Where the West Virginia DOH is at with Mass Concrete

WVDOH History of Mass Concrete

- In 2005, a large bridge crossing the Ohio River was being constructed (Blennerhassett Bridge)
- 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
- “Mass Concrete” Special Provision was drafted and put into that project
- First time “mass concrete” was addressed on a WVDOH project

First WVDOH Mass Concrete Special Provision (SP)

- Mass concrete defined as any member whose least dimension exceeded 4-ft
- Thermal Control Plan (TCP) and thermal monitoring required for all mass elements
- Maximum allowable concrete temperature of 160°F and maximum allowable concrete temperature differential of 40°F
  - Greater temperature differential later permitted
- This SP was good for the thermal control of concrete
- Downside of this SP was the unknowns prior to bidding (i.e. element cure time, insulation, cooling pipes, etc.)

WVDOH History of Mass Concrete (cont.)

- Additional bridges were built with that first mass concrete SP
- Large bridges for which there was little question that the mass concrete measures were justified
- Smaller bridges where its need was questioned
- 4-ft minimum dimension was questioned, as well as the need and additional expense of a TCP
- Often times this SP was inserted into projects, and after the project was awarded, it was removed

Second WVDOH Mass Concrete SP

- Still defined mass concrete as any member whose least dimension exceeded 4-ft
- More prescriptive based than first SP
  - TCP wasn't required
  - Mixes with more supplementary cementitious materials (SCMs) and less cement were required
  - Required 7-day moist cure with plastic
  - Concrete placement temperature 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

Issues with Mass Concrete SPs

- Which projects should SPs be inserted into?
  - First SP was good for larger projects
  - Second SP was good for smaller projects
  - What was a large project and what was a small project?
- Which mass concrete SP, if any, should be used on a project?
- Mass concrete SP was sometimes eliminated from projects after the contract was awarded
  - Contractors often offered a credit to the WVDOH to remove the mass concrete SP from a project
  - This took place after bidding and award of contract
  - Was the credit fair and uniform on all projects?
  - Inconsistent application/removal of this SP

Next Step

- Measures still needed to reduce the potential for thermal cracking and increase concrete durability
- Mass concrete Research Problem Statement submitted
- Mass concrete research project started by WVU

Mass Concrete Research Project (RP-257)

- Goal of this project is to:
  - Define when there is a potential for thermal cracking to occur in newly placed concrete
  - Take the most economic approach to reduce this potential through preventative measures during design and construction

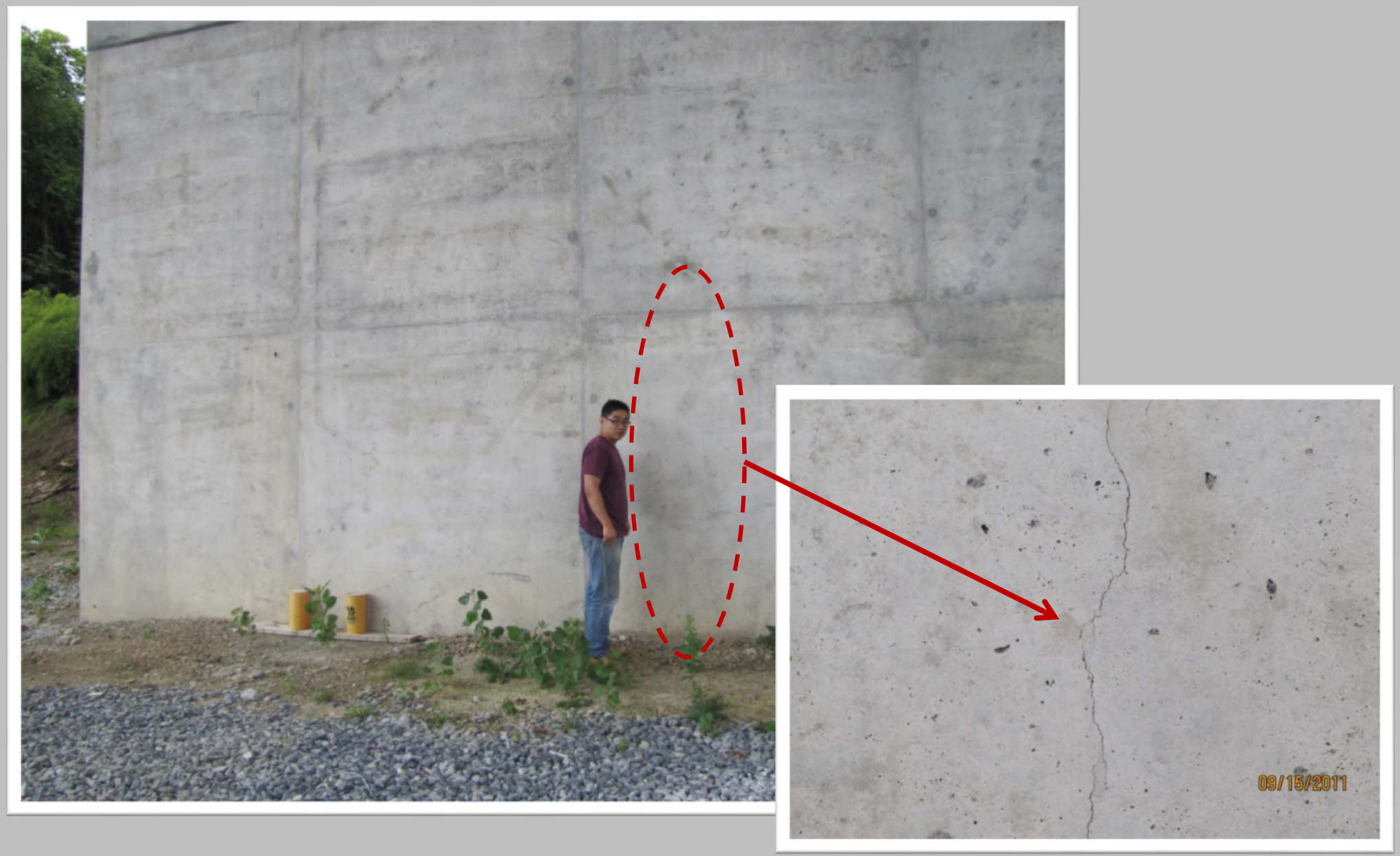
Initial Data Gathering

- 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
  - Similar approaches regarding how to control the temperature in newly placed concrete, but no consistent approach on when to apply these thermal control measures
- Temperature sensors were installed in the concrete elements of bridge projects in several WVDOH districts
  - 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)

Initial Data Gathering (cont.)

- 6-ft concrete cubes were constructed with standard Class B (bridge substructure) mix in four Districts
  - Temperature sensors installed in cubes and monitored
  - Cores taken from cubes to compare actual strength vs. cylinder strength vs. predicted strength

6-ft cube with normal Class B mix
Coring to compare actual in-place strength vs. cylinder strength vs. predicted strength

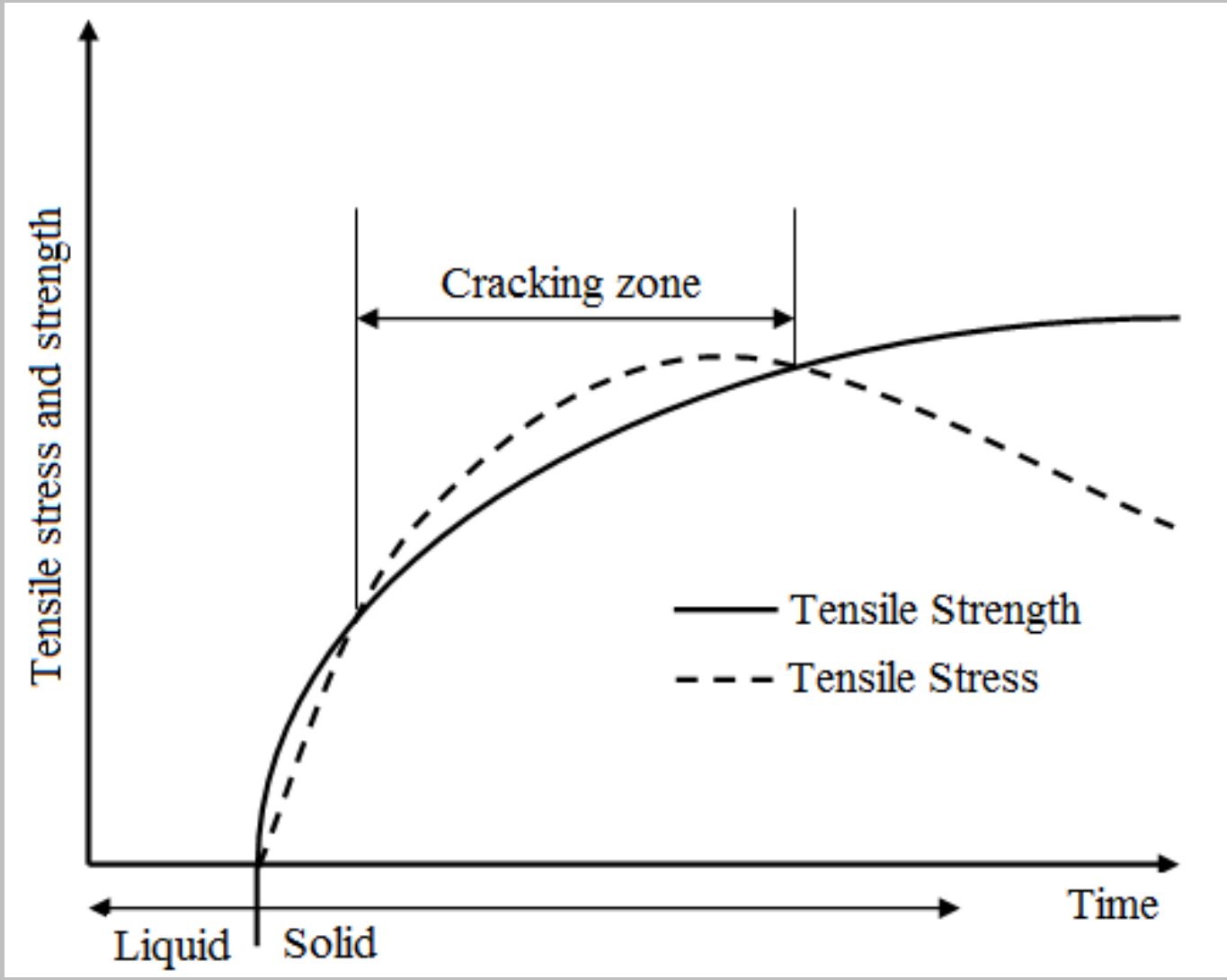
Initial Data Gathering Conclusions

- Concrete temperatures and temperature differentials greater than the limits allowed in the first SP, and thermal cracking were occurring in bridge elements constructed with the current WVDOH mixes
- Measures for thermal control of concrete were still needed

Approach to Problem

- Find a way to incorporate thermal control measures into the WVDOH Standard Specifications and Plans prior to bidding
- Mass concrete defined as a concrete element in 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.)

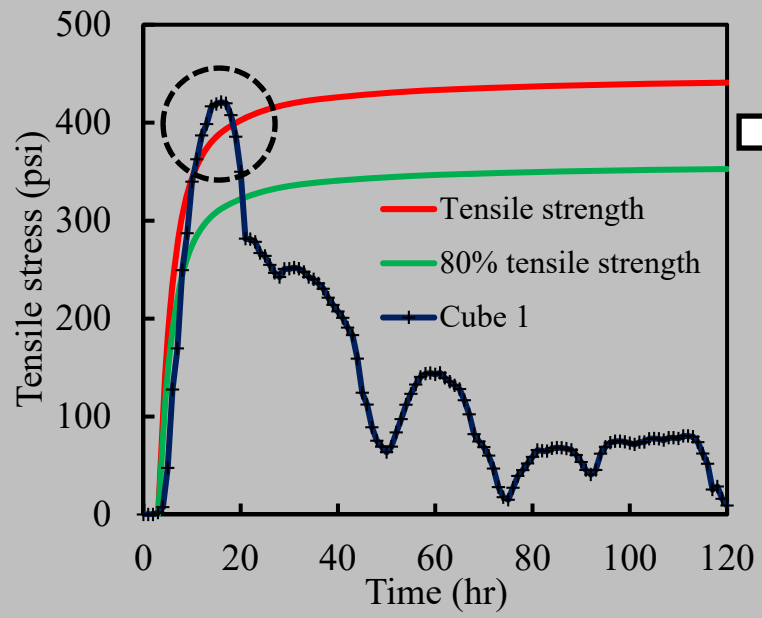
- Several 4-ft test cubes were constructed with the "hottest" Class B mix (bridge substructure mix) allowed by WVDOH specifications
  - Maximum cement content
  - No pozzolans
  - "Hottest" cement from our approved cement sources (high SO_3 & C_3A)
  - Limestone was required as coarse aggregate (lower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

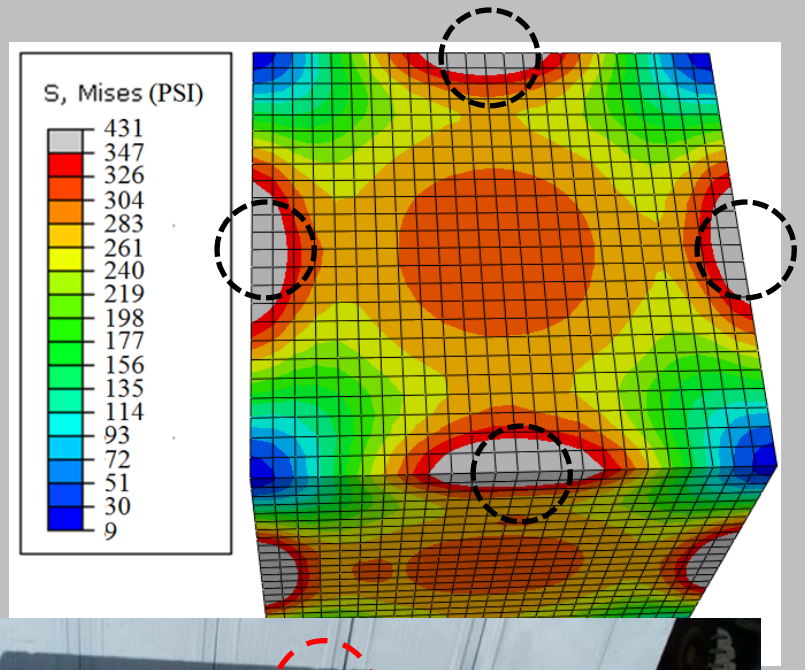
4-ft “Hot” Class B Cube at WVU

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



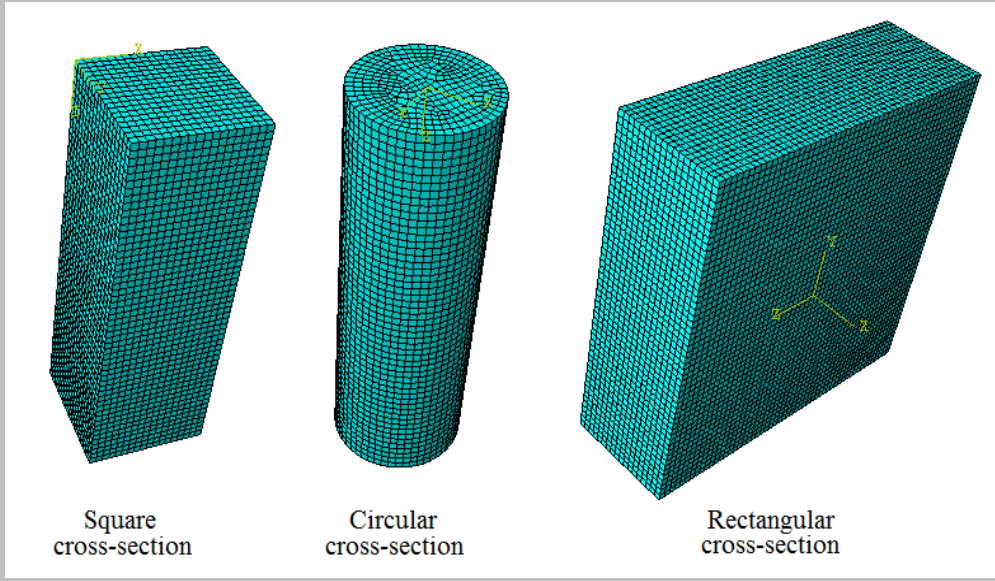


Approach to Problem (cont.)

- 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 “hottest” Class B mix
- Tables show which size 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	1.5 ft	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	4.5 ft	5 ft
Circular										
Square										
Rectangular										

Next Step in Research Project

- New phase of mass concrete research project (RP-312) was started
- Same concept of Tables with Red/Green tables, 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 or GGBFS)
- Class M mix would be an option (instead of Class B) in order to further reduce or eliminate the number of “mass” elements
  - If Class M mix isn’t available, contractor could still use Class B mix, along with Tables developed for Class B mix
- 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

- Two Class M mixes developed in conjunction with Industry
- Class M Requirements
  - Maximum cement factor of 508 lb./yd^3 (56 lb./yd^3 less than Class B)
  - 50% GGBFS (slag cement) 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 permitted in field for acceptance
  - 6% $\pm$ 1.0% air content and 5.5 $\pm$ 1.0 inch slump
- 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
- Additional testing of laboratory batches of Class M was also performed at WVU

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

- Class M test cubes and test slabs were constructed at four WVDOH District locations on hot days
  - Showed that these mixes were able to be batched, transported, placed, and finished during hot weather
- Strengths met the required 28-day strength
- Field testing found several mixes had a w/c > 0.42, even though batch tickets showed 0.42
- Although 28-day strengths were met, 1-day and 3-day strengths were sometimes not met
  - Higher w/c possible cause
  - High dosage of hydration control stabilizing admixture may have also been a cause
- 1-day and 3-day strengths based on 0.42 w/c are critical input parameters in FEM
  - Higher early age compressive strength = higher early age tensile strength = more crack resistant concrete
  - Lower w/c = higher strength
- Conclusion: GGBFS and fly ash Class M mixes are both feasible for use in the field, but early age strength issue needs addressed

Solution to Early Age Strength Issue (Current Phase of Research Project)

- Revise Class B Red-Green tables to be based on 0.49 w/c instead of 0.42 w/c
  - Unlikely that 0.49 w/c would be exceeded in the field for Class B
- Revise Class M Red-Green tables (for both fly ash & GGBFS mixes) to be based on 0.46 w/c instead of 0.42 w/c
  - Class M mix design would still require maximum 0.42 w/c, but basing tables on 0.46 w/c builds in a "safety factor" for field conditions and variations
  - 0.46 w/c was the highest w/c found during field tests
  - 1-day & 3-day strengths would still be required in the Class M mix design, to ensure that the mix is capable of getting these strengths, but these strengths would not be required in the field
    - Addresses Hydration Control Stabilizing Admixture issues

Additional Work in Current Phase of Research Project

- Include R-5 formwork insulation in the revisions to the Class B and Class M Red-Green Tables
  - R-5 insulation = 1 layer of insulation blanket (feasible during construction)
- Include a maximum concrete placement temperature of 75°F in Class M Red-Green Tables and in the Class M Specification
- 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

Class M Mass Concrete Definition Table with R-5 insulation

Mass Concrete Definition Table for Class M Concrete with R5 Insulation (80% Strength Limit)

	1 ft	1.5 ft	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	4.5 ft	5 ft	5.5 ft	6 ft	6.5 ft	7 ft	7.5 ft	8 ft
Circular															
Square															
Rectangular															

DRAFT/PRELIMINARY

- Further analysis are being conducted to determine the best way of removing the insulation layers to maximize the sizes in the Mass Definition Table and minimizing the thermal shock and cracking risk on the concrete surface.

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 and Class M mixes
    - Class M mix is an option instead of Class B
  - Class M mixes:
    - 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
  - Green elements in Tables don’t require TCP

Goals of this Approach to Mass Concrete (cont.)

- Designer use of Red/Green Tables
  - 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)
  - Designers would use Red/Green Tables to note in the Plans which elements are “mass” or “non-mass”

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 (Red area in Tables) in order to detail how thermal issues with those elements will be addressed
  - TCPs result in unknowns prior to bidding 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 standard and uniform manner
  - Minimize the number of mass elements
  - Achieve quality concrete and prevent adverse thermal issues in the most economic manner
- Include mass concrete requirements in the Standard Specifications, not in a SP, which can be added or removed arbitrarily

Questions?

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