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Iowa Mass Concrete for Bridge Foundations Study – Phase II

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tech transfer summary

The research utilized the software packages ConcreteWorks and 4C-Temp&Stress to model the thermal development of mass concrete elements. Through this effort, insight is gained about how to better manage the mass concrete construction process.

Objectives

The objectives of this research are to provide insight on the early-age thermal development of mass concrete, provide recommendations for the Iowa Department of Transportation (DOT) mass concrete specification, and present best practices for mass concrete construction.

Background

The early-age thermal development of structural mass concrete elements has a significant impact on the future durability and longevity of the elements. If the heat of hydration is not controlled, the elements may be susceptible to thermal cracking and damage from delayed ettringite formation, which can also cause cracking in extreme cases.

In the Phase I study, the research team reviewed published literature and current specifications on mass concrete. Also, the team observed construction and reviewed thermal data from the westbound (WB) I-80 and US 34 Missouri River Bridges. In addition, the researchers conducted an initial investigation of the thermal analysis software programs ConcreteWorks and 4C-Temp&Stress.

Research Description

The present study is aimed at developing guidelines for the design and construction of mass concrete placements associated with large bridge foundations. This phase consisted of the following research activities:

- Updating the literature review and preliminary thermal stress analysis
- Observation of mass concrete construction practices
- Reviewing construction observations and data from the WB I-80 and US 34 Missouri River Bridges
- Thermal modeling using the software programs ConcreteWorks and 4C-Temp&Stress
- Developing recommendations

Research Methodology

The Phase II study included an additional review of published literature and a more in-depth investigation of current mass concrete specifications. A national survey was completed by investigating the mass concrete specification of the 51 state highway agencies, including the District of Columbia (DC) and two federal agencies.

In addition, the mass concrete construction of two bridges, the WB I-80 Missouri River Bridge and the US 34 Missouri River Bridge, was documented.

An investigation was conducted regarding the theory and application of the software program 4C-Temp&Stress. The output from ConcreteWorks and 4C-Temp&Stress was then compared with thermal data recorded for the WB I-80 Missouri River Bridge and the US 34 Missouri River Bridge.

ConcreteWorks and 4C-Temp&Stress were further verified by means of a sensitivity study using parameters having the largest effect on the thermal development of mass concrete. Two separate case studies were conducted and documented using ConcreteWorks and 4C-Temp&Stress.

Finally, conclusions and recommendations were developed.

Sensitivity Analysis Results

The sensitivity analysis results are summarized as follows:

- The measured maximum temperature difference is a key parameter for assessing thermal stress in mass concrete. The maximum temperature difference is affected significantly by surface sensor location, so care should be taken to place the sensors the specified depth below the surface.

- The surface sensor is recommended to be installed with at least 3 inches of concrete cover, where the sensor can be attached easily to a steel reinforcing bar.

- Wet curing had the lowest cracking potential for top insulation and may be the best alternative, when practical.

- Formbord (25 mm), plywood, plywood formwork, and timber formwork, which resulted in lowest cracking possibilities in this particular analysis.

- With the same concrete and construction conditions used for computer calculation, similar trends were found for both maximum temperature and maximum temperature difference which both increased with the following:
  - o Increase of the least dimensional size
  - o Increase of fresh placement temperature especially in cooler months, such as October
  - o Increase of cement content

- Shortening the form removal time increases the temperature difference but has little effect on the maximum temperature.

- The use of supplementary cementitious materials, high thermal conductivity aggregate, and low coefficient of expansion aggregate could reduce the cracking potential.

- Cooling pipes controlled the maximum temperature development and reduced the thermal cracking potential. The layout, spacing and number of cooling pipes were important in terms of reducing cracking potential and construction cost.

Key Findings

The results of calculations concerning the maximum temperature and the maximum temperature difference between the two computer programs were different. ConcreteWorks output indicated higher temperature differences, which are calculations of the temperature difference between maximum predicted temperature at the center and minimum predicted temperature at the surface. The surface temperature was influenced significantly by the ambient temperature.

Several forming and insulation methods were provided in ConcreteWorks. The analysis using 4C-Temp&Stress confirmed the recommendations from ConcreteWorks. 4C provided more options on forming and insulation materials. Furthermore, the effect of placement date was also confirmed by ConcreteWorks.

Generally, winter construction indicated larger maximum temperature differences and greater cracking potential. In summer, mass concrete construction had reduced cracking potential when the fresh placement temperature was less than 70°F.

Conventional wisdom regarding mass concrete behavior has been confirmed.

The research yielded these findings:

1. The Iowa DOT maximum allowable temperature difference gradient limits are confirmed to be applicable for bridges similar to that of the WB I-80 Missouri River Bridge and the US 34 Missouri River Bridge.

2. ConcreteWorks is capable of predicting the general trend of thermal development of mass concrete elements.

3. 4C-Temp&Stress may be used to determine acceptable maximum temperature differential limits for various situations.

4. ConcreteWorks has more easily adjusted input than 4C-Temp&Stress, which assists in giving detailed consideration to the influences of various mix designs. The heat development and compressive strength inputs of the 4C program should be changed according to the measured values when the mix design of the concrete is different from the default ones.

Conclusions and Recommendations

1. ConcreteWorks is capable of predicting the general trend of thermal development of mass concrete elements. In a comparison between actual and predicted maximum temperatures for 22 different concrete elements on the I-80 WB Bridge, the errors ranged from underestimates of 35°F to overestimates of about 1°F; the average was an underestimate of 12.3°F. In a comparison between actual and predicted maximum temperature differences, errors ranged from underestimates of 21°F to overestimates of 14°F with an average of 1.9°F. Some adjustment to the inputs and outputs could be made to ensure that the results are conservative. Input values would be easily available to Iowa DOT personnel. Output regarding cracking potential is only available for the first seven days of the placement and cracking potential is described qualitatively as low, medium, and high. Because of a programming limitation, the entire analysis ends in 14 days, while thermal development continues on some typical concrete placements in Iowa for a longer period.

2. 4C-Temp&Stress is also capable of predicting the general trend of thermal development of mass concrete elements. A comparison between actual and predicted maximum concrete temperatures for 26 concrete elements were within 25 degrees, except for stem elements, which had predictions of lesser quality. Many input values would be easily available to Iowa DOT personnel; however, some effort to correlate or calculate some input values is required. The length of time for the output covers the entire thermal development period for the type of construction in the case studies of I-80 WB and US 34. Output is provided as temperatures and the stress ratio (tensile stress: tensile strength) at various locations. Iso-curves are also available for temperature and stress ratio.

3. Sensitivity analyses using both Concrete Works and 4C both confirm actions that are documented in the literature that are effective in controlling the thermal performance of mass concrete elements. For example, reducing the fresh placement temperature, limiting cement content, and substituting fly ash for concrete all tend to improve the thermal performance of mass concrete. The sensitivity studies provide further verification regarding the operation of ConcreteWorks and 4C-Temp&Stress.

4. The Iowa DOT maximum allowable temperature difference gradient limits specified in Control Heat of Hydration DS-09047, August 17, 2010 are confirmed to be applicable for bridges similar to the WB I-80 Missouri River Bridge and the US 34 Missouri River Bridge, where bridge elements are founded on concrete. By having lower limits on the maximum allowable temperature difference at earlier ages, the specification recognizes that concrete is relatively weak shortly after placement and becomes stronger and more able to resist thermal cracking as it matures.

5. Further investigation regarding the influence of subbase material on cracking and how to model cooling pipes in mass concrete elements would be useful.

6. Enhancing ConcreteWorks to have longer analysis periods would increase its usefulness for modeling mass concrete placements that are similar to those for the I-80 WB and US 34 bridges over the Missouri River.

7. The Iowa DOT could consider allowing contractors to have greater latitude in developing plans for mass concrete placements if the potential success of such plans can be verified by 4C-Temp&Stress or ConcreteWorks.

Implementation Benefits

Further understanding of the effect of each parameter on mass concrete thermal properties will help the Iowa DOT and contractors to identify the most convenient and cost-effective methods to reduce the risk of thermal damage in mass concrete construction.