Iowa State University
Institute for Transportation

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

tech transfer summary

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

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The thermal predictions made by ConcreteWorks can be improved through a better understanding of slag hydration and its effects on temperature development in Iowa mass concrete.

Goals

This research project was divided into two parts, with the goals for each as follows:

- **Part A.** Develop a slag hydration model, better understand the effects of slag hydration on temperature development in mass concrete, and improve the thermal predictions made by ConcreteWorks for Iowa mass concrete containing slag
- **Part B.** Develop a new component in ConcreteWorks enabling the prediction of temperature profiles in bridge footings placed on seal slabs and understand the effects of seal slabs on the temperature profile of the footing above

Background and Problem Statement

Part A

In the previous phase of this research (Wang et al. 2020), the researchers found that concrete mixes containing slag, especially at high replacement levels (≥50%), might undergo a higher adiabatic temperature rise (ATR) than concrete with the same amount of fly ash or even concrete with pure portland cement.

While the heat generation curve of ordinary portland cement (OPC) and OPC-fly ash cement features a single peak, the heat generation curve of cement containing slag commonly features two adjacent peaks. Prediction models in ConcreteWorks have not considered the occurrence of two peaks in concrete containing slag, leading to inaccurate temperature estimations.

Because slag is commonly used in Iowa mass concrete mixes, ConcreteWorks needed to be modified to improve the thermal predictions for concrete containing slag.

Part B

A separate concern has arisen regarding how the heat of cement hydration of a seal slab can influence the heat of cement hydration of a bridge footing above. Seal slabs are commonly used when a cofferdam consisting of sheet piling is built to form a watertight enclosure around an excavation. A concrete seal slab is placed within the sheet piling, and the bridge footing is then built on top of the seal slab.

While no temperature control of the seal slab concrete has been believed to be necessary, heat development in the seal slab may affect the early-age temperature development in the footing placed above it. The existing ConcreteWorks has had no component for predicting the concrete temperature of seal slabs.

Further study was needed to determine the extent to which heat development in seal slabs affects early-age temperature development in footings and to model these effects in ConcreteWorks.

Project Description

Part A: Improving Thermal Prediction for Mass Concrete Containing Slags

1. **Characterization of slags.** The fineness, chemical composition, and crystalline/glass phases of three slags commonly used in Iowa were analyzed through Blaine's method, X-ray fluorescence (XRF), and X-ray diffraction (XRD), respectively.

2. **Effect of slags on cement hydration.** Isothermal calorimetry tests were performed on binary mixes made with portland cement and different slags (Grade 100 or 120) at various replacement levels (0%, 20%, 50%, and 75% by weight of binder).

3. **Effect of slag type and replacement dosage on temperature rise.** The mixes' fresh properties were evaluated via quality control tests such as slump, unit weight, air content, and initial temperature measurement. The hardened and thermal properties were evaluated using semi-adiabatic calorimetry, compressive strength, and maturity.

4. **Temperature monitoring in large concrete blocks.** Four large concrete block specimens containing slag at various replacement levels (0, 25, 50, and 75 wt.%) were built and instrumented to obtain ATR values over 28 days.

5. **New slag hydration model.** Data on slag-containing binary mixes were collected from the literature and processed, filtered, and refined to develop a slag hydration model. Prediction equations for the model parameters based on the physical and chemical properties of cement and slag were generated via statistical regression analysis.

6. **Development and validation of a new ATR prediction model.** Three of the large concrete block mixes and three mixes from the literature were used to develop and validate an ATR model. The heat parameters were refined so that the mixes' predicted adiabatic temperature profiles were comparable to temperature profiles measured using 4C Stress&Temp software.

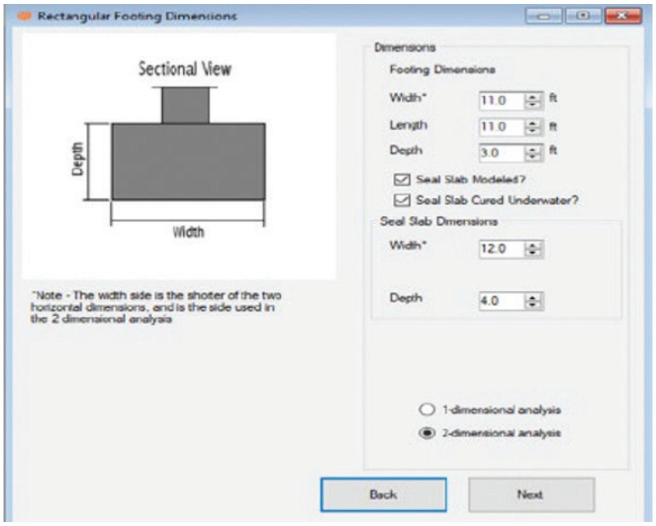
7. **Additional modification and incorporation into ConcreteWorks.** The inputs and equation parameters of ConcreteWorks were modified based on the new hydration and ATR models, and trial thermal and sensitivity analyses were conducted on the modified software.

Large concrete block casting

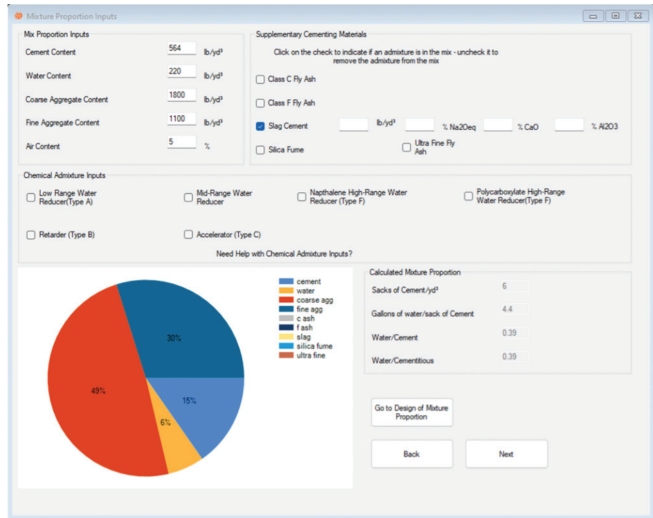
Part B: Developing a New Component in ConcreteWorks for Seal Slab–Footing Thermal Analysis

1. **Development of a seal slab component in ConcreteWorks.** A component was developed to simply model seal slabs in two-dimensional analysis cases for rectangular footings. The input parameters include seal slab and footing dimensions, mix design, time of footing placement, environmental conditions, and others. The output parameters are the same as those for a footing without a seal slab.

2. **Trial analyses using the new seal slab component.** Using the new seal slab component, a series of trial analyses investigated the effects of (1) the time of footing placement, (2) seal slab and footing dimensions, and (3) the construction season or environmental temperature on the temperature profile of footings with seal slabs.



ConcreteWorks screenshot showing seal slab dimension inputs



ConcreteWorks screenshot showing slag cement chemical property inputs

Key Findings

Part A

- The default input values in ConcreteWorks have been updated to include slag chemical compositions, which can be changed when measured data are available, and the new slag hydration model includes slag chemical properties. The newly modified software features improved concrete temperature predictions compared to the previous version, with a decrease in absolute error from 35% to 15.6%.
- Isothermal calorimetry measurements showed that slag replacement does not necessarily decrease the total heat of hydration and may increase the heat of hydration at later stages.
- A higher slag replacement (>50%) led to a significantly lower rate of heat and total heat of hydration compared to the standard mix (Type I/II).
- Slag fineness greatly influenced the rate of heat and total heat of hydration, with both metrics significantly higher for the Grade 120 (finer) slag than for the Grade 100 slag. This effect was greater at higher temperatures, showing that the physical properties of mass concrete slag (e.g., fineness) can be a key factor in maximum temperature rise.
- A three-parameter (3P) model showed the best fit for the data collected from the literature on mass concrete structures. Therefore, a three-parameter ATR prediction model was developed and validated in the present study.
- The modified model showed a 20% reduction in the absolute error when modeling temperature rise.
- Overall, the new ConcreteWorks model predicts the early-age temperature profile with higher accuracy and predicts the maturity and strength of Iowa mass concrete quite well.

Part B

A component was added to ConcreteWorks that allows a seal slab to cure underwater in a flooded cofferdam if the option is selected. The new component is simple, user friendly, and well-integrated with the existing ConcreteWorks software.

The results from the case study indicate the following:

- The maximum core temperature of a footing placed on a seal slab is generally higher than that of a footing with no seal slab (by approximately 3°C).
- The maximum core temperature of a footing placed on a seal slab drops much more slowly than that of a footing without a seal slab. That is, a seal slab enhances the capacity for heat retention in the footing, keeping the core temperature high for a longer period.
- The temperature profile of a footing placed on a seal slab can be affected by factors like seal slab and footing dimensions, time of footing placement, environmental temperature, the mix design of the seal slab and footing, and so on.

Recommendations for Future Development

- Using the literature and available data, a new model can be developed for tertiary cementitious systems.
- Portland limestone cement (PLC) is increasingly being used in Iowa but was not included in this study. The thermal behavior of mass concrete containing limestone cement can be investigated in the future.
- The new seal slab component in ConcreteWorks has not yet been validated with Iowa field data. Field investigations can be conducted to validate this component.
- Additional sensitivity studies of the new seal slab component can be conducted to investigate the effects of various seal slab mix designs on the temperature profile of the footings placed above.

Implementation Readiness and Benefits

ConcreteWorks was successfully modified to improve its thermal predictions for concrete containing slag. The updates include a new slag hydration model that incorporates the chemical properties of commercially available slag and new hydration parameter equations.

Additionally, a new slab seal component was developed that allows the user to select a footing with or without a seal slab for temperature analysis and to understand the effects of the seal slab on the temperature profile of the footing above.

Additional modifications to ConcreteWorks are recommended to incorporate the physical properties of slag, the chemical properties of other cementitious materials, and the behavior of concrete containing PLC and other low-carbon concrete materials.

Reference

Wang, K., Y. Sargam, K. Riding, M. Faytarouni, C. Jahren, and J. Shen. 2020. *Evaluate, Modify, and Adapt the ConcreteWorks Software for Iowa's Use*. Institute for Transportation, Ames, IA.