VTRC

Virginia Transportation Research Council

Virginia's Mass Concrete Experiences: Requirements for a Good Specification

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Outline

- Mass Concrete
- Temperature Measurement
- Testing for strength
- Field Applications
  – Bridge on I-895 over James River
  – Route 33 Bridges at West Point
  – Bridge at Chincoteague
- 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

Problem

- Heat is generated during hydration
- Temperature differences occur between the interior and the exterior surface
- Significant thermal stresses occur due to restraint
- Moisture differences contribute to stresses
- Cracks occur when stresses exceed the strength of the concrete
- Cracks adversely affect durability and structural integrity

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

Temperature Prediction

- Maximum Temp = Initial concrete Temperature plus adiabatic temperature rise (heat energy when no loss occurs) minus heat loss to the surrounding
- Simplistic Method (for placements > 6 ft thick) ignores heat loss
- Refined method: finite element modeling includes control measures (such as cooling, insulation) and the environment

Reducing Thermal Issues

- Use a mixture with reduced heat: low amount of cementitious material
- Limit the maximum temperature: mixture design, precooling concrete, internal cooling pipes
- Limit the temperature difference: curing, insulation

- ACI 207, 224, 301

Mass Concrete Specifications

- Limits on
  - placement temperature
  - Maximum temperature, and
  - maximum difference in temperature between interior and surface concrete

  are commonly used in an attempt to minimize cracking of massive sections

FLDOT Mass Concrete

- Minimum dimension > 36 in
- Volume to surface area > 12 in
- Drilled shafts diameter > 72 in
- Temperature difference < 35 ºF (at higher difference potentially damaging cracks are likely to form)
- Maximum initial concrete temperature is 85 ºF unless precautions are taken (then 100 ºF)
- Class F fly ash 35 to 50% and slag 50 to 70 % if core temp >165 ºF

TXDOT Mass Concrete

- Least dimension: 5 ft
- Max temperature: 160 ºF
- Max temperature difference 35 ºF
- Initial maximum temperature 75 ºF
- Class F fly ash up to 45 %
- ConcreteWorks computer program

VDOT Mass Concrete

- Max temp 160 ºF (if slag concrete 170 ºF)
- Max temp difference 35 ºF
- Class F fly ash 25 to 40 %
- Slag 50 to 75%
- Max initial concrete temperature 95 ºF
- Thermocouples to be cast in-line vertically in the structure to measure the thermal gradient between the core and the surface

Strength Measurement

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

Mass Concrete

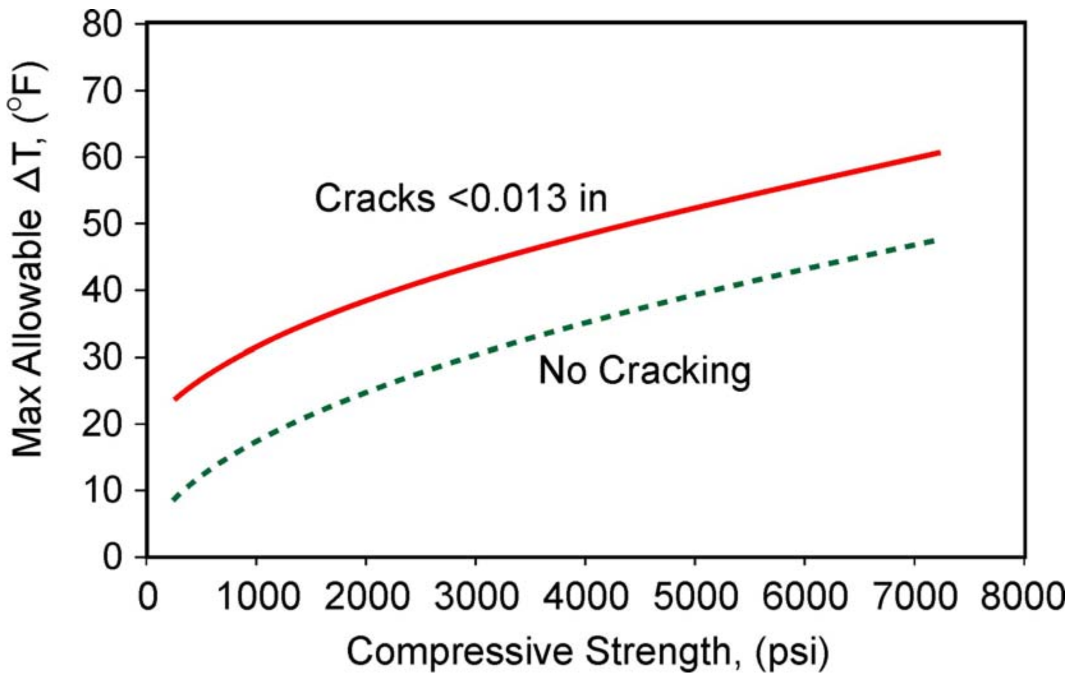
I-895 over the James River

I-895

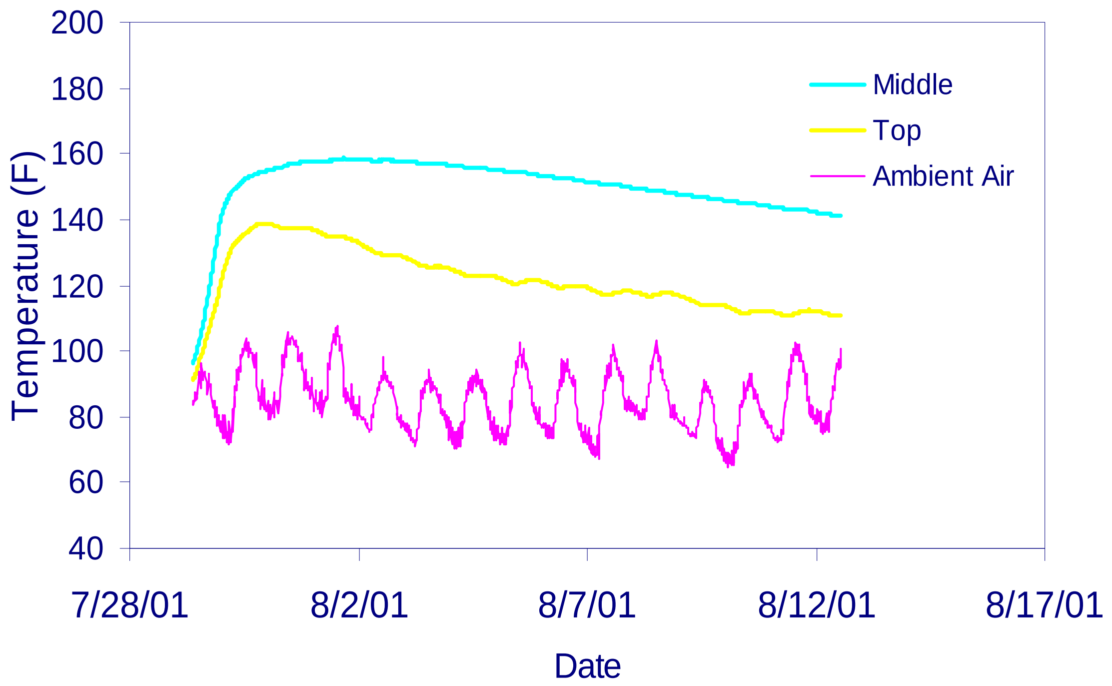
- Large footings (35 x 40 x 10 ft)
- High temperature development
- Slag used as 75% of cementitious material to control temperature

I-895 Footing

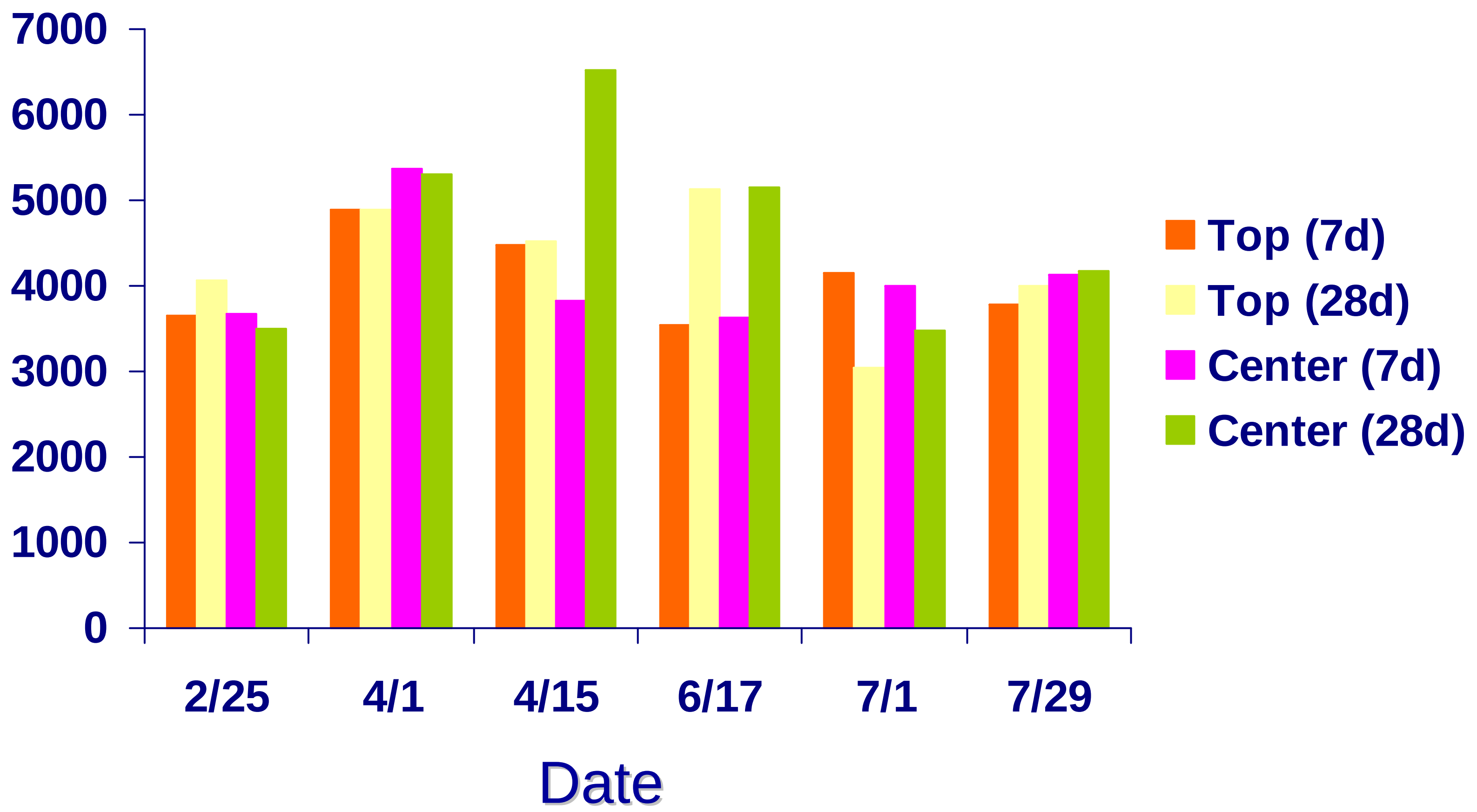
- pc=142 lb/yd^3
- Slag=423 lb/yd3
- 75% slag
- Max w/cm = 0.49
- 30 MPa (4350 psi)



Temperature Data



I-895 Compressive Strength (psi)



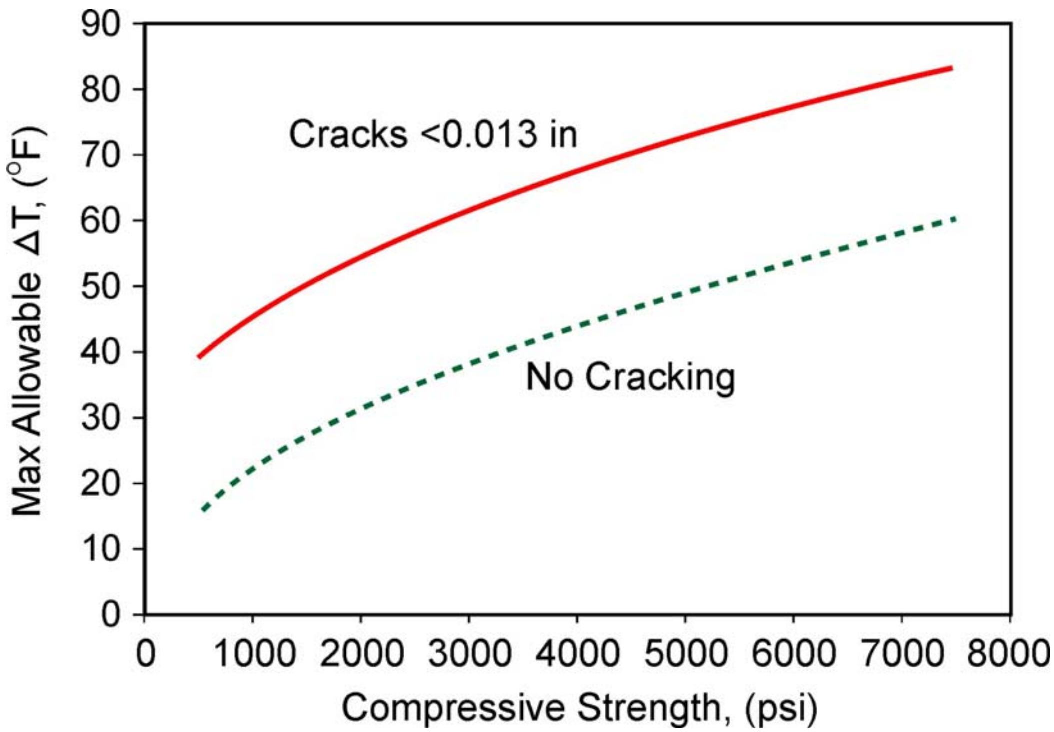
PERMEABILITY

- 561 coulombs
- 840 coulombs

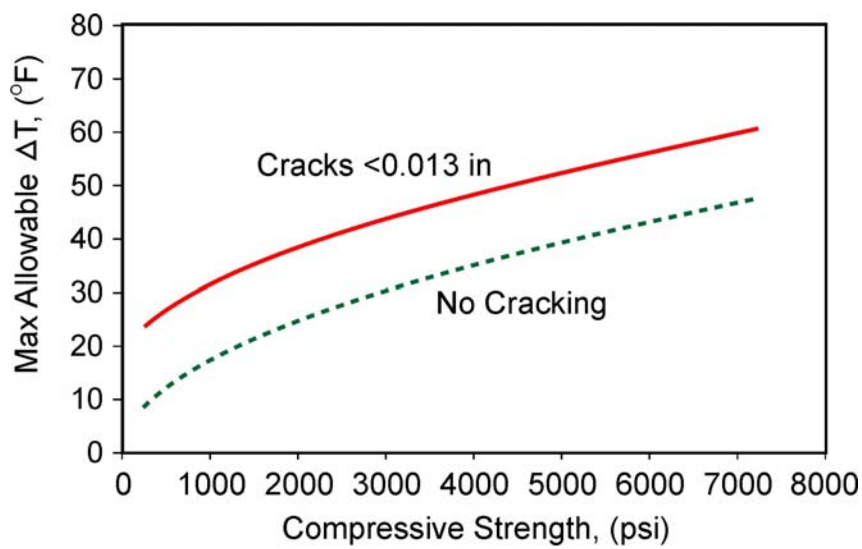
Footings, Columns, Beams

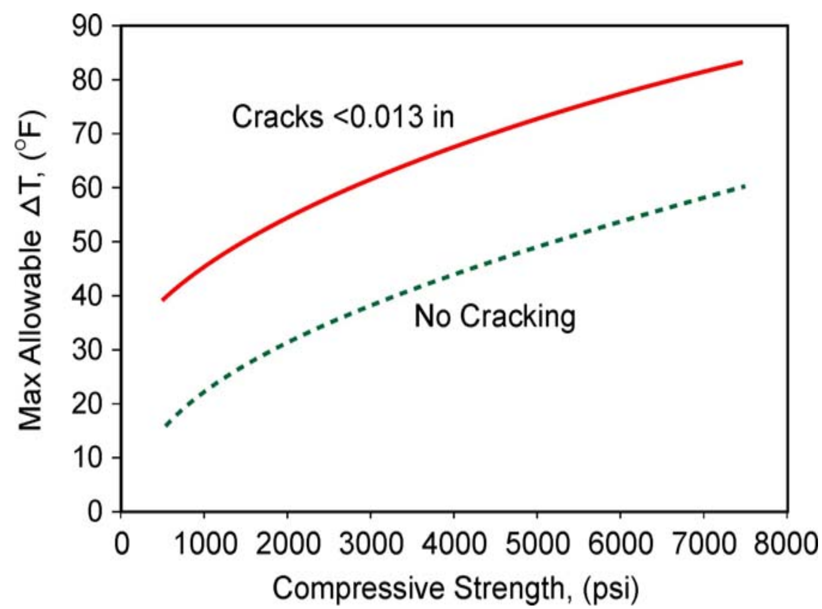
2.5 m (8.2 ft) Square Beam

- 822 lb/yd3 cementitious material with 70% slag
- Max w/cm = 0.33
- 45 MPa (6500 psi)



Footing versus Beam

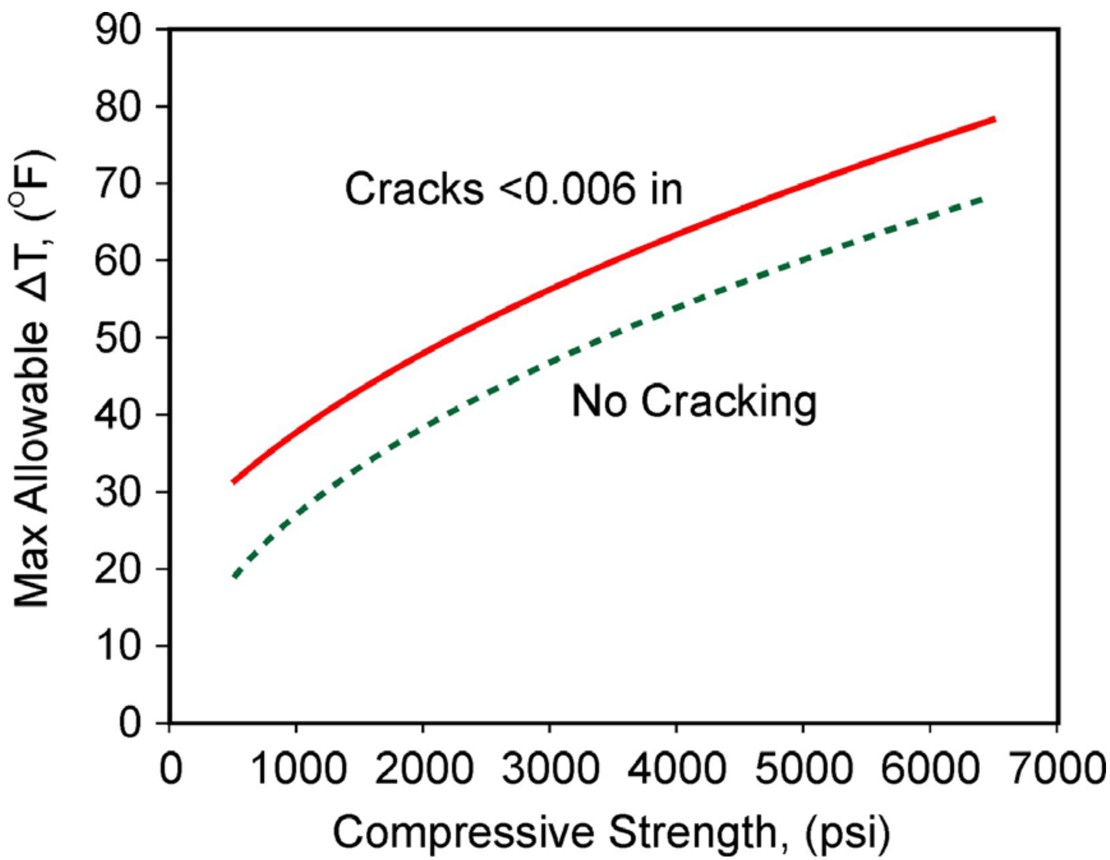




Route 33 Bridges

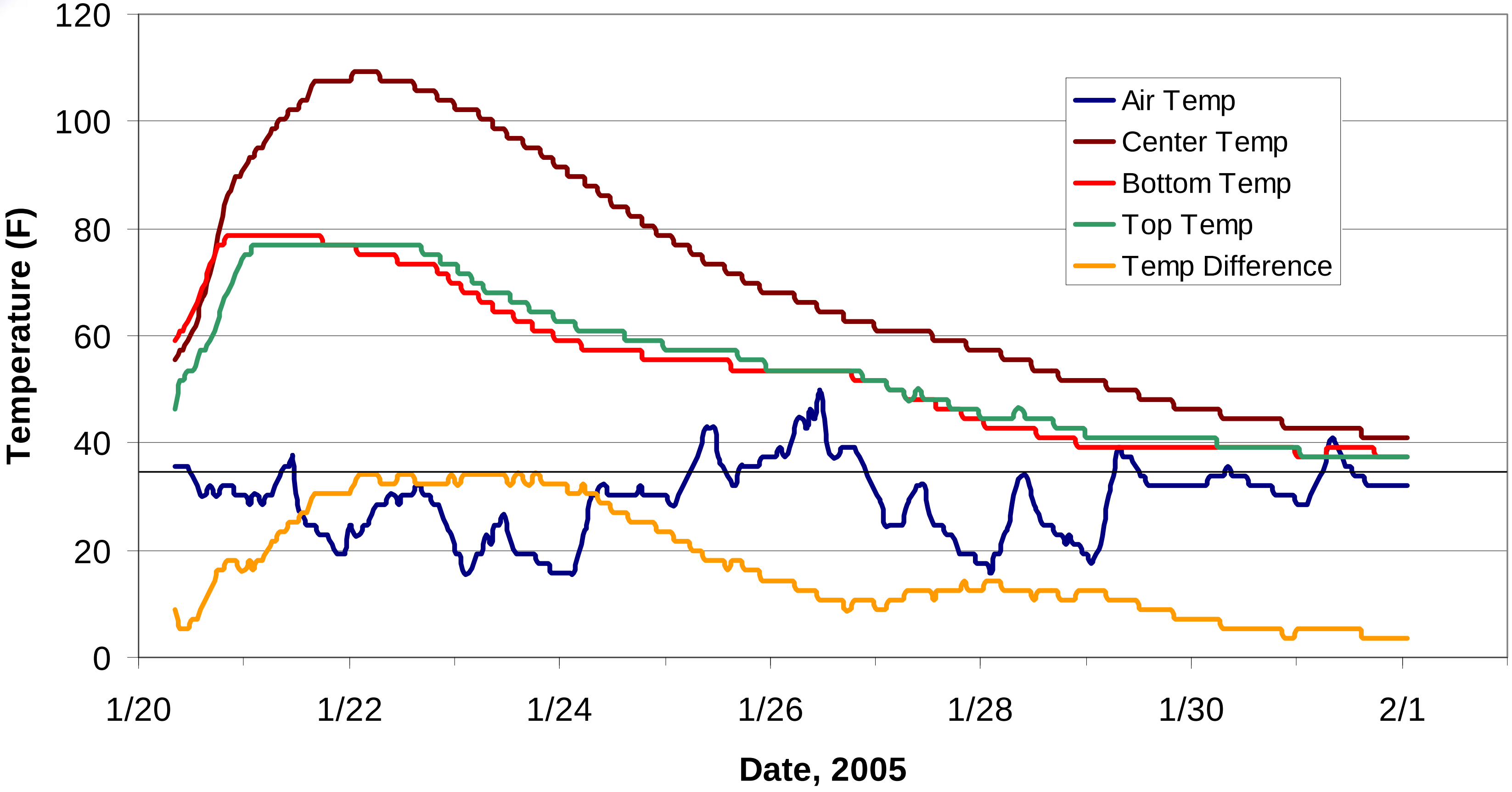
Route 33 Pier Caps

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

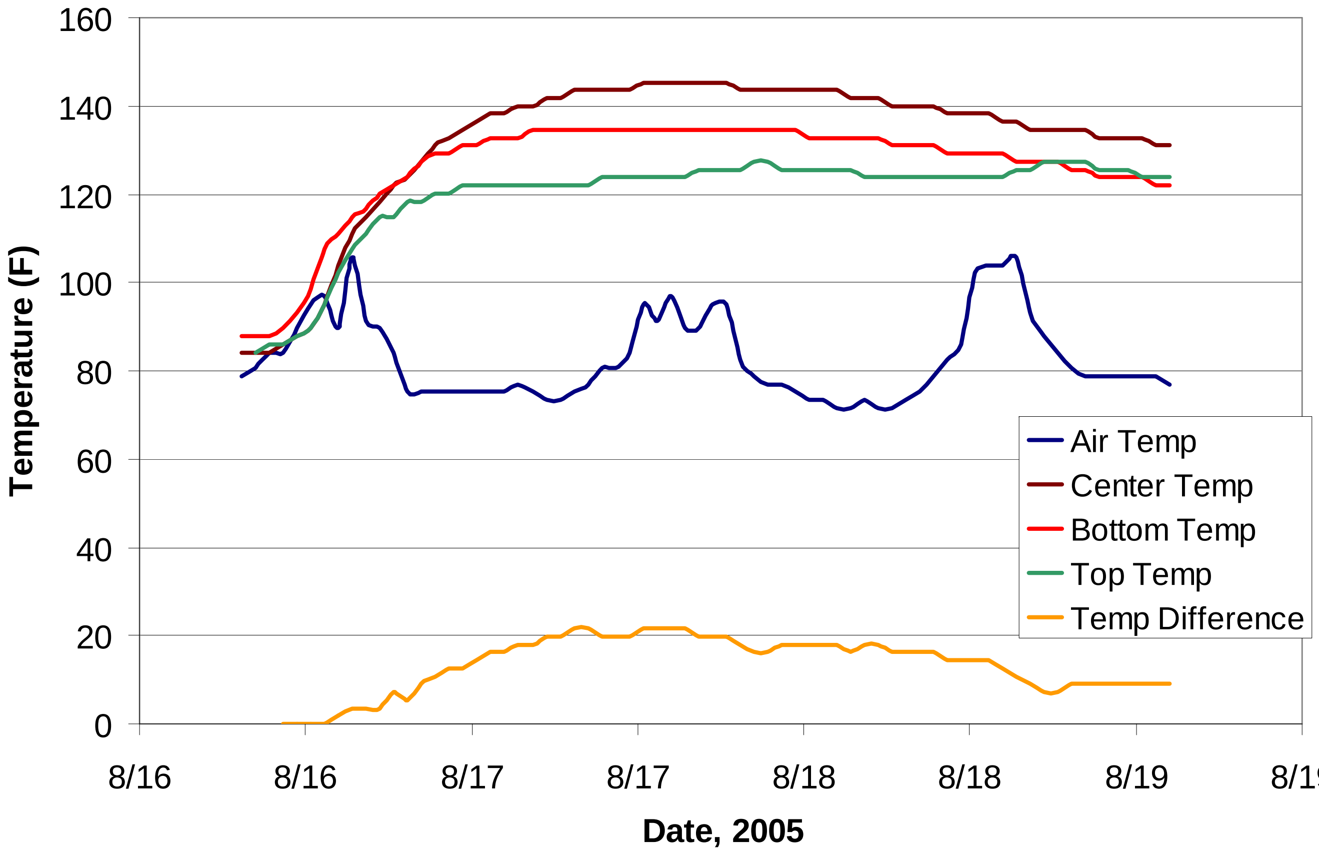


- Column caps 6x6 and 6X6.5 ft

Mattaponi Bridge, Pier Cap 12



Pamunkey Bridge, Pier Cap 47



Strength and Permeability

Footing, Pier, Cap

Values	Strength (psi)		Permeability (coulomb)	
	Mattaponi	Pamunkey	Mattaponi	Pamunkey
Average	3732	3959	449	369
Std Dev	467	495	264	144
Minimum	2770	2793	210	83
Maximum	5420	5073	1804	928
Number	132	202	132	199

Chincoteague Bridge

- On Route 175 over Black Narrows and Lewis Creek Channel. The large bascule footing was placed in 2008.
- Change in the concrete class in bascule footing to A3 and need for mass concrete specification
- Contractor requested twice the cost of concrete for a thermal analysis and thermal monitoring

Bascule Footing

- 110 tons of steel

Thermal Control Plan

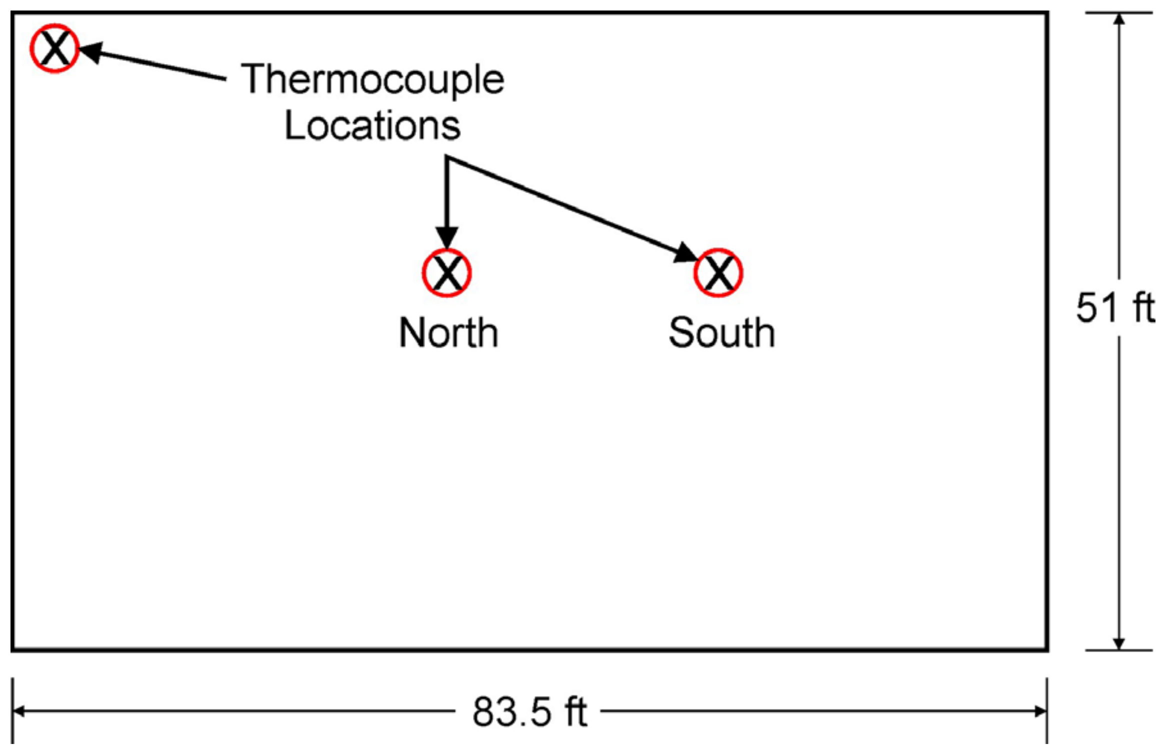
- A thermal analysis model used by the cement producer to estimate the temperature difference for potential cracking.
- Low-heat concrete mixture using 539 lb/yd^3 cementitious material with 30% fly ash. Regular A3 has a minimum cementitious content of 588 lb/yd^3.
- Heavy reinforcement to control cracking
- Water curing and insulation
- Time of placement; late May before the hot weather
- VTRC/VDOT to monitor the temperatures

Mixture Proportions, Strength and Permeability

- Bascule Footing
- pc=378 lb/yd^3
- Class F fly ash=161 lb/yd^3
- Water=246 lb/yd^3
- Max w/cm=0.46
- Samples n=13, str=avg of 3; perm= 1
- Strength: avg=5114 psi; stdev=420 psi
- Perm: avg=373 coulombs; stdev=79 coulombs

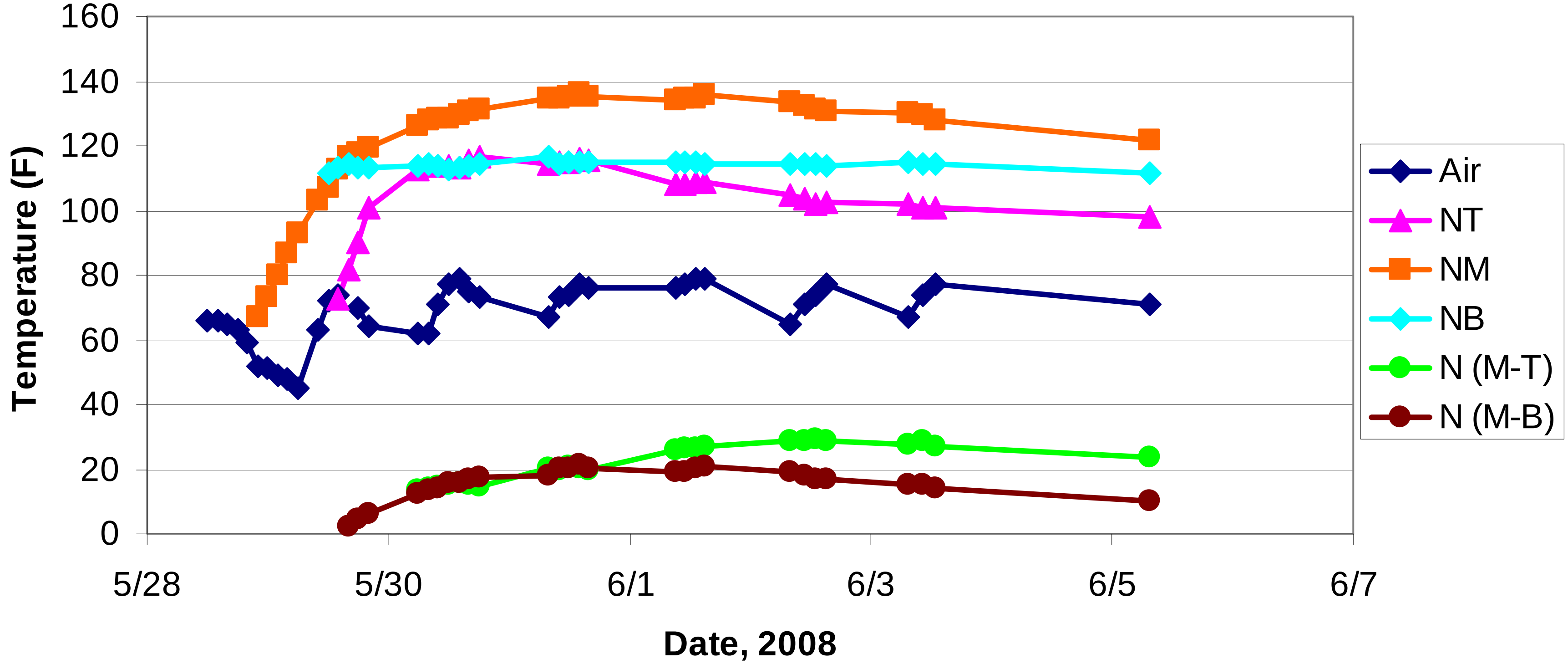
Bascule Footing

- 7-ft deep



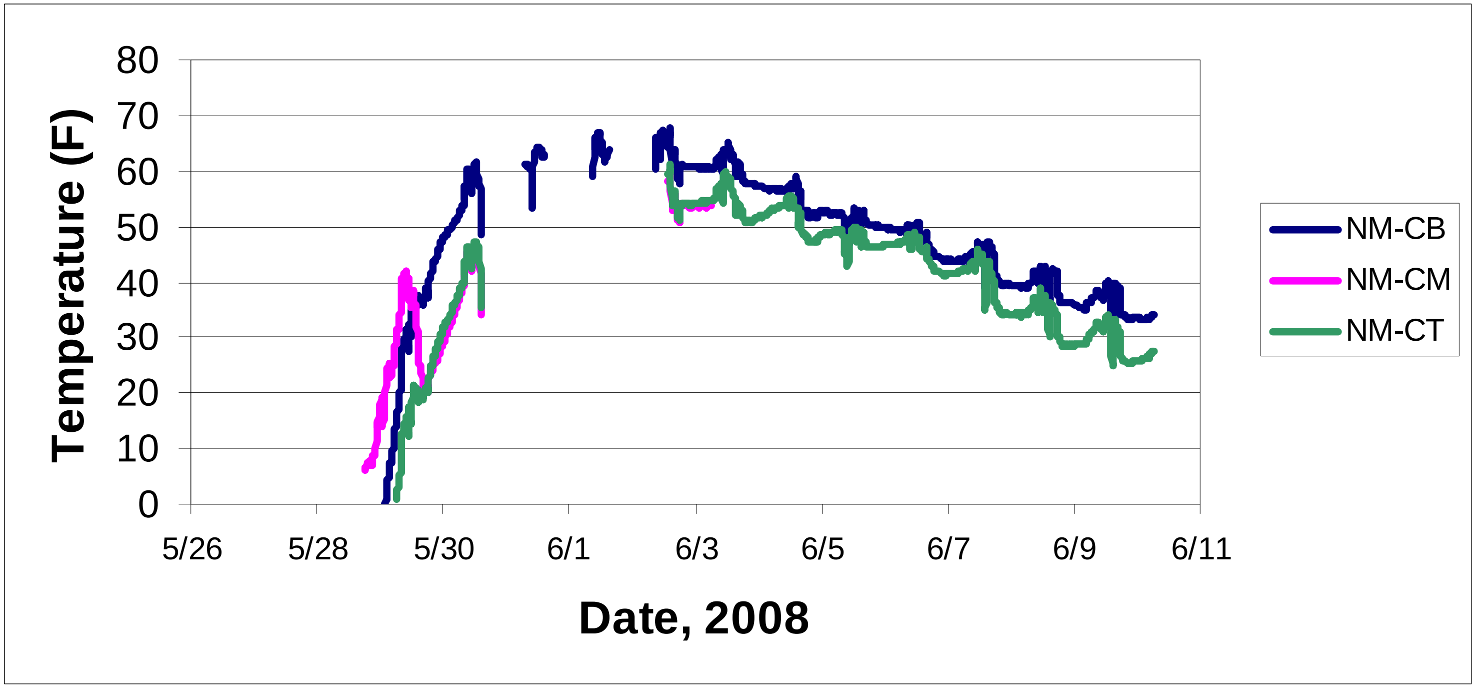
Chincoteague Footing

Maximum and Differential Temperature



Chincoteague Footing

Temperature Difference



Edges and Corners

ACI 207.4R:

- Tensile strains develop more quickly at edges and corners than on the sides or tops of the structure. Increased insulation along the edges and at corners helps.
- The development of steep thermal gradients near exposed surfaces during early ages while the modulus of elasticity is very low is usually not a serious condition.

Specs

- Measure temperature in mass concrete at the core and surface along a vertical direction and at the corners
- Base strength on maturity or temperature matched cure specimens (at least 7 days temperature matching)

Specs

- Any placement of structural concrete with a minimum dimension greater than 3 ft. Smaller dimensions should be considered if Type III cement or accelerators or cementitious material exceeding 600 lb/yd3 is used.

- Drilled shafts with a minimum diameter of 4 ft.

Specs

Prescriptive approach

- Limit initial concrete temperature to 85ºF
- Limit maximum temperature to 160 ºF, unless 40-50% Class F fly ash or 60-75% slag is used; then the maximum temperature may be 170 ºF.
- Temperature differential shall be (35 ºF)
- Require controls on mixture proportions: maximum cementitious material shall be 600 lb/yd^3, and minimum fly ash 25% and minimum slag 50%, specify maximum w/cm, provide insulation

Specs

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

Conclusion

- Mass concrete is prone to cracking. Temperature monitoring is needed.
- Prescriptive specs need initial, maximum, and differential concrete temperature. Limits on maximum cementitious material and minimum SCM, and w/cm are included.
- ERS approach is better. Contractor designs and assumes responsibility for the end product. Contractor provides data to show that for the expected conditions and the specific structure the desired product (with satisfactory strength, durability, limited or no cracking) is achievable.

Questions?