The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRANSPORTATION RESEARCH BOARD

Construction of Mass Concrete Transportation Infrastructure

Monday, August 6, 2018
2:00-4:00 PM ET

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

Purpose

Discuss the construction of mass concrete structures, such as bridge piers and other large volume placements.

Learning Objectives

At the end of this webinar, you will be able to:

- Understand the potential impacts of early-age concrete temperatures on thermal cracking and delayed-ettringite formation (DEF)
- Identify means to control concrete temperatures during design and construction
- Describe the requirements and role of a Thermal Control Plan (TCP)
- Discuss case studies of mass concrete projects

Thermal Control Plans for Transportation Infrastructure

By:

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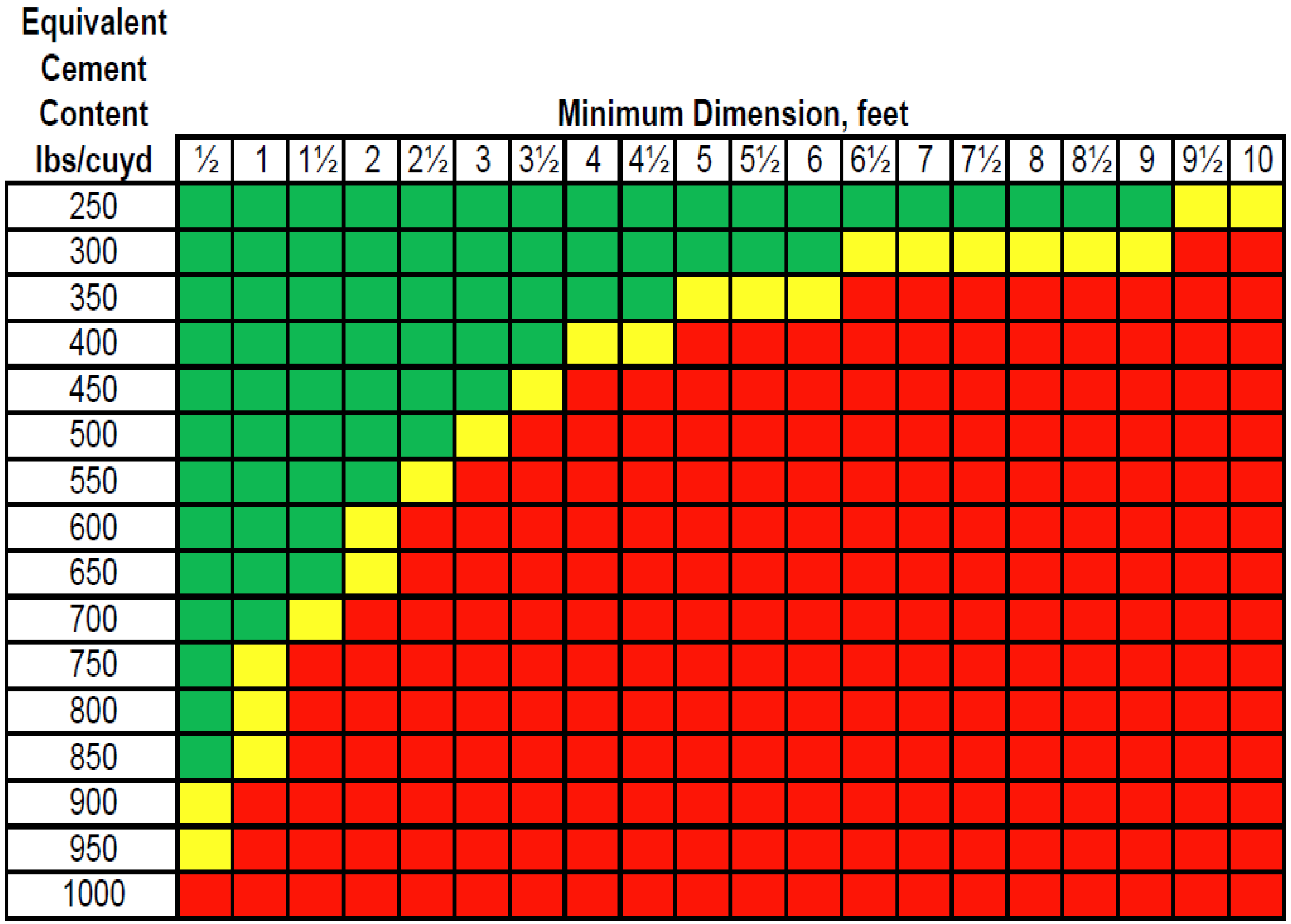
Why Treat a Placement as Mass Concrete?

- Avoid thermal damage during construction
  - Minimize/prevent thermal cracking
  - Avoid thermal shock
- Avoid structural cracking
  - Prevent DEF (delayed ettringite formation)

When does it Behave as Mass Concrete?

- When the <u>maximum temperature</u> exceeds 160°F (typically specified limit to prevent DEF)
- When the <u>temperature difference</u> exceeds 35°F (typically specified limit to minimize/prevent thermal cracking)
- Both are *generic* limits
- Thickness of placement?
- Cementitious materials?

Future ACI 207 Mass Concrete Definition



Equiv. Cement Cont. =

cement +

factor****slag*** +

0.5****fly ash (class F)*** +

0.8****fly ash (class C)*** +

1.2****silica fume*** +

1.2****metakaolin***

factor = 0.8 to 1.0

Requirements for Mass Concrete

Things to Specify

- Maximum temperature limit
- Temperature difference limit
- Completion of thermal control
- Temperature monitoring
- Reasonable sensor locations
- Moisture retention curing
- Cement replacement limits
- Thermal control plan

Things to NOT Specify

- Reduced initial temperature range
- Minimum cement(itious) content
- Crack width limits
- Water curing
- Low slump

Recommended Language

- See Section 8 of ACI 301 (2010 or 2016 version)

What is a Thermal Control Plan?

- Submittal for mass concrete placements
- Based on the specification requirements
- Details the contractor's selected method(s) to:
    - Control the maximum temperature after placement
    - Control temperature differences within the mass concrete
    - Verify and provide proof of thermal control
- Addresses <u>all</u> <u>items</u> related to the contractor's thermal control activities

Items Typically in a Thermal Control Plan

1. Concrete mixture design and its adiabatic temperature rise
2. Upper limit for the temperature of concrete at placement
3. Description of measures and equipment to ensure the temperature in placement will not exceed the specified maximum limit
4. Calculated maximum temperature in the placement based on (3)
5. Description of specific measures and equipment to ensure temperature difference will not exceed the specified limit
6. Calculated maximum temperature difference in the placement based on (5)
7. Description of equipment and procedures for logging of temperatures and temperature differences
8. Drawing showing temperature sensors locations in placement
9. Format and frequency of providing temperature data to the engineer
10. Description of measures to address and reduce excessive temperatures and temperature differences, if they occur
11. Description of curing procedures, including materials and methods, and curing duration
12. Description of formwork removal procedures to ensure curing is maintained and the temperature difference remains below the limit

Thermal Modeling

- Maximum Temperature Estimation (PCA EB547 and various papers)
  - Very simple
  - Doesn't predict the temperature difference
  - Doesn't consider thickness

Maximum Temperature (°F) = Initial Temperature + 0.16*ECC

ECC* = *cement + factor****slag*** +
0.5****fly ash (class F)*** +
0.8****fly ash (class C)*** +
1.2****silica fume*** +
1.2****metakaolin***

Thermal Modeling

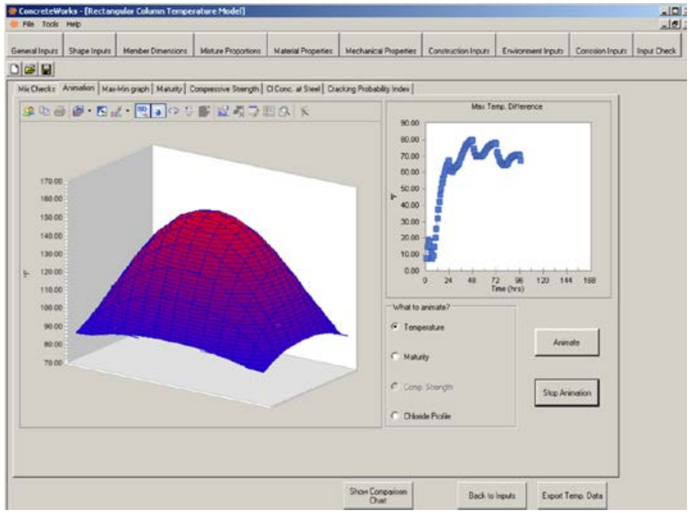
- Maximum Temperature Estimation (PCA EB547)
- Schmidt Method (ACI 207)

- 1D finite difference approximation
- For slabs and walls
- Easy to implement in a spreadsheet
- Use and appropriate number of elements

Thermal Modeling

- Maximum Temperature Estimation (PCA EB547)
- Schmidt Method (ACI 207)
- Texas Concrete Works

- Free
- Easy to use
- 7 shapes
- Cracking risk
- Temperature difference between hottest and coldest



Thermal Modeling

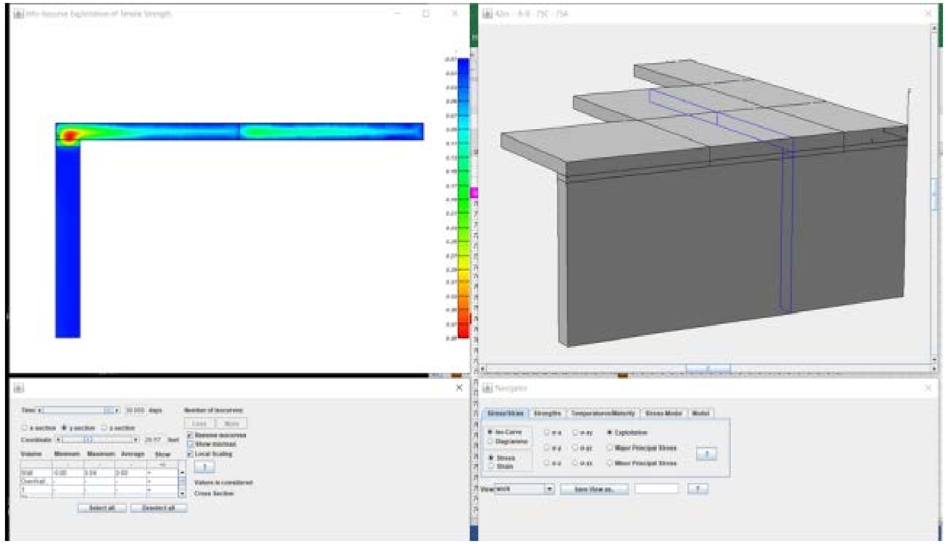
- Maximum Temperature Estimation (PCA EB547)
- Schmidt Method (ACI 207)
- Texas Concrete Works
- Proprietary Models

- 1D, 2D, and 3D models
- Any shape
- Lifts
- Cooling pipes
- Simple or performance-based temperature difference limit
- Specialty consultant (me!)

Thermal Modeling

- Maximum Temperature Estimation (PCA EB547)
- Schmidt Method (ACI 207)
- Texas Concrete Works
- Proprietary Models
- 3D Thermal Stress Models

- Powerful but very complex
- Annual fee per user
- Slow



Control of the Maximum Temperature

- Low heat concrete mixture
  - Maximize cement replacement
  - Minimize cementitious content

Maximum Temperature (°F) =
Initial Temperature + 0.16*ECC

***ECC* = *cement* + factor**slag* +**
0.5**fly ash (class F)* +
0.8**fly ash (class C)* +
1.2**silica fume* +
1.2**metakaolin*

Control of the Maximum Temperature

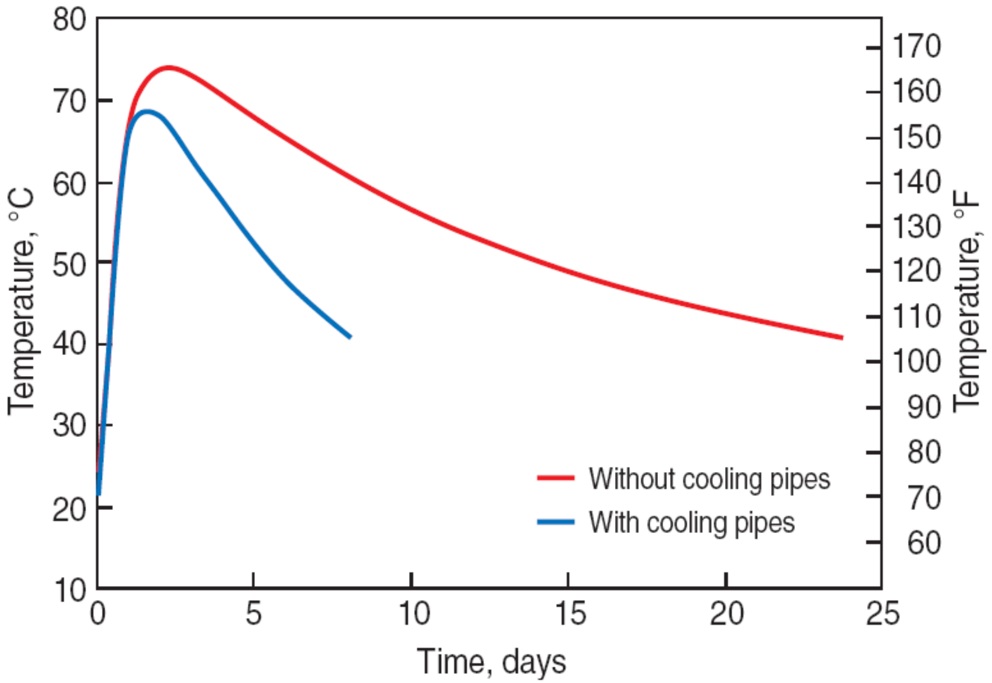
- Low heat concrete mixture design
- Precool the fresh concrete
  - Shade/sprinkle aggregates
  - Chilled batch water
  - Replace batch water with ice
  - Liquid nitrogen

Control of the Maximum Temperature

- Low heat concrete mixture design
- Precool the fresh concrete
- Thinner placements
  - Lower maximum temperature
  - Faster cool down

Control of the Maximum Temperature

- Low heat concrete mixture design
- Precool the fresh concrete
- Thinner placements
- Post-cooling

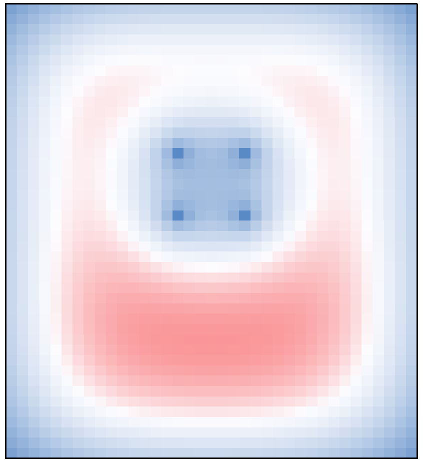


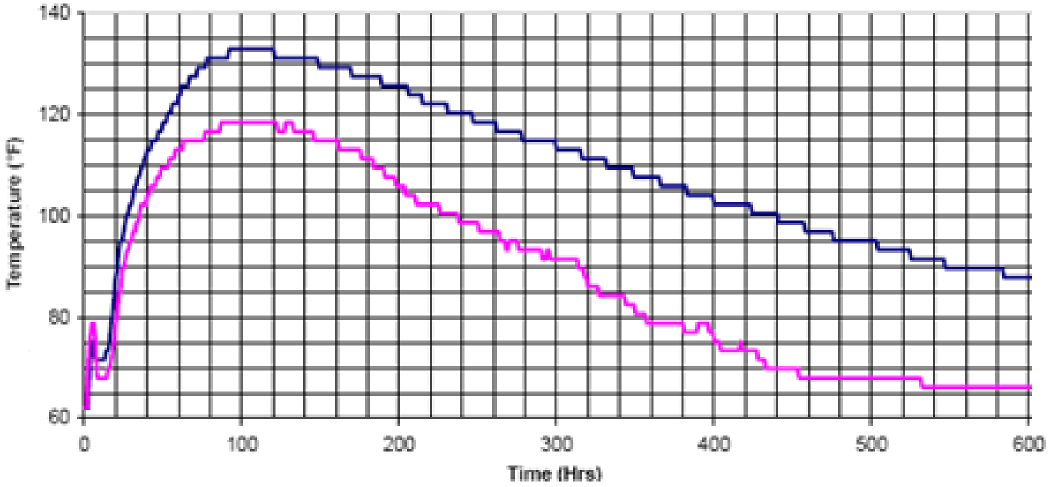
Control of the Temperature Difference

- Use insulation

Monitor Temperatures

- Hourly logging of temperatures
- Daily checking/downloading
- Minimum of 2 locations per placement
  - "Center" at geometric center
  - "Surface" at 2-3" below nearby surface (at midlength and midwidth of the surface)
  - Primary and backup at each location
- When using cooling pipes, hottest is the largest area without pipes





During Construction

- After approval, follow the thermal control plan!
- If temperatures or temperature differences exceed the limit, figure out why and update the thermal control plan (if necessary).
- If the concrete mixture changes, update the thermal control plan.

Summary

- Purpose of thermal control and typical limits
- Minimum requirements of a thermal control plan
- Multiple methods to control the maximum temperature
- One method to control temperature differences
- Monitoring of temperatures and daily reporting

Delayed Ettringite Formation: Mechanisms and Preventive Measures

Kevin J. Folliard, Ph.D.

Professor and Austin Industries Endowed Teaching Fellow

The University of Texas at Austin

TRB WEBINAR: Construction of Mass Concrete Infrastructure

August 6, 2018

Acknowledgements

Michael D.A. Thomas

Thano Drimalas

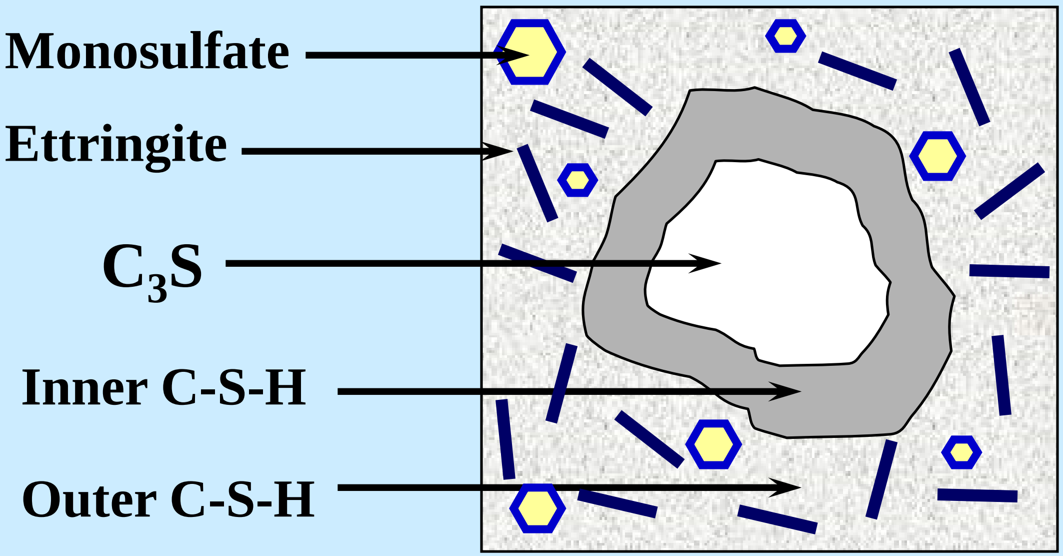
Terry Ramlochan

Texas Department of Transportation

Outline of Presentation

1. Mechanisms of delayed ettringite formation (DEF)
2. Preventive measures
3. Field cases

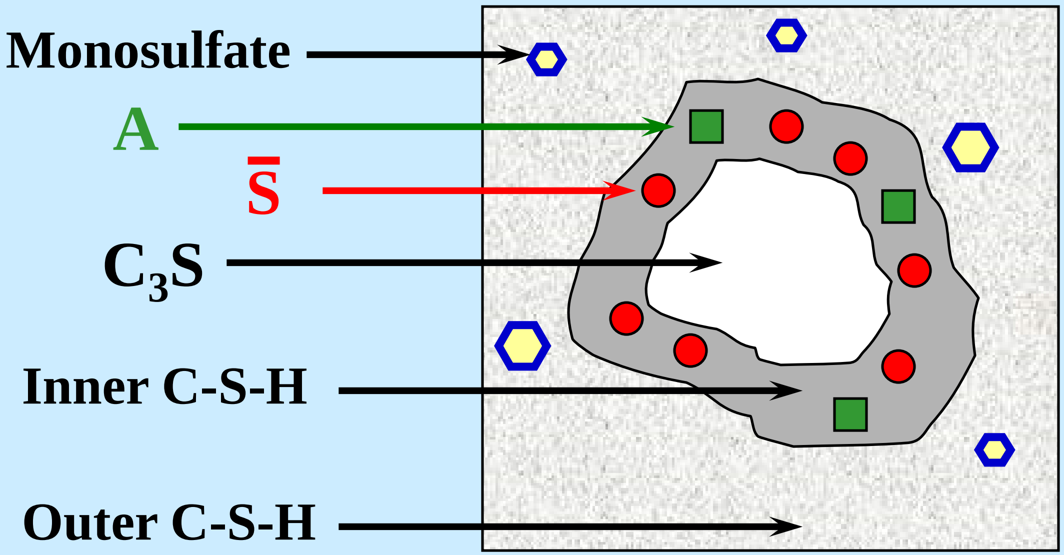
Concrete Cured at 73 °F



Hydration is “normal.” Ettringite and monosulphate formed as part of the outer hydration products.

M.D.A. Thomas

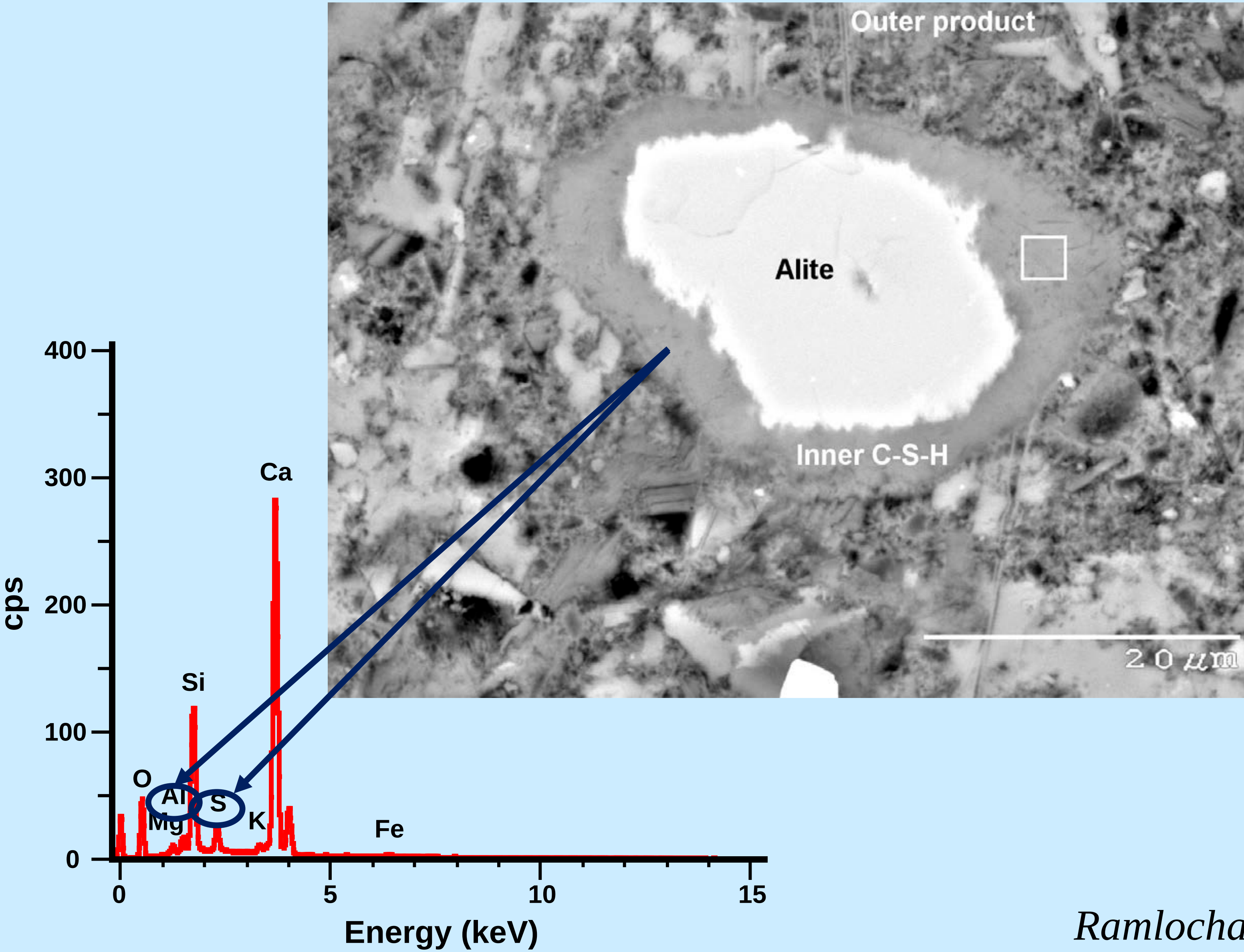
*Concrete Cured at > 158 °F**



Incongruent dissolution of ettringite resulting in both sulfate and alumina being encapsulated in the rapidly forming inner C-S-H, as shown in following SEM image.

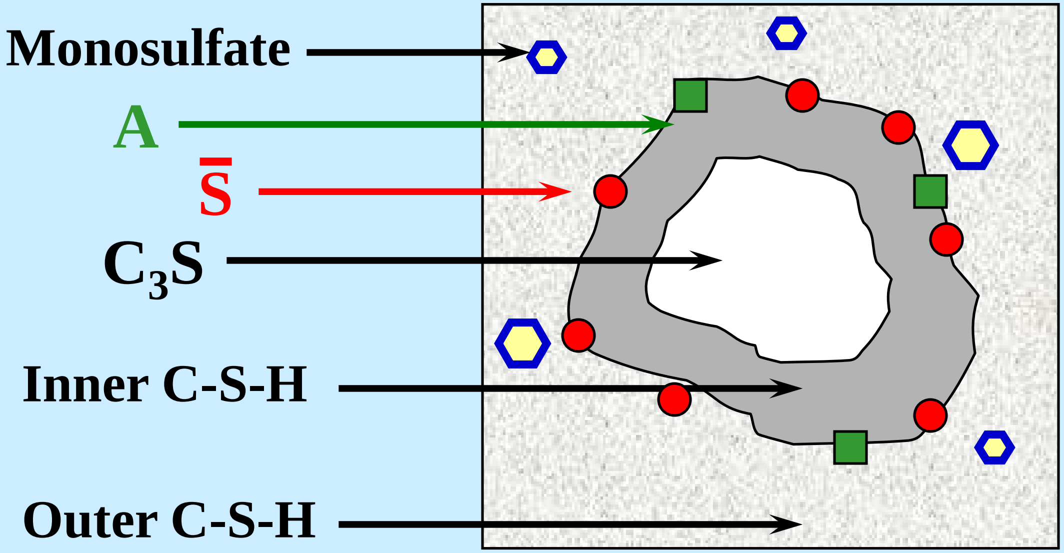
M.D.A. Thomas

Type III mortar after heat curing at 200 °F



Ramlochan, 2002

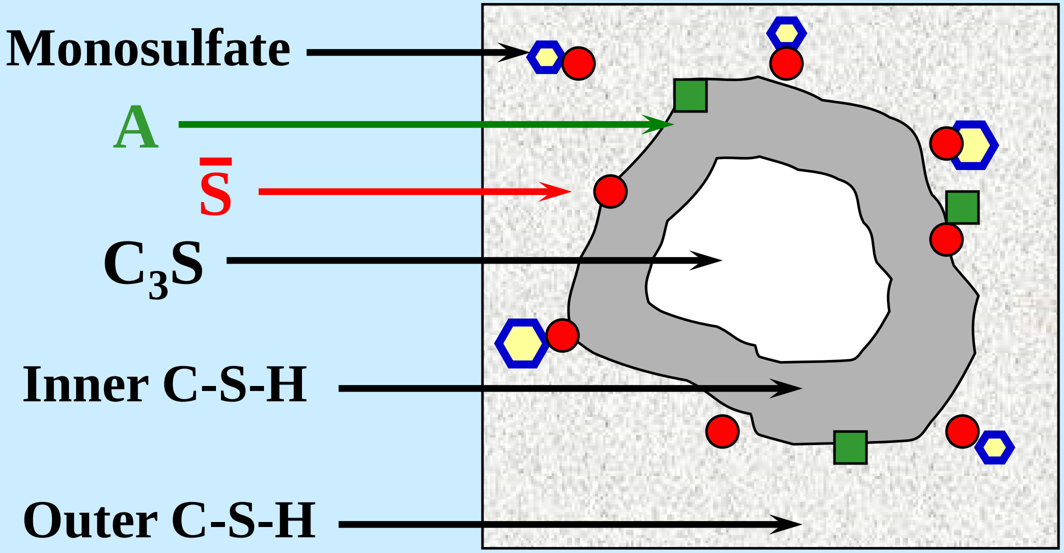
Subsequent storage in water at 73 °F



Sulfate and alumina slowly released from the inner C-S-H

M.D.A. Thomas

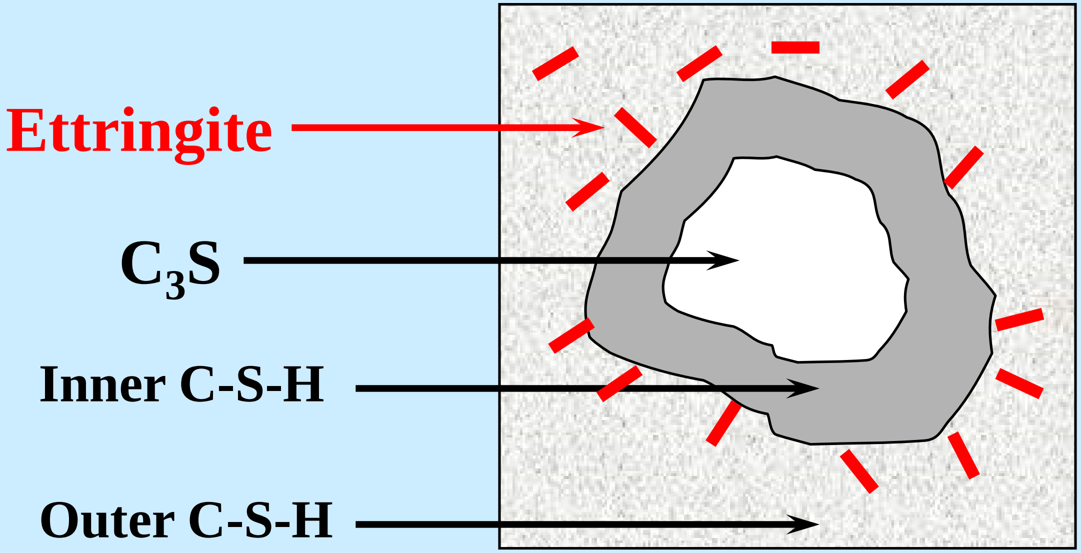
Subsequent storage in water at 73 °F



Sulfate and alumina slowly released from the inner C-S-H

M.D.A. Thomas

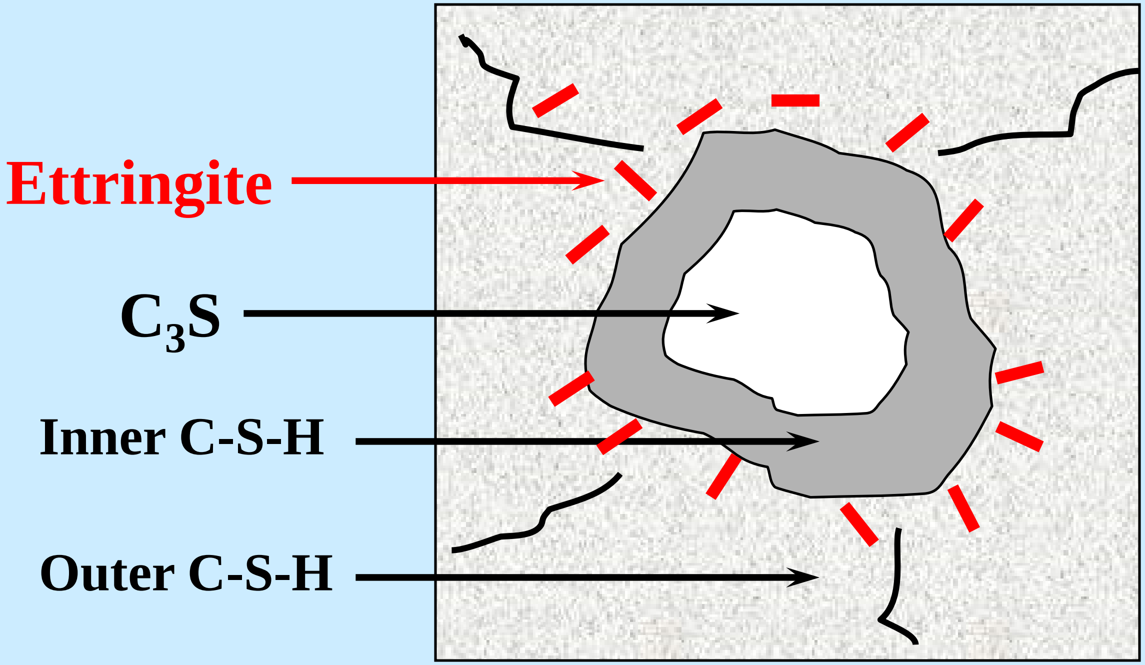
Subsequent storage in water at 73°F



Ettringite formed in the fine pores of the outer C-S-H

M.D.A. Thomas

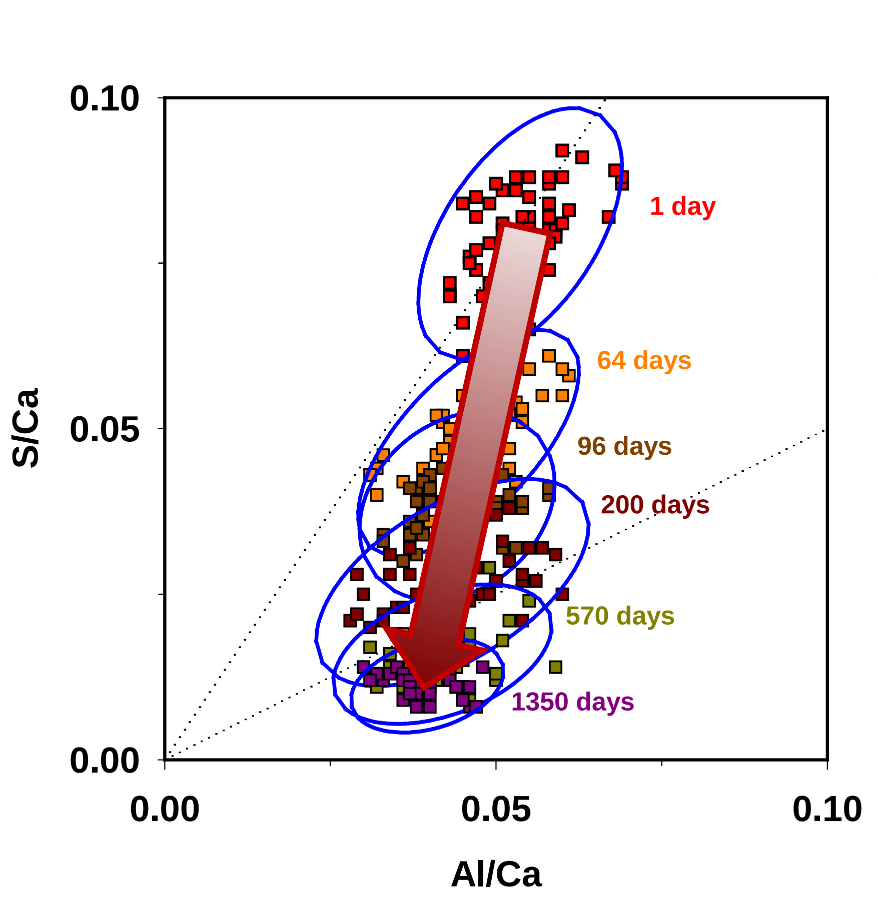
Subsequent storage in water at 73 °F



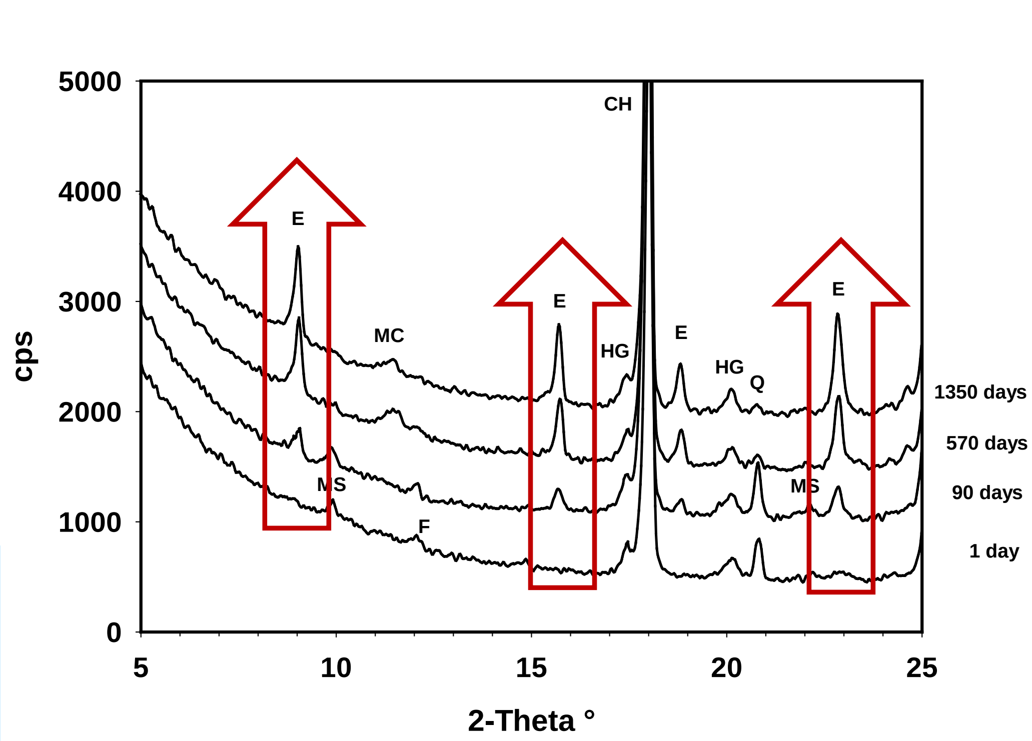
Under certain conditions this leads to expansion of the cement paste. Potential damage is a function of materials, mix designs, curing regime, and microstructure.

M.D.A. Thomas

So as the alumina and sulfate diffuse from the inner C-S-H…

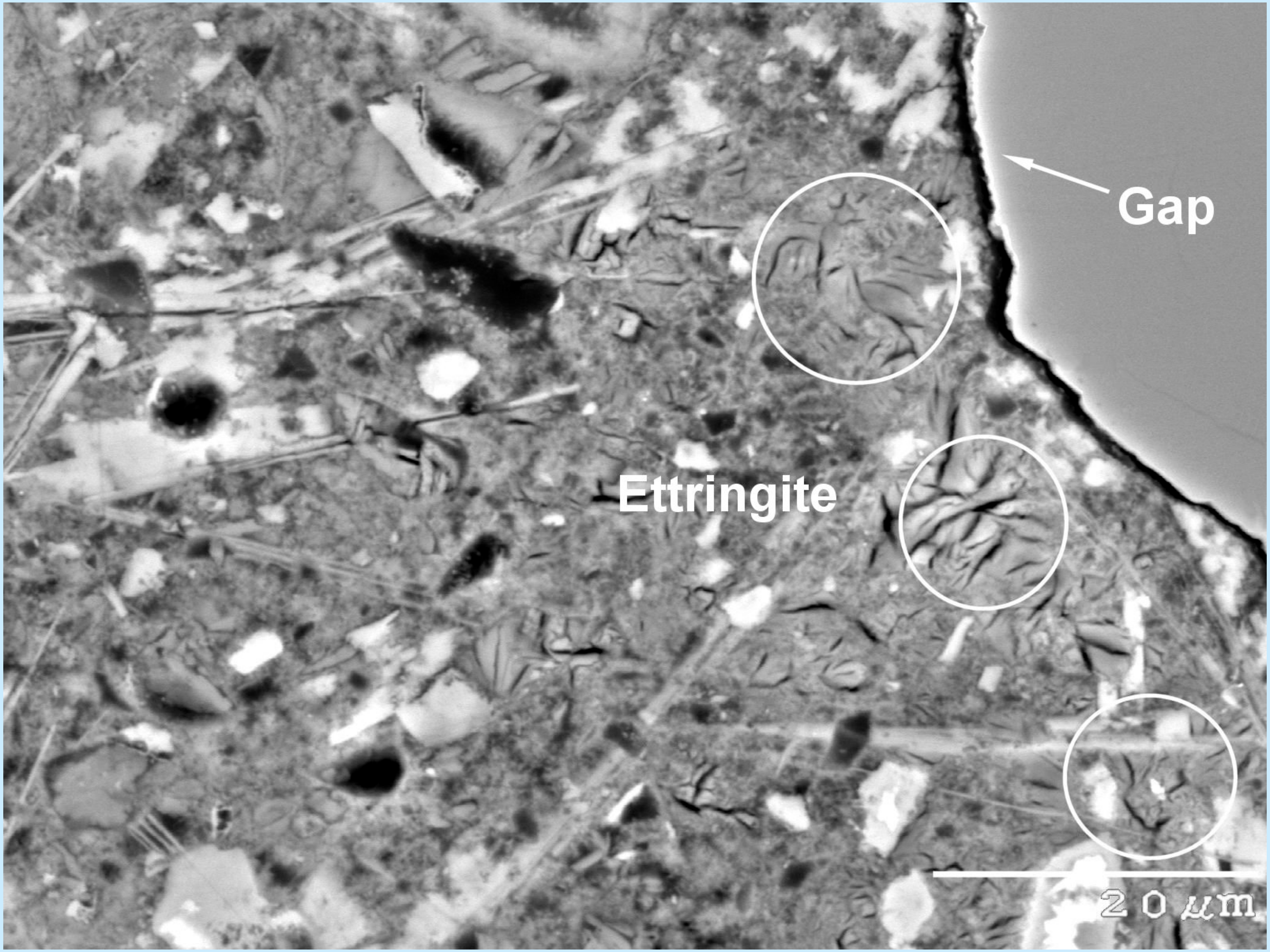


… they react with the monosulfate hydrate to form ettringite in the fine pores of the outer C-S-H, causing expansion and cracking.



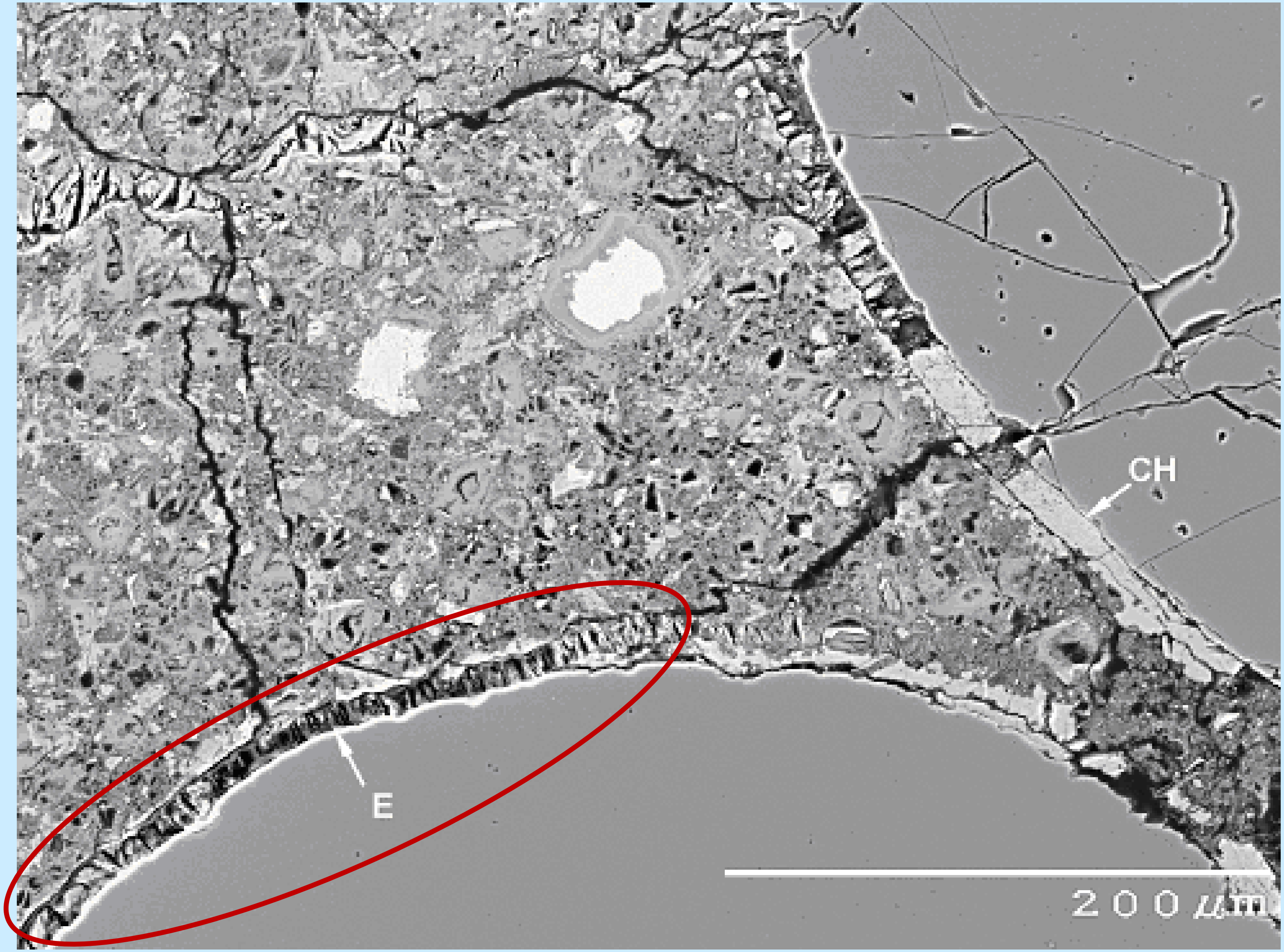
Ramlochan, 2002

200 °F Type III mortar, after two months stored under water



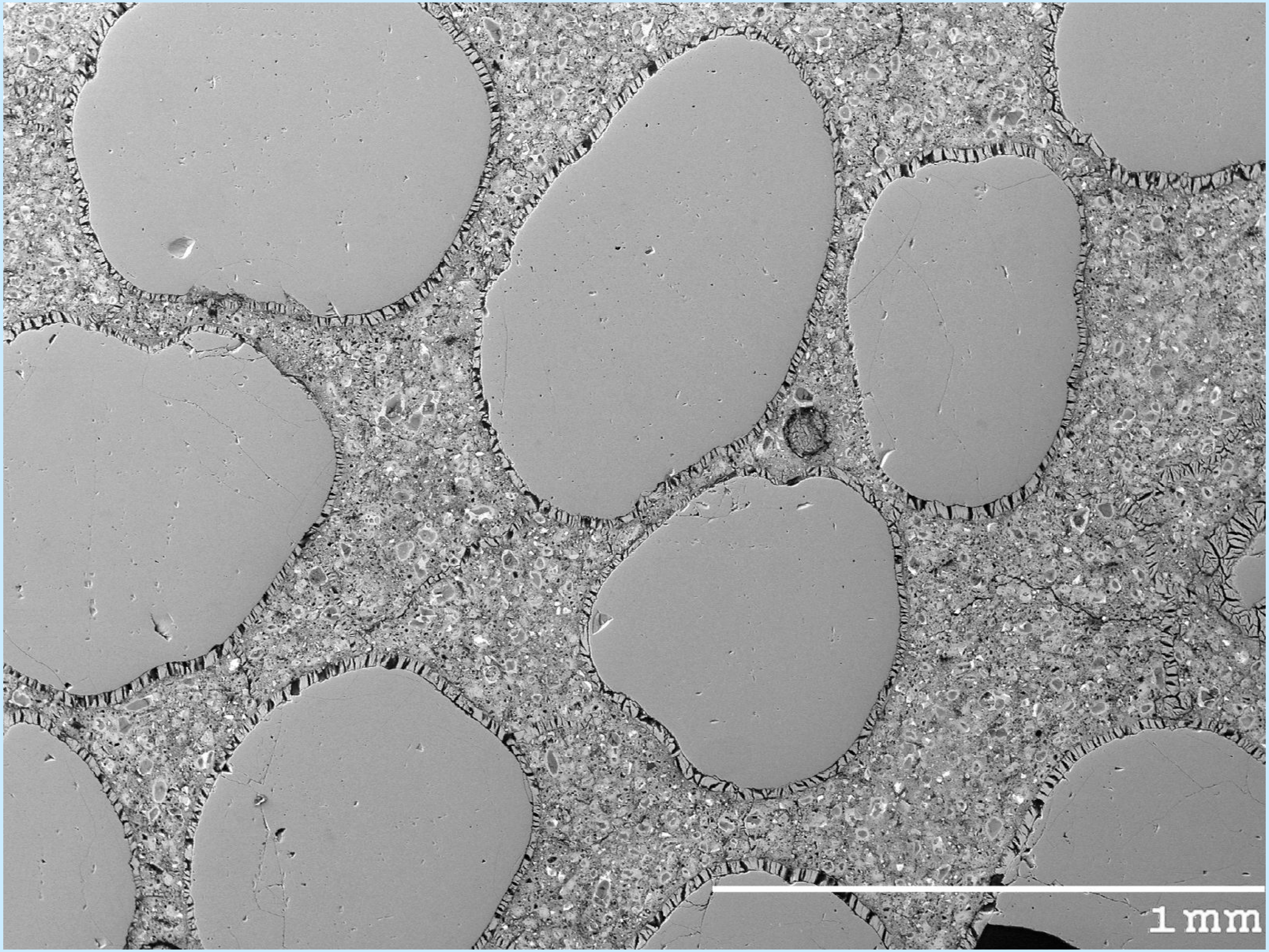
Ramlochan, 2002

200 °F Type III mortar, after six months stored under water



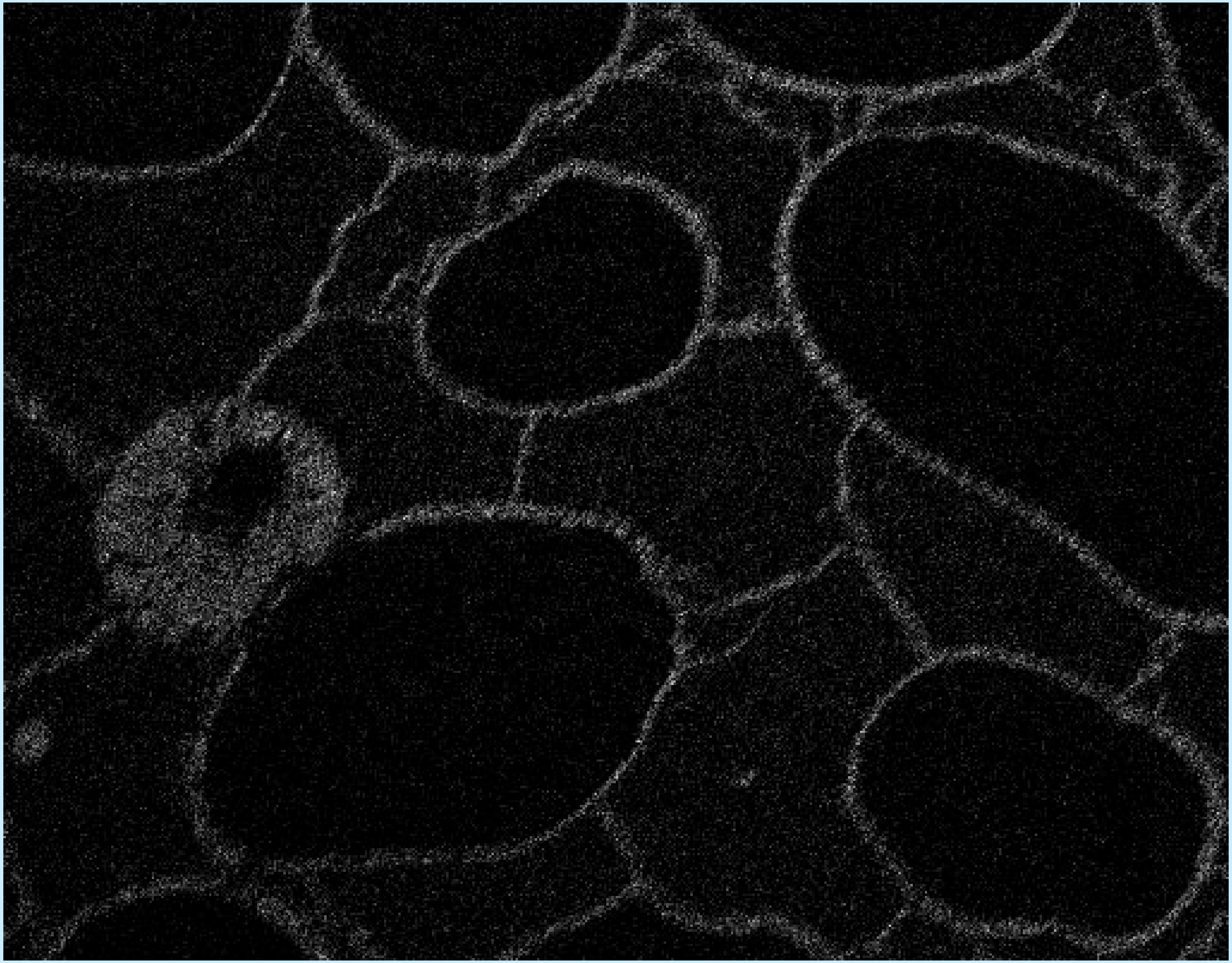
Ramlochan, 2002

200 °F Type III mortar, after four years stored under water



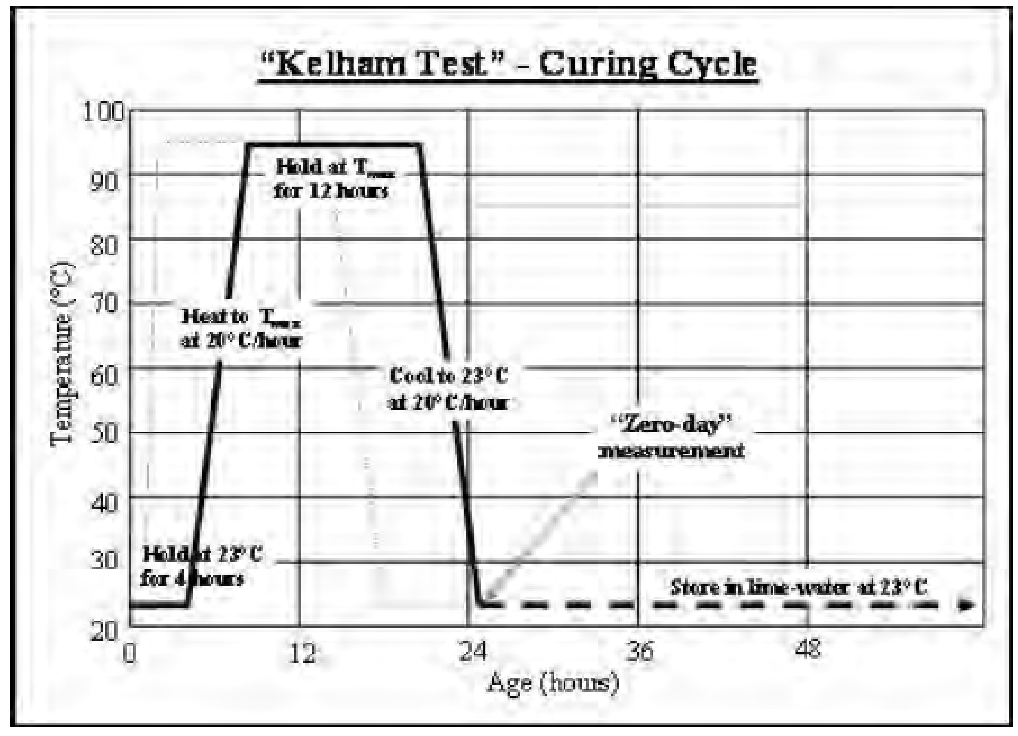
Ramlochan, 2002

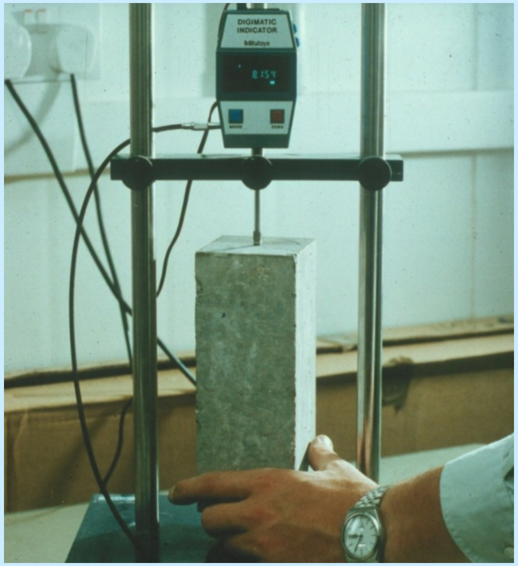
200 °F Type III mortar, after four years stored under water



Ramlochan, 2002

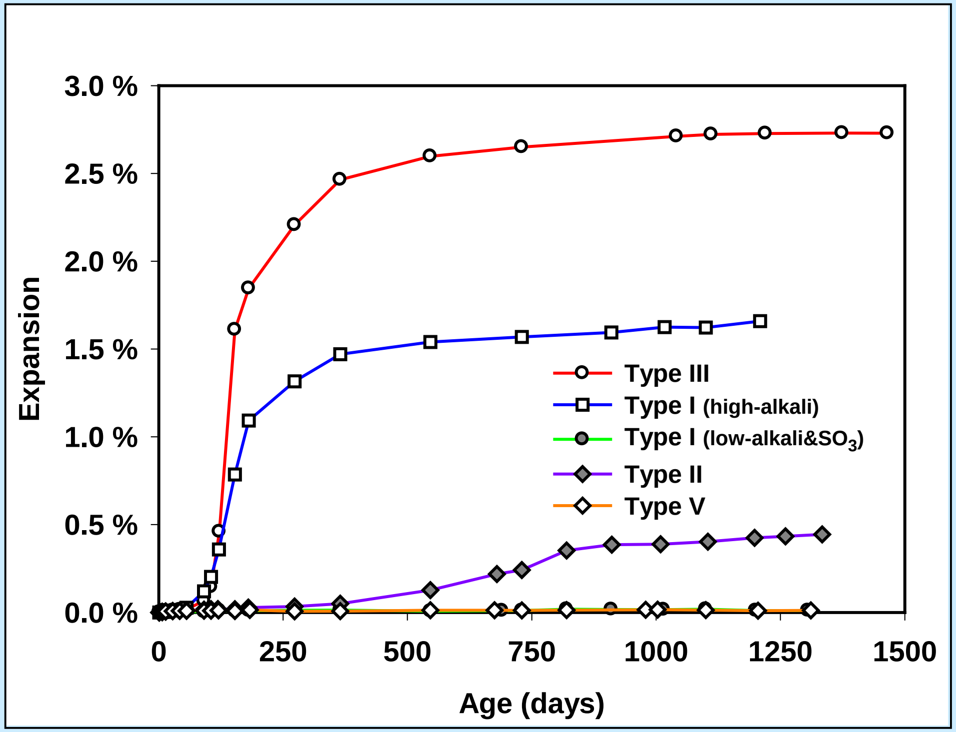
Expansion due to DEF is easily generated in the lab!

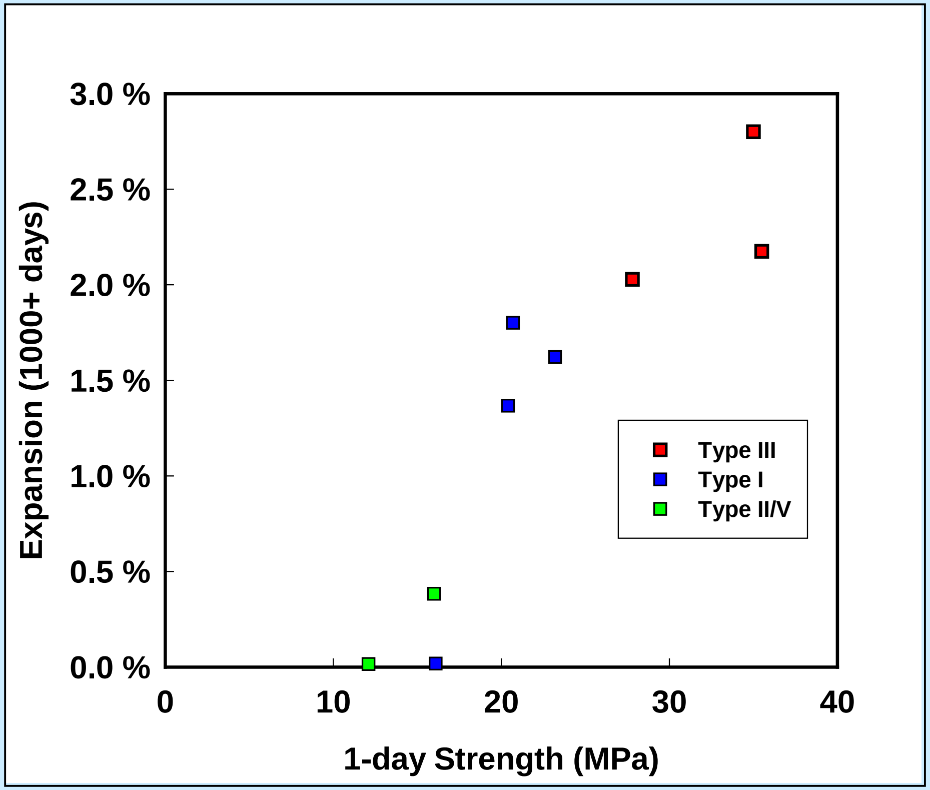




Mortars heat cured at 200 °F

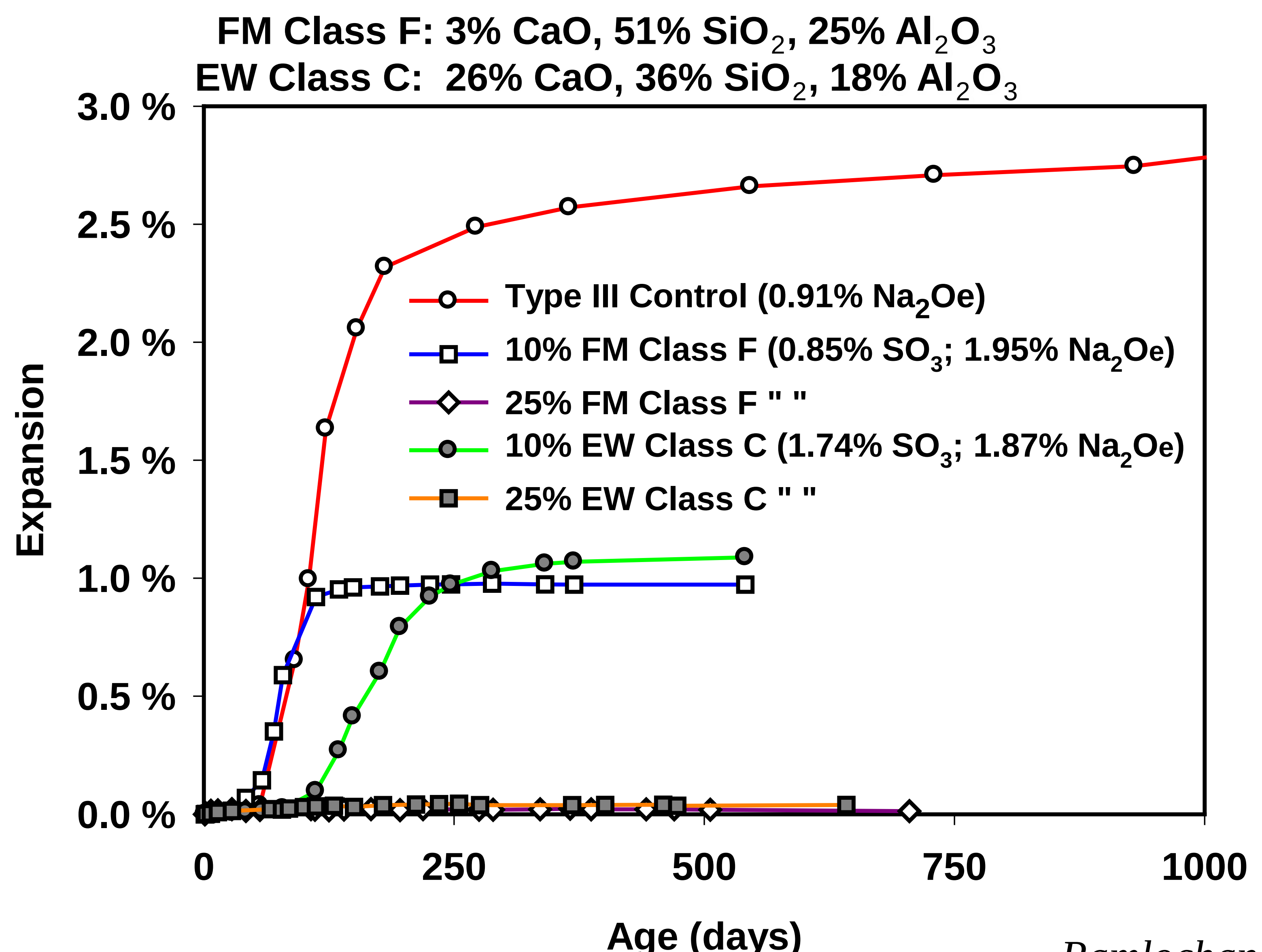
Expansion of selected cements





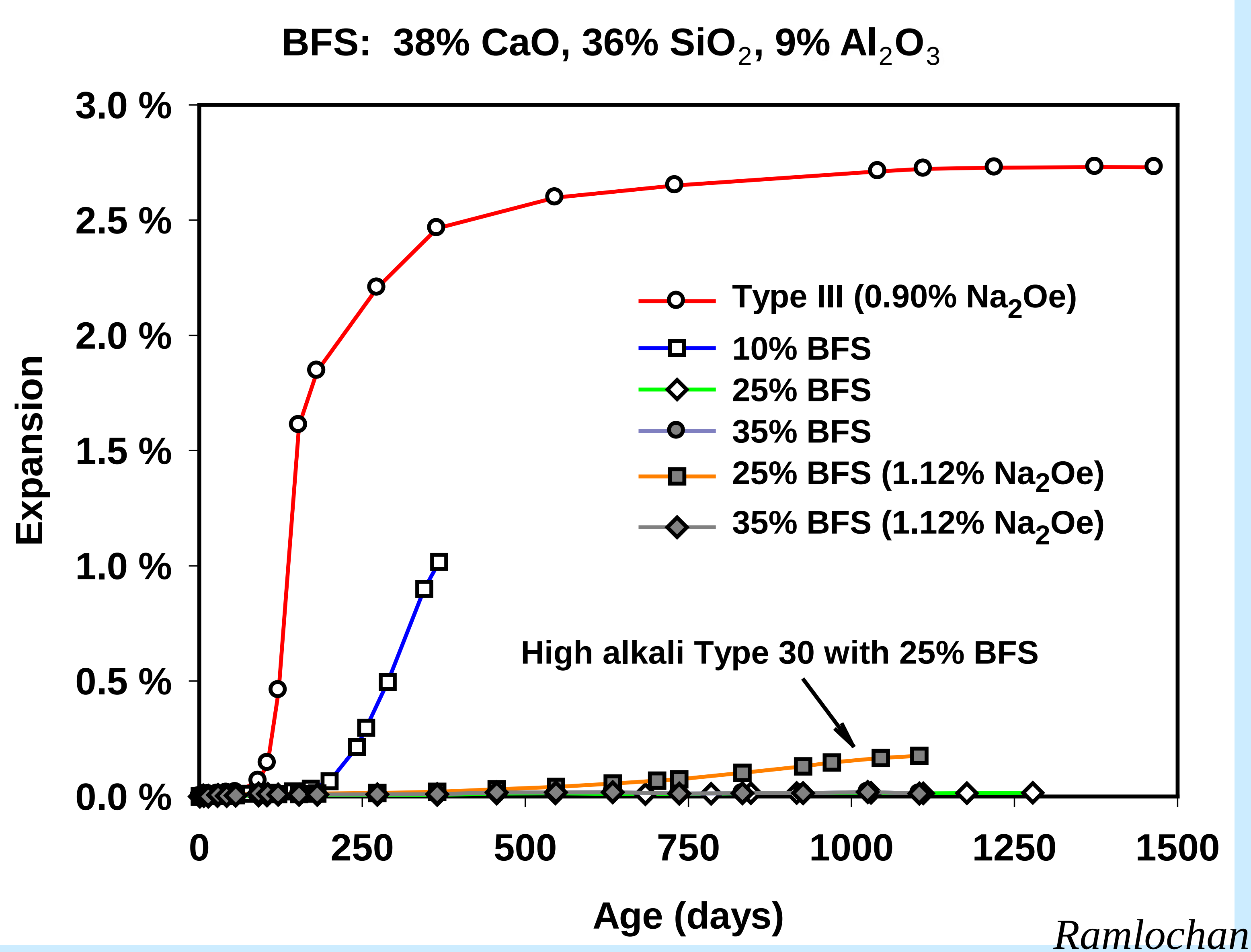
Ramlochan, 2002

Fly ash mortars at 200 °F



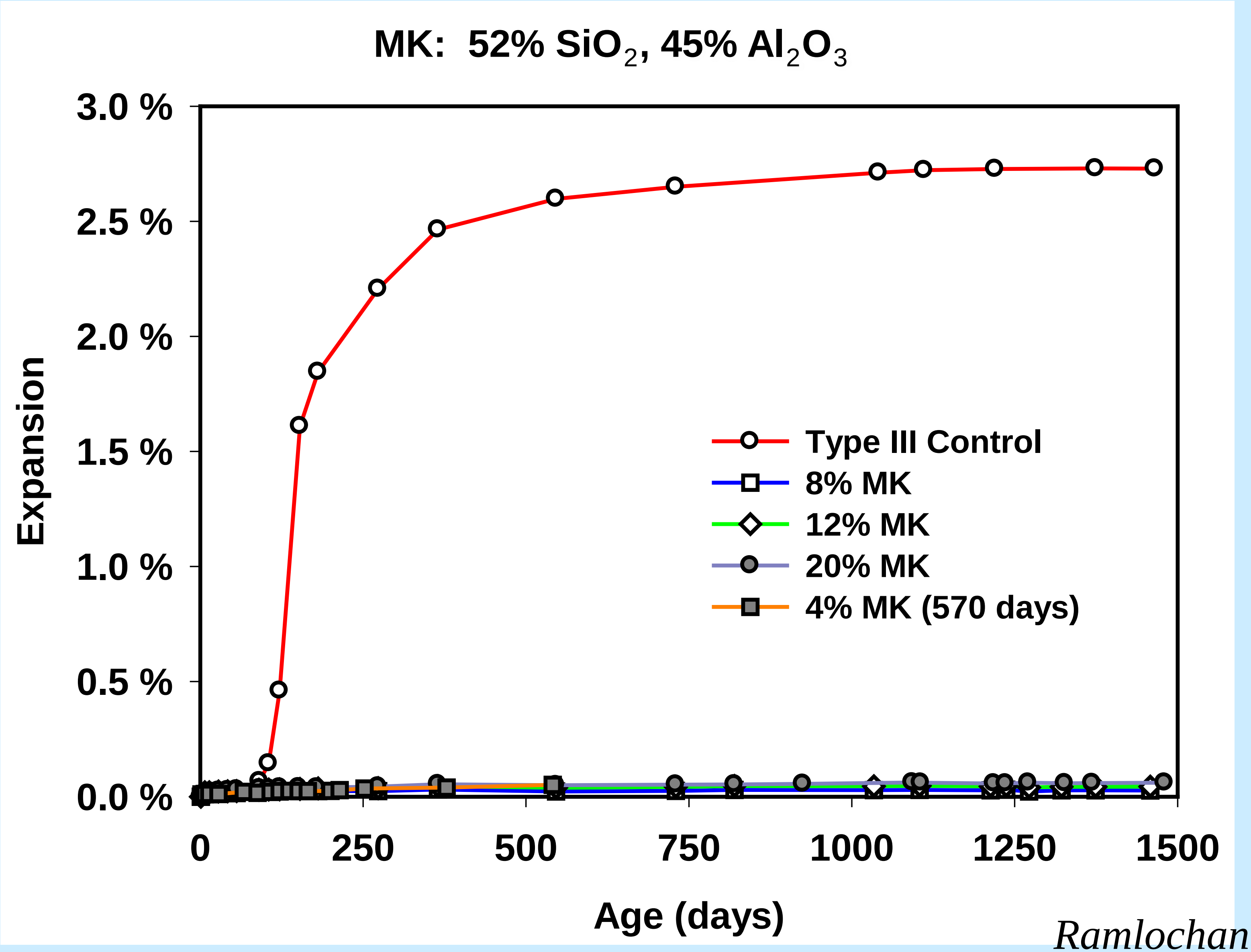
Ramlochan, 2002

Slag cement mortars at 200 °F



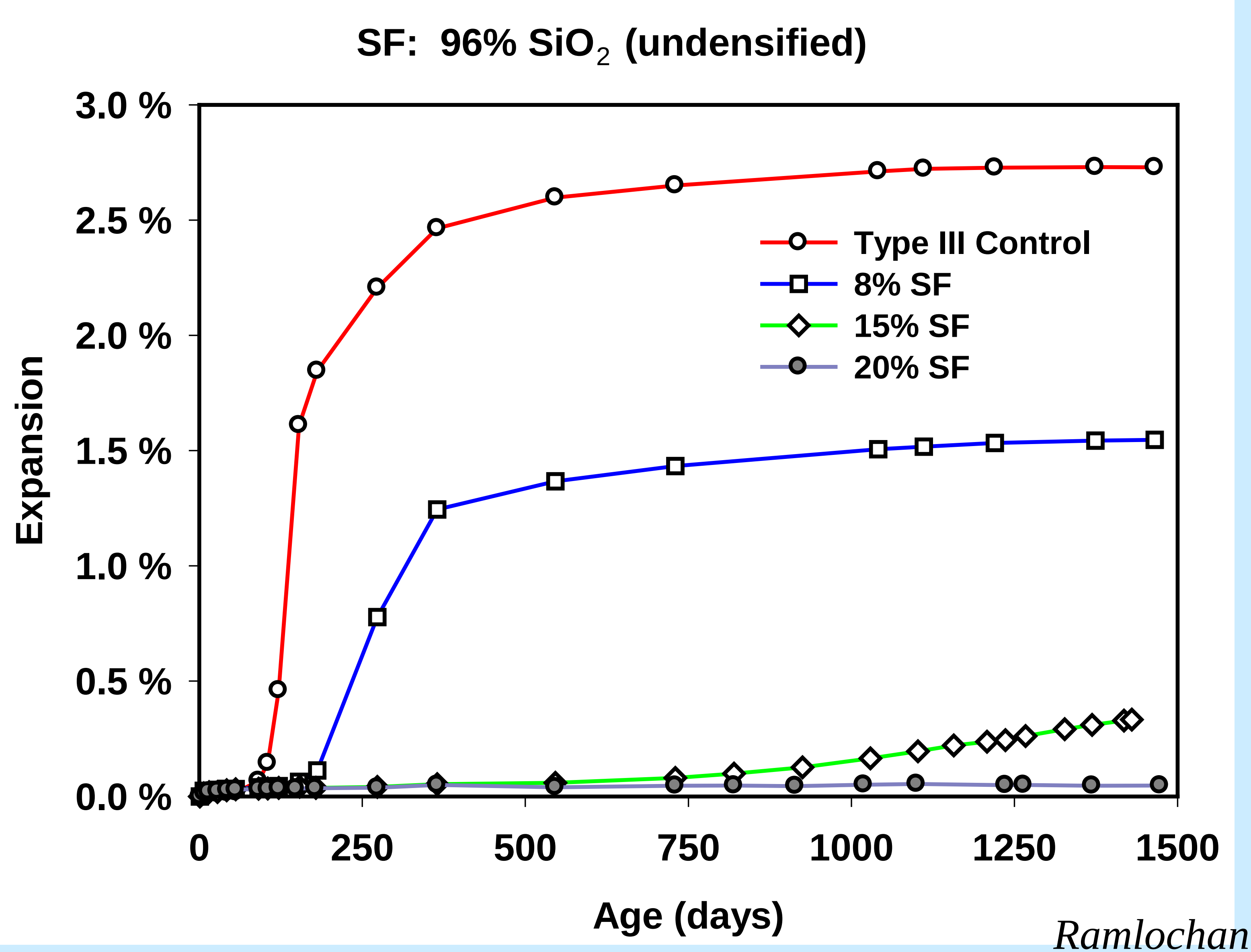
Ramlochan, 2002

Metakaolin mortars at 200 °F



Ramlochan, 2002

Silica fume mortars at 200 °F



Ramlochan, 2002

How to prevent DEF?

1. Avoid curing temperatures above ~ 158 °F.
2. If temperatures above 158 °F are expected, use DEF-resistant concrete:
   - Minimize overall potential for ettringite formation (low-C_3A cements, SCMs, etc.)
   - Use binders that cause ettringite (instead of monosulfate) to form early (upon cooling), rather than forming later from transformation from monosulfate.
   - Optimize pore size distribution to avoid pore sizes most conducive to crystal growth stresses.

Specifications considered/adopted by ACI, PCI, DOTs, etc.

Concrete Temp (T)	Prevention Required
T < 70°C (158°F)	None
70°C ≤ T < 85°C (158°F) (185°F)	Use one of the following approaches to minimize the risk of expansion: 1. Use Portland cement that meets the requirements of ASTM C 150 for Type II, IV or Type V cement and has a fineness value ≤ 400 m^2/kg or , 2. Use Portland cement with a 1-day mortar strength (ASTM C 109) ≤ 20 MPa, or (2850 psi) 3. Use suitable combination of pozzolan or slag (see table)
T > 85°C (185°F)	The internal concrete temperature should not exceed 85°C under any circumstances

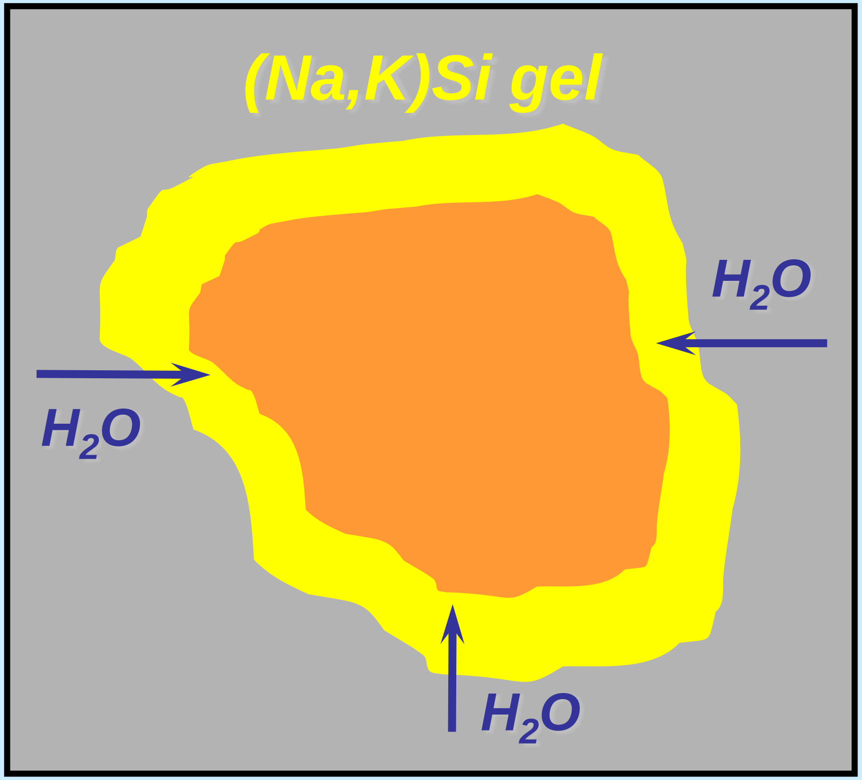
Specifications considered/adopted by ACI, PCI, DOTs, etc.

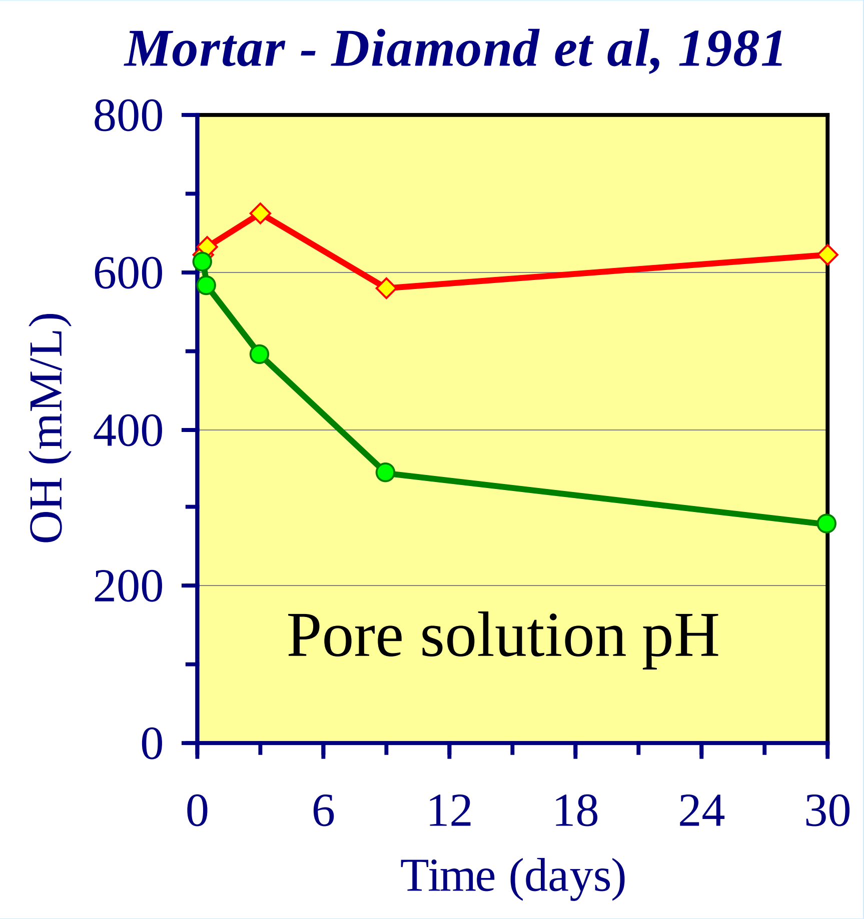
Concrete Temp (T)	Prevention Required
70°C ≤ T < 85°C (158°F) (185°F)	3. Use the following proportions of pozzolan or slag in combination with any Portland cement ≥ 25% fly ash meeting the requirements of ASTM C 618 for Class F fly ash ≥ 35% fly ash meeting the requirements of ASTM C 618 for Class C fly ash ≥ 35% slag meeting the requirements of ASTM C 989 ≥ 5% silica fume (meeting ASTM C 1240) in combination with at least 25% slag ≥ 10% metakaolin meeting ASTM C 618

DEF in Field Structures

Almost all documented involved ASR and DEF

Almost all documented involved ASR and DEF





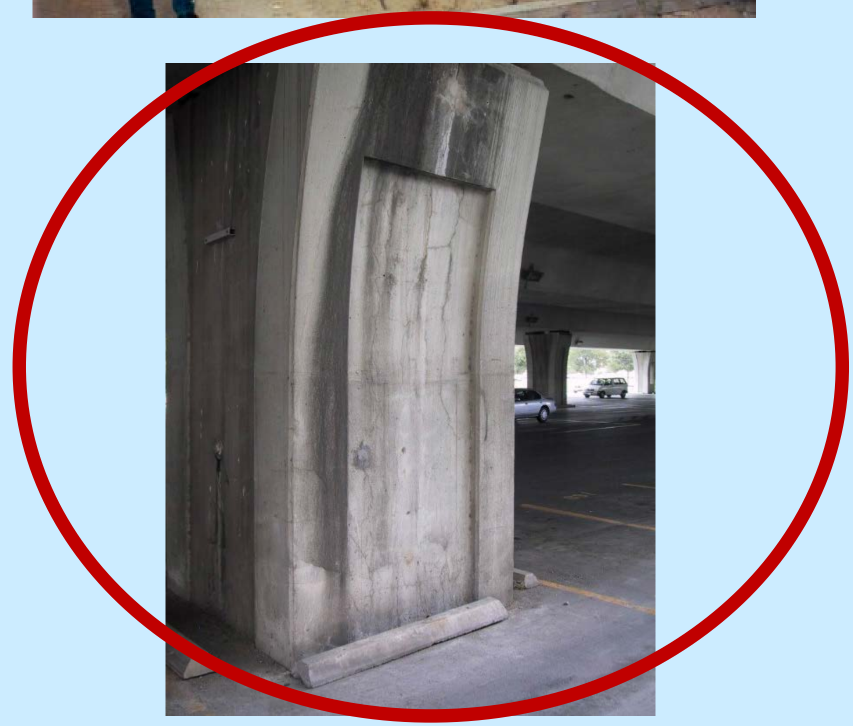
As alkalies are combined in ASR gel, the pore solution pH drops, which favors the formation of ettringite, and hence, DEF.

Texas Box Beams

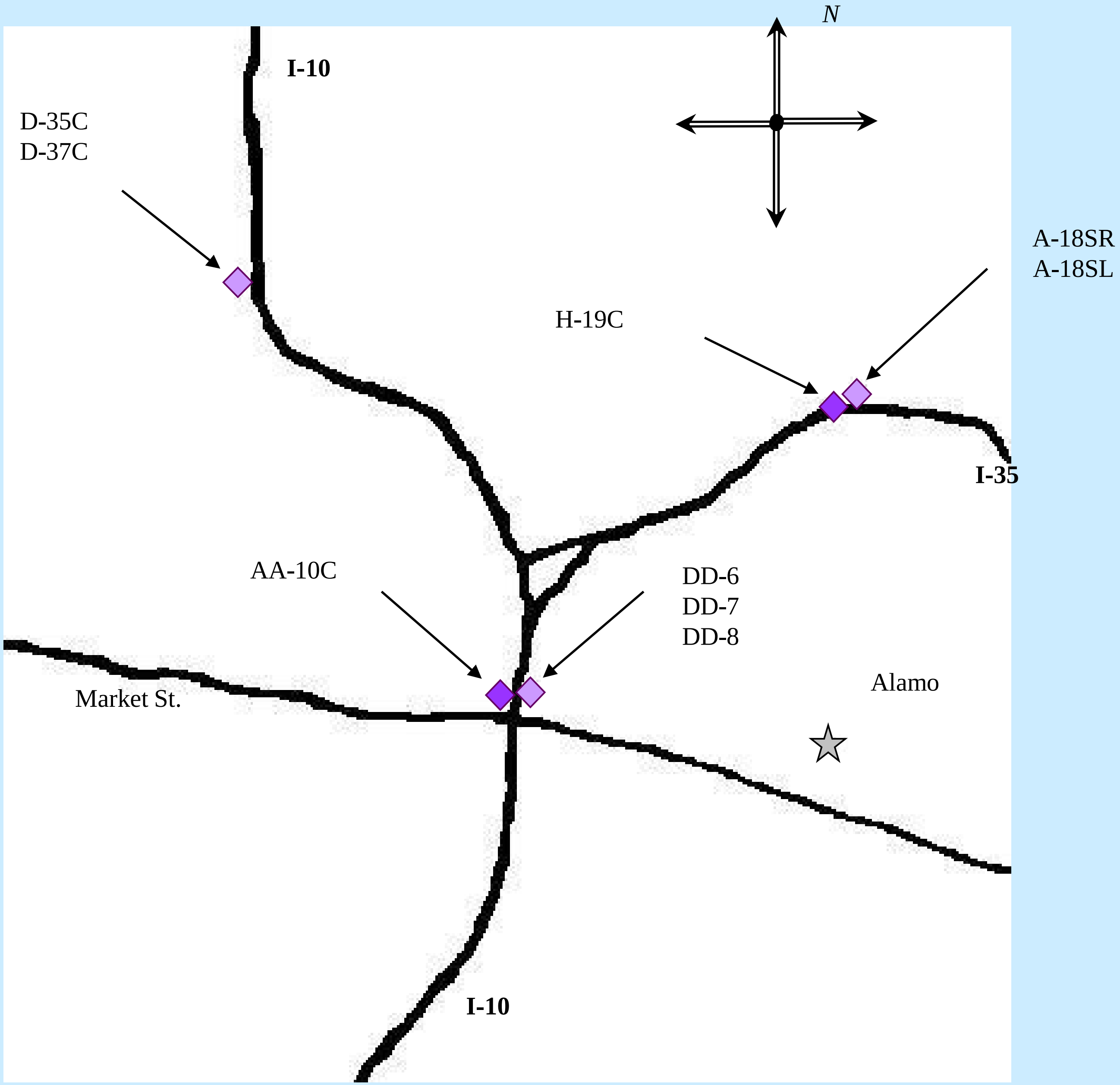

ASR + DEF
ASR only


ASR + DEF
ASR only

There are very few documented cases of DEF by itself



The San Antonio "Y"

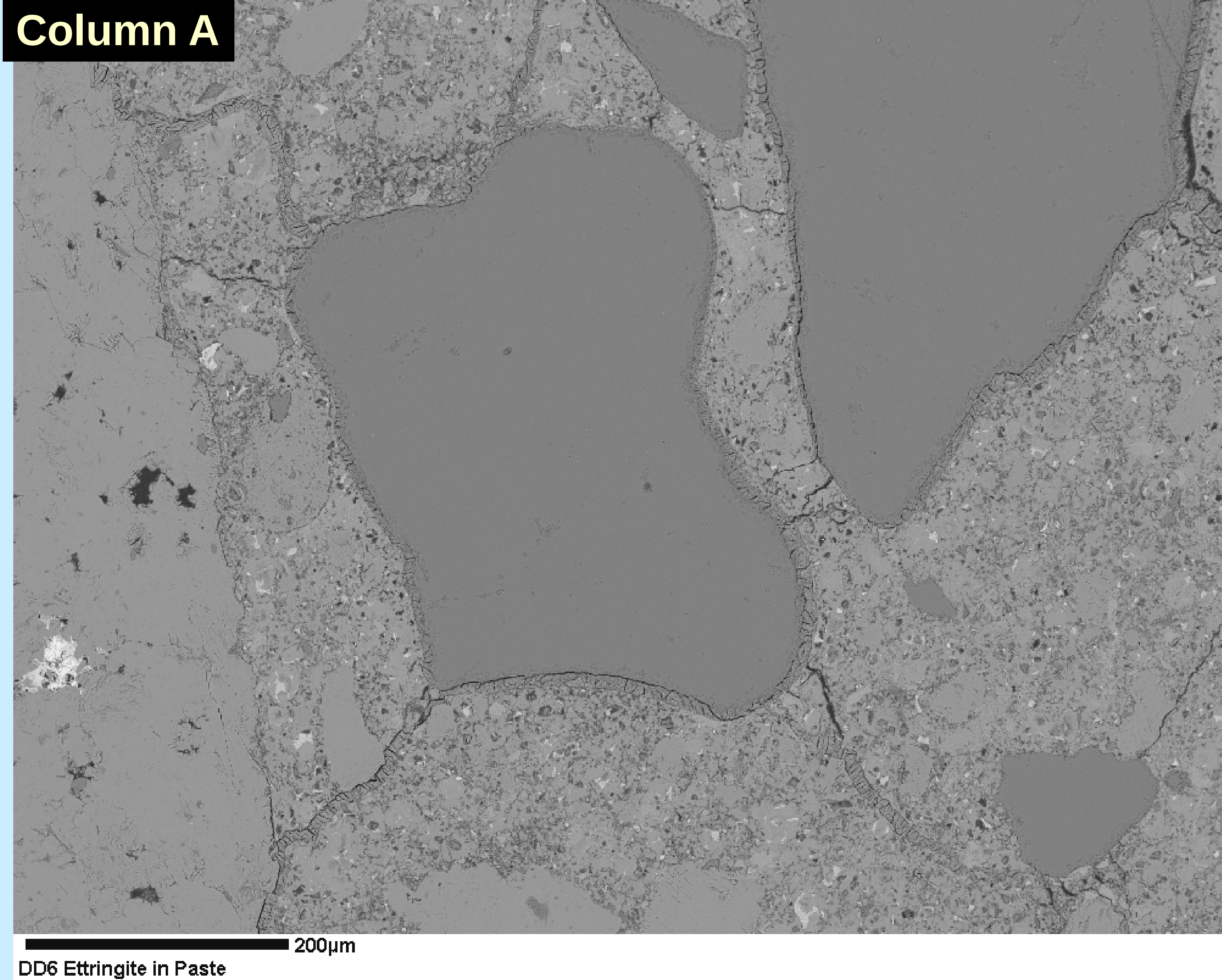


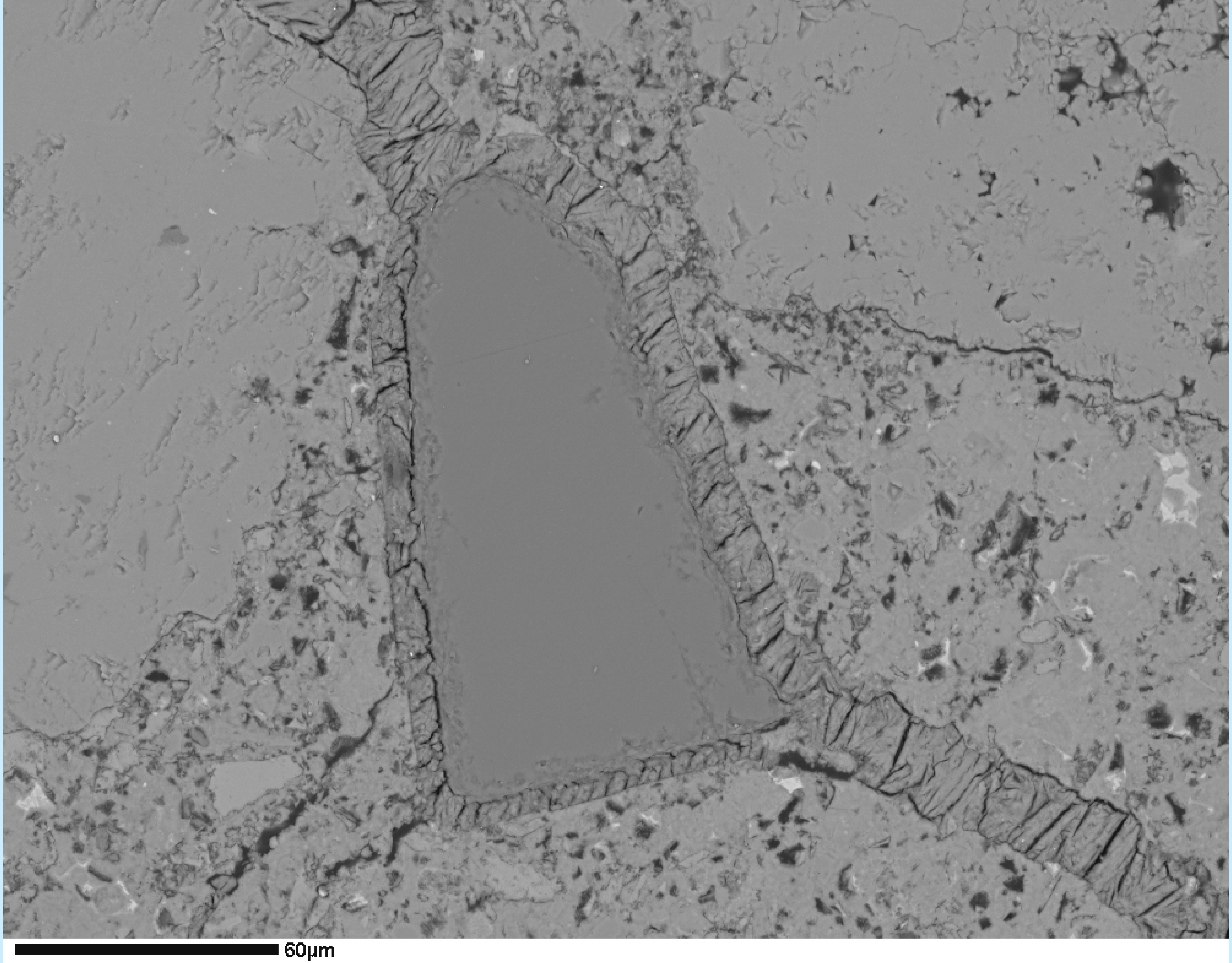
All damaged columns showed symptoms of ASR + DEF, except one…

Column C

Column A

Column A





DD6 Ettringite-Filled Gap Around Aggregate

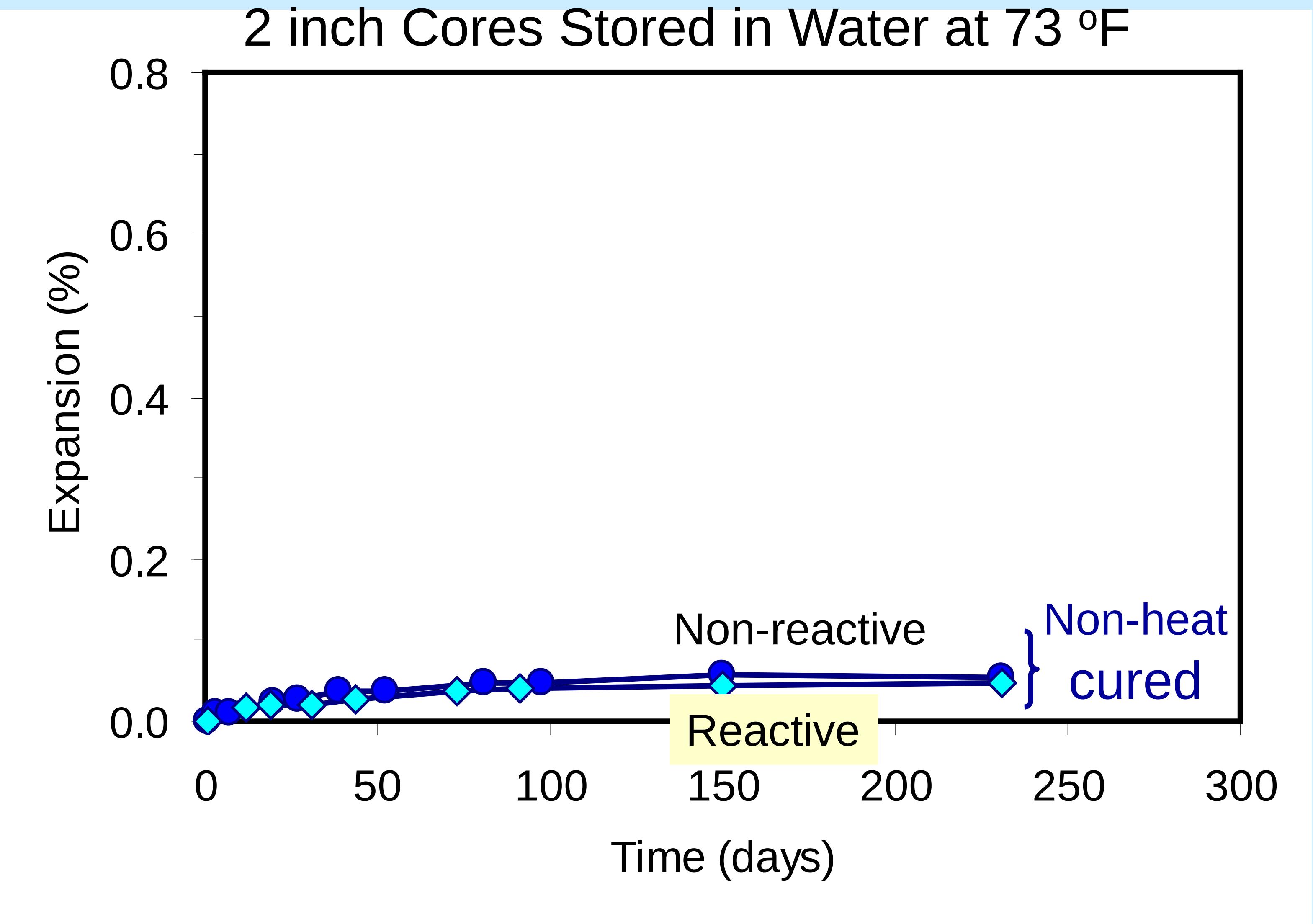
Potential for DEF

2-in cores immersed in water at room temperature 73 ^oF

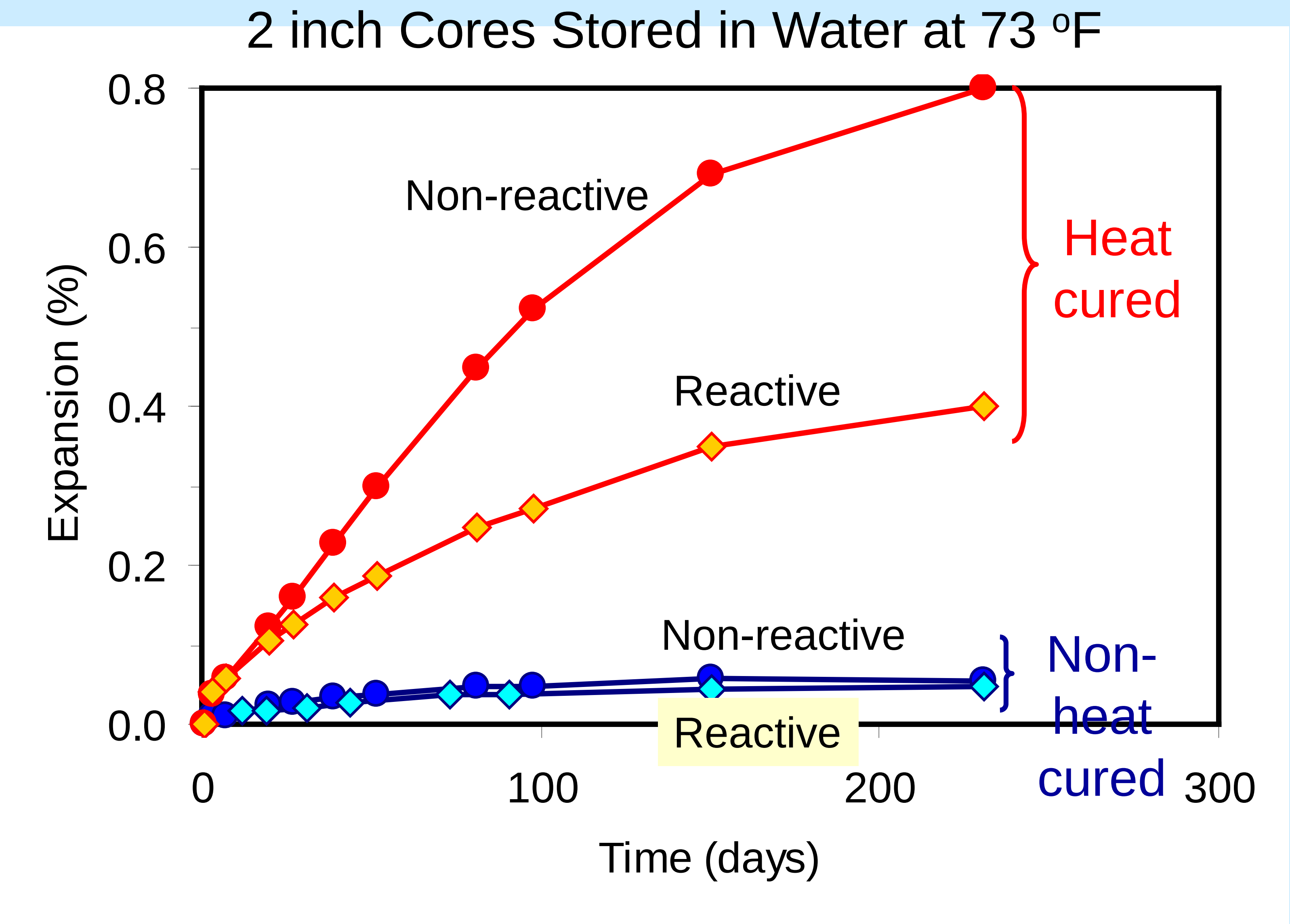
Potential for ASR

2-in cores immersed in 1 M NaOH at 176 ^oF

Expansion of Cores Cut from Laboratory Prisms



Expansion of Cores Cut from Laboratory Prisms



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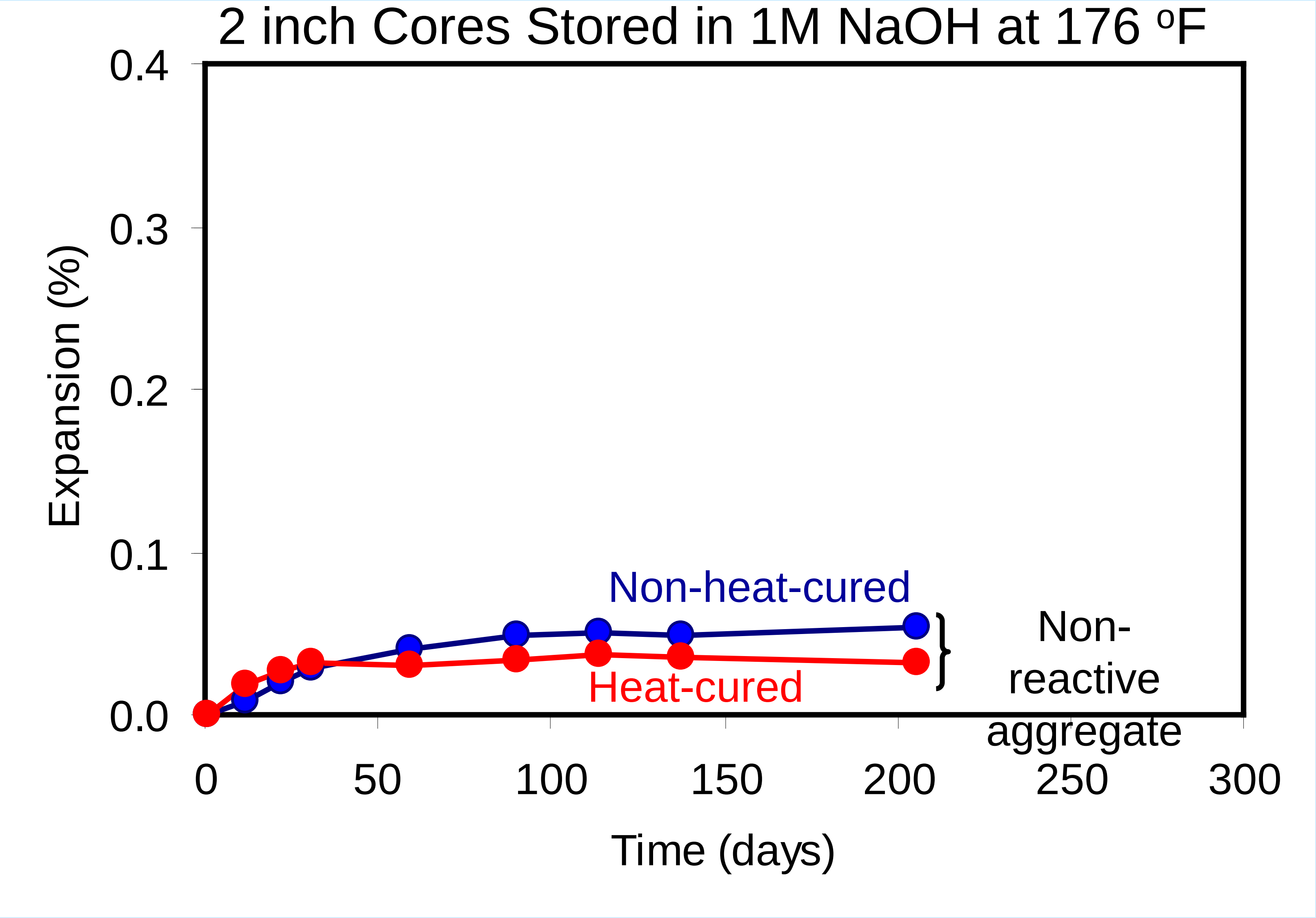
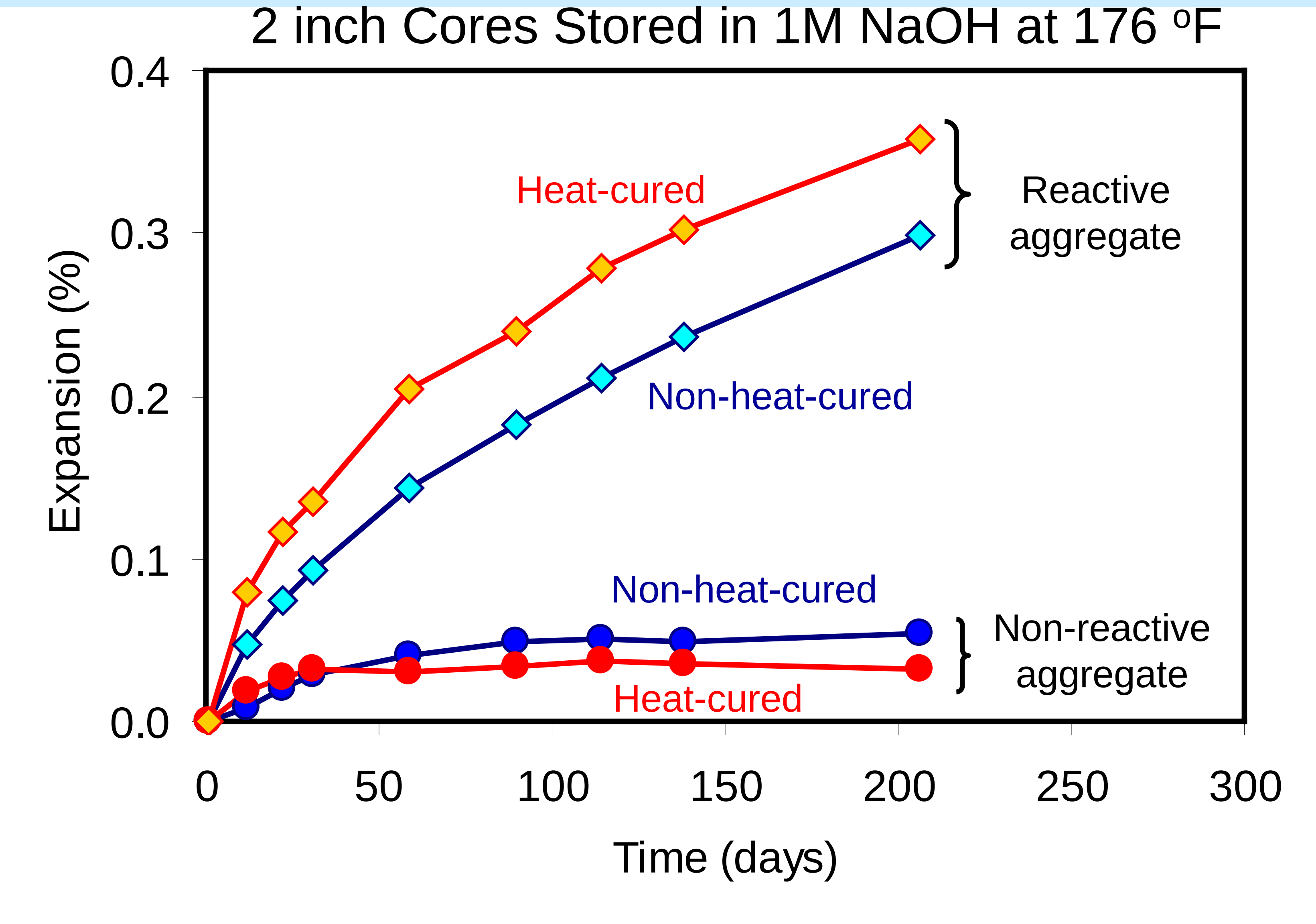


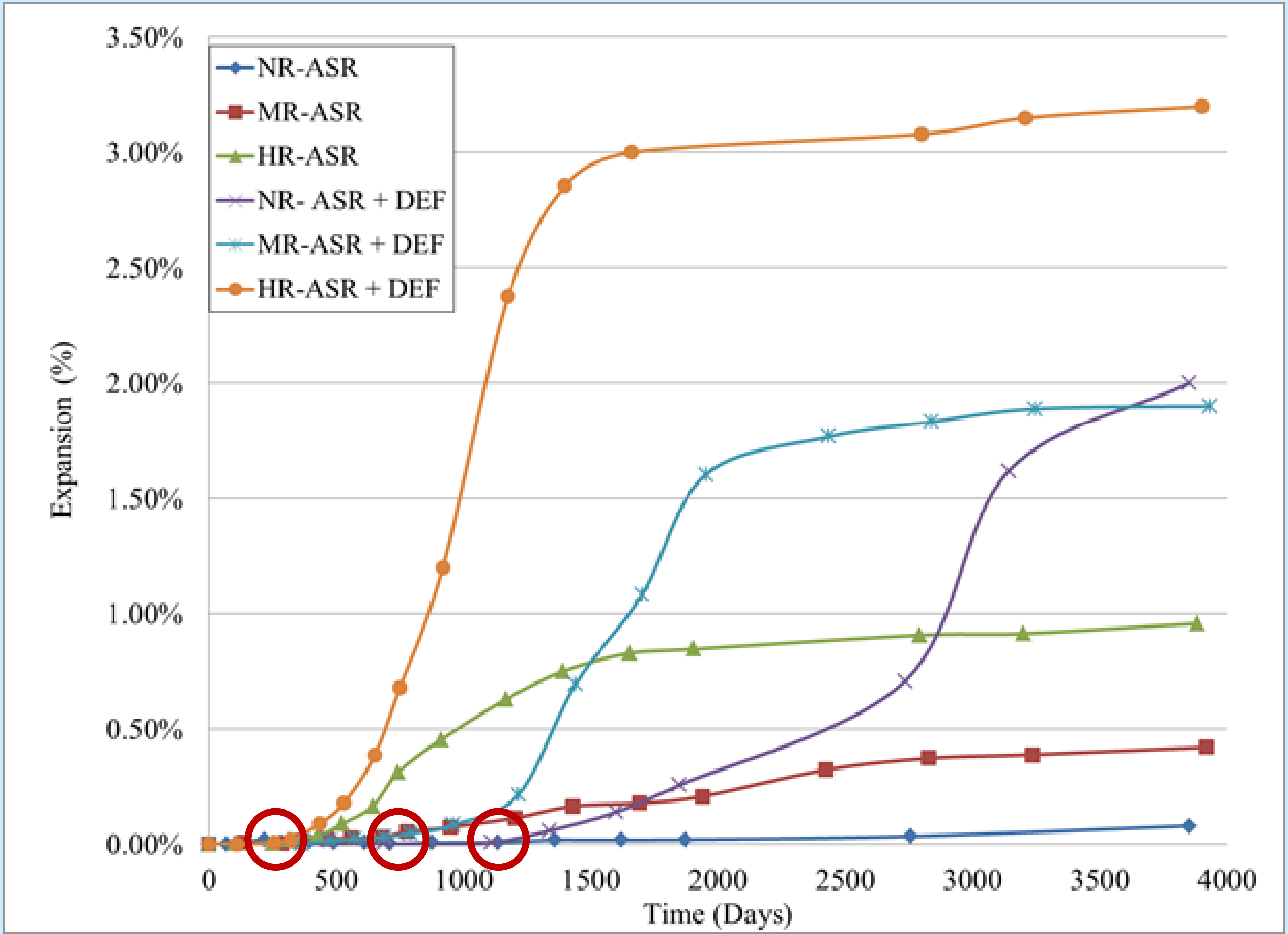
Expansion of Cores Cut from Laboratory Prisms



Mixture ID	Mixture Reactivity	Maximum Internal Temperature
NR	Non-Reactive	55 °C
MR	Moderate-Reactive	56 °C
HR	Highly Reactive	55 °C
NR-H	Non-Reactive (heat-treated)	82 °C
MR-H	Moderate-Reactive (heat-treated)	83 °C
HR-H	Highly Reactive (heat-treated)	83 °C

~ 130 °F (NR, MR, HR)

~ 180 °F (NR-H, MR-H, HR-H)



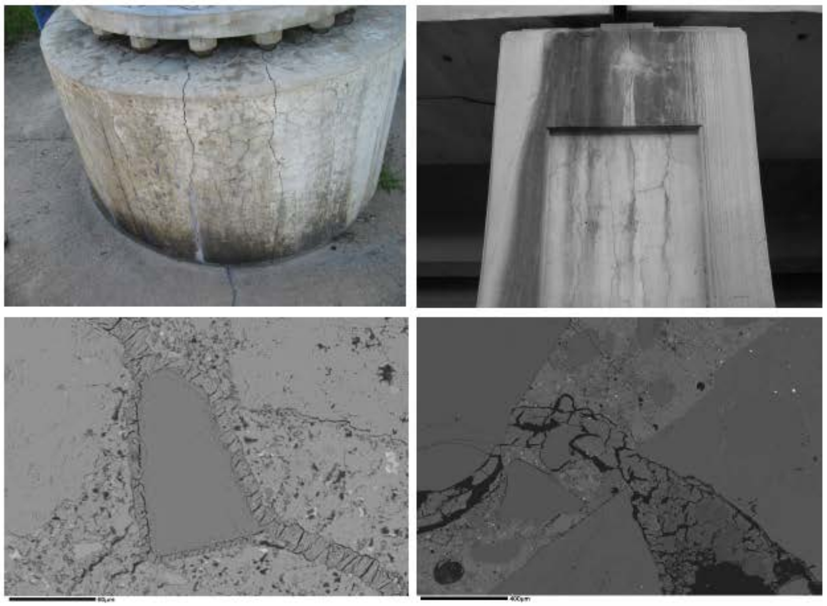
NR-ASR
MR-ASR
HR-ASR
NR- ASR + DEF
MR-ASR + DEF
HR-ASR + DEF
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
Expansion (%)
0
500
1000
1500
2000
2500
3000
3500
4000
Time (Days)

NR-H

MR-H

HR-H

PROTOCOL
FOR THE DIAGNOSIS AND PROGNOSIS OF CONCRETE STRUCTURES AFFECTED BY ALKALI-SILICA REACTION AND/OR DELAYED ETTRINGITE FORMATION



Developed by:
Kevin J. Folliard, Michael D.A. Thomas, and Benoit Fournier

Developed for:
Texas Department of Transportation
TxDOT Project 5218: "Extending the Service Life of Large or Unusual Structures Affected by Premature Concrete Deterioration"

October 2007

1. **Determine cause/extent of damage to date.**
2. **Estimate future potential for expansion**

Summary

1. DEF can lead to significant cracking in lab and field
2. DEF can be prevented by either limiting maximum temperature or by selecting proper materials (SCMs, etc.)
3. ASR often occurs first and then triggers DEF, but on rare occasions, DEF can be the sole cause of distress.

Use of Post Cooling on Caltrans Mass Concrete Bridge Projects

Ric Maggenti,
California Department of Transportation (Caltrans)

Transportation Research Board 97th Annual Meeting

January 2018

Per Caltrans' Structure Construction *Concrete Technology Manual*, June 2013

Mass Concrete

- When measures beyond those typical for concrete construction need to be taken precisely to keep a concrete element from exceeding 160° F,

<u>that element is determined by Caltrans to be **Mass Concrete**</u>.

Tools Available

Passive Controls— Prior to Placement—include

- Control Mix Ingredients
- Control Placement temperature
- Control Mass (lifts)

Active Controls--During Hydration—include

- Insulating Blankets
- Internal Heat Exchanger (cooling pipes)
- Control Curing Medium (water cure)

Prior to SFOBB Caltrans used for Mass Concrete Prescription Specifications Consisting of Passive Controls

- Limited C3A in Cement
- Limited Placement Temperatures
- Limited Cement Content
- Required Flyash

New Memo | Reply | Forward | Delete | Folder | Copy into | Tools | Expand Group

Regards April 3, 2000 meeting

Underline added 2017

Ric Maggenti
07/24/00 05:56 PM

To: Rachel Falsetti/D04/Caltrans/CAGov@DOT
cc: Sharon Naramore/HQ/Caltrans/CAGov@DOT, Karla Meier/HQ/Caltrans/CAGov@DOT, Brian Maroney/D04/Caltrans/CAGov@DOT, Sabbas@tylin.com
Subject: Mass Concrete Spec, SFOBB

The following are from my notes for an April 3, 2000 meeting attended by the members of the joint venture, Caltrans, and a representative of CTL. The meeting was held in the TYLin San Francisco Office to discuss specifications for mass concrete. A presentation , "San Francisco -Oakland Bay Bridge Thermal Analyses" by Ron Burg, Vice President of CTL inc. was given prior to discussion. From the sign-up sheet: Scott Hunter & Karen Cormier-TYL, Henry Russell- HGR, Kang Chen- MGE, Ric Maggenti,Stanley Ku & Brian Maroney-CT. Also present but not on the sign up sheet were Sajid Abbas and Rafael Manzanarez.

Elements defined as Mass concrete need to be identified in the contract. It was agreed that the Mass concrete Spec would be performance based giving temperature parameters the concrete must meet. The Contractor is to instrument the concrete to show concrete is within contract temperature requirements. The Contractor is to submit thermal plans for review as to how the performance criteria is to be obtained, and to construct a model, prior to the actual construction of any bridge member, to demonstrate the plan will meet the performance criteria. The size of the model was not decided, discussion ranging from 1/3 to full scale. Brian believes the model should be full scale. The two objectives the performance criteria the Contractor is to achieve are:

1) The maximum peak temperature is to be 158deg F (60 deg C) as a precaution against Delayed Ettringite Formation (DEF).

2)The maximum temperature differentials is to be based on thermal criteria designed for no thermal cracking. For economy, the maximum temperature differential within the concrete will be based upon the thermal coefficient of expansion of the aggregate or concrete to be used The joint venture was to develop a Table showing the allowed differential verus thermal coefficients of expansion.

The joint venture was to estimate the cost of a 1/3 to full scale model; and, the cost of an internal cooling system for the pier tables and columns.

A flow chart outling the general concept of the specification was developed. It is to be same for both pier tables and columns:

bid	Thermal Control Plan submital	model mock up built and tested	new plan submital if model does not meeet requirement and new model mock up built &tested	thermal plan accepted if model meets contract thermal requirements	begin construction

Main Points

1. Elements defined as Mass concrete need to be identified in the contract.
2. Mass concrete Spec would be performance based giving temperature parameters the concrete must meet.
3. The Contractor is to instrument the concrete
4. The maximum peak temperature is to be 158deg F as a precaution against Delayed Ettringite Formation (DEF).
5. The maximum temperature differentials is to be based on thermal criteria designed for no thermal cracking
6. The Contractor is to submit thermal plans for review

DEMONSTRATING ACTIVE CONTROL

Mass concrete pile caps (footings) on an ongoing project used prescriptive passive specifications.

One pile cap was changed to a high strength concrete. Temperature was controlled by cooling pipes.

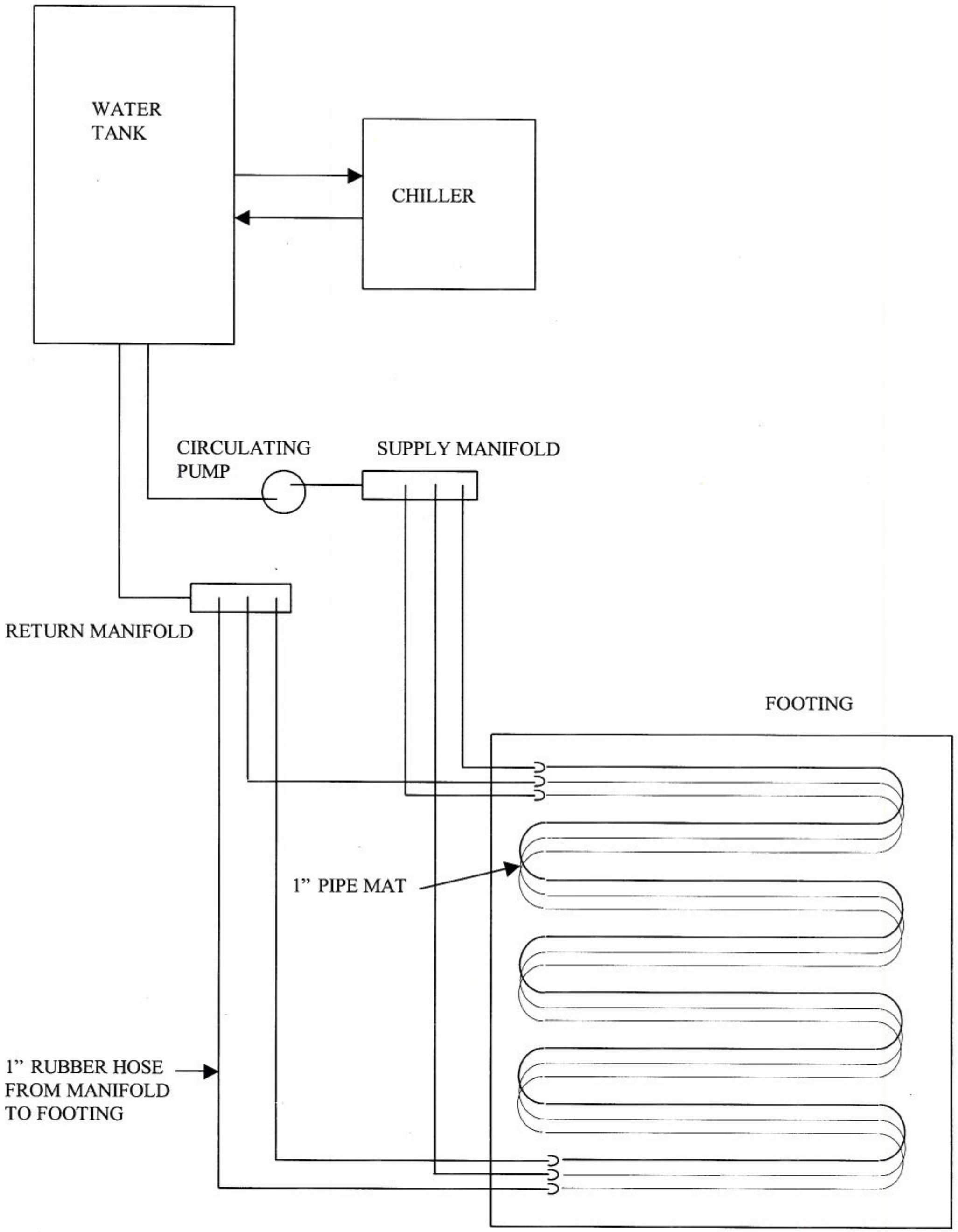
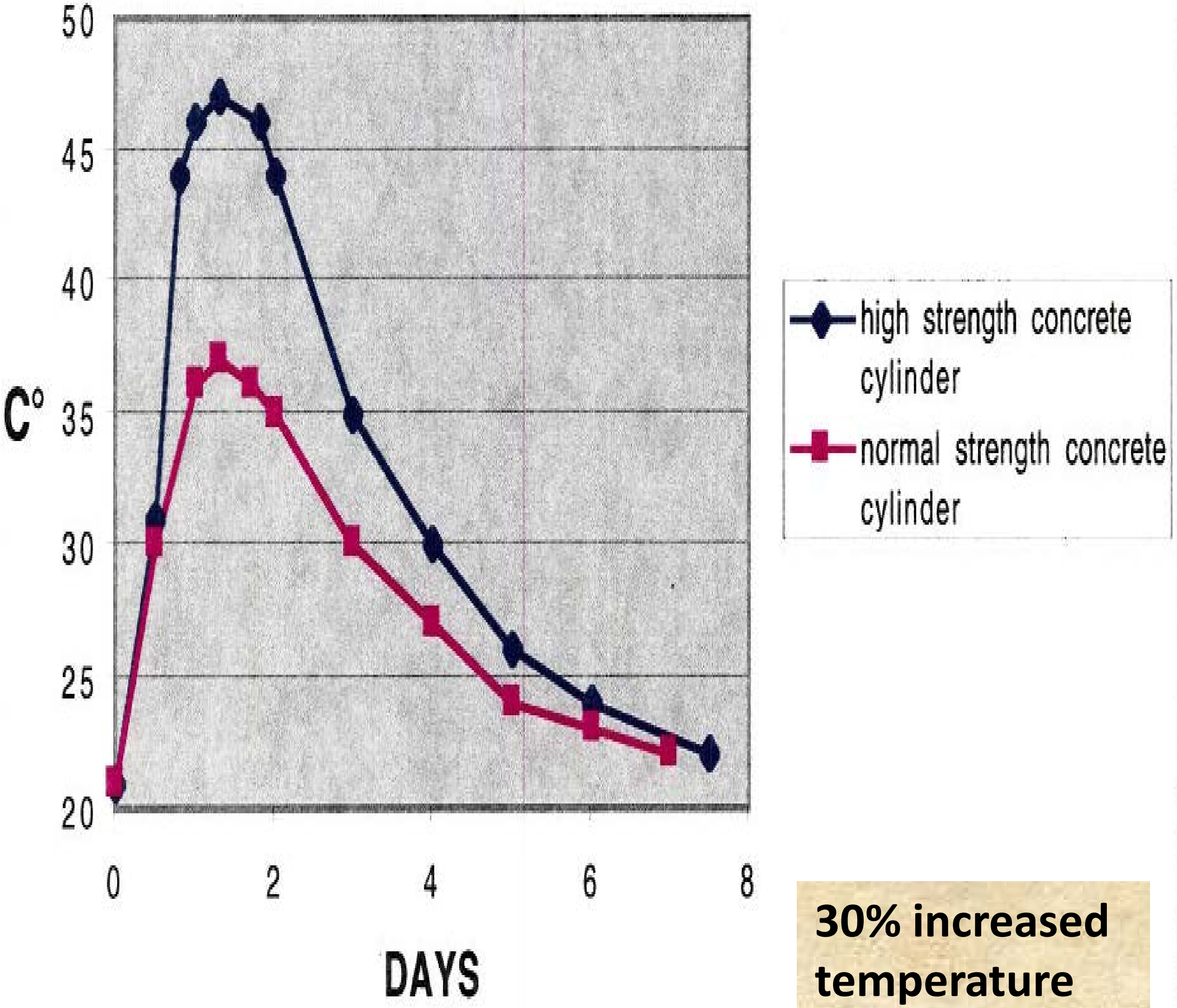


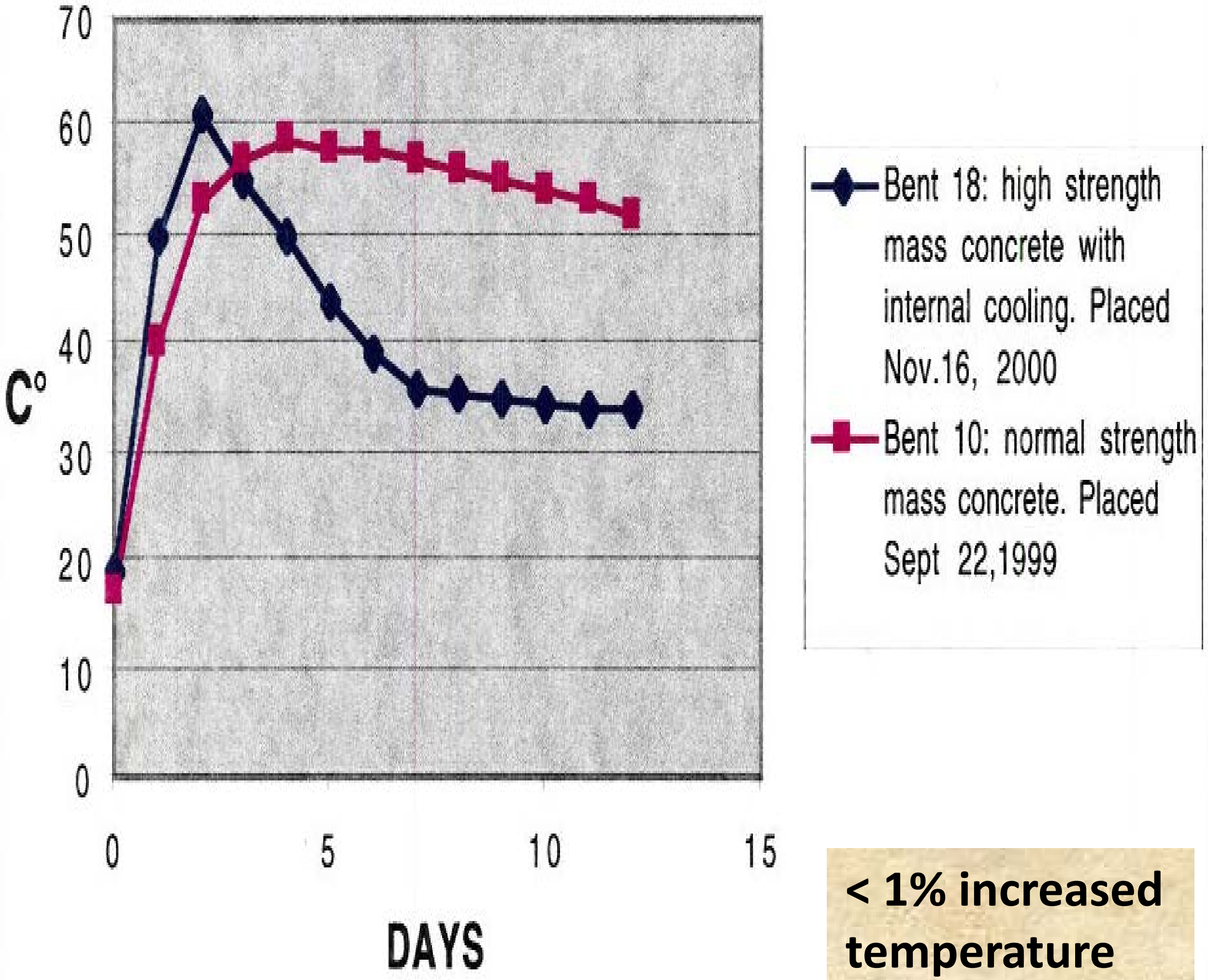
Figure 2. Schematic diagram of cooling equipment (no scale). The flow in each of the cooling pipe mats was approximately 15 gallons per minute.

FIGURE 1: Comparison a High and a Normal strength concrete cylinder cured under same condition



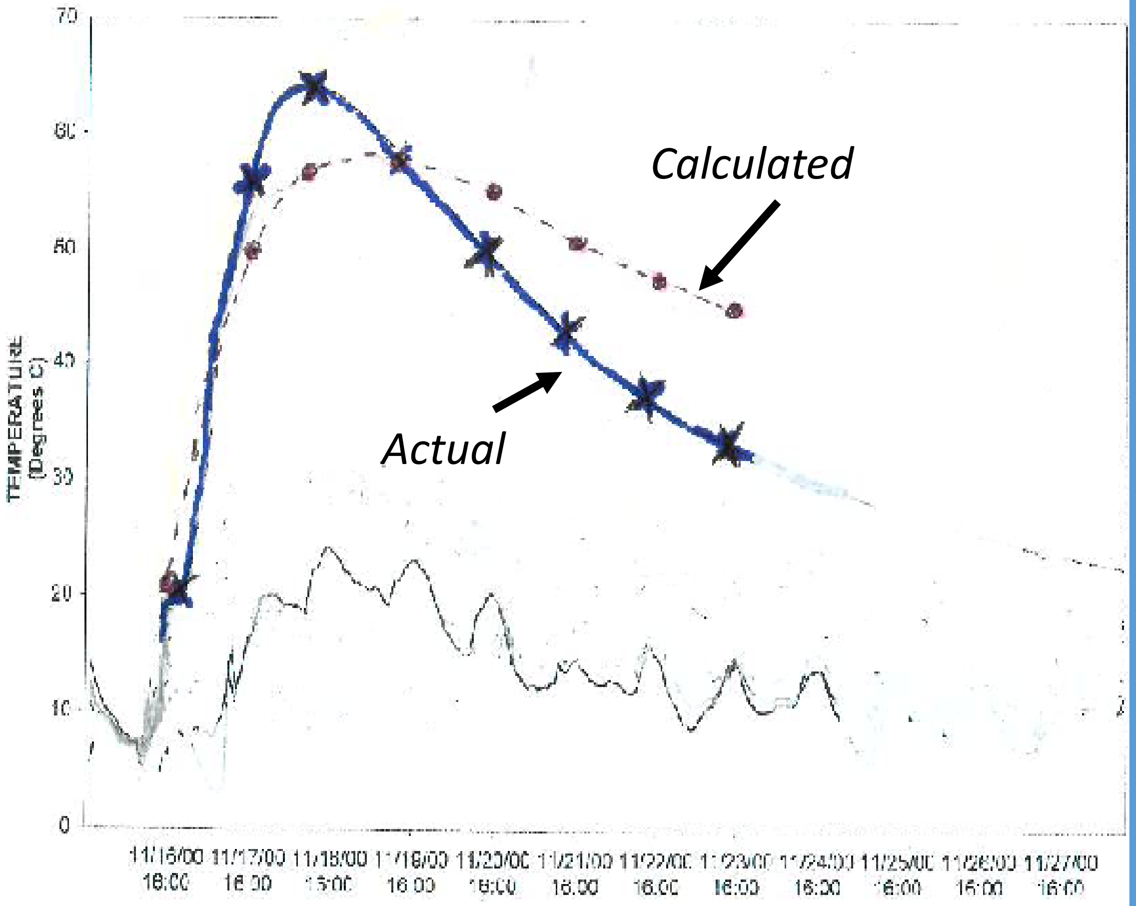
30% increased temperature

FIGURE 2: Comparison of High Strength Concrete with internal cooling to Normal Strength Concrete without internal cooling . Footings Dublin 580/680 Interchange



< 1% increased temperature

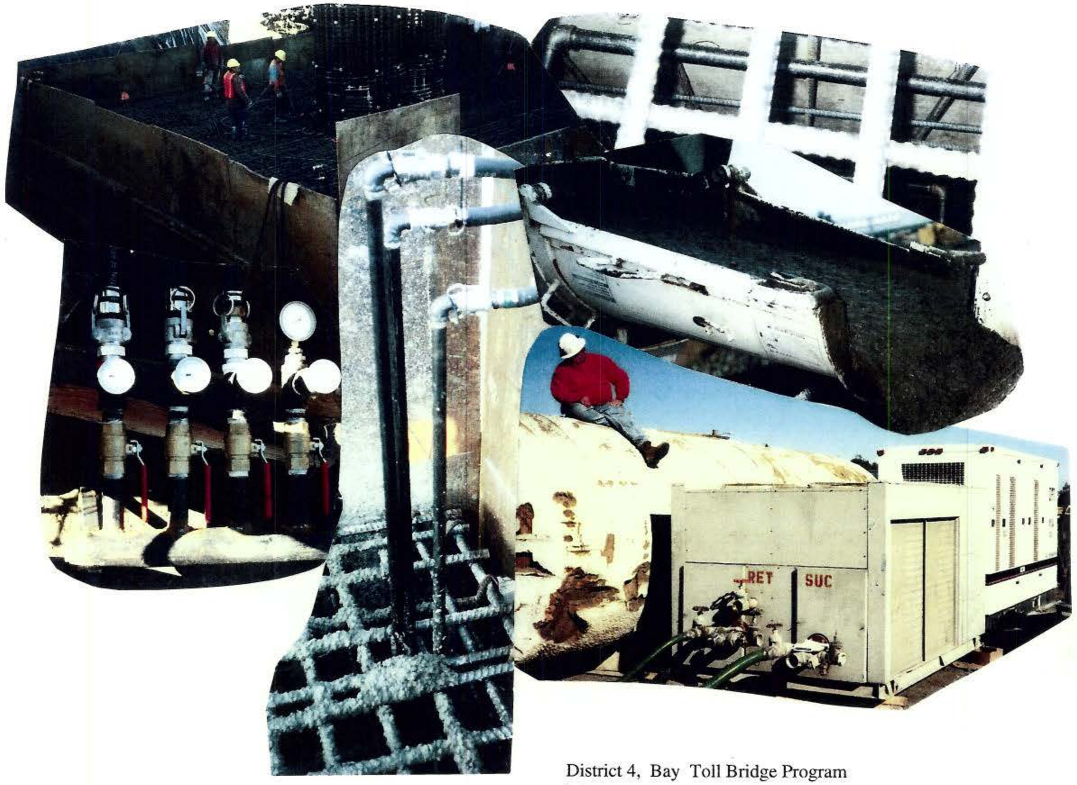
Dublin 580/680 Concrete Temperatures 7 days



Mass Concrete Report

San Francisco-Oakland Bay Bridge East Spans Safety Project:
Skyway Structure
04-Ala/SF-80-Var

Caltrans



District 4, Bay Toll Bridge Program
ESC, Structures Construction
ESC, Materials Engineering and Testing Services
New Technology and Research

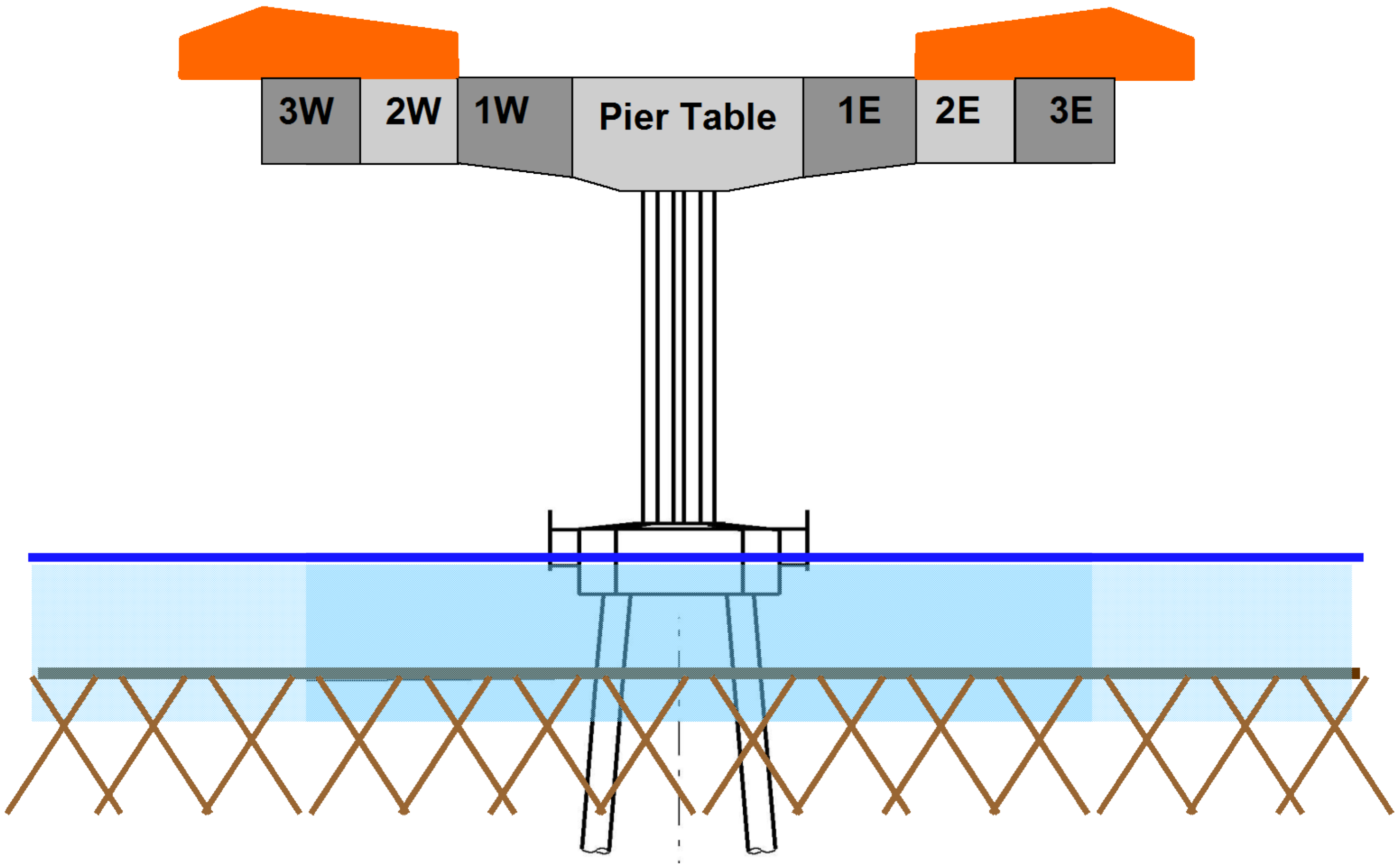
The 580 /680 interchange mass concrete report was a catalyst breaking down resistance to cooling pipes. Specifications were written for SFOBB Skyway providing for this tool.

Excerpt Jan. 2004 Submittal Letter, Thermal Control Plan for San Francisco Oakland Bay Bridge Skyway Pier Tables:

"…Contract documents require specific items in the …plan. These seven items …within this thermal control plan are as follows:

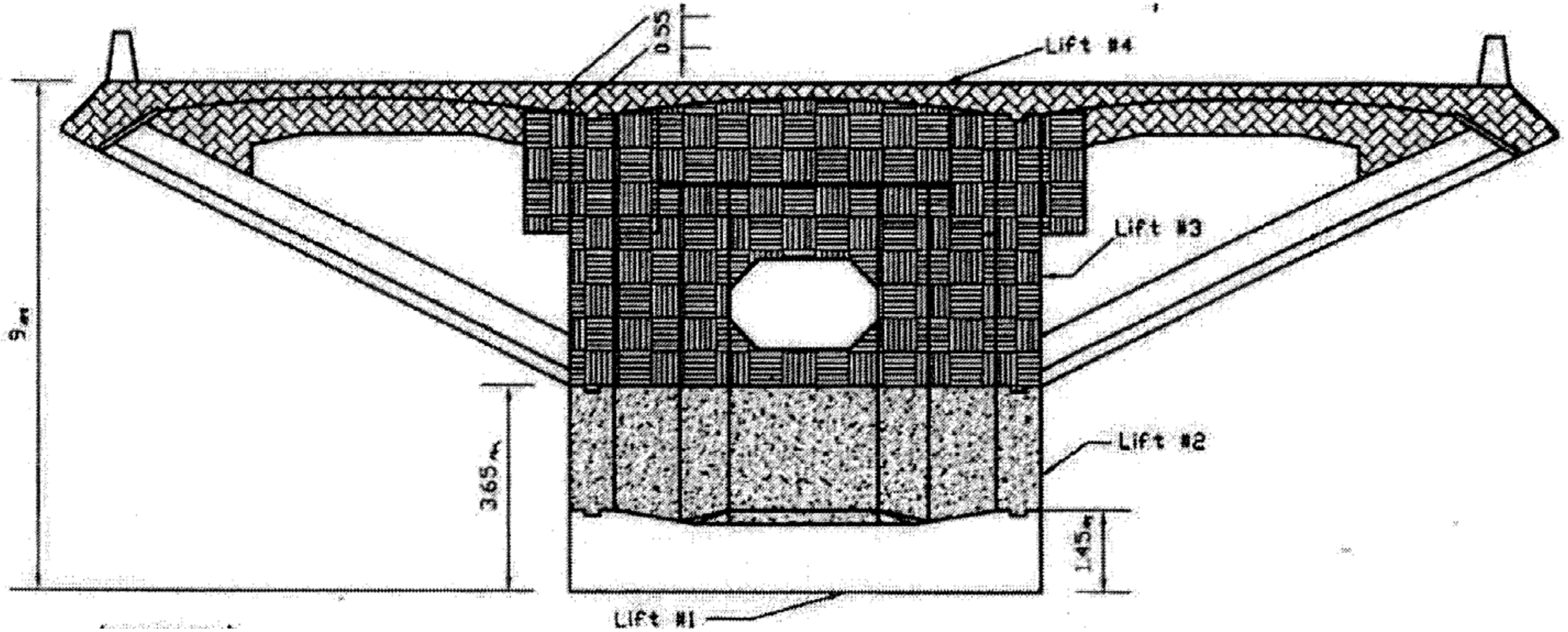
1. ***Length & Method of Curing***
2. ***Procedure to Control …Concrete Temperature***
3. ***…Thermal Modeling, Temperature Sensor Types & Location***
4. ***Data Acquisition***
5. ***…Control of Temperature Differentials***
6. ***… Field Measurements...to Ensure Meeting …Requirements***
7. ***[concrete] Mix Design***

SFOBB Pier Tables High Strength Concrete exceeding 10,000 psi




JUL 8 2003

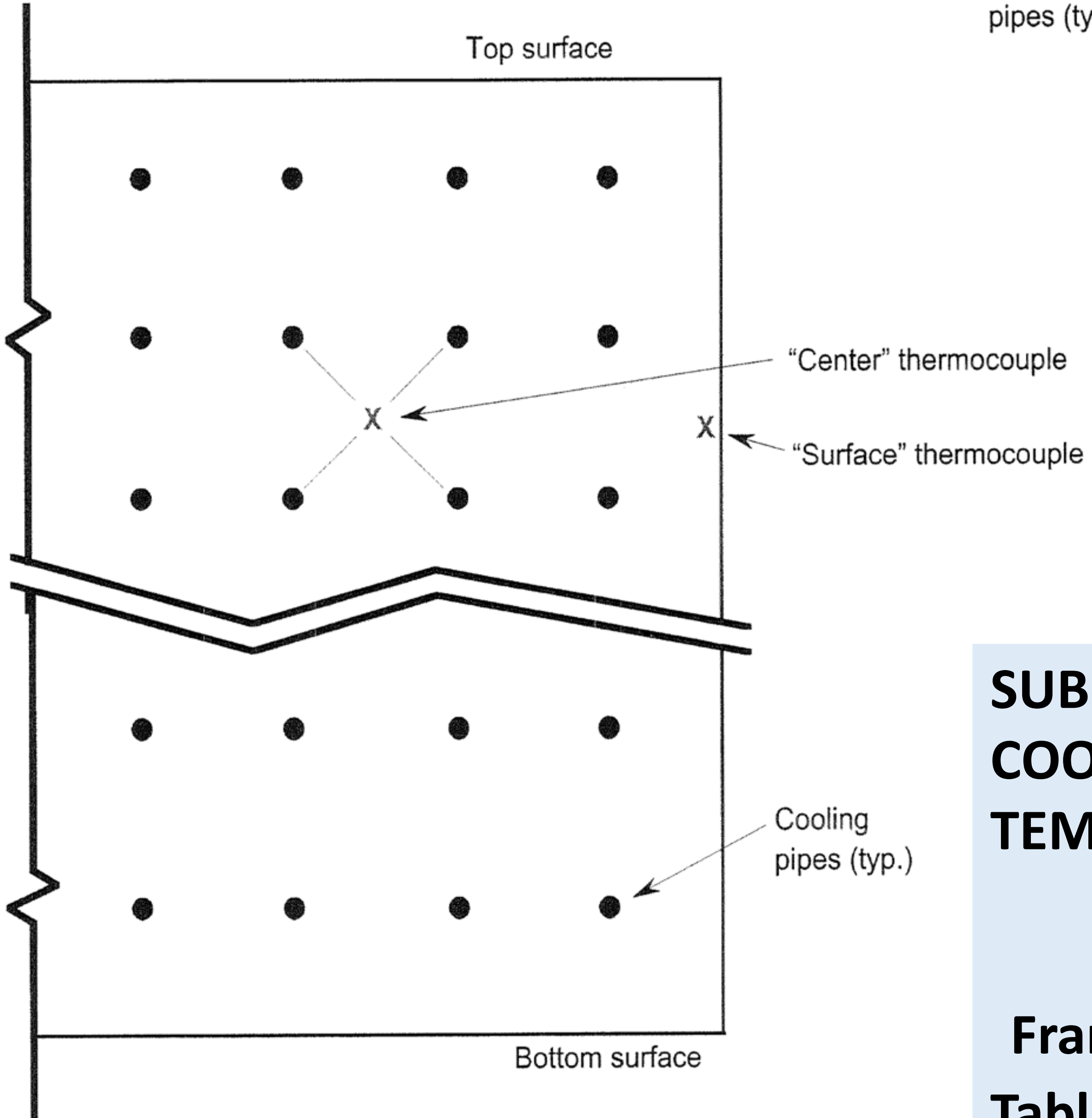
Thermal Control Plan Drawing
Pier Tables 3 thru 16
San Francisco/Oakland Bay Bridge East Span Skyway
January 7, 2004



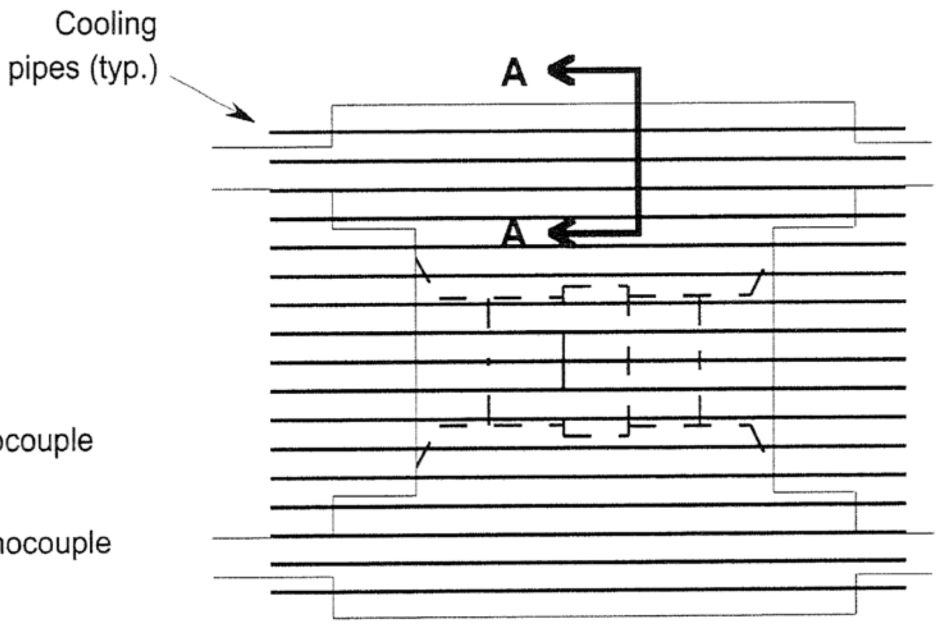
Example of Thermal Results at Various Pipe Spacing Various Insulation Blankets Various Temperature Conditions

Table B - Summary Table* of Placement Restrictions for the Pier Table Diaphragm Lifts (Lifts 2 and 3)

Assumed Temp., °C		Mix No. 8436					
		Pipes at 1000 mm O.C.		Pipes at 750 mm O.C.		Pipes at 500 mm O.C.	
Water and Air	Initial Concrete	R-0.9	R-2.8	R-0.9	R-2.8	R-0.9	R-2.8
3	3	None	None	None	None	None	None
	6	Temp Diff	None	Temp Diff	None	None	None
	9	Temp Diff	None	Temp Diff	None	None	None
	12	Temp Diff	None	Temp Diff	None	Temp Diff	None
	15	Temp Diff	None	Temp Diff	None	Temp Diff	None
	18	Max Temp	Max Temp	Temp Diff	None	Temp Diff	None
	21	Max Temp	Max Temp	Temp Diff	None	Temp Diff	None
	24	Max Temp	Max Temp	Max Temp	Max Temp	Temp Diff	None
	27	Max Temp	Max Temp	Max Temp	Max Temp	Temp Diff	None
	30	Max Temp	Max Temp	Max Temp	Max Temp	Max Temp	Max Temp



Section A-A
Elevation (not to scale)



Plan View (not to scale)

SUBMITTED PLAN SHEET EXAMPLE: COOLING PIPES (HEAT EXCHANGER) & TEMPERATURE SENSOR LOCATIONS

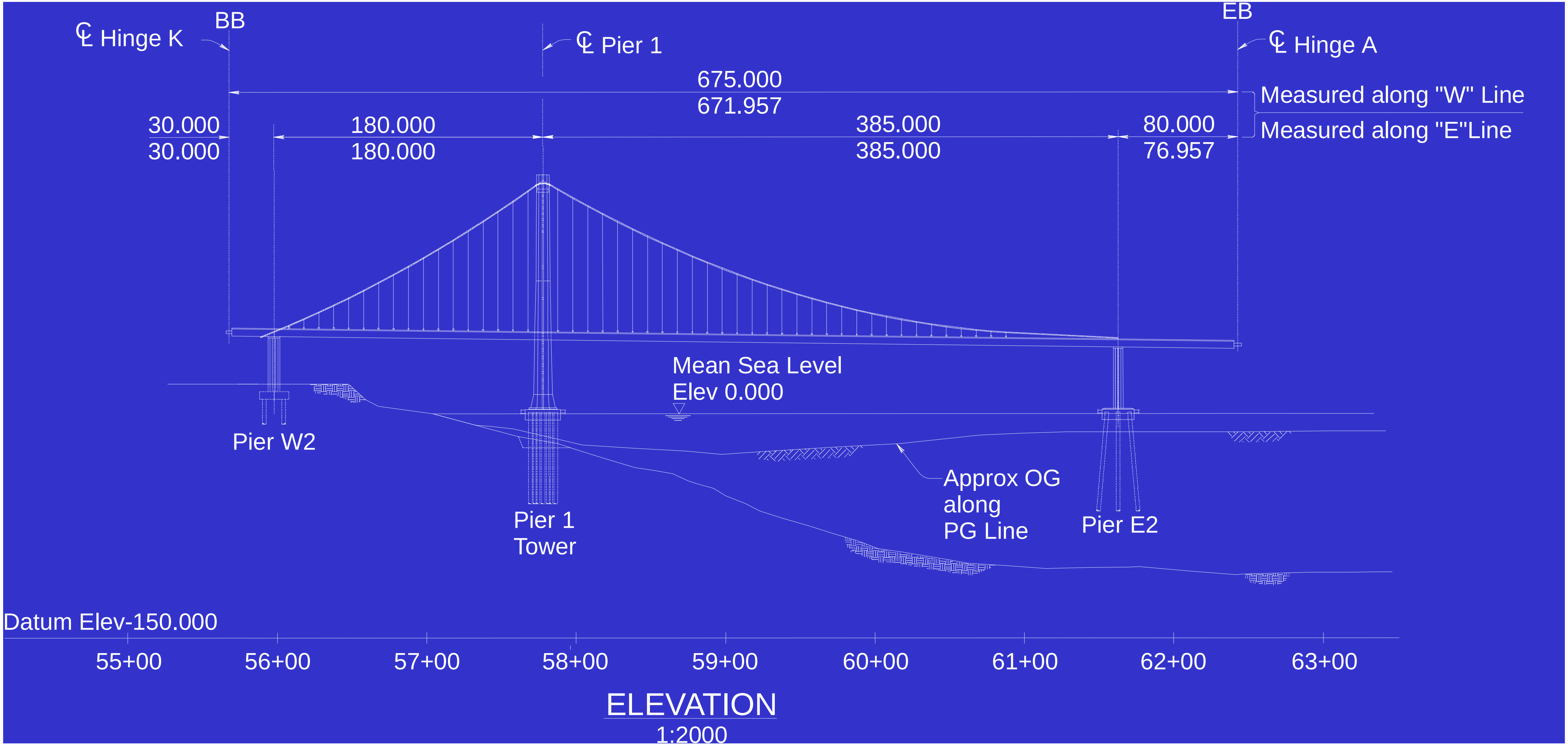
Francisco Oakland Bay Bridge Skyway Pier Table.

(Compressive Strength + 10ksi)

San Francisco-Oakland Bay Bridge.

Self-Anchored Suspension portion under construction

SFOBB SAS Steel Structure has Mass Concrete in Bent Cap Beams and Anchor Block @ W2



Self Anchored Suspension Signature Structure

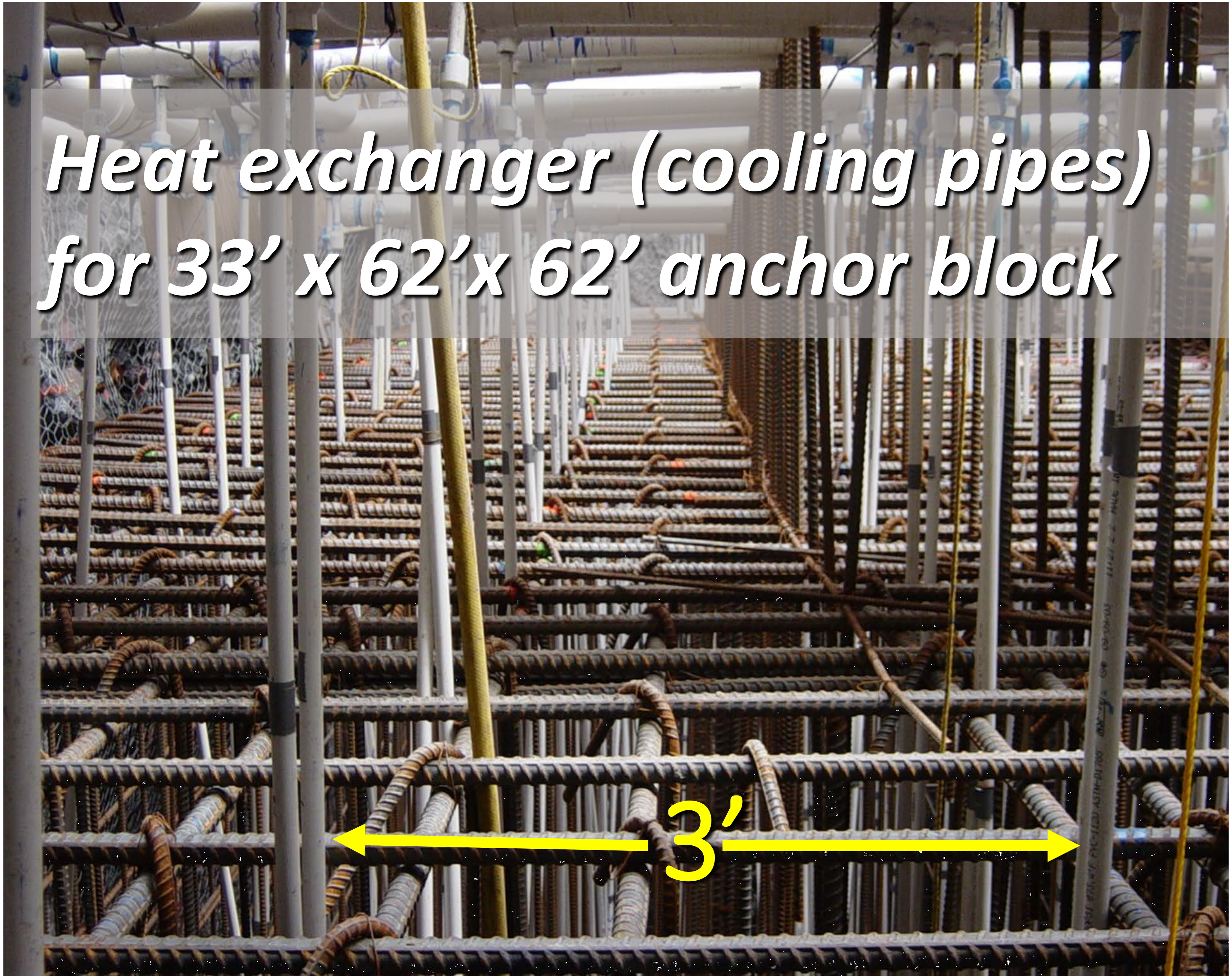
- 62’x62’x33’ Anchor Blocks: 122 F max. peak
- 50 F max. temperature differentials
- F’c 5,076 psi minimum @ 90 D
- 4.4 millionths/F maxCoefficient of Thermal Expansion.

To meet such strict limitations both passive and active thermal control was required.

40% flyash was used in the mix,
< 800 lbs/cy cementitious
Ice and liquid nitrogen to cool concrete prior
Cooling pipe heat exchanger.

Liquid Nitrogen

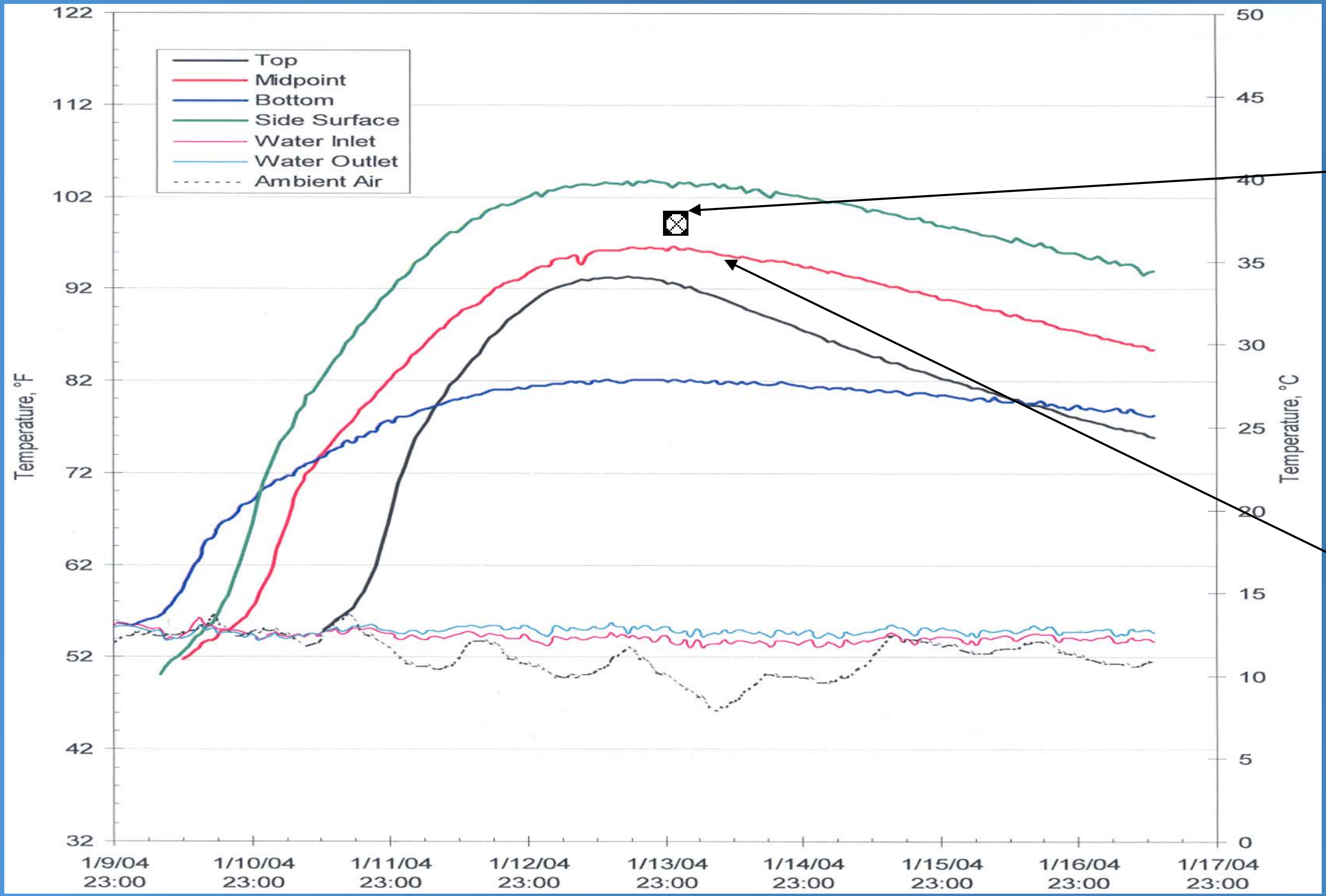
Mix Temperatures in the 40 F range



Two such anchor blocks

One block used Bay water while other used water tank and chiller

Calculated & Actual Footing Temperatures



Predicted maximum temperature of Midpoint = 101°F, at 3.5 days (see Figure 3-6)

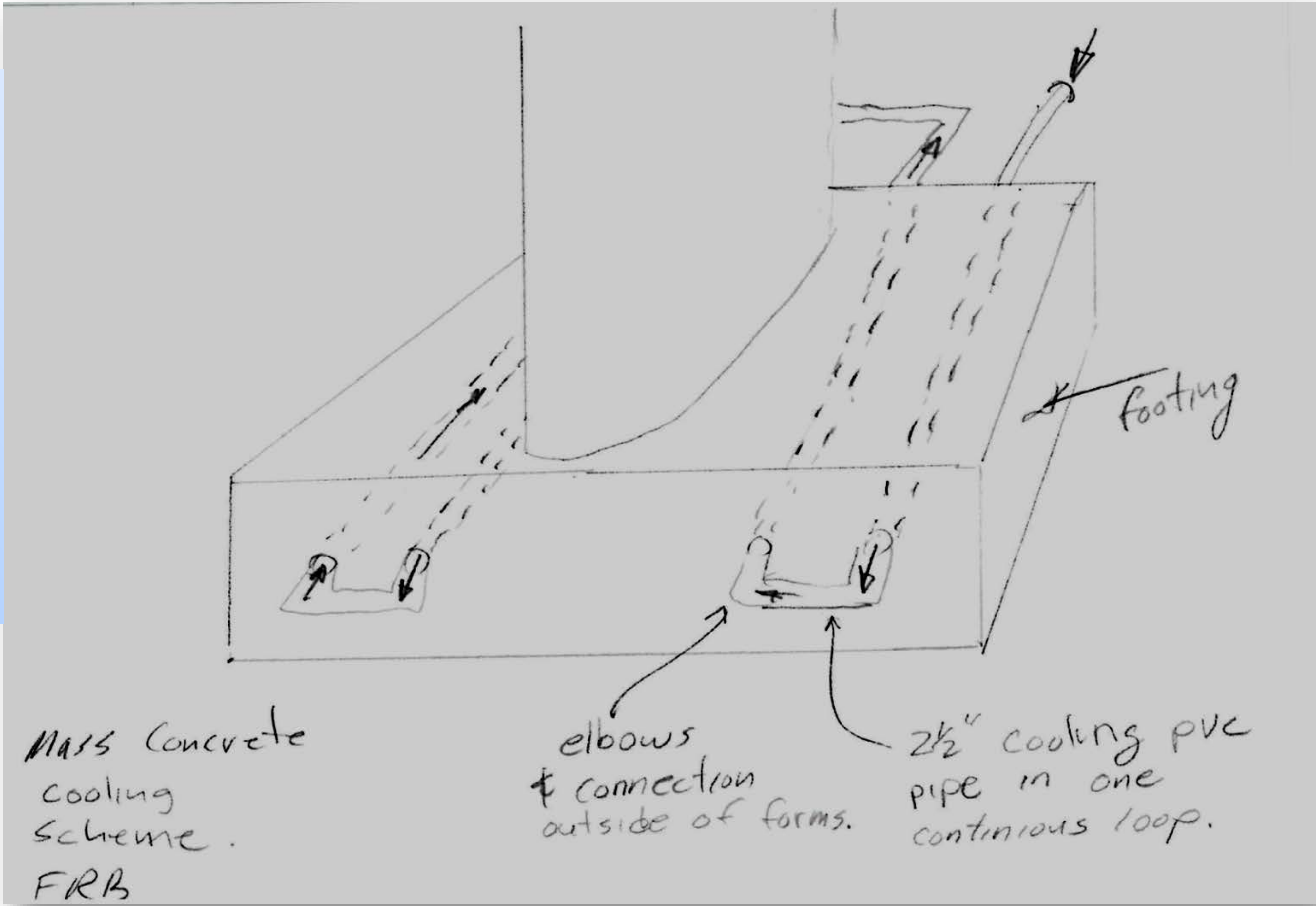
Actual Midpoint temperature of W2E Footing = 97°F, at 3.75 days.

Devil’s Slide BridgeConstruction

2006: Concrete bridge pile caps.

This mass concrete pile cap (or footing) is 48’ long by 40’ wide by 15’ high.

Actual hand-drawn design showing simplicity of cooling pipe layout on an emergency job



Emergency scour job Feather River, Yuba City

Flexible Tubing

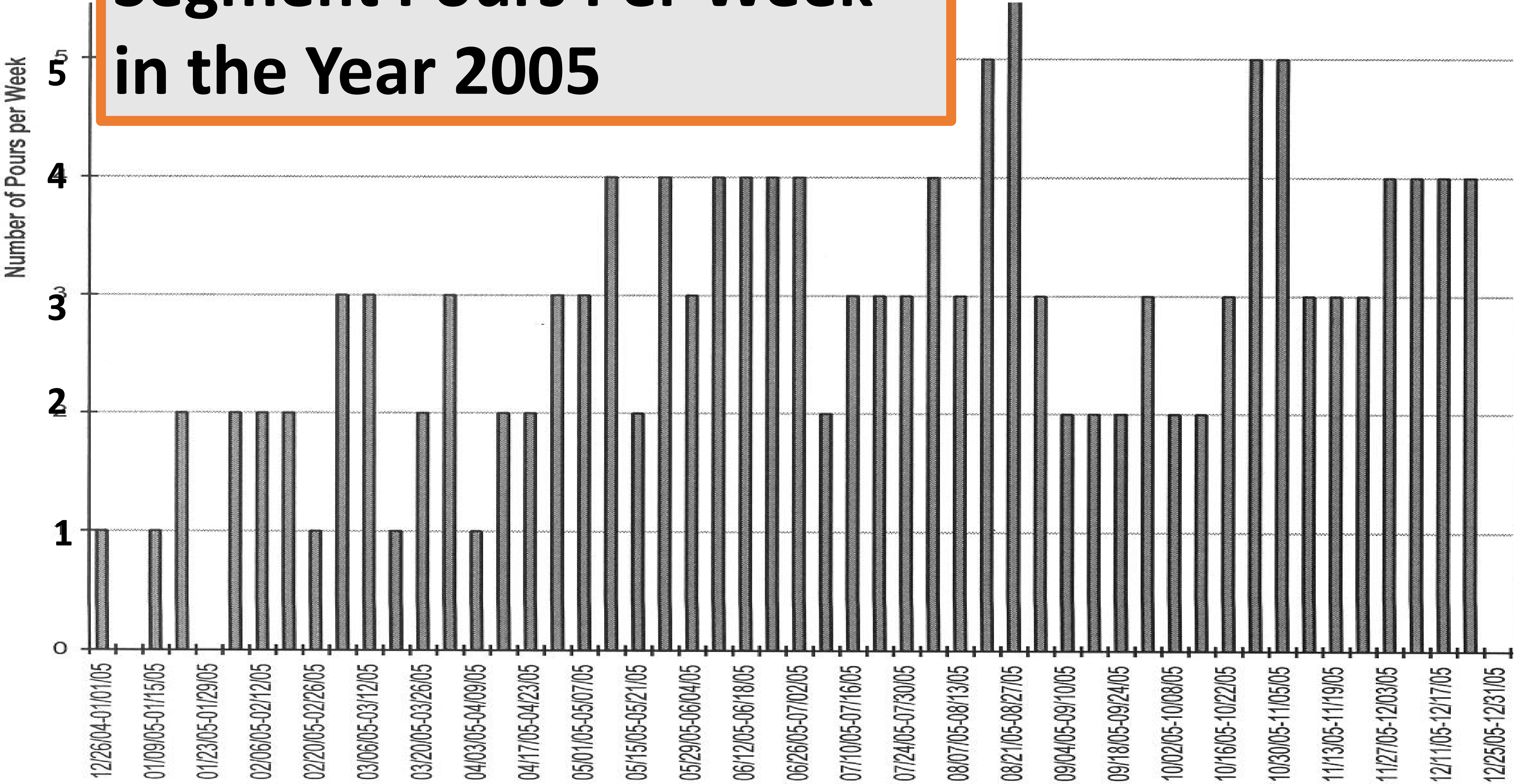
Spanish Creek Arch Bridge

Lightweight high performance concrete for the cast-in-place superstructure segments: *New Benicia-Martinez Bridge & Mass Concrete*

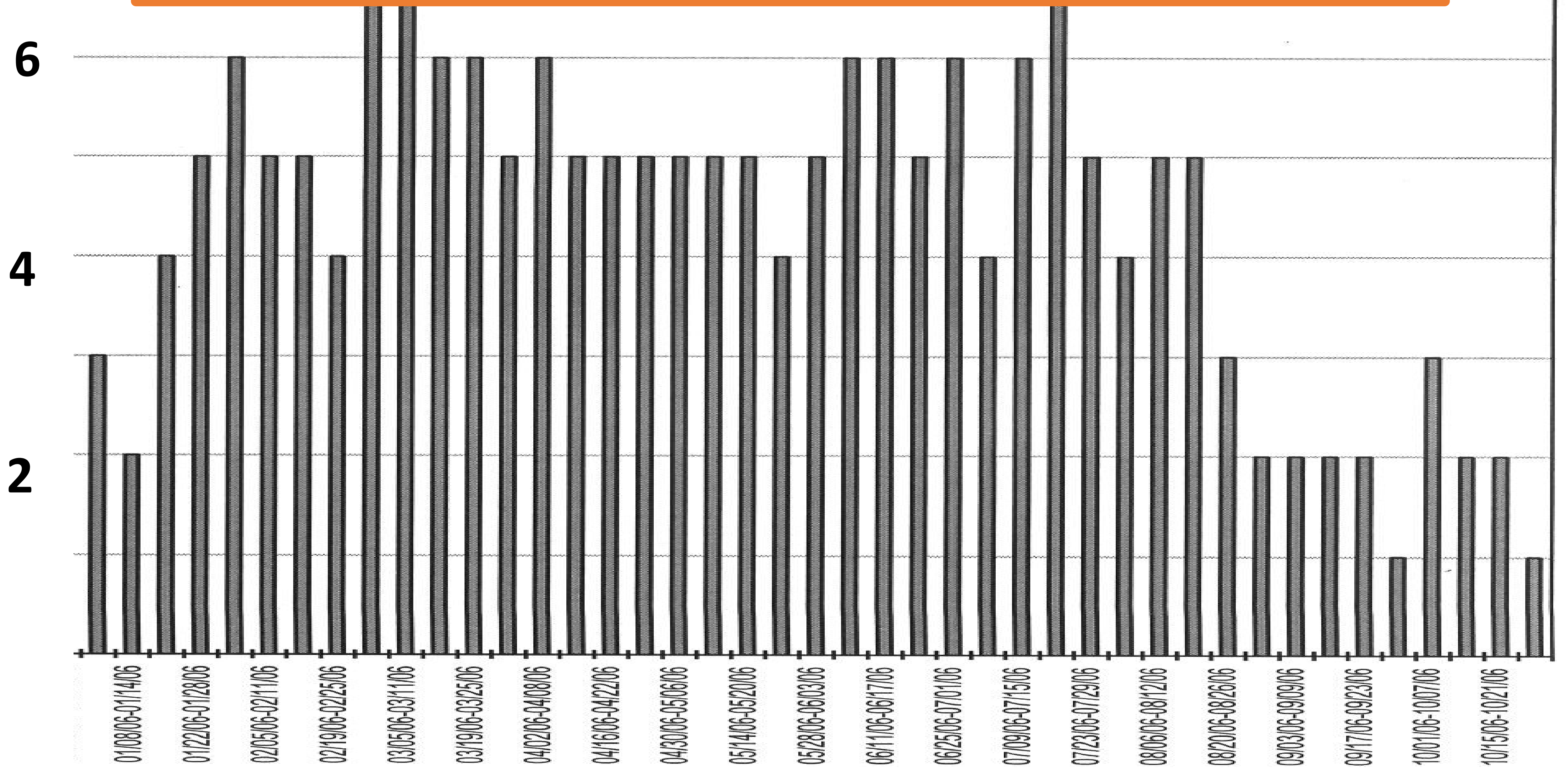
Segmental Construction 663’span across navigational channel

344 Single Box Girder Segments over a 2 year period of time

Segment Pours Per Week in the Year 2005



Segment Pours Per Week in the Year 2006

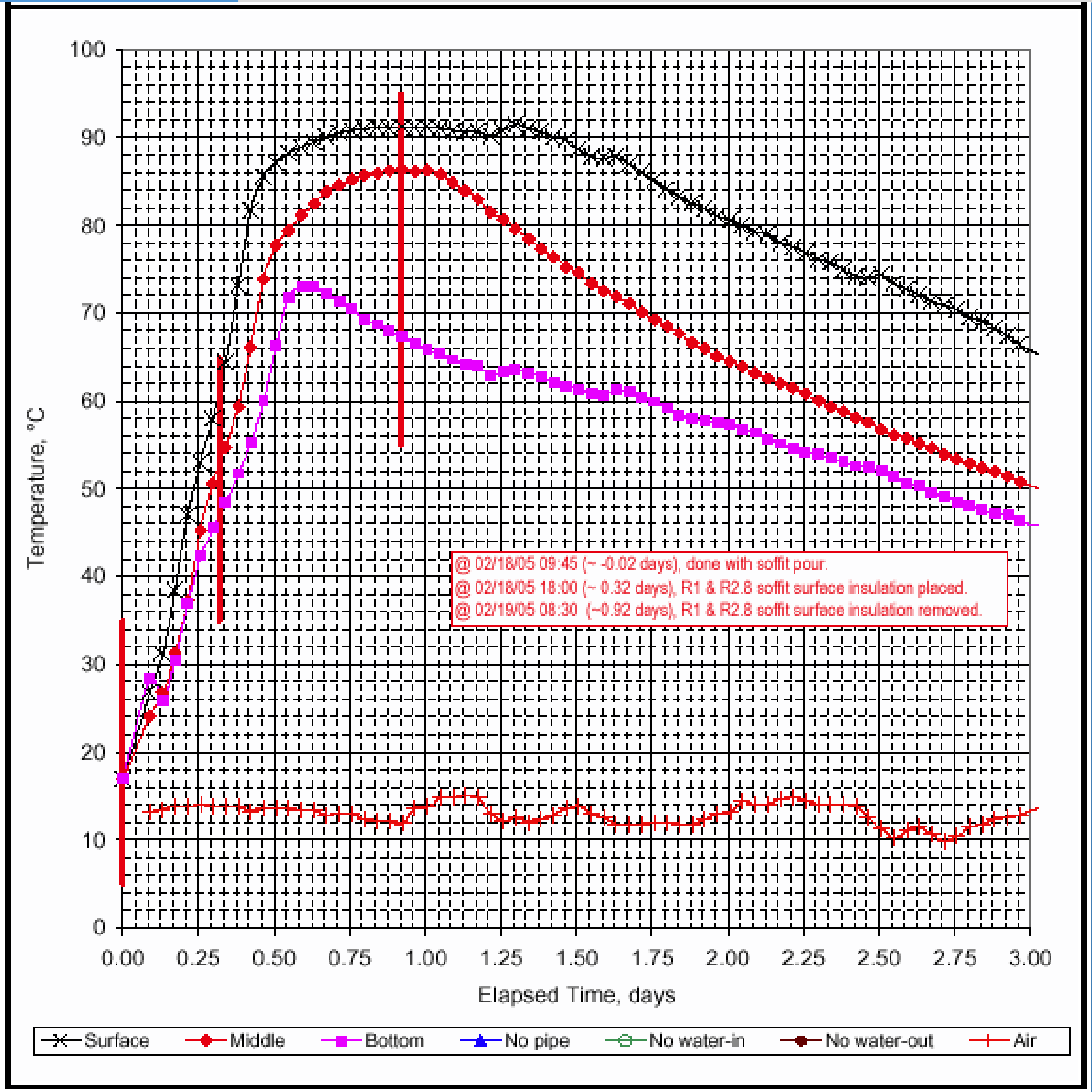


Benicia Bridge

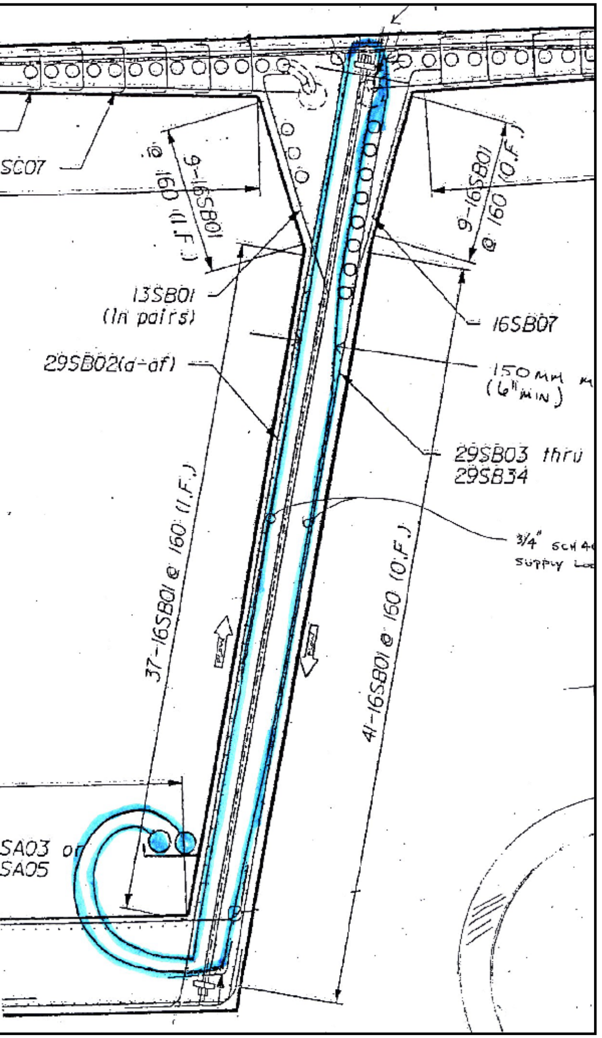
It was anticipated mass concrete issues would apply to segment elements having a minimum dimension no less 3 or 4 ft. Contract applied mass concrete criteria only to first four segments near the pier.

After monitoring the first few segment pours the requirement was revised by Change Order such that any segment with a minimum dimension of 39 inches (1 M) was defined Mass concrete.

Segment 09-03N, poured 02/18/05
Soffit Thermal Data – No Cooling Pipes



- **Maximum Temperature 196 F**
- **This element only 31” minimum thickness**

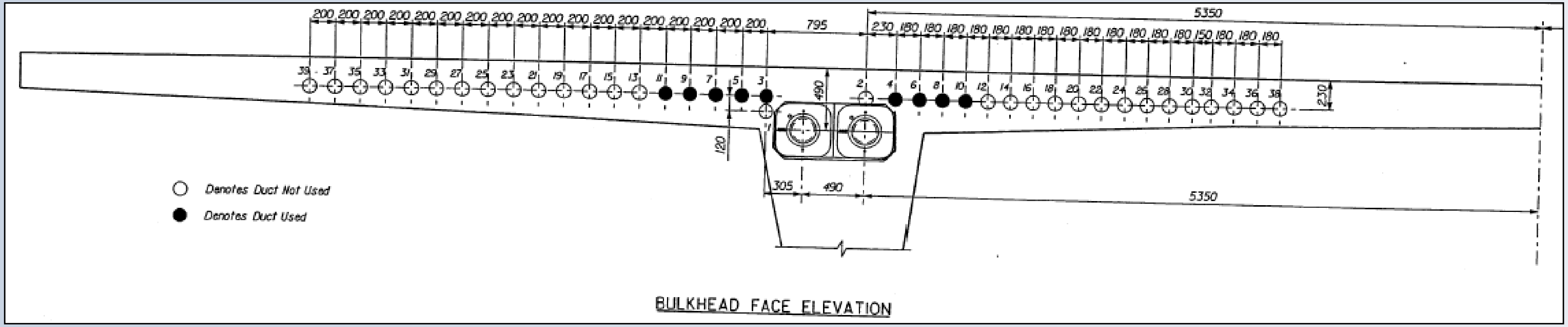


Pipe run vertically in 16’long segment stem wall or web.

Only 22” thick

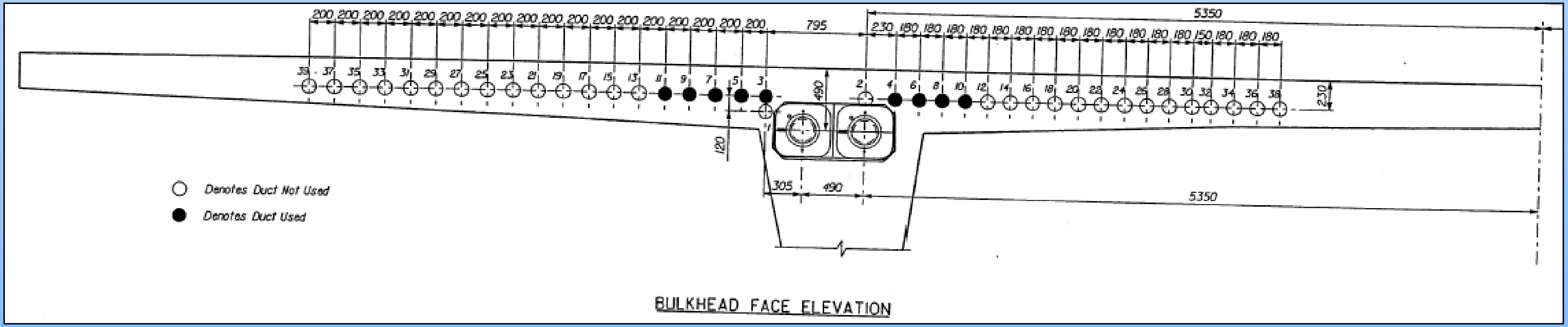
Deck Cooling Pipes

- **In June, 2005 excessive temperatures discovered in thinner deck section. Deck was 19" at the stem, tapering down to 11".** Segments 05-13S & 09-13N, poured 06/28, had deck temperatures reaching 162 °F.
  - **This was without insulation and with concrete chilled with ice and liquid nitrogen.**



Deck Cooling Pipes

- **Deck segments placed earlier did not get as hot due to them being nearer to the stem walls have more pre-stress ducts which dissipated heat.**
  - Segments farther out on the cantilever have fewer pre-stressing ducts



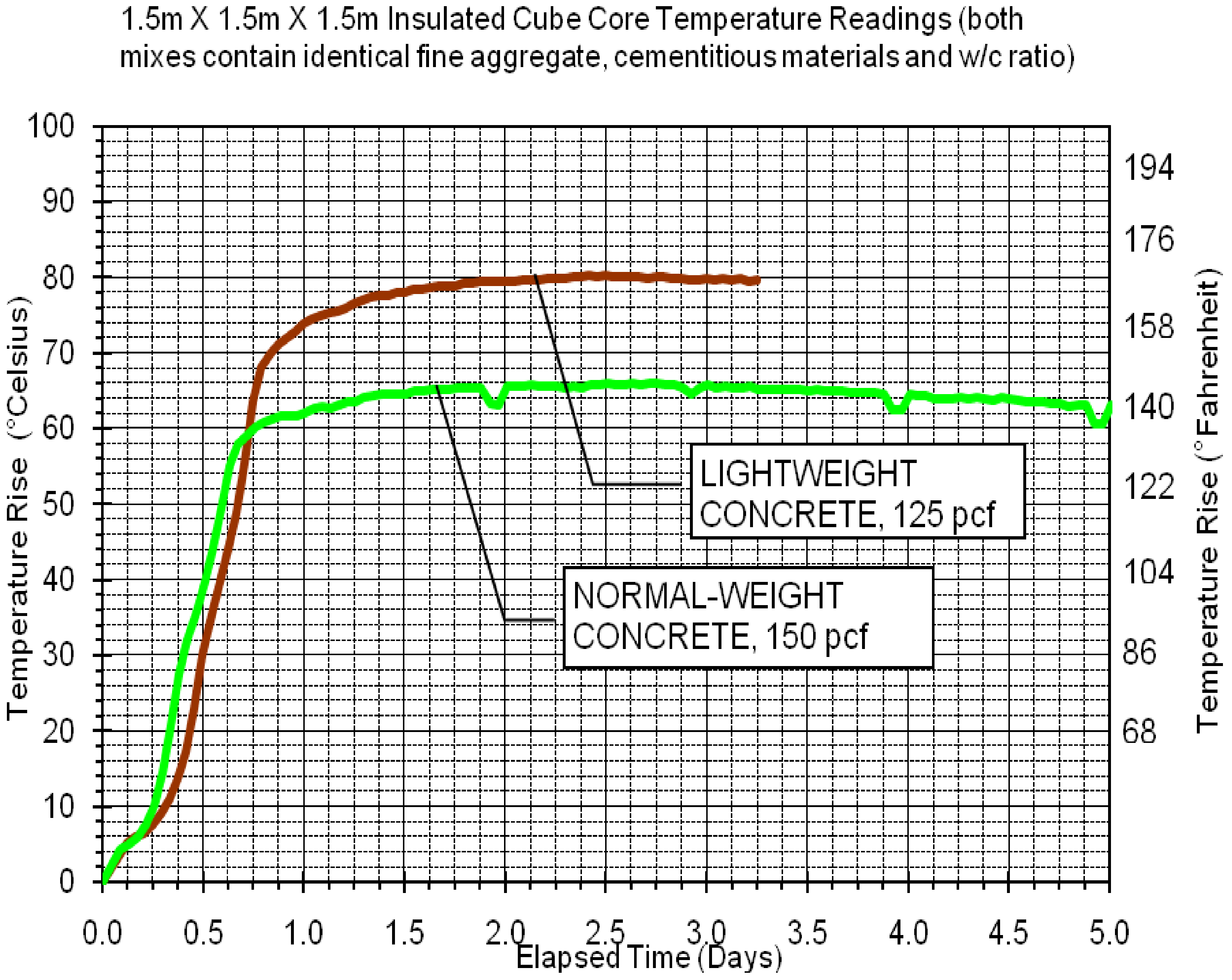
Why on Benicia did the Mass Concrete criteria result in such thin elements?

One reason was a hot mix to create high early strengths to facilitate 344 CIP segments.

Cementitious content was 981 lbs/cy

- 49 lb Flyash
- 98 lb Metakaolin
- 834 lb Portland Cement

Roughly heat rate equivalent 970 lb/cy Portland cement



One meter cubes

Temp. NW = 67 C

Temp. LW = 81 C

Nw = 150lb/cf

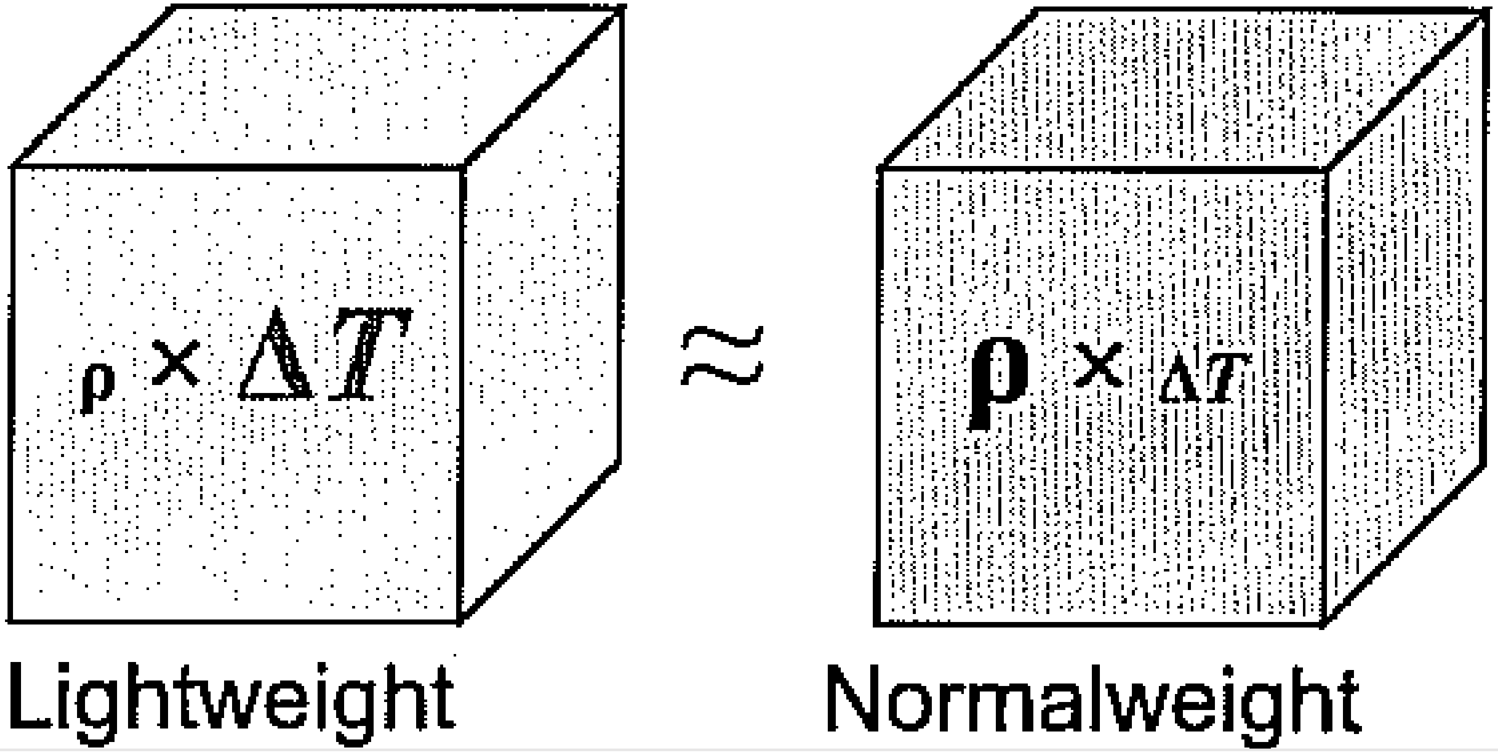
Lw = 125 lb/cf

81/67 = 150/125 = 1.2

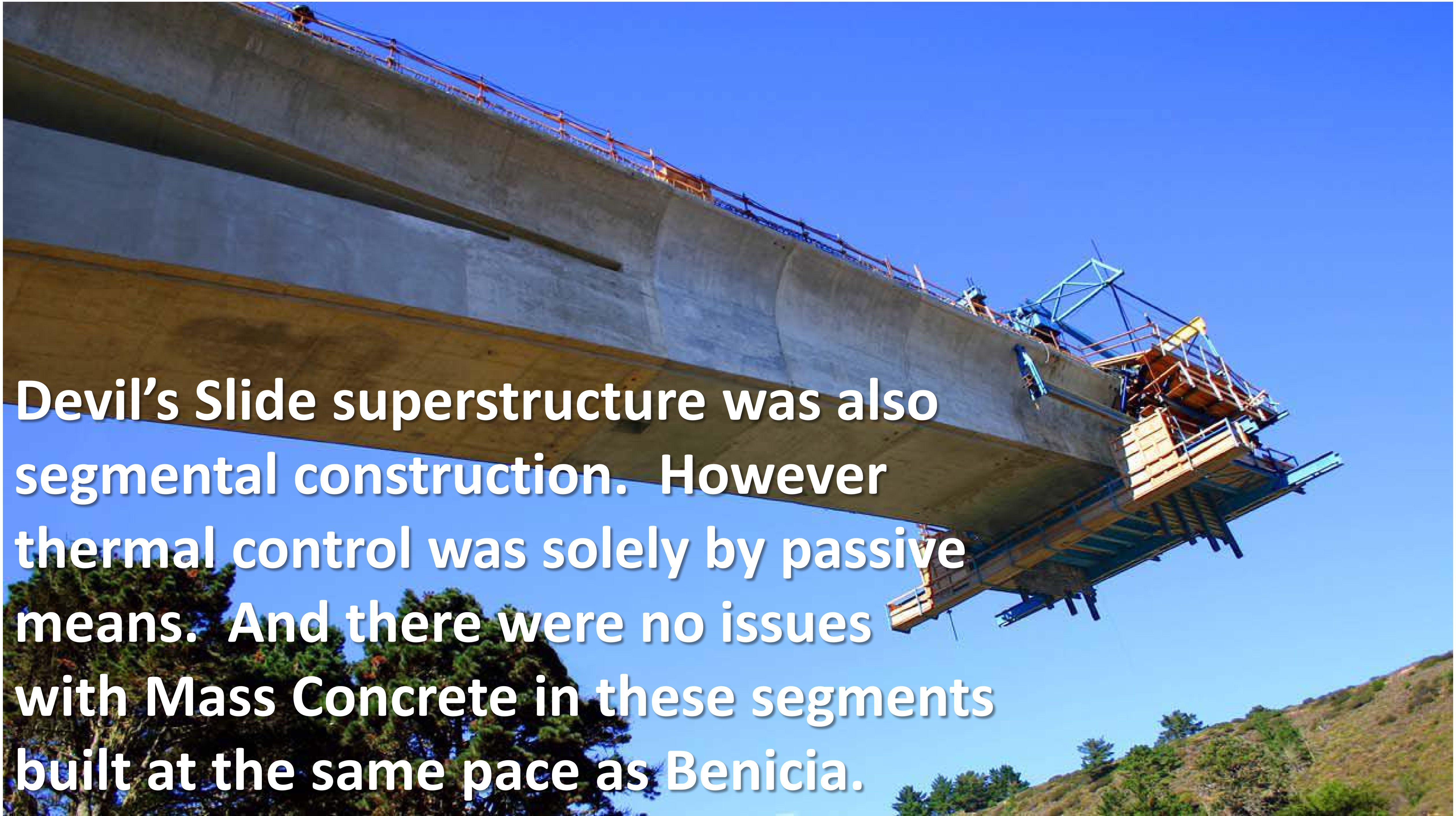
20% increase in peak temperature

125x81
=10050

150x67
=10125



If the specific heat of concrete doesn’t vary with density, the product of temperature increase (ΔT) and density (ρ) will be about the same for equal volumes of lightweight and normalweight concrete containing the same amount and type of cementitious material.


Devil’s Slide superstructure was also segmental construction. However thermal control was solely by passive means. And there were no issues with Mass Concrete in these segments built at the same pace as Benicia.

Caltrans uses both passive and active thermal control. Large cast-in-drilled-hole piles (CIDH), for example, use only passive control by requiring a minimum flyash, maximum placement temperatures, and maximum Portland cement limits.

It is also is becoming more common for large pile caps, columns, pedestals etc. to use High Volume flyash mixes for thermal control.

MCM Construction, Inc
PO Box 620
North Highlands, CA 95660

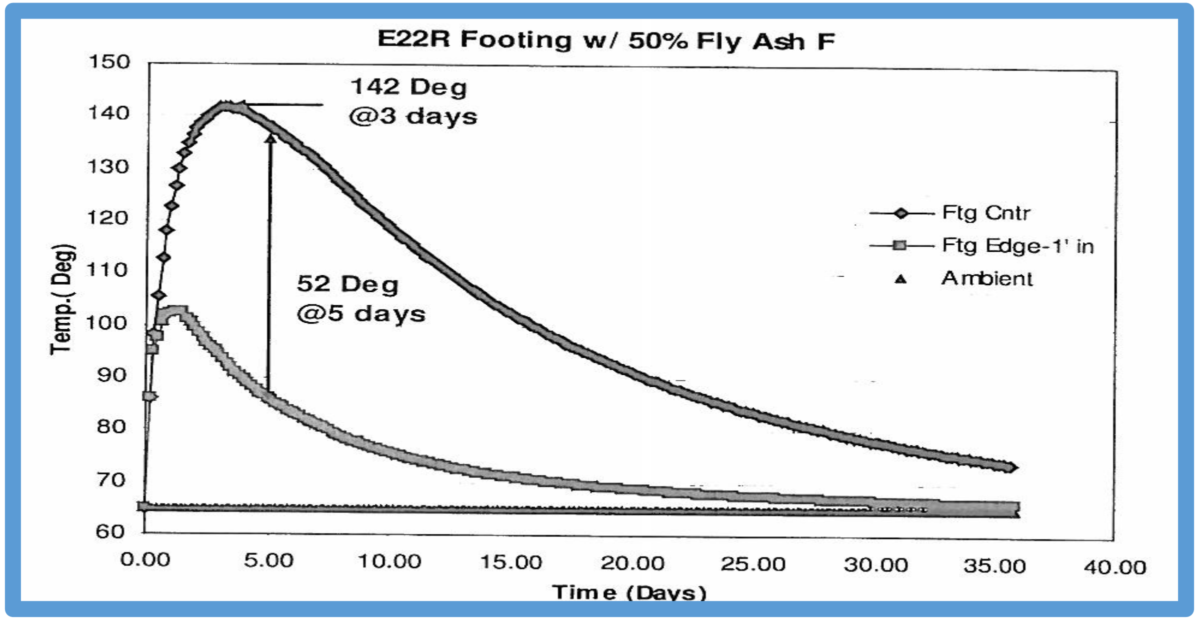
Cal Trans #04-012L04
Oakland Touchdown
Oakland, CA

Mix Design # M409HF30

Below are listed current proportions for the mix as produced from the Central Concrete production facility scheduled to service the project referenced. Note that adjustments to proportions may be necessary to maintain contract performance in the case of delivery from another production location or in the event of material changes necessitated by supply issues

Mix Description : 30 MPA MASS CONCRETE
Design Strength : 30 Mpa @ 56 Days.
W/C Ratio : 0.40
Slump : 6.00 in +/-1.00
Usage : Bridge Footings, Pier 20-22.

	MATERIAL	SSD	VOLUME
CEMENT :	ASTM C-150, Type II/V	337	1.71
FLYASH :	ASTM C-618, Class F	337	2.35
SAND :	SAND ASTM C-33	1280	7.68
AGGREGATE :	ASTM C33 #67	1185	7.08
AGGREGATE :	ASTM C33 #7	585	3.48
AIR :	1.50 %		0.41
WATER :	ASTM C1602-04,C1603-04	267	4.28
ADMIXTURE :		3991	27.00



Letters to Editor, *Concrete International* May, 2008 Vol. 30 #5

…designs, and current demand by the community at large to build at some expected pace are factors that play into the approach to solve a particular problem at hand at any particular time. Design strengths are going up and construction schedules have accelerated to where strength gain is sometimes measured in hours to keep a construction process on pace. When under such constraints where mass concrete is at issue, I believe active measures, particularly cooling pipes, have shown to be not only effective, but almost indispensable.

Questions
?????????

Questions
?????????

Virginia's Mass Concrete Experiences

Celik Ozyildirim, Ph.D., P.E.
Virginia Transportation Research Council
Virginia Department of Transportation

TRB Webinar, 2018

Outline

- Mass Concrete
- VDOT Specifications
- Testing for strength
- Field Applications
  - Bridge on I-895 over James River
  - Route 33 Bridges at West Point
  - Bridge at Chincoteague
- End result specifications

Mass Concrete

- Any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking.

Ref: ACI 116R-00: Cement and Concrete Terminology
207.1R-05: Guide to Mass Concrete (Reapproved 2012)

Mass Concrete

- Any volume of concrete in which a combination of dimensions of the member being cast, the boundary conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat from hydration.

ACI CT-13: ACI Concrete Terminology

Mass Concrete

- Any volume of structural concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat from hydration.

ACI CT-18: ACI Concrete Terminology

Thermal Change

- Dimensions
- Mixture design: cement type, SCM, coefficient of thermal expansion
- Mixture proportions
- Initial mixture temperature
- Ambient conditions, insulation

- Pre and post cooling

Cracking

- Thermal change
- Tensile strength
- Elastic modulus
- Creep

- Reinforcement

Problem
Temperature Differential

- Heat is generated during hydration
- Temperature differences occur
- Cause thermal stresses due to restraint
- Cracks occur when stresses exceed the strength of the concrete
- Cracks adversely affect durability and structural integrity

Thermal Cracks

Problem
High Temperature

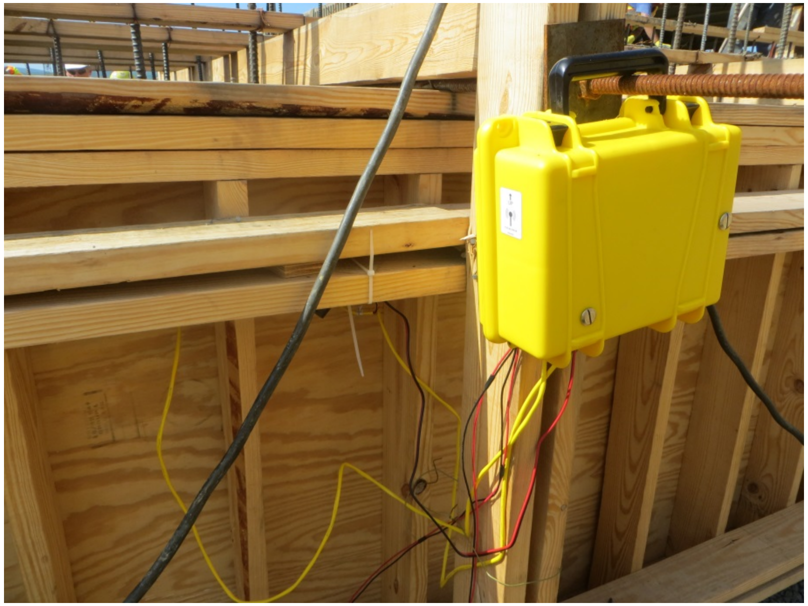
- At later ages delayed ettringite formation (DEF) occurs when initial temperature exceeds 70 ºC (158 ºF). Can be mitigated with pozzolans.

- High early temperatures can reduce expected ultimate compressive strength

VDOT Mass Concrete

- Minimum dimension 5 ft
- Maximum temp 160 ºF (if slag concrete 170 ºF)
- Maximum temp difference 35 ºF
- Class F fly ash 25 to 40 %
- Slag 50 to 75%
- Maximum initial concrete temperature 95 ºF
- Thermocouples placed to measure the thermal gradient between the core and the surface

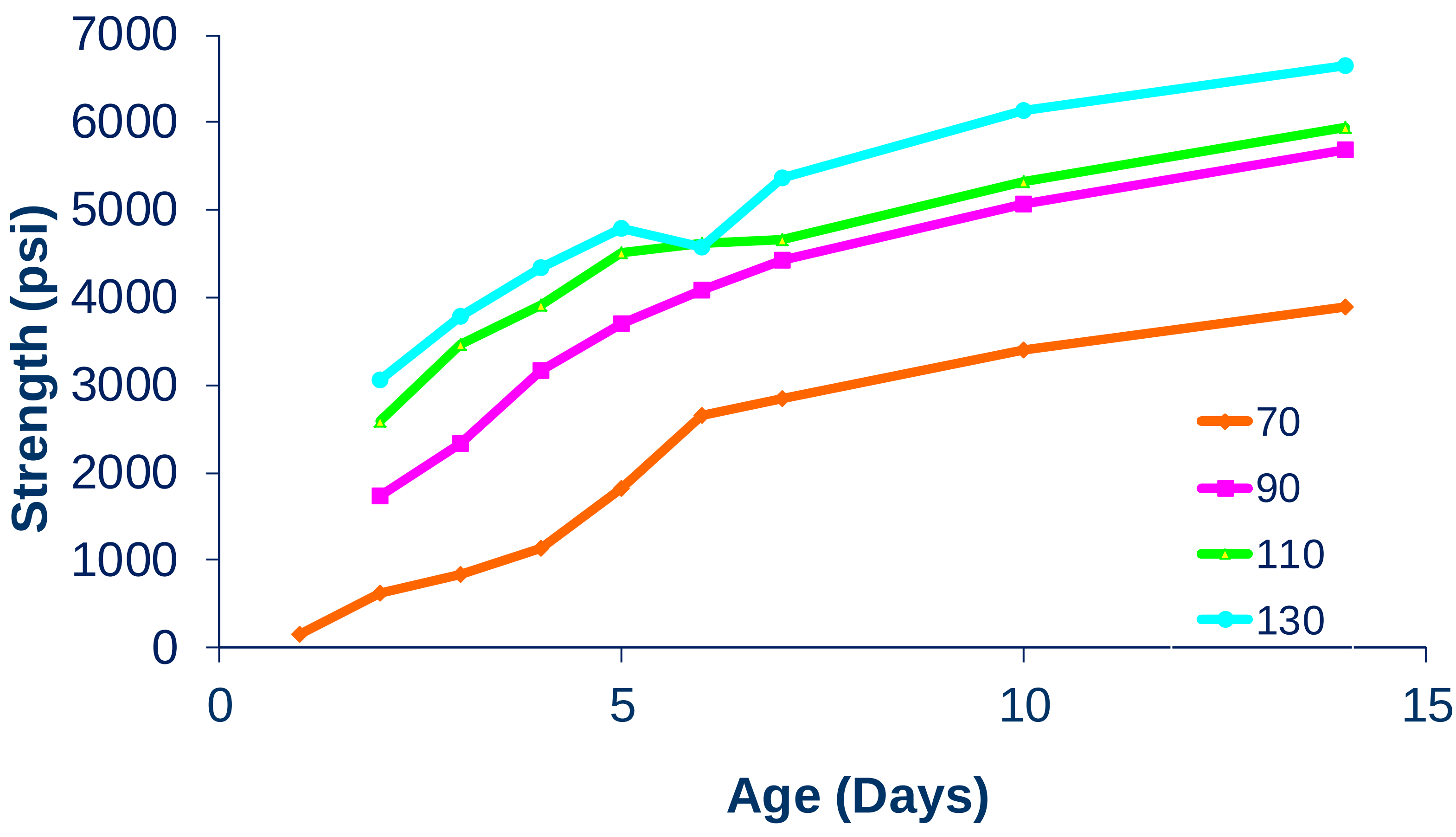
Monitoring Temperature



Strength Measurement

- Maturity:
  - –Maturity index, time-temperature factor
  - –Arrhenius equation, equivalent age
- Temperature-matched curing

Compressive Strength and Temperature



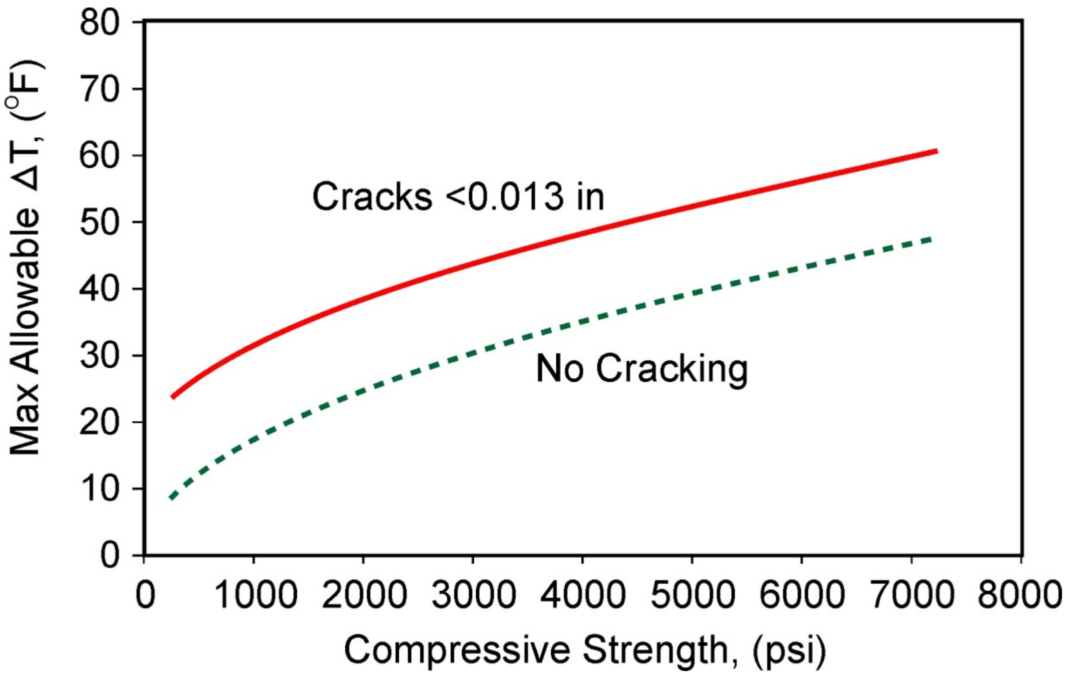
Mass Concrete

I-895 over the James River

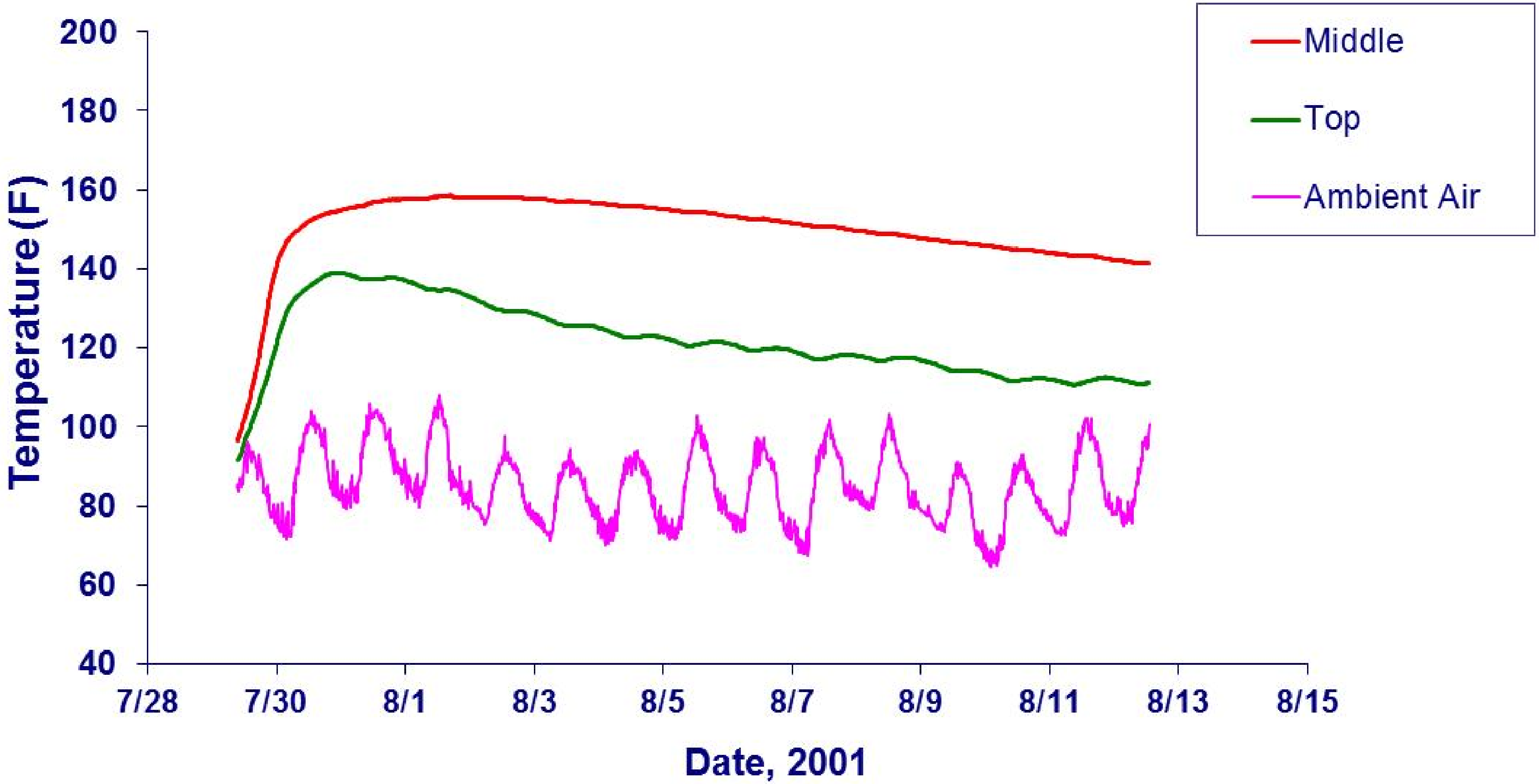
Large footings (35 x 40 x 10 ft)

I-895 Footing

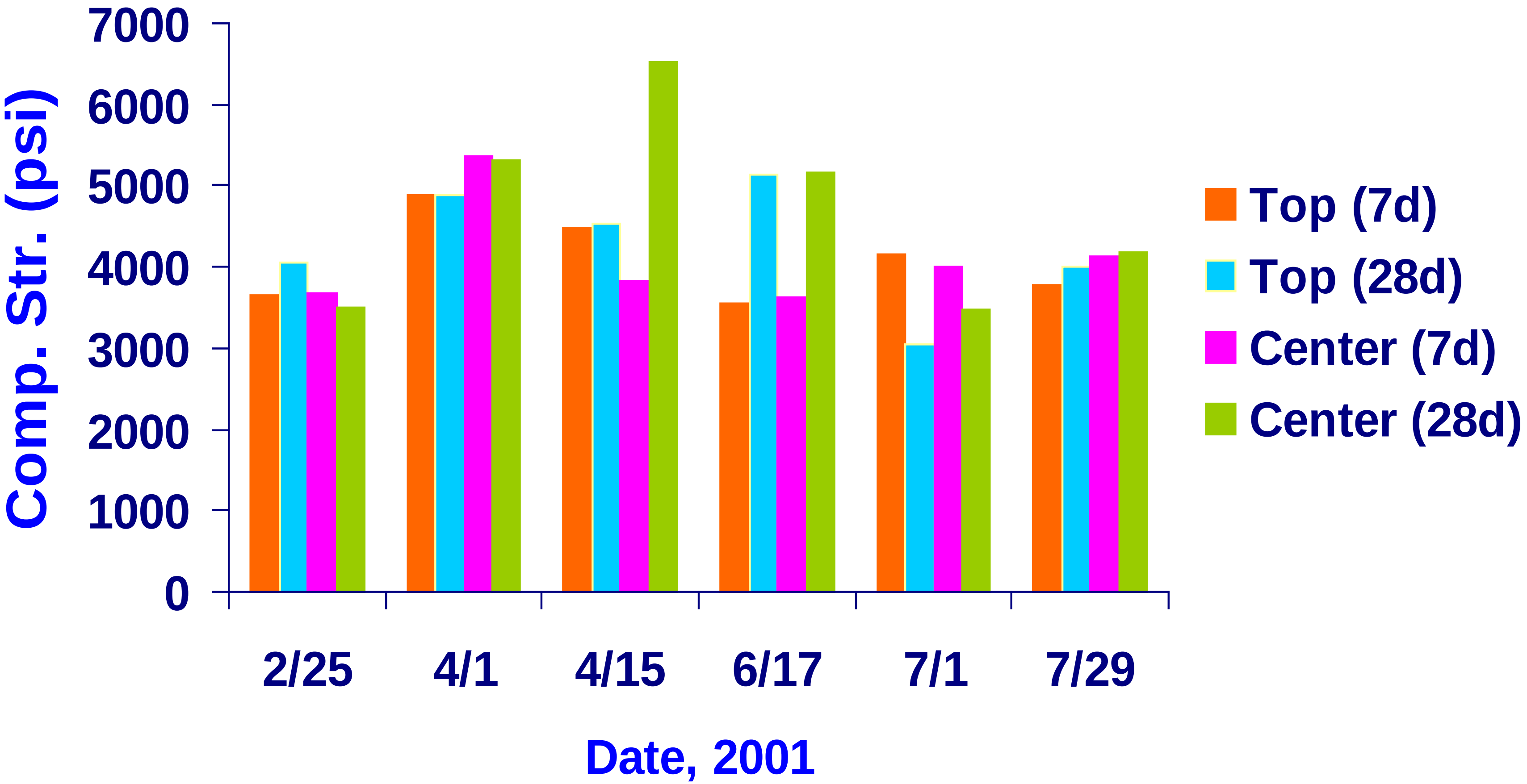
- pc=142 lb/yd^3
- Slag cement =423 lb/yd^3
- 75% slag cement
- Max w/cm = 0.49
- Permeability: 561 and 840 coulombs



Temperature Data



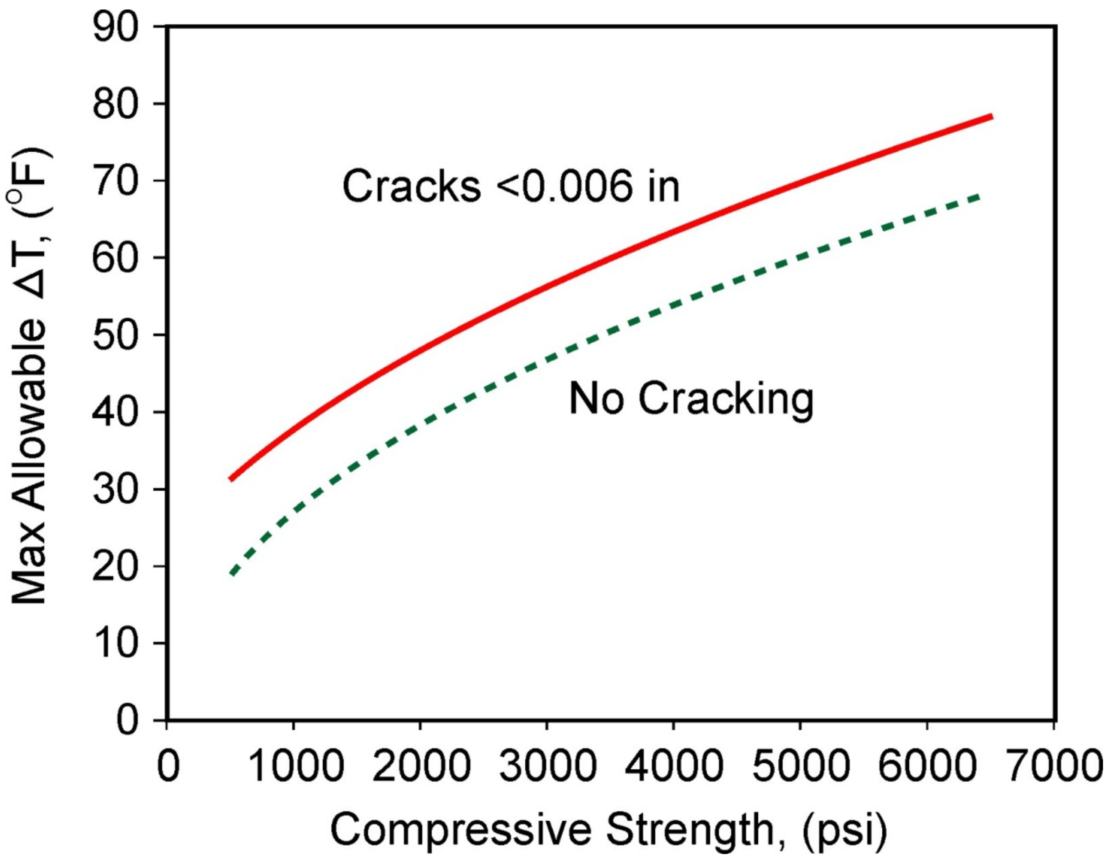
I-895 Compressive Strength (psi)



Route 33 Bridges

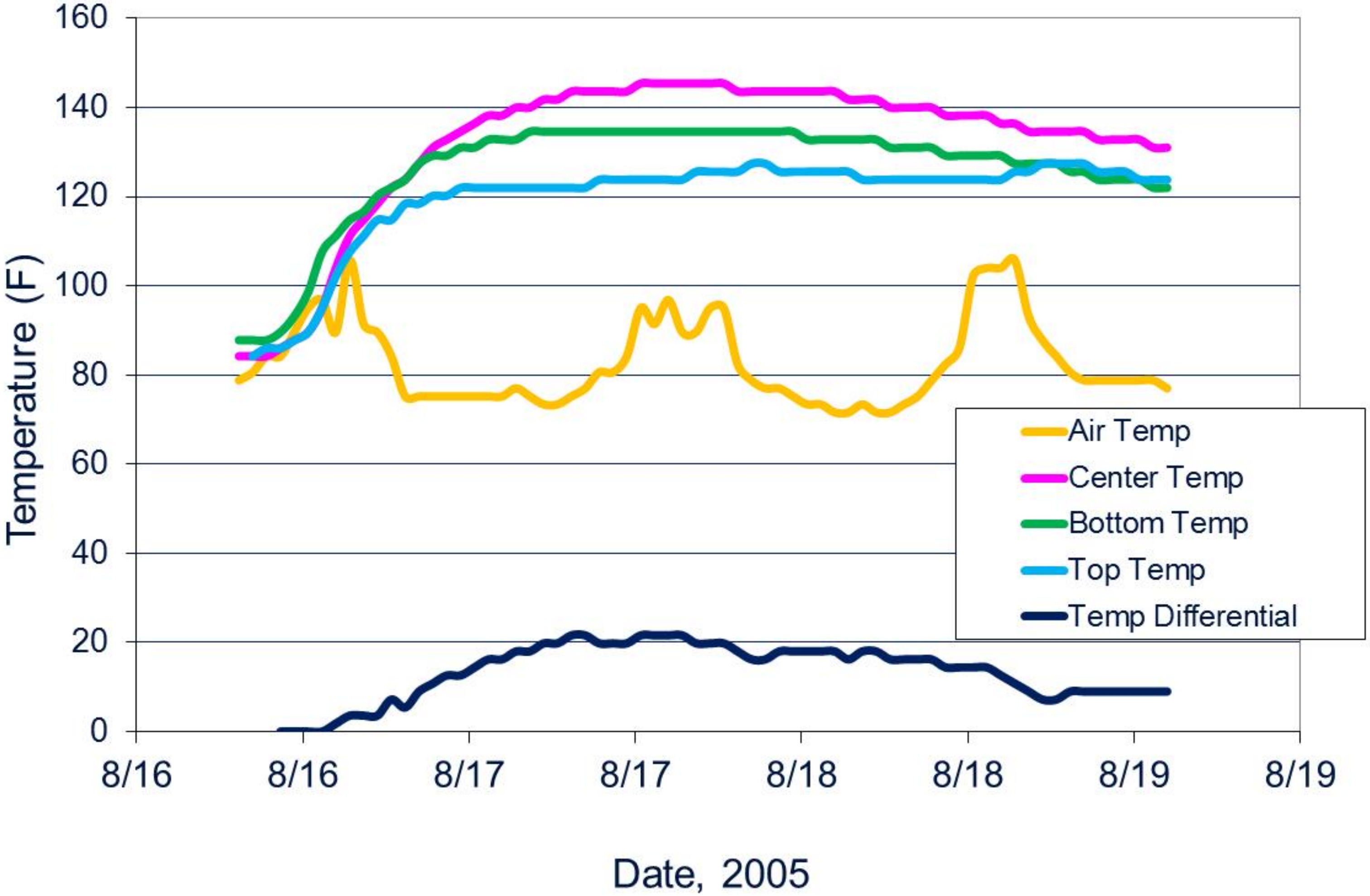
Route 33 Pier Caps

- PC = 353 lb/yd^3
- Class F fly ash
  = 235 lb/yd^3
- 40% fly ash
- Max w/cm = 0.46
- A3: 3000 psi



- caps 6x6 and 6X6.5 ft

Pamunkey Bridge, Pier Cap 47



Route 33:Strength and Permeability
Footing, Pier Cap

Values	Strength (psi)		Permeability (coul.)	
	Mattaponi	Pamunkey	Mattaponi	Pamunkey
Average	3730	3960	449	369
Std Dev	467	495	264	144
Number	132	202	132	199

Chincoteague Bridge Bascule Footing

- 83.5 x 51 x 7 ft, 110 tons of steel, A3 Concrete

Thermal Control Plan

Chincoteague Bridge Bascule Footing

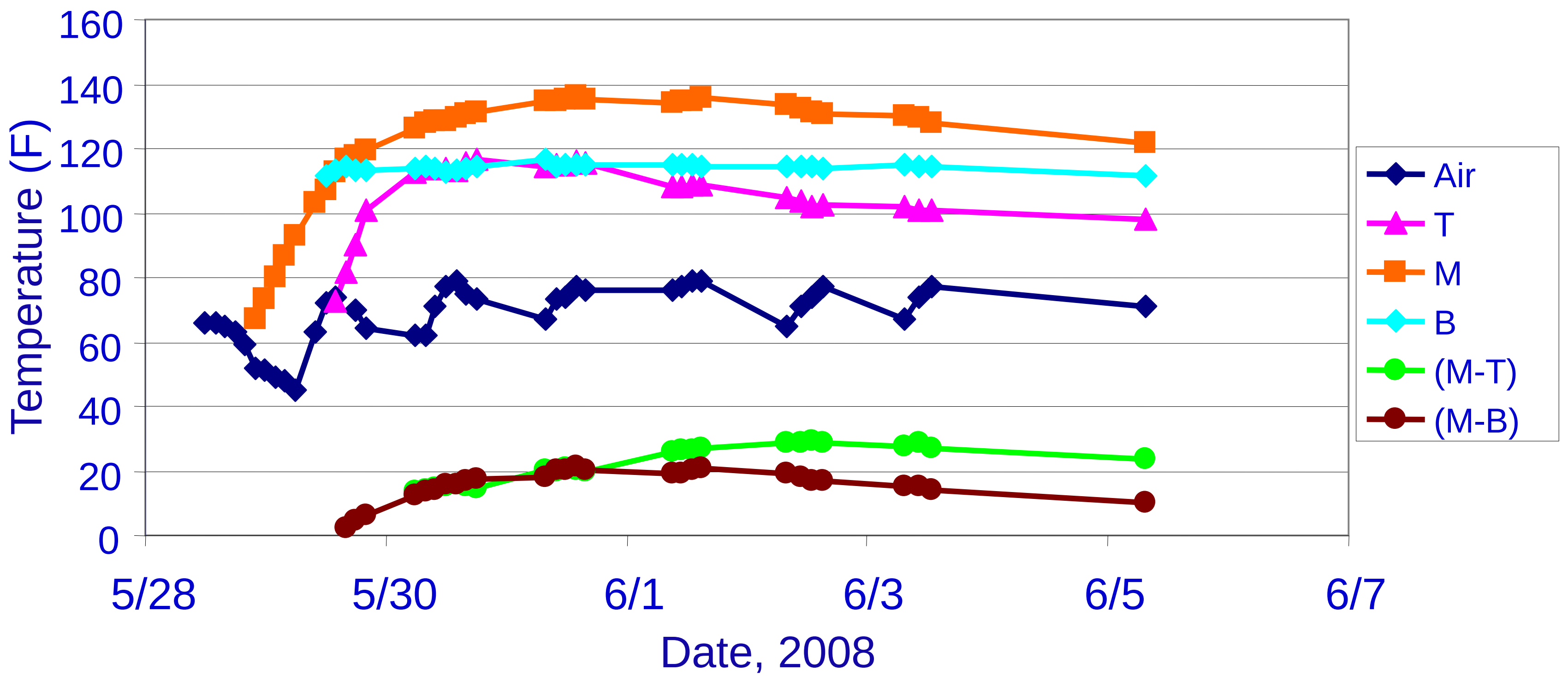
- Low-heat concrete mixture using 539 lb/yd^3 cementitious material with 30% fly ash. Regular A3 has a minimum cementitious content of 588 lb/yd^3.
- Heavy reinforcement to control cracking
- Insulation
- Time of placement; late May before the hot weather
- VTRC/VDOT monitored the temperature

Mixture Proportions, Strength and Permeability

<u>Bascule Footing</u>

- pc=378 lb/yd^3
- Class F fly ash=161 lb/yd^3
- Max w/cm=0.46
- Samples n=13, str.= avg of 3; perm= 1
- Strength: avg = 5,114 psi; stdev=420 psi
- Perm: avg = 373 coulombs; stdev = 79 coulombs

Chincoteague Footing



End Result Specifications

- ERS approach
- Contractor/producer designs the mixture and
- Provides information on trial batching or historic data accompanied by thermal control plan to show that the mixture can produce satisfactory strengths and control cracking (no or limited cracking) for the given structure in a given environment.

New VDOT Mass Concrete (ongoing)!

- Mass concrete: minimum dimension
- Limits on portland cement
- Limits on fly ash and slag cement contents
- Maximum initial concrete temperature
- Maximum temp and temp difference
- Maximum w/cm is 0.45.

Conclusion

- Mass concrete is prone to cracking.
  - Temperature monitoring is needed.
- Prescriptive specs
  - Initial, maximum, and differential concrete temperature.
  - Limits on cement and SCM, and w/cm.
- ERS approach is preferred.
  - Contractor designs and assumes responsibility for the end product.

Thank You.

Celik Ozyildirim, Ph.D., P.E.
Celik@vdot.virginia.gov

Today’s Speakers

- Anton Schindler, *Auburn University,* antons@eng.auburn.edu
- John Gajda, *MJ2 Consulting,* John@MJ2consulting.com
- Kevin Folliard, *University of Texas at Austin,* folliard@mail.utexas.edu
- Ric Maggenti, *Caltrans,* ric.maggenti@dot.ca.gov
- Celik Ozyildirim, *Virginia Transportation Research Council*, Celik@VDOT.Virginia.gov

Get Involved with TRB

- Getting involved is free!
- Join a Standing Committee (http://bit.ly/2jYRrF6)
- Become a Friend of a Committee (http://bit.ly/TRBcommittees)
  - Networking opportunities
  - May provide a path to become a Standing Committee member
- ***Sponsoring Committee: AFN10*** ***(with AFF30, AFN20, AFN30, & AFN40)***
- For more information: www.mytrb.org
  - Create your account
  - Update your profile

Receiving PDH credits

- Must register as an individual to receive credits (no group credits)
- Credits will be reported two to three business days after the webinar
- You will be able to retrieve your certificate from RCEP within one week of the webinar

TRB turns 100 on November 11, 2020

100 YEARS
2020
TRB

Help TRB:

- Promote the value of transportation research;
- Recognize, honor, and celebrate the TRB community; and
- Highlight 100 years of accomplishments.

Learn more at

www.TRB.org/Centennial

MOVING IDEAS: ADVANCING SOCIETY—100 YEARS OF TRANSPORTATION RESEARCH