concrete expands and eventually cracks. It can lead to structural failure. ASR is difficult to distinguish from other causes of cracking in concrete. If concrete cracking problems are incorrectly identified and improperly rehabilitated, the ASR problem may be made worse. Inspectors and engineers need to be able to correctly identify ASR so they can choose the proper rehabilitation strategy and screen aggregates to avoid ASR problems in new construction.

- Handbook for Identification of ASR

Help is now available to assist highway engineers and bridge inspectors to identify alkali-silica reactivity (ASR). This new illustrated handbook of ASR-related damage in concrete pavements and bridge structures helps distinguish ASR-induced cracking from damage by other causes, such as improper curing, corrosion of reinforcing steel, or freezing and thawing. Concrete cracking is often caused by more than one factor. The color photographs in this handbook provide help in visually inspecting for ASR.

Once alkali-silica reactivity (ASR) has been visually detected in concrete, its presence must be confirmed. A new, simple, and fast chemical test for ASR requires no tedious sample preparation. Instead, the concrete surface is treated with a uranyl acetate solution and viewed under ultraviolet light. The uranyl acetate causes the ASR "gel" to fluoresce, imparting a greenish-yellow glow that can be clearly seen under the ultraviolet light. (The technique is described in the ASR handbook). The equipment and chemicals needed for this test are commercially available.

- Mitigating ASR in Existing Concrete

Current options for rehabilitating ASR-damaged concrete are limited. Two chemical treatments have recently been documented, and a new approach to mitigating ASR damage in existing concrete has been evaluated. High molecular weight methyl acrylate and silanes appear to be helpful in inhibiting further ASR damage in pavements and bridges. The chemicals penetrate and fill cracks and bond to the cracked concrete faces, preventing moisture from entering ASR-affected areas. Laboratory tests indicate that treating ASR-affected concrete with lithium hydroxide may also be an effective way to prevent further ASR-related damage.

- Tools for Screening Reactive Aggregates

The obvious way to avoid ASR-related damage in concrete is to refrain from using potentially reactive aggregates. Current standard test methods for screening aggregates - the Mortar Bar Test (ASTM C-227) and the Quick Chemical Test (ASTM C-289) - often underestimate the ASR potential, particularly for slow-reacting aggregates. A new laboratory test quickly and reliably screens potentially reactive aggregates. Mortar bars or concrete prisms are immersed in a sodium hydroxide solution maintained at a temperature of 80 degrees Celsius for up to fourteen days. If the bars or prisms expand by more than 0.1 percent of their original length, the aggregate is potentially reactive and should be avoided. The test may also be modified to determine the maximum acceptable alkali content in cement for use with a potentially reactive aggregate. The test has been submitted to AASHTO for consideration.

- Designing ASR-Safe Concrete Mixtures

Now you can design a concrete mix that will be safe from alkali-silica reactivity (ASR). Use this new specification guide to produce concrete that will resist ASR and the associated expansion and damage. The guide recommends specific combinations of cement, coarse and fine aggregates, and admixtures (both mineral and chemical) to resist ASR in new concrete. Adding pozzolanic materials such as fly ash and silica fume and chemical admixtures such a lithium hydroxide to the concrete mix will produce an ASR-safe concrete. Lithium salts and certain types of fly ashes have been found very effective in inhibiting ASR-related expansion in concrete.

<u>Freeze and thaw conditions</u> -- Freezing and thawing of concrete under saturated conditions has always been a major deteriorating condition for concrete. The test methods for determining the ability on specific concrete to resist freezing and thawing have not really represented existing field conditions.

- Concrete Resistance to Freezing and Thawing - Modified Test

A new procedure offers a third option for evaluating the resistance of concrete to freezing and thawing. Current practice is to use the standard AASHTO T-161 test (ASTM C666), which allows two alternative procedures to be used. Procedure A involves freezing and thawing concrete specimens in water, and Procedure B consists of freezing the specimen in air and thawing it in water. The SHRP alternative involves wrapping the test specimen in moist towels during both freezing and thawing phases, thus realistically simulating the natural freeze-thaw environment of concrete. The procedure is under consideration by AASHTO.

- Avoiding D-Cracking - An Aggregate Durability Test

Avoid cracks caused by freezing and thawing at the joints in concrete pavement (D-cracking) by using this new test to screen aggregates. The test method currently used to screen aggregates for D-cracking potential (AASHTO T-161 or ASTM C-666) takes too long (8-10 weeks). This new, simple laboratory test takes only 8-10 days. Pre-dried aggregates are submerged in water in a pressure chamber and subjected to a pressure of 1150 psi (about 8 MPa). Under pressure, water enters the aggregate pores and compresses the air within the pores. When the pressure is rapidly released, the air compressed in the aggregate pores forces the water out; if the aggregate fracture or fragments, it indicates a susceptibility to D-cracking. A total of 50 test cycles (10 per day) are recommended for each sample set. The fracture percentage indicates the D-cracking potential of the aggregate. Aggregates that pass this test can be readily approved for construction. Aggregates that fail should be subjected to the more rigorous. AASHTO T-161 test. The test method has been submitted to AASHTO for consideration.

- Avoiding Aggregates Susceptible to D-Cracking

Cracking at joints in concrete can be avoided by using aggregates that are not susceptible to being damaged by freezing and thawing. New concrete aggregate specifications based on the hydraulic fracture test (SHRP 2002) can identify such aggregates. Aggregates that are known to be durable based on highway performance records generally show less than 5 percent of fracture after 50 test cycles. The specifications can be used as the basis for developing criteria for selecting aggregates that resist the effect of freezing and thawing. The specifications will be submitted to AASHTO for consideration.

- Mitigating D-Cracking in Existing Concrete

The protection strategies described in this report can help avoid or minimize further damage of in-service concrete evidencing D-cracking problems. The permeability of the concrete is reduced by preventing water from entering and accumulating in concrete joints. Water-saturated aggregate increases the potential for the concrete to fracture during freeze-thaw cycles. Various protective options are reviewed, including penetrating sealers, low-permeability concrete bonding at joints, asphalt overlays, and other alternatives that may help to extend the service life of existing concrete.

- Improving Condition Evaluation - New Soundness Test for Concrete

Evaluating the condition of in-service concrete is now easier with this new laboratory test. Using impact-frequency techniques on the concrete specimen, the test detects changes in the modulus of elasticity of concrete due to weathering or other deteriorating influences. In addition to being rapid and reproducible, the test produces information on the damping characteristics of vibrations induced in the specimen by impact. As the condition of in-service concrete deteriorates through freeze-thaw damage, it causes a decrease of vibrational amplitude and an increase in the damping. The degree of damping indicates the extent of damage to the concrete caused by factors such as ASR, freezing, and thawing. The test can also be applied to predict durability factors of concrete specimens after subjecting them to only a few freeze-thaw cycles using the AASHTO T161 test. This test has been submitted to AASHTO for consideration.

- New Air Entrainment Specifications

This guide provides new specifications for using air entrainment to improve the resistance of concrete to freezing and thawing. Air entrainment is an established method of protecting concrete from frost damage. The increasing use of chemical admixtures in concrete, such as water reducers, superplasticizers and pozzolanic materials, including fly ash and silica fume, makes the revised and improved specifications necessary. The new specifications apply to concrete currently used in highway construction and cover volume, size, distribution, and spacing factors for air in concrete to make the concrete resistant to frost action.

Nondestructive tests for quality control of concrete -- Too often concrete pavements, piers and walls are removed because of a lack of knowledge about the concrete properties. When we have to wait for 28 days to verify compliance with a strength requirement, the structure may already be in service. Coring existing concrete to verify concrete properties invariably results in swiss cheese structure before everyone is satisfied or has enough information to make decision. NDT can prevent these problems.

- Detecting Concrete Flaws and Delaminations

Defects such as voids, cracks, or delamination in concrete pavements and structures can be located using a new, nondestructive test method that can be applied in the field. This technique, known as impact-echo (or pulse-echo), measures transient stress were signals within the concrete generated as a result of an external impact. The test detects differences in characteristics of reflected wave signals that depend upon the condition of the interior of the concrete. The commercially available test equipment costs approximately.

- Measuring Concrete Strength and Maturity in the Field

This new guide details method for estimating the early-age strength of newly constructed concrete structures in the field. The estimate will help you determine when to remove the construction forms, saving construction time an costs. The methods described in the guide are based on "pull out" and maturity tests. The pull-out test measures the force required to pull a specially shaped steel insert out of hardened concrete, which correlates with its compressive strength. The maturity test measures the temperature of the concrete caused by hydration of cement, which correlates with its strength development. Both these techniques are simple and easy to use and give results with acceptable accuracy.

- Measuring Air Entrainment with the Fiber Optic Air Meter

The right amount of air entrainment is very important to concrete quality in any construction work. This new meter meets the need for a rapid and reliable field method for monitoring the air content of concrete during construction. The fiber optic air meter measures the air content of fresh or plastic concrete at the construction site. The device uses a fiber optic sensor probe, which is inserted into the concrete. The intensity of light reflected from air bubbles correlates with the amount of air in concrete. With proper calibration, the light intensity measured by the probe determines the air content.

Mechanical behavior of high-performance concrete -- High-strength concrete was primarily developed for high-rise buildings in order to compete with structural steel, but now high-performance concrete can be developed to be used in structures such as pavements, bridges, training walls and even guard walls on parkways.

- Specifications for High-Performance Concrete

High-performance concrete, with augmented strength, enhanced durability, and extended service life, is increasingly used for a variety of special applications. This guide documents specifications for the production and use of high-performance concrete for highway applications. These special concrete blends are generally characterized by a low-water/cement ratio and may contain fly ash, silica fume, fibers, and chemical admixtures such a water reducers, superplasticizers, and accelerators. Guidelines and recommendations are provided for material selection, proportioning, mixing, placing, and curing three categories, of high-performance concrete (very early strength, high early strength, and very high strength). The guide focuses on specific highway applications, paying special attention to economic feasibility and the use of locally available materials. In addition, an extensive reference database is included in the guide on the mechanical properties and behavior of these concrete mixtures.

- Determining the Modulus of Rupture

This proposed modification to the current standard test method (ASTM C-78) for the modulus of rupture, or flexural strength, of portland cement concrete uses a reinforcing bar at the center of gravity of the test specimen and a device to measure deformation. The use of the reinforcing bar prevents the sudden failure of the specimen and any damage to the deformation measurement device. In addition to flexural strength, the test provides information on flexural strain capacity of concrete.

- Determining Interfacial Bond Strength of Concrete

Now available is a new laboratory test method for determining the interfacial bond strength of two concrete sections. For highway construction projects such as concrete overlays, it is important to determine the quality of bond between the old and new concrete. A good, strong bond will generally indicate a durable pavement or bridge deck with enhanced service life. The direct shear test uses a specimen with an interfacial bond area of old and new concrete. The test measures the strength of the interfacial bond and the relative slip between bonded faces.

- Measuring Compressive Strength of HP Concrete

High-performance concretes are generally stronger than conventional concretes. Testing high-performance concretes for compressive strength using sulfur capping sometimes results in the cap failing before the specimen. By modifying the current standard test method (AASHTO T-22 and ASTM C-39) to use steel caps with neoprene pads instead of sulfur caps, the problem is avoided. The AASHTO T-22 test currently includes the use of steel caps as a supplement to this method. This alternative has been further refined and the modification evaluated.

Optimum highway concrete technology -- The water content is the most critical ingredient of concrete; too little and the concrete may not be workable or capable of being consolidated; too much and the properties having to do with quality may be lost.

- Determining Water Content of Fresh Concrete

The amount of water in the concrete mix affects the quality of concrete during placement and the durability of the hardened concrete. Excessive amounts of water can cause the concrete to be more prone to damage by freezing and thawing and alkali-silica reactivity. Also, too much water in the mix will make the concrete more permeable, allowing salt to penetrate, which will promote corrosion of reinforcing steel. A simple and rapid field test method has been developed for determining the water content of fresh concrete based on microwave drying. This test 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. The test takes only 15 minutes.

- Testing for Consolidation of Concrete

Proper consolidation of concrete increases its density and results in a number of benefits, such as reduction in undesirable air voids, decreased permeability, decreased drying shrinkage, and improved bonding to reinforcing steel. This field test method determines the degree of consolidation, or in-place density of plastic concrete, using a twin probe nuclear density gauge. The measurement of in-place density or thickness of concrete and other construction materials has been made much easier by the development of nuclear gauge technology. The technology measures the decrease in radiation intensity (gamma rays or photons) between the nuclear source and a detector situated across the material. A decrease in radiation intensity correlates with the thickness and density of the material. The twin-probe gauge has an advantage over other nuclear gauges in that it can estimate the density of plastic concrete at various depth and across a larger area.

- HWYCON - An Expert System of Concrete Durability

This computer program serves as a useful advisory tool to assist highway engineers in making decisions related to the diagnosis, material selection, and repair or rehabilitation of concrete pavements and structures. It is a user-friendly, menu-driven program whose knowledge base contains current information on concrete durability from various sources, such as published literature, SHRP research, and other concrete research. Photographic images stored in the computer provide visual information about various types of concrete distress and test methods and procedures. The system uses explanatory tests to assist the user in interpreting the facts, photographs, and procedures. Recommendations for repair and rehabilitation strategies are based largely on the extent of concrete deterioration and the type of distress. HWYCON is designed to run a 386-based desktop computer.

REMR ACCOMPLISHMENTS

The U.S. Army Corps of Engineers Repair, Evaluation, Maintenance and Rehabilitation (REMR) Research Program was initiated in 1984 with a planned six-year expenditure of 36 million dollars of which ten (10) million dollars would be used to research concrete materials and structures infrastructure. The REMR research program also included other areas of infrastructure research:

• Geotechnical	$ 8 million
• Hydraulics Structures	4.5 million
• Coastal Structures	4.7 million
• Electrical & Mechanical	2.5 million
• Environmental Impact	1.5 million
and • Operations Management	2.2 million

The first phase of this research program was completed in 1991, and was so successful that the Congress approved an additional Phase II with similar funding for six additional years starting in 1992.

Significant accomplishment during Phase I developed so many cost effective materials and techniques for repairing existing concrete hydraulic structures that the savings attributed to the first six months of research exceeded the total cost of the six-year research program. The major accomplishments developed in the Concrete and Structures Research Area are listed below:

- Development of a precast concrete stay-in-pace forming system for look wall rehabilitation
- Development of procedures and devices for underwater cleaning of hydraulic structures
- Extension of the technology of nondestructive testing systems for in-situ evaluation of concrete structures
- Evaluation of the effectiveness of a) pressure injection, and b) polymer impregnation repair techniques
- Development of mathematical models for analyzing concrete cracking in lock wall resurfacing
- Development of concrete mixtures for use in underwater repairs
- Development and evaluation of underwater repair techniques using abrasion-resistant concrete
- Evaluation of vinylester, polyester, and epoxy resins, and cement grouts for embedding anchors in hardened concrete
- Development of procedures for repairing wet concrete surfaces
- Development of a user's guide: Maintenance and Repair Materials Data Base for Concrete and Steel Structures
- Development of new stability and safety evaluation procedures for gravity earth retaining structures founded on rock
- Identified in-situ repair techniques to be used in rehabilitating cracked concrete hydraulic structures
- Extended the technology of silica fume concrete

- Extended the state-of-the-art in using anti-washout admixtures for underwater concreting
- Developed procedures for producing service life in cases of deterioration due to freezing and thawing.

ADDITIONAL INNOVATIONS

SHRP and REMR were two of the most successful research programs that have been ertaken during the past 20 years but there have been many innovative ideas and ucts developed by the concrete industry. A few of these innovations are:

- Extended Retardation Chemical Admixtures
- Corrosion Inhibiting Admixtures
- Freeze Protection Chemical Admixtures
- Alkali-Silica Resistant Admixtures
- Anti-Washout Admixtures
- Specialty Pre-packaged Repair Materials

Yes, the technology of concrete is being vastly improved and we have just begun, et us dream about the future; we will probably see many innovations within the next ade.

- Greater utilization of mineral admixtures
- Silica fume properties materials being marketed made out of rice-hull ash
- Greater dependency on prepackaged materials providing specific properties for particular projects
- Tighter controls on the chemical properties of cements so that they may be used with greater efficiency with chemical and mineral admixtures.
- Increased ASTM C494 requirements of existing commodity chemical admixtures.
- Independent QA auditing of materials producers with greater reliance on fresh concrete evaluation techniques for final acceptance.

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