CRACK CONTROL IN CONCRETE POTABLE WATER TANKS

May 06, 2016

AGENDA

- Why does it matter?
- What is the issue?
- The chemistry of Concrete
- Are there solutions?
- Lessons learned

Why Does Water Tightness Matter?

- Loss (leakage) of treated storage is a loss of $’s
- Permit violations – release of chlorinated water into public waterways
- What are reasonable tightness criteria for work on new or rehabilitated tanks
- Cracks in concrete can lead to corrosion of the embedded reinforcing

What is the Issue?

- The goal is a water tight storage system
- What does “water tight” mean?
- Industry standards define “water tight” as “a measurable amount of leakage, but at an acceptable rate”

Industry Standards

- **American Concrete Institute (ACI)**
  - ACI 350.1 – Specification for Tightness Testing of Environmental Engineering Concrete Containment Structures

Type of containment structure	Default hydrostatic test quantitative criterion
Fully lined prior to hydrostatic test	No measurable loss
Required to have secondary containment	No measurable loss
With monolithically placed floors designed to be shrinkage crack free	0.0125% of volume per day
Other types	0.050% of volume per day
Concrete-paved reservoirs and channels	0.100% of volume per day

Industry Standards

- **American Concrete Institute (ACI)**
  - ACI 372R (2013) – Circular Wire and Strand Wrapped Prestressed Concrete Structures

6.2—Liquid-loss limit

6.2.1 *Maximum limit*—Liquid loss in a 24-hour period should not exceed 0.05 percent of the tank volume.

Industry Standards

- **American Water Works Association (AWWA)**
  - AWWA D110 – Wire and Strand Wound, Circular, Prestressed Concrete Water Tanks
    - Section 5.12, "The net liquid loss for a period of 24 hours shall not exceed 0.05% of the tank capacity"
  - AWWA D115 – Tendon Prestressed Concrete Water Tanks
    - Section 6.1.4

Instead of the form of information in Table 5, the criteria can be described as a loss of 0.05 percent in the following time periods:

Class A	96 hr
Class B	48 hr
Class C	24 hr

Translation

- **If acceptable loss (AL) criteria = 0.05% of stored volume in 24 hours**

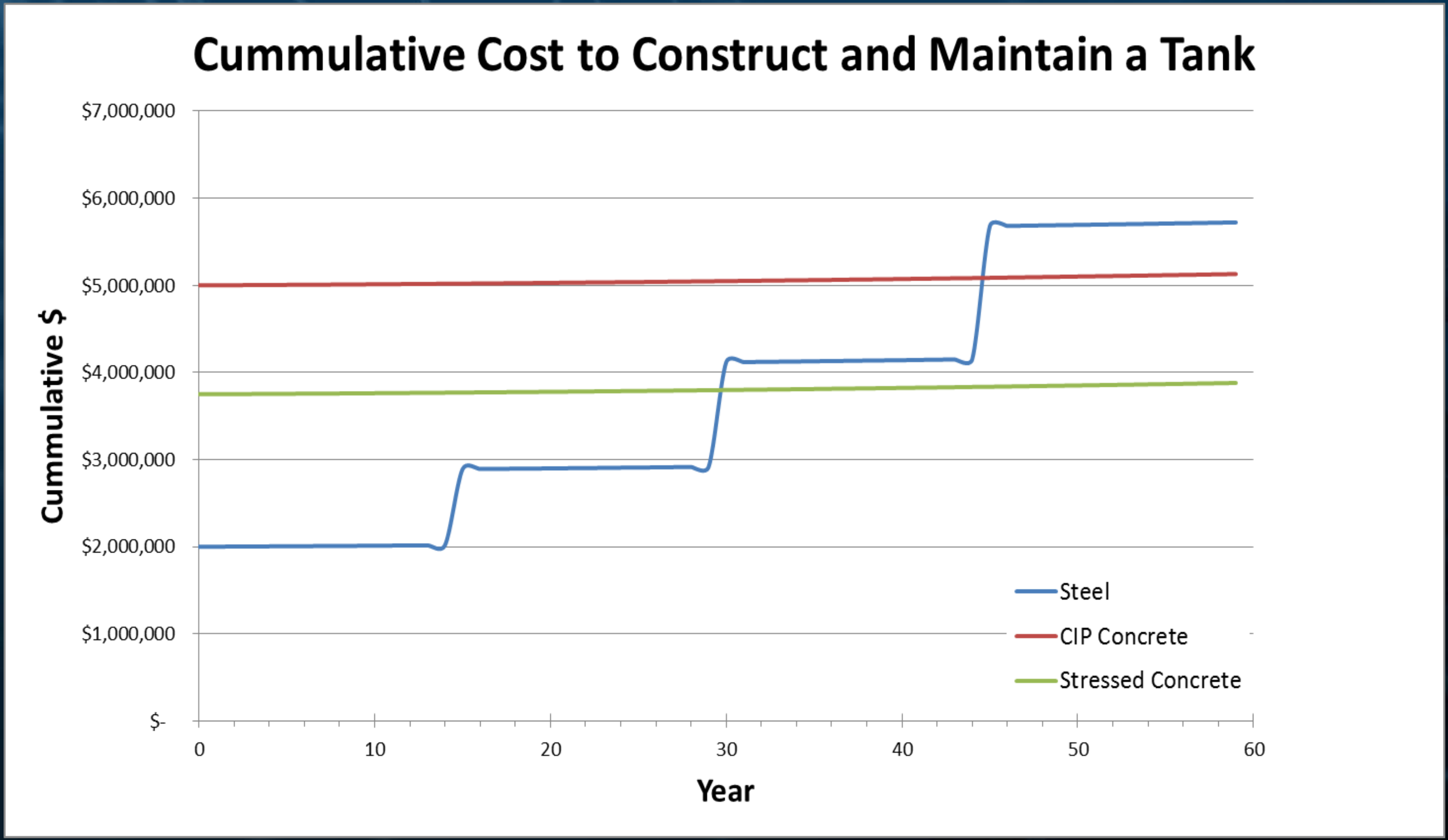
Item	Units	Rectangular	Circular
Storage Vol	MG	5.0	5.0
	cf	668449	668449
Plan dim	ft	150	
	ft	150	170
Depth	ft	30	29
AL criteria		0.0005	0.0005
Loss Vol	cf	334	334
	gal	2500	2500
Level drop	in	0.18	0.18

- ***3/16” level drop in 24 hours!***

Why Build with Concrete?

- Construction cost for concrete tanks is typically more than for steel
- Steel tanks require more and regular maintenance (steel recoating on a ~15-20yr cycle)
- Concrete tanks are good candidates for buried applications
- Concrete tanks can be constructed in various shapes and sizes to maximize site storage or to fit a limited site
- Can be designed to add on to a concrete tank

Why Build with Concrete?



The Chemistry of Concrete

- Concrete is the mixture of hydraulic cement, aggregates and water
- … oh yeah, and the occasional admixture
- Mixing cement and water triggers an exothermic, chemical reaction
- During the chemical reaction the “flowable” concrete changes ***temperature*** and ***volume*** as it solidifies

Translation?

+

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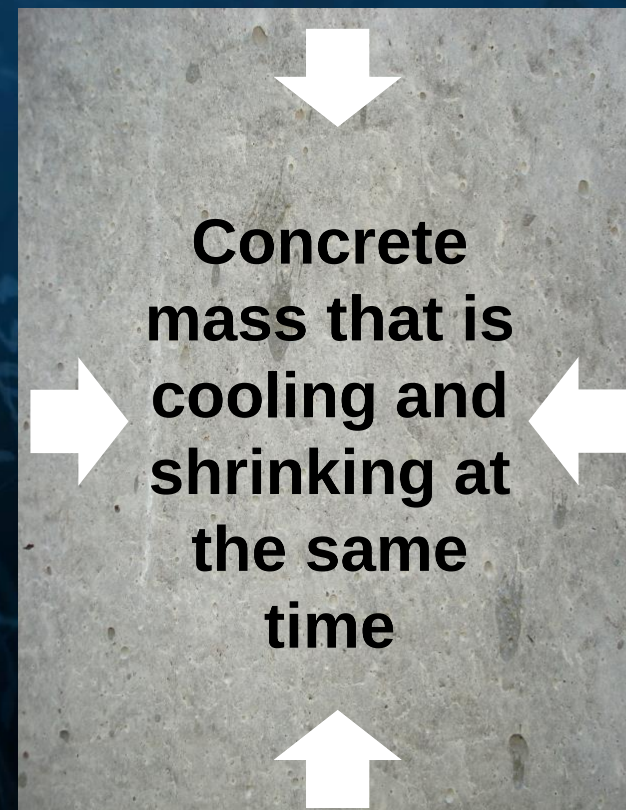
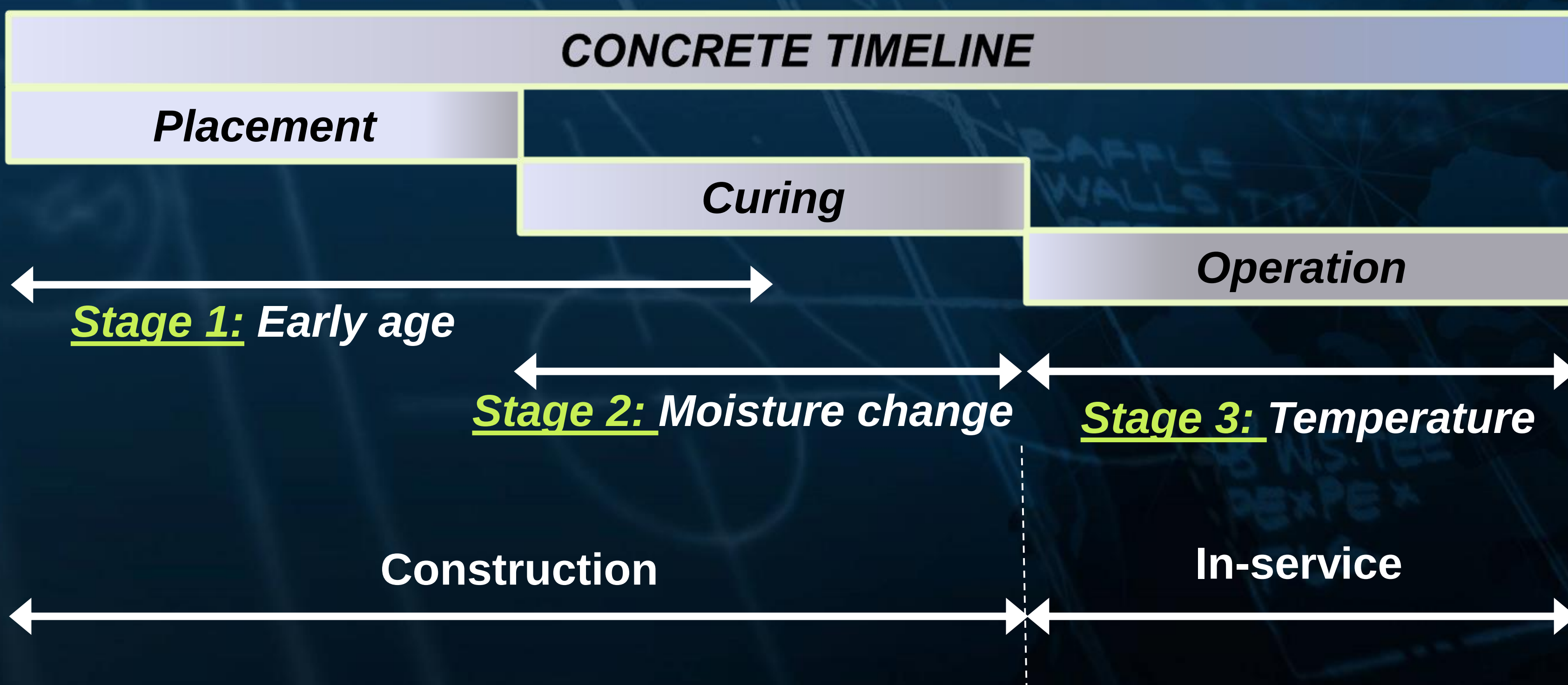


Volume Changes in Concrete

- **Stage 1: Flowable Concrete**
  - Early age volume changes due to:
    - Chemical, Autogenous, Subsidence, Plastic, Swelling
- **Stage 2: Initial Set, "Green" Concrete**
  - Moisture volume changes (drying shrinkage) due to:
    - Absorption, evaporation of trapped water, drying
- **Stage 3: Fully Cured & Hardened**
  - Temperature volume changes due to:
    - External environmental heating, cooling

Volume Changes in Concrete



Are There Solutions?

- **Yes!**
- **New construction project vs rehabilitation project**

New Construction

Installation:
- Mix design
- Reinforcing
- Placement Sequence
- Curing
- Protection

Stage 1 & Stage 2

Rehabilitation

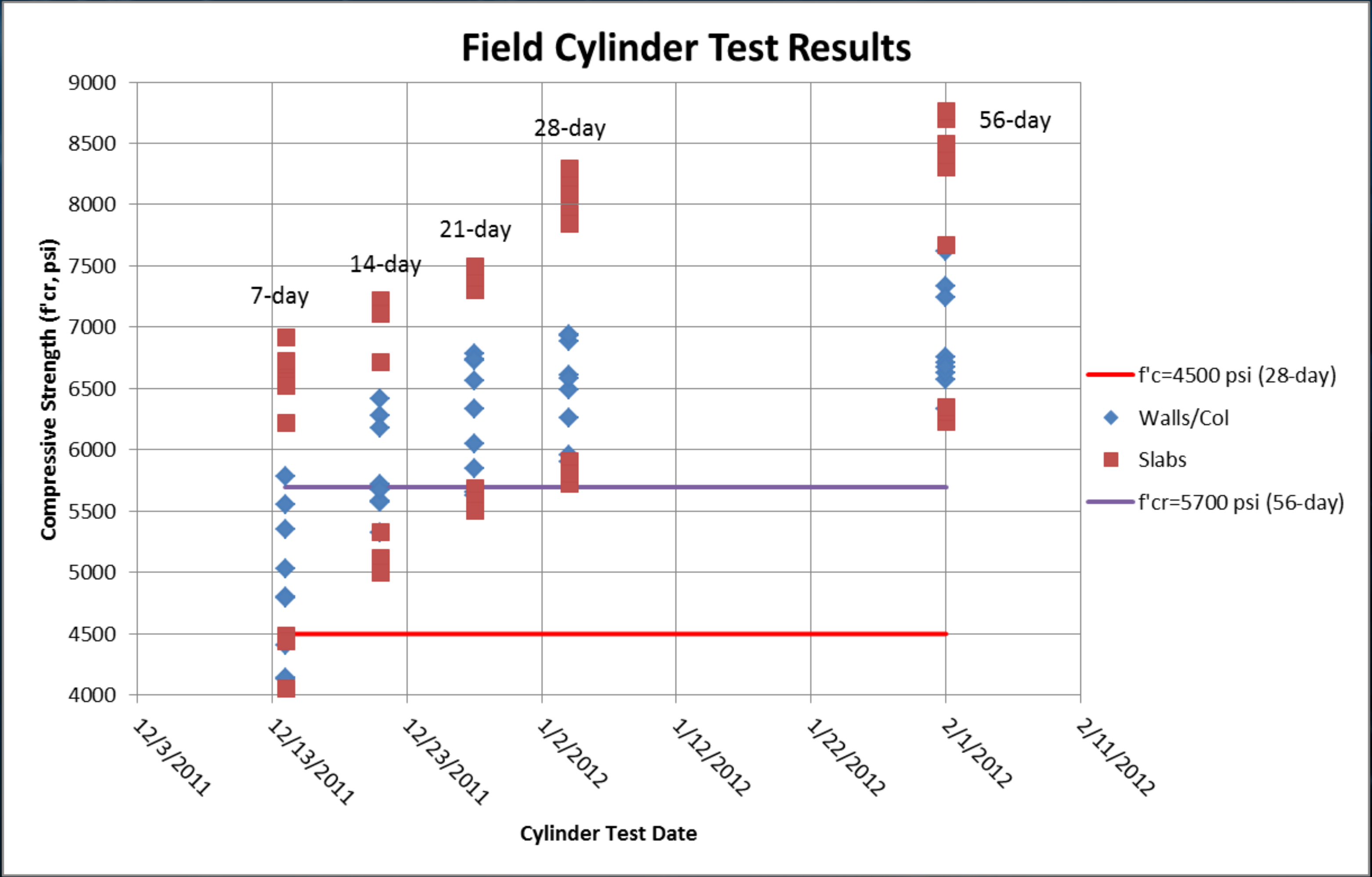
Post Construction:
- Coatings
- Sealants
- Joint Repairs
- Liners
- Insulation

Stage 3

What Could We Adjust?

- Concrete mix design
- Reinforcing layout, concentration, type
- Placement size and sequence
- Curing & thermal control

Current: Mix Design



Current: Mix Design

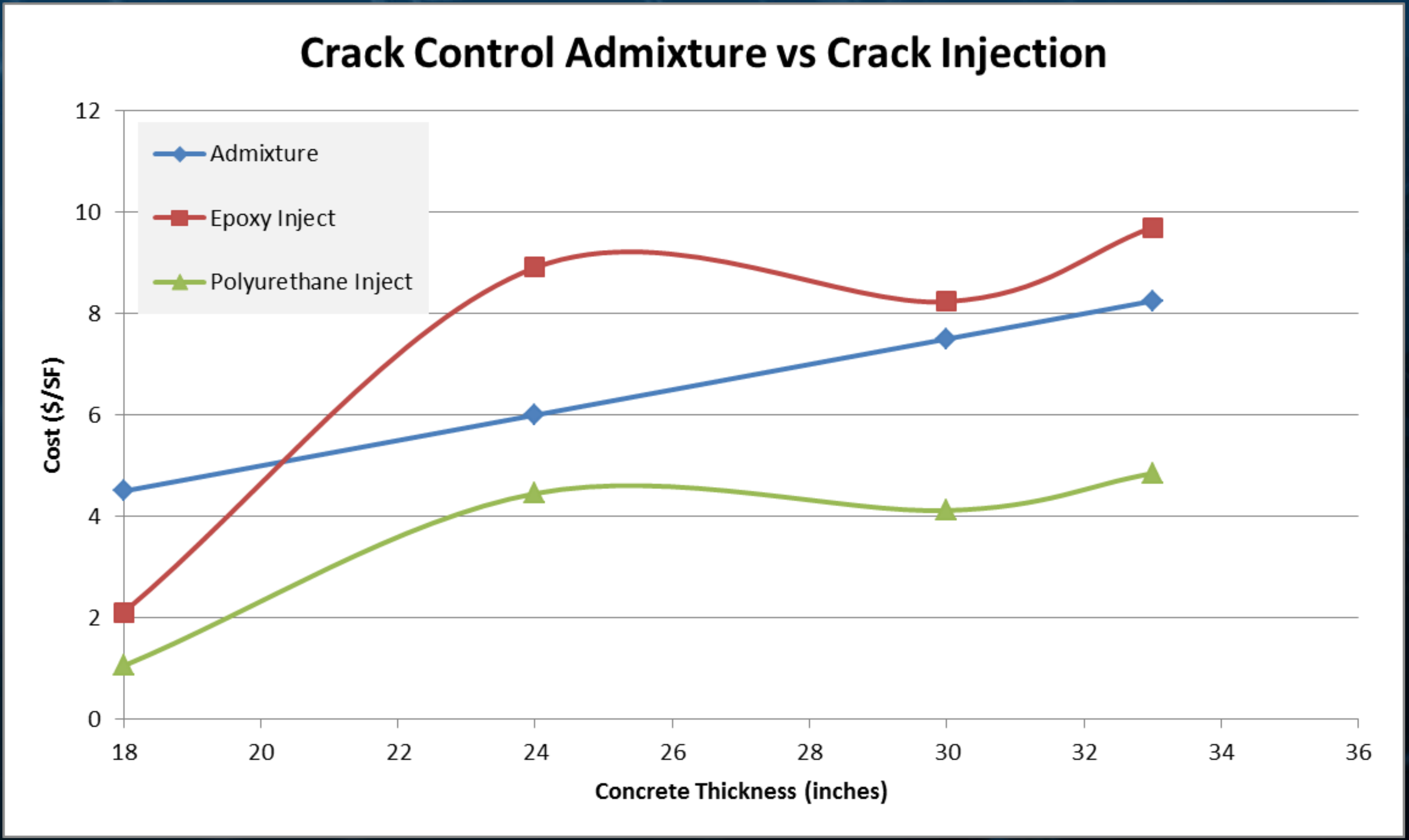
- **f'c – the specified 28-day strength**
  - Want f'c = 4500 psi
- **f'cr – the compressive strength used to select mix proportions**
- **Per ACI f'cr is adjusted based on available test data**
  - In many cases f'cr = f'c + 1200 psi
  - ACI 350, Table 5.3.2.2
- **Higher strength isn't always better**
  - Remember cement + water = heat + shrinkage

Alternative: Mix Design

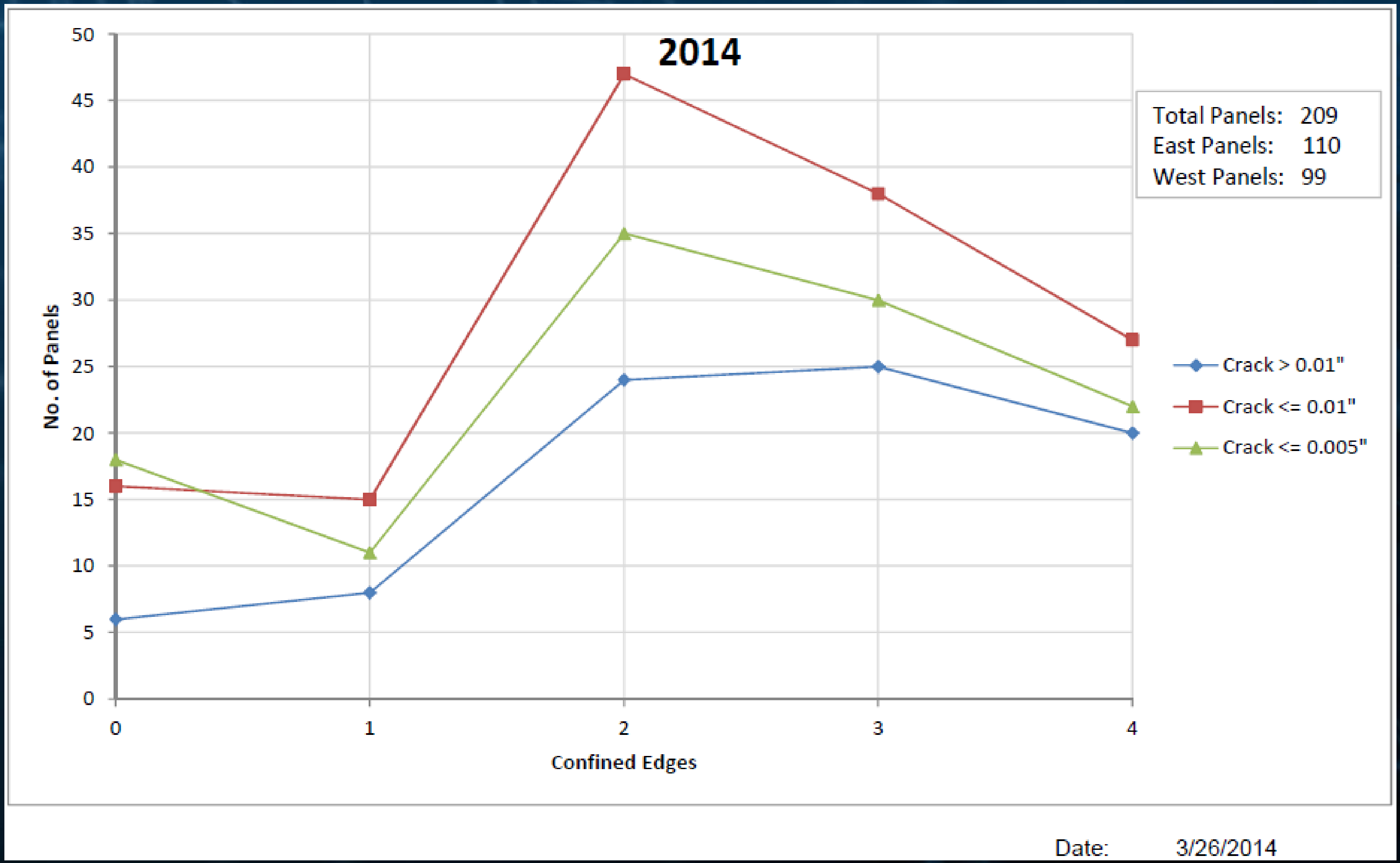
- **Limit more than w/c ratio**
  - As long as water increases, cement content can increase
  - Alternative = place an upper limit on w/c ratio but also water
- **Use larger coarse aggregate**
  - Larger individual stones have less surface area = less cement paste required
  - Alternative = ASTM C33 #467, 1.5”
- **Use supplementary cementitious materials (SCM)**
  - Alternative = Fly ash, blast furnace slag, silica fume, SCM blend
- **Crack control admixtures?**

Alternative: Admixture vs Injection

- Here is what we've seen so far….



Observation: Confined Edges & Cracking



Current: Shrinkage Reinforcing

- ACI & AWWA Codes historically required uniform shrinkage reinforcing in each placement
- Amount of reinforcing based on distance between movement joints/length of placement

TABLE 7.12.2.1—MINIMUM SHRINKAGE AND TEMPERATURE REINFORCEMENT

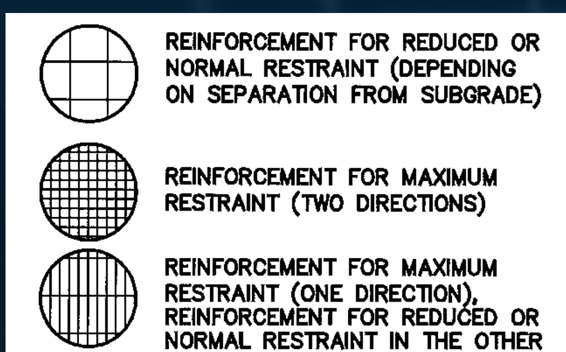
Length between movement joints, ft	Minimum shrinkage and temperature reinforcement ratio	
	Grade 40	Grade 60
Less than 20	0.0030	0.0030
20 to less than 30	0.0040	0.0030
30 to less than 40	0.0050	0.0040
40 and greater	0.0060*	0.0050*

*Maximum shrinkage and temperature reinforcement where movement joints are not provided.

Note: This table applies to spacing between expansion joints and full contraction joints. When used with partial contraction joints, the minimum reinforcement ratio shall be determined by multiplying the actual length between partial contraction joints by 1.5.

Alternative: Shrinkage Reinforcing

- Reinforcing tied to amount of edge restraint
- “Maximum” or “Reduced” restraint
- These are ACI 350 updates currently being balloted



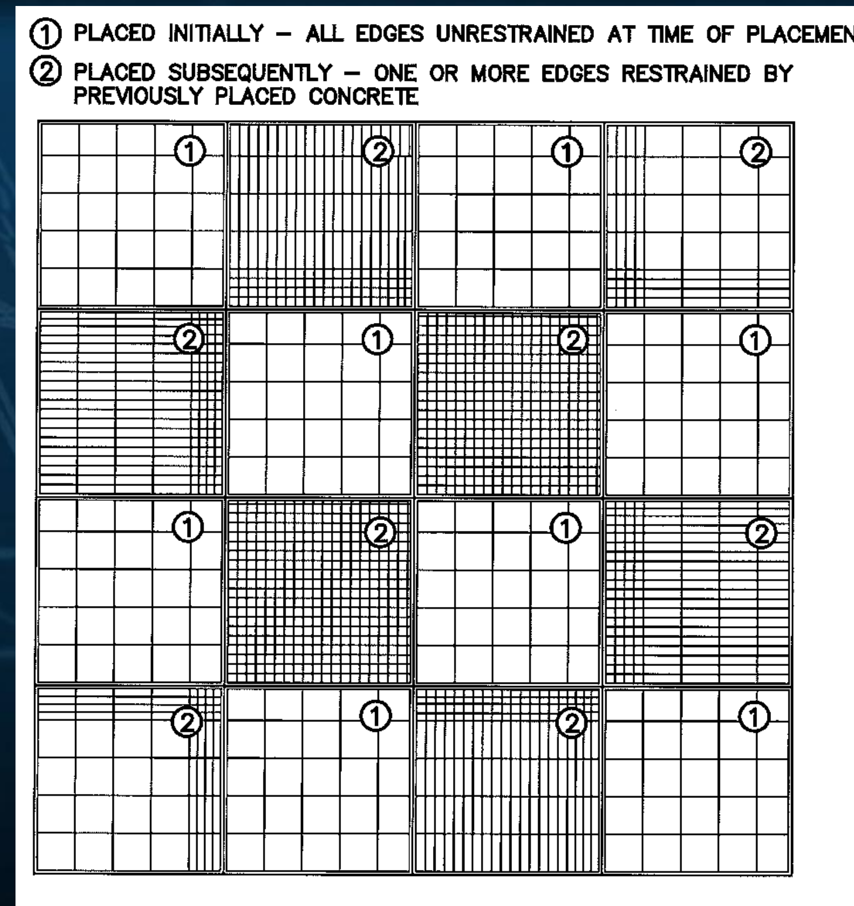
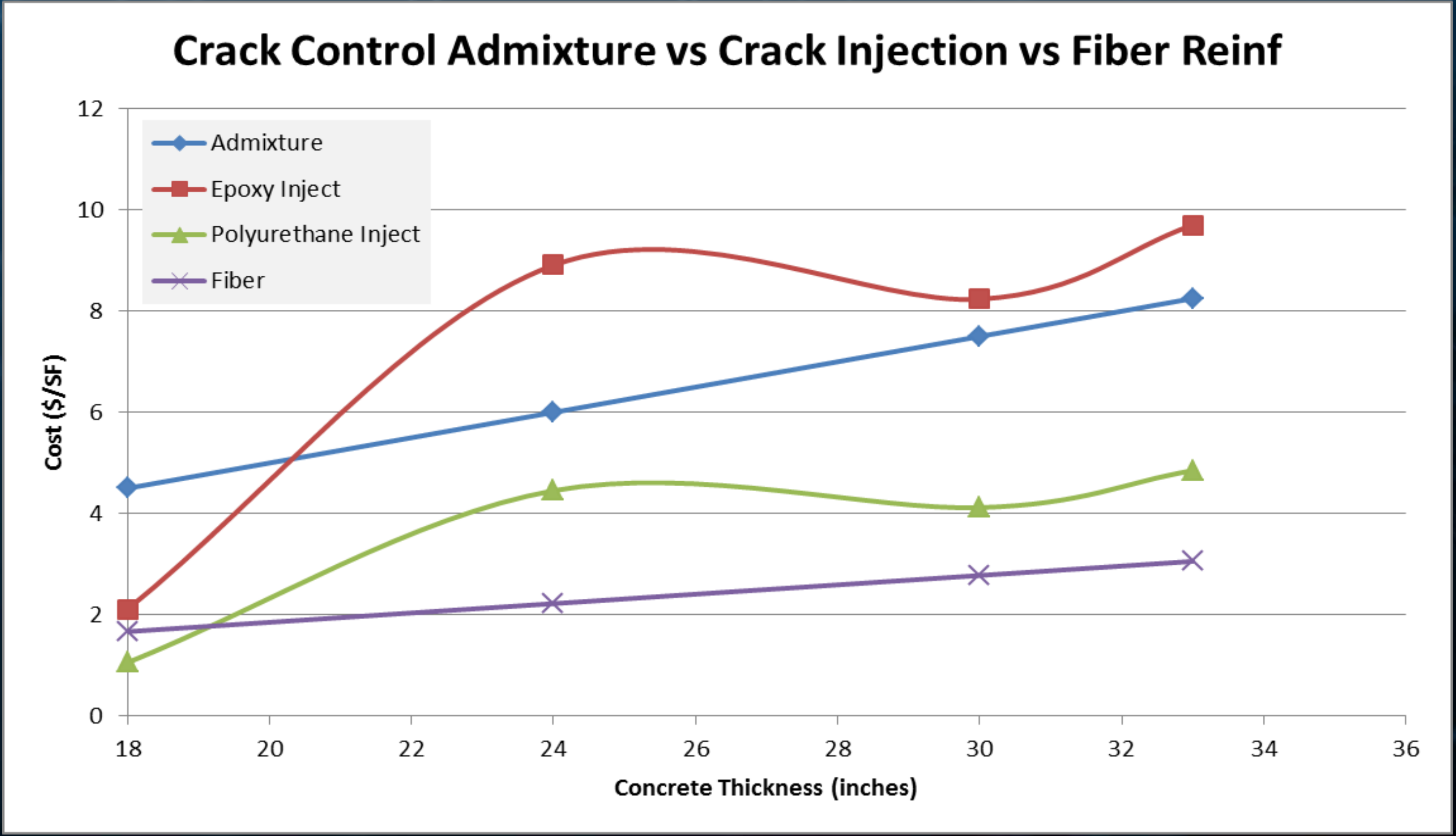


FIG. R12.13.2.6(b)

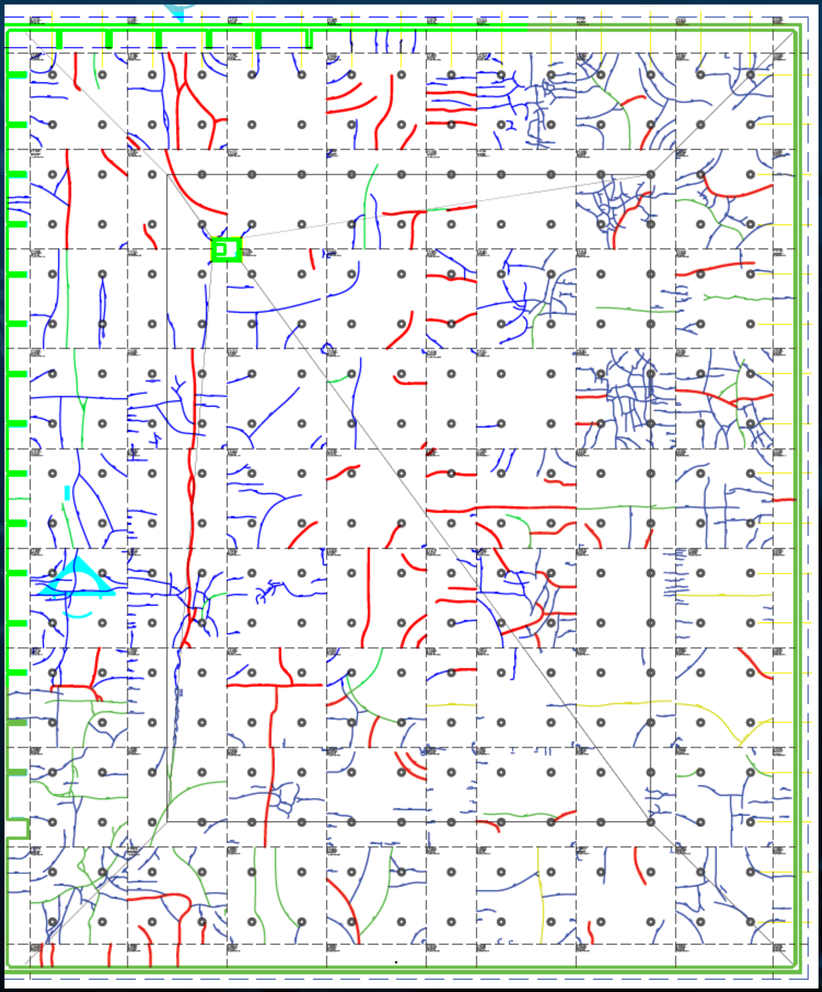
Alternative: Fiber for Shrinkage Reinforcing?

- Fiber reinforcing used in large slab placements to partially replace traditional reinforcing & minimize cracking



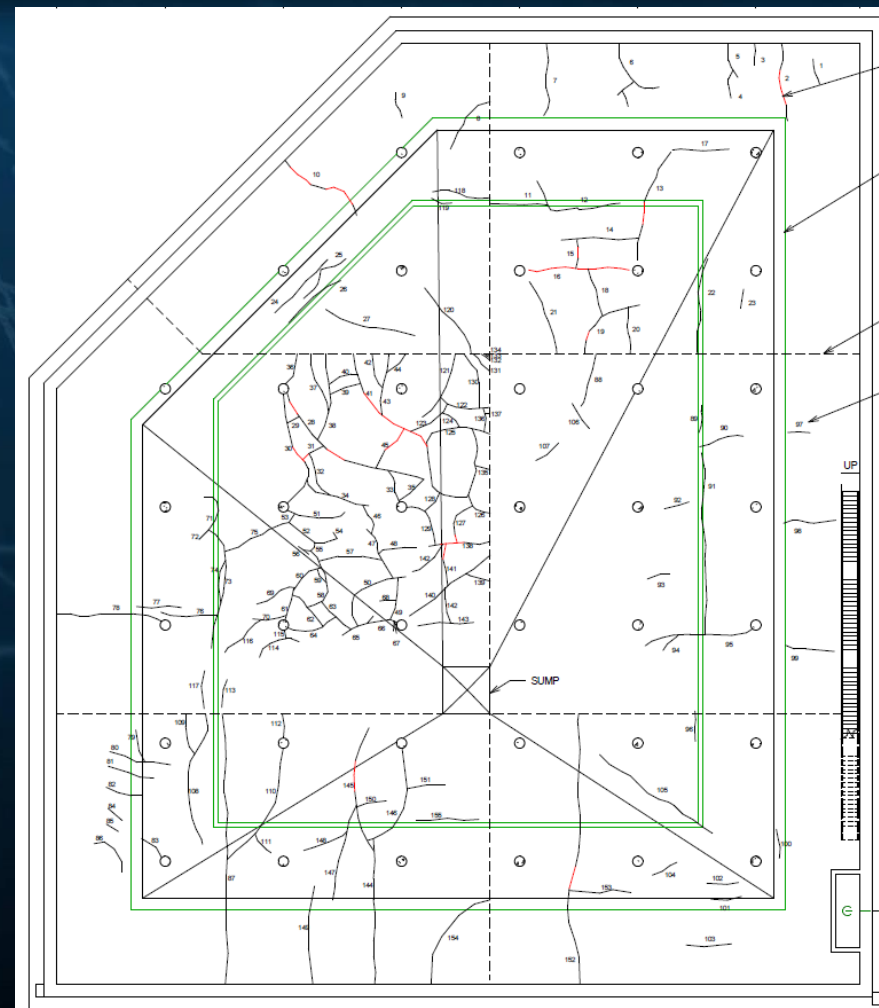
Current: Placement Size

- Historically placement length, plan dims limited to between 30-40ft
- Example: (2) 25MG cells, 40x40 placements



Alternative: Placement Size

- Alternatively try larger placements
- Example: 63ft x 97.5ft placement



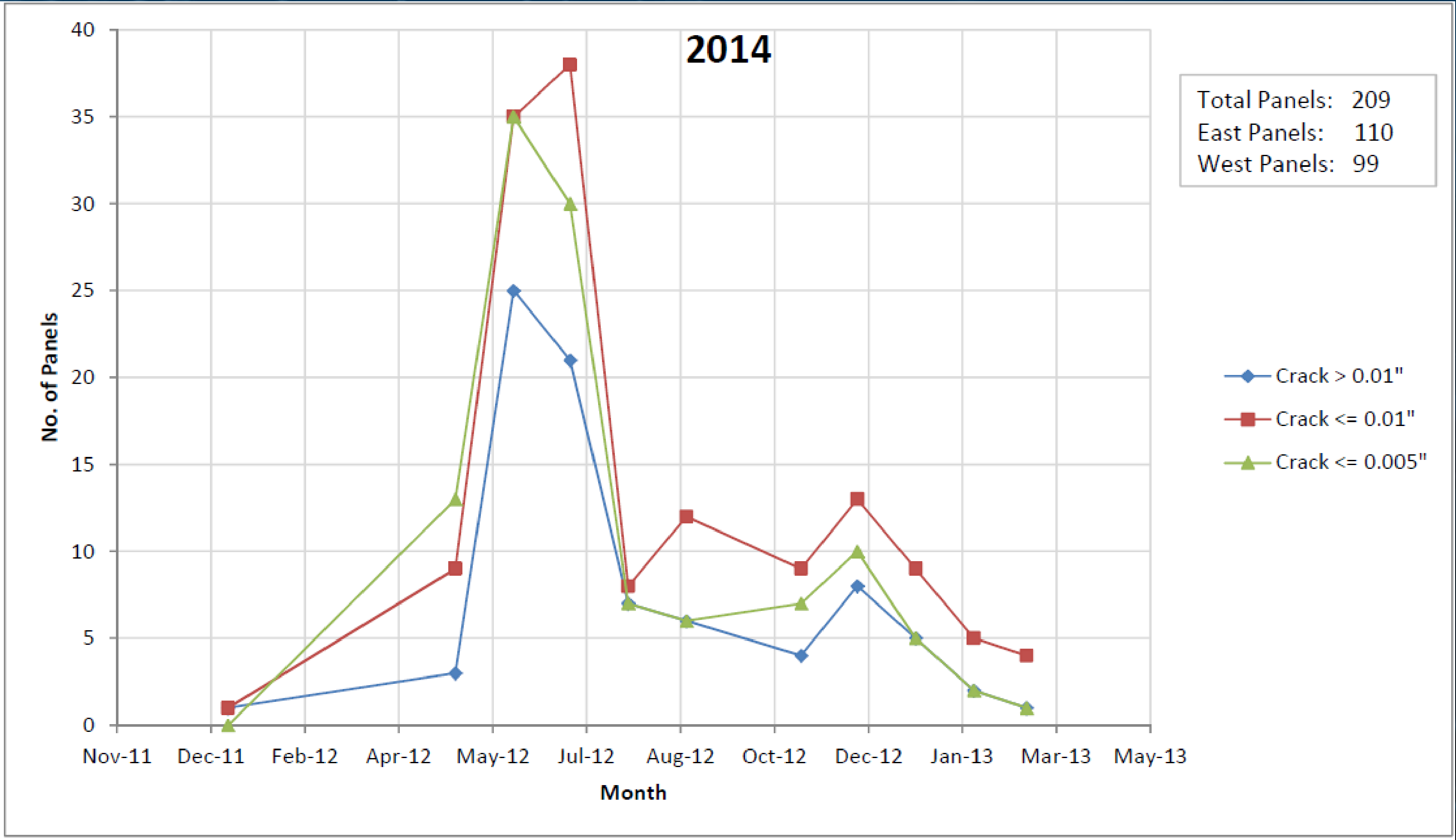
Alternative: Placement Size

- Max size not as important as aspect ratio of placement (W : L)
- Goal = keep aspect ratio in the 1.0 to 1.5 range
- More uniform shrinkage in each direction
- Consider edge restraint vs end restraint

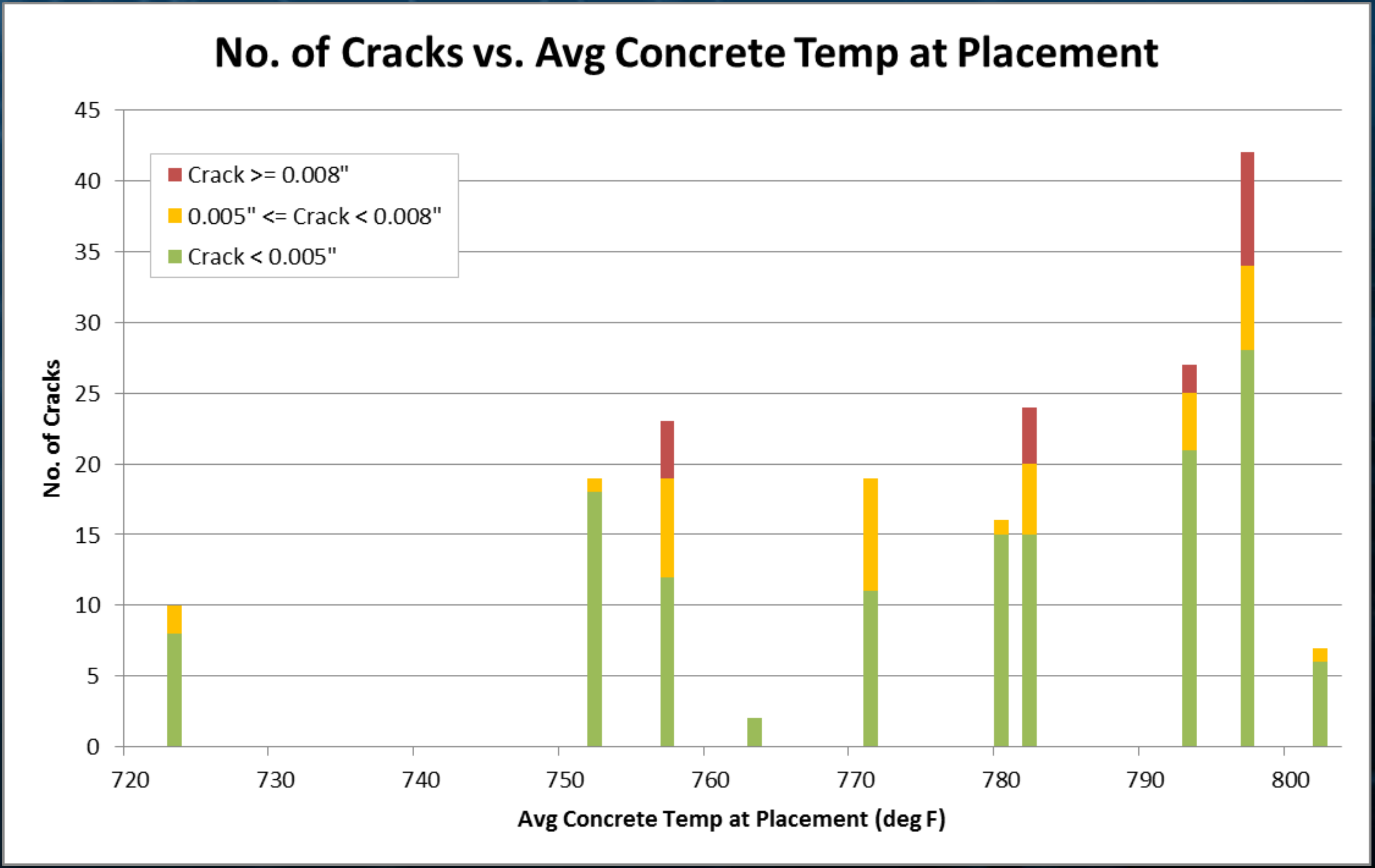
Current: Curing & Protection

- Water curing (7 day vs 14 day)
- Forms in place, geotextile, burlap or plastic sheeting to keep surface consistently wet and protect against convective drying

Observation: Curing & Protection



Observation: Curing & Protection



Alternative: Curing & Protection

- Thermal model of project specific placements, using approved mix
- Develop curing and protection plan based on thermal modeling results

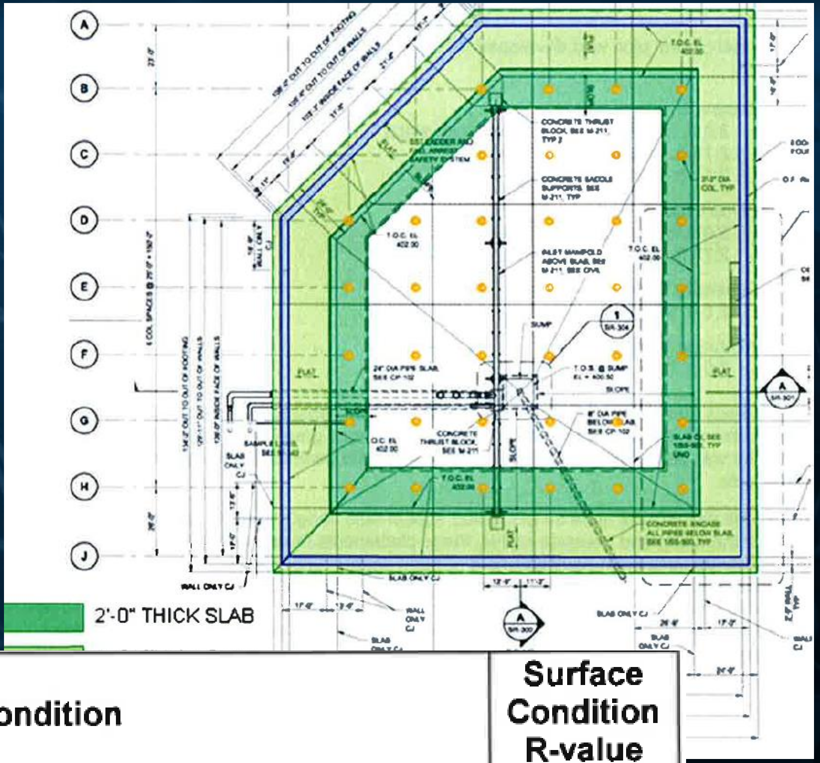
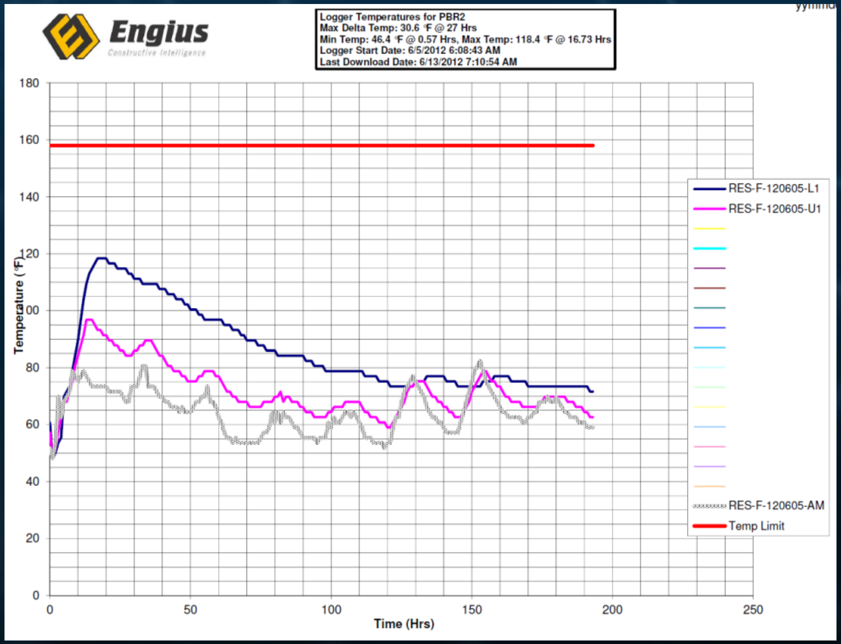
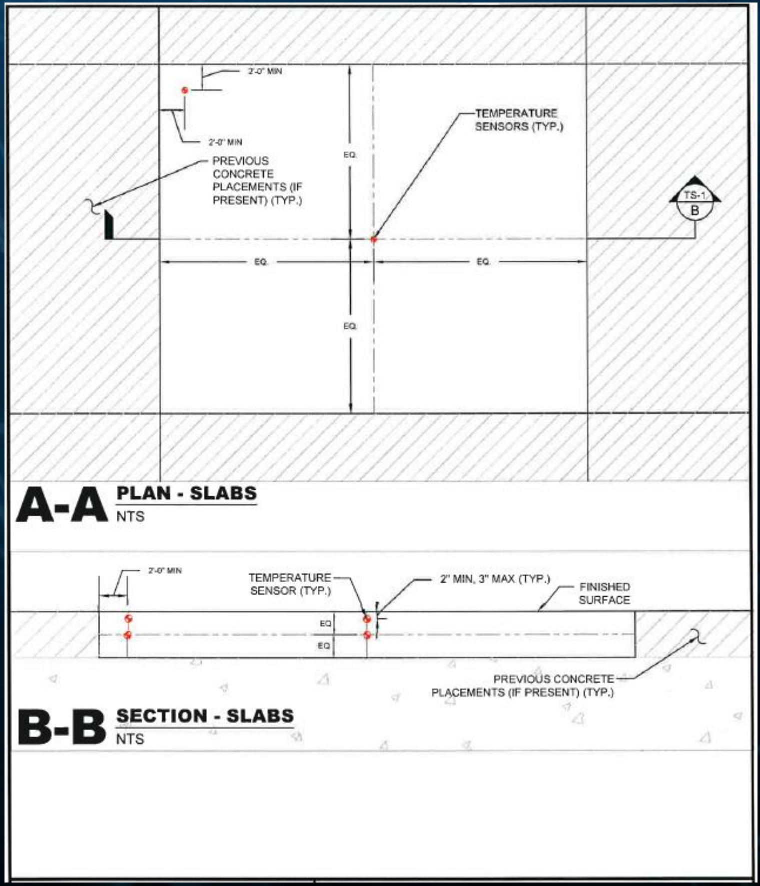


Table	Placement	Surface Condition	Surface Condition R-value
1a	3.25 ft. Thick Foundation Slabs	Constant 15 mph wind; No rain; No surface insulation	R-0.17
1b		Constant 7.5 mph wind; No rain; No surface insulation	R-0.25
1c		Still air conditions; No rain; No surface insulation	R-0.68
1d		1 Layer thin concrete insulating blankets or 3/4-in. thick wood forms	R-1
1e		1 Layer of typical winter concrete insulating blankets	R-2.5

Alternative: Curing and Protection

- Temperature monitoring
- React based on results
- Revise curing & protection plan





What is the Message?

- **Cracking in concrete can be controlled through deliberate changes to what is:**
  - Specified
  - Mix ingredients and proportions
  - Construction procedures
- **What is the future?**
  - ***Performance specified concrete?***

> - ***Strength***
> - ***Durability***
> - ***Water tightness***

QUESTIONS?

Thank You

What Issue Do They Address?

Solution	Stage 1: Early Age	Stage 2: Moisture	Stage 3: Heat/Cool
SCMs (fly ash, slag, etc)		X	
Aggregates	X	X	
Admixtures	X	X	
Placement size/sequence		X	
Add reinforcing bars		X	X
Water curing		X	
Insulation		X	

Solutions for New Construction

- **Concrete mix design**
  - Control cement content
  - Upper limit on water content
  - Partial cement replacement (SCM’s = fly ash, slag, etc.)
  - Admixtures (crack control vs crack healing)
- **Reinforcing layout, concentration, type**
  - Increased concentration at confined edges
  - Traditional steel reinforcing vs fiber reinforcing
- **Placement size and sequence**
  - Increased placement size
  - Checker board vs strips vs monolithic placements
- **Curing & thermal control**

Current: Mix Design (what is specified?)

- **ACI 350, Chapter 4, Durability Requirements**
- **Moderate Exposure**
- **Table 4.3.1**
  - f'c = 4500psi, Type II cement, w/c = 0.42
- **Table 4.1.2.1**
  - 1" Agg, #57 = 535 lbs/cyd
  - ¾" Agg, #67 = 560 lbs/cyd