TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWATX-79/02+114-8		

4. Title and Subtitle	5. Report Date
POLYMER CONCRETE REPAIR OF BRIDGE DECKS	March 1979
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
David W. Fowler and Donald R. Paul	Research Report 114-8
9. Performing Organization Name and Address	10. Work Unit No.
Center for Transportation Research The University of Texas at Austin Austin, Texas 78712	11. Contract or Grant No. Research Study 3-9-71-114
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	Interim
	14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.
Research Study Title: "Polymer-Impregnated Concrete for Highway Application"

16. Abstract

Techniques for polymer concrete (PC) repair of concrete have been developed. PC has proven to be a strong, durable material that bonds well to sound concrete.

The chemicals include monomers, promoters and initiators. The materials are volatile and flammable, but construction experience has shown that these materials can be safely used on large projects. Well graded, dry, clean aggregate is required as a filler.

The preparation of the repair area is similar to the preparation required for other materials. The concrete surface must be sound, dry and clean to insure a good bond. Cracks and holes in concrete and formwork must be sealed to prevent monomer leakage. Monomer may be poured over aggregate which has been placed dry in the hole, or the monomer and aggregate may be premixed before placing. The material should be consolidated and finished by screeding and troweling.

The surface should be kept covered until polymerization has occurred which requires an hour or less.

Examples of thin, shallow, and full-depth PC repairs are given. The cost of chemicals averages about $260 per cu. yd ($340 per cu. m).

17. Key Words	18. Distribution Statement
	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	45	

Form DOT F 1700.7 (8-69)

POLYMER CONCRETE REPAIR OF BRIDGE DECKS

by

David W. Fowler and Donald R. Paul

Research Report Number 114-8

Polymer-Impregnated Concrete for Highway Application
Research Project 3-9-71-114

conducted for

State Department of Highways and Public Transportation

in cooperation with the

U.S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR HIGHWAY RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

March 1979

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

The study supervisors sincerely appreciate the very valuable assistance and suggestions of many people in the Department of Highways and Public Transportation. Particularly, John Nixon, T.R. Kennedy, Jon Underwood, Ralph Banks, Donald O'Connor, and Andy Seely have been very helpful. John Nichols of the Federal Highway Administration has been a very interested and cooperative representative.

The study would not have been possible without the very valuable cooperation of many of the districts. The field repairs have been extremely important to the success of this research. District personnel were very generous with their time and cooperation.

And last, but not least, the graduate research assistants who did much of the work are greatly appreciated -- M.J. Jaber, A.M. Knysh, R. Webster, P. Yimprasert, P. Phinyawat, E. Limsuwan, J. McIntyre, M. Haddad, and M. Hsu. Nancy Zett's efforts for typing the report are sincerely appreciated.

David W. Fowler
Donald R. Paul

ABSTRACT

Techniques for polymer concrete (PC) repair of concrete have been developed. PC has proven to be a strong, durable material that bonds well to sound concrete.

The chemicals include monomers, promoters and initiators. The materials are volatile and flammable, but construction experience has shown that these materials can be safely used on large projects. Well graded, dry, clean aggregate is required as a filler.

The preparation of the repair area is similar to the preparation required for other materials. The concrete surface must be sound, dry and clean to insure a good bond. Cracks and holes in concrete and formwork must be sealed to prevent monomer leakage. Monomer may be poured over aggregate which has been placed dry in the hole, or the monomer and aggregate may be premixed before placing. The material should be consolidated and finished by screeding and troweling.

The surface should be kept covered until polymerization has occurred which requires an hour or less.

Examples of thin, shallow, and full-depth PC repairs are given. The cost of chemicals averages about $260 per cu. yd ($340 per cu. m).

SUMMARY

The development of polymer concrete (PC) repair materials and techniques has been successfully accomplished. The chemicals include monomers, initiators and promoters. Aggregate must be well graded, dry and clean. The area to be repaired must be prepared by removing all unsound concrete, cleaning and drying the concrete surface, and removing corrosion scale from reinforcing. All cracks and holes must be sealed. The placement of the PC may be accomplished in one of two methods: (1) the aggregate is placed dry into the hole and the monomer is poured over the aggregate or (2) the monomer and aggregate are premixed and placed into the hole. The surface is screeded and troweled. Curing occurs in one hour or less. The cost of the chemicals is about $260 per cu. yd ($340 per cu. m). Repairs have proven to be durable and strong.

IMPLEMENTATION STATEMENT

Improved repair techniques and materials for concrete in highway construction are needed. Polymer concrete (PC) has proven to be a strong, durable repair material. Simple repair procedures have been developed that result in sound repairs. Many PC repairs have been made throughout the state as part of this study. Many districts have started making their own repairs.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

The deterioration of concrete bridge decks is an increasing problem for all state highway departments. It has been estimated that approximately 105,000 bridges in the U.S. are in need of repair (1). One of the most common problems is delamination of the concrete, usually caused by corrosion of the reinforcing steel. In some bridges, only a relatively small area of the bridge surface is affected; in others, a large percentage of the surface is delaminated. The concrete has to be removed only down to the vicinity of the top reinforcing steel in some structures; in others, the concrete must be removed full depth.

Ideally, the repair should be made quickly, be ready to be opened to traffic in a few hours, and be permanent. The cost of the materials is usually of secondary importance since repairs are generally labor intensive and require relatively small amounts of materials.

Polymer concrete, a mixture of aggregate and a monomer which is subsequently polymerized to form a strong, durable material, has been used in several parts of the U.S. for repair of bridge decks with excellent results (2-8). The Center for Highway Research at The University of Texas began research on the use of polymer concrete for repair of bridge decks several years ago, and a large number of repairs have been made throughout the State. This report summarizes the recommended repair procedures based on research and field tests.

CHAPTER 2. MATERIALS

2.1 Definitions

Monomers are low viscosity organic materials from which polymers are made.

Polymers are hard, solid materials formed by chains or three-dimensional networks of monomers bonded together.

Polymerization is the chemical process by which a monomer is converted to a polymer. Several methods of achieving polymerization are possible, but, in polymer concrete, polymerization is achieved by the addition of initiators and accelerators.

Initiators, also referred to as catalysts, are chemical agents added to begin the polymerization.

Accelerators, also known as promoters, are chemicals used to accelerate the polymerization process.

Cross-linking agents are monomers that create three-dimensional polymer networks instead of simply long chains.

Inhibitors are chemicals added to monomers to prevent premature polymerization during shipping and storage.

2.2 Monomer Formulations

Methyl methacrylate (MMA) is the primary monomer selected for use in the polymer concrete developed in these studies. MMA has a low viscosity (0.85 cps), less than water (1.0 cps), and after polymerization has good strength and durability properties. It has been used for many years to produce plastics with the trade names Plexiglas and Lucite. MMA is a relatively inexpensive monomer ($0.51 per pound in 1979) and is readily available from manufacturers.

Butyl acrylate (BA) is a monomer added to MMA to provide more ductility. Butyl acrylate also has a low viscosity (0.80 cps) and sells for about the same price as MMA. The primary disadvantage of BA is its sharp, pungent odor.

The cross-linking agent used in this research has been trimethylolpropane trimethacrylate (TMPTMA). TMPTMA is used in some repair formulations to increase the curing rate and to eliminate the surface blisters that sometimes develop as the polymer concrete is curing. The 1979 cost is $2.50 per pound.

Properties of monomers used in this research are shown in Table 2.1.

The initiator used most frequently is lauroyl peroxide (LP). It is one of the safest solid organic peroxides. It comes in flake form and requires several minutes of mixing to be completely dissolved in the monomer, especially at low temperatures, when a higher percentage of LP must be used. The cost per pound is $2.30. Another initiator that has been used extensively by other researchers and to a limited extent in this research is benzoyl peroxide (BzP). It comes in several forms. The dry, granular solid form should be avoided due to the dangers associated with handling and storage. The paste and dispersion forms are safe to use and can be easily dissolved in the monomer. The 1979 price of a 40 percent concentration in dispersion form is $1.53 per pound.

The accelerator is N, N-dimethyl-p-toluidine (DMT), a liquid which can be readily mixed in the monomer. It is used in relatively small concentrations, and the 1979 price is about $5.00 per pound for distilled and about $4.00 per pound for undistilled, which is quite suitable for making polymer concrete.

The proportions of the various monomer systems are shown in Table 2.2. Formulation 1a has been used more than any other in this research, and it has given very good results. Formulation 2 has been used with varying degrees of success. The levels of DMT and BzP are functions of ambient and monomer temperatures, as shown in Fig. 2.1.

2.3 Aggregate

The aggregate should be sound and free of dirt, asphalt, and other organic materials. The aggregate should be as dry as possible since the monomer is not water soluble and moisture on the aggregate interferes with the bond. Figure 2.2 indicates the effect of the moisture content of the aggregate on the compressive strength of PC. It is recommended that the moisture content be no higher than one percent.

Table 2.1. Monomer Properties.

Monomer	Viscosity, cps	Specific Gravity	Boiling Point, °F (°C)	Cost, $/lb
Methyl methacrylate (MMA)	0.85	0.94	214 (101)	0.51
Butyl acrylate (BA)	0.80	0.90	298 (148)	2.50
Trimethylolpropane Trimethacrylate (TMPTMA)	50.0	1.06	297 (147)	0.51

Table 2.2. Monomer Formulations for Polymer Concrete.

Formulation No.	Temperature Range, °F (°C)	Monomers, Percent by Wt.			Accelerator, Percent by Wt. of Monomer	Initiators, Percent by Wt. of Monomer	
		MMA	BA	TMPTMA	DMT	LP	BzP
1a	70 to 100 (21 to 38)	90	10		2	4	
1b	40 to 70 (4 to 38)	90	10		3	6	
2	30 to 100 (-1 to 38)	85	10	5	see Fig 2.1	see Fig 2.1	

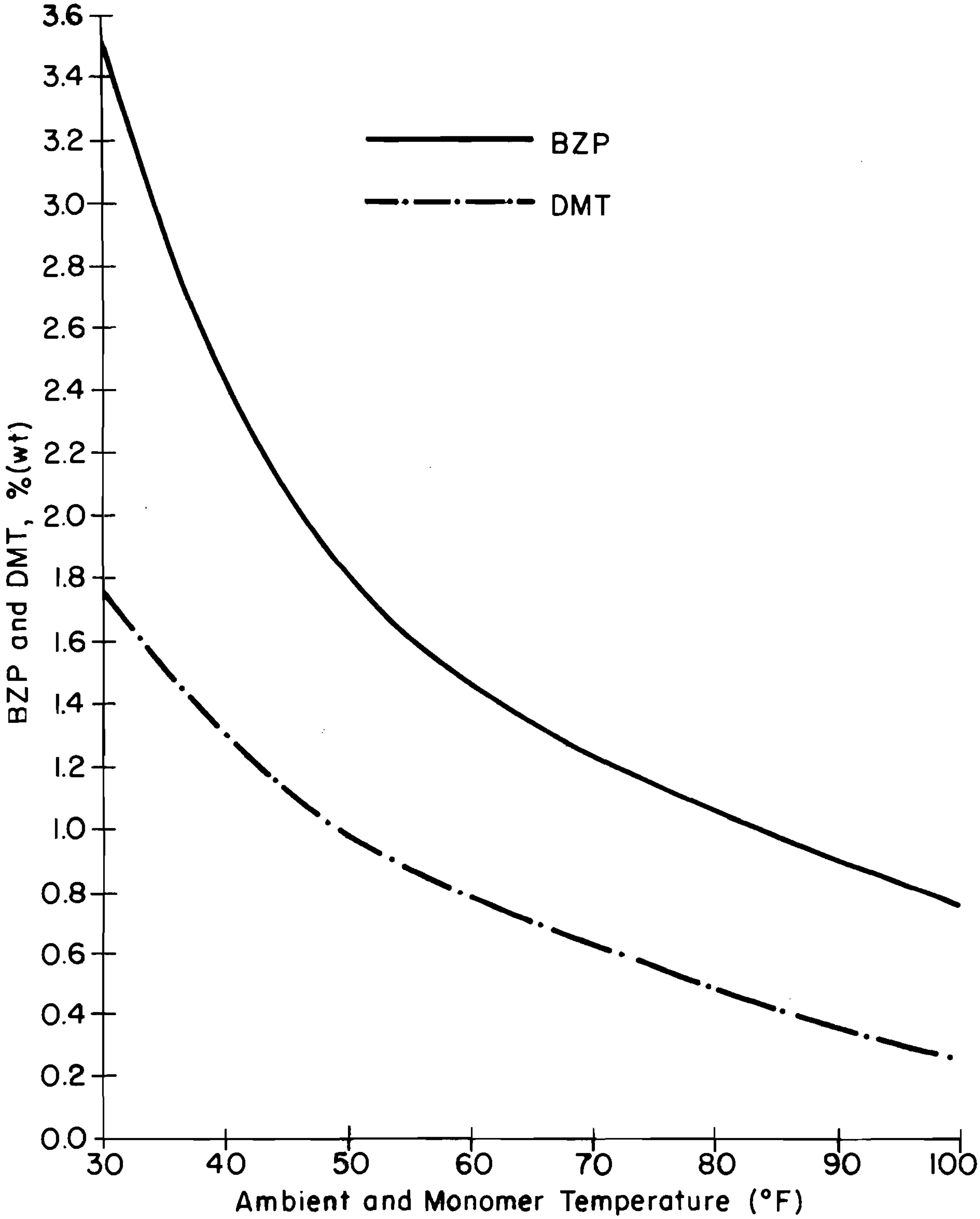

Fig. 2.1. Tentative Recommended Percentages of BzP and DMPT (8).

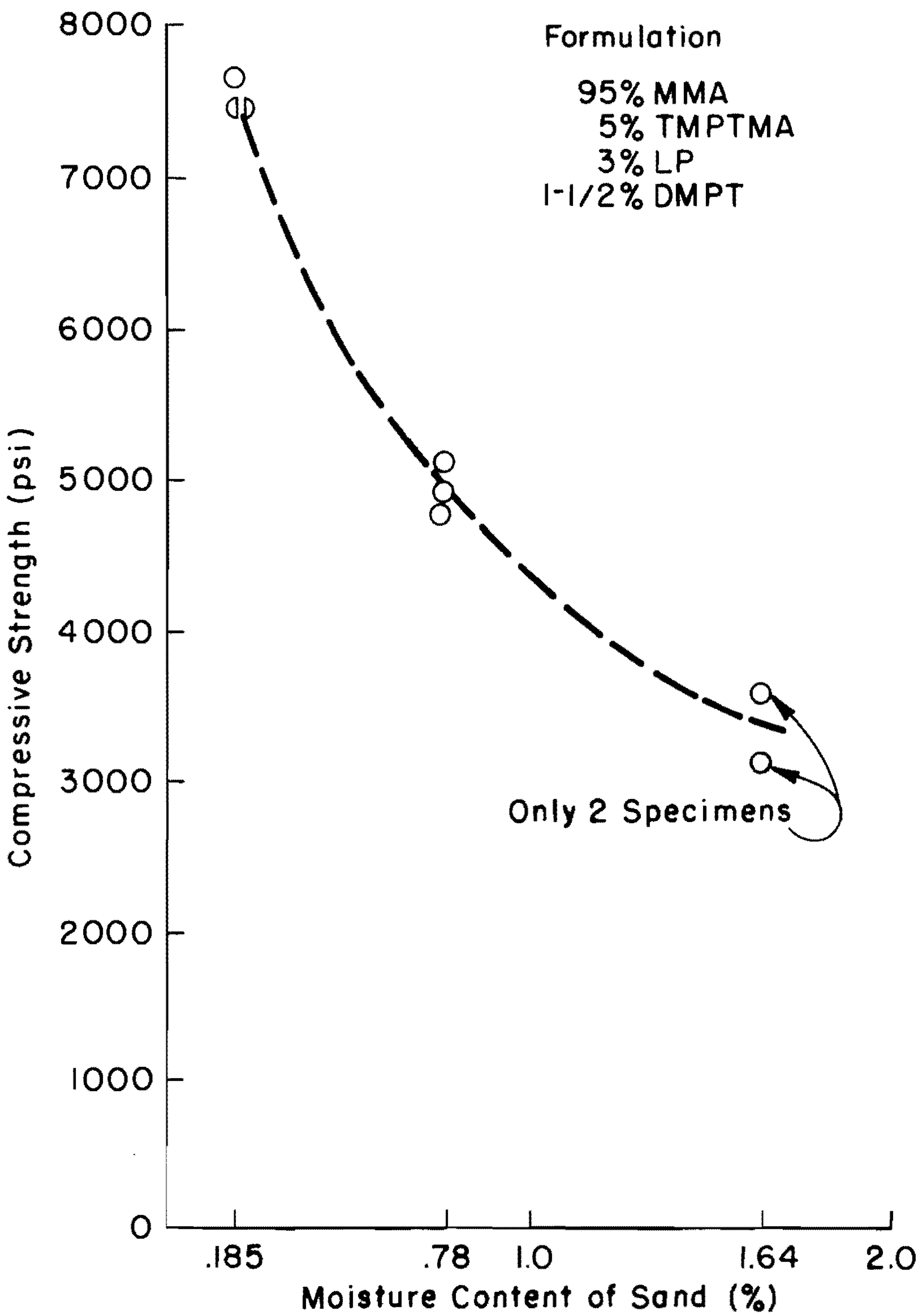

Fig. 2.2. Effect of Moisture Content of Sand on Compressive Strength ( ).

Generally the concrete removed from the deteriorated area should not be used to make polymer concrete since it may be wet, contaminated, unsound, or porous.

The aggregate gradation should be selected to require a minimum amount of monomer to fill the voids and result in the most economical and highest strength PC. Most standard DHT gradations should be satisfactory. In this research, the emphasis has been on keeping the repair procedures simple but adequate. For repairs 3/4 in. in depth or less, a well-graded concrete sand can be used. For deeper repairs, approximately 50 percent (weight) of well-graded concrete sand and 50 percent Grade 3 or Grade 4 coarse aggregate can be used. For coarse aggregate, the following gradations should be adequate:

Retained on a 1-in. sieve	0 to 5%
Retained on a 3/4-in. sieve	10 to 40%
Retained on a 1/2-in. sieve	40 to 75%
Retained on a No. 4 sieve	95 to 100%

An acceptable gradation for fine aggregate is:

Retained on a 3/8-in. sieve	0%
Retained on a No. 4 sieve	0 to 5%
Retained on a No. 8 sieve	0 to 20%
Retained on a No. 16 sieve	15 to 50%
Retained on a No. 30 sieve	35 to 75%
Retained on a No. 50 sieve	70 to 90%
Retained on a No. 100 sieve	90 to 100%
Retained on a No. 200 sieve	97 to 100%

It has been found that commercially available bagged, dry all-purpose sand is adequate for fine aggregate. The optimum ratio of sand to coarse aggregate is the one that requires the smallest volume of water to fill the voids. Generally, about 12 to 15 percent of monomer by weight is required to fill the voids in well-graded aggregate. The monomer system will have a specific gravity of 0.95 to 1.0.

Single gradation aggregate, such as sandblast sand, should not be used. The relatively high percentage of voids and resulting polymer content may cause shrinkage cracks and cause excess wear on the surface.

2.4 Properties

The PC made from MMA develops excellent compressive strength, modulus of rupture, and bond to the adjacent concrete. One of the advantages of MMA over other repair materials is its low viscosity, less than that of water, which permits penetration into the concrete pores, resulting in mechanical bonding in addition to adhesion. On field repairs, 3 x 6-in. (7.6 x 15.2-cm) PC cylinders are made using the same materials as used in the repair. Their compressive strengths generally range from 4500 to 10,000 psi (31,000 to 69,000 kN/m^2), more than adequate for repairing typical structures. The modulus of elasticity values are in the range of 1×10^6 to 3×10^6 psi (6.9×10^6 to 20.7×10^6 kN/m^2).

The moduli of rupture for PC beams range from 1100 to 2000 psi (7600 to 13,800 kN/m^2). Concrete beams, broken and then repaired, usually fail just outside the repaired zone when retested.

CHAPTER 3. SAFETY REQUIREMENTS FOR STORAGE, HANDLING, AND MIXING

The chemicals used for producing polymer concrete are relatively new to the construction industry. It is important that personnel using them have a good understanding of their characteristics and the safety precautions required. Experience has shown that safety can be achieved even on large-scale projects if sound procedures are followed. The manufacturers' instructions and safety precautions should be carefully followed whenever chemicals for concrete-polymer materials are used. A more complete discussion of safety aspects of these materials can be found in Reference 10, which is available from the DHT D-10 library.

3.1 Storage and Handling of Materials

Monomers should be stored in the containers in which they are shipped by the manufacturer. The storage temperature should not exceed 100°F (38°C), 80°F (27°C) or less is preferable. Ventilation should be provided to prevent buildup of monomer vapor concentrations in the storage area. When monomers are taken to the repair site, the drums should be shaded to keep the monomers as cool as possible. High monomer (or aggregate) temperatures tend to reduce the time of curing and sometimes increase the tendency for blisters to occur on the surface of the repair.

Initiators should not be stored in the same area as the monomers or promoters. Storage should be at temperatures recommended by the manufacturer. Promoters should be stored at temperatures recommended by the manufacturer.

Monomers used to produce PC are volatile, flammable, and toxic materials. Construction practice has shown that these materials can be stored and handled safely by following reasonable precautions. Manufacturers' recommendations for storage and handling should be carefully followed. Reference 10 provides guidance for the safe use of chemicals used for polymer concrete.

Dry chemical extinguishers should be kept near storage areas and near the repair site. Water should not be used to fight fires in monomers since it may cause the fire to spread.

Tops of empty monomer drums should never be removed with burning torches or other sparking equipment.

3.2. Monomer Mixing

Personnel handling and mixing monomers should be equipped with respirators with chemical filters, safety eyeglasses, and impervious gloves and aprons. All personnel should be thoroughly trained in the safe handling of chemicals in accordance with manufacturers' recommendations. Mixing should occur in a shaded, well-ventilated area free of ignition sources.

The monomers should be mixed in a clean mixing vessel such as a 5-gallon can or a 55-gallon drum. For small batches of monomer and for short mixing times, a non-sparking mixing paddle, such as wood, may be used.

All sources of fire, sparks or excessive heat must be removed from the mixing area. Electrical equipment should be properly grounded. All motors should be explosion proof. All mixing vessels must be kept clean of rust and other impurities. Copper or copper alloys must not be used in any of the vessels, plumbing, or mixing equipment that comes into contact with the monomer because of the possibility of chemical reactions which may cause accidental bulk polymerization. Spilled monomer should be contained with absorptive material such as sand or dry sawdust and removed. The monomer system may be premixed days or weeks prior to use in the field. However, the promoter and initiator should not be added until the day the monomer is used.

In the field tests described in Chapter 5, the components were generally mixed in the field. The monomers, including MMA, BA, and TMPTMA are mixed together. If LP initiator is used, it is added and stirred until it is dissolved prior to adding the promoter. The promoter is then added just prior to using the monomer in the repair. If the dispersion form of BzP is used as the initiator, all of the liquids including the promoter can be premixed prior to going to the field. The BzP is added just prior to use, and only a short mixing time is required.

It is extremely important to note that the initiator and promoters must never be mixed directly together because of the danger of explosion.

3.3 Disposal of Excess Monomer

Monomer containing both promoter and initiator should be placed in open-top containers partially filled with aggregate. Loose-fitting plastic sheets should be draped over the top of the container during polymerization.

Monomer containing initiator but no promoter should have 1 percent (weight) promoter added to the monomer solution. Monomer with promoter but no initiator should have 2 to 4 percent (weight) initiator added to the monomer solution. The promoted and initiated monomer should be disposed of in the manner previously described. After polymerization, the polymer can be disposed of the same as any other material.

CHAPTER 4. REPAIR PROCEDURES

The repair procedure consists of the following steps: (1) preparation of repair area; (2) placement of polymer concrete; and (3) finishing and curing. The procedure should be used only to repair portland cement concrete; asphalt should not be present in the repair.

4.1 Preparation of Repair Area

All unsound concrete must be removed. The depth of the repair area should extend below the top layer of reinforcement if possible. Delaminated concrete and deteriorated concrete should be removed to leave only sound concrete. Corrosion scale or asphalt on the reinforcing steel must be removed, preferably by sandblasting. The concrete surface against which the polymer concrete is placed must be clean of asphalt, oil and other contaminants. The surfaces must also be dry, to develop good bond between the concrete and polymer concrete. If a surface is damp, a heater or torch should be used to thoroughly dry the surface. The surface should be allowed to cool prior to placing monomer.

4.2 Formwork and Joints

Formwork must be used for full depth repairs, at expansion or construction joints, or to establish grade with asphalt overlays. Wooden forms should be treated with a release agent especially made for use with polymers, with vegetable oil, or with paraffin. All joints in formwork must be watertight. All cracks in concrete or at expansion joints must also be sealed. Polyester putty (used for repairing auto bodies) or silicone or latex caulking compound can be used to seal the joints. It is recommended that the form be pretested for leaks with a small amount of water the day prior to placement of the polymer concrete or with the monomer formulation if the repair is to be made the same day.

4.3 Mixing and Placement of PC

Two methods of mixing and placing are used for polymer concrete in this research. The primary method is to place the premixed aggregate into the repair hole and then pour the monomer over the aggregate. A second method used by others is to premix monomer and aggregate before placement (7).

The first method is the simplest and usually requires less equipment; the second method usually results in less segregation of aggregate and requires slightly less monomer.

4.3.1 Saturation of Aggregate in the Hole

The premixed aggregate is placed dry into the hole and screeded to the required level. The mixed monomer system is poured over the aggregate. A sprinkler can is recommended for small or shallow repairs to minimize erosion of the aggregate. For larger repairs, monomer is poured over the aggregate from larger vessels or by spray bars attached to larger drums. Since the pot life of the monomer may be less than 30 minutes, caution should be exercised to use all monomer within 10 to 15 minutes that the last component has been added and mixed. Consolidation should be accomplished by tamping or vibration, although care must be taken to avoid separation of monomer and aggregate with vibration. After monomer is ponded on the surface, the surface should be screeded smooth with concrete sand added to level the surface. Areas of ponded monomer should be filled with sand to prevent slickspots from occurring after the monomer polymerizes. The surface can be finished with wooden floats or steel trowels. Since the monomers are volatile, the surface of the repair should be covered with a membrane such as polyethylene as soon as the surface is finished, to reduce evaporation losses. It may be necessary to add monomer with a sprinkler can if evaporation, leakage, or other losses cause depletion of monomer on the surface. The surface should be kept wet until polymerization occurs.

4.3.2 Premixing of Aggregate and Monomer

For purposes of estimating quantities of monomer, 12 to 14 percent by weight of aggregate is usually required. If leakage is anticipated or if shallow repairs over porous concrete are made, additional monomer may be required.

The wetted aggregate tends to segregate less when placed than dry aggregate. The authors have some concern that the use of an ordinary mixer with steel mixing blades might have the potential of causing sparks which would cause ignition of the monomer. Other researchers have reported good results with this method, however.

Conventional concrete mixers have been used for larger quantities. Even ready-mix concrete trucks have been used for projects requiring very large quantities of PC.

In the use of mixers, the required amount of aggregate is placed into the mixer and thoroughly mixed. Based on the weight of the aggregate, about 12 percent monomer is then poured into the mixer. Mixing should continue for a few minutes until the aggregate is thoroughly wetted with monomer. Finishing is the same as for the first method (3.4.1).

4.4 Polymerization

The monomer formulations shown in Table 2.2 usually allow 20 to 30 minutes of time for mixing the monomer and making the repair, although this time may be reduced if the monomer is not used immediately after Parts A and B are mixed together or if the ambient temperature is high. As polymerization proceeds, the surface temperature of the repair may reach temperatures of 50 to $100^{o}F$ (10 to $38^{o}C$) higher than ambient. In some cases, especially where TMPTMA is not used, small surface blisters may occur on the surface. The surface blisters quickly wear off the surface and do not have any adverse effects on the repair. Generally, the repair is ready to be turned back to traffic within two hours after the monomer is placed.

4.5 Cleaning Tools and Equipment

Tools can be wiped clean with a rag saturated with an organic solvent such as trichlorethane. Cleanup of a concrete mixer can be performed by first rinsing it with trichlorethane and then operating the mixer with a load of aggregate. In many cases, washing with liberal amounts of water will satisfactorily clean tools and mixers.

CHAPTER 5. FIELD DEMONSTRATION REPAIRS

A large number of field demonstrations using PC have been performed in districts throughout the state. The repairs have included bridge decks, approach slabs, abutments, and pavements. Representative bridge deck repairs are described in this chapter.

5.1 Thin Overlay Repair

A new bridge on MoPac Boulevard in Austin was repaired with a thin PC overlay. Evidently a portion of the bridge surface had been built too high and the surface was jack hammered to remove the excess concrete (Fig. 5.1). Then the area was leveled with portland cement mortar which later spalled.

The repair began at 9:15 a.m. with a temperature of about 70°F (21°C). The mortar was removed to a depth of 3/8 to 1/2 in. (1 to 1.3 cm) over an area of approximately 5 by 8 ft (1.5 by 2.4 m). Since a heavy rain had fallen the previous day, a portable butane-fired infrared heater was placed over each segment of the repair area for 8 minutes (Fig. 5.1). Oven-dried, washed Colorado River sand with 3 percent (weight) portland cement was placed in the void and screeded to a smooth finish. The cement was used to help match the color of the surrounding concrete. The monomer consisted of 90% MMA:10% BA. The initiator-promoter system was 6 percent LP and 3 percent DMT, based on the weight of the monomer. The monomer was poured over the sand until it was saturated (Fig. 5.2). The surface was troweled smooth and covered with a polyethylene film. The monomer was applied at 10:20 a.m. and had polymerized by 11:15 a.m. The area was opened to traffic by noon. The repair has performed extremely well with no signs of delamination, cracking, or excessive wear. The cost of the monomer system, exclusing labor and aggregate, was \$260 per yd^3 (\$340 per m^3). The repair was made in September 1977.

5.2 Shallow Repairs

A large number of bridge decks have been repaired to depths of 1.5 to 3 in. (3.8 to 7.6 cm). An example of one kind of repair was a delaminated area on the

Fig. 5.1. MoPac Boulevard Repair.

Fig. 5.2. Finishing MoPac Boulevard Repair.

U.S. 83 bridge over the Salt Fork of the Red River in Collingsworth County (Fig. 5.3). A saw cut was made around the area to be repaired and the unsound concrete was removed with a jack hammer. The portable infrared heater was used for a few minutes to dry the surface, which had been wetted by the water used to lubricate the saw. The size of the area was about 6 x 8.5 ft (1.8 x 2.6 m) with a depth of 1.5 in. (3.8 cm). The void was filled with a mixture of 60 percent (weight) aggregate which has a maximum size of about 5/8 in. (1.6 cm) and 40 percent (weight) concrete sand. The aggregate had been predried and was mixed at the site in a concrete mixer. The monomer was 90 percent MMA:10 percent BA with 4 percent LP and 2 percent DMT. The temperature was about $80^{\circ}F$ ($25^{\circ}C$). After the aggregate was placed, screeded and tamped, the monomer was poured over the area. The surface was screeded and troweled. Sand was sprinkled over low areas where monomer was poured to prevent slick spots. Polyethylene membrane was used to cover the repair. Additional monomer was used to wet the surface where the sand appeared to be drying out. One hour and 45 minutes elapsed between the start of monomer application and opening the bridge to traffic. The cost of the monomer for the repair was \$238 per yd^3 (\$312 per m^3). The total cost of monomer for the repair was \$63.75. The repair was made in May 1976.

5.3 Full-Depth Repairs

Two full-depth repairs have been successfully made. These repairs were complicated by the need to place a form beneath the bridge and to seal the forms to prevent leakage.

A repair was made on U.S. 80 on the westbound bridge over Grindstone Creek near Weatherford. The bridge, which was about 20 years old, was severely delaminated. The slab was 7 in. (17.8 cm) thick and had been overlaid with asphalt. A 5 x 5-ft. (1.5 x 1.5-m) hole was made through the deck. A plywood form was placed on the underside of the bridge (Fig. 5.4). The form was supported by timbers placed on the bottom flanges of the steel I-beams supporting the slab. A foam rubber gasket was placed between the form and the slab around the perimeter. Silicon adhesive was used to seal the perimeter and the joint in the form. A fast curing PC formulation was also used to seal the form.

The aggregate consisted of 60 percent (weight) crushed stone and 40 percent (weight) sand. The crushed stone had 3.8 percent retained on the 1-in. (2.5-cm) sieve and 60.3 percent retained on the 1/2-in. (1.25-cm) sieve. The

Fig. 5.3. Bridge on U.S. 83 Prior to Repair.

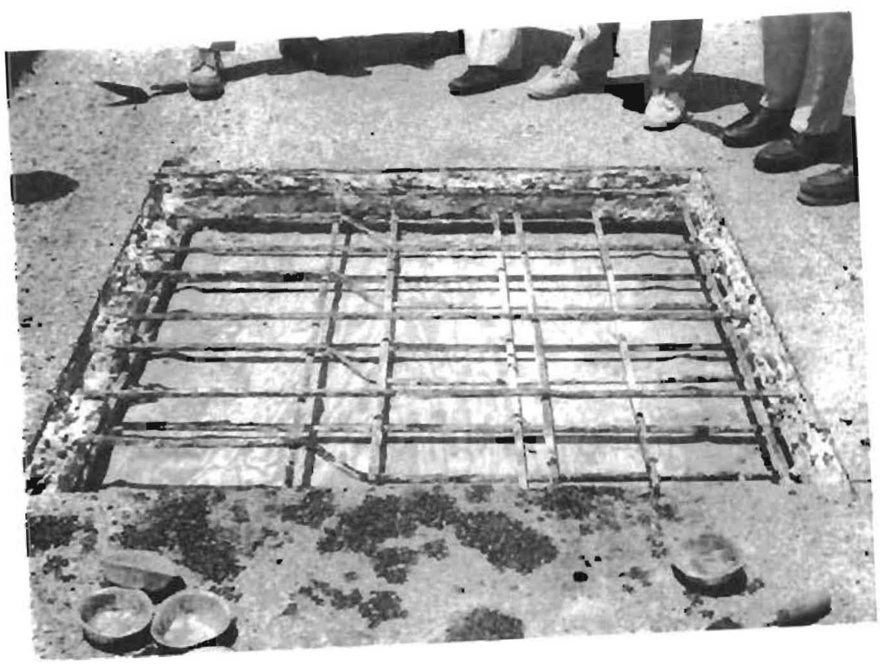

Fig. 5.4. Bridge on U.S. 80 After Placement of Form.

aggregate was predried, premixed, and bagged before being brought to the site. Two inches (5 cm) of aggregate were first placed in the hole and saturated with the monomer system, which was the same as for the previously described repair. A leak developed in one corner of the form. After the monomer began to polymerize, an additional 2-in. (5-cm) layer of aggregate was placed and saturated with monomer. The leak continued. The remainder of the hole was filled with aggregate and the monomer was placed (Fig. 5.5). The monomer application began at 4 p.m. and at 5:30 p.m. polymerization was completed (Fig. 5.6). The area was covered with asphalt and a truck was driven over the area. The temperature was about 95°F (35°C).

The repair required about 28 gallons (106 liters) of monomer, of which about 25 percent was lost due to leakage. The total cost of the monomer was \$149 or \$278 per yd^3 (\$363 per m^3). The repair has performed well for more than a year with no sign of distress. The plywood form is still bonded to the bottom of the repair which was made in July 1976.

The largest full-depth PC repair was made on the Pedernales River bridge on U.S. 181 during extensive conventional repairs. Concrete was removed down to the steel and a concrete overlay was placed. In one area, the concrete had to be removed full depth between the steel beams (Fig. 5.7).

The reinforcing bars were cut to simplify the placing of the form and later welded back. A plywood form was placed beneath the slab and securely supported by wood joists (Fig. 5.8). A 1-in. (2.5-cm) layer of cement grout was placed over the form to seal the bottom. The repair was scheduled for the day after the grout was placed but had to be delayed two days due to rain. On the morning of the repair, the repair area was filled with water, which attested to the effectiveness of the grout seal. The water was blown out and the concrete edges around the full-depth section were dried for a few minutes with the butane heater. Time did not permit the grout or the overlay area to be dried.

The predried aggregate consisted of 60 percent (weight) coarse aggregate and 40 percent (weight) washed sand. The aggregate was mixed in a concrete mixer, placed in wheelbarrows, and wetted with part of the monomer system before placing in the repair to reduce segregation. The monomer consisted of 90 percent (weight) MMA and 10 percent (weight) BA. Based upon the monomer weight, the other components were 4 percent LP, 2 percent DMT, and 1 percent silane coupling agent.

Fig. 5.5. Monomer Application.

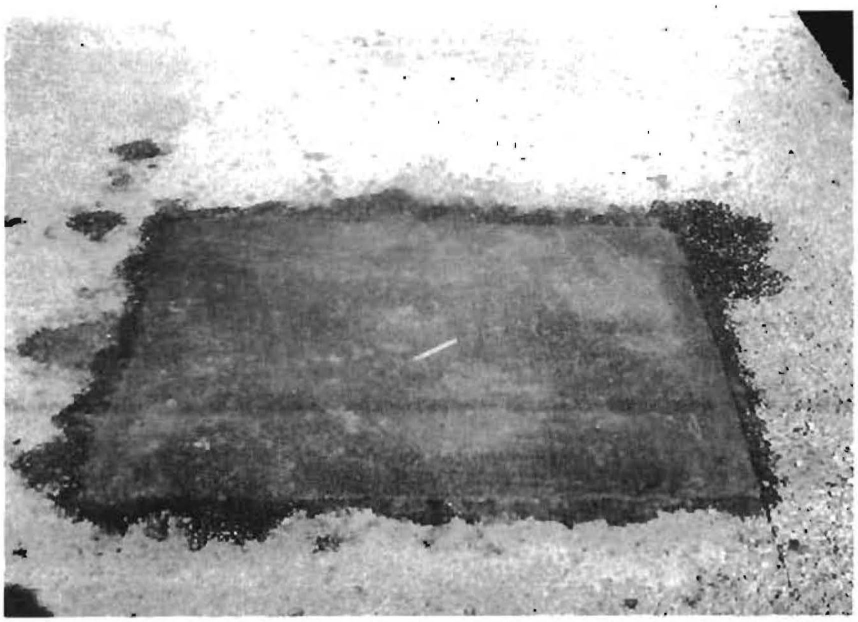

Fig. 5.6. Completed Repair.

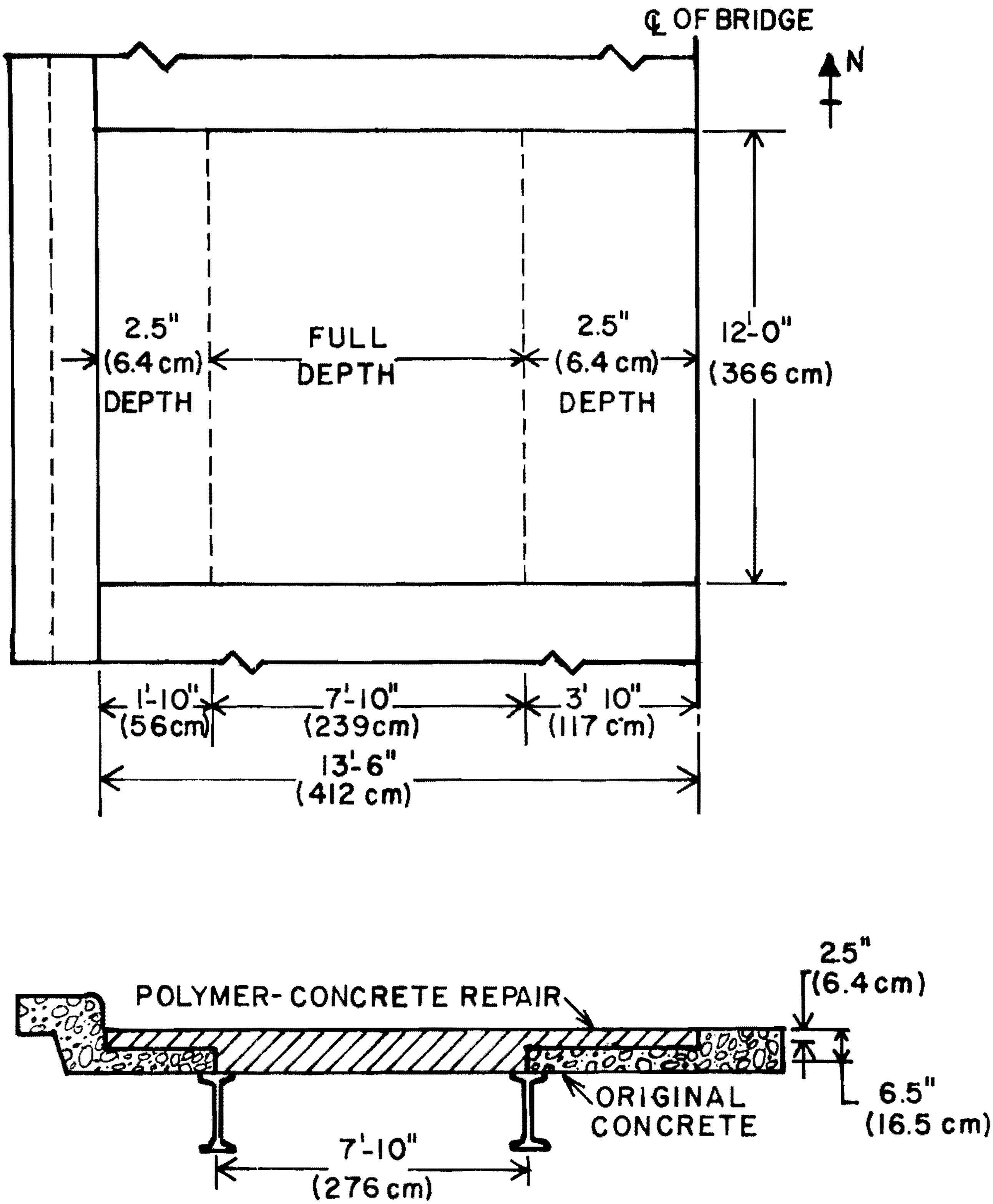

Fig. 5.7. Size and Location of Repair.

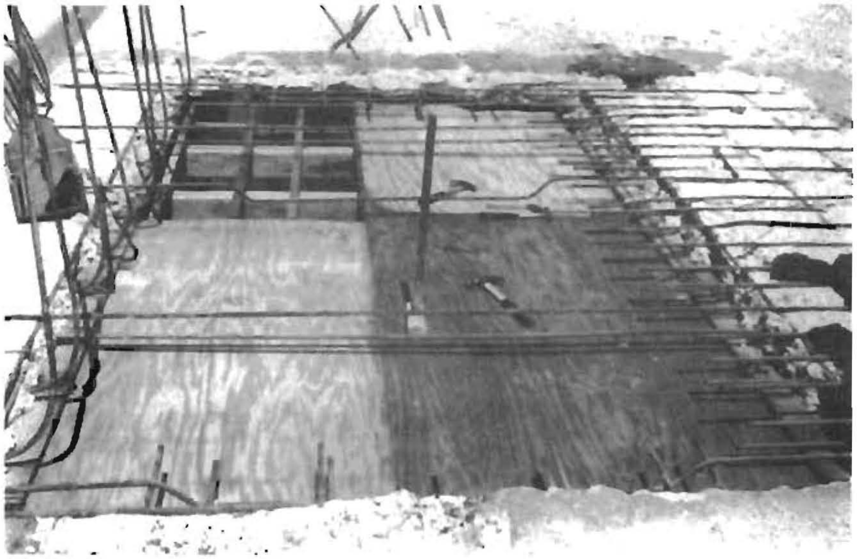

Fig. 5.8. Installation of Form.

Fig. 5.9. Completed Repair.

The first batch was applied at 10 a.m. The repair was divided into two lifts: the first lift of partially wetted aggregate was placed up to the top steel and the second lift was placed to the top surface after the first lift started to polymerize. An electric vibrator was used in each lift to minimize the air voids. During the second lift, a slight leak through the existing concrete developed and the use of the vibrator was reduced to minimize monomer leakage.

The surface was screeded smooth and troweled, after which a steel broom finish was applied (Fig. 5.9). Polymerization was complete by 1 p.m. Some bubbles were observed on the surface of the SE corner, where excess monomer accumulated. Traffic was returned to the bridge at 2 p.m.

On the following Monday, two fine cracks were observed on the surface in the shallow repair section. It was theorized that they were caused by shrinkage or vibration due to traffic prior to complete polymerization.

The cost of the monomer system was \$810 or \$327 per yd^3 (\$428 per m^3), including the silane coupling agent which was used to increase the bond between the polymer and the aggregate. Without the silane, the cost was \$278 per yd^3 (\$364 per m^3). The total cost of the repair including materials (except silane) and labor was \$325 per yd^3 (\$425 per m^3). The repair was made in April 1977.

Cores were taken from both the full-depth repair and the partial-depth repair. The bond between the PC and grout (Fig. 5.10) and between the PC and concrete was found to be very good. In the upper lift more air voids were observed than in the first lift, apparently because of the reduced use of the vibrator. Three 3 x 6-in. (7.6 x 15.2-cm) cylinders made at the time of the repair indicated an average compressive strength of 7220 psi (49800 kN/m^2).

Some surface blisters have been observed on the surfaces of the repairs, especially in hot weather, with the formulation previously described. The blisters quickly wear off without adverse effect on the repair but are undesirable for cosmetic reasons. It has been found in recent repairs that the addition of 2.5 to 5 percent (weight) of a cross-linking agent, trimethylolpropane trimethacrylate (TMPTMA), eliminates blistering. Since the TMPTMA increases the polymerization rate, it has been possible to decrease the LP and DMT to 3 percent and 1.5 percent, respectively.

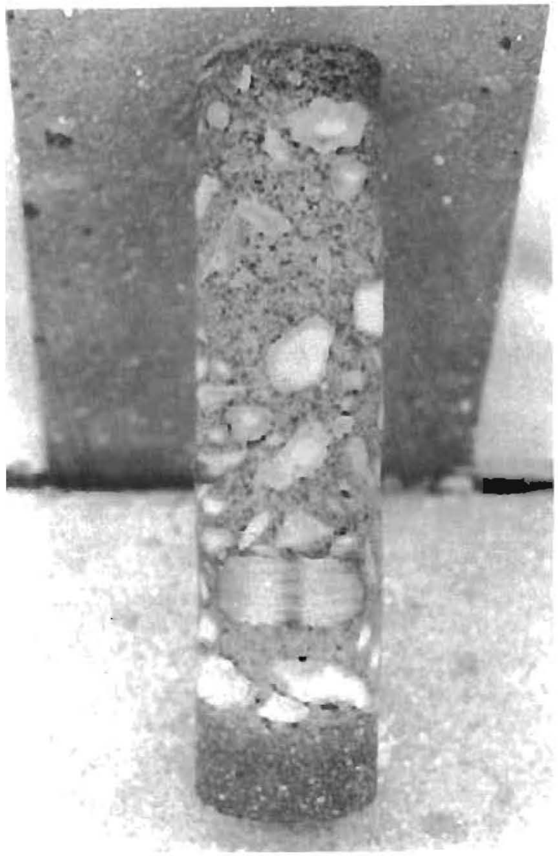

Fig. 5.10. Two-inch Core From Full-Depth Repair.

5.4 Approach Slabs at Expansion Joints

Several repairs have been made at expansion joints. One typical repair was on the southbound bridge on Loop 410 at Ingram Road in San Antonio. The structure, built in 1956, has a 7-in. (17.5-cm) concrete slab supported by steel I-beams. The approach slabs had spalled at the expansion joints, and areas to be repaired were selected on the north and south ends of the bridge (Fig. 5.11). These areas had been repaired previously but were beginning to crack and spall. Area 1 consisted of several small patches on the south end of the west lane, varying in depth from 0.25 to 1.5 in. (0.6 to 3.2 cm). Area 2 consisted of one rectangular section, 16 ft 9 in. (5.1 m) long by about 1 ft (0.3 m) wide with an average depth of 4 in. (10 cm) at the north end of the east lane. The work began with the removal of the bad material with an air hammer down to sound concrete, or a minimum of 0.25 in. (0.6 cm) at the edges. Loose debris was blown off with an air hose. The same preparation was used on both Areas 1 and 2.

The aggregate used for this repair was crushed stone and sand in a ratio of 2 parts sand to one part crushed rock. The sand was washed and graded and the rock was #6A crushed limestone (approximately 3/8 in., or 1 cm), as is commonly used in hot mix asphalt. The aggregate mixture was pre-dried to remove water which would prevent monomer penetration into pore space. The aggregate was placed and troweled to a smooth surface.

5.5 Monomer System

The monomer system consisted of two monomers, methyl methacrylate (MMA) and butyl acrylate (BA); an initiator, lauroyl peroxide (LP); and a promoter, undistilled N, N-dimethyl-para-toluidine (DMPT). The formulation of the monomer system, by weight, was 90 percent MMA, 10 percent BA, 6 percent LP, and 3 percent DMPT. Care was taken to never let the LP and DMPT come in direct contact with each other. The MMA, BA and LP were blended and the DMPT was added just prior to application of the mixture to the aggregate.

Starting at 12:30 p.m., 3000 cc of monomer was poured slowly over the aggregate mixture so as to disturb the sand as little as possible. The monomer was sufficient to saturate the aggregate. A light layer of sand was spread over the aggregate mixture to soak up the excess monomer and to provide a smooth wearing surface. The wetted sand was quickly troweled smooth

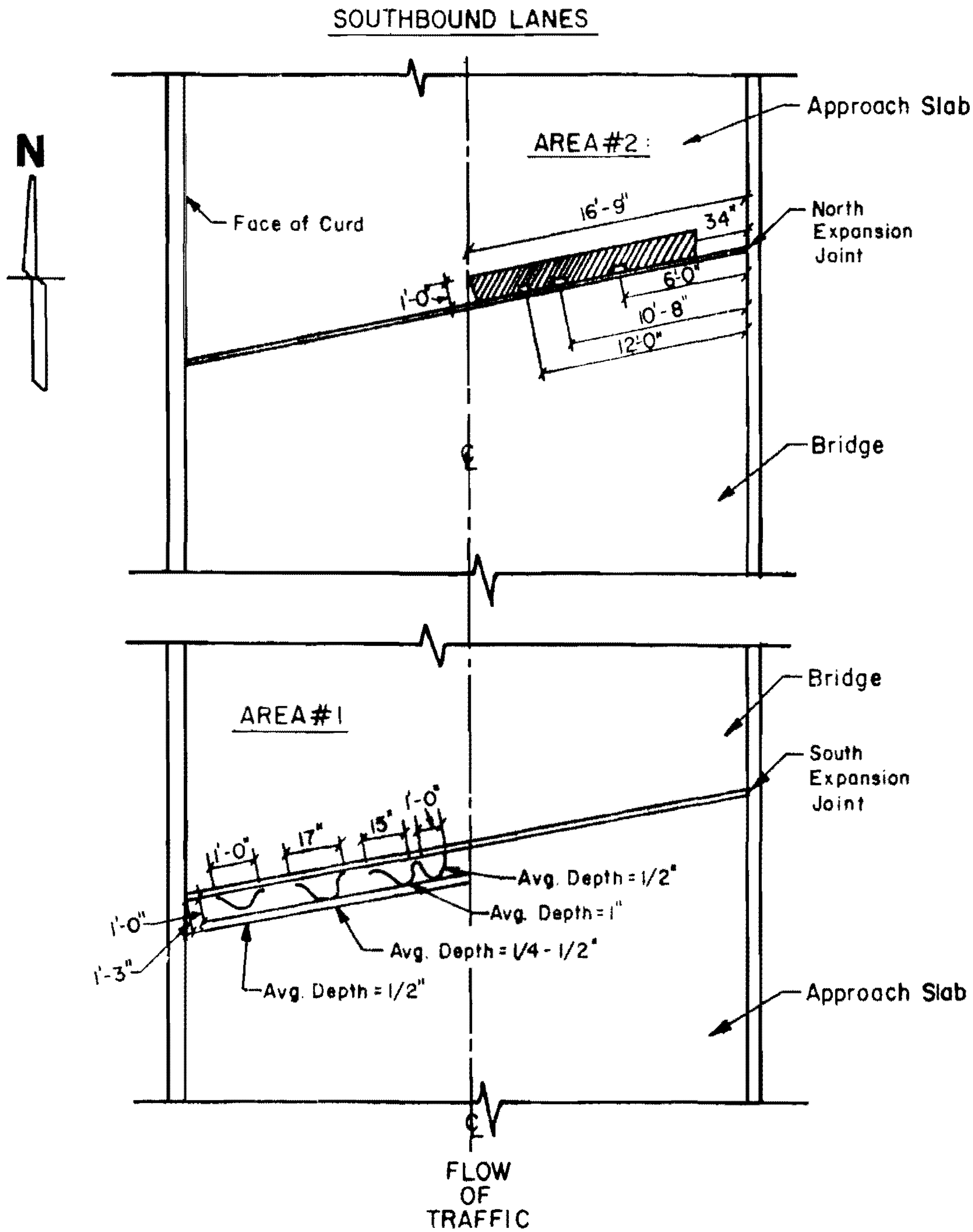

Fig. 5.11. Location of Repairs.

and the repair was covered with polyethylene to reduce evaporation losses due to the windy conditions. Small amounts of monomer were added prior to curing to replenish the monomer lost to evaporation and to absorption into adjacent concrete.

The repair of Area 1 started with the removal of old concrete at 11:30 a.m., progressed with the addition of monomer at 12:00 noon, and was completed with polymerization of the monomer by 1:00 p.m., at which time the lane was reopened to traffic. A total of 3100 cc of monomer was used to complete the repair. The cost of the monomer was $4.29.

Area 2 was repaired in the same manner as Area 1, with one major exception. After removal of the spalled concrete (Fig. 5.12)., holes were observed in the concrete where the anchors for the expansion joint plate penetrated the concrete deck (Fig. 5.12). The holes were sealed with polyester putty, commonly used for auto body repair at prices ranging from $9.00 to $12.00 per gallon. The putty and catalyst were mixed and placed to seal the holes (Fig. 5.13 and 5.14) and allowed to harden for a few minutes.

After sealing all holes, aggregate was placed, tamped (to reduce voids), and troweled smooth. Monomer was added to saturate the aggregate. A light layer of sand was added to fill voids around coarse surface aggregate, to soak up excess monomer, and to give a smooth wearing surface. The patch was covered with polyethylene to reduce evaporation during curing. Small amounts of monomer were added to replenish evaporated and absorbed monomer prior to final polymerization (Fig. 5.15).

A total of 6.34 gallons (24 liters) of monomer was used in the repair of Area 2. Mixing of the monomer was performed in 2.1-gallon batches. The concrete was removed at 2:00 p.m., the monomer was added to the aggregate mixture at 2:30 p.m., and polymerization was completed at 3:30 p.m. The lane was opened to traffic by 4:00 p.m. The cost of the monomer was $33.23.

During placement of the polymer-concrete, several 3 x 6-in. (7.6 x 15.2-cm) test cylinders were cast to evaluate the strength of the repair material. The materials were the same as used in the actual repairs and the cylinders were tested two days after the repairs. The average compressive strength for two cylinders was 5035 psi (34700 kN/m^2). The repair was made January 1977.

Fig. 5.12. Removal of Deteriorated Concrete.

Fig. 5.13. Joint Ready for Polymer Concrete.

Fig. 5.14. Polyester Putty-Filled Cracks at Joint.

Fig. 5.15. Completed Repair.

5.6 Observations on Repairs

The repairs that have been made have generally performed very well. Some of the more recent repairs that have been made using 5 percent of the cross-linking agent TMPTMA, BzP and DMT have shown some cracks within a short time. The cross-linking agent was primarily used to eliminate blistering on the surface of the repair. It is recommended that, if blistering does occur, a maximum of 2 percent of TMPTMA should be used (formulation 3 or 4 in Table 2.2). The best way to eliminate blistering is to keep the monomer cool prior to placement. If the monomer drums are exposed to direct sunlight for several hours prior to placement in the repair, the higher monomer temperature causes a higher exotherm, which increases the tendency to blister.

CHAPTER 6. RECOMMENDATIONS

Polymer concrete repairs for bridge decks are fast, durable, and lasting. The procedures are relatively simple but should be carefully followed to insure a good, sound repair.

6.1 Monomer System

The recommended monomer system is as follows:

90 percent by weight of methyl methacrylate (MMA)
10 percent by weight of butyl acrylate (BA).

In hot weather, it may be desirable to add TMPTMA to minimize surface blistering. That formulation of monomer should be as follows:

88 percent MMA
10 percent BA
2 percent trimethylolpropane trimethacrylate (TMPTMA).

The promoter-initiator system based on the monomer system is:

4 percent by weight of lauroyl peroxide (LP)
2 percent by weight N, N-dimethyl-p-toluidine (DMT)

for a temperature range of 70° to 100°F (21 to 38°C).

For 45° to 70°F (4 to 38°C), the promoter-initiator system should be:

6 percent LP
3 percent DMT.

In lieu of the LP-DMT system, benzoyl peroxide (BzP) and DMT may be used according to the percentages based on temperature shown in Fig. 2.1.

6.2 Aggregate

Aggregate should be dry, sound, clean, and well graded to produce a minimum void ratio. For very shallow repairs (3/4 in. or less), well graded concrete sand can be used. For deeper repairs, standard DHT gradations can be used. A combination of equal parts by weight of concrete sand and either grade 3 or 4 coarse aggregate has proven satisfactory. Aggregate should have one percent moisture or less.

6.3 Repair Procedures

The repair procedures are as follows:

1. Remove all unsound concrete.
2. Clean all exposed reinforcing steel of corrosion by wire brushing or sand blasting.
3. Dry concrete surface to remove moisture as necessary.
4. Seal cracks or holes in concrete or forms to prevent leakage of monomer. Polyester auto body putty, silicone caulking and latex caulking are effective sealants.
5. Mix monomers just prior to placing in repair according to instructions in Chapter 4. It is important that all initiator (BzP or LP) is completely dissolved. Under no circumstances should the accelerator (DMT) and the initiator (LP or BzP) come into contact with each other in concentrated form because a violent reaction may occur. Monomers should be kept cool prior to mixing, and mixing should occur in a shaded area.
6. Polymer concrete may be placed in two ways:
   a. Placing pre-dried, pre-mixed aggregate in repair and pouring monomer solution over aggregate until it is saturated. This is the simplest method, but may result in more segregation of aggregate.
   b. Premixing aggregate and monomer either by hand or with a mixer. The wetted aggregate tends to segregate less than dry aggregate when placed. The authors have some concern that the use of an ordinary mixer with steel mixing blades might have the potential to cause sparks which would cause ignition of the monomer. Other researchers have reported good results with this method, however.
7. Vibrate the PC to minimize honeycombing. For repair depths of more than 3 in. (7.5 cm) it may be desirable to place the PC in 2 or 3-in. (5 or 7.5-cm) layers to facilitate vibration.
8. Finish the surface by screeding and/or troweling. If excess monomer accumulates on the surface, additional aggregate should be placed to avoid "slick" spots.
9. Cover the surface with polyethylene film to minimize evaporation. If aggregate becomes dry on the surface due to absorption in the adjacent concrete or aggregate or to leakage, add additional monomer with a sprinkler can.

During polymerization, heat will develop, and the PC will be hard when it has cooled. After this, the repaired area may be opened to traffic. The elapsed time between application of monomer and completion of polymerization is a variable that depends upon air temperature, concrete temperature, aggregate temperature, volume or thickness of repair, and monomer formulation. Generally, the cure time ranges between 30 and 90 minutes.

REFERENCES

1. Anonymous, "U.S. Bridge Dangers Cited," <u>ASCE News</u>, June 1977, Vol 2, No. 6.

2. Dikeou, J., W. Cowan, G. DePuy, W. Smoak, G. Wallace, M. Steinberg, L. Kukacka, A. Auskern, P. Columbo, J. Hendrie, and B. Manowitz, <u>Concrete-Polymer Materials, Fourth Topical Report</u>, USBR REC-ERC-72-10 and BNL 50328, Jan., 1972.

3. Kukacka, L., J. Fontana, A. Romano, M. Steinberg, and R. Pike, <u>Concrete-Polymer Materials for Highway Applications, Progress Report No. 3,</u> BNL 50417 and FHWA-RD074-17, Dec., 1973.

4. Kukacka, L.E., J. Fontana, and M. Steinberg, "Polymer Concrete for Repairing Deteriorated Bridge Decks," <u>Transportation Research Board</u>, 542, 1975, Washington, D.C., pp. 20-28.

5. Jaber, M.J., "An Investigation of the Use of Polymers for the Repair of Concrete", Unpublished Master's Thesis, The University of Texas at Austin, January 1975.

6. Knysh, A.M., "An Investigation of the Use of Polymer-Concrete for the Repair of Portland Cement Concrete," Unpublished Master's Thesis, The University of Texas at Austin, May 1977.

7. Kukacka, L.E. and Fontana, J., "Polymer Concrete Patching Materials -- Users' Manual," Implementation Package 77-11, Vol 1, Brookhaven National Laboratory, Upton, N.Y., April 1977.

8. Fowler, D.W. and Paul, D.R., "Polymer-Concrete for Repair of Bridge Decks," <u>Proceedings of Second International Congress on Polymers in Concrete</u>, Austin, Texas, October 1978, pp. 337-350.

9. Haddad, Mustafa, Unpublished research.

10. Fowler, D.W., Kukacka, L.E., Paul, D.R., Schrader, E.K. and Smoak, W.G., "Safety Aspects of Concrete-Polymer Materials," <u>Proceedings of International Symposium on Polymers in Concrete</u>, SP-58, American Concrete Institute, October 1976, pp. 123-138.