Where WVDOH is at with Mass Concrete

History of Mass Concrete and the WVDOH

- In 2005, a large bridge crossing the Ohio River was being constructed (Blennerhassett Bridge)
- Because of the large size of some substructure elements, a “Mass Concrete” Special Provision (SP) was drafted and inserted into that project
- This project was clearly a candidate for “Mass Concrete” measures
  - Pier Caps with a 9-ft minimum dimension
  - Pier Columns with a 13-ft minimum dimension
  - Footers with a 12-ft minimum dimension

First WVDOH Mass Concrete Special Provision (SP)

- Defined mass concrete as any member whose least dimension exceeded 4-ft
- Required a Thermal Control Plan (TCP) and thermal monitoring for all those elements
- Maximum allowable temperature of 160°F and maximum allowable temperature differential of 40°F
  - Maximum allowable temperature differential later permitted to be greater than 40°F based on increasing compressive/tensile strength of concrete (temperature differential vs. compressive strength curve established)
- This SP was good for the thermal control of concrete
- Downside of this SP was the unknowns that a contractor had prior to bidding (i.e. element cure time, insulation, cooling pipes, etc.) which could add time and money to the project

History of Mass Concrete and the WVDOH (cont.)

- Additional bridges were built with that first mass concrete SP
- Some of these were large bridges for which there was little question that the mass concrete measures were justified
- However, this SP was also being included in some smaller bridges, in which its need was questioned
- The 4-ft minimum dimension was questioned, as well as the need and additional expense of a Thermal Control Plan (TCP)
- Often times this SP was inserted into projects, and after the project was awarded, it was removed after the WVDOH was offered a credit by the contractor, to whom the project was awarded

Second WVDOH Mass Concrete SP

- Still defined mass concrete as any member whose least dimension exceeded 4-ft
- More prescriptive based that first SP
  - TCP wasn't required
  - Mixes with more supplementary cementitious materials (SCMs) and less cement were required
    - Maximum cement content
    - Minimum pozzolan content
  - Required thermal monitoring & 7-day moist cure with plastic
  - Required the concrete temperature at placement to be between 50-70°F
- This SP was easier for contractors to bid
- Helped to reduce thermal issues, but didn't provide the level of thermal protection that the first SP did, especially on larger projects

History of Mass Concrete and the WVDOH (cont.)

- The second SP was good for smaller projects, but it wasn’t suited for larger projects
- The issue became when to use which SP
- What was a large project and what was a small project?

Third WVDOH Mass Concrete SP

- Third Mass Concrete SP was basically the same as the first mass concrete SP, except that a penalty for exceeding the maximum temperature or maximum temperature differential was included
- Only used a couple of times in Design-Build projects
- Same issues as first SP

Issues with Mass Concrete SPs

- Which projects should SPs be inserted into?
  - Is mass concrete necessary on all projects?
  - Large bridge projects
  - Smaller projects (i.e. one with a 4-ft thick footer)
- Mass concrete SP was sometimes eliminated from projects after the contract was awarded, when it was decided concrete element size was borderline or not necessary
  - Contractors often offered a credit to the WVDOH to remove the mass concrete SP from a project
  - Was the credit fair and uniform on all projects?
  - This took place after bidding and award of contract

Next Step

- Measures were still needed for thermal control of concrete, to reduce the potential for cracking and increase concrete durability
- Research Problem Statement was submitted regarding mass concrete, outlining the previously noted issues and problems
- RP-257 (mass concrete research project) was started by Dr. Chen at WVU

RP-257

- The goal of this research project is to define when there is a potential for thermally induced cracking to occur in newly placed concrete and how to take the most economic approach to reduce this potential through preventative measures which can be taken during design and construction.

Initial Data Gathering

- Concrete temperature data was gathered by WVU to see if there was a problem with concrete temperatures and if mass concrete measures were necessary
  - **Other states were surveyed for their mass concrete specifications and experience**
    - **Results were inconsistent**

2009 WVDOH Survey

- To find out what other states are requiring and specifying about mass concrete and mass concrete issues
- To provide a reference guide to WVU researchers
- 27 state agencies responded
- 12 agencies have no specification for Mass Concrete
- Additional data from Iowa DOT received in 2013
- Conclusion: Although there are similar approaches regarding how to control the temperature in newly placed concrete (i.e. cooling tubes, using less cement in a mix, etc.), there is not a consistent approach on when to apply these thermal control measures.

State	Max. Dimensions, ft	Max. Temperature, °F		Max. Temp. Difference, °F
		initial	curing	
1. Arkansas	-	75	-	36
2. California	Structure: >7ft	-	160	Thermal control plan
3. Florida	Every structure >3ft and v/s: >1ft, drilled shafts >6ft		180	35
4. Georgia	>2 ft and v/s: >1 ft		-	50
5. Illinois	>4 or 5 ft		160	35
6. Iowa* (10/2012)	>4ft (exc. Caisson), >5ft for footing	70	160	20 (<24 hrs), 30 (24-48 hrs), 40 (48-72 hrs), 50 (>72 hrs)
7. Maryland	>6 ft	-	160	35
8. Massachusetts	>4 ft		154	38
9. Minnesota	>4 ft		160	35
10. New Jersey	>3 ft and v/s: >1 ft		-	-
11. New York	none		-	-
12. North Dakota	5x5 ft	-	160	50
13. Rhode Island	>4 ft		-	-
14. South Carolina	Structure: >5 ft ; Circular shape: diameter >6ft	80	-	35
15. Texas	>5 ft	75	160	35
16. West Virginia	>4 ft	-	160	35
17. Virginia	>5 ft	95	160, (slag, 170)	35

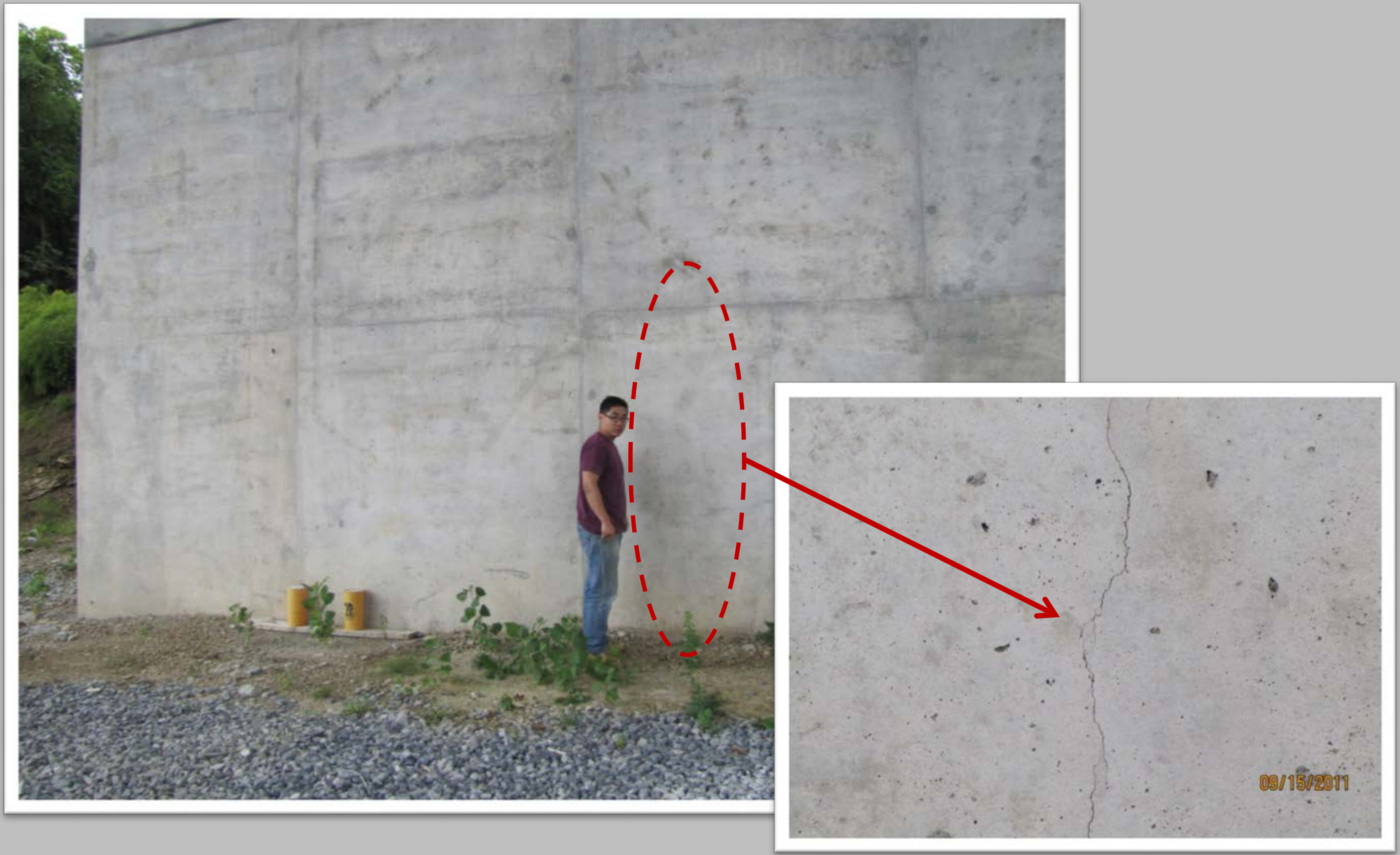
Initial Data Gathering

- Concrete temperature data was gathered by WVU to see if there was a problem with concrete temperatures and if mass concrete measures were necessary
  - Other states were surveyed for their mass concrete specifications and experience
    - Results were inconsistent
  - **Temperature sensors were installed in the concrete elements of several WVDOH bridge projects in several districts, and those elements were monitored**
    - **Current mixes and construction practices were used**
    - **Cracks noted in bridge elements which had higher temperatures differentials**

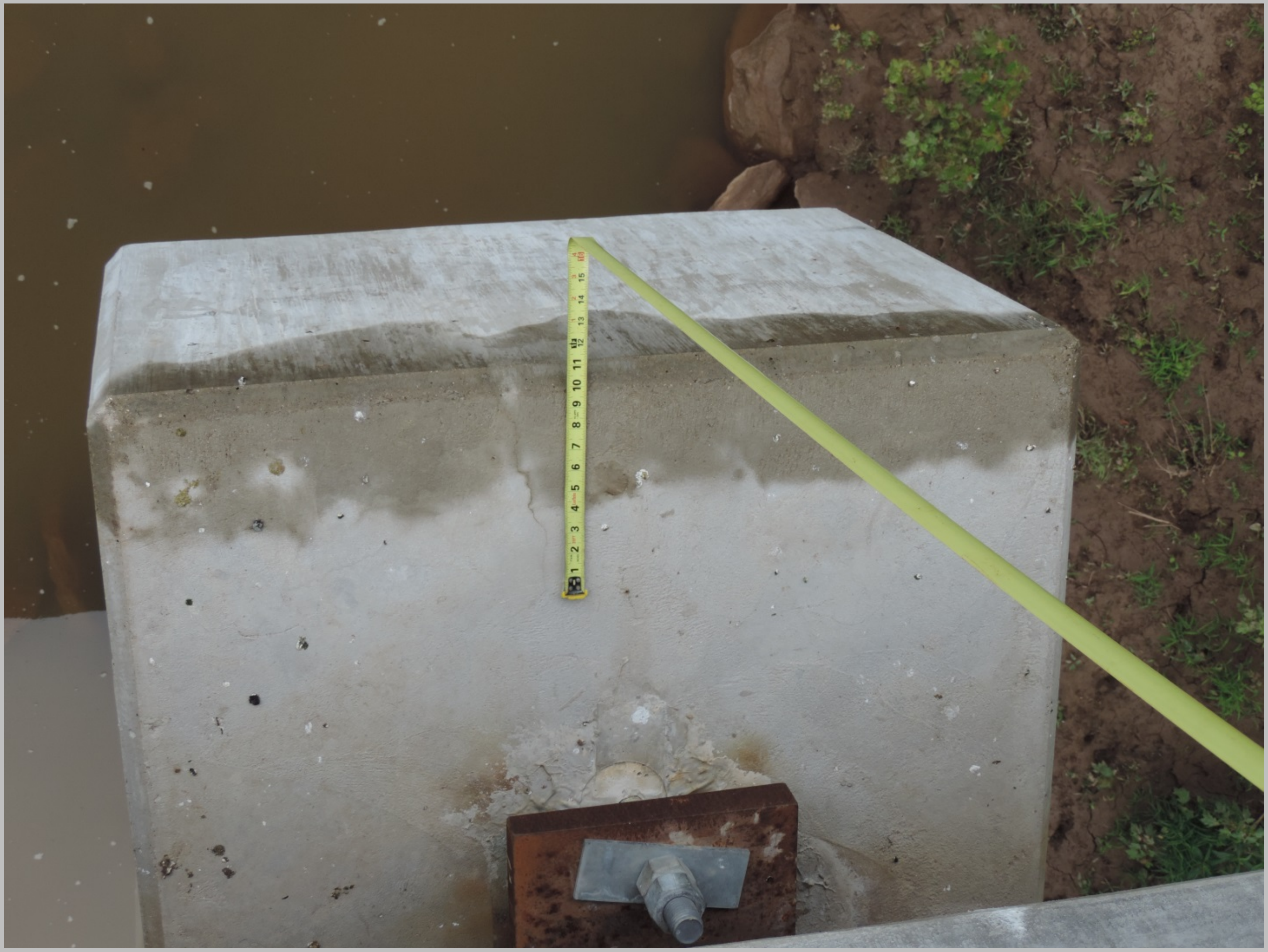
6-ft diameter pier column which had high temperature differential

Thermal crack in “Mass Concrete” pier column which had high temperature differential (close up of previous picture)

Thermal crack in "Mass Concrete" pier stem which had high temperature differential



Thermal crack in "Mass Concrete" pier cap which had high temperature differential (looking down at top of pier cap)



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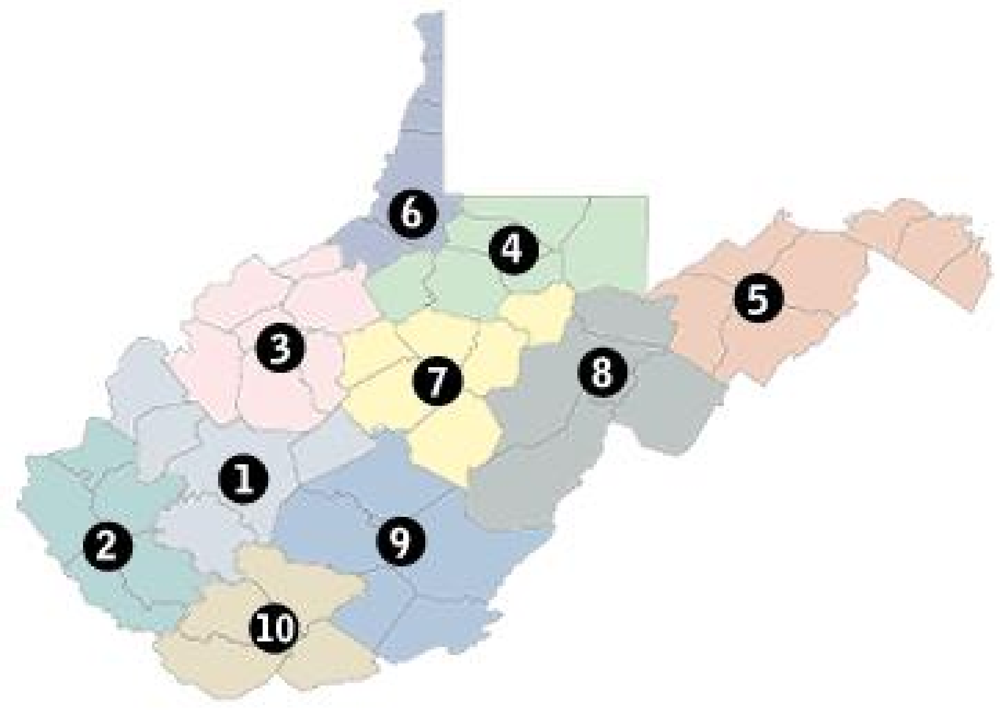
    - Cracks noted in bridge elements which had higher temperatures differentials
  - **6-ft concrete cubes were constructed with standard Class B (bridge substructure) mix in several Districts**
    - **Temperature sensors installed in cubes and monitored**
    - **Cores taken from cubes to compare actual strength vs. cylinder strength vs. maturity**

FIELD STUDY



DOH DISTRICT #	*STRUCTURE*
DISTRICT 10	**CLEAR FORK ARCH BRIDGE #2**
DISTRICT 10	**CLEAR FORK ARCH BRIDGE #1**
DISTRICT 7	**LUCILLE STALNAKER BRIDGE**
DISTRICT 4	**ICES FERRY BRIDGE**
DISTRICT 3	**SOUTH MINERAL WELLS INTERCHANGE**
DISTRICT 2	**5TH AVENUE BRIDGE**
DISTRICT 1, 5, 6, and 9	**6-FT CUBE**

6-ft cube with normal Class B mix

Coring 6-ft cube to compare actual in-place strength vs. cylinder strength vs. maturity

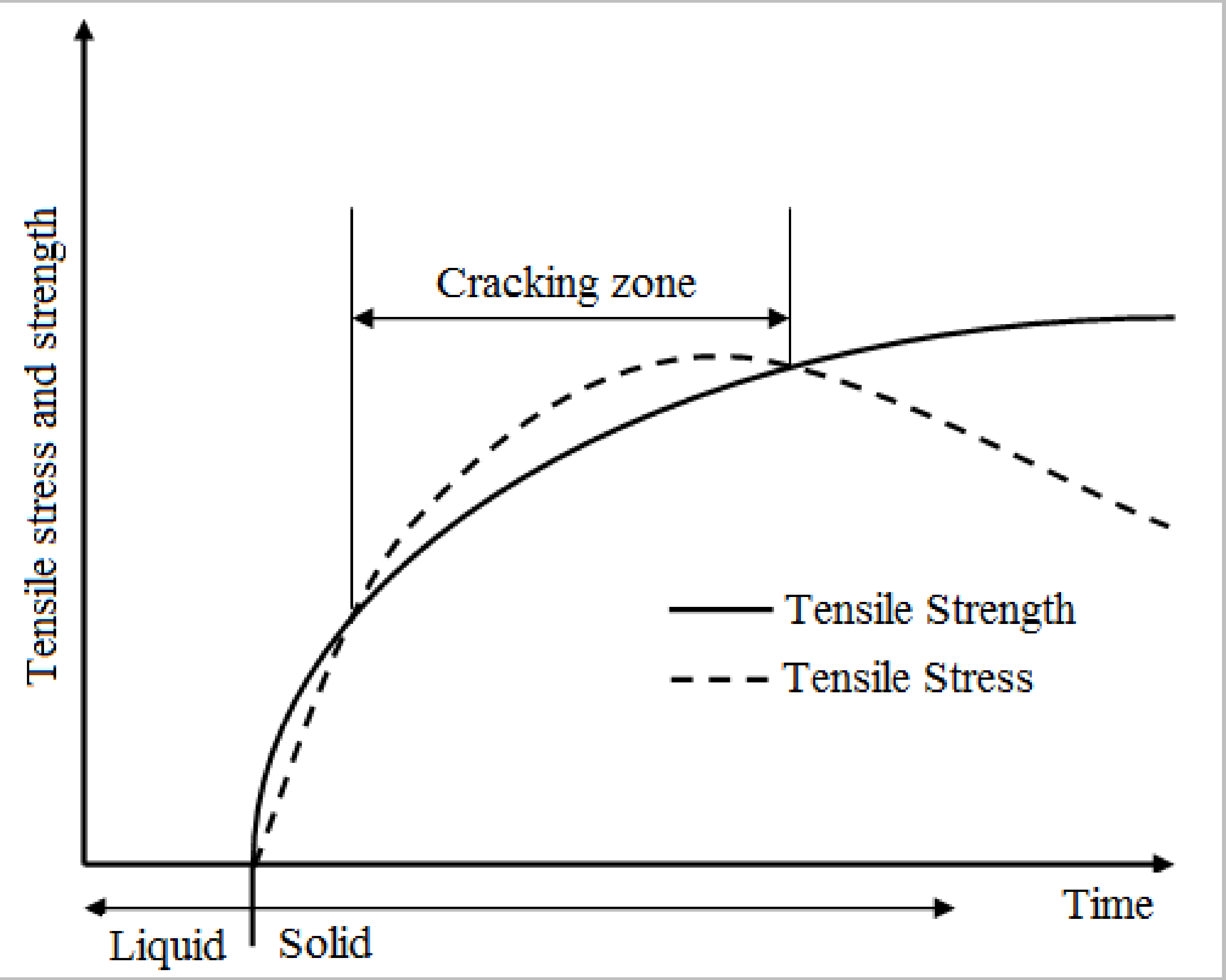
Initial Data Gathering

- Concrete temperature data was gathered by WVU to see if there was a problem with concrete temperatures and if mass concrete measures were necessary
  - Other states were surveyed for their mass concrete specifications and experience
    - Results were inconsistent
  - Temperature sensors were installed in the concrete elements of several WVDOH bridge projects in several districts, and those elements were monitored
    - Current mixes and construction practices were used
    - Cracks noted in bridge elements which had higher temperatures differentials
  - 6-ft concrete cubes were constructed with standard Class B (bridge substructure) mix in several Districts
    - Temperature sensors installed in cubes and monitored
    - Cores taken from cubes to compare actual strength vs. cylinder strength vs. maturity
- **Conclusion: Thermal cracking, concrete temperatures, and concrete temperature differentials greater than the limits allowed in the first SP were occurring with the current WVDOH mixes**
- **Therefore: Measures for thermal control of concrete were still needed**

Approach to Problem

- To find a way to incorporate thermal control measures into the WVDOH Standard Specifications and Plans, prior to bidding
  - Come up with a definition of "mass concrete"
- Mass concrete was defined as a concrete element which, due to thermal differentials in the newly placed concrete element, <u>the maximum tensile stress is greater than 80% of the predicted tensile strength</u>

Tensile stress and strength vs. Time



Approach to Problem (cont.)

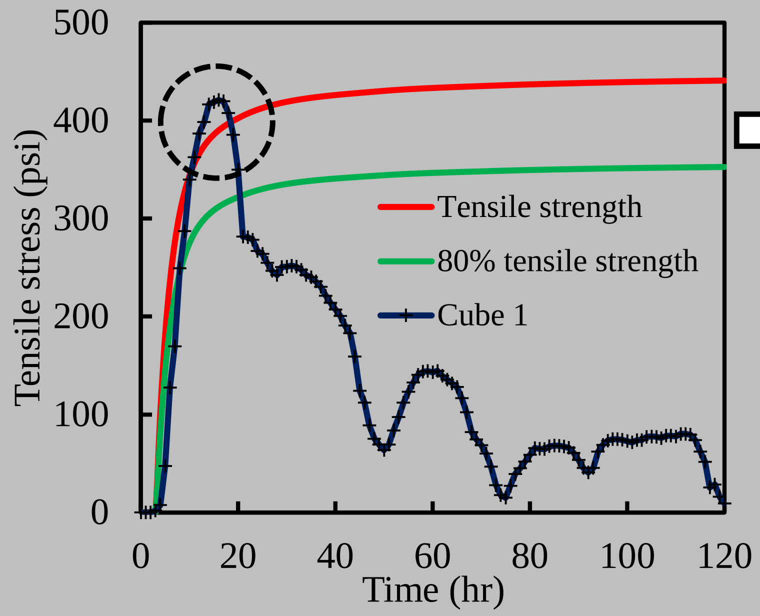
- Several 4-ft test cubes were constructed with the “hottest” Class B mix (bridge substructure mix) allowed by WVDOH specifications
  - Maximum cement content
  - No pozzolans
  - “Hottest” cement from our approved cement sources (high SO_3 & C_3A)
  - Limestone was required as coarse aggregate (lower CTE)
    - “Best construction practice” that came out of this phase of research
- This provided a thermally worst case scenario for bridge construction, as far as mix designs were concerned
  - Cubes were instrumented
- WVU used finite element modeling (FEM) to predict the thermal properties of these cubes
  - WVU tried Concrete Works initially but found they could more accurately predict temperatures and differentials with their finite element model

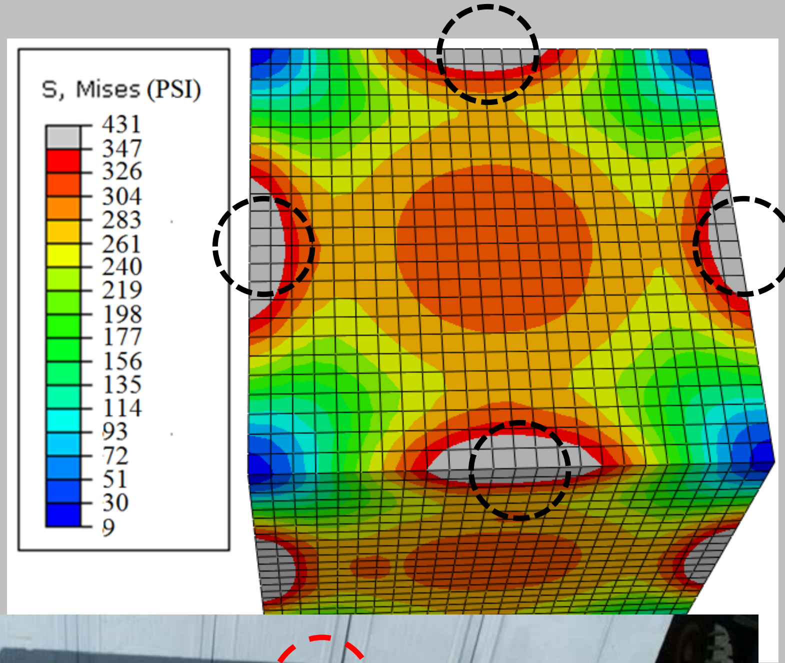
4-ft "Hot" Class B Cube at WVU

Approach to Problem (cont.)

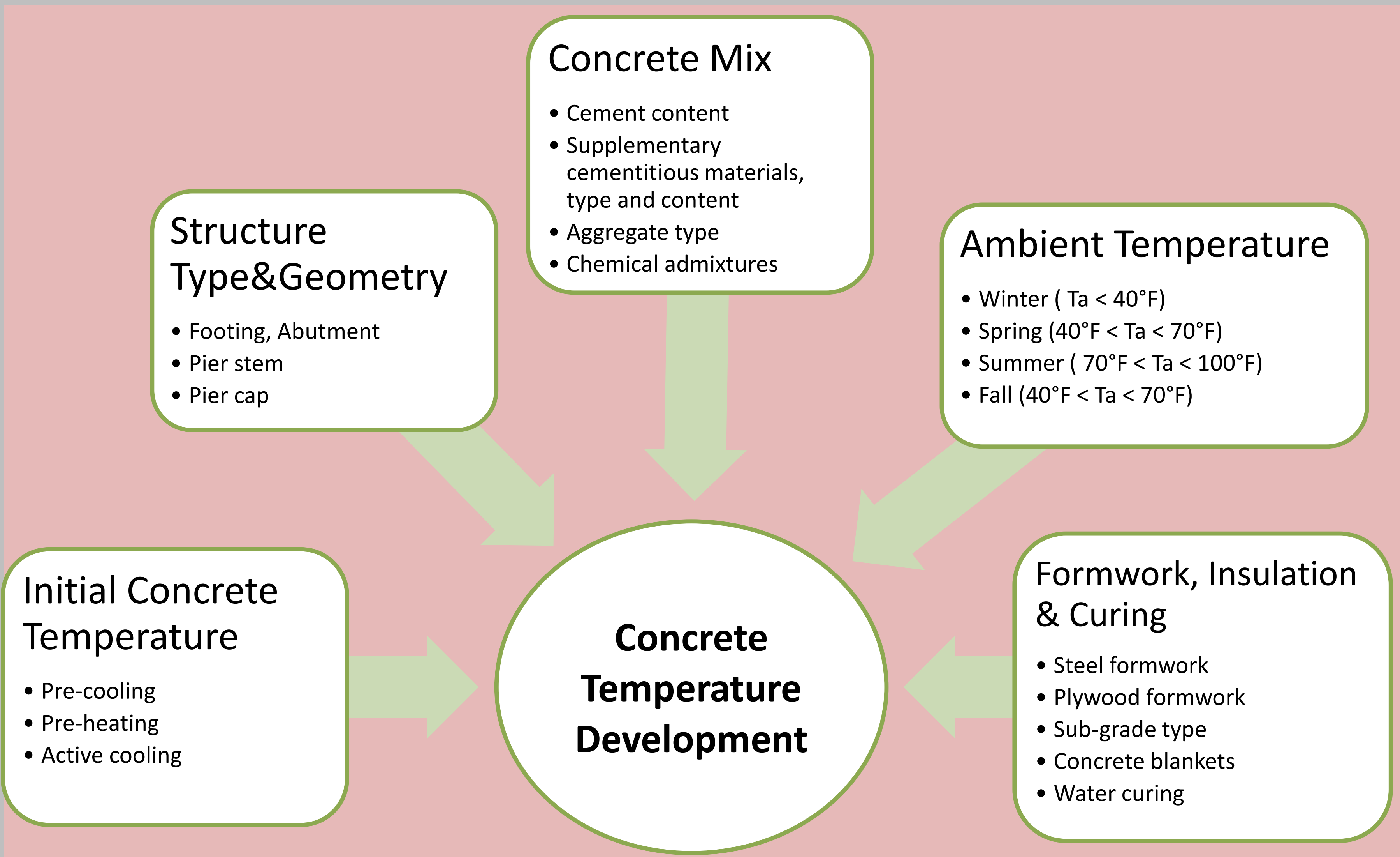
- Actual and predicted thermal properties were compared
- WVU's FEM analysis was found to be very accurate for concrete temperature prediction
- This FEM enabled the Researchers to predict when there would be a thermal problem in the concrete
- Cubes which cracked, did crack in the locations where they were predicted to crack

Stress Results





Factors affect concrete temperature development

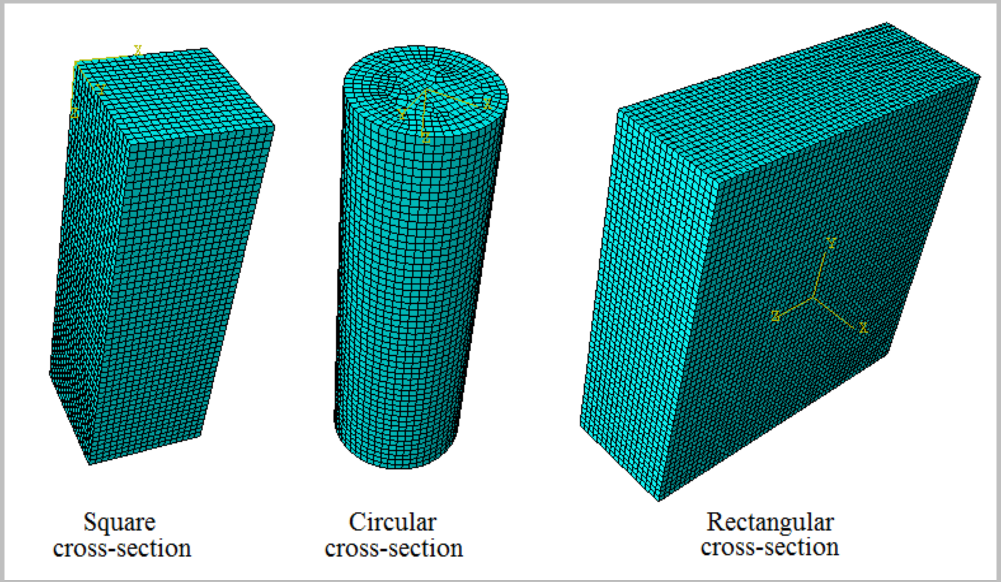


Approach to Problem (cont.)

- Using the FEM, Red/Green Tables were constructed for different types of bridge substructure elements (i.e. pier stems, pier caps, footers, etc.) based on “thermally worst case/hottest” Class B mix
  - Tables showed different sizes of each element
- Tables show which elements are mass (red) and which are non-mass (green)

Mass Concrete Definition Table

- Geometries:
  - -Circular: D x 3D
  - -Square: D x D x 3D
  - -Rectangular: D x 3D x 3D
  - (min dimension: D)
- If the maximum tensile stress is greater than 80% of the estimated tensile strength, the element is mass concrete (red).



Mass Concrete Member Definition Table (80% Strength Limit)

	0 ft – 1 ft	1 ft – 1.5 ft	1.5 ft – 2 ft	2 ft – 2.5 ft	2.5 ft – 3 ft	3 ft – 3.5 ft	3.5 ft – 4 ft	4 ft – 4.5 ft	4.5 ft – 5 ft
Circular	Green	Green	Green	Green	Green	Green	Green	Red	Red
Square	Green	Green	Green	Green	Green	Red	Red	Red	Red
Rectangular	Green	Green	Green	Red	Red	Red	Red	Red	Red

How Tables Would Be Used

- Designers could use tables to **design bridges to minimize the number of "mass" elements (i.e. round columns instead of square)**
- Designers could also use tables for typical WV bridges to **designate particular concrete bridge elements as either "mass" or "non-mass" in the project Plans**
- This would provide more information to Contractors, and **fewer unknowns, prior to bidding** on a project and hopefully result in a **more accurate and economical bid price**

Next Step in Research Project

- New phase of mass concrete research project was started and numbered RP-312
- Same concept of tables with “mass” (red) and “non-mass” (green) elements, but now tables would be based on “cooler” mixes rather than a Class B mix
- “Cooler” (Class M) mixes have less cement and more pozzolans (fly ash and GGBFS)
  - Class M mixes still used “hottest” cement in order to again look at “worst case scenario”
- Also looking at “best construction practices” (i.e. formwork insulation, etc.)
- Goal is to make the size of the “non-mass” elements larger (more green area in the tables)

Class M mixes ("cooler mixes")

- Contractors could contact Concrete Suppliers prior to bidding to check the availability of the Class M mix
  - Class M mix would be an option (not required) in order to further reduce or eliminate the number of "mass" elements
  - Red/Green Tables are being developed based on Class M mixes
  - If Class M mix isn't available, contractor could still use Class B mix, along with Tables developed for Class B mix
- Thermal control plans (TCPS) are required by 1st and 3rd SPs to address how mass concrete elements will be addressed
  - Mass concrete elements result in unknowns because the Contractor has to develop a Thermal Control Plan after the project is awarded
  - TCPs required after award = More unknowns prior to bidding
  - TCPs not needed for Green elements in Tables
- Plans would include Red/Green Tables for Class B (standard) and Class M mixes
- Knowing, prior to bidding, which, if any, elements are mass will reduce the number of unknowns
- Fewer unknowns prior to bidding = better unit bid prices

Class M mixes (cont.)

- Two Class M mixes developed in conjunction with Industry
  - One mix with cementitious material content of 50 % GGBFS (slag cement)
  - One mix with cementitious material content of 30% fly ash
- Class M Requirements
  - Maximum cement factor of 5.4 bags (508 lb./yd^3)
    - 50% GGBFS or 30% fly ash replacement by weight
  - Maximum water-cement ratio of 0.42
  - Minimum 28-day compressive strength of 4300 psi in mix design
    - 56-day strength will be permitted in field
  - 6% $\pm$ 1.0% air content and 5.5 $\pm$ 1.0 inch slump in consistency
- 4-ft cubes cast at WVU with Class M mixes
  - Cubes were instrumented and additional testing was performed in order to develop Red/Green Tables for the two Class M mixes
- Laboratory testing was also performed at WVU on additional batches from a ready-mix supplier and laboratory batches of Class M
  - Resulting information is being used in development of Red/Green Tables for the two Class M mixes

Industry Concerns with Class M

- Class M mixes have a w/c of 0.42 and 508 lbs. of cementitious materials
- This results in 213 lb. of water per yd^3
- Industry had concerns about producing this mix in hot weather
  - Not enough water in the mix to be replaced with ice to cool the mix
  - Water is still needed in the mix for slump and for admixtures to work (can’t be all chemical slump)

Class M Field Tests

- Test placements and 3-ft test cubes were constructed at four WVDOH District locations on hot days
  - 2 Class M GGBFS mixes
  - 2 Class M fly ash mixes
- Test placements at three of the Districts showed that these mixes were able to be batched, transported, placed, and finished during hot weather
  - Data from test placement at fourth District was useless, as the ready-mix supplier batched the Class M mix with wrong type and size of aggregate
- Strengths from these Class M mixes met the required strength prior to 28-days
- Conclusion: GGBFS and fly ash Class M mixes are both feasible for use in the field

Current Work

- Improvement of FEM model
  - Tweaking input parameters
  - Additional lab batches and testing
- Completion of Red/Green tables for Class B and Class M mixes for all bridge substructure elements (i.e. different shapes and sizes)
- Work on “best management practices”
  - Requiring formwork insulation (how much insulation)
  - Revising Red/Green Tables to include insulation as an input parameter
- Should footers be considered mass concrete?
- Discussion about allowing contractors to submit alternate mix designs to the one specified in the Class M SP as long as the thermal properties (i.e. adiabatic temperature rise) are less than or equal to the prescriptive mix specified in the Class M SP
  - More performance-based

Goals of this Approach to Mass Concrete

- Red/Green Tables
  - Show, prior to bidding which elements in a project are mass and non-mass
  - Tables with Class B mixes
  - Tables with Class M mix (Class M mix is optional and not required)
    - Increase the maximum size of “non-mass” elements (more Green area in the tables and less Red)
    - Reduce the total number of mass concrete elements
    - Example: a 5ft diameter column may be considered “mass” with a Class B mix, but may be considered “non-mass” if a Class M mix is used
  - Some very large elements will always be “mass” and will require a thermal control plan

Goals of this Approach to Mass Concrete (cont.)

- Designer use of Red/Green Tables
  - Designers could include Tables in plans to allow Contractors to know which elements would be considered “non-mass” with the use of a Class M mix
  - When designing a bridge, Designers could use the tables to minimize the number of “mass” elements
    - i.e. Round columns instead of square, etc.
    - Gives them options during design (i.e. multiple round pier columns instead of one large rectangular pier stem)

Goals of this Approach to Mass Concrete (cont.)

- Contractor use of Red/Green Tables
  - Contractors could contact Concrete Suppliers prior to bidding to check the availability of the Class M mix
    - Contractors may be willing to pay more for Class M if it eliminates the need for a Thermal Control Plan (TCP)
  - TCPs are required for mass elements in order to detail how thermal issues with those elements will be addressed
  - TCPs result in unknowns because the Contractor has to develop them after the project is awarded
    - Contractor doesn’t know added cost prior to bidding (i.e. cooling tubes, additional curing time prior to form removal, etc.)
  - Knowing, prior to bidding, which elements are mass will reduce the number of unknowns
  - Fewer unknowns prior to bidding = better and more accurate bids

Summary

- Red/Green Tables, Class M mixes, Designer & Contractor use of tables are intended to:
  - Define the concrete elements in a project as mass or non-mass, prior to bidding, in a <u>standard and uniform manner</u>
  - Minimize the number of mass elements
  - Achieve quality concrete and prevent adverse thermal issues in the most economical manner
- Include mass concrete requirements in the Standard Specifications, not in a SP which can be added or removed arbitrarily
- Final Report
  - Tentatively, everything is scheduled to be completed by the end of June 2017

Questions?

Mike Mance, PE

WVDOH, MCS&T Division

(304) 558-9846

mike.a.mance@wv.gov