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Institute for Transportation

Evaluate, Modify, and Adapt the ConcreteWorks Software for Iowa's Use

tech transfer summary

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RESEARCH PROJECT TITLE
Evaluate, Modify, and Adapt the ConcreteWorks Software for Iowa's Use

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To help engineers predict and control early-age thermal development, which has a significant impact on the performance and long-term serviceability of mass concrete structures, such as bridge foundations, ConcreteWorks was tailored and enhanced for use in Iowa.

Background

High temperature differentials in mass concrete members at early ages may cause thermal cracking, thereby impacting their long-term durability. To minimize the risk of cracking, temperature prediction tools are often used to assist decision makers and determine preventive measures. ConcreteWorks is a computer program that helps analyze and manage the temperature of early-age mass concrete in specific geographical locations.

Problem Statement

A previous research project sponsored by the Iowa Department of Transportation (DOT) analyzed the ConcreteWorks and 4C-Temp&Stress software programs and recommended that ConcreteWorks is much easier to use than 4C-Temp&Stress, while capable of predicting the general trend of thermal development of mass concrete elements (focused on structural elements with the smallest dimension of 6.5 feet or less). However, the same investigation also indicated there are some features in the ConcreteWorks program that do not fit typical Iowa concrete construction situations appropriately.

For example, some units are in the metric system, some default input data (e.g., materials and properties) do not align with Iowa mass concrete materials and practice, only four weather stations in Iowa were incorporated, and the program provides limited temperature output up to 14 days and cracking potential up to 7 days only.

Objectives and Goals

This project aimed to evaluate, modify, and adapt the ConcreteWorks software to enhance its usefulness for mass concrete construction activities in Iowa. The long-term goals are to improve the longevity and performance of Iowa bridge foundations and other mass concrete structures by better understanding the thermal behavior of Iowa mass concrete, properly managing temperature development in mass concrete, and reducing concrete thermal cracking potential.

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The mission of the Institute for Transportation (InTrans) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

The following objectives were set to reach these goals:

- Identify the parameters and modification methods that are necessary for adapting the software for use in Iowa
- Investigate the key properties of typical Iowa mass concrete mixes that are required by ConcreteWorks as input data
- Evaluate the usefulness of the modified software on an actual mass concrete project
- Provide rational recommendations for the Iowa concrete industry to effectively use the modified ConcreteWorks software application
- Provide insight regarding how to refine Iowa specifications and requirements for mass concrete analysis, potentially eliminating unwarranted analysis affects and reducing construction costs

Project Description

Various tasks were performed as part of this study. The following major research activities were carried out as part of this project:

- Measure key properties of mass concrete mixes commonly used in Iowa in the laboratory
- Investigate a real-time mass concrete project (I-35 NB to US 30 WB bridge footing)
- Modify ConcreteWorks based on the test and field data and with suggestions from the technical advisory committee (TAC)
- Conduct and compare thermal analyses using ConcreteWorks and another software program, 4C-Temp&Stress, for laboratory and field concrete mixes
- Refine ConcreteWorks based on analysis results and feedback and review comments from the project team
- Develop recommendations

Key Findings

- Some prediction models used in ConcreteWorks and the 4C program are quite different and thereby furnish different results. For example, the thermal conductivity, specific heat, and heat of hydration simulation processes in the software are different. 4C overestimates both the maximum temperature and differential temperature as with the footing analyzed in this study.
- Among all three tools used (4C and new and old ConcreteWorks) for temperature analysis of the Pier 4 footing of the I-35 NB to US 30 WB bridge, the new ConcreteWorks predicted the closest value of the maximum temperature (149.16°F) to that measured in the field (149.00°F). The new ConcreteWorks prediction of the time to reach the maximum temperature (52 hours) is also close to that of the field-measured value (50 hours).
- The measured temperature difference between the core and top of the footing was within the Iowa DOT limits for most of the early-age period. The 4C prediction of this parameter was relatively high in comparison to both ConcreteWorks predictions and the field measurements. However, the new ConcreteWorks prediction was very similar to the measured profile.
- The new ConcreteWorks predicted slightly higher values of maturity and compressive strength than those measured from the field concrete.
- Comparing the new ConcreteWorks predictions of temperature profiles of the four concrete mixes tested in the laboratory, the maximum temperature was observed to be the lowest in Mix 2 (133.36°F) containing a total of 45% fly ash and the highest in Mix 1 (148°F) containing only 20% fly ash.
- ConcreteWorks furnished a higher maximum temperature and a higher differential temperature for mixes containing slag (Mix 3 and 4) when compared with the mix with no slag (Mix 2). This may be related to the heat of hydration model for slag concrete in ConcreteWorks.
- Overall, the new ConcreteWorks predicts the early-age temperature profile, maturity, and strength of Iowa mass concrete quite well.

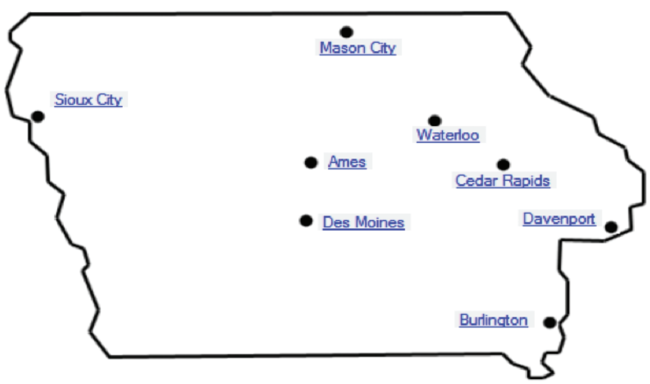
Implementations Readiness

The earlier version of the ConcreteWorks software was modified based on revisions proposed by the TAC and knowledge attained by analyzing the results of the laboratory tests and the I-35 NB to US 30 WB bridge pier footing investigation. The thermal analysis was performed using the ConcreteWorks and 4C software. A summary of the new ConcreteWorks features from this work are as follows.

- Many default input values in the new ConcreteWorks software have been updated based on the results obtained from this research project (both laboratory and field applications). They are available for use when analyzing Iowa mass concrete and can also be changed when measured data are available.
- A soil initial temperature model has been added, which makes the predictions by the new ConcreteWorks more accurate.
- The thermal analysis can be performed up to 31 days. However, the cracking probability can be generated for only up to 7 days.

- The environmental data for eight cities in Iowa are pre-incorporated in ConcreteWorks. They can be selected and used as environmental input data, as required by the software, for Iowa mass concrete temperature analysis. If changes are necessary, these environmental parameters can be manually entered.

- The new ConcreteWorks can generate the profiles of temperature development at any selected point and temperature differential between any two selected points on a mass concrete member. The generated results can also be compared with the Iowa DOT limits incorporated into the software.



Only four cities in Iowa—Des Moines, Waterloo, Mason City, and Sioux City—were available to select for the project location in the earlier ConcreteWorks, and the weather data for four additional major cities were added—for Ames, Cedar Rapids, Davenport, and Burlington

Implementation Recommendations

- The modified ConcreteWorks can be used for the analysis of the temperature development profile and the cracking probability of a range of mass concrete elements, such as rectangular/partially submerged footing, rectangular/T-shaped bent cap, and rectangular/circular column.

- The modified ConcreteWorks can be used to generate the temperature development profile at any point and temperature differential between any two points in the mass concrete member. The generated results can also be compared with the Iowa DOT temperature differential limits incorporated in the software.

- The weblink for the ConcreteWorks workshop conducted in this project can serve as a major resource for engineers that are interested in learning how to use ConcreteWorks. The ConcreteWorks user manual developed in this project can also serve as a reference to help users input data and interpret results properly. Additional workshops/short courses can be conducted to teach potential users on how to use the manual and further understand the new software.

- Some of the default values (material properties, hydration parameters, formwork insulation, etc.) can be further modified if the measured data are available.

Recommendations for Further Research

- It was observed in this study that, compared to portland cement and fly ash containing mixes, the concrete mixes containing slag might exhibit a higher adiabatic temperature rise if used in mass concrete construction. Considering the interaction of slag and portland cement, further research can be performed to investigate the heat generation in slag-containing concrete mixes. A new model can also be developed to predict the temperature development profile of mass concrete members where such mixes are used.

- In addition, limestone cement is increasingly used in Iowa but was not included in this study. Investigation into the thermal behavior of mass concrete containing limestone cement may be necessary in the very near future.

- In a bridge foundation design and construction, cofferdams are built to form watertight enclosures surrounding excavations. These enclosures normally consist of sheet piling driven around the perimeter of the excavation. A concrete seal coat is placed within the sheet piling, and the bridge footing is then built on the seal coat slab. A concern was raised in the present study on how the temperature profile of the seal coat slab can affect the early-age temperature development in the footing placed above it. Currently, the ConcreteWorks software doesn't have the component for predicting the concrete temperature of seal coat slabs. This demands further study.

Implementation Benefits

The results indicate that the modified ConcreteWorks software predicts the early-age temperature profile, maturity, and strength of Iowa mass concrete quite well. The long-term goals are to improve the longevity and performance of mass concrete constructed in Iowa with an emphasis on bridge foundations.

As many default data in the public ConcreteWorks software are replaced with Iowa concrete values, the modified software is even more user-friendly and reliable for Iowa's use. A hands-on short course on learning how to use ConcreteWorks was welcomed by Iowa engineers.