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RESEARCH PROJECT TITLE
Calibrating the Iowa Pore Index with Mercury Intrusion Porosimetry and Petrography – Phase II

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Calibrating the Iowa Pore Index with Mercury Intrusion Porosimetry and Petrography – Phase II

tech transfer summary

A new Iowa Pore Index test device and updated procedures were developed to more accurately represent the water intrusion process and aid in a better understanding of coarse aggregate freeze/thaw susceptibility.

Objective

The researchers aimed to test the efficiency and repeatability of current Iowa Pore Index (IPI) procedures, and improve them through the introduction of a new third-generation (3G) IPI fluid intrusion device that can measure the volume of intruded water at various time intervals ranging from 0.1–2.0 seconds, as well as measure intrusion at variable pressures up to 70 psi (480 kPa).

Additionally, through petrographic thin section analysis, the researchers sought to link IPI test results and qualitative rock properties (e.g., pore types). With this information, the IPI test may yield more reliable and accurate results that may be more useful when assessing the durability of a particular coarse aggregate sample.

Problem Statement

The IPI test has served as a reasonable measure to analyze pore distributions of coarse aggregate, but the device and procedures currently in use need to be updated to make the process more automated, more exact, and to better understand coarse aggregate freeze/thaw susceptibility.

Background

In order to effectively assess coarse aggregate quality for use in portland cement concrete (PCC), it is crucial to understand a source's petrophysical properties, because they influence the overall durability and longevity of the road systems of which they are a part.

Capillary pores, or pores with throat diameters between 50 nm to 10 μm, accelerate premature deterioration of pavement in environments with repetitive freeze/thaw cycles. To test for capillary pore abundances and porosity of a specific coarse aggregate source, the original IPI test was created as a tool to differentiate durable and non-durable coarse aggregate sources using pressurized water intrusion.

Among the numerous methods for characterizing the porosity of coarse aggregates, water intrusion is advantageous because it is inexpensive, non-destructive, and quick. The IPI test involves a device and a procedure for measuring the volume ratio of macropores to micropores of coarse aggregate via water intrusion. The current device keeps track of intrusion only at two time steps (1 minute and 15 minutes) and only operates at 35 psi.

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With the IPI test, water intrudes a 4,500 g sample of oven-dried coarse aggregate over the span of 15 minutes at a constant pressure of 35 psi (240 kPa). Although the device has been automated since, the basic idea has remained unchanged.

With prior devices, two volumes of intrusion were measured: the primary load and secondary load, which relate to macropores and micropores, respectively. A high secondary load (i.e., high microporosity) has been correlated with shorter pavement service life.

The IPI was initially developed by the Iowa Department of Transportation (DOT) in the 1980s. This method is used by several state DOTs and accepted as an American Association of State Highway and Transportation Officials standard (AASHTO TP 120-16) due to its non-hazardous, quick, and simple procedure for quantifying pore distributions (i.e., macro- and micropores).

Project Description

To derive more information about a coarse aggregate's pore system, this study used a device capable of measuring the volume of intruded water at various time intervals ranging from 0.1–2.0 seconds, as well as measuring intrusion at variable pressures up to 70 psi (480 kPa). Using this new device, 21 carbonate samples (10 dolostones and 11 limestones) were compared to "traditional" IPI measurements.

Additional tests included the following:

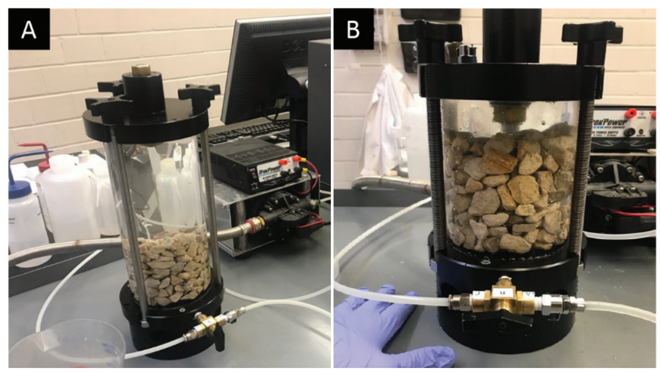
- By decreasing the apparatus chamber size, higher total intrusion was recorded, and IPI values were more correlative with traditional measurements
- By analyzing the effect of variable pressure intrusion (15, 35, and 60 psi), it was observed that the transition point between intrusion of macropores and micropores was sample-dependent, based on lithology (i.e., limestone or dolostone)
- By assessing the incremental intrusion of each source, new primary and secondary loads were calculated, which may be more characteristic of individual lithologies and predictive of future performance

After analyzing the 21 sources, including comparisons to second-generation (2G) device data, the research team developed three different methods—heterogeneity, special investigation, and operational—of using this 3G IPI device and interpreting intrusion data.

Key Findings and 3G Device Benefits

Benefits of utilizing the 3G IPI device include the following:

- **Automation reduces operator error.** The 2G device relies on the operator's perception of intruded volumes through measuring fluid levels by eye with graduated cylinders. Incorporating the FlowTrac II automated fluid intrusion device in the 3G IPI procedure mitigated many of the perception issues. Also, the improved automation can measure fluid intrusion in time increments varying from 0.1 s to 2 s.
- **Smaller sample sizes offer greater flexibility.** Sample size has typically remained constant for IPI devices with 4.5 kg of aggregate analyzed. With the smaller chamber size of the 3G device, sample size was decreased to 1 kg. While samples from producer stockpiles are easy to obtain, using a smaller sample size makes it possible to run the IPI test on shorter sections of core that may not be long enough for 2G measurements.



3G IPI device (a) with 1,650 cm^3 chamber and (b) with smaller 1,100 cm^3 chamber

- **Reduced soak time.** The 2G device required longer to fill the sample chamber prior to measurement. During this time, water was able to intrude the coarse aggregate's pore system due to spontaneous imbibition without being measured in the primary load index (PLI) graduated cylinder. This likely resulted in PLI measurements being lower than reality. With the 3G device, initial soak time decreased and, therefore, PLIs that are more representative of actual lithologies were measured.

- **More accurate PLI and SLI.** Because of the intrusion automation, it was possible to track fluid intrusion as a function of time with greater accuracy. Thus, it was found that a transition from PLI-type intrusion to secondary load index- (SLI-) type intrusion occurred sooner than 60 seconds, which had been the boundary between primary and secondary intrusion in the 2G device. Because incremental intruded volumes can be recorded as quickly as every 0.1 s, more information can be derived than through using the 2G device, which only measures intrusion volume after 60 s and 900 s. The rate of intrusion can be calculated and inferred from plots, which provide an additional method to interpret IPI results by incorporating other lithologies.

- **Faster operation and leak detection.** Additionally, the device reads out variation in system pressure, which can be used to determine if intrusion is a result of a leak. The previous 2G device included a third graduated cylinder that would analyze potential leaks for 15 minutes after testing. Not needing the additional 15 minutes to run the leak detection cylinder makes the 3G device more time-efficient.

- **Higher pressure can investigate smaller pore sizes.** One aspect of the IPI that has remained rather constant through the evolution is the pressure of intrusion utilized to quantify the pore ratios. A water pressure of 35 psi, or 240 kPa, has been the standard since its development in the 1980s. However, with the capabilities of this new device, pressure of intrusion can be varied up to 70 psi. With this change, which was only achieved through the evolution of the IPI device, the times at which PLI and SLI are measured may need revision to shorter time intervals.

Implementation Readiness and Benefits

Of the three different methods developed for using the IPI device and interpreting intrusion data, the special investigation method yields the highest quality data but is probably too time intensive for routine quality assessment and quality control. Therefore, the operational method is recommended for using the 3G IPI device for measuring IPI indices on a routine basis. With this method, lithology-specific transition points have been calculated to use within the traditional IPI calculations.

By utilizing a more automated device and pairing results with traditional petrophysical methods (like helium porosity or mercury porosimetry), IPI results may be more indicative of individual lithologies, which may have been miscategorized in the past.

With these newly calculated intervals, primary and secondary load indices should more accurately represent the water intrusion process and aid in a better understanding of coarse aggregate freeze/thaw susceptibility and, ultimately, PCC pavement durability.