SPECIAL PROVISIONS
FOR
MASS CONCRETE – CONTROL OF HEAT OF HYDRATION

Polk County
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Effective Date
November 19, 2019

THE STANDARD SPECIFICATIONS, SERIES 2015, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE SPECIAL PROVISIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

150577.01 DESCRIPTION.

A. Produce a mass concrete placement free of cracks caused or worsened by concrete heat of hydration. Accomplish this through appropriate concrete mix design and control of concrete temperatures and temperature differences. Use of concrete pre-cooling, concrete post-cooling, application of insulation or external heat, and/or selection of reduced heat of hydration concrete mix may be appropriate for this purpose.

B. Compliance with this specification may result in long durations of temperature control which could impact the sequence and schedule of planned work. The Contractor shall implement procedures to control concrete temperature that are compatible with the work plan and project schedule.

C. Mass concrete is defined as any concrete placement with a least dimension greater than 4.5 feet. Mass concrete with a least dimension between 4.5 feet and 6.5 feet must satisfy Tier 1 temperature control plan requirements. Mass concrete with a least dimension greater than 6.5 feet must satisfy Tier 2 temperature control plan requirements. Tier 1 and Tier 2 temperature control plan requirements are defined in Article SP-150577.03, A.

D. This specification does not apply to concrete drilled shafts.

E. Apply Section 2403 and Division 41 of the Standard Specifications with the following modifications.

150577.02 MATERIALS.

A. Cement shall be Type I, II, IP or IS.

B. Use any combination of Ground Granulated Blast Furnace Slag or Class F fly ash. Class C fly ash may also be used with a maximum substitution of 20%. The maximum total substitution of Portland cement shall not exceed 50%, including the amount of blended cement.

C. Cementitious content shall be a minimum of 560 pounds per cubic yard.

D. Maximum water to cementitious ratio shall be 0.45.

E. Air entrainment shall be used. To improve workability and aid in air entrainment, water reducing or retarding admixtures may be used in accordance with the contract documents.

150577.03 CONSTRUCTION.

A. Thermal Control Plan.

1. General.

a. Develop and submit a written Thermal Control Plan (TCP) to the Engineer describing the procedures that will be used to maintain compliance with the maximum temperature and maximum temperature difference requirements of Article SP-150577.03, B. The TCP shall provide sufficient detail to demonstrate the Contractor has performed adequate planning to verify and control maximum temperature and maximum temperature difference for the full duration of thermal control. Submit the TCP at least 30 calendar days before the first intended structural mass concrete placement.

b. Do not place concrete covered by this specification until the equipment and materials necessary to facilitate the plan are on site and ready for use, and the TCP has received written approval by the Engineer.

c. Approval of the TCP does not relieve the Contractor from meeting the requirements of this specification.

2. Tier 1 Thermal Control Plan (concrete least dimension ≤ 6.5 feet).

For mass concrete placements with a least dimension less than or equal to 6.5 feet, the Contractor shall provide a thermal control plan that includes, but is not limited to, the following:

a. A listing of the mass concrete placements addressed by the TCP, including dimensions of each placement.

b. The approved concrete mix design.

c. The limits for concrete temperature, including initial placement temperature, maximum temperature after placement, and maximum temperature difference.

d. Procedures to maintain initial concrete placement temperature within the limits specified in Article SP-150577.03, B. This may include pre-cooling of mix components, scheduling of placements to optimize ambient weather conditions, or other approved means.

e. Procedures to manage concrete temperature and temperature difference after placement, as may be necessary. This may include insulation of formwork and finished surfaces, external heating, or other approved means.

f. Procedures and equipment used to monitor concrete temperature and temperature difference in accordance with Article SP-150577.03, B, 5, including the location, quantity, and manufacturer's product data for the temperature sensors.

g. Procedures for corrective intervention during the thermal control period (addition or extraction of heat, as feasible) for production concrete, should temperature monitoring indicate potential or confirmed non-compliance with the maximum temperature or maximum temperature difference limit specified in Article SP-150577.03, B.

3. Tier 2 Thermal Control Plan (concrete least dimension > 6.5 feet).

a. For mass concrete placements with a least dimension greater than 6.5 feet, the TCP shall be developed by a Professional Engineer, licensed in the State of Iowa and competent in the modeling, design and temperature control of concrete in mass elements (TC Engineer). The TC Engineer shall formulate, implement, administer and monitor the TCP, making adjustments as necessary to ensure compliance with the contract documents.

b. The use of thermal modeling shall be required. Thermal modeling shall predict temperature and temperature difference in the mass concrete placements and estimate the duration of thermal control. Thermal modeling shall consider the proposed thermal control measures and anticipated range of placement conditions and temperatures.

c. At the Contractor's option, a Tier 2 TCP may be submitted for mass concrete placements with least dimension less than or equal to 6.5 feet.

d. The Tier 2 TCP shall include all requirements of the Tier 1 TCP, in addition to the following:

1) A list containing at least three mass concrete projects, of similar dimension and thermal control requirements to those shown on the plans, completed by the TC Engineer in the last 3 years. The list of projects shall include names and contact information of owner's representatives who can verify the TC Engineer's participation on those projects.

2) The calculated or measured adiabatic temperature rise of the concrete mix design.

3) The predicted maximum temperature in the mass concrete based on the expected conditions at the time of placement and the use of proposed measures to control temperature.

4) The predicted maximum temperature difference in the mass concrete based on the expected conditions at the time of placement and the use of proposed measures to control temperature difference.

5) Details of proposed measures to control mass concrete temperature and temperature difference, consistent with the TC Engineer's thermal model. The proposed measures shall be as needed to ensure compliance with maximum temperature and maximum temperature difference requirements.

6) The range of conditions, including concrete placement temperature range and ambient temperature range, for which the TCP is appropriate.

7) The estimated duration of thermal control.

B. Thermal Control Requirements.

1. Concrete Placement Temperature.

a. The concrete temperature at time of placement shall not exceed 70°F and shall not be less than 40°F.

b. Maximum concrete temperature at the time of placement may be modified by the TC Engineer, when supported by thermal analysis, in conjunction with a Tier 2 TCP. In no case shall maximum concrete temperature at time of placement exceed 90°F.

2. Maximum Concrete Temperature.

a. The maximum temperature within the mass concrete shall not exceed 160°F.

b. The maximum temperature will be evaluated at each temperature sensor location placed in accordance with Article SP-150577.03, B, 5 (includes standard, conditional and discretionary sensors, as applicable).

3. Temperature Difference Limit.

a. The maximum temperature difference between the interior of the section and the surface of the section shall not exceed the specified limits.

b. The maximum temperature difference will be evaluated at each surface sensor location placed in accordance with Article SP-150577.03, B, 5 (includes standard, conditional and discretionary sensors, as applicable). Temperature difference will be calculated as the difference between the temperature of the center of mass sensor and the temperature at each surface sensor location, respectively.

1) Mass concrete placements subject to Tier 1 and Tier 2 TCP requirements shall satisfy the temperature difference limits in the following table:

Hours after placement	Maximum temperature difference, °F
0-24	20
24-48	30
48-72	40
72	50

2) **Alternate Temperature Difference Limit (ATD).**

a) The temperature difference limit may be modified by the TC Engineer, when supported by thermal analysis, in conjunction with a Tier 2 TCP.

b) The ATD shall be developed by the Contractor and TC Engineer using measured properties of the concrete mixture. Pre-development of a compressive strength maturity curve for the concrete mixture shall be required, in accordance with Materials I.M. 383. The ATD shall only be considered valid for the specific mix tested. In the absence of a valid and approved ATD, the temperature difference limits of Article SP-150577.03, B, 3, a shall apply.

(1) Required Pre-Testing to Develop the ATD.

(a) The Contractor shall obtain test results using cylinders from the same batch of concrete that are properly fabricated, cured at standard laboratory conditions, and are 14 to 56 days old at the time of testing.

(b) Two cylinders will be tested in accordance with the current version of AASHTO T336 (CTE). Three cylinders will be tested in accordance with the current version of ASTM C496 (tensile strength). Three cylinders will be tested in accordance with the current version of ASTM C469 (elastic modulus), and these cylinders will then be tested in accordance with ASTM C39 (compressive strength). Testing shall be performed by an AASHTO-accredited laboratory with experience performing the listed test methods.

(c) All ASTM C39, ASTM C496, and ASTM C469 testing shall be performed on the same day. The test reports must include a statement from the laboratory that this requirement was met, and test reports must be included with the TCP.

(d) The laboratory shall report the individual and average value for each test method, and these averages shall be used in the calculations described in Article SP-150577.03, B, 3, b, 2. The strength and modulus shall be reported in units of psi and CTE shall be in units of inch per inch per °F.

(e) The following equations shall be used to determine the T-factor and E-factor to be used in accordance with Article SP-150577.03, B, 3, b, 2:

$$T\text{-}factor = \frac{f_t}{f_c}$$

$$E\text{-}factor = \frac{E}{\sqrt{f}_c}$$

<u>Where:</u>

T-factor = *tensile strength factor*
E-factor = *elastic modulus factor*
f_c = *compressive strength (psi)*
f_t = *tensile strength (psi)*
E = *elastic modulus (psi)*

(2) Calculation of the ATD.

The following equation shall be used to calculate the ATD. The ATD shall be limited to a maximum of 75°F.

$$ATD = \varphi * \frac{T\text{-}factor\ * \sqrt{IPS}}{E\text{-}factor * R\text{-}factor * CTE}$$

<u>Where:</u>

ATD =	*alternate temperature difference limit (°F)*
T-factor =	*determined by pretesting per* Article SP-150577.03, B, 3, b, 1
E-factor =	*determined by pretesting per* Article SP-150577.03, B, 3, b, 1
R-factor =	*restraint factor, taken as 0.38 unless otherwise justified and approved*
CTE =	*coefficient of thermal expansion of the concrete (in./in./°F)*
IPS =	*in-place compressive strength of the production concrete, calculated using maturity methods per IM 383 (psi)*
φ =	*0.90*

(3) Use of the ATD.

The TCP shall report the estimated ATD at 1-hour intervals, in graphical or tabular format. The estimated ATD shall be based on the predicted thermal behavior of the concrete mass, the pre-tested material properties, and the pre-developed maturity curve for the mix. The TCP must demonstrate that the predicted concrete temperature difference will not exceed the estimated ATD at any time during the thermal control period. The estimated ATD shall not be considered the contractual ATD. The contractual ATD shall be calculated with the equation in Article SP-150577.03, B, 3, b, 2 at the time of construction, using the in-place compressive strength of the production concrete as determined using concrete maturity methods per Materials I.M. 383, based on the temperature sensor data that provides the lowest estimate of concrete maturity.

4. Duration of Thermal Control.

Thermal control of each placement shall begin when concrete is first placed into the formwork. Thermal control shall be maintained until the temperature of the interior is within the maximum temperature difference limit (from Article SP-150577.03, B, 2, a or SP-150577.03, B, 2, b) of the average ambient air temperature. The average ambient air temperature shall be determined by averaging the daily high and low temperatures over the preceding seven calendar days.

5. Temperature Sensing and Recording.

a. The purpose of temperature monitoring is to demonstrate that the maximum temperature and maximum temperature difference limits are not exceeded.

b. Temperatures shall be recorded automatically by approved commercial temperature monitoring equipment furnished by the Contractor. The monitoring equipment shall be capable of continuously recording a minimum of one reading per hour for the entire duration of thermal control. When electronic sensors are used, the Contractor shall ensure the sensors have sufficient power supply to achieve the required monitoring interval and duration. The equipment shall be accurate to within +/- 2ºF in the temperature range of 32ºF to 185ºF.

c. One pair (two sensors) shall be installed at each designated location for redundancy. The Contractor shall be required to extract and report temperature data from one primary sensor per location but shall be prepared to extract and report temperature data from the backup sensor should the primary sensor malfunction. For sensors that require a separate data logger and/or data readout device, the Contractor must have prompt access to a backup data logger and/or readout device, should the primary device(s) malfunction.

d. The required number of temperature sensors shall be dependent on the mass concrete placement size, location and boundary conditions. Most mass concrete placements will utilize four pairs (eight total) of temperature sensors placed in accordance with Article SP-150577.03, B, 5, e, 1. Mass concrete elements with large volume, potential for water inundation, or other circumstances identified by the Engineer shall merit the placement of additional sensor pairs. The contractor shall be required to apply and maintain thermal control measures in a uniform and consistent manner across the entirety of the concrete element, such that surfaces and locations without temperature sensors are sufficiently represented by surfaces and locations with temperature sensors, to the TC Engineer's and Engineer's satisfaction.

e. Temperature sensors (one pair at each location) shall be installed in accordance with the following:

1) Standard Sensor Locations.

- Center of mass of the placement.
- Midpoint of the side surface or top surface which is the shortest distance from the center of mass (2 inch to 4 inch cover).
- Midpoint of the side surface or top surface with is the second-shortest distance from the center of mass (2 inch to 4 inch cover).
- Ambient air temperature. Ambient air temperature sensors shall be located at the project site, in a fully shaded location in the vicinity of the mass concrete placement, away from artificial sources of heat.

2) Conditional Sensor Locations.

- For mass concrete placements exceeding 400 cubic yards volume, provide one additional pair of temperature sensors per each 400 cubic yard interval of concrete placed. The location of the sensor pair(s) shall be recommended in the TCP by the TC Engineer, subject to the Engineer's approval.
- For mass concrete placements for which post-cooling is utilized, provide two additional pairs of temperature sensors for monitoring the temperature of the cooling water. One pair of sensors shall be placed to monitor water temperature at the inlet of the cooling pipe system, and one pair of sensors shall be placed to monitor water temperature at the outlet of the cooling pipe system.

3) Discretionary Sensor Locations.

In circumstances where the TC Engineer or Engineer deems the prescribed standard sensor locations may be insufficient for monitoring the concrete placement, the Engineer may direct placement of up to 3 additional pairs of temperature sensors, paid in accordance with Article SP-150577.05. The discretionary sensors are intended for areas of the concrete placement that may be subject to unique boundary conditions or may otherwise be unrepresented by the standard temperature sensors. The Engineer shall provide the Contractor notice of the location and quantity of discretionary sensors at least 2 days in advance of the scheduled mass concrete placement.

C. Production Concrete.

1. General.

a. Place mass concrete in accordance with the contract documents and the approved TCP. Use only the approved concrete mix design identified in the TCP. The location of construction joints shall be as shown in the plans.

b. No work will be allowed on a concrete element while it is in thermal control, unless a plan for maintaining the specified temperature difference limit during such work is submitted and approved.

2. Pre-cooling of Concrete.

Pre-cooling of the concrete mix or mix components may be permitted using approved methods. Approved methods may include pre-wetting or pre-cooling of mix components, substitution of cubed or flaked ice for mix water, and/or liquid nitrogen injection. Use of dry ice shall not be permitted to pre-cool concrete. Designate the methods of pre-cooling in the TCP, if applicable.

3. Post-cooling of Concrete.

a. Post-cooling (cooling pipes embedded in the mass concrete elements) may be used at the Contractor's option, for purposes of controlling maximum concrete temperature or temperature difference and/or expediting the duration of thermal control.

b. For mass concrete placements with cooling pipes, the temperature sensors in the concrete placement shall remain near the locations specified in Article SP-150577.03, B, 5 but shall be shifted to be midway between the nearby cooling pipes. Concrete cover to the sensor shall remain 2 to 4 inches as specified in Article SP-150577.03, B, 5.

c. The TC Engineer may propose modification to these requirements in situations where cooling pipes are used at the Contractor's option:

- Cooling pipes shall consist of small diameter (3/4 or 1 inch) plastic pipe.
- Cooling pipes shall be uniformly spaced throughout the mass concrete placement. A minimum of 3.0 linear feet of cooling pipe shall be installed per each cubic yard of concrete.
- Joints between sections of pipe should be outside the concrete, when feasible. Pipe joints located within the concrete mass shall be detailed in the TCP and shall be subject to the Engineer's approval.
- Cooling water shall constantly flow through the cooling pipes during the entire duration of thermal control.
- The flow rate of cooling water shall not be less than 3.0 gallons per minute in each cooling pipe. Higher flow rates may be required to achieve adequate cooling.
- Do not allow the cooling water in the cooling pipe system to freeze. When using water from a natural source, take measures to avoid blockage of pumps and pipes with debris/silt. Such measures may include debris guards, screens, or other means.
- The temperature rise of the water in the cooling pipes, from entry to exit, shall not exceed 3°F. Use multiple shorter cooling pipe loops rather than fewer longer cooling pipe loops.
- Use cooling water of a consistent temperature. Do not permit the cooling water to change in temperature by more than 20°F per hour. Do not use cooling water that is colder than 33°F or warmer than 90°F.
- The pipe-to-surface spacing shall be less than the pipe-to-pipe spacing.
- All cooling pipes shall have valves to regulate the flow of cooling water.
- Protect cooling pipes from damage during the placement of concrete. Have repair materials on site for use, as needed.
- Obtain permits, where necessary, for using hydrant or natural water as cooling water in the cooling pipes.
- Where practical, route cooling pipes into and out of the concrete placement through construction joints. Use blockouts to facilitate patching where pipes penetrate other surfaces.

d. After thermal control is complete:

- Flush cooling pipes with fresh water if the cooling water contained glycol. Properly dispose of such materials.
- Inject cooling pipes with an approved non-shrink grout.
- If cooling pipes penetrate a finished surface, cut-off cooling pipes 4 in. below the surface and patch the surface with an approved non-shrink patching material. For surfaces visible to the public, patching material shall be of consistent color and general aesthetic compatibility with the mass concrete element.

4. Insulation.

When insulation is used, insulation should be uniformly installed on each surface that requires insulation. Do not allow water or wind to compromise the effectiveness of the insulation.

5. **External Heating.**
If external heat must be applied, apply heat uniformly across the entire surface. Do not concentrate heat. Do not allow any portion of the surface to become warmer than the interior temperature. Designate the details and methods of external heating in the TCP, if applicable.

D. Temperature Reporting.

1. Recording of temperature data shall begin at the initiation of thermal control, and shall continue until the completion of thermal control, as defined in Article SP-150577.03, B, 4. Recorded temperature data shall be reviewed by a representative of the Contractor at intervals not exceeding 8 hours. A copy of all recorded temperature data shall be furnished to the Engineer as the information is obtained.

2. A final report shall be furnished to the Engineer within 7 days of completion of monitoring for each mass concrete placement. The final report shall include, but not be limited to the following:
   - **a.** All measured hourly temperature data (time, date and temperature) from each temperature sensor, in tabular format.
   - **b.** Identification and location of each temperature sensor.
   - **c.** A single graph showing the time versus temperature data for each temperature sensor location within the placement, for the full duration of thermal control. The maximum temperature limit shall also be shown on the graph.
   - **d.** A single graph showing the time versus temperature difference data, calculated in accordance with Article SP-150577.03, B, 3, for the full duration of thermal control. The maximum temperature difference limit shall also be shown on the graph.
   - **e.** A statement of whether the maximum temperature and/or temperature difference limit was exceeded. If the maximum temperature and/or temperature difference limit was exceeded, indicate at what time(s) and at what sensor location(s).

E. Corrective Actions.

1. If the temperature or temperature difference within the mass concrete placement exceeds the limits of this specification, corrective action shall be taken by the Contractor. Immediate steps shall be taken to bring the concrete element back into compliance with temperature requirements, as feasible and as recommended by the TC Engineer. Future placement of mass concrete shall be suspended, and a revised TCP shall be submitted to the Engineer for approval. Do not resume placement of mass concrete without written approval from the Engineer.

2. Following completion of thermal control for any mass concrete element that exceeds specification limits for maximum temperature or temperature difference, an investigation plan shall be developed and implemented by the Contractor and TC Engineer, subject to the Engineer’s approval. The investigation plan shall assess whether the non-compliant temperature or temperature difference may have impacted the structural integrity or durability of the mass concrete element.

3. A corrective action plan shall be proposed by the Contractor and TC Engineer, based on the results of the investigation. Final determination of corrective actions shall be by the Engineer which may include, but shall not be limited to price adjustment, epoxy injection of cracks, a combination of both, or removal of the non-complying concrete. The cost of investigation and corrective action shall be borne by the Contractor. No compensation of time or expense will be granted by the Contracting Authority for investigation or correction of non-compliant mass concrete elements.

150577.04 METHOD OF MEASUREMENT.
Measurement of discretionary temperature sensors shall be by count for each installed, for sensors placed at the direction of the Engineer in accordance with Article SP-150577.03, B, 5, c. Other temperature sensors will not be measured for payment.

150577.05 BASIS OF PAYMENT.

A. Article 2403.05, A, 4 of the Standard Specifications shall not apply to mass concrete. Protection of mass concrete shall be included in the contract unit price for Structural Concrete.

B. Costs for complying with this specification shall be considered incidental to the contract unit price for structural concrete, with the exception of discretionary temperature sensors. For discretionary temperature sensors placed at the direction of the Engineer in accordance with Article SP-150577.03, B, 5, c, payment will be a price of $500 each per sensor. Payment is full compensation for all labor, material and equipment for placement and operation of the sensor, and processing and reporting of the sensor data.