RDT

Brief

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Advanced Research of an Image Analysis System for Hardened Concrete

A National Pooled Fund Effort

Introduction

For decades, testing laboratories have analyzed hardened concrete to determine the structure of its air-void system. Analysis has been routinely conducted for research purposes or to verify the quality of concrete placed in a structure or pavement. The characteristics of the air-void system in concrete, such as void size and spacing, serve as valuable tools in assessing the resistance of concrete to freezing and thawing. Knowledge of the air-void system characteristics can, therefore, help determine concrete durability and long-term performance.

ASTM C-457, *Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*, is the accepted test method for determining the characteristics of the air-void system in hardened concrete. ASTM C-457 provides two methods for determining air-void system parameters: the linear traverse (Procedure A) and the modified point count (Procedure B). Many agree that in order to get the most accurate results with either method, a human operator must participate to distinguish among the various concrete constituents (air, paste, aggregate). Over the past 30 years, several researchers have proposed completely automated systems using image analysis to replace the human operator. However, while there are some commercial image analysis systems currently available for evaluating hardened concrete, it is felt that a human operator is still needed for the utmost confidence in data and results.

Although human-based tests are considered most reliable, they have several disadvantages. The procedures are extremely time-consuming and tedious, and the quality of results depends on the skill and experience of the operator. Developing an automated system that would produce ASTM C-457 results to the same or better degree of accuracy as current human-based results would be a significant improvement and would have great impact in the area of concrete testing and research.

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MoDOT

A national pooled fund study, with the Missouri Department of Transportation (MoDOT) serving as the lead agency, is currently underway with full intentions of developing and validating an image analysis system (including hardware specifications and accompanying software) capable of determining the parameters of the air-void system in hardened concrete as specified by ASTM C-457 *Procedure A* (linear-traverse method). The National Nuclear Security Administration-Kansas City Plant (NNSA-KCP) is the contractor carrying out the primary tasks of the pooled fund study.

A Prototype Image Analysis System

Through a cooperative effort since 1998, MoDOT and NNSA-KCP have successfully developed a prototype image analysis system with a baseline capability of analyzing hardened concrete and determining its air-void system characteristics. A government contractor for the U.S. Department of Energy, NNSA-KCP has developed an extensive capability through years of experience in image processing, pattern recognition, and system integration for used in weapons applications. NNSA-KCP has applied this same technology to determining the properties of the air-void system in hardened concrete and to developing the prototype system.

The current image analysis system uses a high precision, two-dimensional computer-controlled stage to move the concrete sample under a research grade microscope. The image acquisition system consists of a color CCD camera, a frame grabber for image capture, and a dual processor (450MHz) tower PC. An intense light source illuminates the polished surface of the concrete sample from a very low, grazing angle to accentuate the voids and improve contrast. Customized image processing and pattern recognition software has been developed to identify air voids and extract void characteristics. These characteristics are then used to calculate air-void system parameters, such as air content, average void size, spacing factor (L), specific surface (α), void frequency (n), paste-air ratio, and others. All system components are linked via a graphical user interface, which aids the operator in the image acquisition, analysis, and review processes. Image acquisition typically takes approximately 12 hours with system analysis requiring 7 to 8 hours, however, with little to no human operator intervention. This prototype system has been found to provide consistent results, which have been in general agreement with results obtained by a human operator.

Based on success of the previous work with MoDOT and the potential of the prototype image analysis system, a national pooled fund effort was proposed to fully develop the system to a sufficient level of accuracy. System optimization and validation to be accomplished through the pooled fund study should bring the system capability to the level of accuracy needed to replace tedious human-based analyses. Significant advancements in computer technology since development of the prototype system should also reduce the total time required for system operation to half that currently needed.

Prototype image analysis system developed by the Missouri Department of Transportation and the National Nuclear Security Administration-Kansas City Plant.

Pooled Fund Study Objective

The primary objective of the pooled fund study is to improve and expand the detection and analysis capabilities of the prototype image analysis system. The focus of the 2-year study, to be completed in the summer of 2004, will be on the following:

- Coordination of concrete imaging efforts with other states,
- Validation and testing of the image analysis system on a broad range of concrete samples,
- Identification and development of software and hardware enhancements.

These enhancements are intended to meet the needs of diverse users in the field of concrete materials, construction, and research.

In addition to funds contributed by Missouri and NNSA-KCP, eleven states are contributing and participating in the pooled fund effort. These states include Arkansas, California, Colorado, Illinois, Indiana, Minnesota, Montana, Nebraska, Ohio, Virginia, and Wisconsin. A technical advisory committee (TAC) with representatives from each participating state, the Federal Highway Administration (FHWA), and NNSA-KCP has been formed to provide technical oversight and input as the study progresses. The committee held their first meeting in May, 2002, in St. Louis, Missouri. During the meeting, initial coordination efforts took place to plan for collection of concrete samples from all participating states and elsewhere to provide a variable source of data for system validation. The original prototype system validation was based on a limited number of concrete samples from Missouri. For the pooled fund study, a much broader range of concrete samples, providing a variety of aggregate types, paste characteristics, and air-void systems, is needed to quantify and improve system analysis capability.

Defining Accuracy of the Image Analysis System

As previously emphasized, the goal of the pooled fund effort is to develop an image analysis system that produces results of equivalent accuracy to a human-based linear traverse (ASTM C-457 *Procedure A*). However, a clear understanding of the accuracy and variability of the current ASTM C 457 linear traverse method is essential to establishing criteria for the automated system. ASTM C 457 is a process based on statistical sampling. For a given concrete sample, the parameters determined for the air-void system are estimates based on measurements taken from only a fraction of the air voids visible on the sample surface; moreover, the visible voids are only a fraction of the voids existing throughout the full sample.[1] Since results are statistical estimates based on a limited number of actual measurements, a certain degree of uncertainty inherently exists (as demonstrated by multiple tests of a single sample by a single operator). In addition to this inherent variability, other sources of variability such as differing equipment among laboratories, variation in quality of sample surface preparation, and, most importantly, human operator subjectivity are known to contribute to the overall variability of ASTM C 457 results.

A primary task of the TAC will be to investigate the sources of variability and establish requirements for the final image analysis system. As a means of assessing and quantifying respective levels of variability, an expanded round robin testing program among the participating state laboratories and FHWA is currently underway as part of the pooled fund study. The testing program focuses on five, pre-selected concrete samples from various locations throughout the country. Testing has been structured to evaluate each source of variability for obtaining a better understanding of their roles in influencing ASTM C 457 results. Results will enable an acceptable, standard level of accuracy to be established for the image analysis system.

Anticipated Results

The pooled fund study, Advanced Research of an Image Analysis System for Hardened Concrete, should produce an image analysis system capable of and accurate enough to produce results in accordance with human-based ASTM C 457 (*Procedure A*). Through expanded detection capabilities and better-defined system accuracy, this

study is anticipated to improve the current prototype system resulting in an automated image analysis system that is more accurate, efficient, and reliable. This will have a significant impact on concrete testing and research.

[1] Hover, K.C., "Air Content and Unit Weight of Hardened Concrete," *Significance of Tests and Properties of Concrete and Concrete-Making Materials, STP 169C*, American Society for Testing and Materials, Philadelphia, PA, 1994, pp. 296-314.

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