Control of Temperatures in Mass Concrete with Emphasis in the Use of HDPE Pipes as Part of a Cooling System - a Case Study at the Charles W. Cullen Bridge, Delaware.

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Abstract — *This paper discusses different approaches used today to manage temperatures in mass concrete and provides comments about their feasibility as a function of particular job conditions such as access, weather and progress schedule. It serves as a summary of findings mostly resulted from experimentation made during the construction of the Charles W. Cullen Bridge (Indian River Inlet Bridge), a cable-stayed bridge located in Sussex County, Delaware. The reader will notice that often, a combination of techniques becomes the best way to effectively keep temperatures within the required limits and at the same time minimize project delays. The objective is to share empirical acquired knowledge and data in regards to mass concrete handling when the use of high early strength concrete mix is necessary and temperatures needs to be managed. Particular attention is given to the use of cooling pipes in combination with insulating blankets and pre-cooling of concrete.*

Key words — *gradient, heat of hydration, mass concrete, thermocouples.*

INTRODUCTION

Project particularities and climate forecast are the main elements to be considered when choosing the means to cope with temperature in mass concrete. Volume configuration, access to the structure, sequence of construction of other structural elements, technical specifications, schedule requirements, and length of placement time are among the project particularities that may affect the method to be implemented.

For instance, a bridge foundation to be poured in hot weather may only need a large coarse aggregate-low heat cement concrete mix poured at a rate of ten inches of height per hour to keep temperature development under control. The same foundation poured now in cold wether may need the addition of insulating material. The type and/or thickness of material may vary but it is usually selected as a function of the R-Value which is an indicator of the thermal conductivity of a material. The foundation poured in hot weather may not need insulating material since weather conditions may not be absorbing as much heat as cold weather would. Therefore, the difference between the temperature measured at the center of the volume and the outside portion may not soar as much. The thermocouples that measures temperature used to calculate the gradient (or differential) are usually located at the geometric center of the volume and approximately three inches, usually from any of the outside faces of the concrete.

As construction management and technology evolves, the performance bar is raised to new heights. Construction speed and project complexity is expected to increase by todays clients. To satisfy these expectations, engineers and/or managers shall select carefully the method or methods to both control temperature and allow for the progress of the construction to continue with minimal delays. This paper examines various methods to cope with mass concrete temperatures and discuses from a practical point of view the virtues and benefits of each one. Experimentation made in actual construction projects has led to the discussion and conclusions presented here.

MASS CONCRETE

Mass concrete is defined by the ACI (American Concrete Institute), [1] Committee 207 as 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. The thermal behavior is what distinguishes mass concrete. As the cement and water reacts, temperature rise significantly within a large concrete mass. Due to uneven increase and decrease of temperature within the concrete mass, tensile stresses and strain may develop affecting the integrity of the resulting structure. Practices to cope with mass concrete temperatures were developed largely from concrete dam construction during the early 1900. Many states of the US and other countries has adopted and further developed the guidelines published by professional organizations such as the ACI.

Since the early 1900, different methods to control temperature behavior has been proven and evolved as times goes by, in response to the ever demanding construction industry [1]. Among the alternatives available today are the following: use of low heat cement, mix proportioning, use of large coarse aggregate, place concrete in layers at a slow pace, installing temporary insulating material around the concrete volume, use of cold water when mixing the concrete, and installing cooling pipes inside the concrete volume [2].

There are two parameters of significant relevance to be limited during the early hydration of the cement to prevent cracking and durability problems, peak temperature and temperature gradient (or differential). Both, the peak temperature and the temperature gradient are measured using thermocouples to ensure non of them exceeds the maximum permissible limits. These limits varies depending on the particularities of each project, but it is normal to see the peak temperature to be set at 160, 165, or 170 degrees Farenheight. The maximum concrete temperature is limited for a variety of reasons. The primary reason is to prevent damage to the concrete. Studies have shown that the long-term durability of certain concretes can be compromised if the maximum temperature after placement exceeds the range of 155 to 165 F (68 to 74 C). The primary damage mechanism is delayed ettringite formation (DEF). DEF can cause internal expansion and cracking of concrete, which may not be evident for several years after placement [4]. Other reasons to limit the maximum concrete temperature include reducing cooling times and associated delays, and minimizing the potential for cracking due to thermal expansion and contraction. Temperatures over 190 F (88 C) can also reduce expected compressive strengths.

The temperature gradient is the difference measured from the hottest portion (typically the center) of the volume and the outside portion of the volume near the surface. This is usually limited to a maximum of 30 degrees during the first 24 hours, 40 degrees during the following 24 hours and 50 degrees farenheight after 48 hours. Thermal cracking will occur when contraction due to cooling at the surface causes tensile stresses that exceed the tensile strength of the concrete.

USE OF LOW HEAT CEMENT

There are different types of cement. Some of them generates more heat than others depending on chemical composition and mineral content. All tough low heat cement (Type IV) is the best choice for mass concrete projects, it is rarely available. This frequently forces managers and/or engineers to use Type I/II cement which is a moderate heat of hydration cement. It is standard practice to dosage the smallest amount of cement per cubic yard that will give the compressive strength required.

Is is normal to try different cement combinations. Sometimes, a blend of Portland cement with slag (Ground granulated blast-furnance slag) exhibits a lower heat generation during the first 72 hours measured from the placement of fresh concrete. It is also common to use a blend of Portland cement and fly ash when trying to reduce the heat generation of concrete.

MIX PROPORTIONING AND USE OF LARGE COARSE AGGREGATE

The use of large coarse aggregate and increased coarse aggregate proportions in the concrete mix is also standard practice to help dicipate the heat of hydration. This may not be a feasible option when using concrete pumps to place the mix. Larger aggregate in the mix may clog the hose interrupting the pumping, sometimes even damaging the pump.

PLACEMENT RATE

The reason to reduce the speed at which a concrete volume is placed is based on the concrete capacity to dissipate heat. Given that the heat dissipation of the concrete happens slow, it is believed that placing at a slower pace will allow the concrete placed to dissipate more heat before the concrete pour is completed. This practice may no deliver drastic changes in temperature development but it doesn't hurt to implement it since there is almost no cost or schedule consequences.

USE OF INSULATING MATERIAL

Mainly to keep the temperature differential below the limit value by minimizing drastic heat loss, the concrete volume is covered after the placement is completed with insulating material. Sudden cooling of the concrete surface while the interior is still warm may cause thermal cracking.

The outside temperature of the concrete volume can be influenced by adding or removing insulating material. This provides certain control over the temperature differential.

Insulating material may include insulating blankets, styrofoam boards, wood. Dirt has been used as an insulating material to cover foundations. However, practical implications such as cleaning and removing the dirt to continue construction makes the use of dirt unsuitable in many situations.

PRE-COOLING BY USING COLD WATER

The initial temperature of concrete has a direct effect on the peak temperature the concrete will develop. Therefore, the lower the temperature of the concrete at placement, the lower the peak temperature reached. During hot weather, it is normal to use cold water in the concrete mix. One of the most cost effective ways is to replace a determined weight of water with an equivalent weight of ice. As much as 1,200 pounds per truck load is not rare to use.

COOLING PIPES

The use of cooling pipes becomes an excellent alternative to both, keep the peak temperature and temperature differential below the limits. Depending on weather conditions, sometimes is ideal to implement in conjunction with insulating material. Frequently this becomes the perfect combination to keep control of temperature development because cooling pipes allows for adjustments as a function of time and temperature at the interior portion of the mass by pumping colder or warmer water and/or by changing the water flow speed.

Depending on climate and job site conditions, and specifications, the ACI allows for the use of aluminum, steel or PVC pipes as embedded cooling pipe material in mass concrete. Today, it is popular to use continuous PVC or Thin wall HDPE pipe for the following reasons:

1) There is no corrosion problems.
2) It is easy to install and minimal couplings and fittings are required minimizing leakage potential.
3) Although PVC or HDPE thermal conductivity is not as high as that one of steel or aluminum, its effectiveness has been proved time after time.

The next step after choosing the pipe material is to determine the pipe diameter and pipe spacing within the concrete volume. These depends on the concrete geometry and generally follows a grid arrangement.

Heat exchange models of cooling pipes shows that the pipe spacing is directly proportional to the pipe diameter. This is easy to understand by looking at Figure 1 and noting that with a larger diameter the heat transfer surface of the pipe increases and the radial distance heat (q) must travel decreases. This implies that the larger the pipe diameter the faster the heat exchange will be.

There are refined thermodynamic equations to approach the analysis of the heat transferred radially from the concrete to the water and the heat transported along the pipe by the water. However,

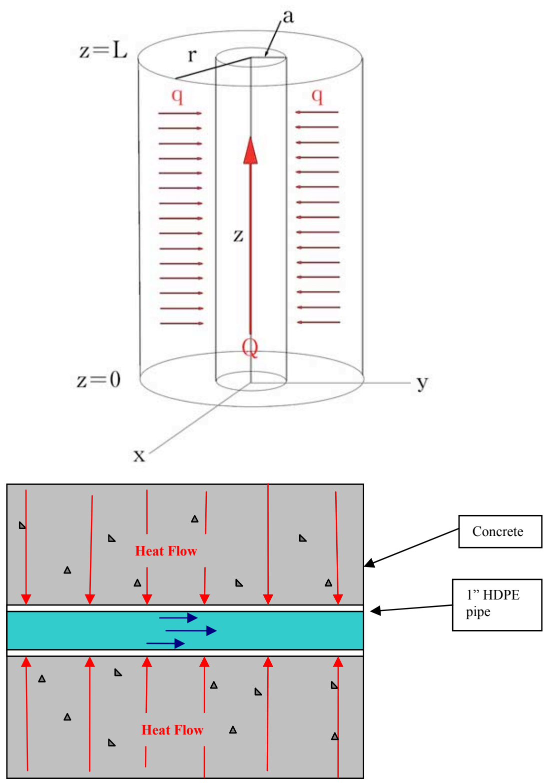

Figure 1
Concrete Sleeves with Cooling Pipe

considering the practical limits of size and functional requirements, the analysis doesn't necessarily has to become a complex thermodynamic exercise in order to determine diameter and spacing. Furthermore, the ability to adjust the flow rate and the water temperature provides the necessary tools to influence the temperature development of the concrete volume. Mass concrete pours are closely monitored meaning that temperature is usually checked every four to six hours.

Cooling Pipes Case Study - Indian River Inlet Bridge, Delaware

As part of an actual bridge construction project in the state of Delaware, USA, a mass concrete plan was developed which includes the use of cooling pipes and insulating material.

The study contemplates control of temperature development in a reinforced concrete edge girder element of a segmental cast in place bridge.

The project performance specifications limits were:

1) The peak temperature shall not go above 160 F during curing.
2) The temperature differential shall not exceed 30°F during the first 24 hours, 40°F between 24 to 48 hours, 50°F between 2 to 7 days and 60°F between 7 to 14 days.

Two mockups were built to study the particular behavior of the proposed concrete mix. The first mockup was 5' wide, 6' long and 6' toll. Width and height were same as the actual edge girder of the bridge. To measure and collect temperature, thermocouples were set at the center of the volume and center of the faces, two inches off the surface of the formwork. Cooling pipes were not used on the first mockup since the sole purpose was to collect data and determine if measures beyond insulating material were necessary.

Table 1
Concrete Mix Used for Mockups and Edge Girder.

MIX DESIGN - 1CY	42-7000	
Cement Type III, Lehigh	425	Lbs
Slag, St. Lawrence	425	Lbs
Sand, Joseph	1248	Lbs
Stone, Douglasville #8	1500	Lbs
Water	265	Lbs
DARAVAIR 1000	10	Oz
ADVA FLEX	73	Oz
RECOVER	24	Oz
DCIS	256	Oz

As shown on table 1, the mix proposed do not have low heat cement, has small coarse aggregate and its cement content is hight. This three characteristics aren't desirable for a mass concrete element since the mix will generate high heat of hydration. However, the need for mix with rapid early strength gain was mandatory to achieve project schedule goals for the contractor and owner.

Given that the construction of the edge girder was going to last thru all seasons, hot weather and cold weather conditions had to be taken into consideration.

The information acquired from the first mockup is summarized as follows:

- The limit value for the peak temperature (160°F) was exceeded at hour 18 and stayed above the limit until hour 84.
- The peak temperature was reached and held between hour 35 and hour 40 at 192.2°F.
- The temperature differential was exceeded between hour 39 and 56.

No pre-cooling or post-cooling of the concrete was implemented for the first mockup. Based on the results observed, additional cooling means were needed.

The second mockup was 5' wide, 6' tall and 10' long. Length was increased to 10' to better mimic the edge girder.

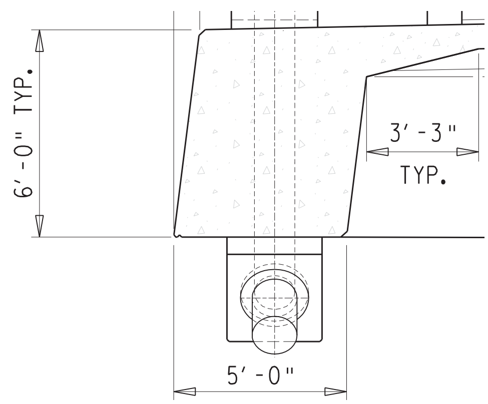

Figure 2
Edge Girder Cross Section Drawing.

For the second mockup, the use of cooling pipes was considered and implemented. The main purpose of the analysis performed was to anticipate or predict the temperature development of the second mockup during the hydration process. For this purpose, we selected to use the Schmidt Method since it has been reported to frequently give more accurate results compared to the PCA Method and the Graphical Method provided by the ACI 207.2R. [3] The Schmidt method was developed as a numerical solution to the Fourier law governing heat transfer, shown in Eq. (1)

$$\frac{d}{dx}\left(k \cdot \frac{dT}{dx}\right) + \frac{d}{dy}\left(k \cdot \frac{dT}{dy}\right) + Q_H = \rho \cdot C_p \cdot \frac{dT}{dt} \qquad (1)$$

where Q_H is the heat generation term, W/m^3; ρ is the density, in kg/m^3; C_p is the specific heat, in J/kg/°C; and T is the temperature, in °C.

The Schmidt Method is a simplified finite difference method. Temperatures are calculated for discrete nodes at discrete time steps. The time step is calculated according to Eq. (2)

$$\Delta t = \frac{(\Delta x)^2}{2\alpha} \qquad (2)$$

where α is the thermal conductivity of the concrete, in W/m/°C; Δt is the time step used, in seconds; and Δx is the node spacing, in m.

A spread sheet was developed to calculate the temperature development of the mass concrete volume based on various parameters including:

- Volume dimensions
- Cement content per CY
- Concrete specific heat
- Concrete unit weight
- Time step
- Diffusion constant
- Air temperature
- Ground temperature
- Water temperature
- R-Value

The R-value is a unit thermal resistance for a particular material or assembly of materials (such as an insulation panel). The R-value depends on a solid material's resistance to conductive heat transfer. The numerical value is directly proportional to the capacity of the material to resist heat transfer.

The spread sheet model computes a one dimensional row of temperature values across the shortest dimension of the concrete element in which an average of the contiguous nodes affects the corresponding value at a particular node. This calculation is repeated every time step which is typically divided in fractions of a day, in our case we used increments of 0.125 days which is equal to 3 hours.

Table 2

Initial Temperature Development of Second Mockup - Edge Girder with Cooling Pipes.

(Colors on the Table Match those on the Graph)

Date	Time	Data in Degrees Celsius						Data in Degrees Fahrenheit					
								1	2	3	4	5	6
		Hour	Center	Side	Tank	Return	Ambient	Center	Side	Tank	Return	Ambient	Diferential
1/11/2011	11:00am	0	35	35	9	23	6	95	95	48.2	73.4	42.8	0
1/11/2011	12:00pm	1	17	16	14	15	5	62.6	60.8	57.2	59	41	1.8
1/11/2011	1:00pm	2	17	17	13	13	4	62.6	62.6	55.4	55.4	39.2	0
1/11/2011	2:00pm	3	18	16	12	12	4	64.4	60.8	53.6	53.6	39.2	3.6
1/11/2011	3:00pm	4	18	17	11	11	3	64.4	62.6	51.8	51.8	37.4	1.8
1/11/2011	4:00pm	5	18	21	11	11	3	64.4	69.8	51.8	51.8	37.4	5.4
1/11/2011	5:00pm	6	19	23	11	10	2	66.2	73.4	51.8	50	35.6	7.2
1/11/2011	6:00pm	7	20	24	11	10	2	68	75.2	51.8	50	35.6	7.2
1/11/2011	7:00pm	8	22	26	12	11	2	71.6	78.8	53.6	51.8	35.6	7.2
1/11/2011	8:00pm	9	24	27	13	13	1	75.2	80.6	55.4	55.4	33.8	5.4
1/11/2011	9:00pm	10	26	28	13	13	1	78.8	82.4	55.4	55.4	33.8	3.6
1/11/2011	10:00pm	11	28	28	12	12	0	82.4	82.4	53.6	53.6	32	0
1/11/2011	11:00pm	12	30	28	11	11	0	86	82.4	51.8	51.8	32	3.6
1/11/2011	12:00am	13	32	28	11	11	-1	89.6	82.4	51.8	51.8	30.2	7.2
1/12/2011	1:00am	14	33	28	10	10	-2	91.4	82.4	50	50	28.4	9
1/12/2011	2:00am	15	34	28	10	9	-2	93.2	82.4	50	48.2	28.4	10.8
1/12/2011	3:00am	16	35	28	10	9	-2	95	82.4	50	48.2	28.4	12.6
1/12/2011	4:00am	17	36	29	9	9	-2	96.8	84.2	48.2	48.2	28.4	12.6
1/12/2011	5:00am	18	37	29	9	9	-2	98.6	84.2	48.2	48.2	28.4	14.4
1/12/2011	6:00am	19	38	30	9	9	-2	100.4	86	48.2	48.2	28.4	14.4
1/12/2011	7:00am	20	39	31	10	9	-2	102.2	87.8	50	48.2	28.4	14.4
1/12/2011	8:00am	21	39	31	10	10	-2	102.2	87.8	50	50	28.4	14.4
1/12/2011	9:00am	22	39	32	10	10	-1	102.2	89.6	50	50	30.2	12.6
1/12/2011	10:00am	23	40	32	11	11	0	104	89.6	51.8	51.8	32	14.4
1/12/2011	11:00am	24	40	32	11	11	1	104	89.6	51.8	51.8	33.8	14.4
1/12/2011	12:00pm	25	40	32	11	11	3	104	89.6	51.8	51.8	37.4	14.4
1/12/2011	1:00pm	26	40	32	11	11	3.5	104	89.6	51.8	51.8	38.3	14.4
1/12/2011	2:00pm	27	40	32	11	11	3	104	89.6	51.8	51.8	37.4	14.4
1/12/2011	3:00pm	28	40	32	11	11	2	104	89.6	51.8	51.8	35.6	14.4
1/12/2011	4:00pm	29	40	32	11	11	1	104	89.6	51.8	51.8	33.8	14.4
1/12/2011	5:00pm	30	40	32	11	11	0	104	89.6	51.8	51.8	32	14.4
1/12/2011	6:00pm	31	40	32	11	5	-1	104	89.6	51.8	41	30.2	14.4
1/12/2011	7:00pm	32	39	31	10	3	-1	102.2	87.8	50	37.4	30.2	14.4
1/12/2011	8:00pm	33	40	31	10	3	-1	104	87.8	50	37.4	30.2	16.2
1/12/2011	9:00pm	34	40	30	9	3	-2	104	86	48.2	37.4	28.4	18
1/12/2011	10:00pm	35	40	29	8	1	-2	104	84.2	46.4	33.8	28.4	19.8
1/12/2011	11:00pm	36	41	29	7	0	-3	105.8	84.2	44.6	32	26.6	21.6
1/13/2011	12:00am	37	42	29	7	0	-4	107.6	84.2	44.6	32	24.8	23.4
1/13/2011	1:00am	38	42	28	6	-1	-4	107.6	82.4	42.8	30.2	24.8	25.2
1/13/2011	2:00am	39	42	28	5	-1	-4	107.6	82.4	41	30.2	24.8	25.2
1/13/2011	3:00am	40	43	27	5	-1	-4	109.4	80.6	41	30.2	24.8	28.8
1/13/2011	4:00am	41	43	27	4	-1	-4	109.4	80.6	39.2	30.2	24.8	28.8
1/13/2011	5:00am	42	43	26	3	-2	-5	109.4	78.8	37.4	28.4	23	30.6
1/13/2011	6:00am	43	44	26	3	-2	-5	111.2	78.8	37.4	28.4	23	32.4
1/13/2011	7:00am	44	44	26	3	-3	-5	111.2	78.8	37.4	26.6	23	32.4
1/13/2011	8:00am	45	44	25	3	-4	-4	111.2	77	37.4	24.8	24.8	34.2
1/13/2011	9:00am	46	44	25	3	2	-2	111.2	77	37.4	35.6	28.4	34.2
1/13/2011	10:00am	47	44	24	6	5	0	111.2	75.2	42.8	41	32	36
1/13/2011	11:00am	48	43	24	7	7	1	109.4	75.2	44.6	44.6	33.8	34.2
1/13/2011	12:00pm	49	42	24	8	8	2	107.6	75.2	46.4	46.4	35.6	32.4
1/13/2011	1:00pm	50	41	23	9	9	3	105.8	73.4	48.2	48.2	37.4	32.4
1/13/2011	2:00pm	51	40	23	10	9	3	104	73.4	50	48.2	37.4	30.6
1/13/2011	3:00pm	52	39	23	10	10	4	102.2	73.4	50	50	39.2	28.8
1/13/2011	4:00pm	53	38	23	10	10	4	100.4	73.4	50	50	39.2	27
1/13/2011	5:00pm	54	37	23	11	10	2	98.6	73.4	51.8	50	35.6	25.2
1/13/2011	6:00pm	55	36	23	11	10	1	96.8	73.4	51.8	50	33.8	23.4
1/13/2011	7:00pm	56	35	23	11	11	0	95	73.4	51.8	51.8	32	21.6
1/13/2011	8:00pm	57	34	23	11	10	-1	93.2	73.4	51.8	50	30.2	19.8
1/13/2011	9:00pm	58	33	22	11	10	-2	91.4	71.6	51.8	50	28.4	19.8
1/13/2011	10:00pm	59	33	22	11	10	-3	91.4	71.6	51.8	50	26.6	19.8
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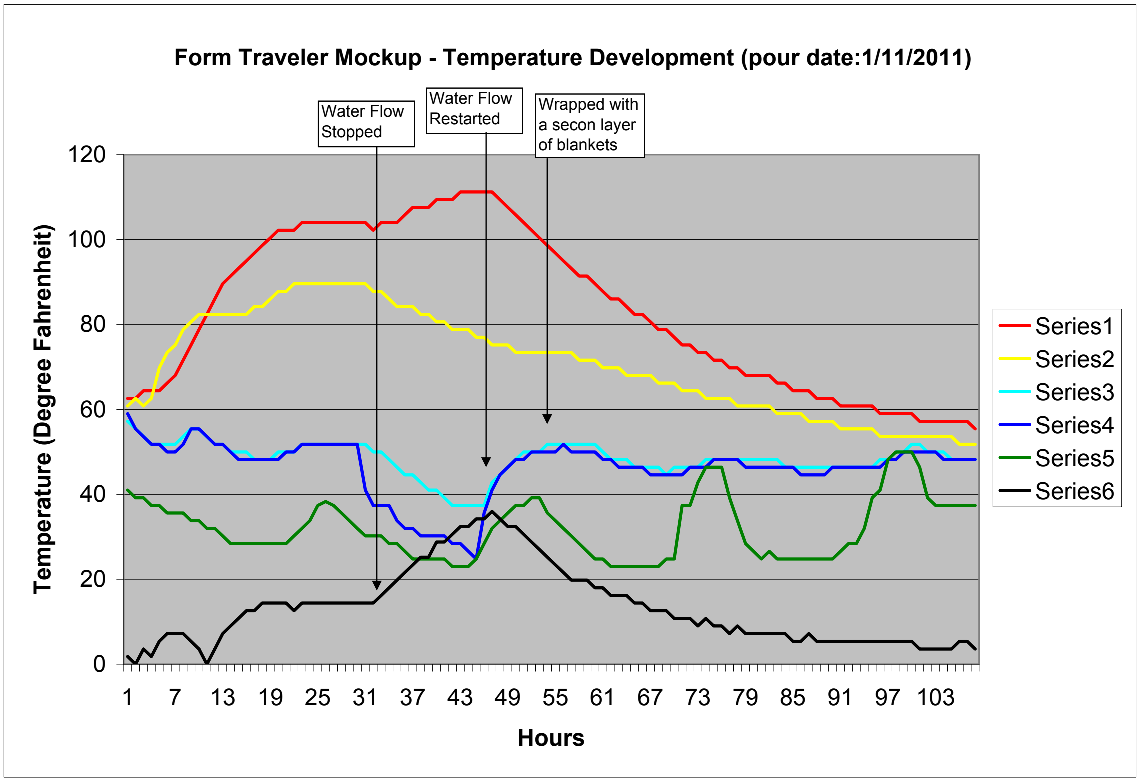

Figure 3
Graphical Representation of Temperature Data in Table 2.

Three rows of two cooling pipes 1 inch in diameter were used as shown in Figure 4 spaced at 16 inches approximately. From the analysis made with the spreadsheet it was concluded that the initial concrete temperature must be below 80°F and the temperature of the water flowing thru the pipes has to be below 60°F.

The water flow was set to be above 4 gallons per minute per pipeline.

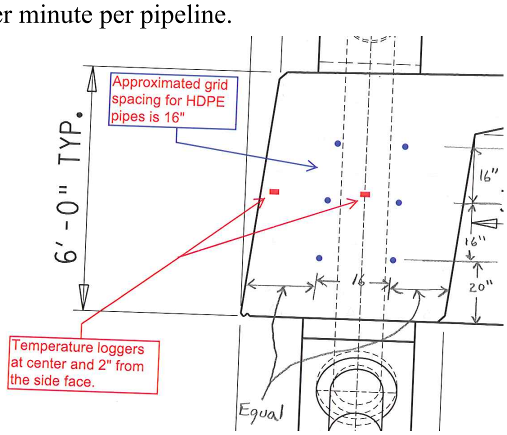

Figure 4
Edge Girder Mockup Cross Section with Cooling Pipes Location.

In our initial approach, one of the concerns was to effectively manage the water temperature differential between the inlet and outlet of the pipelines. The differential resulted to be very small at approximately 1°F. This was a very valuable discovery that allowed for a more cost effective management of the operation. A tank filled with approximately 300 gals of water and 50 pounds of ice at approximately 45°F can be constantly pumped up to 10 hours during summer with no additional labor required. The way the system was set to function permited the water from the outflow to return to the tank, entirely recycling the water.

During winter, no ice was necessary to add to the tank and a biodegradable anti-freeze agent was added to the water. Two layers of insulating material was necessary to increase the R-Value to approximately 3.0.

During summer, the use of ice in the water tank was necessary. It was also needed to pre-cool the concrete mix with the inclusion of ice into the truck. Approximately 100 pounds of water were replaced with an equivalent amount of ice per cubic yard. The addition of ice was performed at the batching plant facility, approximately 30 minutes away from the project.

Table 2 and following graph display the data corresponding to the temperature development of the edge girder mockup (called at that time Form Traveler Mockup). It can be observed how temperatures are influenced by stopping and re-starting the water flow thru the pipes. Also by varying the number of layers of insulating material. No external heater was needed nor used

TEMPERATURE MONITORING SYSTEM

There are a few different systems used in the United States, including Puerto Rico. One of the most widely used is the IntelliRock System.

Figure 5
IntelliRock System.

The intellirock handheld reader communicates with the embedded loggers to gather temperature data.

The software provided with the system facilitates the transfer of maturity and temperature data from the reader to a computer in secure, unalterable electronic files enabling subsequent distribution, documentation and/or analysis.

CONCLUSIONS

Based on the observations made in regards to the case study discussed on this paper, I would like to offer the following comments and suggestions as practical learned lessons. These conclusions resulted directly from experimentation.

1. It was observed that water temperature increases approximately 1.5°F per hour during the first 6 hours due to the concrete heat of hydration. Then, the water temperature seams to stay steady suggesting that a thermal balance has been reached between the cooling pipe system and the concrete.
2. Attention must be paid to temperature lectures from the thermocouples relative to the temperature at the water source. The use of a tank or container is highly suggested because it facilitates the addition of ice (when needed).
3. The flow thru the cooling pipes varies with the location of the pipes. Due to the difference in head, 7 gallons per minute were measured on the lower pipes and 5 gallons per minute on the upper pipes. This difference was easily manipulated by closing the valves of the upper pipes a little. Although, no issues resulted from this situation, uniform flow shall be the goal. A regular submergible pump of 20 to 30 gallons per minute was ideal in our case. Pump size shall be evaluated for other job since a larger structural element may require additional pipelines and a higher pumping capacity.
4. The diameter of the pipes and the spacing may vary from job to job. However, pipes larger than one inch ID may bring other issues, including conflict with rebar and post-tensioning elements embedded in the concrete. Pipes one inch in internal diameter may be suitable for most jobs. Spacing depends on the geometry of the mass and other embedded components. I have observed that pipes one inch in diameter, spaced between 12 to 18 inches, in a symmetrical fashion will perform well. Less than 12 inches may be too close and more than 18 inches may be too far. Careful analysis shall be given if a spacing less than 12 inches and more than 18 inches is desirable.
5. Pipe arrangement and exterior insulating material can be placed in a manner so that subsequent concrete pours confront minimal or no delay because of mass concrete spec requirements. Means and method shall be evaluated by contractor to design a temperature

management operation around the productivity and progress of the job. It is possible, most of the time, to find a combination of techniques that can be implemented with minimal adverse schedule impact.

6. Our case study confirmed that combining internal and external temperature control means provides sufficient information and tools to react and adjust thermal behavior before exceeding allowable limits, resulting in a successful operation. Similar projects might benefit from these approach toward mass concrete temperature management.
7. Further consideration to this topic may be beneficial to develop a standard field reference manual (or guidelines) including materials and equipment to facilitate the decision making process at the job site. This will help builders to cost-effectively plan successful temperature management protocols.

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