Concrete Durability

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The concrete and structures technical area of SHRP directed funds to develop remedies for corrosion-damaged concrete bridges and to improve concrete technology. More than 40 products and numerous reports were developed under the program, and of these, 14 can be broadly categorized as relating to concrete durability. As part of the US Federal Highway Administration (FHWA) implementation process to evaluate and promote worthy products, a Concrete Durability Showcase contract was awarded to Construction Technology Laboratories, Inc. in April 1994. This technical brief highlights the status of the products in the showcase. The products are grouped by subject in three categories, including concrete permeability, quality control tests, and freeze-thaw conditions.

CONCRETE PERMEABILITY

A low permeability concrete generally possesses high strength and is resistant to the ingress of water and salt solutions. The reinforcing steel in concrete structures begins to corrode earlier and corrodes faster when the surrounding concrete is porous because chloride, oxygen, and moisture can more easily reach the steel. Measuring permeability helps detect durability problems and allows timely and cost-effective protection of the concrete structure. Three new tests developed under the SHRP program were intended to provide new tools to monitor concrete permeability.

Field Test for Concrete Permeability

Under SHRP contract C-101, Assessment of Physical Condition of Concrete Bridge Components, a field test for concrete permeability was developed. The objective of this product (SHRP 2031) is to provide a rapid field test that correlates with standard laboratory techniques which measure permeability from cores removed from the structure in question. The non-destructive field device measures air flow under vacuum and gives a reasonable indication of relative permeability. The measure is relative because it is representative of only the top 10 mm and not of the concrete mass in its entirety. Furthermore, to maintain the vacuum, the device requires a smooth surface but it would be more useful if rough or textured surfaces could be tested. Although the importance of permeability to concrete durability is recognized, FHWA was unsure how this test could be used by highway agencies. Five units are available as part of an equipment loan program. Details of the development of this product are reported in Condition Evaluation of Concrete Bridges Relative to Reinforcement Corrosion, Volume 7: Method for Field Measurement of Concrete Permeability (SHRP-S-329). The product has been provisionally adopted as AASHTO TP 26-94.

Laboratory Test for Concrete Permeability

Under SHRP contract C-201, Concrete Microstructure, a laboratory test for concrete permeability was developed. This test method
(SHRP 2007) involves forcing air under pressure through a specimen and measuring the rate of pressure decay; that rate corresponds to the permeability of the specimen. However, the research was conducted using specimens of mortar and cement, and the equipment is inapplicable for testing actual concrete. Furthermore, the data provided by the equipment are apparently inconsistent with theory. The device, described in Development of Transient Permeability Theory and Apparatus for Measurement of Cementitious Materials (SHRP-C-627), needs further research and will not be implemented by FHWA.

**AC Impedance Test for Concrete Permeability**

The movement of ions such as chloride and sulfate through concrete depends on the concrete's degree of permeability: low permeability concrete shows greater resistance to ionic movement than does high permeability concrete. Permeability of concrete correlates with its electrical AC impedance characteristics. Under SHRP contract C-205, Mechanical Behaviour of High Performance Concretes, a test was designed to provide a reasonable alternative to the standard AASHTO T-277 (Standard Test Method for Rapid Chloride Permeability of Concrete) and to provide a more rapid determination of concrete permeability. However, the test (SHRP 2026) is labour intensive in the first stage of concrete core preparation and therefore the time savings are not significant. Furthermore, the results are not reproducible and the AC impedance test (now AASHTO TP 22-94) requires calibration with the standard test. Additional information can be found in Mechanical Behaviour of High Performance Concretes, Volume 3: Very Early Strength Concrete (SHRP-C-363).

**QUALITY CONTROL TESTS**

Work under SHRP contract C-206, Optimization of Highway Concrete Technology, resulted in five products relating to optimization or quality control of concrete.

**Flaw Detection by the Impact-Echo Method**

This technique (SHRP 2012) measures transient stress wave signals within the concrete generated as a result of an external impact. The test, described in Optimization of Highway Concrete Technology (SHRP-C-373), detects differences in characteristics of reflected wave signals that depend upon the condition of the interior of the concrete and thus locates defects such as voids, cracks or delamination.

Six impact-echo devices were procured as part of the Concrete Durability Showcase. Advanced training courses have been completed and field testing is underway. Initial reports recommend additional research and development. Users have had difficulty taking measurements and interpreting the wave signals to distinguish noise from data.

After the equipment was developed, a second possible application was conceived. Pavement thickness was measured using the impact-echo technique, but the accuracy achieved (± 13 mm) was deemed inadequate. Another production unit which allows the accurate measurement of wave speed at each test location has been procured. The software has been improved to filter the wave signal and eliminate some noise which should allow the user to measure pavement thickness more accurately (± 4 mm). Initial field evaluation suggested that additional tests are needed on pavement sections with different bases to determine their effect on the accuracy of thickness measurements. State highway agencies see greater benefits in using the impact-echo method for measuring pavement thickness than flaw detection. The method has been adopted as AASHTO provisional standard TP 28-94.

**Test for Water Content of Fresh Concrete**

The amount of water in a concrete mix affects the quality of the concrete during placement and the durability of the hardened concrete. Excessive water can exacerbate freeze-thaw damage and alkali-silica reactivity, and make the concrete more permeable. This test (SHRP 2027) consists of drying a representative sample of fresh concrete in a microwave oven. The water content is calculated by the weight loss of the sample after drying. Development information is provided in Optimization of Highway Concrete Technology (SHRP-C-373). The test is simple, rugged and reasonably accurate. The equipment is inexpen-
sive and readily available. The test is sufficiently reproducible and accurate for field control, although more field evaluation would be useful. An AASHTO provisional standard (TP 23-93) exists for the product.

HWYCON - Concrete Expert System

HWYCON (SHRP 2039) is a computerized expert system designed to assist highway agencies diagnose concrete distress, design and specify concrete, and repair and rehabilitate concrete pavements and structures. HWYCON makes recommendations based on observations input by the user. Although the recommendations suggest a possible solution, they do not solve an entire problem, but they can be used in the decision-making process. HWYCON is a useful educational tool. A separate technical brief about HWYCON is available from C-SHRP, and a full description of the system is provided in Users Guide to the Highway Concrete (HWYCON) Expert System (SHRP-C-406).

Test for Consolidation of Concrete

Proper consolidation of concrete increases its density and results in a number of benefits, such as reduction of undesirable air voids, decreased permeability, decreased drying shrinkage, and improved bonding to reinforcing steel. This field test method (SHRP 2028) determines the degree of consolidation, or in-place density of plastic concrete, using a twin probe nuclear gauge. The test method is now AASHTO provisional standard TP 24-94. Details of the research are provided in Optimization of Highway Concrete Technology (SHRP-C-373). The gauge used during the research is not sufficiently rugged for use in the field and a field version was not available as of November, 1994. The product is expensive and operator certification and radiation monitoring are required and, as a result, this product has seen little practical use in the field.

Field Measurement of Concrete Strength and Maturity

This subject has been extensively studied by numerous organizations and the SHRP report, Field Manual for Maturity and Pullout Testing on Highway Structures (SHRP-C-376), summarizes the knowledge, current at the time of printing. The report constitutes SHRP product 2022.

FREEZE-THAW CONDITIONS

Six products resulted from the work conducted under SHRP contract C-203, Resistance of Concrete to Freezing and Thawing. The work is documented in a report (SHRP-C-391) of the same title.

Aggregate Durability Test Method and Aggregate Specifications

A new test (SHRP 2002) to screen aggregates for D-cracking potential was developed and new concrete aggregate specifications (SHRP 2021) were defined based on the results of that test. In the new test method, pre-dried aggregates are submerged in water in a pressure chamber. Under pressure, water enters the aggregate pores and compresses the air within. When the pressure is released rapidly, the air compressed in the aggregate pores forces the water out; if the aggregate fractures or fragments, it indicates a susceptibility to D-cracking. The fracture percentage after a cycle of tests indicates the D-cracking potential of the aggregate. A large sample size of 600 to 800 pieces of aggregate is needed to ensure a coefficient of variation less than 10%. The test (AASHTO provisional standard TP 12-93) is labour intensive and requires considerable technician time.

The original version of the hydraulic fracture equipment was based on a small chamber design. Following testing, five larger units were built but subsequent testing of those yielded data which were not acceptable. The original test results may have been dependent on the scale of the unit. Therefore, five small chambers will be purchased by FHWA for precision/bias testing, however there is no guarantee that the original test results will be reproduced.

Guidelines for Mitigating D-Cracking in Existing Concrete

This product (SHRP 2004) is a report which describes protection strategies to help avoid or minimize further damage of in-service concrete pavement showing signs of D-cracking problems. Various
options are reviewed, including penetrating sealers, low-permeability concrete bonding at joints, and asphalt overlays. These methods are intended to reduce the permeability of the concrete by preventing water from entering and accumulating in concrete joints. The procedures do assist in keeping some of the moisture out, but the bottom layer of the concrete pavement is not sealed and moisture seeps up into the concrete. This product will not be implemented by FHWA.

**Modified Freeze-Thaw Test**

Standard practice to evaluate the resistance of concrete to freezing and thawing is to use the AASHTO T-161 (ASTM C 666) test, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing. The SHRP modification (SHRP 2018) is to wrap the test specimen in moist towels during both freezing and thawing phases. The objective of the modification is to realistically simulate the natural freeze-thaw environment of concrete. Research showed that the modification results in a more uniform cooling rate and that the new procedure is slightly more severe than the standard test procedure, but that a dramatic improvement has not been achieved. The modified test has been provisionally adopted as AASHTO TP 17-93, and is likely to be incorporated as Method C in the standard AASHTO T-161 test.

**Soundness Test for Concrete**

Using impact-frequency techniques on concrete specimens, this new test (SHRP 2019) detects changes in the modulus of elasticity of concrete due to weathering or other deteriorating influences. As the condition of in-service concrete deteriorates through freeze-thaw damage, it causes a decrease of vibrational amplitude and an increase in damping. The degree of damping indicates the extent of damage to the concrete. The test has been provisionally adopted as AASHTO TP 18-94. However, the test equipment does not offer a significant cost/benefit advantage over existing methods (ASTM C215, Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens) and the product, therefore, will not be implemented by FHWA.

**Air Entrainment Specifications**

Under the SHRP contract, air void spacing parameters were measured for various concretes, but no conclusions regarding their suitability for acceptance purposes were drawn and no revisions to current air content specifications were made. This product (SHRP 2020) will not be implemented by FHWA.