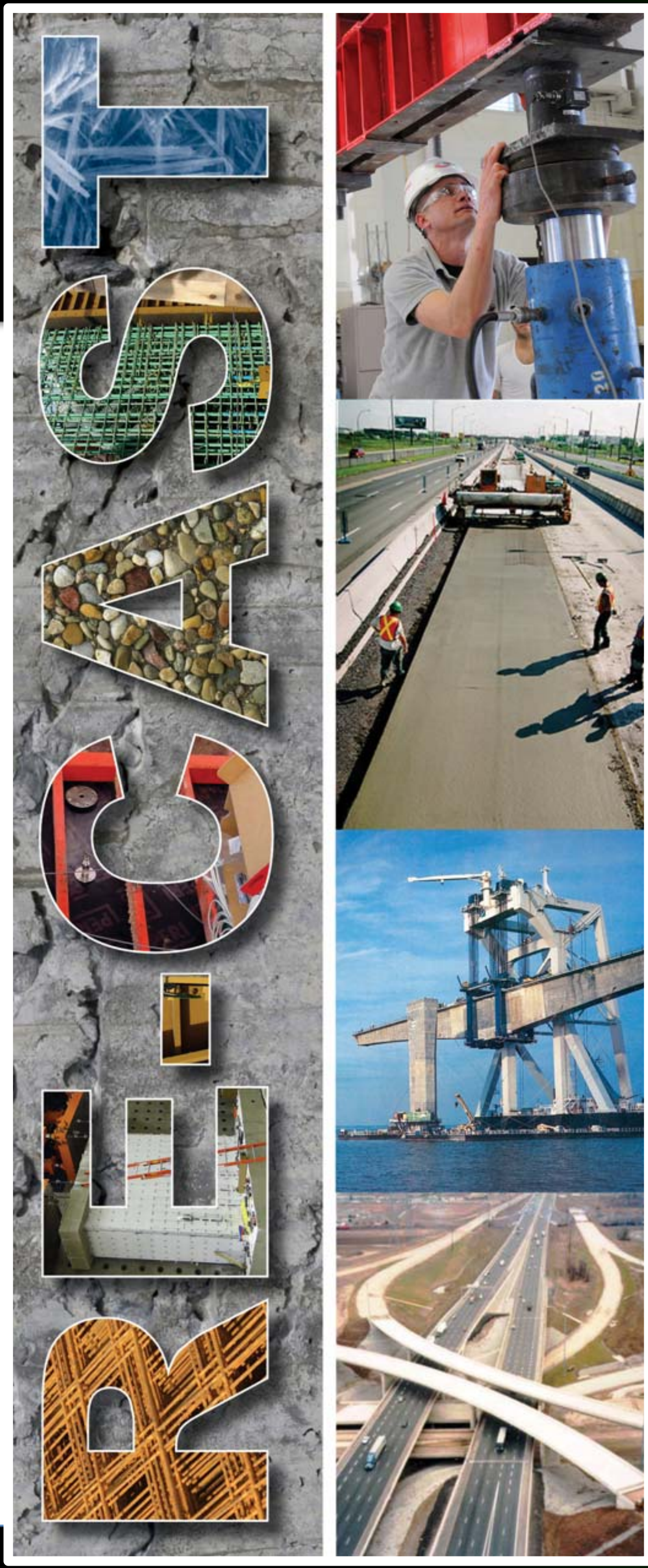

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Formwork Pressure Measurements and Prediction of High Performance Concrete with Adapted Rheology

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16. Abstract

This study was conducted under RE-CAST Project 1B “Formwork Pressure Measurements and Prediction of High Performance Concrete with Adapted Rheology.” High performance concrete with adapted rheology (HPC-AR) is a term for a wide range of concrete materials for which flow and workability is a major design objective. HPC-AR includes self-consolidating concrete (SCC), but HPC-AR is a term that encompasses “semi-SCC”, flowable grouts, and other materials with desirable rheological performance. The term “adapted rheology” refers to the material designer’s task to produce concrete to match the specific needs of a given construction scenario. Thus, HPC-AR is not simply a new name for SCC, but it emphasizes the control of material behavior to achieve easy and reliable placement of concrete that provides superior hardened properties as required by the application.

The project focused on understanding mechanisms responsible for SCC formwork pressure drop over time. The fresh state properties of SCC, mortar, and cement paste mixes like workability, static yield stress gain and temperature change over time were evaluated and correlated with the formwork pressure data. The mix parameters for the concrete, mortar mixes like water to cementitious ratio, the addition of fly ash, aggregate content, maximum aggregate size, aggregate moisture content, addition viscosity modifying agent, the addition of fibers were investigated. Emphasis was also placed on studying the influence of formwork dimensions on the formwork pressure. The results showed that the formwork pressure drop over time was highly dependent on the thixotropy which can be measured from static yield stress and dynamic yield stress gain over time.

This final report provides a summary of a laboratory test program conducted at the University of Illinois and a field test program conducted in Toronto, Ontario. Details of the laboratory test program are documented in the M.S. thesis by Kavya Vallurpalli [1] which is permanently available for download at

http://hdl.handle.net/2142/97509. The field test program is documented by several published papers, including Gardner et al [2] and Khayat et al [3].

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Project 1.B Formwork Pressure Measurements and Prediction of High Performance Concrete with Adapted Rheology

FINAL REPORT

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January 15, 2018

I. INTRODUCTION

This study was conducted under RE-CAST Project 1B "Formwork Pressure Measurements and Prediction of High Performance Concrete with Adapted Rheology." High performance concrete with adapted rheology (HPC-AR) is a term for a wide range of concrete materials for which flow and workability is a major design objective. HPC-AR includes self-consolidating concrete (SCC), but HPC-AR is a term that encompasses "semi-SCC", flowable grouts, and other materials with desirable rheological performance. The term "adapted rheology" refers to the material designer's task to produce concrete to match the specific needs of a given construction scenario. Thus, HPC-AR is not simply a new name for SCC, but it emphasizes the control of material behavior to achieve easy and reliable placement of concrete that provides superior hardened properties as required by the application.

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II. RESEARCH OBJECTIVES

The research objectives motivating this study were to**:**

1. Improve methods for measuring and modeling formwork pressure of HPC-AR, and improve methods by appropriate laboratory experiments and analysis.
2. Study fresh and hardened properties, and the transition from one to the other. The transition from liquid to solid is not merely a function of hydration, but of rheological behavior. HPC-AR must exhibit "robustness" and "stability" in real-world application. Develop better understanding of gelation and microstructure development to develop predictive models for material properties.
3. Develop improved mixture design methodology to produce HPC-AR with reliable, stable, robust performance while having desired flow and hardened properties.
4. Conduct field tests of placement of HPC-AR in tall forms. Measure formwork pressure, fresh properties, robustness, and assess all aspects of constructability.

III. LABORATORY TEST PROGRAM

The experimental program in this project was designed to measure the formwork pressure and pressure decay accurately and to understand the mechanism behind the pressure variation with different parameters. The program included measurement of material properties of constituents, SCC slump flow, rheological measurements, and a column pressure test.

The test matrix considered variables such as SCC water:cementitious ratio, addition of fly ash, aggregate moisture content and gradation, addition of viscosity modifying admixture, and addition of fibers. The text matrix also considered various formwork dimensions.

The experimental program measured the thixotropy and rheology of the SCC mixtures. An ICAR rheometer was used, and the effect of many variables were assessed when making rheological measurements. The formwork pressure was measured using a static column setup, pressure sensors, and a datalogger to track pressure with time.

Analysis of formwork pressure was assessed by several models that have been proposed by past research. Building off work by Lange and Tejeda [4], the column pressure measurements were interpreted and SCC mixtures were compared.

IV. FIELD TEST PROGRAM

A field test program supported in part by this project was conducted at the St. Mary's Cement site in Toronto, ON, Canada. The extensive study was a collaboration of several universities and industry sponsors. The focus of the study was to measure lateral pressure by casting eight tall columns 6.00 m (20 ft) in height, and examining how the measured lateral pressure envelopes varied with rates of concrete placement of 3, 5, and 10 m/h (10, 16, and 32 ft/h). Variables included reinforcement density and levels of concrete thixotropy.

The full details of the field test program are documented in a published article by N.J. Gardner et. al. [2]. The factors affecting SCC are further discussed by the same team in a document by K.H. Khayat et. al. [3]. A prior study in Stockholm served as an essential precursor to the Toronto field test program [5].

The Toronto field test program included analysis of formwork pressure using six prediction methods. While the models differed in terms of input data and formulation, it was shown that all six equations could be successful and effective for prediction of formwork pressure.

V. CONCLUSIONS

The project produced new insight into testing SCC, analyzing formwork pressure, and validating analytical models used for formwork pressure. A method for achieving the accurate yield stress values using the ICAR rheometer was developed. The accuracy of the pressure data obtained using pressure sensors was also evaluated. Based on the results obtained, the accuracy of the Lange and Tejeda model in predicting the formwork pressure of self consolidating concrete was studied. The results showed that within first few hours of the pressure decay, the reversible changes in concrete dominate the pressure decay and slight variation in the mix proportions, mixing procedure alter the pressure decay significantly indicating the sensitivity of SCC mixes. The formwork dimensions also affect the pressure decay indicating the importance of including the formwork dimension parameter while developing the models for prediction of formwork pressure.

Recommendations were made for reducing the variation in the mix properties, the importance of focusing on the particle to particle interaction within concrete for understanding its thixotropic properties that seem to be the primary cause of the pressure decay in the initial hours after casting before the hydration process becomes dominant. From the mix design point of view, using the oven dried aggregates (with fines sieved off) and aggregate with low absorption capacity is recommended as it offers better control over the mix in terms of available water in the concrete mix for workability and hydration thereby controlling the variation formwork pressure. The formwork dimensions (height, diameter, and height to diameter ratio) have a significant on the pressure decay so its effect should be considered when developing the models for the estimation of formwork pressure. Reversible effects dominate the pressure decay for the first few hours so to understand the pressure decay completely the fresh properties of concrete and cement paste with emphasis on the thixotropy and its behavior under constrained and creep load conditions need to be studied. A small variation in the material proportions affect the pressure decay, yield stress data significantly making the prediction of the field lateral pressure exerted by a concrete mix based on the results obtained in the laboratory studies.

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