UPDATE ON THE STRATEGIC HIGHWAY RESEARCH PROGRAM (SHRP)

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INTRODUCTION

Back in the early 1980s in the United States, the media, the public, and political leaders were shocked to find that we had a massive problem with the condition of our highway infrastructure. Money alone would never solve the problem. We also needed better technology. This background led to the creation of the Strategic Highway Research Program (SHRP).

SHRP is a large five-year program of research to address some of the biggest, most expensive problems that U.S. highway agencies face. It focuses on four major technical research areas:

- the performance of asphalt materials;
- long-term durability of pavements;
- improved concrete and the protection of reinforced concrete structures; and
- efficient methods of highway maintenance, including control of snow and ice.

Advocates had recommended for years that these topics receive higher research priority, but little progress had been made in the 1970s as highway program budgets were curtailed and research activity slowed across the board. In 1987, the U.S. Congress authorized $150 million to be devoted to an intensive five-year research program to develop innovative technologies to solve key problems in these areas.

To leaders who saw the mounting highway infrastructure crisis as an impossible problem, SHRP offered relief through innovative technology. To highway managers who may have seen research as irrelevant or unproductive, SHRP offered controllable, useful products. To researchers who had seen their financial support erode for more than a decade, SHRP offered new opportunities.

Now, we are only one year away from the end of this massive research program. Our attention has turned to implementing the results that are starting to emerge. In my comments today, I will provide a brief overview of the key findings and early products of SHRP.

ASPHALT AND ASPHALT MIXES

Asphalt is the single most important material in the U. S. highway industry. As a nation, we spend more than $10 billion each year building asphalt pavements, and more than 95 percent of our paved roads are surfaced with asphalt.

Much of the hot-mix asphalt produced in the United States comes from high capacity drum mixers. U.S. asphalt plants produce very high volumes at unusually low cost. Currently, hot mix asphalt sells for an average of about $25 per ton in the United

States. This process is inexpensive. Productivity is high.

Performance, unfortunately, is not. The United States has serious problems with rutting and stripping of asphalt pavements. More than one mile out of three is rated in poor or fair condition. There are many reasons for this. Some of these--inadequate investment in pavements; rapid, unexpected growth in heavy truck volumes; and extreme climatic conditions, for example--lie largely outside our control. But one key cause of these problems is something we can change, namely the durability of the asphalt mixes that we design and the selection of the binder to be used in them.

The binder itself is part of the problem. We are producing binder from about 120 different sources of crude oil and with a variety of different refining techniques. Our specifications for binder are based primarily on viscosity or penetration--physical features that relate to the effort needed to mix and compact hot mix asphalt, but which are inadequate to predict how well the resulting pavement performs--whether it weakens with age, forms ruts, cracks in low temperature, strips in moist weather, fails to adhere to aggregate, or develops symptoms of fatigue. Binders that pass identical specifications perform very differently. One of the driving causes of SHRP is to develop new specifications and tests that will allow us to select binders according to their performance, with respect to six features:

-aging
-fatigue
-permanent deformation
-moisture sensitivity
-adhesion
-low-temperature cracking

Mix design is the other part of the problem. Most asphalt mix design is now done using the Marshall method. These mixes are often not well suited to the specific traffic or climate conditions to which the pavement is exposed, resulting in premature distress. As in the case of the binder, the underlying technical problem is that our mix design tools and mixture specifications do not distinguish between different levels of performance. One of SHRP's aims is to develop specifications and techniques that will yield better predictions of the performance of asphalt-aggregate mixes.

During the past four years, the Strategic Highway Research Program has conducted a massive $50 million program of research to develop performance-based specifications for asphalt binder and asphalt-aggregate mixtures. This program has involved intensive study of about 30 reference binders and 11 reference aggregates. Research teams in numerous institutions throughout the United States and in several other countries have been exploring a vast array of new analytical techniques to isolate the properties of binders and mixtures that affect their performance, and to use their findings to develop new performance-based specifications. Many new techniques, including ion-exchange chromatography, size-exclusion chromatography, nuclear-magnetic resonance, and CT scans, were employed in this research. It is now converging in several useful findings, for both binders and mixtures.

Binder Findings

The chemical composition of an asphalt binder has a direct, substantial effect on its performance. Several different techniques being applied in SHRP have led different parts of the research team to the same conclusion, namely that the amphoteric fraction in binder principally controls whether the binder is prone to crack in low temperature or rut in high temperatures. This same fraction appears to build the viscosity of the binder, control its temperature susceptibility, govern its adhesion and moisture sensitivity, and influence its long-term aging. Amphoterics have acid and base portions in the same molecule. They comprise only 10-15 percent of binder, but they have major effects on the rheology of binder, and they influence whether the binder will crack and rut.

This new understanding of asphalt chemistry has important implications. The chemical characterization approaches used to identify high-performance materials can be used directly by refiners in their selection and blending decisions. This chemical nature of binder performance is also closely tied to a number of measurable physical properties. This chemical nature of binder is also directly tied to rheological properties of binder that describe its behavior under stresses caused by climate and loading. SHRP is developing a battery of physical tests that can be used by highway agencies to ensure that the binders they receive are in the appropriate performance ranges.

SHRP's asphalt binder specification gauges the performance of modified as well as unmodified binders. In this specification, grades are identified for each of 12 pavement temperature regimes. Cold climates, for example those typical of the northern areas of the U.S. and Canada, are described by three of these regimes. (Figure 1)

The leftmost grade is for the most severe service conditions, where the lowest expected winter temperature is -29°C or below. This grade will have the least change of stiffness with temperature.

The other two grades are intended for increasingly less severe service conditions. The corresponding, temperature dependency lines show increasingly larger slopes, indicating a larger effect of temperature on stiffness.

This specification is based upon a master stiffness curve for each binder. It describes how the stiffness modulus varies with loading time and temperature. Two test methods are used to calculate the stiffness master curve. One of these is the bending beam rheometer test. It is a new test developed by a SHRP contractor to measure bending stress and elastic properties in the low-temperature range. A beam of asphalt is loaded and the binder specimen is deformed. When the load is released, the beam rebounds toward its initial position. This apparatus measures how much the beam deforms and how quickly it rebounds.

The other is the dynamic shear rheometer, used at the high-temperature end of the scale. This device measures viscous properties of binder.

Together, these two tests are used to estimate the binder's stiffness master curve. In turn, a special computer software package then calculates three properties from the stiffness master curve, namely the binder's susceptibility to permanent deformation, fatigue cracking, and low-temperature cracking.

Further characterization of the binder's disposition towards low-temperature cracking is provided by the direct tension test. In this test, a simple "dog-bone" binder specimen is pulled to rupture at several test temperatures. The strain, stress, or energy to fail can be determined from the test results.

These tests are conducted on binders aged in the laboratory to simulate short and long-term aging in the field. Aging is accomplished with the thin film oven and the pressure aging vessel used in combination.

The pressure aging vessel procedure was developed by a SHRP contractor to simulate within several days the aging of a binder that occurs over 5 to 10 years in a pavement. A thin film of binder is exposed in the vessel to 300 psi compressed air at a temperature of 60°C or above.

SUperior PERformance-based asphalt PAVEments (SUPERPAVE)

Asphalt-aggregate mixtures, like the asphalt binder itself, can also be designed and evaluated in terms of six performance features: aging, fatigue cracking, permanent deformation, moisture sensitivity, adhesion, and low-temperature cracking. SHRP has developed a specification, design system, and battery of tests to build Superior, performance-based asphalt pavements--Superpave.

The Superpave mixture specification explicitly considers traffic and yearly rainfall, as well as temperature range. For any combination of these three key variables, the specification identifies a range of allowable results for each performance test. It also allows the user agency to designate the acceptable risk for each form of distress, so as to select an appropriate combination of efficiency and performance.

Superpave is designed using a performance-based mix design and analysis system. This system incorporates procedures for selecting an optimum mix design, characterizing its performance, evaluating the need for modifiers to enhance specific performance features and rapidly measuring the conformity of field mixes and pavements to design criteria.

To design Superpave, each performance feature is rated using an accelerated laboratory test. Generally, these test methods are more complex and costly than the tests now used in the Marshall of Hveem mix design. We believe the additional expenditures for test and compaction equipment are worth it, because this will allow us to design mixes for conditions where the old methods had resulted in costly premature distress.

Gyratory compaction has been tentatively selected as the compaction method for Superpave. It provides good field simulation capabilities, is compact and fairly inexpensive, and is adaptable to field use for quality control purposes.

Two methods are being considered to measure rutting characteristics of the mixtures. One is the simple shear test developed for SHRP. The other is the repeated-load compression test, which uses a series of uniaxial compressive loads.

For prediction of low-temperature cracking, both the fracture temperature and tensile strength at fracture appear to be important. To measure these, SHRP is considering the indirect tensile test.

We are presently including both short-term and long-term aging tests for mixtures. In both instances, the stiffness at a fixed temperature is measured periodically to estimate the effects of short and long-term aging on the mixture behavior.

An initial screening of binder and aggregate combinations for adhesion and moisture sensitivity is made using a procedure called the net adsorption test, developed by a SHRP contractor. A solution of asphalt binder in toluene is repeatedly passed over a representative sample of aggregate and the binder adsorption measured spectrophotometrically. Water is then introduced and the resulting binder desorption is measured.

These binder and mixture test methods are now being tested by state highway agencies and other organizations to evaluate their precision, effectiveness, and practicality. SHRP is also doing research to confirm that these tests can reliably predict performance by comparing their predictions with the known performance of field pavements.

We believe that we can avoid many of the performance problems that are apparent in asphalt pavements in the United States. New performance-based specifications for binders and asphalt mixtures are the key to doing this. Through the massive volume of research done for SHRP, and through the exploratory applications of new techniques in the United States and around the world, we believe that these specifications will be completed, as planned, by March, 1993.

We are currently working with many state highway agencies and standard-setting groups to acquaint them with the new specifications, work out any problems associated with their use, buy the new test equipment, and be ready to phase them into new designs and contracts. This represents a substantial change, but I believe that U.S. highway agencies are convinced that it is the most efficient way to improve the performance of asphalt pavements. Asphalt can meet the demands of tomorrow's traffic if we design it for that level of performance. I believe that more than half of our 50 states will be using Superpave in some of their jobs by the late 1990s.

LONG-TERM PAVEMENT PERFORMANCE (LTPP)

Over the years, our understanding of how pavements perform has progressed slowly because of the complexity of the subject. Pavement performance depends upon traffic loads, truck volumes and suspensions, axle loads, tire types and pressures, temperature, rainfall, soils, drainage, asphalt properties, aggregate gradation and angularity, layer structure and thickness, and so on and so on. Because pavements are so complex, engineers remain unable to answer many basic questions about them, despite a tremendous volume of research.

During the last ten years, 20,247 papers on pavement research have been added to the Transportation Research Board's Transportation Research Information System (TRIS). About 2,000 new research papers on such topics as pavement design, construction, materials, and truck weights are written each year. Most of this research provides useful results--but results that are not widely applicable.

SHRP's Long-Term Pavement Performance (LTPP) program aims to produce broadly applicable pavement design relationships. It attacks the multi-factor area of pavement research by collecting and evaluating consistent data on many different pavements across a wide range of site conditions. LTPP is the largest and most comprehensive pavement performance field test in history. The program is collecting uniform, comparable, long-term data on pavement condition, climate, traffic, and load conditions. It was designed to meet the technical information needs of agency managers and policy leaders, as well as to provide design tools for pavement engineers. The research results include:

- Improvements to project-level engineering design practices used in the AASHTO Guide for the Design of Pavement Structures
  - -- Re-calibration of design equations used in the Guide
  - -- Improved construction quality control
  - -- Improved traffic estimation procedures
  - -- Improved rehabilitation procedures
  - -- Predictive equations for specific distresses
- Enhanced ability to compare design options: drainage improvement versus thickness; or use of existing technology versus new technologies such as stone mastic asphalts; and to choose the most appropriate for a particular project and site.
- Improved tools for pavement management to be used across a highway agency's entire network, including:
  - -- Improved prediction equations for estimating future conditions so that actual and expected performance can be compared;
  - -- Improved pavement assessment techniques for distress identification and monitoring, and for structural assessment; and
  - -- Improved traffic monitoring techniques.
- A better technical basis for policy decisions (on issues such as weight limits, allocation of road user tax burden, budget priorities, etc.).

At present, the AASHTO equations are the world's most predominantly used pavement design method. They were developed and adopted by AASHTO after the AASHO Road Test of 1958-60 in Ottawa, Illinois. The equations are based on statistical relationships that describe how pavement serviceability is related to load repetitions, materials properties, and layer thicknesses.

In the United States, these relationships are the basis for the AASHTO Design Guide. Although the Guide is revised periodically--most recently in 1986--the basic form of the central design equations has remained unchanged through thirty years of use. Nevertheless, we know that the design procedures need to be improved because pavements that are designed according to the procedures often do not perform as well as expected. We see engineers in different regions making rough ad-hoc adjustments to bring the design equations into closer alignment with their own observations.

Based on the data about actual field performance gained from LTPP, the equations will be refined to predict performance better over longer time periods. The data will reveal key factors that will explain performance variations related to soil and drainage conditions, which are missing or treated inappropriately in the current equations. The LTPP data also may make it possible to modify the equations to reflect regional differences. Different factors or terms may be used to characterize key performance variables in different environmental zones.

The development of SHRP's consistent, broad-based pavement performance data base will make it possible to reformulate and augment the AASHTO design equations to predict specific distresses. Equations that predict measurable field distress values can be applied to pavement management as well as to design of new construction and rehabilitation projects. Distress-specific equations will give highway engineers an important tool for monitoring the causes of pavement problems, and for designing remedies. The observed distress progression will be checked against that predicted by the design equations. Pavements wearing out more quickly than predicted will be identified and the probable cause such as unanticipated traffic rates or materials deficiencies will be verified. The life cycle predictions will be revised and long-term plans adjusted accordingly.

Even the most intelligently designed pavement will fail if the construction quality is poor or the pavement materials are inferior. Probably 40-50 percent of the overall performance prediction variance in the currently used design equations is caused by construction deviations. Construction quality control obviously is very important in assuring that pavements perform as well as expected.

The LTPP data will yield realistic ranges for variations in key performance factors influenced by construction, and relate those variations to long-term performance. The 1986 revision of the Guide introduced reliability factors to account for variations from design values or assumptions, and the LTPP data will be used to refine the reliability factors. This will lead to refinements in construction quality-control procedures.

Using this information, engineers can modify pavement designs accordingly and recognize when specification of "high performance" materials is appropriate. Such materials would include drainable base courses, high-strength concretes, high stability asphalt mixes such as stone mastic asphalt, high crush count aggregates, and so on.

Because of the slow annual rate of change, this experiment will not be completed for twenty years. Even the earliest new performance equations to be developed in the LTPP experiment will not emerge for several more years. Nevertheless, other useful products are already emerging, including:

- a standardized approach for measuring traffic;
- a distress identification procedure that will lead to greater uniformity among the states; and
- new calibration procedures for structural assessment devices.

This increased uniformity in how we characterize the condition of our pavements and the key factors that affect them has several benefits. It improves our pavement management systems by making them more reliable and comparable with the performance information generated by SHRP. It increases the applicability of the independent pavement research being done by encouraging greater uniformity in measurement techniques.

CONCRETE AND STRUCTURES

Concrete Deterioration

In spite of the long and successful use of concrete within constructed facilities, many factors affect its ultimate quality. Cracking and spalling may be caused by improper placement, inappropriate curing conditions, repeated freeze-thaw cycles, or the use of silica-rich aggregates with incompatible alkali-rich cements. The resulting problems diminish pavement serviceability and are expensive to repair.

SHRP has developed a Guide to Evaluation of Concrete Thermal Effects that contains easy-to-use tables showing conditions that are likely to lead to thermal problems. Guidance for avoiding such problems is given. All that is needed to use the tables is a knowledge of the concrete temperature, air temperature, cement type, and cement content of the concrete mix. If the combination of key factors appears too risky, the guide recommends changes, for example reducing the cement content, switching cement type, substituting fly ash, cooling or heating the concrete mix, or using insulation.

In addition to helping in the selection of appropriate materials for longer-lasting pavements, the Guide will enable highway agencies to make more efficient use of crews and equipment by extending the paving season.

Curing Concrete for Maximum Durability

SHRP has developed a Handbook of Packing-Based Aggregate Proportioning that provides guidance for blending sand, and coarse aggregate fractions. Where the ingredients of concrete are packed properly, the concrete can be worked easily and the least amount of cement paste is used. Quality, as well as economy, is enhanced. The hardened concretes made from properly mixed concretes are denser after curing. Denser concretes are less permeable to water and salt, so that structures are less vulnerable to chloride-induced corrosion. If an alkali-silica reactive aggregate must be considered for use, denser concrete offers more protection against the intrusion of water.

Protecting Concrete Against Alkali-Silica Reactivity

Alkali-Silica Reactivity (ASR) occurs when silica in aggregates reacts with alkali in the cement to form a gel-like substance. The gel combines with water and expands. Within a few years, this expanding gel can crack the concrete. The process is irreversible, and can lead to serious cracking.

Some areas of the United States are more susceptible to ASR problems than others. But, ASR often goes unreported because it is difficult to recognize.

Accurate detection of ASR is important. It is the key to choosing the best rehabilitation strategy. It also helps highway agencies avoid making the same mistake again. But ASR often goes undetected. It is easy for inspectors to confuse the cracks caused by ASR with other types of damage. Often more than one problem is present at the same time.

If the problem is misdiagnosed, the treatment will be inappropriate. For example, cathodic protection (an effective treatment for combatting corrosion) would not prevent the spread of ASR damage in bridges. In fact, cathodic protection of an ASR-damaged structure could aggravate the ASR problem. Yet it would be easy for an inspector to overlook ASR problems once corrosion was spotted.

Proper diagnosis and assessment involves two steps: visual inspection, and chemical testing. SHRP's ASR Handbook has color photographs that take the guesswork out of spotting ASR problems. In the early stages of reactivity, ASR gel usually cannot be seen by the unaided eye. SHRP has developed a field test for detecting ASR before obvious signs of distress are visible. This field test uses a uranyl acetate fluorescence method to detect whether an ASR product has been formed in the portland cement concrete.

The steps of the field test are:

- expose the concrete (remove the mortar)
- clean with water or air
- apply a 5% solution of Uranyl Acetate and wait 5 minutes before viewing the test area with an ultraviolet light
- use an ultraviolet light with a special box to keep out other light
- if ASR is present, it will appear greenish yellow.

Where available materials are prone to ASR damage, special care must be taken to select compatible cement and aggregates. Current tests (ASTM tests C-289 [Chemical Method] and C-227 [Mortar-Bar Method]) are valuable tools for screening reactive aggregates and cement-aggregate combinations, respectively. Ongoing SHRP work will further develop these tests to make them more rapid, reliable, and informative. More reliable tests will save money in the long run by helping highway engineers recognize and identify problem materials and by indicating where low-alkali cements should be considered.

ASR can be avoided in new construction through use of lower alkali cements, by avoiding the use of reactive aggregate, and by incorporating pozzolanic or other supplemental cementitious materials into the concrete. SHRP is refining procedures and requirements for testing and using of pozzolanic and other admixtures in ASR mitigation.

Bridge Corrosion

The United States faces a $20 billion repair bill for corrosion problems due to chloride-induced corrosion of reinforcing steel in concrete bridges. Several parking garages have collapsed because of reinforcement corrosion, and chunks of concrete falling off bridge soffits and substructures have killed people.

By the time the effects of corrosion can be seen, extensive damage has already been done. SHRP has a research program devoted to early assessment of corrosion damage, its rehabilitation, better ways to assess bridges, and select the most cost-effective repair method.

Corrosion Rate Measurement

There are several devices for measuring the corrosion rate of reinforcing steel in concrete. Most are in the prototype stage. Tests have shown that it is important to be able to measure the area of the section of rebar under test. This is best done with a "guard ring". Based on our experiments to date, it appears that the guard ring which performs best at high and low corrosion rates, and with rebars at different depths, is the one developed by the Spanish CENIM laboratory, and we are now testing on five bridges in various U.S. climates.

Membrane Assessment

Waterproof membranes are often used to keep deicing salts from getting to the reinforcing steel. Unfortunately, it is very difficult to confirm that a membrane is effective without removing the asphalt overlay and the membrane. SHRP is working on a nondestructive method using impact-echo techniques. By correlating impact-echo data with a small number of cores taken through the membrane, SHRP is refining the technique so that it can be used to determine the degree of damage to a membrane. This research is also examining what level of imperfection due to pinholing, blistering etc., is acceptable, before a membrane is considered to have failed.

In related work, a SHRP contractor who specializes in ground penetrating radar is developing new software for automatic recognition of delaminations and related concrete damage through an asphalt overlay. This system uses ground-penetrating radar units, a computer, distance measurement equipment, and specially-developed bridge deck software. The system locates and measures the area of delaminated concrete. It operates at speeds of up to 25 mph and can penetrate depths of up to 2 feet.

In-situ Chloride Content

To fix a corrosion problem, it is important to know the degree to which contamination has progressed. Presently, core samples have to be taken from the bridge to the laboratory for long, expensive testing. A new rapid field chloride test employs the use of a drill (1/2") and vacuum pick-up of the dust from the hole. Three grams of dust are weighed, mixed with 80 ml of a special acid solution, and left to digest for 3 minutes. A neutralizing solution is added and after one minute a chloride measuring probe is inserted into the solution. The millivolt activity of the chloride ions is read directly. The total test can be run in 6 minutes.

Permeability Indicator

Corrosion of reinforced steel can proceed much more quickly when the surrounding concrete is porous and permits chloride ions to migrate more quickly. Knowing the permeability of the in-situ concrete is important for scheduling corrosion protection or rehabilitation of a bridge. A new device has been developed by SHRP to measure the permeability of the concrete in the field. The portable device applies a temporary vacuum seal to the concrete surface and measures the air flow. A reading can be obtained once a minute, and allows a large amount of information to be gathered at close intervals. The device can be used both horizontally and vertically.

All of these devices will be fully described in manuals to be issued in mid-1992. SHRP is also in the process of reviewing a report on other assessment techniques used on bridges, such as the half cell potential measurement technique, delamination detection techniques, and resistance measurements.

Cathodic Protection

Diagnosing the extent of corrosion problems is crucial, but we also need improved techniques for repair and rehabilitation. In particular, we need a reliable assessment of the many techniques and devices that are now being used, but which require too much guesswork.

SHRP has reviewed the performance of 287 cathodic protection systems in North America. Over 50 systems have been examined in depth, and there is ongoing work to look at the latest and the earliest installations (some built in 1973 are still operating). SHRP is reviewing the performance of the different types of cathodic protection systems, as well as their cost, and life expectancies. We are also evaluating new ideas such as sacrificial anode systems which do not require power supplies.

Electrochemical Chloride Removal

One potentially promising new technology is electrochemical chloride removal. Four field trials are now starting. One Norwegian company is already offering a commercial method of applying chloride removal. At least two other companies will probably be offering the technology soon.

Rehabilitation Manual

As the United States repairs the large number of reinforced concrete structures suffering from chloride-induced damage to the reinforcing steel, highway agencies need better diagnostic procedures, engineering know-how about how to perform each operation, economic knowledge about the cost and life of different approaches, and management guidance about how to contract for these activities. SHRP will be packaging all of this know-how, existing and new, so that it can be applied with confidence by bridge engineers.

The final product of SHRP's structures research will be a manual for rehabilitation, which will describe how to assess the condition of the structure and how to select the best rehabilitation option for a given bridge deck.

This manual will be issued as a book as well as a computer program. It will help field engineers deal with the complex problem of corrosion of reinforcement due to sea and deicing salt attack.

MAINTENANCE

Highway maintenance costs local and state governments $20 billion a year. It accounts for about one-third of total U.S. annual highway expenditures. Maintenance expenditures will probably double in the next 10 years.

Maintenance workloads and costs are increasing as the highway system ages and traffic levels increase. During the 1950s and 1960s U.S. highway funds were spent mostly on new construction. As the system aged during the 1970s and 1980s, the size, weight, and volume of traffic also have increased. Together age and traffic are driving maintenance costs up.

SHRP is assessing the effectiveness of six surface treatments. On flexible pavements, we are testing chip seals, thin overlays, slurry seals, and crack sealing; for rigid pavements, joint and crack sealing, and undersealing.

State highway agencies are applying carefully monitored surface treatments at more than one hundred test sites. These sites have been selected to span a wide range of traffic, climate, soil, and prior pavement conditions.

How will this help maintenance engineers? First, it gives them a reliable basis for deciding <u>when</u>, in the course of a pavement's life cycle, they should do maintenance work. In the U.S., we usually wait until surface distress is obvious--even severe--before applying new surface treatments. Placing new treatments on a bad foundation may shorten their expected life, and may not be economical in the long run.

Second, comparative evaluation of different approaches in different climate and traffic conditions will provide a reliable framework for choosing the most effective techniques.

Many materials and techniques are available for spall repair, joint resealing, and crack sealing in concrete pavements; and for pothole repair and crack sealing in flexible pavements.

According to a survey of state officials, proprietary high-performance materials appear to be one of the least expensive options for pothole patching when crew costs and patch life are taken into account. To obtain more systematic, reliable information on how different techniques perform, SHRP is working with a number of states in careful <u>field</u> tests to place various patching materials under different climatic and installation conditions.

The results of this test will allow engineers to select the maintenance materials that are most cost-effective in their circumstances.

Worker Safety

Maintenance work takes place near high-speed traffic. Unlike construction work zones, where semi-permanent barriers and controls are possible, maintenance work zones change location frequently. As a result, many maintenance workers are killed or injured each year.

SHRP held a design competition in 1988 to find new ways to protect maintenance workers. We are now developing and testing them. Here are a few:

- a Remote-Controlled Truck designed to protect maintenance workers from drivers who run into the back of stopped or slow-moving vehicles. Many agencies use "shadow vehicles" with energy-absorbing safety cushions to protect highway crews. But, the driver in the shadow vehicle is still at risk.
  The operator of SHRP's Shadow Vehicle will be positioned in a safer spot: beside the highway. The remote-controlled truck moves when signalled, at speeds up to 8km/hr.
- an Infrared Intrusion Alarm that tell workers when a vehicle is entering the work zone. It gives them four to seven seconds to clear the area.
- a Portable Speed Bump that is just like a regular speed bump--except it is mounted on rubber mats and can be moved from work zone to work zone.
- a Flashing Stop/Slow Paddle which is two signs in one. A highway worker can change signs with a flick of a wrist, and drivers travelling in the opposing direction are not given a confusing message. The sign is equipped with flashing lights to attract the attention of the approaching driver.
- Lighting Devices: Marker lights for the outer edge of the snow plow blade to give the operator a better sense of the location of the plow's edges and increase the motorists' awareness of the plow blade.

Saving maintenance dollars means doing a lot of little things right. As more and more of our highway funds are needed for maintenance, we must continue to improve all the materials and tools we use.