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16. Abstract

This report details a study which demonstrated the capability of different polymer concretes (mortars) to repair shallow feather-edged spalls in concrete pavement which had been damaged by a chemical fire. The study evaluated materials in the laboratory, selected candidate materials for the repairs, and monitored their performance in the field. Generally good results were reported, except for an isolated deeper area spanning a joint.

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REPAIR OF FIRE-DAMAGED CONCRETE PAVEMENT ON IH-45 NEAR ANGUS, TEXAS

by

David P. Whitney
David W. Fowler

Research Report Number 1948-1F

Research Project 7-1948

Repair of Fire-Damaged Concrete Pavement on I-45 (Evaluation Near Corsicana, Texas)

conducted for the

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH
CONSTRUCTION MATERIALS RESEARCH GROUP
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

November 1994

IMPLEMENTATION STATEMENT

This report summarizes the study, including laboratory and field evaluations of polymer concretes used for repairing shallow surface spalling in portland cement concrete pavement near Angus, Texas. The emphasis in this study was on finding materials which would effect long-lasting repairs of shallow surface spalls, which are more susceptible to early debonding than deep spalls. Although the spalls were caused by fire damage, these materials will work for repairing concrete spalling from any source. Since the process of preparation and installation of these repair materials is very rapid, they are particularly suited to urban traffic and to rural bridge or ramp application where short windows of opportunity for down time of any lanes may be otherwise prohibitive. Since these particular materials, which were so successful, were also developmental in nature it is recommended that the Texas Department of Transportation take the following actions:

1. Develop a standard procedure for evaluating new candidate materials for repairing various damage conditions in concrete.
2. Maintain a list of accepted materials for repairs of concrete exposed to different service conditions.

Prepared in cooperation with the Texas Department of Transportation

DISCLAIMERS

David W. Fowler, P.E. (Texas No. 27859)
Research Supervisor

ACKNOWLEDGEMENTS

The authors wish to thank the Texas Department of Transportation (TxDOT) for their support in the conduct of this study. A special expression of gratitude must be made to the Corsicana Area Office Engineers, Joe Nelson and Darwin Myers, and to the maintenance force under the supervision of Raymond Lewis in Corsicana, Texas, for without their cheerful assistance in surface preparation, equipment, and traffic control at the repair site, this project could not have been done.

The authors are also grateful to Ms. Yinhong Bao, Mr. Donguk Choi, Mr. Eric Ueber, Mr. Paul Walters, Mr. Juan McLanee, Mr. Hanh Nguyen, Ms. Joy Whitney, Dr. Jamal Zalatimo, Dr. Venkatesh Iyer, Mr. Gordon Shepperd, Mr. Ruben Lopez, and Mr. Alan Draper for their numerous contributions of technical and administrative support.

LIST OF REPORTS

Because the scope of this study was limited to repairing the fire-damaged concrete pavement site on IH-45 near Angus, Texas, this report is the only one submitted under this project.

ABSTRACT

This report details a study which demonstrated the capability of different polymer concretes (mortars) to repair shallow feather-edged spalls in concrete pavement which had been damaged by a chemical fire. The study evaluated materials in the laboratory, selected candidate materials for the repairs, and monitored their performance in the field. Generally good results were reported, except for an isolated deeper area spanning a joint.

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SUMMARY

Several rapid-repair materials were evaluated in the laboratory with the four best candidates, all polymer concretes, chosen for repairing light spalling in concrete pavement. Repairs of fire-damaged concrete on IH-45 near Angus, Texas, were completed, tested, and monitored over one year. This reports documents the repairs and results from the testing and monitoring. Conclusions and recommendations based on the findings of this study are offered for consideration.

CHAPTER 1. INTRODUCTION

Repair of damage to portland cement concrete pavements has evolved into a continuous maintenance process for transportation departments everywhere. While conventional hydraulic cement grouts and mortars work well in deep rectangular repairs, they tend to debond or spall in shallow repairs, and they typically require too much time to cure sufficiently before the next rush-hour trafficking. Bituminous materials have long been used to fill shallow spalls, but they are soon pushed out of the potholes under traffic in the heat of the summer sun. For these reasons transportation maintenance forces have searched for new materials and methods which would allow for repairs to be made and returned to traffic between daily rush hour cycles.

On July 14 and 15, 1993, researchers from The University of Texas at Austin's Center for Transportation Research (CTR) Construction Materials Research Group (CMRG) repaired five areas in a 106.4-m (350-foot) section of continuously reinforced jointed concrete pavement on IH-45 near Angus, Texas.

1.1 BACKGROUND

CTR Project 1948 grew out of a request by the Dallas District Office of the Texas Department of Transportation (TxDOT) for assistance in repairing the fire-damaged pavement near the Corsicana Resident Office.

On February 14, 1991, Joe H. Nelson, III, Resident Engineer for Corsicana, and James Huffman, District Engineer for the Dallas District, accompanied CTR's David W. Fowler and Frank McCullough on a condition survey of the damaged sections for the purpose of determining the extent of the damage and consequently the scope of this study. Most of the damage was in the top inch of the 25.4-cm (10-inch) slabs, although the slabs numbered 43 and 44 did have some spalling deeper than 7.6 cm (3 inches). Photographs of the damaged slabs were provided to the researchers by the District for the purpose of estimating quantities of materials needed to make repairs.

1.2 SCOPE OF STUDY

The scope of this study supported two major objectives: (1) repairing the spalling on IH-45 with rapid-setting materials applied through different methods, and (2) developing techniques and specifications which could be used in urban conditions with high traffic volumes to minimize closure times.

TxDOT wanted a skid-resistant material which could permanently restore the pavement damage to grade with the least amount of lane-closure time. Extensive laboratory and field testing had previously been conducted on the materials selected for these repairs, but the researchers had little experience with these materials for use in such shallow spalls with relatively large surface areas. Two major considerations were apparent in the selection of these candidate materials. The first was that the shallowness of the spalls precluded using coarse aggregate of any kind. The second was that at the high temperatures encountered on Texas pavements in mid-July, the very high surface area-to-volume ratio would tend to prematurely evaporate volatiles needed for workability and could accelerate set times to unworkable limits.

1.3 DESCRIPTION OF THE REPAIR SITE

On IH-45 in Navarro County about 3.2 km (2 miles) north of the Freestone County line, a southbound section of continuously reinforced jointed pavement approximately 200.6 m (660 feet) long had been damaged from a highway accident which caused drums of chemicals to fall from the bed of a moving truck. The tumbling drums caused several small impact spalls and chipping, but larger fire-induced spalls occurred when some of the chemicals in the drums caught fire and burned on the pavement. Damaged slabs were identified and labeled consecutively with the numbers 1 through 44 with respect to the initial impact slab. The photographs supplied by the District and repair area schematics prepared by CMRG's Venkatesh Iyer are shown in Figures A-1 through A-17 in the Appendix.

CHAPTER 2. THE REPAIR MATERIALS

Laboratory evaluations have been conducted by CMRG on all these materials for their physical properties and bond strengths. Much of the testing was done by researchers in conjunction with other projects. In addition to the six materials discussed in this report as the materials used in the repair of the shallow spalls on IH-45, several other materials were considered as potential candidates for this study. Some of these other materials included:

1) Pyrament® patching mortar, a rapid-setting, high-strength proprietary prepackaged modified portland cement product. This material achieves high strength very rapidly, but the manufacturer did not recommend that the material be used on shallow repairs.
2) Set 45®, a commercially available magnesium phosphate patching mortar system which cures in less than two hours. Extensive experience with this material indicated that it would bond well only in the deeper spalls, and that even these patches would have a limited lifespan.
3) High molecular weight methacrylate (HMWM) is a proprietary, commercially available system typically used for sealing cracks in concrete. After a close inspection of the damage on the highway, no appreciable cracking was apparent. Although the monomer makes an excellent binder for patching mortar, it is too expensive to be considered for making patching mortar.

2.1 TRANSPO T-230®

T-230® from Transpo Industries, Incorporated of New Rochelle, New York, is a commercially prepackaged two-component methacrylate primer and two-component methacrylate mortar frequently used for patching spalls in concrete and for overlaying industrial floors. It features excellent workability, bond and compressive strengths acceptable for trafficking in two hours, and adjustable set times. The mix was made according to the directions on the Transpo T-230® mortar bag.

This material has an excellent track record in the field and in the CMRG laboratory, but did not work in this field trial because of problems discussed in the next chapter. It is included as a viable candidate because, if an additional field repair trip with fresh material had been made, there would have been every reason to believe it would have performed well at a cost that would have competed well with those of the other candidate materials.

Primer: 3.78 L (1 gallon) T-41S® liquid primer
.0001476 m^3 (5 fl oz) white initiator powder (50% benzoyl peroxide)

Mortar: 1 bag (13.59 kg or 30 lb) gray T-230, mortar powder
1,600 cc liquid binder

2.2 POLYURETHANE-MODIFIED UNSATURATED POLYESTER RESIN SYSTEM

Because unsaturated polyester resins are readily available and relatively inexpensive binders (compared to other organic polymers) for polymer mortars, they have been used for many years to repair and protect damaged concrete. Problems generally associated with their usage included high shrinkage, which stresses mechanical bonds at the interface between the repair material and the substrate. Also, in damp environments the concrete substrate can keep the moisture at the interface alkaline, and this can critically deteriorate the bond with time.

Work in the CMRG laboratory on a polyurethane-modified unsaturated polyester resin system provided a system which compensated to reduce the shrinkage stress problem, and the urethane portion of the network apparently enhanced the interface bond sufficiently to retard if not eliminate the alkaline deterioration of the binder at the substrate interface without the use of a primer. In an effort to prove the viability of this system, it was compared against several commercial systems in numerous laboratory tests for known performance parameters.[1]

The polyurethane-modified unsaturated polyester resin mortar (PUP) is a flowing, almost self-leveling mix with an adjustable fast set time and 2-hour traffic time.

2.3 TEXACO DEVELOPMENTAL EPOXY SYSTEMS FOR POLYMER CONCRETE OVERLAYS AND REPAIRS

These two-component systems were specially designed by Texaco Chemical Company for CMRG to give good bond to concrete, good workability, and fast cure time. The "K" system was formulated for higher ambient temperature applications and was chosen for its low viscosity for ease in mixing, its ability to perform under severe freezing and thawing, its excellent tensile strength, and its abrasion resistance. The "M" system was formulated for colder ambient temperature applications and was chosen for its ability to perform well in freezing and thawing and for its rapid strength development (relative to other epoxy systems) under all but the lowest (4.44° C or 40°F) tested ambient temperatures. It was originally intended that the "K" system be a premixed mortar system and that the more viscous "M" system be used in multiple layer applications.[2]

2.4 POLYCRETE PC-100® EPOXY SYSTEM

Polycrete PC-100® Epoxy Binder for aggregate-filled patching and overlay composites is a commercially available low viscosity, two-component unfilled epoxy binder which has an elongation greater than 30%. It was mixed according to directions on the package and was applied to the spall via the broom and seed method described under section 3.2.3.

2.5 REPAIR MATERIALS ASSIGNED TO SPECIFIC AREAS OF DAMAGE

The final repair materials were chosen for their workability, their rapid cure times, and their durability in repairs to portland cement concrete specimens during the laboratory evaluations. The following is a brief description of each of the materials used in this project. Figure 1 schematically shows the slab locations on IH-45 where each of the repair materials was placed.

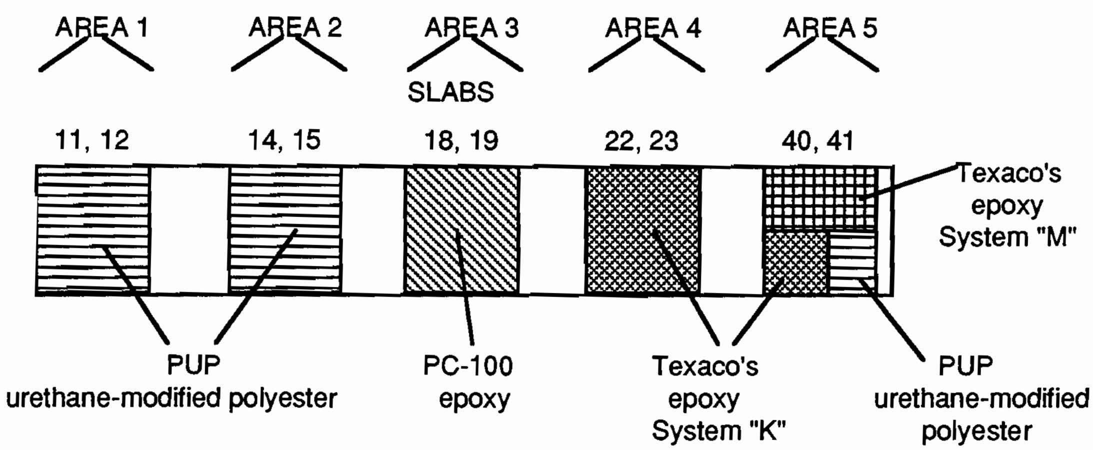


Figure 1. Repair materials were assigned to five large repair areas.

CHAPTER 3. SHALLOW SPALL REPAIR FIELD STUDY

3.1 SITE PREPARATION

Because the spall damage had occurred years earlier, TxDOT had filled the spalls with asphalt concrete. Much of this material had been pushed out of the hole by traffic, leaving large asphalt-lined shallow depressions where the spalls were located and lumps of tracked-out asphalt built up around the trailing edges and adjacent areas of the spalls. This made for a rougher ride than the original untreated spalls, as well as covered up the true extent of the damage.

To prepare the repair areas, TxDOT provided traffic control, converging two lanes of southbound traffic into one lane of traffic immediately adjacent to the lane being prepared, separated only by a row of cones. The TxDOT maintenance crew jack-hammered, shoveled, and sandblasted all of the asphalt concrete from the spalls and cleaned the surface of dust and moisture with clean, dry compressed air. As a result of this preparation, the spalled surfaces exposed only a clean, dry, and sound concrete substrate to which the various repair materials would be bonded. This preparation took a total of approximately five hours for the four-man crew to complete, which included completing one lane, switching traffic from the other lane, and completing the second lane.

Had the spalls not been filled with asphalt, sandblasting and air cleaning may have been all that was necessary for preparation, resulting in a total preparation time of less than one hour. Once the spalls were cleaned out, it became obvious that all the damage was relatively shallow and that none of the pavement would have to be removed full depth over a lane width, as was earlier thought.

3.2 PLACEMENT OF REPAIR MATERIALS

3.2.1 Transpo T-230®

The mixing of the T-230® was done in the mixing bag supplied exactly as specified by the manufacturer, and good results were experienced with this material in the laboratory and in previous field installations. On this day, however, the material was placed in the spall, and after two hours it still had not begun to harden. It is likely that because of seasonal delays, the materials were warehoused for a year, and the reactive benzoyl peroxide initiator incorporated into the powder material had decomposed sufficiently to cause problems. Manufacturer specifications indicated a shelf life of six months, but the material had already been purchased for these field repairs, and researchers neglected to test the material just before the installation.

The uncured T-230® material was scraped out of the spall and replaced with PUP, which cured in sufficient time to turn the lanes back to traffic that evening.

3.2.2 Urethane-Modified Unsaturated Polyester Resin System

Most of the materials were preweighed at the laboratory into packages containing typical one-batch quantities, but all of the PUP mortar ingredients were blended at the jobsite into premixtures as shown below. Mix proportioning was done on a weight basis.

Preblend a dry brown mortar powder in the concrete mixer:

25% (20% of matrix) class "C" fly ash
75% (60% of matrix) dried all-purpose bagged sand

These liquid resin components were mixed together well in a plastic bucket according to the order shown below.

54% (11.3 % of matrix) polyester resin (Alpha Resin Corporation)
13% (2.8% of matrix) styrene monomer (Southwest Solvents and Chemicals)
9% (1.9% of matrix) polyol (UT CMRG's proprietary polyol)
18% (3.8% of matrix) MDI polyisocyanate (Premium Polymer, Inc., Austin, Texas)
5% (1.1 % of matrix) cumene peroxide (based on polyester resin)
0.25-0.5% (0.05-0.11% of matrix) cobalt naphthelate (based on polyester resin)

The liquid resin mixture was put in the concrete mixer and mixed well with the preblended dry brown mortar powder mixture. The creamy smooth mortar which resulted was then poured into the well-cleaned spalls and screeded level with the top of the pavement. To provide better skid resistance, 0.31 cm to 0.95 cm (1/8-inch to 3/8-inch) traprock was sprinkled into the surface of the wet mortar.

3.2.3 Texaco Chemical Company "K" and "M" Epoxy Systems

In both systems, a standard epoxy resin and one of Texaco's proprietary hardener systems were mixed, broomed onto the spalled surface, and liberally sprinkled with 1/8-inch to 3/8-inch crushed basalt. The binder was allowed to set before the excess stone was swept off. This "broom and seed" process was repeated on top of each previous layer until the surface reached grade. Although the lower viscosity "K" epoxy was originally intended to be part of a premixed mortar system, the ambient temperature was sufficiently high so that the working time was too short for this resin system to be blended with the fillers before applying to the substrate. The individual binder system formulas are shown below.

3.2.3.1 Texaco Chemical Company "K" Epoxy System. The contents of two partially filled one-gallon jugs, premeasured and labeled by Texaco chemists as "System K Hardener," were added and blended well into a partially-filled five-gallon can, which was premeasured and labeled by Texaco Chemists as "System K Resin." The resulting 17-L (4.5-gallon) mixture weighed 18.8 kg (41.5 lb). This mixture then was broomed onto the repair surface for the multiple layer application described above and most often referred to as the broom and seed method.

Actual mixture proportions for the Texaco Chemical Company "K" epoxy system are shown for reference.

Resin:Hardener volume ratio is 3.1:1.0
Resin:Hardener weight ratio is 3.3:1.0

3.2.3.2 Texaco Chemical Company "M" Epoxy System. The contents of two partially filled one-gallon jugs, premeasured and labeled by Texaco Chemists as "System M Hardener," were added and blended well into a partially-filled five-gallon can, which was premeasured and labeled by Texaco Chemists as "System M Resin." The resulting 17-L (4.5-gallon) mixture weighed 19.38 kg (42.8 lb). This mixture then was broomed onto the repair surface for the multiple layer application described above and most often referred to as the broom and seed method.

Actual mixture proportions for the Texaco Chemical Company "M" epoxy system are shown for reference.

Resin:Hardener volume ratio is 2.5:1.0
Resin:Hardener weight ratio is 2.8:1.0

3.2.4 Polycrete PC-100® Epoxy System

The contents of one partially filled 18.9-L (5-gallon) can, premeasured and labeled by Polycrete chemists as "PC-100® Hardener," were added and blended well into another partially-filled 18.9-L (5-gallon) can, which was premeasured and labeled by Polycrete chemists as "PC-100® Resin." This mixture then was broomed onto the repair surface for the broom and seed method described above.

Actual mixture proportions for the PC-100® epoxy system are shown for reference.

Resin:Hardener volume ratio is 2.0:1.0

CHAPTER 4. MONITORING AND FIELD TESTS

Project repairs were made on slabs in the two southbound lanes between mile markers 215 and 216 on IH-45. The repairs were monitored for one year and tested for bond strengths at approximately six months and again after one year.

4.1 SIX-MONTH SURVEY

On January 12, 1994, approximately six months had elapsed since the repairs were made, and on that date, after having arranged for traffic control with the Corsicana area office, Jamal Zalatimo and Gordon Shepperd of CMRG conducted a condition survey of the repair site and repaired one of the areas which had begun to ravel at the edges of the pavement joints. The objectives of the survey were to:

1) photographically document the condition of the repairs and
2) repair any distress experienced by the original repairs.

4.1.1 Status Report

As early as late November 1993, TxDOT maintenance forces began reporting some failed portions of the repaired areas. By January 1994, extensive damage to the first repair area, slabs 11 and 12, was apparent at the region where underlying substrate pavement joints intersected. This area was where the Transpo T-230 had failed to polymerize and had to be shoveled out and replaced with the PUP system. Also, the PUP mortar had been allowed to bridge over the joints and apparently cracked and spalled as the substrate joints moved differentially (Figures 2 and 3).

Everything else, including the other PUP repair areas, appeared to be in good condition, having both good non-skid surfaces and well-bonded patches (Figures 4 through 7).

4.1.2 Repairing the Repairs

The distressed area was almost exclusively badly cracked PUP which had debonded and broken into large chunks. This debonded repair material together with any adjacent unsound concrete was cleaned, sandblasted, and then repaired with a user-formulated methyl methacrylate-based (MMA) polymer concrete (Figure 8). This material was used because its formula can be easily adjusted by the user in the field to give desired working and curing times even at cold temperatures, and January temperatures in North Texas can be very unpredictable. This adjustability is more difficult with polyester systems and is not possible with epoxies. The general formula for this binder system is shown below.

Figure 2. Repair area 1, consisting of the repairs to slabs 11 and 12, shows large areas of delaminated and broken chunks of PUP material.

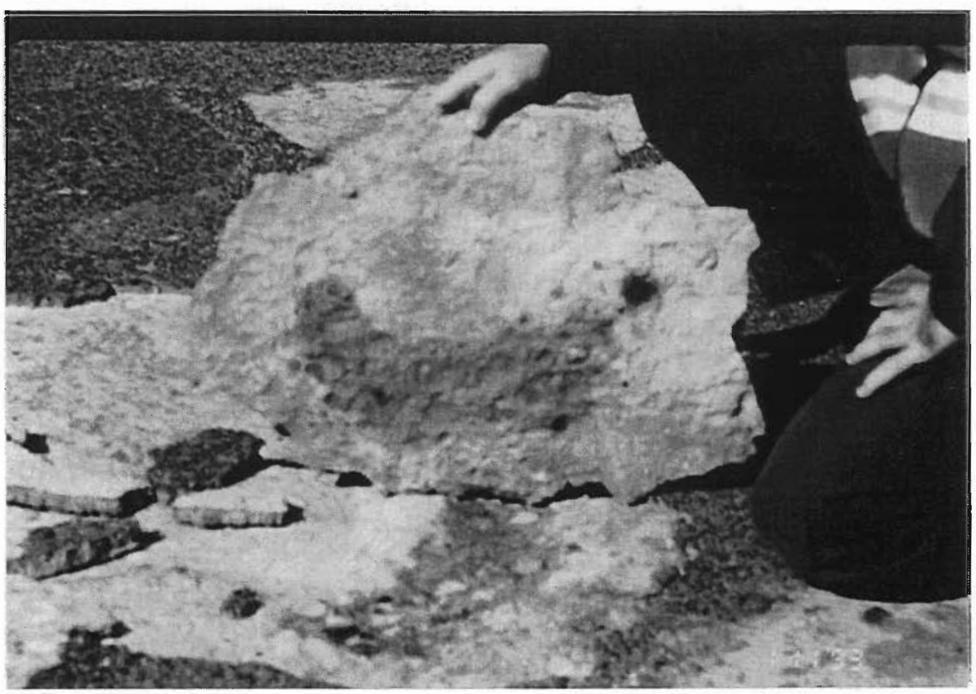


Figure 3. Large piece of debonded PUP mortar shows large dark area where material never bonded to the substrate.

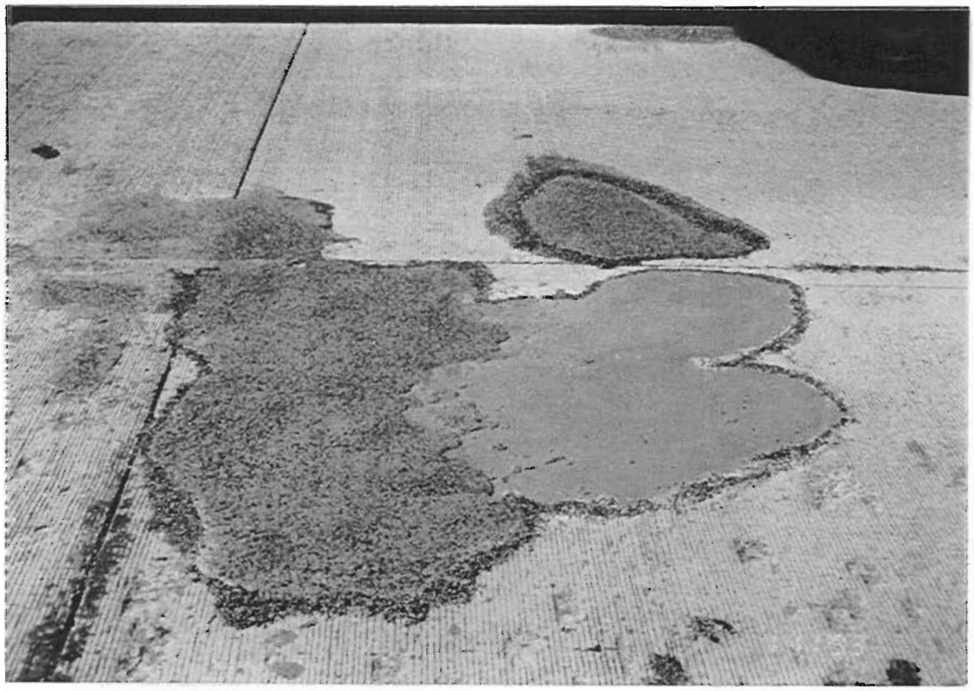


Figure 4. Area 2, consisting of slabs 14 and 15, still appears to be in good condition.

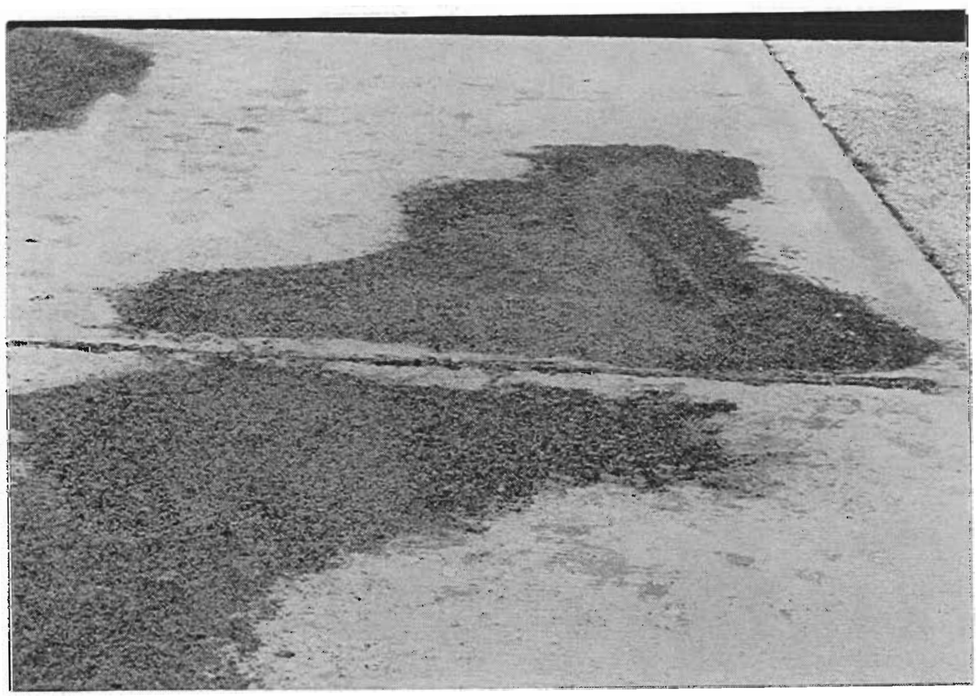


Figure 5. Area 3, consisting of slabs 18 and 19, still appears to be in good condition.

Figure 6. Area 4, consisting of slabs 22 and 23, shows no deterioration.

Figure 7. Area 5, consisting of slabs 41 and 42, shows that repairs were made of different materials. No significant deterioration has occurred.

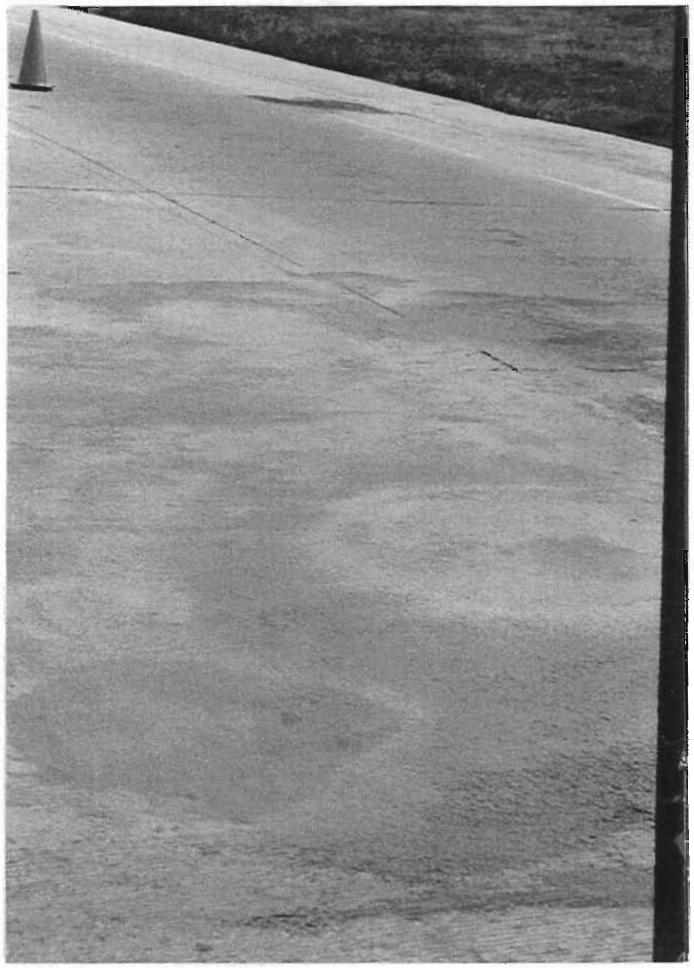


Figure 8. MMA-based polymer mortar repairs to failed PUP repairs in repair area 1 (slabs 11 and 12).

Preblended liquids:
95% methyl methacrylate (MMA)
5% trimethylol propane trimethacyrlate (TMPTMA)
0.5% dimethyl para-toluidine (dmpt)

On the jobsite, once the distressed area is properly prepared (sound concrete, clean, and dry), the following initiator is added and thoroughly mixed into the preblended liquids to begin the curing process.

2.5% benzoyl peroxide 40% dispersion (or 2% BZP 50% paste or powder)

Working and curing times may be adjusted by adding more (for accelerating) or using less dmpt (for retarding).[4]

4.2 ONE-YEAR EVALUATION

On August 29, 1994, a little over one year after the repairs were made, another condition survey was made and tensile bond tests were performed on the five repair areas of a 106.4-m (350-foot) section of IH-45 near Angus, Texas.

4.2.1 Visual Survey

Although some of the tensile strengths were relatively low, all pavement repairs appeared to be in good condition with no appreciable edge breakage or spalling and no significant cracking. Photographs of individual repair sites are shown as Figures 9 through 16.

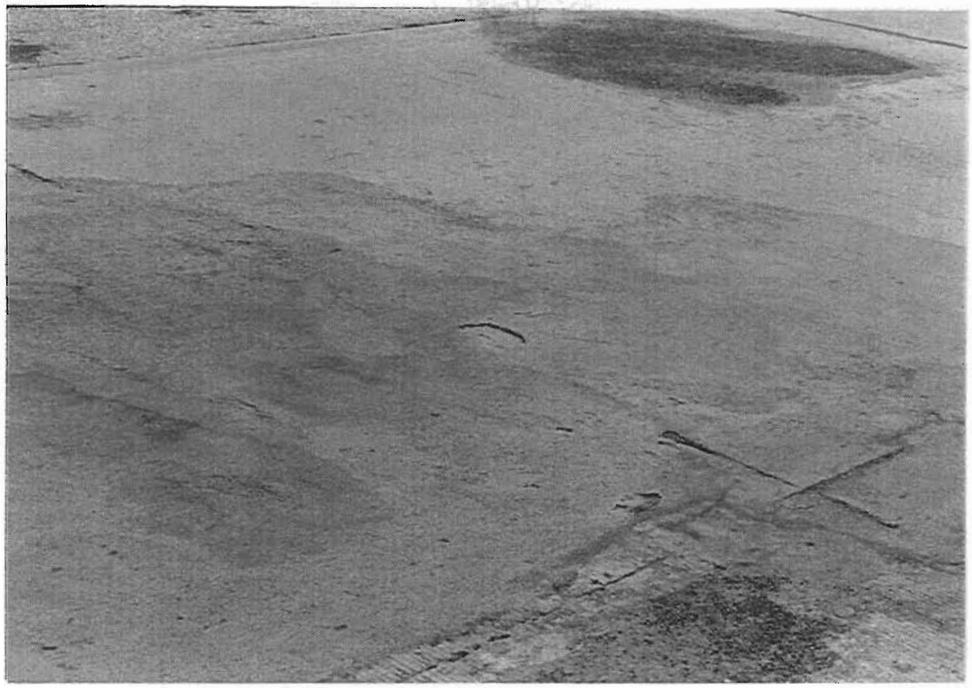


Figure 9. MMA repairs to area 2 are in good condition after six months.

Figure 10. Detail of cardboard inclusions in MMA mortar for stress relief over substrate joints shows little deterioration.

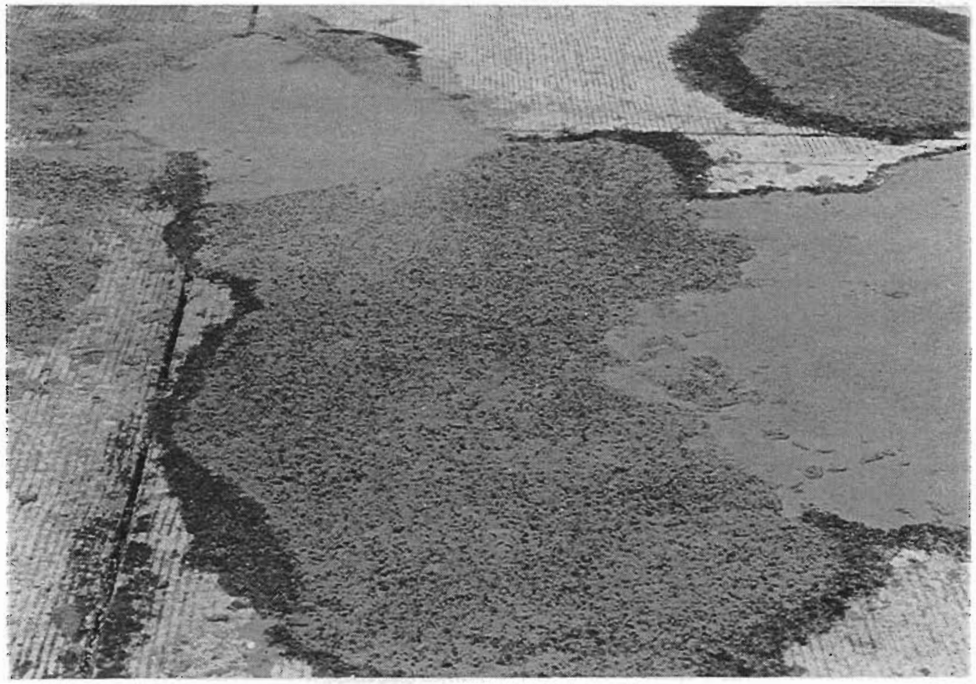


Figure 11. PUP mortar in repair area 2 (slabs 14 and 15) is still in good condition after one year.

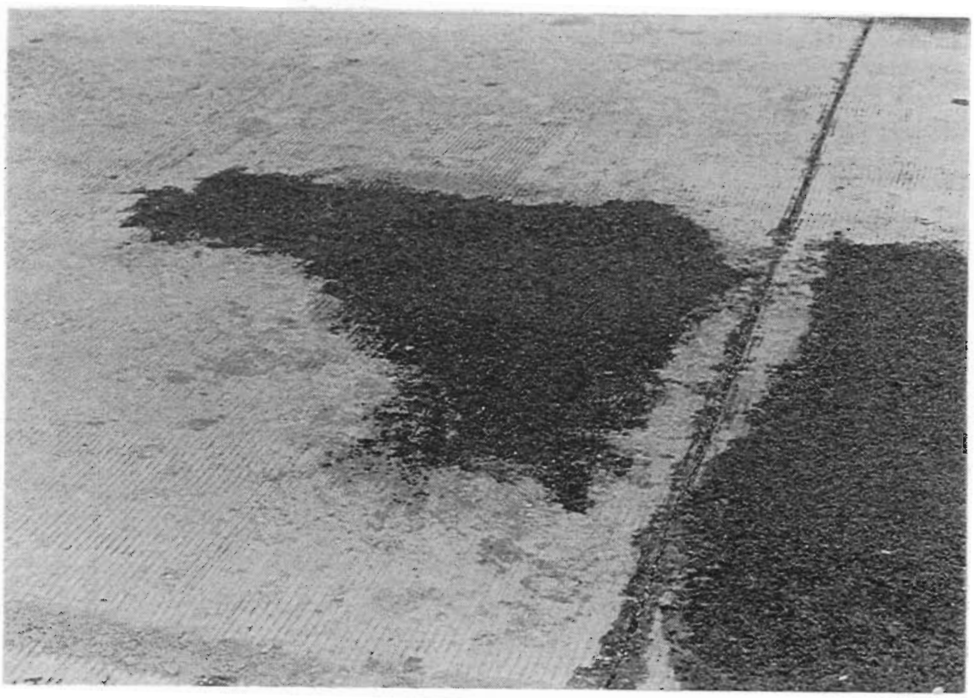


Figure 12. After one year, epoxy system in repair area 3 (slabs 18 and 19) shows no sign of deterioration.

Figure 13. After one year, epoxy system in repair area 4 (slabs 22 and 23) shows no sign of deterioration.

Figure 14. Overall condition of repair area 5 (slabs 41 and 42) is good.

Figure 15. Some reflective cracking from substrate through epoxy mortar has occurred at one year.

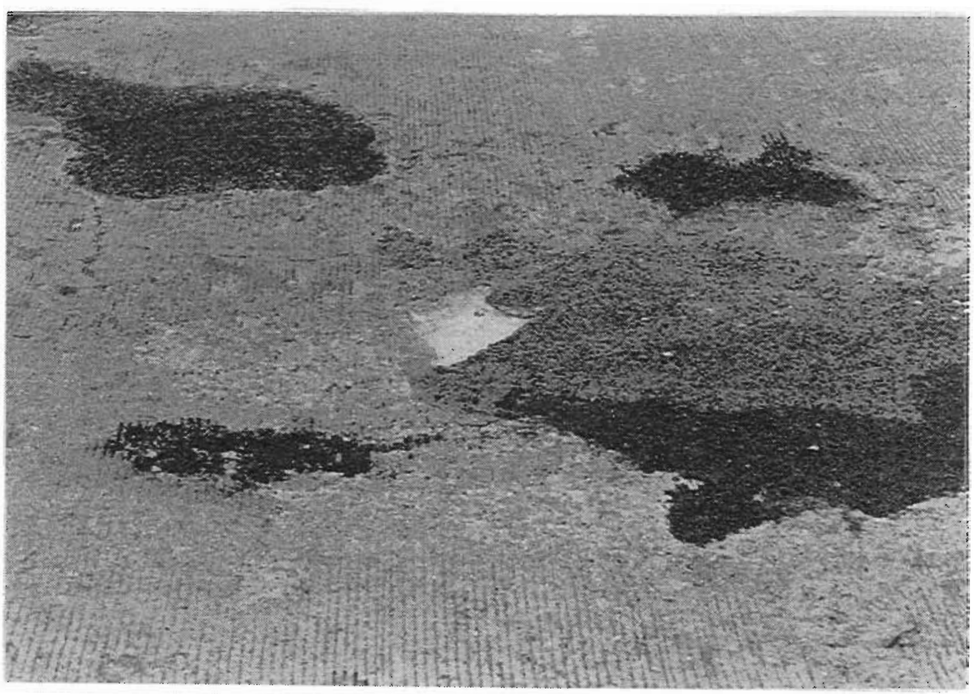
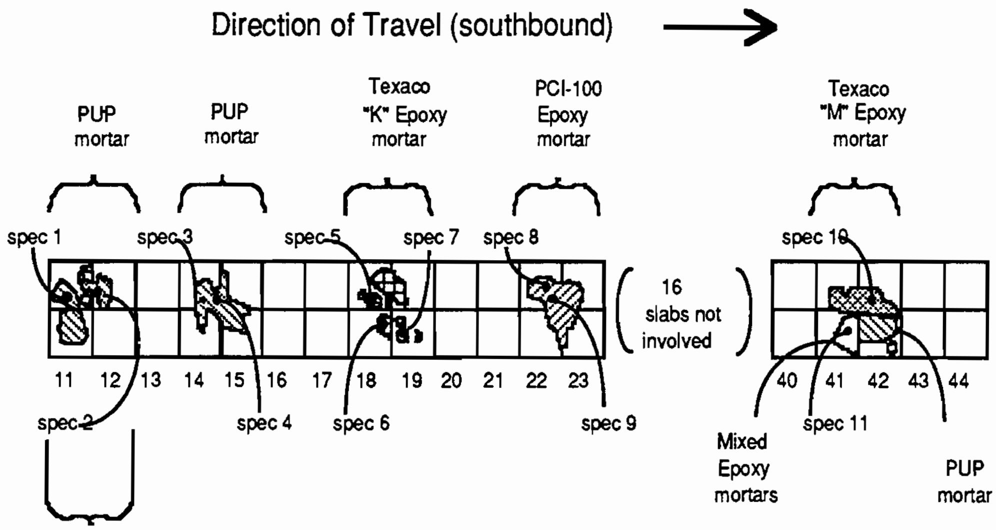


Figure 16. After one year, a few small pieces of concrete covered by PUP mortar have spalled out over intersecting substrate cracks in repair area 5.

4.2.2 Bond Tests

Bond tests were performed according to the ACI 503R method described in the American Concrete Institute's *Manual of Concrete Practice*.[5] An exception to the test used a 4-inch-diameter core instead of the normally specified 2-inch-diameter core. Figure 1 diagrams the approximate locations where bond strengths were evaluated. Results from the tests are detailed in Table 1.



*Slabs no. 11 and no. 12 were repaired first with Transpo's T230 (Acrylic) Patching Mortar, but the mortar did not cure. The spalls were cleaned out and refilled with PUP. After the first six months several major PUP failures occurred and were patched with an MMA - based UT user-formulated system.

Figure 17. Diagram of the relative locations of repairs and tests on IH-45 near Angus, Texas.

Table 1. Tensile Bond Strengths for IH-45 Spall Repairs as Determined by ACI 503R Method

SPECIMEN NO.	MATERIAL	STRESS, PSI	FAILURE TYPE
1	User-Form. MMA	318	SUBSTRATE COHESION
2	User-Form. MMA	159	SUBSTRATE COHESION
3	PUP	199	SUBSTRATE COHESION
4	PUP	239	SUBSTRATE COHESION
5	TEXACO K	80	INTERFACE ADHESION
6	TEXACO K	40	INTERFACE ADHESION
7	TEXACO K	40	INTERFACE ADHESION
8	PC-100	175	INTERFACE ADHESION
9	PC-100	175	INTERFACE ADHESION
10	TEXACO M	64	INTERFACE ADHESION
11	TEXACO M	88	INTERFACE ADHESION

AVERAGE User Form. MMA = 239 PSI
AVERAGE PUP = 219 PSI
AVERAGE TEXACO "K" = 53 PSI
AVERAGE TEXACO "M" = 76 PSI
AVERAGE PCI-100 = 175 PSI

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Performance

The performance of all the materials tested in the shallow spalls on IH-45 has been good with the exception of that of the Transpo T-230, which uncharacteristically did not cure in enough time to leave it in the spall. The PUP system, too, had some early problems, but only in the same repair area where the T-230 was replaced by leftover PUP. The rest of the PUP repairs are in good condition, and after one year have bond strengths significantly higher than those of any of the other repair materials.

Bond strengths are a useful comparison of the continuing performance of the repair materials, but these results are useful primarily in monitoring the decline of bond strength for each material. Specifically, low-elongation (high modulus) binders in polymer concrete often exhibit much higher bond strengths initially but with time may show reductions in bond strength well below the initial and concurrent bond strengths of the high-elongation (very low modulus) binders. At the same time, the high-elongation binder systems may start off with significantly lower bond strengths, but as long as these strengths remain high enough to withstand the typical stresses exerted at the interface, they may outperform the rigid systems with higher initial bond strengths.

The important performance conclusion to date is that all four of the surviving systems, as well as the user-formulated MMA system, are still well-bonded and look good. As long as this trend continues, availability, safety, ease of use, and cost may determine which system receives the highest recommendations.

5.1.2 Availability

5.1.2.1 Polyurethane-Modified Unsaturated Polyester Resin. While all the repair materials tested are available, the PUP system is not commercially available and the formulation of this material is too complicated for the typical maintenance man or contractor's pothole-patching forces to master. There is little likelihood of a formulator gaining enough interest in the PUP system without any appreciable existing market. The main purpose of using PUP on this project was to improve the more common and less expensive unsaturated polyester resin binders for polymer concrete repair systems. In the laboratory the introduction of urethanes into the polyester gave a tough inter-networked binder system with more elongation, lower shrinkage, and excellent durability particularly at the bond interface. In the laboratory, PUP performed so well that it became the system to beat.

5.1.2.2 Texaco's "K" and "M" Epoxy Systems. During the course of this study the Texaco Chemical Company was purchased by Huntsman Chemical Company. The epoxy systems "K" and "M" are not currently on the market, and there are no plans to put them on the market at this time, but they may still be purchased on special order from the Huntsman Corporation, Attention: David Alexander, 7114 N. Lamar, Austin, TX 78752 (512/483-0044).

5.1.2.3 PolyCrete's PC-100 Epoxy System. This system was specifically developed for DOT applications and is currently available from PolyCrete, Inc., 219 Howard St., Waverly, NY 14892 (607/565-8035).

5.1.2.4 MMA Acrylic System. The user-formulated system was formulated for TxDOT by CMRG more than ten years ago on CTR Project 246. It performs very well, but must be purchased as several chemical constituents available commercially through different distributors. As in the PUP system, accuracy in premixing is critical. MMA repair materials are available as commercially prepackaged products from Transpo Industries, Inc., 20 Jones St., New Rochelle, NY (800/321-7870) and Silikal Resin Systems, Reidville Industrial Park, 173 Interstate Lane, Waterbury, CT 06705 (800/477-4545).

5.1.3 Safety Comparisons

Considerations for safety are not significantly different from one of these materials to the next. The epoxies are generally more toxic than the unsaturated polyester or acrylic systems, but all should be handled with the same safety concerns for proper ventilation and avoidance of physical contact through the use of rubber gloves, protective clothing and boots, and splash goggles. The polyester and acrylic systems are typically slightly more flammable, and their curing initiators tend to be more dangerously sensitive to contamination than those of the epoxy systems. All spills and equipment should be cleaned up and/or disposed of in accordance with manufacturers' recommendations and local regulations.

5.1.4 Ease of Use

All the commercial products are formulated and prepackaged for ease of use. They come in smaller single-use packages; normally two or three components are individually presized in convenient field use packages which accommodate typical pothole sizes. Even the user-formulated systems, CMRG's PUP and MMA, can easily be prepackaged in the warehouse or lab for maintenance tasks scheduled in the near future.

5.1.4.1 Epoxy Systems. In the field, major temperature fluctuations can present problems for any single epoxy formulation. For this reason manufacturers typically can make a formulation work within a given temperature range of twenty degrees Fahrenheit.

These cold versus hot temperature formulations allow enough work time yet a short enough cure time to allow the repair to be called rapid. Temperatures below 55°F are normally too low for these epoxy systems. Typically the resin is too viscous to mix well at this temperature, and the cure time is too long. A good cure may not occur until even later, when the substrate temperature rises above 15.5° C (60° F). Also, once the epoxy temperature rises above 29.4° C (85° F), the working time may not be adequate for mixing and placing. For epoxies, a good strategy would be to avoid their use during the heat of the day in the warm months of the year and to avoid their use altogether during the coldest months.

Moist conditions, on the other hand, are are of much less importance to epoxy systems than to the others. Because epoxies form strong chemical bonds with the surface of the substrate and aggregate fillers, high humidity and damp or moist conditions often have no significant effect on the bond or cure of epoxy systems. Care should be made to avoid standing water and free water on aggregates, however.

One other consideration is that for very shallow spalls, less than 1.9 cm (3/4 inch) deep, the epoxies having higher viscosities work well for broom and seed applications which can be feather-edged. The other filled systems work better in larger spalls deeper than 1.27 cm (1/2 inch).

5.1.4.2 MMA-Based Systems. The acrylic systems have an advantage in ease of use during extreme temperatures. Their formulas can easily be accelerated for use in cold temperatures and even retarded for use during hot weather. Most commercially prepackaged MMA systems recommend precoating the substrate surface with a primer before filling the spall with the polymer mortar/concrete.

Free moisture can be a big problem for acrylic systems. Because bond from such a system is dependent upon mechanical attachment to the surface of the substrate and the aggregates in the matrix, free water can prevent good bond by filling pores and coating surface irregularities, forming a bond barrier between the binder and the substrate or aggregate filler.

5.1.4.3 PUP. The PUP system, by virtue of its being formulated for a specific use under specific temperature conditions, is easily adjustable to customize a working matrix for given temperature ranges between 10° C and 37.7° C (50° F and 100° F).

The urethane component in this system makes it extremely sensitive to moisture. In fact, moisture sensitivity is the major reason for short shelf life problems with PUP. Care must be taken to avoid moisture from any source until the matrix is well mixed and placed on the dry substrate. Only then is the effect of moisture unimportant.

5.1.5 Cost Comparisons

Epoxy system costs are generally higher than those of the others, and the MMA acrylic systems tend to be the least expensive. The following Table 2 is presented as a rough guide for the costs of these systems. Actual prices may vary considerably based upon volume purchases, transportation charges, suitability of local aggregates, market demand, and increased production of developmental products like the epoxy systems, "K" and "M."

Table 2. Cost Comparison of Repair Materials Used in This Study

MATERIAL	PRICE PER UNIT WITHOUT AGGREGATES $/LB.	WITH AGGREGATES $/CU.FT	WITH AGGREGATES $/SQ.YD
PUP	18	34	25
Texaco "K"	16-25	38*	22
Texaco "M"	18-30	43*	24
Polycrete P-100	25-30	65*	37
Transpo T-230	35	35	27
MMA User-Form.	9-15	23	17

* Texaco K, Texaco M, and PC-100 epoxy systems were applied via the broom and seed method, resulting in much higher resin content than with preblended mortar systems. For this reason they do not compare favorably in the dollar/cubic foot prices. The other materials shown here are inherently lower in viscosity and are preblended with aggregates and fillers before being applied in a thin layer as a mortar or as concrete, so they are compared on a volume basis.

5.2 RECOMMENDATIONS

Study findings indicated several conditions under which one system type performed better than another. While several systems were considered, the limited scope and funding of this study did not allow a comprehensive evaluation of all types and certainly not of all the proprietary versions of each type. There are now many other excellent repair systems which warrant consideration for shallow spall repairs, and many manufacturers offer systems tailored for specific repair conditions. Therefore, the materials recommendations apply only to the materials described in this report.

For shallow spalls less than 1.27 cm (1/2 inch) deep, the epoxies were easier to apply and have demonstrated excellent durability over the last one-and-one-half years. Spalls deeper than 1.27 cm (1/2 inch) were more economically and more easily filled with the premixed non-epoxy polymer mortars, but this can also be accomplished with many applications of broom and seed epoxy methods or by preblending a mix of sand

and coarse aggregate into the mixed epoxy resin system. Epoxy system manufacturers should be consulted as to recommended levels of sand and aggregates. The deepest spalls (over 2.54 cm or 1 inch) were best filled with polymer concretes consisting of the polymer mortars extended with a 50-90% addition 1.27 cm (1/2 in.) coarse aggregates.

Moist conditions require the less moisture sensitive epoxies, and ambient temperatures outside the 15.5° C to 32.2° C (60-90° F) range normally require adjustable-set non-epoxy systems. Whenever adverse conditions can be anticipated, calls to the manufacturer for recommendations prevent system incompatibilities with the repair application. The following comparison (Table 3) is presented for ease of system selection under various conditions.

Table 3. Polymer System Guidelines for Shallow Spall Repairs

Conditions	Texaco "K"	Texaco "M"	PCI-100	User Formulated MMA	Transpo T230
< 1/2" deep, dry	yes, broom & seed	yes, broom & seed	yes, broom & seed	not recommended	discuss with manufacturer
>1/2" deep, dry	preblend polymer concrete	preblend polymer concrete	discuss with manufacturer	preblend polymer concrete	preblend polymer concrete
>1" deep, dry	preblend polymer concrete	preblend polymer concrete	discuss with manufacturer	preblend polymer concrete	preblend polymer concrete
foggy, misty	yes	yes	yes	not recommended	discuss with manufacturer
cooler than 60° F	not recommended	not recommended	not recommended	preblend polymer concrete	discuss with manufacturer
hotter than 90° F	not recommended	not recommended	not recommended	preblend polymer concrete	discuss with manufacturer

1 in.=2.54 cm
°F=(°F-32)/1.8

With burgeoning repair and rehabilitation concerns, it is recommended that the department follow up with the development of a screening methodology which could enable district or the division labs to rapidly determine the acceptability of newly available repair materials. This encourages competition from suppliers, resulting in more effective products and methods at reduced costs.

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2. Zalatimo, J. H., and Fowler, D. W. "Investigation of the Mechanical and Durability Properties of Texaco Epoxy Polymer Concrete Systems Part III." Report for Texaco Chemical Company, The University of Texas at Austin. December 1992.

3. Whitney, D. P., Zalatimo, J. H., Boatner, C. R., and Fowler, D. W. "Fort Worth Bridge Protection: Monomer Sealant and PC Overlays." Technical Memorandum, The University of Texas at Austin. January 1991.

4. Fowler, D. W., Meyer, A. H., and Paul, D. R. "Implementation Manual for Polymer Concrete Repair." Research Report 246-4F, Project 3-18-79-246, Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin. December 1983.

5. ACI 503R-30. "Use of Epoxy Compounds with Concrete, Appendix A-1, Field Test for Surface Soundness and Adhesion." ACI Committee Report, *ACI Manual of Concrete Practice Part 5*, American Concrete Institute, Detroit, Michigan. 1993.

APPENDIX

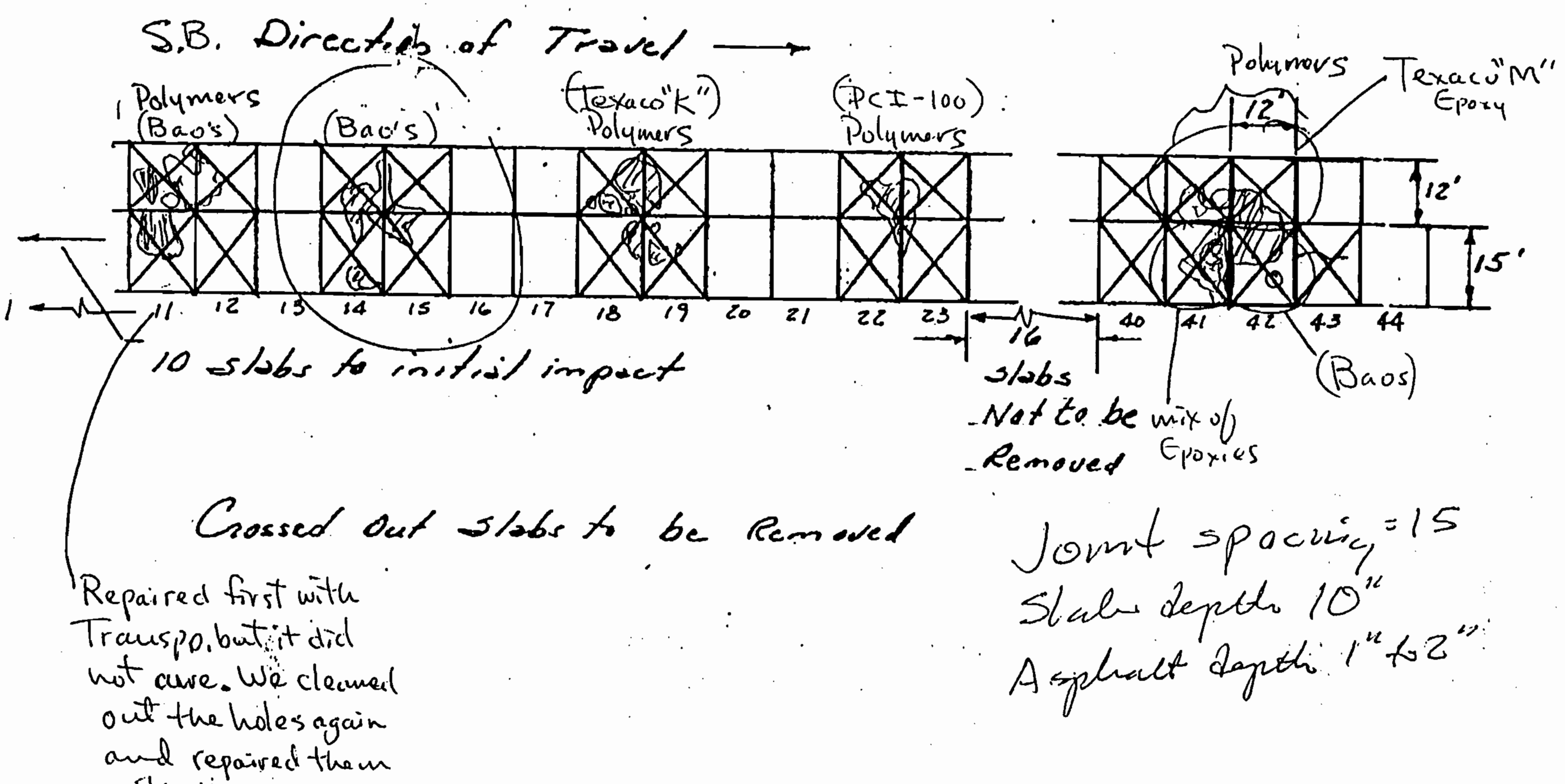

Figure A-1. Field sketch showing relative positions and sizes of spall damage. Actual repair material placements are also indicated.

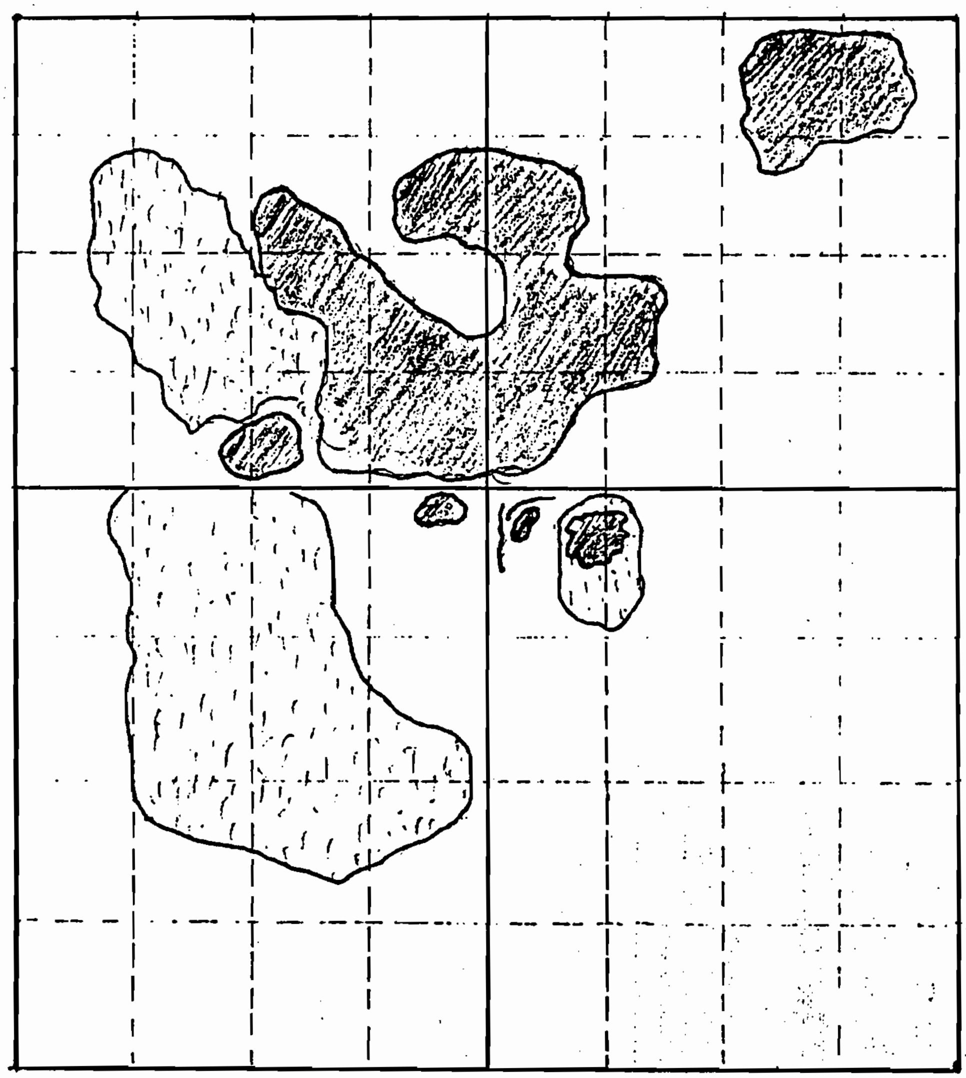

Figure A-2. Schematic of damage to slabs 11 and 12. The repair area for slab 11 is 35.5 sq ft, requiring 8.9 cu ft of material. The repair area for slab 12 is 41.5 sq ft, requiring 10.4 cu ft of material.

Figure A-3. Slab 11 shows light surface spalling in the foreground and asphalt filling the deeper spalls in the background.

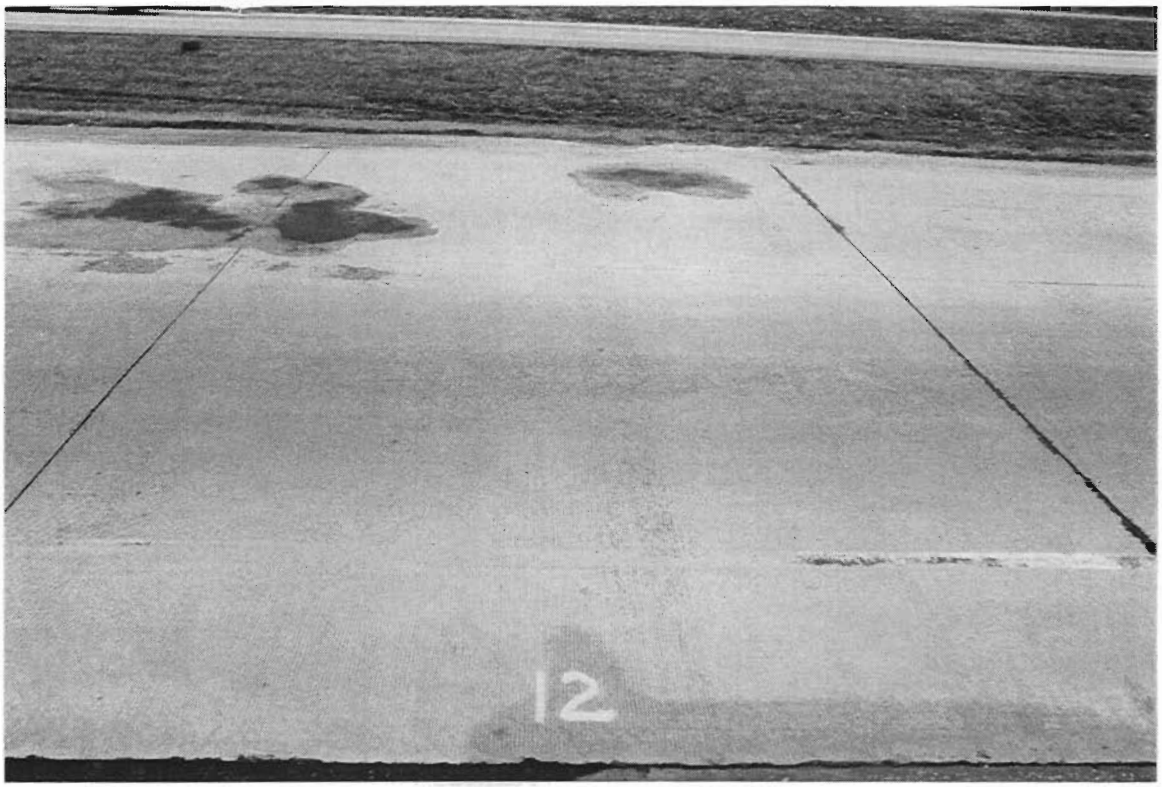

Figure A-4. Slab 12 shows mostly deeper spalling on the interior lanes.

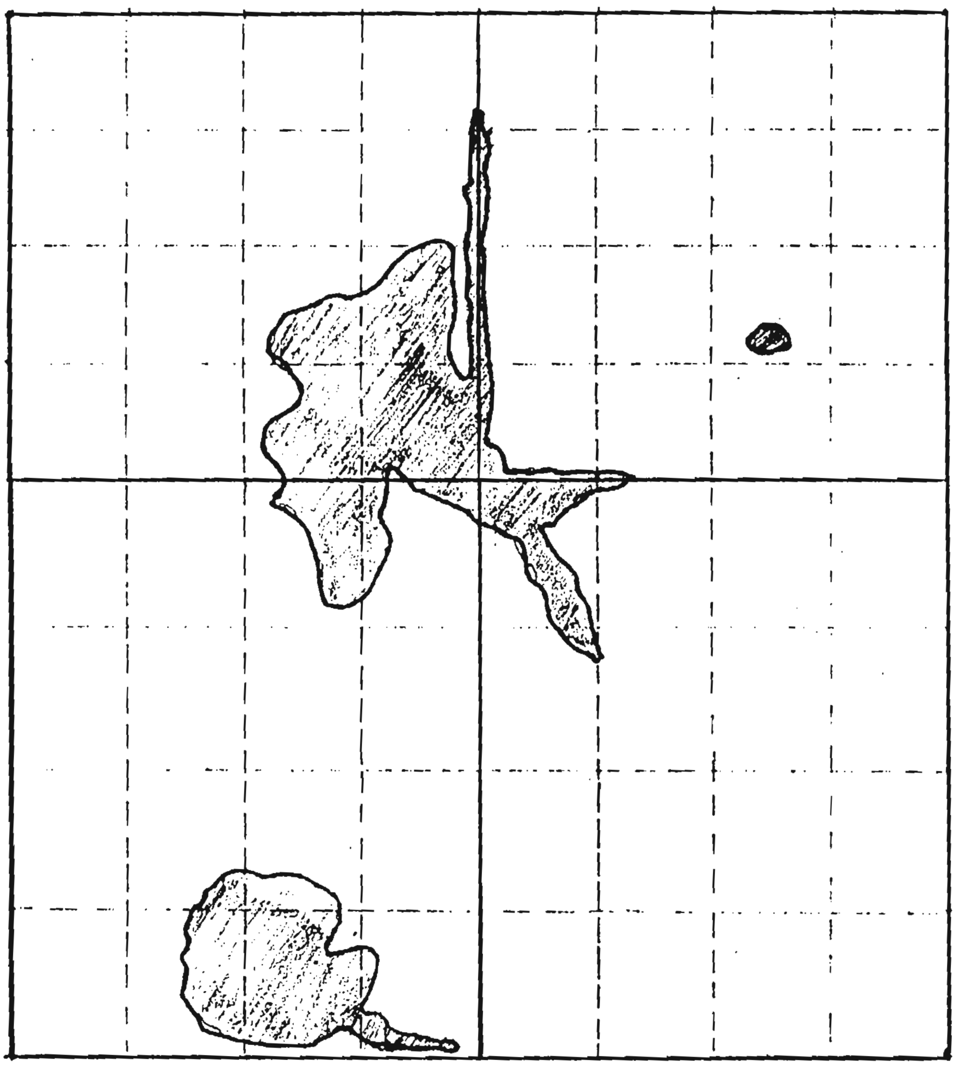

Figure A-5. Schematic of damage to slabs 14 and 15. The repair area for slab 14 is 39.8 sq ft, requiring 9.9 cu ft of material. Slab 15's repair area is 11.05 sq ft, requiring 2.9 cu ft of material.

Figure A-6. Slab 14 shows asphalt-filled spalls in both outside and inside lanes.

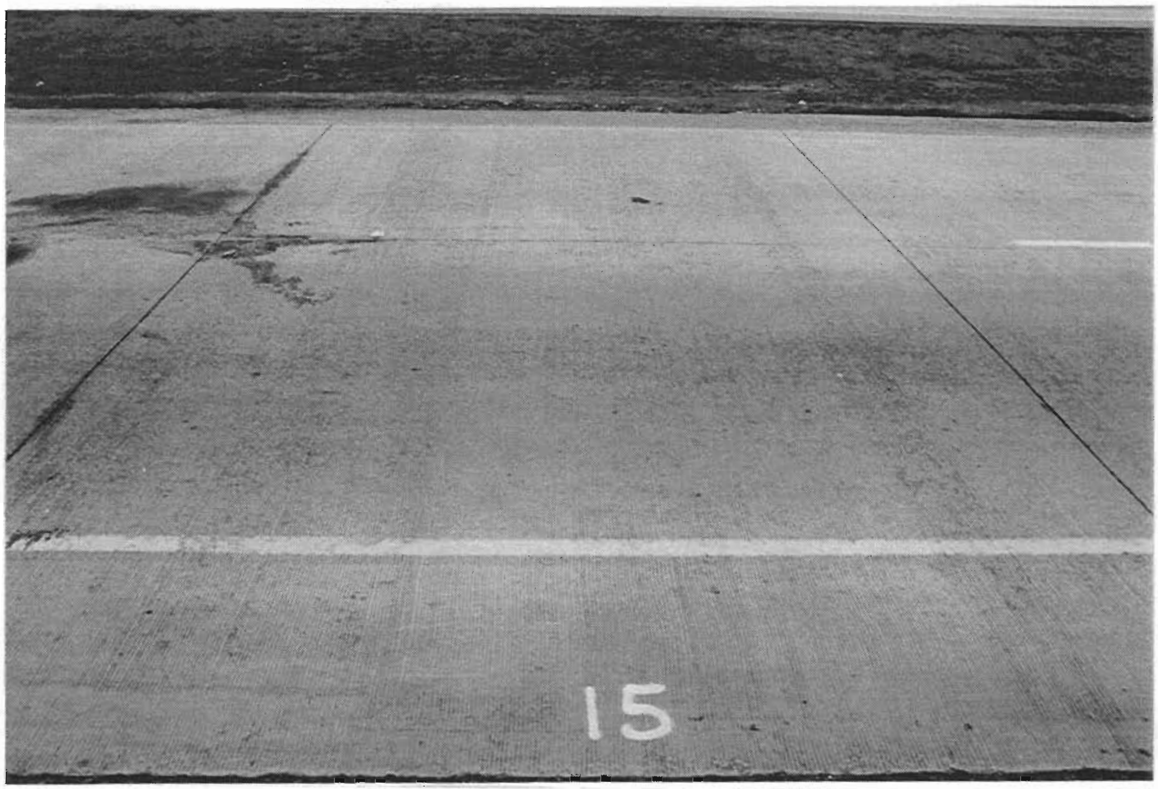

Figure A-7. Slab 15 has incurred damage mostly adjacent to the longitudinal and transverse joints where spilled chemicals collected and then burned.

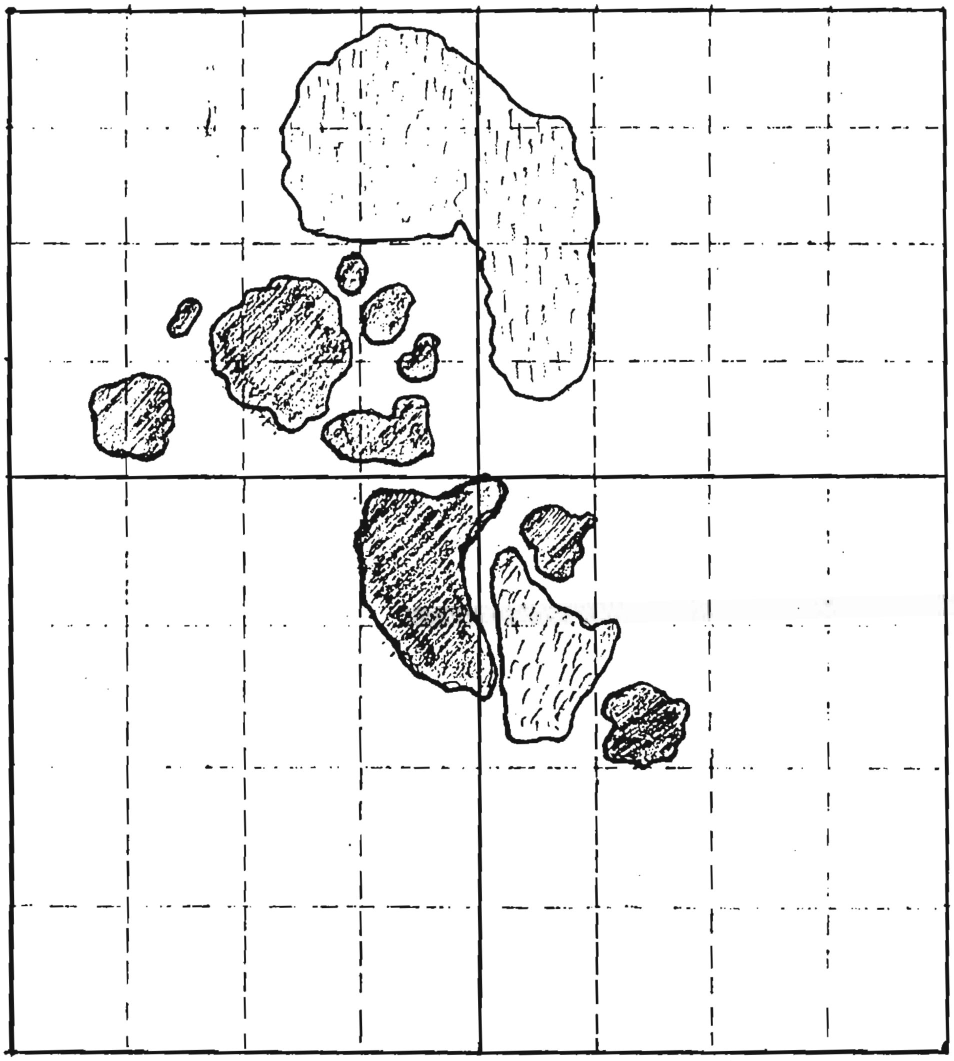

Figure A-8. Schematic of damage to slabs 18 and 19. Slab 18 repair area is 38.2 sq ft, requiring 9.6 cu ft of material. Slab 19 repair area is 6 sq ft, requiring 1.5 cu ft of material.

Figure A-9. Slab 18 shows asphalt patches indicative of deeper spalling.

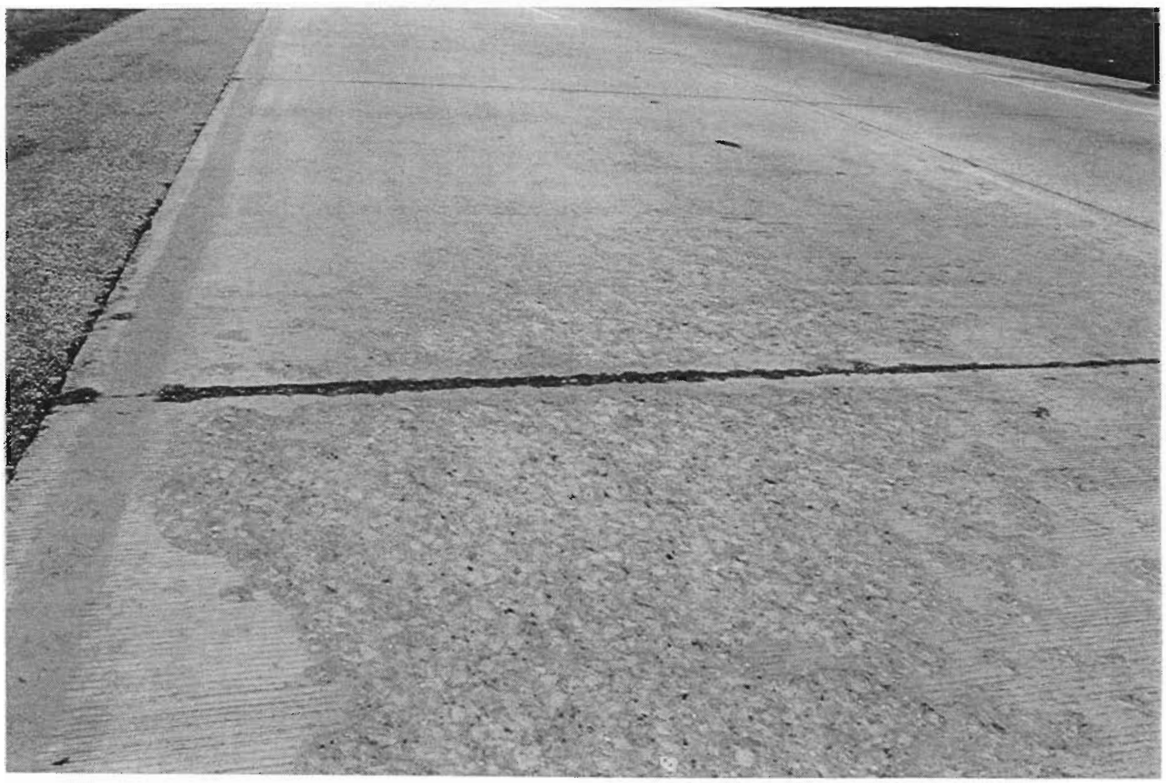

Figure A-10. An area of light spalling is also apparent on the inside lanes of slab 18.

Figure A-11. Slab 19, like slab 18, has deeper spalls in the outside lanes and an area of light spalling on the inside lanes.

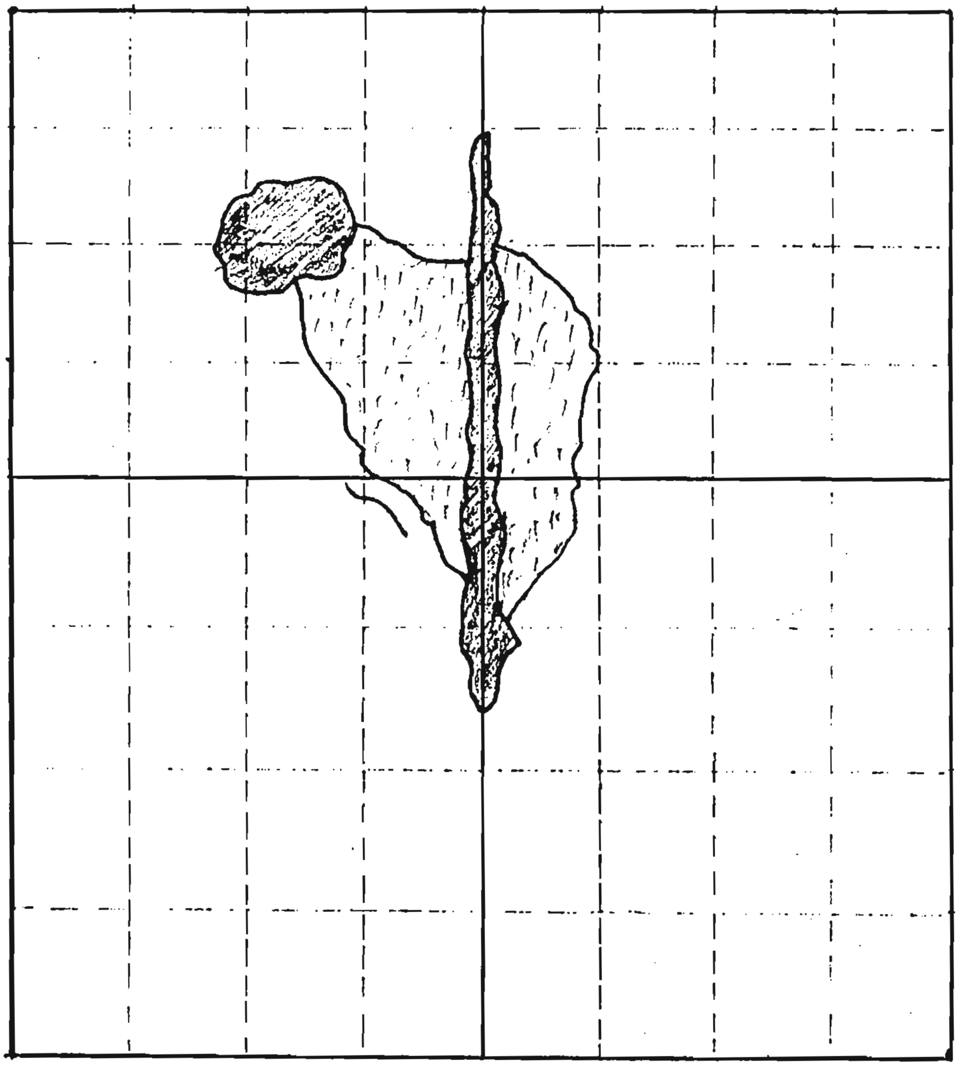

Figure A-12. Schematic of damage to slabs 22 and 23. Slab 22 repair area is 15 sq ft, requiring 3.75 cu ft of material. Slab 23 repair area is 8.2 sq ft, requiring 2.1 cu ft of material.

Figure A-13. Slab 22 shows one deeper spall in the middle of the inside lanes and another along the transverse joint with an area of light spalling between the two.

Figure A-14. Slab 23 has a small area of light spalling adjacent to the deeper spalling at the transverse joint.

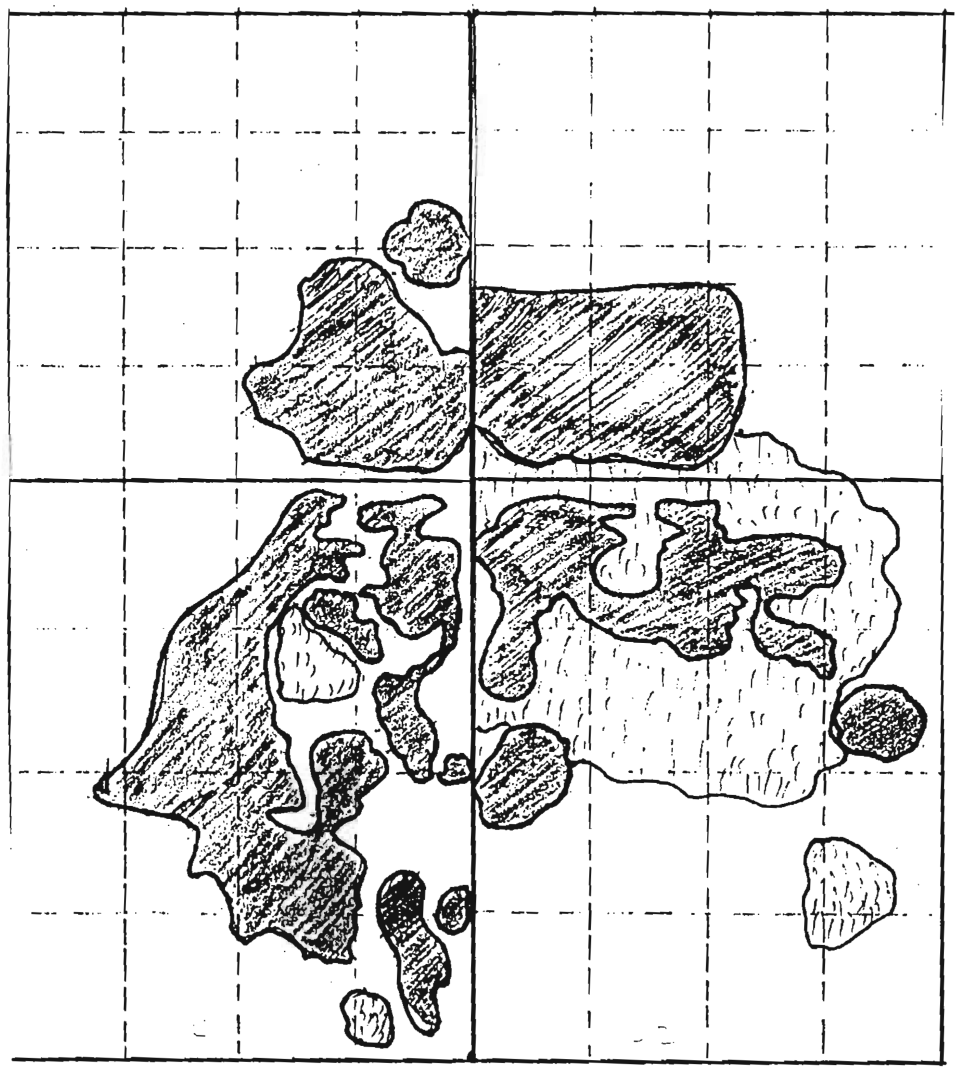

Figure A-15. Schematic of damage to slabs 41 and 42. Slab 41 repair area is over 77 sq ft, requiring more than 19 cu ft of material. Slab 42 repair area is almost 64 sq ft, requiring 16 cu ft of material.

Figure A-16. Slab 41 shows several large areas of deeper spalling.

Figure A-17. Slab 42 shows a few areas of deeper spalling surrounded by a large area of light surface spalls.