A GUIDE TO THE LONG TERM PAVEMENT PERFORMANCE EXPERIMENTS IN ARIZONA

The National Experiment

The Long-Term Pavement Performance (LTPP) studies of the Strategic Highway Research Program (SHRP) address the need for improved technology for pavement design, construction, maintenance, and rehabilitation. The LTPP experiments are classified into two groups: General Pavement Studies (GPS) and Specific Pavement Studies (SPS). While the GPS program focuses on existing pavements, covering the most commonly used pavement types in the United States and Canada, the SPS program includes specially constructed pavements that will help develop a better understanding of the effects on performance of a few targeted factors not widely covered in the GPS. Through the construction and evaluation of the specially constructed test sections, the SPS program explores options for construction of new pavements, the application of maintenance treatments to the existing pavements, and the rehabilitation of distressed pavements.

The SPS program includes nine experiments, designated SPS-1 through SPS-9, that address the effects of structural factors, maintenance treatments, rehabilitation alternatives, environmental effects, and asphalt concrete mixtures on pavement performance:

- **SPS-1**: Strategic Study of Structural Factors for Flexible Pavements
- **SPS-2**: Strategic Study of Structural Factors for Rigid Pavements
- **SPS-3**: Preventive Maintenance Effectiveness of Flexible Pavements
- **SPS-4**: Preventive Maintenance Effectiveness of Rigid Pavements
- **SPS-5**: Rehabilitation of Asphalt Concrete Pavements
- **SPS-6**: Rehabilitation of Jointed Portland Cement Concrete Pavements
- **SPS-7**: Bonded Concrete Overlays of Concrete Pavements
- **SPS-8**: Study of Environmental Effects in the Absence of Heavy Loads
- **SPS-9**: Validation of SHRP Asphalt Specifications and Mix Design and Innovations in Asphalt Pavements

* not constructed in Arizona

To ensure practical and implementable experiments, the experimental design and construction guidelines for these experiments were developed in cooperation with state and provincial highway agencies. To help evaluate the performance of the pavement structures constructed as part of the SPS program, a comprehensive data collection plan was developed.
for each experiment. This plan provides detailed procedures for collection of information on pavement structure and materials; traffic type and volume; climate; pavement performance as measured by deflection, distress, profile, and friction; and applied maintenance and rehabilitation. As monitoring of the test sites is expected to continue for 15 to 20 years, the frequency of data collection has been addressed.

The SPS experiments within the LTPP program will include nearly 100 test sites with almost 1000 test sections nationwide. As these sections are monitored from their infancy, a comprehensive database will provide complete information on the construction, materials, traffic environment, performance, and other features of these sections. This information will contribute to the development of many usable products, such as methodologies for selecting the optimum combinations of design features for new construction or other optimum rehabilitation options for distressed pavements. Also, products such as test methods and material evaluation will result from these experiments. The implementation of the SPS program will contribute to changes in pavement design and construction practices that will improve pavement performance and utilization of resources.

Arizona's LTPP and Other Experiments

From 1990 through 1995, ADOT has led the country in constructing ten LTPP SPS sites with over 100 experimental test sections throughout the state. An ATRC Research Note describes most sites in more detail and briefly reports the findings of any recent evaluations. The LTPP sites are clearly marked with blue and white signs on the shoulder or near the right-of-way fence and white thermoplastic markings on the pavement (Figures 1 & 2). The locations of these sites are shown in Figure 3. Other non-LTPP sites noted on Figure 3 and/or described in a research note are not marked and must be located via mileposts. Any questions on these test sections should be directed to Mr. Lonnie Hendrix or Mr. Larry Scofield at (602) 831-2214 or (602) 831-1353 respectively.

For Additional Information Contact:

ATRC / 7755 S. Research Drive, Suite #106 / Tempe, AZ 85284 / (602) 831-2620
SPS-1, Strategic Study of Structural Factors for Flexible Pavements
US93 NB MP 52.7-49.8

SPS-2, Strategic Study of Structural Factors for Rigid Pavements
I-10 EB MP 105.8 - 109.0

SPS-3

SPS-4
Concrete Pavement Joint Resealing
US60: EB MP 168.9-191.2

SPS-5
Rehabilitation of Asphalt Concrete Pavement
I-8 EB MP 159.0 - 161.0

SPS-6
Rehabilitation of Jointed Portland Cement Concrete Pavements
I-40: EB MP 202.2-204.9

SPS-9(p), Validation of Superpave
US93 NB MP 53.4-52.9, 46.8-46.4

SPS-9(a)
Superpave Binder Study
I-10 WB MP 122.3 - 112.3

SPS-9

SPS-10

H-106
Spall Repair and Joint Seal
I-17 NB MP 200 - 204

SPS-11

Arizona SHRP Binder Study
I-17 NB MP 224.5-225.8
I-17 SB MP 219.7-220.7

HOOVER DAM

SPS- PROJECTS and LOCATIONS
CONSTRUCTION OF LTPP SPS-1 TEST SECTIONS

The Arizona Department of Transportation is constructing the fourth Special Pavement Studies-I (SPS-I) project in the United States. This SPS-I project is part of the FHWA's national Long Term Pavement Performance (LTPP) Program SPS-I experiment, Strategic Study of Structural Factors for Flexible Pavements. The project consists of 16 experimental test sections scheduled to be built May-June 1993, in conjunction with a major construction project on U.S. 93 north of Kingman, Arizona.

Background

Flexible pavement design and evaluation developments in the past 20 years have concentrated on modeling the pavement structure as an elastic multilayered system. The layers are characterized by their thickness, modulus of elasticity (stiffness), and Poisson's ratio with layer thickness and elastic modulus or stiffness being most important. Highway agencies lack information on the interaction of these key factors with other variables such as climate. Therefore controlled field experiments are necessary to answer the following questions:

To what extent does asphalt concrete thickness or the type and thickness of the base layer influence pavement performance and what is the relative importance of each? How do environmental factors influence the relative importance?

To what extent does the influence of pavement drainage on pavement performance vary from wet to dry climatic zones and what is the relative importance in each zone?

Objective

The objective of this study is to more closely estimate the relative influence of strategic factors that influence the performance of flexible pavements. The factors addressed in this study include drainage, base type and thickness, and asphalt surface thickness. The study objective includes a determination of the influence of environmental region and soil type on these factors. Accomplishing this objective will provide substantially improved tools for use in the design and construction of new and reconstructed flexible pavements.
The LTPP sections will evaluate these design parameters:

- Asphalt Concrete Thickness: 4" and 7"
- Base Thickness: 8" and 12"
- Base Type: Aggregate base, asphalt treated base and combination
- Drainage: With and without edge drains

Some of the key products of this national experiment will include:

- Evaluation of existing flexible pavement design methods.
- Development of improved design equations for new and reconstructed pavements.
- Determination of the effects of specific design features on pavement performance.
- Development of a comprehensive data base for state engineers and researchers.

Development of the national pavement data base is the vehicle or tool to expedite the analyses needed to produce the other products. This data base will permit centralized and efficient distribution of massive quantities of data to participating highway authorities, researchers, and other interested parties.

In addition to the LTPP sections, ADOT is constructing test sections to compare current design methods with the LTPP sections. A high-speed weigh-in-motion system will be installed in one of the sections to accurately monitor the classification and weight of traffic traveling over the test sections.

 Layout of Experimental Test Sections, Arizona SPS-1 Project

*For Additional Information Contact:*

ATRC / 7755 S. Research Drive, Suite #106 / Tempe, AZ  85284 / (602)831-2620
PERFORMANCE OF PCCP SPALL-REPAIR MATERIALS IN ARIZONA

Five PCCP spall-repair materials are performing satisfactorily after six years in service on Interstate 17 in Phoenix, Arizona. The materials represented four rapid-set materials and one epoxy system.

Background

During the early 1980's the Arizona Department of Transportation (ADOT) began partial-depth spall repair of portland cement concrete pavements using commercially available products. Both flexible and rigid products were tried with mixed results. The inability to attain consistently good results with available products was due to the difficulty associated with controlling field installation procedures and predicting product performance from laboratory tests. Typically, commercial products were submitted to a central testing facility where they were subjected to a battery of tests. Products successfully passing the tests were included on an approved products list for use on construction projects.

The inconsistent field performance resulting from this acceptance process encouraged ADOT to construct partial-depth spall repair experimental sections to determine the most cost effective products. This study, conducted in 1986, consisted of surveying the states to establish the state of the practice, identifying the most promising products, reviewing current construction practices, developing an experimental design, and constructing and evaluating preliminary test sections on an active construction project (IR-17-1(165)).

A large concrete pavement rehabilitation project (IR-17-1(160)) had been scheduled for construction in 1987 and it was anticipated that the preliminary test sections constructed in 1986 would provide, with limited field data, sufficient results to recommend partial-depth spall repair products for use on the upcoming construction project.

Additionally, previous to the 1986 experimental sections, MC-64 by H.C. Epoxy had been installed in an ad hoc effort in limited quantities on I-17 Southbound near Peoria Road.

Approach

In 1986 a one-mile section of I-17 in the Phoenix metropolitan area was selected for preliminary field testing of six products under experimental conditions: UPM by Sylvax Chemical Corporation, CALTRANS Formula Set-45 by Master Builders, Percol X-60-11 80A (flexible) by Arnco, Celroc 10-60 by Celtite, Durapatch Hiway by L&M Construction Chemicals, Inc., and Type III cement with accelerators. For each product approximately 16 spall repairs (100 sq ft) were placed in the southbound roadway. In addition to evaluating the
six products, an attempt was made to establish the effect of patch size, patch depth, joint sealing, and of providing a bond break at the joint. These test sections were installed, by change order, on an active construction project (IR-17-1(165)).

Since only 3-5 months of field performance was available from the preliminary test sections prior to making product recommendations, both the preliminary test sections and the upcoming construction project (IR-17-1(160)) were to be evaluated for their service lives. This would allow a comprehensive evaluation of each product's performance when placed under experimental test conditions and under actual construction conditions.

Subsequently, four products were recommended for the construction project as a result of the preliminary field testing; CALTRANS Formula Set-45, Durapatch Hiway, Celroc 10-60, and Type III cement with accelerators. All the products were extended with 25 lbs of aggregate per 50 lb bag of product. The aggregate met the requirements of AASHTO M43 #7 gradation. All four products were installed between April 1987 and February 1988. Approximately six miles of northbound and southbound I-17 were rehabilitated using these products. Test sections for each product extended for approximately one mile in both roadway directions. Approximately 2300 partial-depth spall repairs were performed on the construction project. Traffic at this location was approximately 100,000 ADT.

During construction of the IR-17-1(160) project a change order was initiated to include two additional rapid-set spall repair materials; HD-50 by Dayton Superior and Pyrament 505 by Lone Star Industries. In February 1988, approximately 56 sq ft of HD-50 and 48 sq ft of Pyrament 505 were successfully installed. Both products had been extended with aggregate as previously described.

Rapid-set spall repair materials are typically classified as organic (polymer) or inorganic. The inorganic products can be classified into four major categories: Portland cement based, gypsum based, magnesium phosphates, and modified high alumina cements.

CALTRANS Formula Set-45 is a magnesium phosphate based material, Durapatch Hiway is a high alumina, fiber-reinforced, non-shrink material. Celroc 10-60 is a blend of hydraulic cements (including high alumina) and super plasticizers. The Type III cement mixture consisted of a 9 bag mix with calcium chloride and a super plasticizer. Pyrament 505 is a blended cement and HD-50 is cement-based compound with rapid hardening modifiers and polymers. MC-64 is a two-component, polyamide epoxy with reground rubber filler.

Findings

Since construction of the preliminary test sections in 1986 and the construction project in 1987, numerous field evaluations have been performed. The test sections constructed in 1986 were taken out of service as a result of subsequent construction in 1990. The product performances evaluated in these sections supported the four product recommendations made in 1987.

The final field evaluation of the 1987 construction project (IR-17-1(160) test sections was made in the spring of 1993. The evaluation consisted of a visual examination and a check for delamination by sounding with a hammer. Four hundred and sixty-seven spall repairs were evaluated. Due to traffic control limitations, the Type III spall-repair material was not evaluated.

Figure 1 provides a schematic drawing of typical spall repair locations on a roadway. Figure 2 represents their locations within the pavement surface (see figure 1 for explanations), while Figure 3 indicates the distribution of spall repairs by product type.

All the rapid-set spall repairs were performing satisfactorily after six years in-service. The overall failure rate was approximately 2%. Table 1 indicates the results of the 1993 survey and the approximate number of spall repairs
occurring within the test sections.

**Spall-Repair Locations**

- Approximately 80% of the spall repairs are located in lanes 2 and 3. The spall repairs are equally distributed between lanes 2 and 3.
- Spall repairs were equally distributed between the leave and approach side of the transverse joint, differing only by 7%. No statistical difference was determined for occurrence at this location.
- Approximately 90% of the spall repairs surveyed in the final evaluation were less than 3 sq ft. in size.

**Product Performance**

- All the products evaluated from the 1987 construction performed successfully for the six years of service monitored in the test sections.

The average failure rate was 2.4% overall with product averages ranging from 0.7% to 4.8%.

- Informal evaluations of the MC-64 product indicated that it is performing satisfactorily after seven years of service with approximately a 1% failure rate.
- Five percent of the spall repairs exhibited delamination around the perimeter of the repairs.
- Seven percent of the spall repairs exhibited delamination of the repair materials themselves.
- Most spall repairs which exhibited delamination in early surveys were still performing satisfactorily at the final evaluation. The use of delamination, through hammer soundings, as a failure criteria should be re-examined.
- Celroc 10-60 and CALTRANS Formula Set-45 exhibited the most significant surface abrasion.

### Table 1 Descriptive Statistics for 1993 Spall-Repair Survey

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Total Number of Spalls Existing</th>
<th>Number of Spalls Surveyed</th>
<th>Percentage of Spalls with Perimeter Delamination</th>
<th>Percentage of Spalls with Material Delamination</th>
<th>Percentage of Spalls Which Failed</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALTRANS Set-45</td>
<td>420</td>
<td>155</td>
<td>4.5</td>
<td>5.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Durapatch Hiway</td>
<td>616</td>
<td>155</td>
<td>4.6</td>
<td>2.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Celroc 10-60</td>
<td>558</td>
<td>124</td>
<td>6.5</td>
<td>13.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Pyrament 505</td>
<td>31</td>
<td>13</td>
<td>15.4</td>
<td>15.4</td>
<td>0.0</td>
</tr>
<tr>
<td>HD-50</td>
<td>25</td>
<td>22</td>
<td>4.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Overall</td>
<td>1650</td>
<td>467</td>
<td>5.4</td>
<td>6.9</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Distribution by Spall Repair Location (By Product)

Figure 1 - Location of Typical Spall Repairs

Figure 2 - Distribution of Spall Repairs by Location

Distribution by Product Type
(467 Spall Repairs)

Figure 3 - Distribution of Spall Repairs by Product Type

For Additional Information Contact:

ATRC / 7755 S. Research Drive Suite #106 / Tempe, AZ 85284 / (602) 831-2620
The Arizona Department of Transportation completed construction of the second Special Pavement Studies-2 (SPS-2) project in the United States in October 1993. The Arizona project consists of 21 experimental test sections designed to effectively evaluate the structural factors that effect rigid pavement performance. One-year testing of PCC molded beams and cylinders and cores was recently completed. The rate of strength development varied greatly between the two PCC mix designs.

Background

This SPS-2 project is part of the FHWA's national Long Term Pavement Performance (LTTP) Program SPS-2 experiment, Strategic Study of Structural Factors for Rigid Pavements. At present, highway agencies lack sufficient information on the influence of concrete strength and pavement drainage on the performance of portland cement concrete (PCC) pavements. Although these factors appear in the AASHTO Guide for Design of Pavement Structures, they were incorporated into the equations through rational engineering considerations and not as the direct result of a structured field experiment. Other factors that influence the structural and functional performance of concrete pavements such as joint spacing, joint orientation, and shoulder type are not directly incorporated in the AASHTO Design Guide. Highway agencies lack information on the interaction of these key factors with other variables such as climate. Therefore, controlled field experiments such as SPS-2 are necessary to answer the following questions:

- To what extent does concrete strength or type of the base layer influence pavement performance and what is the relative importance of each? How do environmental factors influence the relative importance?
- To what extent does the influence of pavement drainage on pavement performance vary from wet to dry climatic zones, and what is its relative importance in each zone?
- Is there a benefit of using dowels or skewed joints or would undoweled or perpendicular joints provide similar performance? Does the relative performance depend on climatic conditions?

Approach

The objective of this study is to more precisely determine the relative influence of the strategic factors that effect performance of rigid pavements. The primary factors addressed in this
study include drainage, base type, concrete strength and thickness, and lane width. The study objective includes a determination of the influence of environmental region and soil type on these factors. Accomplishing this objective will provide substantially improved "tools" for use in the design and construction of new and reconstructed rigid pavements. The LTPP sections will evaluate these factors:

- Concrete Thickness: 8" and 11".
- Base Type: Lean concrete, dense graded aggregate base, permeable bituminous treated base, and bituminous treated base (BTB).
- Concrete Flexural Strength: 550 psi and 900 psi at 14 days.
- Lane Width: 12 ft. and 14 ft.
- Drainage: With and without edge drains.

In addition to the twelve LTPP sections, ADOT constructed an additional nine (undoweled) test sections. The additional sections will evaluate load transfer, an additional thickness, asphalt concrete (AC) vs PCC pavement performance, and the use of a BTB base course. They were incorporated into the experiment to benchmark ADOT current design procedures and allow a direct comparison between ADOT rigid and flexible design procedures.

Project Data

The SPS-2 project was constructed as part of an 18-mile mill and overlay project on Interstate 10 west of Buckeye, Arizona. The 21 test sections occupied approximately three miles of the eastbound lanes. Each test section is composed of a 500-foot long monitoring section with 200-300 feet of transition between each section. Tanner Companies was the general contractor. The project was opened to traffic on October 28, 1993. At least fifteen more of these projects will be constructed around the US in eight different climate/soil zones. Four other SPS-2 projects were completed by the end of 1993 and another seven were scheduled for completion in 1994. Two are planned for 1995.

PCC Trial Batches

To achieve the narrow band of PCC flexural strength required by LTPP (550 ± 25 and 900 ± 40 psi), trial batches were required. The contractor offered to conduct the trial batches at the plant instead of the lab. Three beams and three cylinders were molded from three separate batches for each mix design for a total of nine each. A refrigerated trailer was placed on site to store specimens while curing which minimized transport disturbance. The same technicians were used to ensure consistent beams and cylinders. Trial batches of five mix designs were required to achieve a satisfactory design for the 550 psi mix.
and seven were required for the 900 psi mix. Cement, flyash, water, air entraining admixture and even mix time were varied to try to hit the target strength.

Final PCC Mix Designs

The mix designs chosen produced trial batch results that fell within the required range. The two designs are summarized below. An additional 550 psi mix design was used for the undoweled state supplementary sections which was nearly identical except a second coarse aggregate (1.5") was added. Mixing time was 60 seconds.

<table>
<thead>
<tr>
<th></th>
<th>550 psi</th>
<th>900 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>400 lb</td>
<td>800 lb</td>
</tr>
<tr>
<td>Flyash</td>
<td>100 lb</td>
<td>0 lb</td>
</tr>
<tr>
<td>Water</td>
<td>232 lb</td>
<td>292 lb</td>
</tr>
<tr>
<td>Air Ent.</td>
<td>2 oz/cy</td>
<td>0 oz/cy</td>
</tr>
<tr>
<td>WR</td>
<td>25 oz/cy</td>
<td>40 oz/cy</td>
</tr>
<tr>
<td>Sand/agg</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>W/C</td>
<td>0.47</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Construction Highlights

After the existing AC surface and AB were removed, the subgrade was over excavated one foot, replaced, and recompacted to simulate new construction. Tight tolerances on the thickness of each course were checked by means of elevations that were shot at five transverse locations in the study lane every 50 feet. PCC paving was at night due to daytime temperatures in excess of 100 degrees. To achieve homogeneous test sections, no cold joints were allowed within the 500-ft monitoring sections. Additional crew, parts and equipment were on hand to prevent a stoppage. The final smoothness of the three miles of PCC was excellent, with an average profile index of less than one.

Test Section Sampling and Testing

Each pavement course was sampled extensively as it was placed. Subgrade and base course material was sampled within each of the 21 sections. Up to twenty tests were ran on each sample. Deflection testing with the falling weight deflectometer was conducted in and between wheel paths on every course. Nuclear density readings were performed extensively within each section. The PCC was sampled and molded into 3 beams and 3 cylinders for each section, one each for a break at 14 days, 28 days, and one year. The samples were placed in a refrigerated trailer on-site for curing. A beam breaker in the trailer was used for the 14 day breaks. The other samples were transported to the lab in the trailer and stored in a fog room until testing. Cores were also taken in each section and tested at the same intervals. Air content and slump were monitored both at the plant and the paver to ensure production of a mix as close as possible to the trial batch. Typically, a half inch of slump and a half percent of air was lost in route to the paver. Finally, large quantities of aggregate, cement, flyash, admixtures, and asphalt were sampled and sent to a LTPP storage facility in Reno, Nevada where they will be held for possible future analysis.

Data Collection and Monitoring

A high-speed weigh-in-motion system is installed at the site to accurately monitor the classification and weight of traffic traveling over the test sections and thereby provide a precise number of ESALs for the life of the pavement. Distress surveys, roughness measurements, and deflection testing is performed annually. A weather station on site collects continuous data on temperature, precipitation, and solar radiation. Sections are permanently marked with aluminum caps in the shoulders supplemented with thermoplastic markings and descriptive signs at the right-of-way fence.

Findings

PCC Test Results

All PCC molded samples and cores were broken at 14 days, 28 days, and one year. Those test results are shown in Tables 1 and 2. The target strength was met for the 550 psi mix. The 900 psi mix fell below the desired range. The lower strength may have occurred due to higher
W/C ratio used in production for finishability or due to different means of measuring moisture in the sand bin during trial batches and production. The variability in flexural strengths from beams was quite low. In fact, beams were at least or more consistent than cylinders and cores in most cases. This is due to the extraordinary means taken to ensure consistent molding and minimize handling disturbance.

A significant difference in strength development is noted between the two mix designs. The 550 psi mix gained 46% in flexural strength from 14 days to one year, while the 900 psi mix gained only 16%. Compressive strength development was similar. This resulted in the two strengths of concrete being closer together than the experimental design intended. One likely possibility is the delayed pozzolanic reaction of the Class F flyash used in the 550 psi mix. Another explanation is incomplete mixing of the 800 pounds of cement in the 900 psi mix during the 60 second mixing time. This will be studied further as more data is available. Some states SPS-2 results have been similar. There is no distress noted within the test sections after 15 months in service.

<table>
<thead>
<tr>
<th>Type of Sample</th>
<th>Mean Strength in psi of 13 Samples (std dev, %)</th>
<th>14-day</th>
<th>28-day</th>
<th>1-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Flexural</td>
<td></td>
<td>564 (5.9)</td>
<td>633 (7.7)</td>
<td>826 (9.3)</td>
</tr>
<tr>
<td>Cylinder</td>
<td></td>
<td>3343 (10.8)</td>
<td>4140 (8.5)</td>
<td>6286 (4.9)</td>
</tr>
<tr>
<td>Compressive</td>
<td>360 (7.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split Tensile</td>
<td></td>
<td>468 (10.0)</td>
<td>408 (10.3)</td>
<td>617 (7.8)</td>
</tr>
<tr>
<td>Core Compressive</td>
<td></td>
<td>3992 (8.7)</td>
<td>4385 (10.6)</td>
<td>5867 (13.0)</td>
</tr>
<tr>
<td>Split Tensile</td>
<td></td>
<td>468 (10.0)</td>
<td>408 (10.3)</td>
<td>617 (7.8)</td>
</tr>
</tbody>
</table>

Table 2. Test Results for 900 psi Mix

<table>
<thead>
<tr>
<th>Type of Sample</th>
<th>Mean Strength in psi of 6 Samples (std dev, %)</th>
<th>14-day</th>
<th>28-day</th>
<th>1-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Flexural</td>
<td></td>
<td>837 (6.9)</td>
<td>868 (6.3)</td>
<td>965 (6.9)</td>
</tr>
<tr>
<td>Cylinder</td>
<td></td>
<td>6183 (3.5)</td>
<td>6654 (3.4)</td>
<td>7636 (5.9)</td>
</tr>
<tr>
<td>Compressive</td>
<td>487 (3.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split Tensile</td>
<td></td>
<td>583 (7.4)</td>
<td>532 (11.1)</td>
<td>655 (7.9)</td>
</tr>
<tr>
<td>Core Compressive</td>
<td></td>
<td>6268 (5.0)</td>
<td>6753 (4.1)</td>
<td>7868 (9.0)</td>
</tr>
<tr>
<td>Split Tensile</td>
<td></td>
<td>583 (7.4)</td>
<td>532 (11.1)</td>
<td>655 (7.9)</td>
</tr>
</tbody>
</table>

For Additional Information Contact:

ATRC / 7755 S. Research Drive. Suite #106 / Tempe, AZ 85284 / (602)831-2620
SHRP MAINTENANCE TREATMENT EFFECTIVENESS STUDY

The twenty-two experimental pavement sections constructed as part of the SHRP AC maintenance cost effectiveness study are already indicating differences between pavement maintenance strategies.

Background

Two years ago (January 1990), this newsletter reported on ADOT's involvement in the Strategic Highway Research Program's (SHRP) Long Term Pavement Performance (LTPP) Study. As was previously described, the LTPP study had as its fundamental goal the development of better and longer lasting pavements. This goal is being achieved through testing and evaluation of roughly 800 in-service pavements (which make up the General Pavement Study or GPS experiment) and 1100 newly constructed or resurfaced pavements (which make up the Special Pavement Study or SPS experiment) from throughout the United States. LTPP is now in the fifth year of a planned 20-year investigation.

One of the many key elements of the LTPP program is a study to evaluate the effectiveness of four different kinds of maintenance treatments, i.e., chip seals, slurry seals, crack seals, and thin (1.25-inch) overlays, on existing asphalt concrete pavements. This study is the third in the SPS experiment series (SPS-3) and was developed as a result of requests from many states. It is intended to address the questions of cost effectiveness and optimum timing of the four different maintenance treatments. SPS-3 is a nationwide experiment involving 33 states and 80 different sites. Nine states in SHRP's Western Region participated in constructing 22 of the sites (see Figure 1). Arizona with its four SPS-3 sites, is well above the national average in terms of its cooperation and commitment to the study success.

Approach

The SPS-3 experiment was designed to take into consideration six major factors that were thought to have a significant influence on maintenance treatment performance and cost effectiveness:

- Moisture (wet vs. dry environment)
- Temperature (freeze vs. no-freeze environment)
- Subgrade soil texture (fine grained vs. coarse grained)
- Traffic (low vs. high)
• Structural adequacy as defined by the Sn Ratio (ratio of in-place AASHTO flexible pavement structural number to the required AASHTO structural number: less than 1 vs. greater than or equal to 1)
• Existing pavement condition (good, fair or poor)

Besides the four different maintenance treatment sections at each site (complying to experiment specifications for materials and construction), there was one additional Control section identified and as many state constructed supplemental sections as desired by the individual state DOT's involved. The Control section was actually a "do nothing" section intended to provide a basis for comparison on how the pavement would have performed without any treatment. SHRP agreed to monitor the state's supplemental sections and include all data in the SHRP data base. All sections at every site were 500 feet long with 50-foot minimum before and after zones.

Findings

A review of ten SPS-3 sites was undertaken by representatives of five western states, TTI, FHWA, SHRP headquarters and the Western Region Coordination Contractor (WRCOC) in August, 1991. An additional seven sites were visited by the WRCOC and respective state representatives. Discussion has been held with the State Representative on the remaining five sites. The following is the consensus of their review.

Chip Seals: Numerous chip seals have had considerable chip loss. Their condition is as follows: 7 good, 3 fair, 5 poor, 6 failed, 1 overlayed due to subgrade failure. In reviewing the chip seals it appears that too light of emulsion application is a major contributor to chip loss. Other contributing factors may be opening to high speed traffic too soon, brooming too soon, and problems with instability of the CRS-2h emulsion.

One benefit learned during construction was that it is extremely important to calibrate the chip spreader on a continuing basis. Hauling of the equipment appeared to affect the calibration; thus, the specific calibration method used was essential to maintaining uniformity across the width. The CRS-2h emulsion is unstable and the long hauls encountered on this project appeared to influence viscosity considerably. On site viscosity testing for this type of emulsion is recommended. The viscosities encountered ranged from a low of 60 to a high of 450 + poise. The specification was 150 to 300 poise.

Slurry Seals: The performance of the slurry seals to date has been excellent. All slurry seals are considered in good condition. Some cracking has come through on some sites and there is some sheen in the wheel path on a few of the sections. Benefits learned during construction is to employ a good mix design and to use a high quality crushed fine aggregate that is compatible with the emulsion.

Crack Seal: To date, the performance of the high quality material is mixed. In the colder climates, there appears to be a considerable number of failures due to debonding of the material from the side wall. This could have occurred due to the type of router utilized which may have fractured the side wall during construction or the side walls may not have been clean enough. Use of the hot air lance was difficult in that if the lance was moved slow enough to heat the side walls, it could char the asphalt.

Thin Overlays: The majority of the thin overlays appeared to be in good condition. On some of the sites, however, there was more reflective cracking than with other repair strategies.

In general, the SHRP SPS-3 experiment seems to be a success and will likely "pave" the way for future studies of maintenance treatment effectiveness.

For Additional Information Contact:

ATRC / 7755 S. Research Drive, Suite #106 / Tempe, AZ 85284 / (602) 831-2620
EVALUATION OF PCCP JOINT SEALANTS

After nearly four years in service, a recent evaluation showed that all four silicone sealants and two out of three compression seals installed in twenty-four experimental sections were performing well with less than two percent failure. Unsealed joints were also performing well. Nine different joint sealants and five joint configurations were evaluated.

Background

As part of a nationwide study of cost-effective pavement maintenance methods by the Strategic Highway Research Program (SHRP), ADOT sponsored the construction and evaluation of a concrete pavement joint sealing experimental test site (SPS-4). The test site for this project was a newly constructed 2.15 mile segment within the eastbound lanes of US-60 (Superstition Freeway) between Sousmann and Ellsworth Roads in Mesa, Arizona. Joint seal installation was completed in March 1991. The 24 sections vary in length between 359 and 567 feet and contain between 25 and 38 joints in each section. Details for the five joint configurations studied are shown in Figure 1. Table 1 is a summary of the joint construction for these 24 sections. Joints were cut to 1/3 of the slab thickness.

Approach

Two experimental test zones were established on this project to evaluate a total of 24 (two replicates of twelve sections) test sections using 9 different joint sealants and 5 different joint configurations. Both zones are located in the eastbound travel lanes and are slightly less than 1 mile long, with approximately 0.3 mile between sections. Two of the test sections are formal Strategic Highway Research Program (SHRP) sections, while the remaining 22 are state sections.

Two of the sealants installed at the test site are hot applied sealants, one conforming to the ASTM D 3405 specification and one conforming to ASTM D 3406. Four materials are silicone sealants; one non-sag and three self-leveling. Three seals are compression seals. Listed below are the material names and descriptions:

- Crafco RoadSaver 221, an ASTM D-3405 rubberized asphalt sealant.
- Crafco 444 Superscl, an ASTM D-3406 fuel resistant, coal tar sealant.
- Crafco Silicone-SL, a self-leveling silicone.
- Dow 888, a non-sag silicone.
- Dow 888-SL, a self-leveling silicone.
- Mobay Baysilone, a self-leveling silicone.
- Delastic V-687 compression seal
- Watson Bowman WB-812 compression seal
- Watson Bowman WB-687 compression seal
- Unsealed

Each state section is approximately 375 ft in length and contains 25 or 26 joints. The two SHRP sections are 511 and 567 ft in length with 34 and 38 joints, respectively. Twelve randomly selected joints in each section were inspected. The following tasks were performed:

- Visual observations were made of the distresses exhibited in each of the sampled joint-seal treatments. Twelve transverse joints and 3 longitudinal joints were surveyed in each section.
The IAVAC device (a vacuum tester developed by Iowa DOT) was used to test a 4-ft section of each of the 12 transverse joints surveyed in each test section.

Pull-out tests were performed on each of the experimental materials.

In order to identify the types, severities, and amounts of distress present in each joint-seal treatment, each sampled joint seal was visually inspected. Among the primary distresses evaluated and recorded (on a foot-by-foot basis) were adhesion loss, cohesion loss, spall distress, stone intrusion, and sunken system failure was also documented, taking into consideration possible overlaps of different treatment failure modes. For the preformed compression seals, extrusion, twisting, and compression set were also examined. In unsealed sections, measurements were taken of the depth to stones in the joint and the amount of edge spalling on a foot-by-foot basis.

A 4-ft section of each of the surveyed transverse joints was also evaluated using the IAVAC. The data collected from this testing will be examined later to determine what type of correlation exists between the results obtained from the IAVAC device and the visual inspection. The results will be reported in a future research note.

Findings

Overall seal failure was defined as any of the following: full-depth adhesion failure, full-depth cohesion failure, full-depth spalling, compression set, or edges filled with stones in compression seals. Based on the overall failure percentage, each treatment was rated for performance according to the following criteria:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Failure Level, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>0 to 10</td>
</tr>
<tr>
<td>Good</td>
<td>11 to 20</td>
</tr>
<tr>
<td>Fair</td>
<td>21 to 35</td>
</tr>
<tr>
<td>Poor</td>
<td>36 to 50</td>
</tr>
<tr>
<td>Very Poor (Failed)</td>
<td>51 to 100</td>
</tr>
</tbody>
</table>

Table 1 lists the overall failure percentages of each transverse joint treatment observed in the field inspection. A brief discussion of the condition and performance of each experimental material after approximately 44 months of service is provided in the following sections.

Crafco RS 221 ASTM D 3405 Hot Pour

The Crafco RS 221 sealant was by far the worst performing sealant of all the joint treatments at the U.S. 60 test site. Overall failure rates were 53.8 percent for the transverse joints and 47.6 percent for the longitudinal joints, translating to performance ratings of very poor and poor, respectively. The dominant mode of failure was full-depth adhesion loss, with only small amounts of full-depth cohesion loss and spalling. A fair amount of full-depth cohesion loss was found in the longitudinal joints of State Section 11- (10.3 percent). High amounts of partial-depth adhesion failure were also present in these sections in both the transverse and longitudinal joints.

Crafco RS 444 ASTM D 3406 Hot Pour

Significant amounts of full-depth adhesion and cohesion failure and stone-intruded surface were observed in experimental zone 1 (State Section 08) for the Crafco RS 444 sealant. However, very little failure was observed in experimental zone 2 (State Section 23). Construction records indicate that the material used in the last five or more joints in State Section 8 may have been defective due to premature initial setting of the sealant. It is believed that the material was overheated before application, thus causing the higher failure rate. Large amounts of partial-depth cohesion loss were also observed in both sections. The longitudinal joints showed a trend similar to that found in the transverse joints, with much higher failure rates in zone 1 than in zone 2.

Dow 888 Silicone

Dow Corning's non-sag 888 silicone sealant was performing very well, with the only failures being a small amount of full-depth spalling in the transverse joints (0.5 percent) and small amounts of full-depth adhesion and cohesion failure (totaling 0.5 percent) in the longitudinal joints. The cohesion failures can more than likely be attributed to deficiencies in construction and not material failures.

Crafco 903-SL Silicone

Crafco’s 903-SL self-leveling silicone sealant was also performing very well. The only failures observed were small amounts of full-depth spalling and full-depth adhesion loss in both the transverse and
longitudinal joints. A very small amount of full-depth cohesion failure was observed in the longitudinal joints, which probably resulted from a construction deficiency and not material failure.

Mobay Baysilone 960-SL Silicone

The Mobay Baysilone 960-SL self-leveling silicone sealant exhibited the highest rate of full-depth spalling in transverse joints (1.7 percent) of all the materials examined. However, overall performance was still very good. Only small amounts of adhesion or cohesion failure were present in either transverse or longitudinal joints. Cohesion failure in silicone sealants is not common, but has also been observed in this particular material at other test sites.

Dow 888-SL Silicone

The Dow 888-SL self-leveling silicone sealant material was performing well. Small amounts of full-depth adhesion failure and full-depth spalling were the only distresses observed in both the transverse and longitudinal joints.

Dow 890-SL Silicone

Dow's 890-SL self-leveling, low-modulus silicone sealant was placed in transverse joints having three different widths, ranging from 0.125 in to 0.375 in. The sealant placed in the narrowest transverse joints (0.125-in) showed the largest amount of failure (1.3 percent), while the sealant placed in the other two joint widths (0.250-in and 0.375-in) exhibited less failure (0.4 percent). Typically, full-depth adhesion loss and full-depth spalling were the primary failure modes. The width was the same for all of the longitudinal joints, where small amounts of full-depth spalling and full-depth adhesion loss were observed.

Delastic V-687 Compression Seal

The Delastic V-687 was found to be the worst performing of the compression seals examined. The predominant failure mode was the presence of stones between the seal and the joint edge, accounting for 33.0 percent of the total failure. These stones in effect held the seal open at the edge, allowing moisture and additional material to enter the joint. Small amounts of full-depth spall and compression set were also observed in this seal. This particular seal may contain less webbing material than the other compression seals installed at the site. This may offer some explanation as to the poorer performance of this type of seal, and will be investigated further and discussed in more detail in a later report.

Watson Bowman WB 687 Compression Seal

Watson Bowman's 687 compression seal was found to be performing very well. Only slight amounts of full-depth spalling, compression set, and edges filled with stones were observed.

Watson Bowman WB 812 Compression Seal

Watson Bowman's 812 compression seal was also found to be performing very well. The only failure observed was a very small amount of edges filled with stones (0.1 percent).

Unsealed

The unsealed joints were performing very well at the time of this survey. These joints did not exhibit full-depth spalling amounts which were significantly higher than any of the sealed sections. Somewhat greater amounts of partial-depth spalling (2.7 percent) were observed in the transverse joints, however, compared to other treatments. Mean depths to stones (incompressibles) in the joints were 1.9-in and 1.4-in for transverse and longitudinal joints, respectively. Depths were usually lower near the junction of the transverse and longitudinal joints (i.e. near the pavement edge). Faulting was not evident in the unsealed sections.

Conclusions

With the exception of the two hot applied materials (Crafco 221 and 444) and the Delastic V-687 compression seals, all of the sealant materials, including the unsealed joints, were found to be performing quite well. Results of the pull tests demonstrated that all the silicone materials failed in cohesion, thus indicating that adhesive bond to the joint edges is quite good. Construction records indicate that the depth to the top of sealant was often less than the specified minimum of 0.250-in. This has lead to some partial-depth failures, but results of this inspection do not indicate significant amounts at this time.
Figure 1. Joint Configurations

Table 1. Summary of transverse joint-treatment failures

<table>
<thead>
<tr>
<th>Type of Sealant</th>
<th>Joint Config.</th>
<th>Overall Failure % joint length</th>
<th>Performance Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crafco 221 ASTM 3405 hot pour</td>
<td>1</td>
<td>53.8</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Crafco 444 ASTM 3406 hot pour</td>
<td>1</td>
<td>15.4</td>
<td>Good</td>
</tr>
<tr>
<td>Dow 888 silicone</td>
<td>1</td>
<td>0.5</td>
<td>Very Good</td>
</tr>
<tr>
<td>Crafco 903-SL</td>
<td>1</td>
<td>0.7</td>
<td>Very Good</td>
</tr>
<tr>
<td>Mobay Baysilone 960-SL</td>
<td>1</td>
<td>1.8</td>
<td>Very Good</td>
</tr>
<tr>
<td>Dow 888-SL silicone</td>
<td>1</td>
<td>0.9</td>
<td>Very Good</td>
</tr>
<tr>
<td>Dow 890-SL silicone</td>
<td>1</td>
<td>0.4</td>
<td>Very Good</td>
</tr>
<tr>
<td>Dow 890-SL silicone</td>
<td>3</td>
<td>0.4</td>
<td>Very Good</td>
</tr>
<tr>
<td>Dow 890-SL silicone</td>
<td>4</td>
<td>1.3</td>
<td>Very Good</td>
</tr>
<tr>
<td>Delastic V-687 compression seal</td>
<td>5</td>
<td>37.7</td>
<td>Poor</td>
</tr>
<tr>
<td>Watson Bowman WB 687 compression seal</td>
<td>5</td>
<td>2.2</td>
<td>Very Good</td>
</tr>
<tr>
<td>Watson Bowman WB 812 compression seal</td>
<td>5</td>
<td>0.1</td>
<td>Very Good</td>
</tr>
<tr>
<td>Unsealed</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Failure of site</td>
<td></td>
<td>6.7</td>
<td>Very Good</td>
</tr>
</tbody>
</table>

For Additional Information Contact:

ATRC / 7755 S Priest Drive, Suite #106 / Tempe, AZ 85284 / (602)831-2620
ASPHALT PAVEMENT REHABILITATION RESULTS

After nearly five years in service, a recent evaluation of ten different strategies for rehabilitating asphalt concrete (AC) pavement showed that all strategies are performing well except for one.

Background

A Specific Pavement Study (SPS-5), Rehabilitation of Asphalt Concrete Pavements, as part of the Strategic Highway Research Program (SHRP), was constructed by ADOT in the summer of 1990 on the eastbound lanes of Interstate 8 near Casa Grande, Arizona. This study is now included as part of the FHWA Long Term Pavement Performance Program (LTPP).

The principal objective of this national pavement performance experiment is to determine the additional pavement life that can be expected from a variety of asphalt concrete pavement rehabilitation methods. The Arizona Transportation Research Center (ATRC) has closely monitored these eleven test sections during the past four years and most recently conducted a pavement distress survey in February 1995. The field notations are transferred to CADD drawings, which can then be used in the analysis of the data.

Approach

The rehabilitation factors applied to the SPS-5 test site included a minimum and maximum level of surface preparation. The experimental design called for only pothole repair and crack filling for the minimum preparation and 2 inches of milling for the maximum. Due to the presence of rutting and a friction course, which could not remain, milling depths had to be increased to approximately 1 and 3 inches. Also used were two types of overlay material (virgin and recycled AC - 30% RAP), and two AC overlay thicknesses (2-inch and 5-inch). This resulted in eight test section combinations. In addition, a control test section was included which received only routine maintenance (i.e., pot hole repair and crack sealing). ADOT added two supplementary state sections. One was an "inverted design" in which a 3-inch recycled overlay was placed over a 4-inch virgin AC layer after 4-inches of milling. The second was a 2-inch asphalt rubber AC overlay after 1 inch of milling.

Findings

According to weigh-in-motion equipment at the site, the ADT over these sections (eastbound) averages 2,000 with 40 percent truck traffic. ESALs are estimated at
130,000 annually. The site has an average annual precipitation of 7 inches with summer highs averaging near 110 and winter lows near 40 degrees.

The distress survey was conducted as a visual assessment of the performance of each strategy. Rutting was not evident in any section. Profilometer data does not show any significant difference in smoothness to date. Table 1 shows the amount of cracking measured within each 500-foot monitoring section.

The worst performing rehabilitation strategy is the 2-inch recycled mix with minimum preparation. There was a 65 percent increase in linear cracking from the last evaluation 12 months ago. Cracking appears to be evenly divided between transverse and longitudinal with transverse cracking spaced at 15-20 foot intervals. Areas of alligator cracking are beginning to form at the junction of transverse and longitudinal cracks.

The extensive alligator cracking noted in the 2-inch virgin overlay with minimum preparation appears to be some type of base failure. A significantly higher percentage of cracking was not noted in this section at the time of construction. The cracking is confined to a well defined area along the centerline, but does not occur in the wheelpath. The cracking does not seem to be progressive.

Most of the cracks in the 2-inch asphalt rubber overlay, which all developed during the last 12 months, are in the wheel paths and are easily seen due to the presence of fines being pumped up from the base though the cracks.

The control section, which has received almost no maintenance, is completely block and alligator cracked. It is scheduled to be milled and overlayed in late 1995.

The LTPP contractor, as well as the ATRC, will continue to perform monitoring to include profilometer testing, deflection testing, and distress surveys. The results from the Arizona experiment, when combined with results from other sites in eight climatic / soil zones, will provide state highway agencies with much better tools to effectively and efficiently rehabilitate asphalt concrete pavements.

Table 1. Pavement Cracking on SPS-5 Test Sections (February 95 survey)

<table>
<thead>
<tr>
<th>Section Description</th>
<th>Virgin Max, 5&quot;</th>
<th>Virgin Min, 5&quot;</th>
<th>Recycled Max, 5&quot;</th>
<th>Recycled Min, 5&quot;</th>
<th>Virgin Max, 2&quot;</th>
<th>Virgin Min, 2&quot;</th>
<th>Recycle Max, 3&quot;</th>
<th>Rubber Min, 2&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section Number</td>
<td>SHRP 40507</td>
<td>SHRP 40504</td>
<td>SHRP 40503</td>
<td>SHRP 40508</td>
<td>SHRP 40509</td>
<td>SHRP 40502</td>
<td>SHRP 40506</td>
<td>SHRP 40505</td>
</tr>
<tr>
<td>Linear Cracking</td>
<td>0</td>
<td>0</td>
<td>49</td>
<td>0</td>
<td>78</td>
<td>875</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>(Feet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>156</td>
</tr>
<tr>
<td>(Sq feet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

For Additional Information Contact:

ATRC / 7755 S. Research Drive, Suite #106 / Tempe, AZ 85284 / (602)831-2620
CONCRETE PAVEMENT REHABILITATION UPDATE

After five years in service, an evaluation of fifteen test sections that represent different strategies for rehabilitating portland cement concrete (PCC) pavement showed that test sections rehabilitated with an asphalt rubber surface or an 8-inch asphalt concrete overlay, both over a crack-and-seat preparation, or an overlay with sawed and sealed joints, were performing better than those treated with other strategies.

Background

A Specific Pavement Study (SPS-6) experimental project, Rehabilitation of Jointed Portland Cement Concrete Pavements, as part of the Strategic Highway Research Program's (SHRP) Long Term Pavement Performance (LTPP) effort was constructed by ADOT in the summer of 1990 on eastbound Interstate 40 near Flagstaff, Arizona.

The principal objective of this national experiment is to develop improved performance prediction models to be used to determine the additional pavement life that can be expected from a variety of jointed Portland Cement Concrete (PCC) pavement rehabilitation methods. The Arizona Transportation Research Center has monitored the test sections during the past four years and most recently conducted a pavement cracking survey in July 1995. The field results have been transferred to CADD drawings which are used in the analysis of the data.

Approach

The rehabilitation strategies applied to the SPS-6 test site were characterized by: (1) the degree of surface preparation of existing PCC pavement and the level of reconditioning of drainage features; (2) the type of treatment applied to the original PCC pavement structure and; (3) the type and thickness of asphalt concrete (AC) pavement overlay. The rehabilitation methods ranged from minimal to maximum restoration of the existing PCC pavement both with and without AC overlays. Maximum restoration included slab replacement and full-depth spall repair. Minimum restoration included some patching and partial-depth spall repair. Other pavement treatments included crack and seat of the existing concrete, followed by asphalt concrete overlays or saw and seal of the AC over the PCC joints.

Nineteen 500-ft to 1000-ft sections were constructed at the SPS-6 test site. Eight of these were designed to meet SHRP SPS-6 experiment requirements and eleven sections were added by ADOT to evaluate performance of other rehabilitation strategies not included in the SHRP SPS-6 experiment design. Figure 1 shows a
schematic layout and the experimental configuration of the SPS-6 test site. Sixteen of the nineteen sections received treatments that included at least a 4-inch thick overlay. A rubblized section with an 8-inch overlay is not considered valid due to an area of extensive reconstruction of base course within the section. Two sections received restoration treatments but no overlay. Nothing was done on one section designated as the control section. By 1992 the control section and two sections that had received only restoration treatments with no overlay were in serious disrepair. These three sections were overlaid and discontinued from further study in 1993. Cracks in the remaining sections were sealed in March 1995.

Findings

According to weigh-in-motion equipment at the site, the ADT over these sections (eastbound only) averages 7,500 with an 80/20 lane split and an average 40 percent truck traffic (ASTM class 4-13). ESALs are estimated at 1.8 million annually. The site has an average annual precipitation of 23 inches with summer highs averaging in the low 80's and winter lows in the high teens.

Figures 2-4 summarize the pavement cracking data for the SPS-6 site. Only data for the eight LTPP sections and one state section is shown. Six other state sections with a 2-inch asphalt rubber layer over a 3-inch AC overlay were performing outstanding, with only one of the two control sections having any type of cracking after five years. Most of the longitudinal cracking observed during the last survey and reported in previous research notes is occurring along the pavement center line, between the travel and the passing lane. This cracking is almost exclusively in the paving joint of the half-inch asphalt concrete friction course (ACFC) due to the presence of the guide string along that joint and possible low density at the joint. Because of this unique situation, the longitudinal cracking associated with the ACFC paving joint is not used as a primary indicator of performance and is not reflected in the figures. The small amount of longitudinal cracking shown in Figure 2 is not associated with the paving joint and, when combined with the transverse cracking shown in Figure 3, is a much better measure of the success of each rehabilitation strategy (Figure 4). A vast majority of transverse cracks noted in the pavement overlay are reflection cracks due to the PCC joints and cracks beneath. All cracking in the overlays was measured in lineal feet and the total length of cracks for any section is given for 500 ft length of the travel lane. Only the travel lane is evaluated. No other significant distress was noted.

Conclusions

A comparative analysis of pavement cracking (see Figures 2 through 4) showed that:

1. Cracking was most extensive on the section that was overlayed with 2" Asphalt Concrete (AC) on top of 2" Asphalt Rubber Asphalt Concrete (ARAC) material and the two sections that received minimum and maximum restoration treatments with a 4" AC overlay.

2. On the basis of total cracking, it can be concluded that the best performing sections (strategies) to date are:

   (a) 2-inch ARAC over 3-inch AC (2 sections each of control, crack-and-seat, and rubblize).
   (b) 4-inch AC overlay with saw-and-seal joints.
   (c) Crack-and-seat section with a 2" ARAC overlay on top of 2" AC.
   (d) Crack-and-seat section with an 8" AC overlay.
State supplementary sections
Overlayed in 1993

Figure 1. Layout of Arizona SPS-6 Test Sections

Figure 2. Longitudinal pavement cracking at SPS-6 site
Figure 3. Transverse pavement cracking at SPS-6 site

Figure 4. Total pavement cracking at SPS-6 site

For Additional Information Contact:
ATRC / 7755 S. Research Drive, Suite #106 / Tempe, AZ 85284 / (602)831-2620
Recently, the Arizona Department of Transportation (ADOT) successfully placed 8500 tons of asphalt concrete designed with the new SUPERPAVE (SUperior PErfoming Asphalt PAVEments) mix design system. Four sections were constructed on US 93 north of Kingman using a 3/4-inch and a 1-inch mix design. Both mixes were considerably coarser and contained 0.5 to 0.9 percent more asphalt than ADOT's standard mixes. Compaction of the test sections ranged between 92 - 94 percent of maximum theoretical density.

Background

These four sections were built in conjunction with a project to widen the roadway from two to four lanes, and was part of the Federal Highway Administration's (FHWA) national Long Term Pavement Performance (LTPP) Program SPS-9 experiment, "Validation of SHRP Asphalt Specifications and Mix Design and Innovations in Asphalt Pavements."

SUPERPAVE is a product of the Strategic Highway Research Program's 5-year, $50 million asphalt research projects to improve the performance and durability of our nation's asphalt concrete roads. The SUPERPAVE system provides a comprehensive means for the design of paving mixtures tailored to the unique performance requirements dictated by the traffic, climate and structural section at a project site. It applies to all types of mixes for use in new construction and overlays. It directly addresses the reduction and control of rutting, fatigue cracking, and low temperature cracking through materials selection and mix design. SUPERPAVE includes performance-based binder and mix specifications and performance based tests to support the specifications.

The Asphalt Institute in Lexington, Kentucky performed the mix designs for the Arizona project. Project samples of mineral aggregate and asphalt cement were sent to the Asphalt Institute. The traffic design level of 4 million ESALs on US 93 warranted a level 2 mix design, but only a level 1 (volumetric) design was possible due to lack of equipment. Level 2 design would have subjected the mix to a shear test to evaluate its resistance to rutting and fatigue cracking. Also, an indirect tensile creep test would have predicted the amount of low-temperature cracking over time.

The project AC-30 asphalt cement met the requirements of SUPERPAVE binder Performance Grade (PG) 64-16. That grade was selected by the SUPERPAVE weather database with the job site latitude and longitude and implies that the designers expect the binder to perform in a climate that has a seven-day maximum pavement temperature of 65ºC (149ºF) and a minimum pavement temperature of -16ºC (3ºF).

Approach

Four test sections were constructed from 1000' to 1800' long with 500' monitoring sections. Two sections contain the 1" nominal mix and two sections contain the 3/4" nominal mix. The sets of test sections were constructed on shallow fill 5 miles apart and on different days of production. Seven inches of asphalt concrete was placed over 4" of dense-graded aggregate base. Successive lifts of 2.5", 2", and 2.5"
were placed on the same day. Approximately 8,500 tons of SUPERPAVE mix were placed over a period of 3 days.

The Arizona Transportation Research Center (ATRC) used nuclear densiometers to establish a rolling pattern that would achieve the target density called for in the mix design. The rolling pattern established was 4 breakdown passes with a tandem steel wheel roller in vibratory mode, 22 intermediate passes with 15- and 25-ton pneumatics rollers, and 2 finish passes with a static tandem wheel roller. The nuclear readings were correlated to pavement cores to ensure accurate measurements. A gyratory compactor was not available to compact specimens in the field as they were in the mix design.

Findings

Since ADOT had no prior experience with any SUPERPAVE mix, the central materials lab performed a parallel Marshall design prior to construction to develop a "feel" for this new mix. Marshall results showed air voids in the 2-3 percent range. The SUPERPAVE design called for 4 percent air voids with 4.9 percent binder for the 1" mix and 5.2 percent for the 3/4" mix. The gyratory compaction yielded a design asphalt content higher than that chosen with the Marshall design for the same aggregate. This result was contrary to previous experience which would have predicted lower asphalt content with a coarser mix and gyratory compaction.

The in-place mix asphalt content was 0.5 to 0.9 percent (5.0 percent) higher than other mixes on this project. The aggregate blend chosen with the SUPERPAVE design was considerably coarser than typical ADOT mixes (e.g., 54 percent versus 75 percent passing the 3/8" sieve on the 1" mix). Figures 1 and 2 graphically show the differences in gradation. Aggregate for the 1" mix had 98 percent fractured faces and the 3/4" had 72 percent fractured faces. The current SUPERPAVE specifications requires 100 percent fractured faces for surface courses. These factors resulted in a mat behind the paver that appeared very rich and shiny and very "bony" especially compared to the mats observed on the rest of the project.

The mix was prone to segregate due to the coarseness of the mix. The mix segregated when placed from bottom dump trailers into a windrow. Coarser material rolled to the bottom of the windrow, which resulted in random areas in the mat with significant surface voids. There was some concern that these areas may ravel with time and a treatment such as a friction course may be necessary. A defect in the paver's kickback paddles created a segregated area in the middle of each pass and aggravated this segregation potential. After three months under traffic the surface appears less "rich" and "bony" and will not be covered with a friction course.

In general, the mixes were stable under the rollers. The compaction effort required was not significantly different from the rest of the project but additional pneumatic passes were required to minimize the boniness and surface voids. The 3/4" mix did occasionally behave as a tender mix, particularly on the first lift placed directly on the aggregate base. Subsequent lifts behaved more stable. Final mat densities, as determined by cores, ranged from 92 to 94 percent of maximum theoretical density.

During paving, plate samples and cold feed samples were taken every 500 tons of plant mix. The project lab ran Marshall tests. Results averaged for: (1" mix, 3/4" mix) stability (3800, 3500), flow (17, 15), percent AC (5.0, 5.0) and percent air voids (3.3, 4.3). Also, bulk samples of the mix, mineral aggregate, asphalt cement and full-depth cores were obtained for extensive testing by a private lab. The LTPP regional engineer will enter the field and lab testing results into the LTPP national database. Samples were also shipped to the FHWA Materials Reference Library in Reno, Nevada. Also, bulk samples are being held for Level 2 testing at the Asphalt Institute when the equipment becomes available later this year.

Extensive testing will be performed on these sections in the future. The LTPP Regional Engineer in cooperation with the ATRC will conduct periodic roughness, distress, deflection, and skid testing. Cores will be taken periodically to characterize the changes in binder and mix properties with time.
Figure 1. Gradation for 1" Mix
Figure 2. Gradation for 3/4" Mix.
THE ARIZONA SHRP H-106 JOINT RESEALING STUDY

The SHRP Innovative Materials test section for concrete pavement joint resealing located on I-17 in Phoenix was recently evaluated. After two and a half years, only 3 percent of the joints have experienced joint seal failure, with adhesion failure the most common. Silicone sealants are experiencing much less failure than hot-applied sealants.

Background

As part of a nationwide study of cost-effective pavement maintenance methods by the Strategic Highway Research Program (SHRP), ADOT sponsored the construction and evaluation of a concrete pavement joint resealing test site. The 1-mile long test site is installed in the high speed northbound and southbound lanes of I-17, a jointed concrete pavement constructed in 1963 with 15-ft joint spacing. The site is one of five sites constructed nationwide in 1991 to evaluate sealant performance for maintenance of jointed concrete pavements under various climatic conditions. A report on the preliminary findings for all five sites has been published, and a final report documenting the long-term performance will be completed in 1999.

Approach

An experimental matrix of eight different sealant materials and three installation methods (or configurations) is used in this experiment. Twenty joints (two replicates of ten joints) have been sealed using each material/configuration combination. Preparation of the 320 joints began on April 1, 1991, and resealing was completed in 5 nights.

Four of the sealants installed at the test site are rubberized asphalt containing various blends of polymers, rubbers, and asphalt cements conforming to the ASTM D 3405 specification. The remaining four materials are silicone sealants; one non self-leveling and three self-leveling. Listed below are the material names and descriptions:

- Crafco RoadSaver 221, an ASTM D 3405 rubberized asphalt sealant.
- Crafco RoadSaver 231, a low-modulus ASTM D 3405 rubberized asphalt sealant.
- Koch 9005, an ASTM D 3405 rubberized asphalt sealant.
- Meadows Hi-Spec, an ASTM D 3405 rubberized asphalt sealant.
- Dow 888, a non self-leveling silicone.
- Dow 888-SL, a self-leveling silicone.
- Mobay 960-SL, a self-leveling silicone.
- Crafco RoadSaver 903-SL, a self-leveling silicone.

Since recent research indicates that preparation and installation techniques can significantly affect joint seal performance, sealants were installed in three different configurations: recessed, overbanded, and flush-filled. All joints were widened to 0.5 inch using dry and water-cooled saws. Sawing slurry was removed by airblasting. The joint walls were sandblasted with one pass for each joint face and then airblasted. Backer rod was installed to limit the thickness of the hot-applied sealants to 0.5 inch and the silicone sealant thickness to 0.375 inch. Each sealant was placed in the joint, using conventional sealing equipment, according to the configuration profiles shown in Figure 1.
Sealants installed using configuration 1 were recessed below the pavement surface 0.125 to 0.25 inch. To produce an overband on the pavement surface for configuration 2, joints were slightly overfilled and hot-applied sealants were formed using a notched squeegee. Prior to overband placement, the adjacent pavement surface was sandblasted and airblasted. Hot-applied sealants were also installed filling the joints flush with the pavement surface; this method is designated as configuration 3.

Detailed surveys of the condition of the experimental seals were completed at 1, 4, 9, 12, 18, and 31 months after installation, noting any loss of adhesion, formation of edge spalls, overband wear, cohesion distress, and intrusion of stones into the sealants. Results are compiled in a database, and statistical analysis has been completed on the distresses to date. Four additional annual evaluations are planned to provide long-term data on the performance of each seal.

Properties of each sealant material were determined in the laboratory, and attempts were made to correlate material properties with field performance. However, the small amount of seal failure to date does not allow a meaningful analysis to be completed. As future surveys record additional seal distress, it is anticipated significant relationships between material properties and field performance will become evident.

Findings

Several observations can be made from the results of the installation and the six site inspections that have been performed during the first 2.6 years. Observations from the installation process are described in a March 1993 Research Note. The most recently observed seal performance indicators, with regard to material performance and configuration, are described in the following sections.

Performance of Materials

The overall percentages of adhesion, cohesion, and spall failure observed during the November 1993 condition survey are shown in figure 2. Total joint seal failure amounts to 3.3 percent of the entire site, with the majority of failure being experienced as full-depth adhesion loss. Cohesion loss is the next most common failure, followed by full-depth spalls. Silicone sealants are exhibiting less distress, generally, than hot-applied sealants, as shown in table 1. Examples of silicone and overbanded hot-applied sealants after 2.6 years of service at the test site are shown in figures 3 and 4. Based on sealant material type, the following distress trends have been observed:

- **Full-Depth Adhesion Failure** – Meadows Hi-Spec and Crafco RoadSaver 231 have developed 4.4 and 4.6 percent full-depth adhesion failure along their joint edge length, respectively. This is significantly more than the Crafco RoadSaver 221 (2.5 percent) and Koch 9005 (1.3 percent) hot-applied materials. No full-depth adhesion failure has been observed along joints sealed with silicone sealant materials.

- **Partial-Depth Adhesion Loss** – Partial-depth adhesion loss, which generally develops into full-depth adhesion failure over time, averages between 13 and 19 percent for Meadows Hi-Spec, Crafco 221, and Crafco 231. Adhesion loss for Koch 9005 averages 3.7 percent, while there is less than 0.1 percent adhesion loss with silicone sealants.
Figure 2. Joint seal distress for each material and configuration.

- **Cohesion Failure** – Cohesion failure generally is occurring where the sealant has softened, sunken into the joint reservoir, filled with sand, and torn under the weight and expansion stress. Koch 9005, a sealant that tends to soften and harden excessively under extreme temperature conditions, has developed the greatest amount of cohesion failure, 1.8 percent. Meadows Hi-Spec, Crafco 231, and Crafco 221 have developed 1.3, 0.9, and 0.3 percent cohesive failure, respectively, along their joint lengths.

- **Concrete Spall Distress** – Spall distress is not a large problem on the I-17 test site. Deterioration of the surrounding concrete at one joint has caused the length of spalled joint edge to exceed 1 percent for Hi-Spec, but when this joint is discounted the amount of new full-depth spalling associated with any of the materials is less than 0.5 percent. Partial-depth spalls amount to 0.3 percent or less of the joint edge length for any material.

- **Stone Intrusion** – The extremely hot temperatures to which the sealants have been subjected have softened some of the hot-applied sealants to the point that stones and other objects have become embedded in the surface of the sealant, with some of the stones completely penetrating the sealant thickness. The Koch 9005, Crafco 231, and Crafco 221 sealants contain an average of about one embedded stone per 1 foot of joint length. Meadows Hi-Spec shows more resistance to intrusion, averaging one embedded stone for every 4 feet of joint length. Stones have not intruded in the silicone sealants.

**Performance of Installation Methods**

- **Full-Depth Adhesion Failure** – The performance

<table>
<thead>
<tr>
<th>Table 1. Summary of sealant distress.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealant Distress</td>
</tr>
<tr>
<td>Full-depth adhesion failure, %</td>
</tr>
<tr>
<td>Full-depth spall failure, %</td>
</tr>
<tr>
<td>Full-depth cohesion failure, %</td>
</tr>
<tr>
<td>Partial-depth adhesion failure, %</td>
</tr>
<tr>
<td>Partial-depth spall failure, %</td>
</tr>
<tr>
<td>Stone Intrusion, stones/ft</td>
</tr>
</tbody>
</table>
of the hot-applied sealants indicate that the configuration, or method of installation, has an effect on the formation of full-depth adhesion failure. Hot-applied sealants installed in configuration 1 have developed 7.8 percent adhesion failure, while sealants installed using configurations 2 and 3 developed 0.2 and 1.8 percent, respectively. Silicone sealants, which were all installed in configuration 1, have not developed adhesion failure.

- **Partial-Depth Adhesion Loss** - Observations to date of the hot-applied sealants also indicate that partial-depth adhesion loss is related to the method of installation. Adhesion loss has developed along 33 percent of the joint edge length of joints in which sealant was installed using configuration 1. Only 0.3 and 4.3 percent of the joint edge length are exhibiting adhesion loss when the same sealants were installed using configurations 2 and 3, respectively. Silicone sealants have not developed partial-depth adhesion loss.

- **Concrete Spall Distress** - Very little spall distress has occurred since sealant installation. The average amount of partial- and full-depth spall distress for sealants installed in the three configurations ranges from 0.03 to 0.2 percent. No trends have developed that relate spall distress at the I-17 site with the method of installation.

As is expected, analysis indicates that cohesive and stone related failures are more related to material properties than to the method of installation.

**Conclusion**

Overall seal failure at the I-17 test site increased from 0.2 to 3.3 percent between October 1992 and November 1993. This is a moderate increase; however, the amount of overall failure remains small and currently does not permit differentiation between the performance of most of the sealant materials and placement methods. Yearly evaluations are planned until the pavement is overlaid in 1995 or 1996. It is hoped that by then significant differences can be drawn from the seal performance.
THE ARIZONA SHRP H-106 SPALL REPAIR STUDY

The SHRP Innovative Materials test section for partial-depth spall repair of concrete pavements located on I-17 in Phoenix was recently evaluated. After two and a half years, 14 of the 19 material procedure combinations have a 100 percent survival rate. For repairs that have failed, UPM and Percol have the highest failure rates since the last evaluation.

Background

As part of a nationwide study of cost-effective pavement maintenance methods by the Strategic Highway Research Program (SHRP), ADOT is sponsoring a concrete pavement spall repair test section. Spalling, a common distress in jointed concrete pavements, contributes to decreased pavement serviceability, accelerates further pavement distress and, if left unrepaired, may create a safety hazard for highway users. ADOT's site, on I-17 in Phoenix, is one of four sites constructed nationwide in 1991 to evaluate the performance of various rapid-setting repair materials and pavement preparation methods, and to identify cost-effective methods of repairing partial-depth spalls in concrete pavements. Installation of the test site was started on May 29, 1991 and completed in 8 working days. The pavement section, a 9-in thick, 15-ft jointed, non-doweled concrete pavement constructed in 1961, was exhibiting high frequency partial-depth spalling.

Approach

A partial matrix of ten materials and four procedures were incorporated into the experimental design to obtain a statistically significant number of repairs for evaluation. The combinations chosen resulted in 380 patches being installed. The following ten rapid setting repair materials were installed:

- Type III PCC.
- Duracal, a gypsum-based concrete.
- Set-45, a magnesium phosphate concrete.
- Five Star Highway Patch, a modified high alumina concrete.
- MC-64, an epoxy concrete.
- SikaPronto 11, a high molecular weight methacrylate concrete.
- Percol FL, a flexible polyurethane concrete.
- Pyrament 505, a blended hydraulic cement concrete.
- Penetron RM 3003, a flexible epoxy-urethane concrete.
- UPM High Performance Cold Mix, a bituminous cold mix.

Installation of spall repair materials is a multi-step procedure. Suitable spalls are selected, joint and patch boundaries are sawed where required, deteriorated concrete is removed in the specified manner, and then the patching materials are installed in accordance with manufacturer's recommendations. For the spalls being repaired using a rigid material, prior to removing the deteriorated concrete, the existing transverse and longitudinal joints bordering the repair area were sawed using either a double-bladed concrete saw or with two passes of a single-bladed saw. Three techniques of concrete removal were used at the Arizona site. These methods are:

Sawing and chiseling—A diamond blade concrete saw was used to saw the repair
boundaries 1 to 2 days prior to patching. Pneumatic hammers with a maximum weight of 30 lb were used for the initial removal. Pneumatic hammers with a maximum weight of 15 lb and hand tools were used to remove the concrete near the patch boundaries. This procedure is also referred to as the "rigorous" procedure.

Chiseling Only—Initial removal of the deteriorated concrete was completed using pneumatic hammers with a maximum weight of 30 lb. Pneumatic hammers with a maximum weight of 15 lb and hand tools were used for removal of the concrete near the patch boundaries. This procedure is also referred to as the "chip and patch" procedure.

Cold Milling—A carbide-tipped milling machine with a drum diameter of 3 ft and width of 1 ft was used to remove deteriorated concrete. The small amount of sound material at patch corners which could not be removed by the milling machine was removed by light chipping hammers. This procedure is also referred to as the "mill and patch" procedure.

Water blasting with a high-pressure (30,000 psi) device was tried and discontinued after 2 days of equipment failures and excessively slow production rates.

Laboratory testing was done in conjunction with field testing. The lab data has been analyzed in an attempt to find correlations between material properties and field performance. At this point, there have been no significant correlations established between the observed field performance of the repairs and the laboratory-determined properties. Efforts to correlate the lab and field data will continue with each successive field evaluation.

The test installations have been monitored on a periodic basis. These repairs were first evaluated 1 to 3 days after installation to determine the extent of construction-related problems, such as initial shrinkage cracking. Six additional evaluations at 1, 4, 8, 12, 15, and 29 months after installation, have been performed to date. Additional evaluations will continue under an FHWA/LTPP study to provide long-term data on the performance of the repairs.

Findings

Based on the observed performance of the repairs during the latest field evaluation, the following comments can be made:

- Placement of a cementitious cover material over many repairs has resulted in an increase in the number of "failed" repairs. In some instances, the cover material has begun to break away and reveal the experimental repairs remaining in-place. If the cover material continues to degrade, it is possible that several of the repairs noted as failed in November 1993 will be counted as surviving in 1994. Should this occur, all necessary corrections will be made to the analysis effort performed for the 1993 evaluation data.
- Of the 19 different material/procedure combinations, 14 are still exhibiting 100 percent surviving after more than 2 years. Of these repairs which have experienced failures, UPM (chip and patch) and Percol (mill and patch) experienced the most failures between the last two evaluations.

The following observations were made of the individual repair materials during the November 1993 field evaluation:

**Type III PCC:**
- Cracks within the patch area had widened since the previous evaluation.
- Additional staining of the repair areas was noted.
- Minor development of additional spalling in adjacent pavement had occurred.
- One instance of previously debonded area is now missing.

**Duracal:**
- Additional debonding of the repairs from the underlying pavement noted.
- Additional distress noted along perimeter of repairs.
- Staining of the repair surfaces increased from previous evaluation.

**Set 45:**
- Very little additional cracking noted from previous evaluation.
- Some staining of repair surfaces was noted.
- One patch was missing broken piece of material.
- Some additional debonding of the repairs from the underlying pavement was noted.
• Two additional failures noted since previous evaluation.

**Five Star:**
- Minimal increase in repairs exhibiting stains on surface.
- Small amounts of additional debonding from underlying pavement were noted.
- Lack of joint sealant in existing slab joint location noted for several repairs.

**MC-64:**
- Widening of perimeter crack noted for majority of repairs.
- Minimal areas of crazing noted.
- Several instances were noted where adjacent shoulder is higher than patch surface.
- Additional debonding and development of adjacent pavement spalls.

**SikaPronto:**
- Additional areas of repairs debonding from underlying pavement noted.
- Several instances where adjacent shoulder is significantly above the surface of the repair were also noted.
- Minor amounts of additional adjacent pavement spalling.
- Additional widening of perimeter cracks noted.

**Percol FL:**
- Mill and patch repairs had very rough surfaces and experienced widening of the perimeter cracks.
- Some additional spalling of the repair material was noted.
- Minor development of hairline cracks within the repair areas.

• Development of alligator-like cracking within repair area was noted for several repairs.
• Several of surviving patches covered with light-colored cementitious skin patch.
• Six additional failures noted, mostly as a result of skin patches covering remaining repair material.

**Pyrament 505:**
- Several repairs experienced additional crazing and the development of fine, hairline cracks.
- Some additional spalling of the adjacent pavement was also noted.
- Minimal amounts of edge wear noted.

**Penetron RM 3003:**
- Three additional repairs failed since previous evaluation.
- Widening of perimeter cracks noted since previous evaluation.
- Further development of adjacent pavement spalls noted since previous evaluation.

**UPM:**
- Formation of new cracks within patch area noted.
- Minor development of additional edge deterioration noted since previous evaluation.
- Seven additional failures noted.

Overall, the performance of the repairs has been good. Very little additional distress was noted during the most recent evaluation. With the additional failures noted, the updated percent surviving for each repair material-procedure combination is shown in figure 1.

![Figure 1. Summary of percent surviving—October 1992 versus November 1993.](image)
Figure 2. Typical Duracal repair, using rigorous method

Figure 3. Typical MC-64 repair, using mill and patch procedure.

Figure 4. Typical Penetron repair, using rigorous patching method.

For Additional Information Contact:
ATRC / 7755 S. Research Drive, Suite #106 / Tempe, AZ 85284 / (602)831-2620