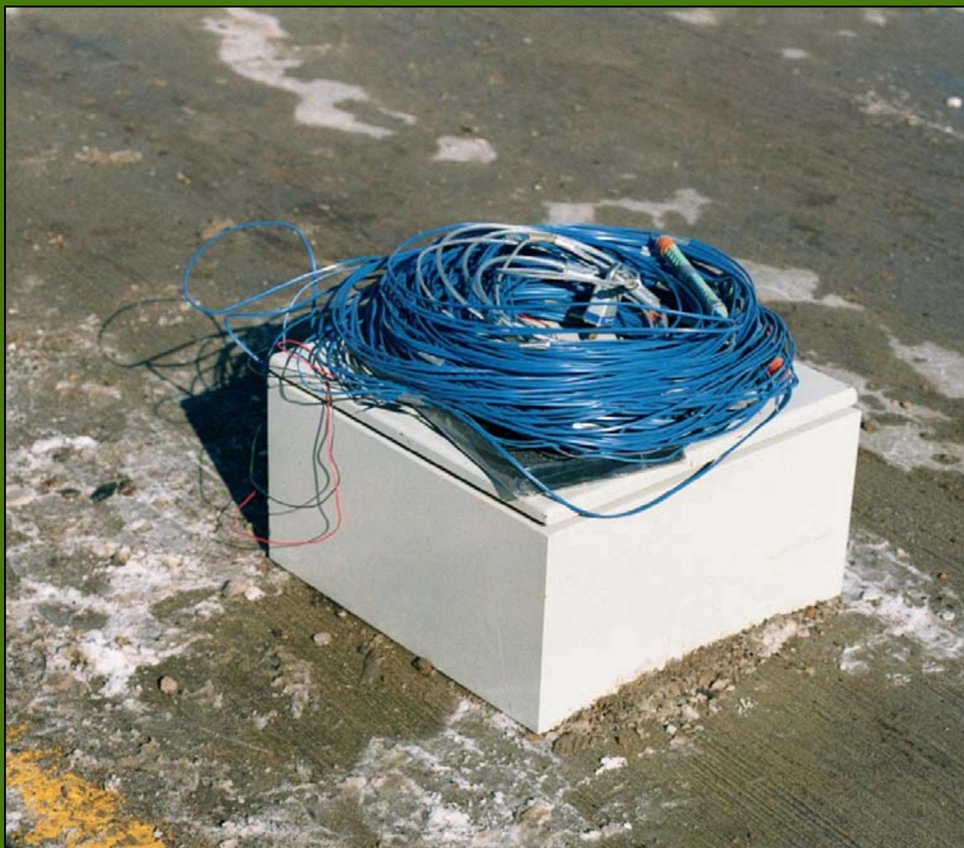


40
35
30
25
20
15
10
5
0
-5
-10
-15
Temperature (degrees C)
0
1
2
3
4
5
6
Time (days)
M0-1 = 1,036 °C-H
M1-2 = 1,066 °C-H
M2-3 = 1,004 °C-H
M0-2 = 2,102 °C-H
M0-3 = 3,106 °C-H
M= (33.2+10)*24 + (34.4+10)*24 +(31.8+10)*24


M= (33.2+10)*24 + (34.4+10)*24
+(31.8+10)*24 + (28.5+10)*24
M0-1 = 1,036 °C-H
M1-2 = 1,066 °C-H
M2-3 = 1,004 °C-H
M3-4 = 923 °C-H
M0-2 = 2,102 °C-H
M0-3 = 3,106 °C-H
M0-4 = 4,029 °C-H
Temperature (degrees C)
Time (days)
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
6

Maturity Equipment



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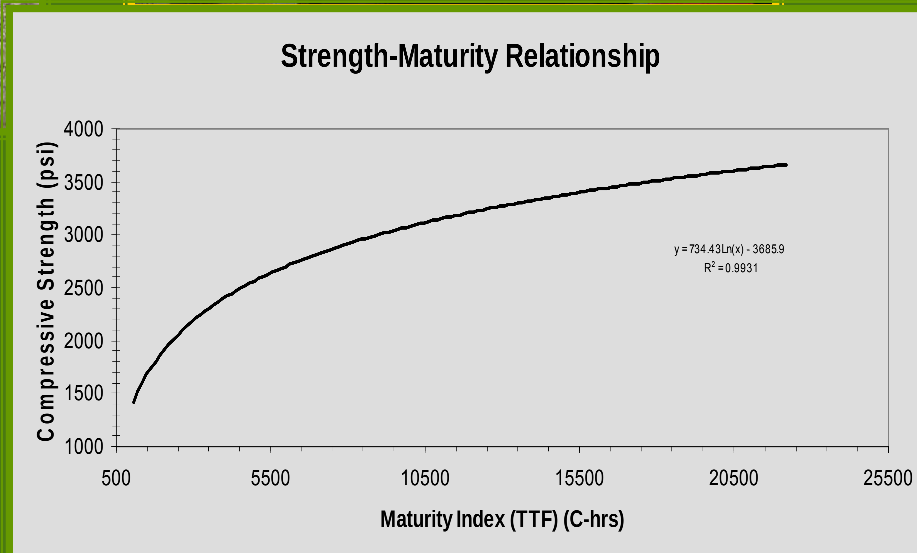
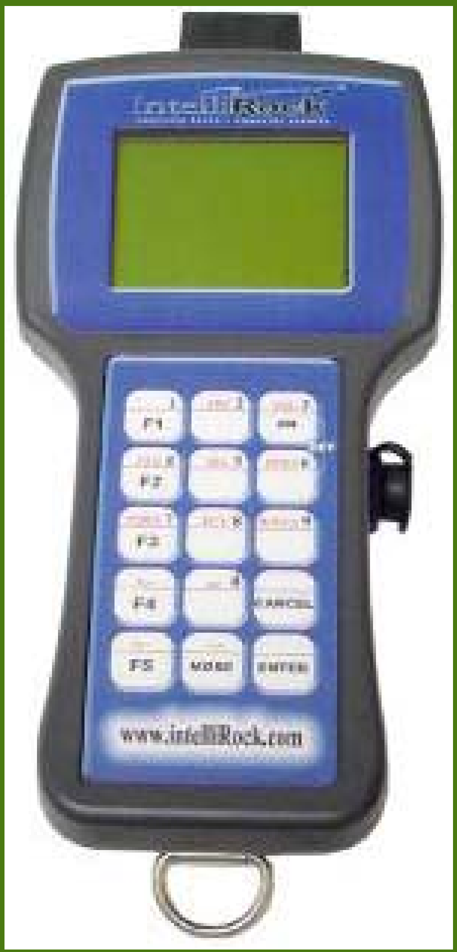
Implementing the Concrete Maturity Method

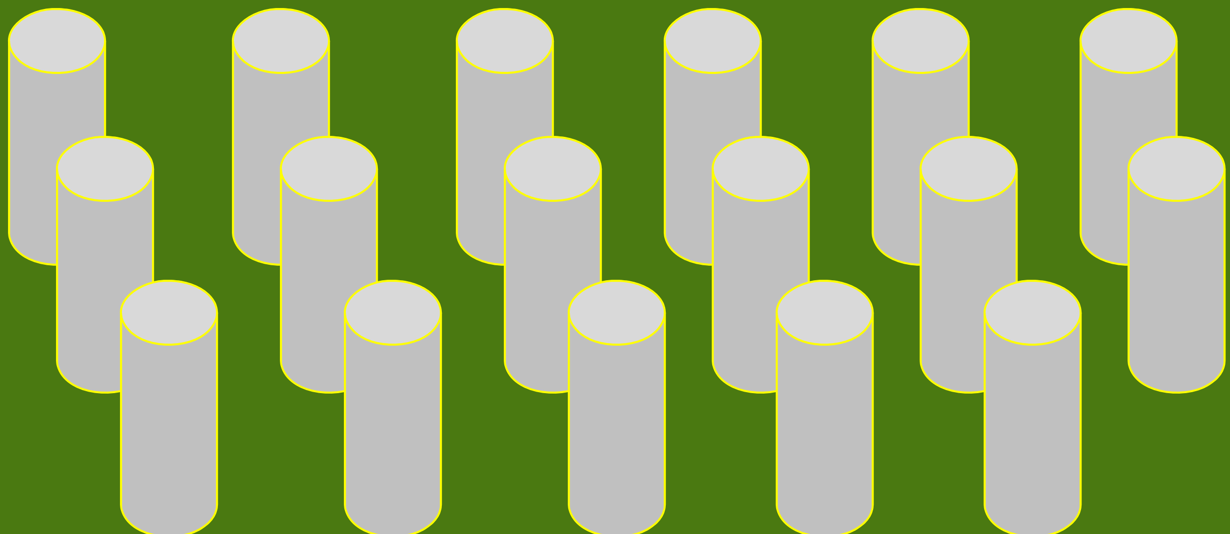


1. Develop a mixture specific calibration curve
2. Embed maturity loggers into plastic concrete
3. Take maturity (TTF) measurements
4. Use the calibration curve to estimate strength from maturity (TTF) measurements

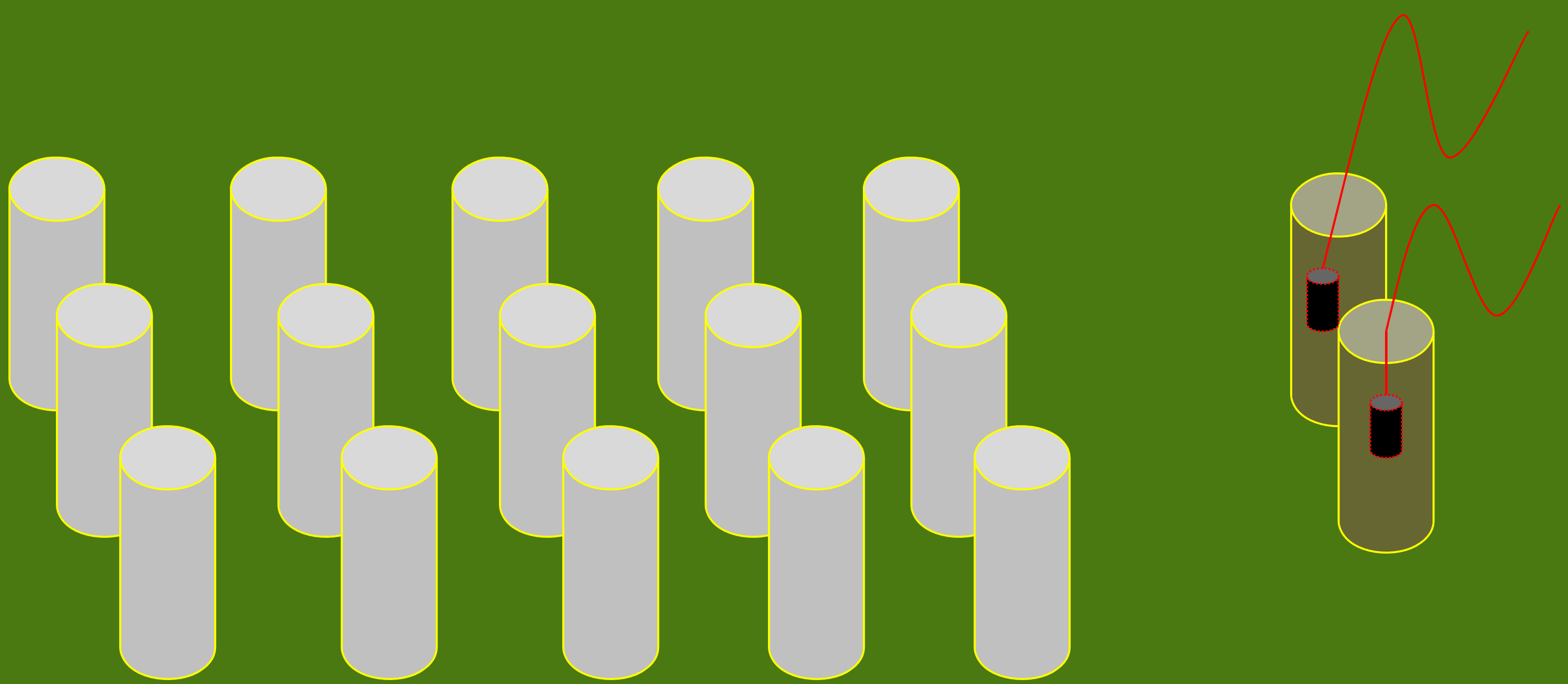
Laboratory Test Data



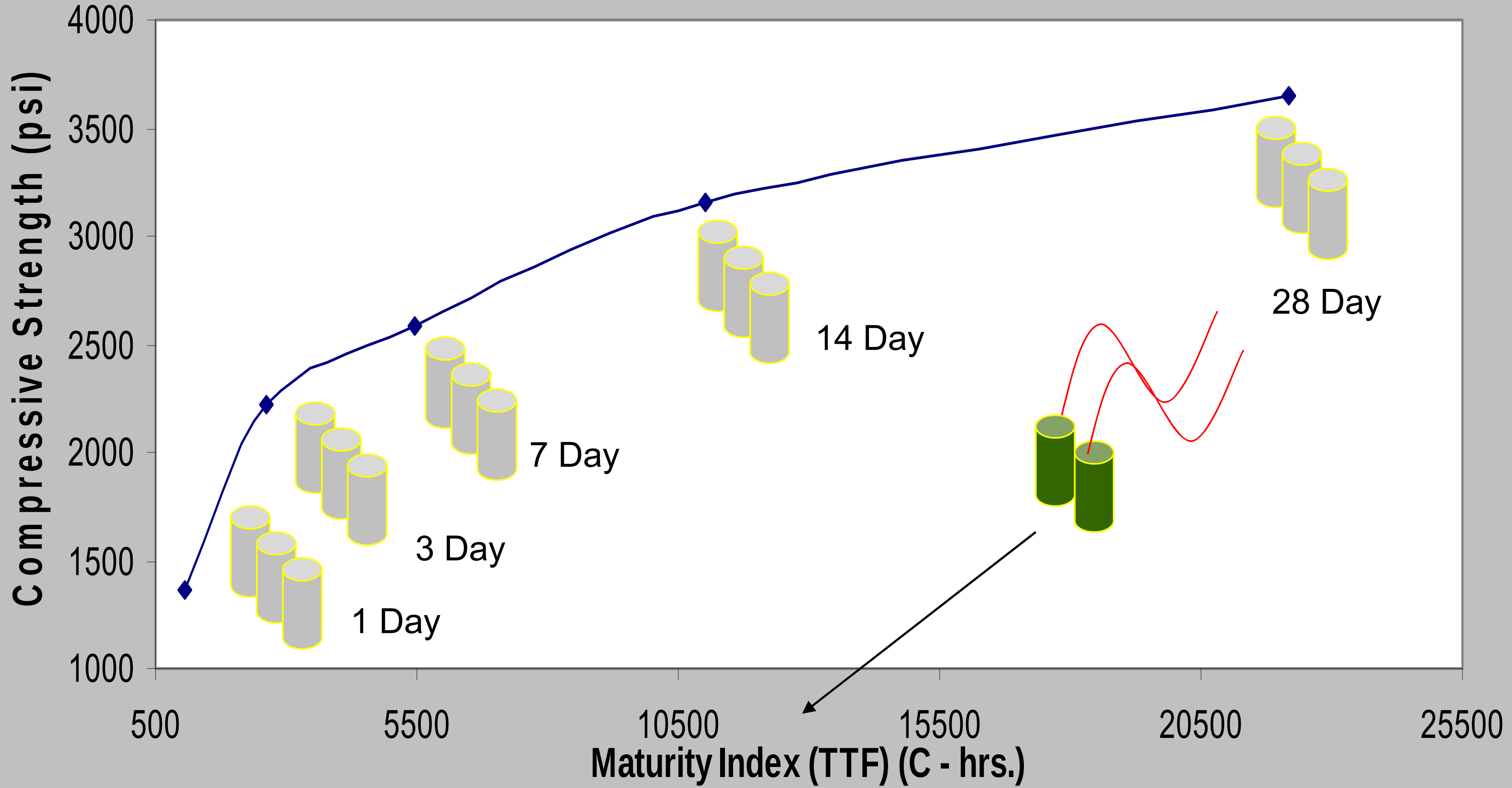
Developing a mixture specific curve

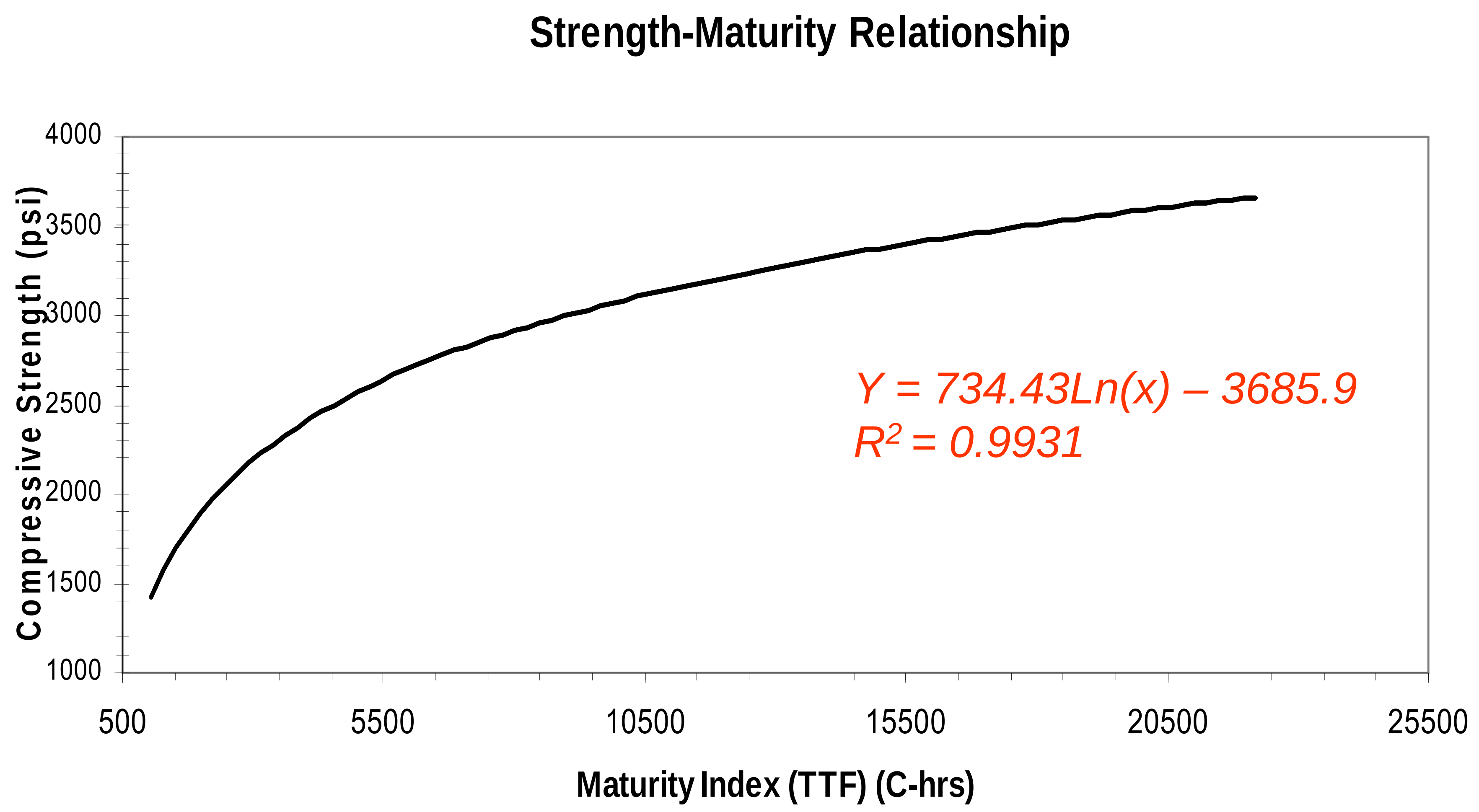


Developing a mixture specific curve



Strength - Maturity Relationship





Strength-Maturity Relationship
Compressive Strength (psi)
4000
3500
3000
2500
2000
1500
1000
500
5500
10500
15500
20500
25500
Maturity Index (TTF) (C-hrs)
Y = 734.43Ln(x) – 3685.9
R2 = 0.9931

- Maturity equation – defines the strength-maturity relationship (logarithmic best fit curve)

  $Y = 734.43Ln(x) – 3685.9$

- The R^2 value indicates the reliability of the strength-maturity relationship

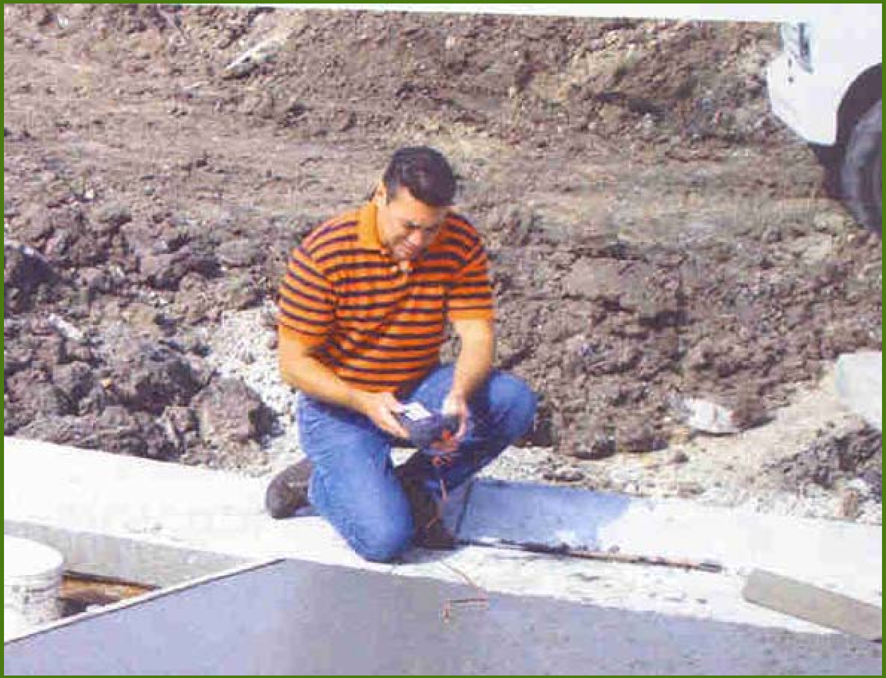
  $R^2 = 0.9931$

Logger Placement Frequency

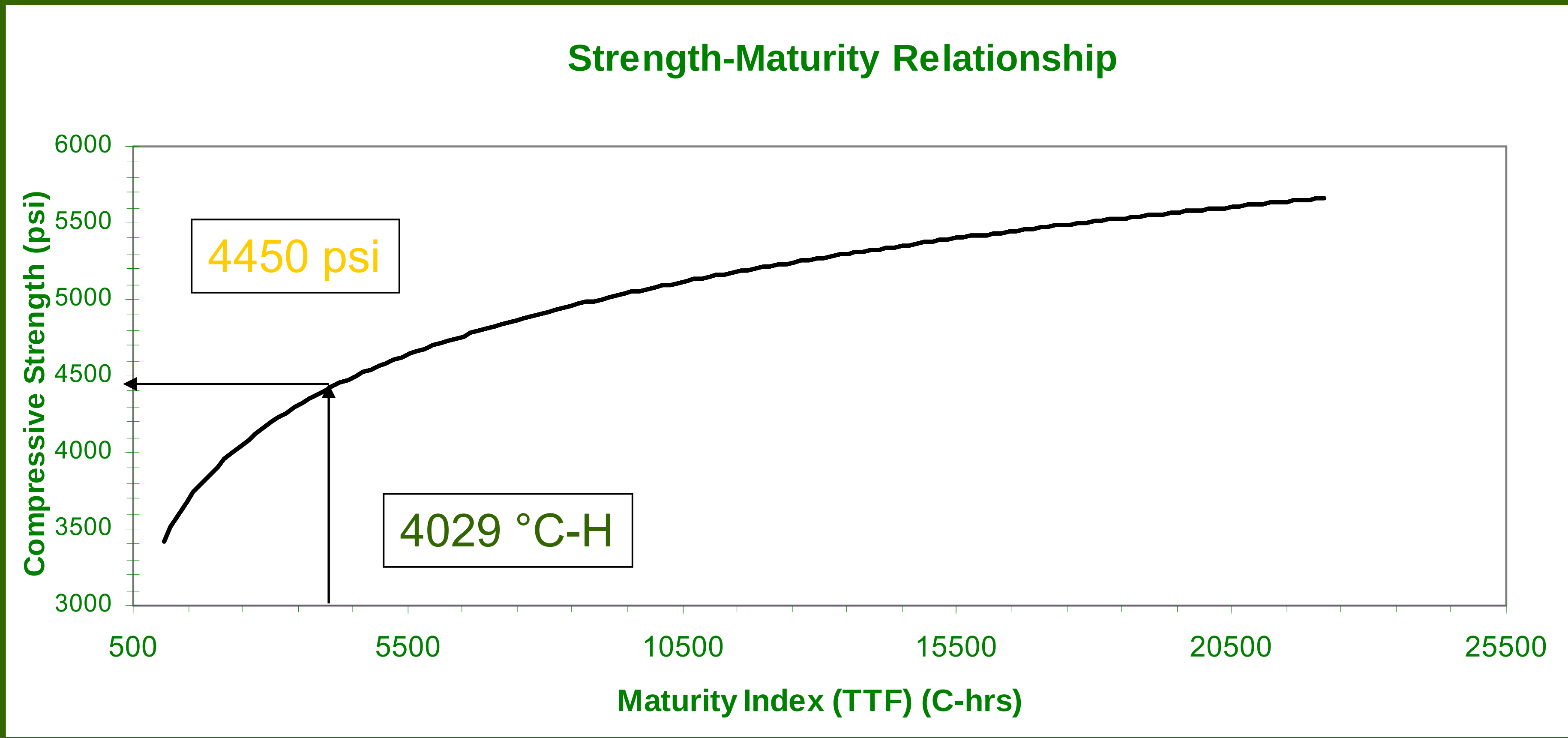
- Pavement
  - 1 / 2500 sqft.
- Structures
  - 1 / 100 cubic yards

Field Activities

- Embed loggers
  - Minimum 10” from pavement edges
  - Minimum 4” cover in structures (mid-depth ideal)
- Activate loggers
- Take maturity (TTF) measurements



Using the Strength-Maturity Relationship Curve



Case Study

- Project: Transcontinental Street Panel Replacement

  Contractor: Fleming Construction

  Owner: Jefferson Parish

  Concrete Supplier: Lafarge Corporation

STRENGTH-MATURITY RELATIONSHIP LOG

ASTM C 1074

Project: Transcontinental street panel replacement (Fleming Construction)	
Ready Mix Supplier: Lafarge	
BTI No.: N/A	Date: 3/3/04
Technician(s): C. Perkins & M. Cheek	

MIX DATA

Mix I.D.: 161	HRWR: ( )Yes (X) No
Design slump (in.): N/A	Design air content (%):
Design strength @ 3 days: 4000	

TEST DATA

TEST		RESULTS
Slump (in.)	(ASTM C 143)	8
Air Content (%)	(ASTM C 231 or C 173)	2.6
Concrete Temperature (°C)	(ASTM C 1064)	23.9
Ambient Temperature (°C)		21.6
Unit Weight (pcf)	(ASTM C 138)	N/A

Number of Specimens this set: 14 | Specimen description: 6 x 12 | Time Made: 9:30

LABORATORY TEST DATA

Sample ID	Area (sq in)	Date Tested	Age at test (days)	Total load (lbs.)	Comp. strength (psi)	Average Comp. strength	Fracture type	Temp. (°C)	Elapsed Time (hr:min) Age	TTF (°C-hr)	Average TTF
1A	-	3/4/04	1	55000	1950	-	A	21	23:23	778	-
1B	-	"	1	57500	2030	1990	A	21	23:27	778	778
1C	-	3/4/04	1	65000	2300	-	B	21	31:32	1044	-
1D	-	"	1	70000	2480	2390	B	21	31:31	1034	1039
1E	-	3/5/04	2	89000	3150	-	A	22	48:15	1551	-
1F	-	"	2	84500	2990	3070	A	22	48:18	1578	1565
1G	-	3/6/04	3	108000	3820	-	B	22	73:50	2394	-
1H	-	"	3	112500	3980	3900	B	22	73:49	2375	2385
1I	-	3/10/04	7	136000	4810	-	A	19	166:00	5246	-
1J	-	"	7	137000	4850	4832	A	19	165:59	5208	5227

Datum Temperature (°C): -10

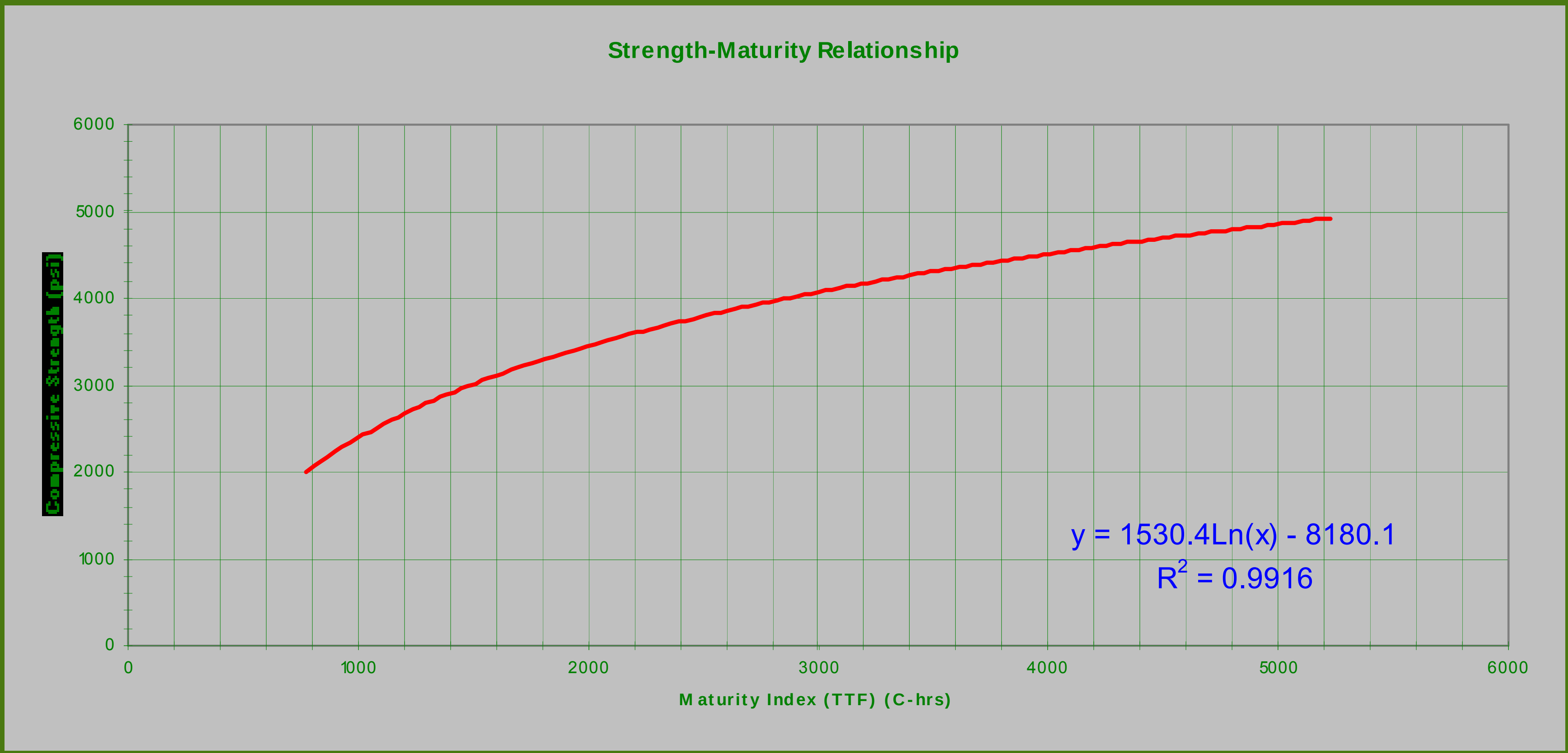
Sample I.D./sensor serial number: M / 2000196 | Sample I.D./sensor serial number: N / 2001088

Remarks: Break schedule – 24hrs, 36 hrs, 48hrs, 72hrs, and 7 days

°F to °C = 0.555(°F – 32)

Maturity Index (TTF) = $\Sigma(T_a - T_o)\Delta(t)$

Calibration Curve for Lafarge Mix No. 161




FIELD MATURITY DATA LOG

ASTM C 1074

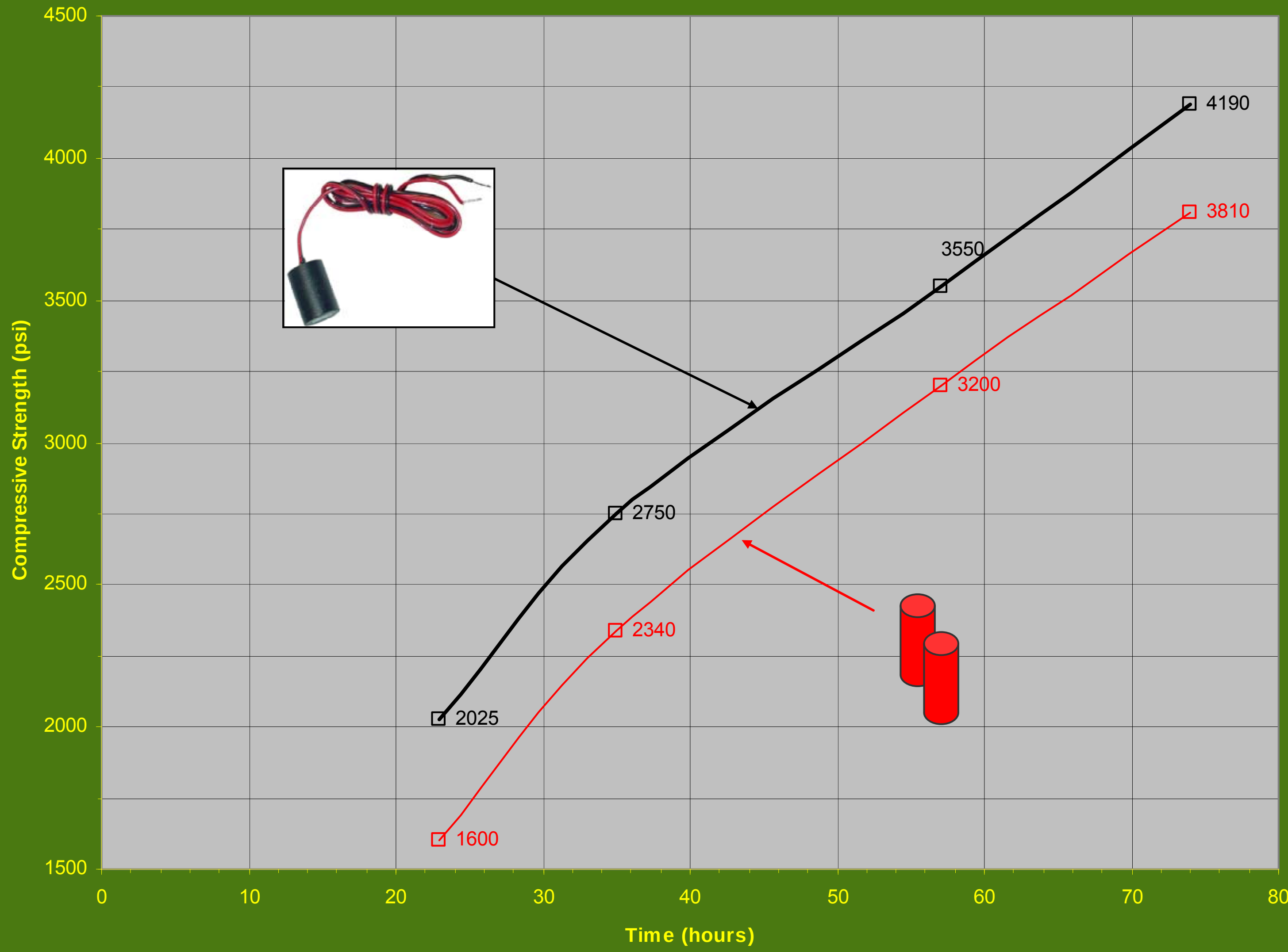
Project: Transcontinental Street panel replacement (Fleming construction)	
BTI No.: N/A	
Ready Mix Supplier: Lafarge	Mix ID: 161
Technician(s): D. Christophe	Inspection Date: 3/11/04

FIELD DATA

Structure	Street panel 7" thick	Street panel 7" thick
Member	Panel on east side of Transcontinental lake bound lane adjacent to 4973 Avron	Panel on east side of Transcontinental lake bound adjacent to 4973 Avron
Sensor Serial No.	2000678	2000058
Sensor Location	@ centerline 15' North of expansion joint, 60' North of Avron	@ centerline 18' south of end of placement
Required Strength (psi)	4000	4000
Required TTF	2850	2850
Curing Method	Curing compound	Curing compound

Reading No.	Elapsed Time (hr:min) Age	Air Temp. (°C)	Con. Temp. (°C)	TTF (°C-hr)	Est. Strength (psi)	Elapsed Time (hr:min) Age	Air Temp. (°C)	Con. Temp. (°C)	TTF (°C-hr)	Est. Strength (psi)
1	22:51	24	29	796	2000	22:12	24	25	844	2050

Maturity Readings vs. Cylinder Breaks



Thank You

Any Questions