



CONCRETE

MAKING A GOOD BUILDING MATERIAL BETTER

GARY HOFFMAN

Most of the bridge decks and many of the supporting structures in the United States are constructed of portland cement concrete, as are more than 200 000 kilometers (126,000 miles) of pavement. Highway projects consume about 7.26 million tonnes (8 million tons) of portland cement each year, helping to make it the most widely used construction material in the world today. But the service life of many of those pavements and structures is being cut short as a result of less-than-optimal mix designs, poor-quality aggregates, corrosion of the reinforcing steel, and other problems. According to a recent report, more than 43,000 bridges in the United States are in need of significant maintenance or rehabilitation—or even replacement (1).

The Strategic Highway Research Program set out to find ways to increase the service life of concrete pavements and structures and to develop and refine methods for protecting and rehabilitating existing pavements and bridges. The \$22 million concrete and structures component of the program consisted of two subprograms: one concentrated on improving the materials added to a portland-cement concrete mix, and the other addressed the problems caused by corrosion of the reinforcing steel in concrete.

IMPROVING MATERIAL SELECTION AND USE

Poor concrete durability can shorten a structure's service life and necessitate frequent repairs. These repairs drive up maintenance costs and can make travel particularly hazardous on bridges, where drivers have limited space to maneuver around deck-surface distress problems. To remedy such problems, SHRP investigated and refined several test methods and other tools for improving material selection and use.

Hydraulic Fracture Test

Repeated cycles of freezing and thawing can cause significant damage to concrete pavements and

bridge decks. Any water in the porous concrete will expand when it freezes, which can lead to cracks, delaminations, and spalling. One frequent result of freeze-thaw cycles is D-cracking, which usually starts at the bottom of the slab and propagates upward, along the joints. This phenomenon can eventually lead to concrete failure.

The hydraulic fracture test developed by SHRP can identify aggregates susceptible to D-cracking. A coarse aggregate sample is placed in a pressurized water chamber, which forces water into the aggregate pores. If the aggregates fracture when the pressure is released, potential problems are indicated.

Slump Test

Quality control at the job site is a key means of ensuring concrete durability. Although the slump test is an indicator of the uniformity and consistency of a concrete batch, it tells little about the water-cement ratio, which is an important determinant of concrete strength and durability. As the water-cement ratio increases, the strength of the concrete typically decreases.

To meet the need for a field test capable of measuring the water-cement ratio of concrete delivered to the job site, SHRP researchers used a conventional household item—the microwave oven. A sample of the as-delivered concrete is weighed and then dried in the oven. The sample is then weighed again, and the difference in mass indicates the total water content. The whole procedure usually takes about 15 minutes.

Impact Echo Technology

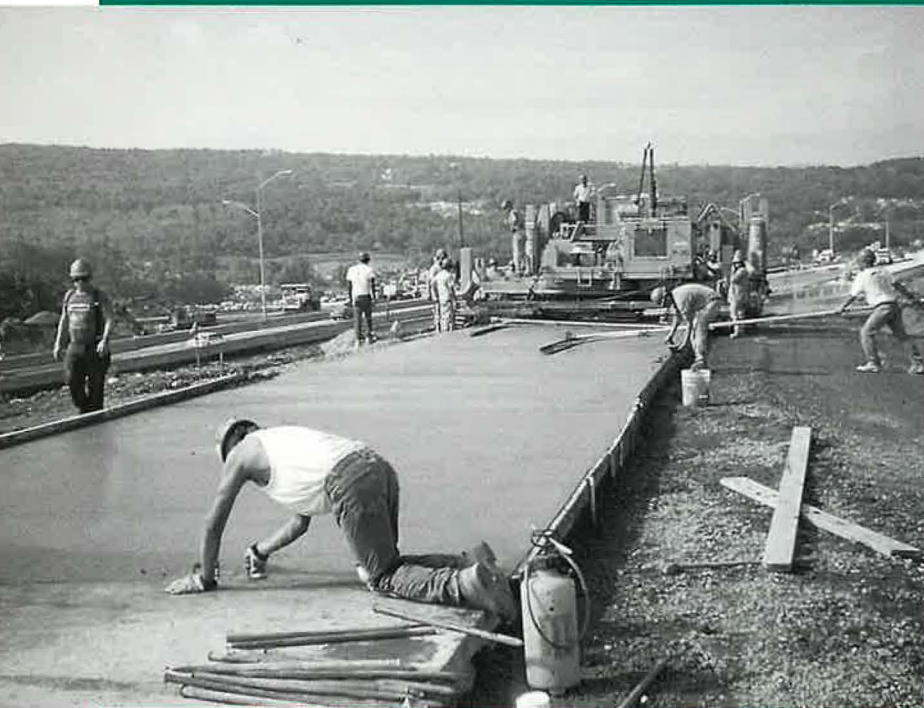
Most concrete problems start deep within the concrete, where they cannot be detected by sight. The impact echo device, a 50-year-old technology allows quick and easy location of internal voids and delaminations in concrete up to 1 meter (3 feet) thick—without the need to remove cores from the pavement.

SHRP researchers improved this technology by facilitating use of the impact echo device in the

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IMPROVING RESISTANCE TO ALKALI-SILICA REACTIVITY

Using SHRP test methods, the Pennsylvania Department of Transportation determined that the Pocono mountains area is loaded with aggregates highly susceptible to alkali-silica reactivity (ASR). Would the addition of admixtures, such as fly ash and ground granulated blast-furnace slag, increase a pavement's resistance to such reactivity? The department decided to find out by constructing 12 43-meter (140-foot) test sections containing admixtures as part of the new Lackawanna Valley Industrial Highway. The test sections will be monitored for five years, during which period more will be learned about the life of a pavement built with aggregates that are highly susceptible to alkali-silica reactivity. The project is being sponsored by the Federal Highway Administration as part of a nationwide program to evaluate and implement the ASR technologies developed and studied under SHRP.



The Lackawanna Valley Industrial Highway includes test sections containing admixtures. The Pennsylvania Department of Transportation is monitoring the sections to compare their resistance to alkali-silica reactivity with that of the rest of the road.

field. The lightweight device emits a low-frequency stress pulse that travels through the concrete until reaching a crack, a void, or the other edge of the concrete. A transducer on the surface measures the wave displacement and sends the data to a portable computer for conversion to a frequency spectrum that indicates the thickness of the pavement and the location of any voids or defects.

HWYCON

A key objective of the SHRP concrete program was to develop a decision-making tool that would assist agencies in determining the best treatment for a specific concrete problem and site. The result is HWYCON, a Windows-based program that prompts the user through a series of questions about distress evident at a project site, determines the probable cause of the distress, and suggests possible solutions. HWYCON has three diagnostic modules: pavements, bridge decks, and bridge-support elements. The American Association of State Highway and Transportation Officials is reviewing the program for possible inclusion in AASHTOWare software.

Alkali-Silica Reactivity Test

A problem common to concrete pavements and structures in almost all areas of the country is alkali-silica reactivity (ASR), which occurs when silicates in aggregates or additives react with alkalis in the cement and form a gel-like substance. When moisture permeates the concrete, the gel expands. Over time, this expansion can cause cracks in the concrete, which makes the structure vulnerable to damage from freeze-thaw cycles. The process can lead to severe structural damage.

SHRP researchers improved existing methods for evaluating an aggregate's susceptibility to alkali-silica reactivity by developing a quick and reliable test. Mortar bars are carefully measured and then immersed for 14 days in a solution of sodium hydroxide. If the bars expand by more than 0.1 percent during that time, the aggregate is potentially reactive and should be avoided. If no nonreactive aggregate is available, an admixture should be considered to mitigate the reactivity. The test method has been approved as an AASHTO standard (2).

Although certain crack patterns suggest the presence of alkali-silica reactivity, the problem cannot be diagnosed with certainty unless visible evidence of the gel-like product of the reaction exists. Because the gel is virtually undetectable to the eye, SHRP researchers developed a simple field test to detect alkali-silica reactivity. The concrete

to be tested is treated with a uranyl acetate solution and then viewed under ultraviolet light. The solution will cause any ASR gel to cast off a yellowish-green glow.

Concrete Performance Specifications

SHRP researchers also documented specifications for the production and use of high-performance concrete for highway systems. On the basis of that information, the Federal Highway Administration has produced a working definition of high-performance concrete that includes performance criteria and standardized test procedures.

ASSESSING CONCRETE CONDITION

SHRP researchers developed or evaluated six new methods for assessing the condition of concrete bridge components.

Corrosion Rate Test

Using the results of three commercially available devices for measuring the rate of corrosion in the reinforcing steel, researchers developed a standard test method for determining the corrosion rate of uncoated steel in reinforced concrete (3). The standard has been provisionally adopted by AASHTO.

Ground-Penetrating Radar

Evaluating the condition of concrete bridge decks covered with hot-mix asphalt usually requires that the overlay be removed. A research team evaluated and enhanced a ground-penetrating radar inspection system that works on both exposed and asphalt-covered concrete. The system consists of a radar antenna mounted on a van, a data acquisition system, display and signal-processing equipment, and software for converting the data into usable information. The device can also be used to analyze the thickness of pavement layers.

Deck Membrane Integrity Test

To prevent chlorides from reaching the reinforcing steel in the deck, many states install membranes between the asphalt overlay and the underlying concrete bridge deck. Choosing among the many membrane products can be difficult. Researchers evaluated the effectiveness of several membrane products and developed a membrane rating system. The results have been incorporated into a new standard test method (4).

Sealer Effectiveness Tests

Highway agencies sometimes apply penetrating sealers to bridge surfaces to prevent or retard the

IMPROVING IMPACT-ECHO DATA-ANALYSIS PROCEDURES

Determining the condition of portland cement concrete pavements or structures usually means removing 100-millimeter or larger cores from the concrete, hauling them to the laboratory for analysis, and patching the holes left in the concrete. This process is time-consuming and labor-intensive.

Impact-echo technology makes the job faster and easier and leaves no holes to patch. A low-frequency sound wave, or stress pulse, is sent into the concrete, and the response is measured. A computer program then analyzes the data and develops a frequency spectrum, which pinpoints the location of cracks, voids, or other defects in the concrete.

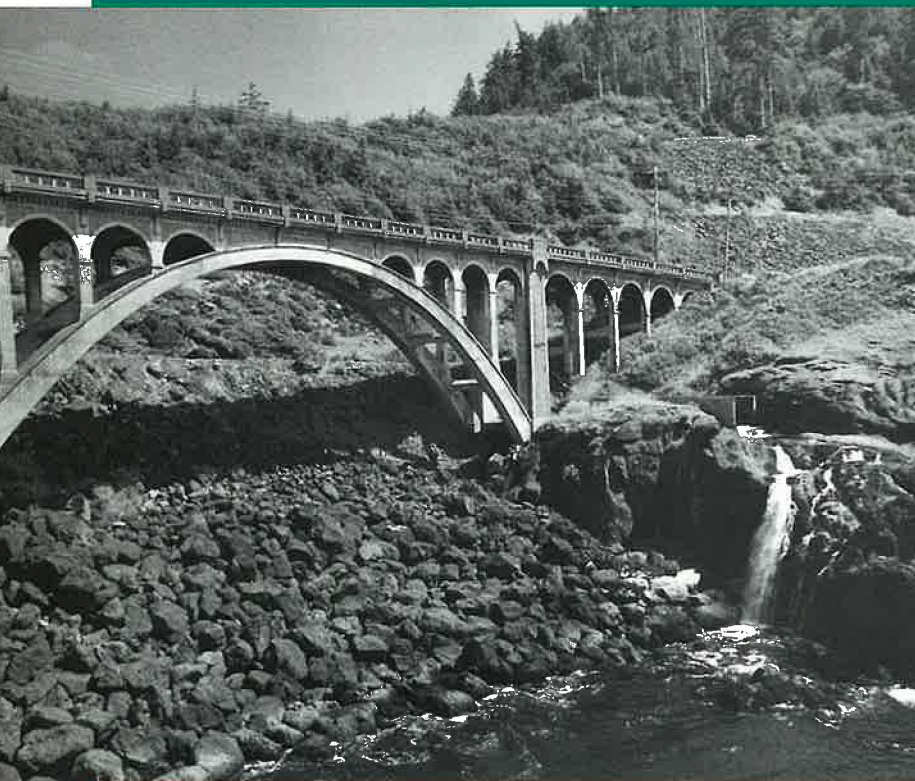
This technology, which can also be used to determine the concrete's thickness, is not new; in fact, it is more than 50 years old. However, until recently, the procedures for analyzing the data generated were complicated and time consuming, making the technology impractical for highway work. SHRP researchers accelerated the procedures and made their results easier to interpret. Because the test is extremely fast, more pavements and structures can be tested. And workers are at less risk because they can quickly take a reading and move out of harm's way.

PRESERVING HISTORY AND SAVING MONEY WITH CATHODIC PROTECTION SYSTEMS

After 60 years of service, the bridges along Oregon's coastal highway require extensive repair. Chloride ions in deicing chemicals and seawater have permeated the portland cement concrete, leading to corrosion of the reinforcing steel. In turn, the expansive forces of the corrosion have caused the concrete to crack.

After replacing one at a cost of \$43 million, the Oregon Department of Transportation decided to repair the remaining bridges and outfit them with cathodic protection systems. While rehabilitating the bridges, workers referred to photographs of the original arches to ensure retention of the original design of the architectural and historic landmarks. Then cathodic protection systems were installed in accordance with the guidelines developed under SHRP.

The department repaired the Yaquina and Depoe Bay bridges and outfitted them with cathodic protection systems at a cost of \$19.1 million—one-third of the estimated cost to replace the two bridges.



OREGON DEPARTMENT OF TRANSPORTATION

The bridges along Oregon's coastal highway—architectural and historic landmarks—are being preserved with cathodic protection systems installed according to guidelines developed under SHRP.

intrusion of chlorides and moisture. Researchers evaluated two field methods for determining the effectiveness of in-place penetrating sealers. The first method measures the change in resistance between two electrodes placed on the surface of the concrete. The second measures the amount of water absorbed by the concrete during a 10-minute test period. Both test methods have been provisionally adopted by AASHTO (5,6).

Concrete Chloride Content Test

An accurate determination of the chloride ion concentration in concrete is essential to assess the condition of bridges. Conventionally, this determination has been a time-consuming and expensive process, requiring concrete samples to be collected and shipped to a laboratory for analysis. Researchers evaluated several field tests for determining chloride ion content and developed a detailed procedure for such tests. They also developed an efficient and relatively simple procedure for drilling and collecting powdered concrete samples. The procedure has been adopted by AASHTO (7).

Concrete Permeability Test

The less permeable concrete is to water, the more durable the concrete is and the longer it takes chloride ions to get to the level of the reinforcing steel. Researchers developed the surface air-flow permeability test to provide a quick, nondestructive means of measuring the permeability of in situ concrete pavements and structures. The portable device applies a vacuum to the surface of the concrete and then measures the air flow through the concrete; the greater the air flow rate, the more permeable the concrete. The test takes only a minute, making it practical for field use.

HALTING AND PREVENTING CORROSION

Much of the deterioration in highway structures can be blamed on chloride ions, which are present in seawater, deicing salts, and even some aggregates. The chloride ions can cause the reinforcing steel to corrode and expand, leading to cracks and delaminations in the concrete. SHRP researchers evaluated two similar systems—electrochemical chloride extraction and cathodic protection—for halting and preventing corrosion.

In electrochemical chloride extraction, an anode and electrolyte are applied to the concrete surface, and the anode system is charged with electricity. The negatively charged chloride ions in the concrete are drawn toward the anode at the

surface and away from the reinforcing steel. The amount of chlorides present in the concrete can be reduced by 20 to 50 percent, depending on the level of corrosion and the design of the structure. The treatment takes 6 to 10 weeks to complete and can be expected to last for 10 years.

Some structures are better suited for electrochemical chloride extraction than others. The guidelines developed by SHRP researchers are useful in assessing a site's suitability for the electrochemical chloride extraction process.

Cathodic protection, in which a uniform, low-level electrical current is applied to the reinforcing steel, is a long-term strategy for preventing or controlling the corrosion process. SHRP researchers developed guidelines for installing, operating, and monitoring cathodic protection systems. The Federal Highway Administration recently published a field inspection guide to help bridge inspectors better understand these systems (8).

FORGING A PATH

When the Strategic Highway Research Program ended in 1993, many of the specifications, test methods, and procedures required further testing, development, and demonstration. The Federal Highway Administration, aided by a technical working group of concrete experts from around the country, ensured that the necessary next steps would be taken. Additional field testing is being conducted, workshops are being held, equipment specifications have been written, and specifications have been revised as necessary. In addition, FHWA plans to hold an international conference on concrete bridge corrosion and protection in Florida in December 1997.

The United States has made a significant investment in concrete roads and bridges. These structures are a critical component of our transportation system, which is essential to maintain-

ing and improving quality of life and the economy. The new specifications and tests developed as a result of the Strategic Highway Research Program will help the nation get the most out of that investment by providing tools for extending the life of existing pavements and structures and for designing more durable concrete mixes.

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