

1. Report No. FHWA/TX-79/03+114-9F		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle CONCRETE-POLYMER MATERIALS FOR HIGHWAY APPLICATIONS				5. Report Date March 1979	
				6. Performing Organization Code	
7. Author(s) David W. Fowler and Donald R. Paul				8. Performing Organization Report No. Research Report 114-9F	
9. Performing Organization Name and Address Center for Highway Research The University of Texas at Austin Austin, Texas 78712				10. Work Unit No.	
				11. Contract or Grant No. Research Study 3-9-71-114	
				13. Type of Report and Period Covered Final	
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763				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 <p>The use of concrete-polymer materials for highway applications has been studied with the objective of providing durable materials that would reduce maintenance in highway structures. Several significant developments resulted from this research. Partial-depth polymer impregnation was developed for improving durability of bridge decks. The process includes drying the concrete, cooling the surface, applying a low viscosity monomer solution to a sand cover, and permitting it to soak into the concrete, and applying heat to polymerize the monomer in the concrete to a depth of 0.5 in. (1.3 cm) or more. Post-tensioned polymer-impregnated beams were made and tested to determine the structural behavior. Beams with an I-shaped cross-section and a span of 8 ft (2.7 m) were fully impregnated with a monomer solution. High strength wire tendons were post-tensioned and the beams were tested to determine the flexural and shear behavior. Significant increases in strength and stiffness were observed. Time-dependent deflections were reduced by an order of magnitude. Polymer concrete was developed for repairing bridge decks. Clean, dry, graded aggregate is placed in the repair area and a monomer system that has sufficient promoter and initiator to polymerize at ambient conditions is applied to fully saturate the aggregate. Polymerization occurs in 30 to 45 minutes, producing a sound and durable repair. A polymer concrete overlay was developed to waterproof bridge decks. A thin layer of dry sand is covered with coarse aggregate. Two monomer solutions are applied and polymerization occurs at ambient temperature.</p>					
17. Key Words concrete-polymer, highway, partial-depth, post-tensioned, beams, bridge decks, overlay			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) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 32	22. Price

CONCRETE-POLYMER MATERIALS FOR HIGHWAY APPLICATIONS

by

David W. Fowler and Donald R. Paul

Research Report 114-9F

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.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

## PREFACE

Research Study 114 was initiated 1 September 1970 to develop partial-depth polymer impregnation of bridge decks. The use of polymers in concrete was quite new and surface impregnation under field conditions was an unproven concept. But due to the willingness of the Department of Highways and Public Transportation Research and Development committee to let the study supervisors, which included J.T. Houston, the study was approved and impregnation procedures were developed and implemented. Research was also conducted and implemented in the areas of polymer concrete repair and polymer concrete overlays for bridge decks.

Study 114 would never have been successful without the many people at the Department of Highways and Public Transportation who provided guidance, encouragement, and assistance. John Nixon, T.R. Kennedy and Jon Underwood of D-10; Andy Seely of D-5; Don O'Connor of D-9; and Ralph Banks of D-18 are due our sincere thanks for their help. Edward Kristaponis and John Nichols of the Federal Highway Administration have been very supportive and helpful.

The work could not have been accomplished without the help of the many graduate students who worked on the research. Their ideas and dedicated work lead to many of the developments in the study.

David W. Fowler  
Donald R. Paul

## ABSTRACT

The use of concrete-polymer materials for highway applications has been studied with the objective of providing durable materials that would reduce maintenance in highway structures. Several significant developments resulted from this research.

Partial-depth polymer impregnation was developed for improving durability of bridge decks. The process includes drying the concrete, cooling the surface, applying a low viscosity monomer solution to a sand cover, and permitting it to soak into the concrete, and applying heat to polymerize the monomer in the concrete to a depth of 0.5-in. (1.3-cm) or more.

Post-tensioned polymer-impregnated beams were made and tested to determine the structural behavior. Beams with an I-shaped cross-section and a span of 8-ft (2.7-m) were fully impregnated with a monomer solution. High strength wire tendons were post-tensioned and the beams were tested to determine the flexural and shear behavior. Significant increases in strength and stiffness were observed. Time-dependent deflections were reduced by an order of magnitude.

Polymer concrete was developed for repairing bridge decks. Clean, dry, graded aggregate is placed in the repair area and a monomer system that has sufficient promoter and initiator to polymerize at ambient conditions is applied to fully saturate the aggregate. Polymerization occurs in 30 to 45 minutes, producing a sound and durable repair.

A polymer concrete overlay was developed to waterproof bridge decks. A thin layer of dry sand is covered with coarse aggregate. Two monomer solutions are applied and polymerization occurs at ambient temperature. The resulting overlay is about 1/2-in. (1.3-cm) thick and has a coarse surface texture which results in excellent skid resistance.

## SUMMARY

Concrete-polymer materials have been developed for highway applications. Partial-depth polymer impregnation procedures were developed for bridge decks to provide a more durable and water resistant surface. Polymer-impregnated post-tensioned beams were found to have significantly greater strength and stiffness and much less creep deformation. Polymer concrete repair techniques were developed for highway bridge decks. A polymer concrete overlay was developed that provides a waterproof surface and excellent skid resistance.

## Implementation Statement

Concrete-polymer materials have been developed and implemented in Texas. Polymer-impregnation has been performed under contract on two bridge decks in Texas. Polymer concrete is used in many districts for repairing concrete bridge decks. A polymer concrete overlay has been applied to a bridge deck in District 3, and two more are planned.

## TABLE OF CONTENTS

CHAPTER		PAGE
1	INTRODUCTION . . . . .	1
	1.1 Background . . . . .	1
	1.2 Definitions . . . . .	
	1.3 Safety . . . . .	2
2	PARTIAL-DEPTH POLYMER-IMPREGNATED CONCRETE . . . . .	4
	2.1 Drying . . . . .	4
	2.2 Cooling . . . . .	5
	2.3 Monomer System . . . . .	5
	2.4 Monomer Application . . . . .	5
	2.5 Polymerization . . . . .	5
3	POST-TENSIONED POLYMER-IMPREGNATED BEAMS . . . . .	7
	3.1 Fabrication of Beams . . . . .	7
	3.2 Flexural Behavior . . . . .	9
	3.3 Shear Behavior . . . . .	9
	3.4 Time-Dependent Behavior . . . . .	9
4	POLYMER CONCRETE FOR REPAIR OF CONCRETE . . . . .	12
	4.1 Monomer Formulations . . . . .	12
	4.2 Aggregate . . . . .	12
	4.3 Properties . . . . .	15
	4.4 Preparation for Repair . . . . .	15
	4.5 Mixing and Placement of PC . . . . .	15
	4.6 Polymerization . . . . .	16
	4.7 Results . . . . .	16
5	POLYMER CONCRETE OVERLAYS . . . . .	17
	5.1 Preparation of the Surface . . . . .	17
	5.2 Placement of Aggregate . . . . .	18
	5.3 Monomer Formulations . . . . .	18
	5.4 Monomer Application . . . . .	18
	5.5 Results . . . . .	20
6	CONCLUSIONS . . . . .	21
	REFERENCES . . . . .	22

LIST OF TABLES

TABLE		PAGE
4.1	Monomer Formulations for Polymer Concrete . . . . .	13
5.1	Monomer Systems . . . . .	18

LIST OF FIGURES

FIGURE		PAGE
3.1	Nominal dimensions and loading arrangement . . . . .	8
3.2	Load-Deflection Responses for PIC and Control Beams . . . . .	10
4.1	Tentative Recommended Percentages of BzP and DMPT . . . . .	14
5.1	Tentative Recommended Percentages of BzP and DMPT . . . . .	19

## CHAPTER 1. INTRODUCTION

### 1.1 Background

Concrete-polymer materials have been used for many highway applications. Research was begun at the Bureau of Reclamation and Brookhaven National Laboratory in 1966 (1) on polymer-impregnated concrete for a wide range of applications.

In 1970 research was begun at the Center for Highway Research for the Texas Department of Highways and Public Transportation (DHT) with the objective of developing a partial-depth polymer impregnation process for bridge decks to provide greater durability. Later the scope was enlarged to include polymer concrete for repair of bridge decks. Research was also performed to determine the behavior of post-tensioned polymer-impregnated concrete beams. The final phase of the study was the development of a thin polymer concrete overlay for bridges.

This report summarizes the highlights of the research findings. Previous research reports of Study 114 "Concrete-Polymer Materials for Highway Applications" should be referred to for more complete information on each topic.

### 1.2 Definitions

#### 1.2.1 Materials

(1) Monomers are low viscosity organic materials from which polymers are made.

(2) Polymers are materials formed by chains or three-dimensional networks, of monomers bonded together.

(3) Polymer-Impregnated Concrete (PIC) is precast portland cement concrete which is impregnated with a liquid monomer system which is subsequently polymerized.

(4) Polymer Concrete (PC) is a mixture of aggregate and monomer which is subsequently polymerized.

(5) 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.

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

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

(8) Cross-Linking Agents are monomers that create three-dimensional polymer networks instead of long chains. Cross-linking agents are used primarily in polymer concrete to increase the rate of polymerization.

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

### 1.3 Safety

Monomers used to produce concrete-polymer materials are volatile, flammable, and toxic materials. Construction practice has shown that these materials can be stored and handled safely in large projects by following recommended precautions. Manufacturers' recommendations for storage and handling should be carefully followed. Reference 2 provides guidance for the safe use of chemicals for concrete-polymer materials.

Chemicals should be stored in cool, shaded areas. Initiators should not be stored in the same area as monomers or promoters. Personnel handling and mixing monomers should be equipped with respirators with chemical filters, safety eyeglasses, and impervious gloves and aprons. Mixing should occur in clean mixing vessels in a shaded, well-ventilated area. All sources of fire or sparks should be removed from the mixing area. Electrical equipment should be properly grounded and motors should be explosion proof.

Extreme caution should be exercised to prevent promoters and initiators from being mixed together in concentrated form because of the danger of a violent reaction.

After monomer and initiator are mixed together, the solution should be used as soon as possible, especially when promoter is present, since the pot life is usually less than one hour. Excess monomer solution can be disposed of by placing it in open-top containers partially filled with aggregate.

Additional initiator and/or promoter can be added to the monomer to shorten the pot life for monomers used for impregnation. After polymerization, the polymer can be disposed of the same as any other inert material.

## CHAPTER 2. PARTIAL-DEPTH POLYMER-IMPREGNATED CONCRETE

Partial-depth polymer impregnation procedures have been developed for the surfaces of bridge decks to provide improved durability (3,4). The polymer-impregnation results in significantly less water and chloride penetration into the concrete (5).

Two bridge decks have been impregnated in Texas, at Big Spring and at Lubbock, using specifications developed as part of Research Study 114. The cost of impregnation at Big Spring was \$10 per sq yd and at Lubbock \$15 per sq yd. The impregnated depth for these bridges was found to be less than 0.5 in. (1.3 cm) in many areas, and the polymer appeared to be spotty and non-uniform (6). This was attributed partly to the experimentation with drying times and temperatures and soaking times outlined in the specifications (4).

The following recommendations are made for future polymer impregnation. These are based on laboratory tests (7) and field tests (4,6).

### 2.1 Drying

Clean, well-graded concrete sand should be placed to a depth of 3/8 in. (1 cm) prior to drying. Not more than 5 percent of the sand should be retained on a No. 16 sieve and not more than 5 percent should pass a No. 100 sieve.

Hot forced air or infrared heaters should be used for drying. Insulated covered enclosures will be required for hot forced air and in some cases may be desirable for infrared heaters. The temperature should be raised at a rate not exceeding 100<sup>o</sup>F (38<sup>o</sup>C) per hour. The bridge deck should be dried at a surface temperature of 250 to 300<sup>o</sup>F (121 to 149<sup>o</sup>C). If infrared heaters are used, the surface should be dried for a minimum of 6 hours and, if warm forced air is used, for a minimum of 8 hours. One temperature sensor should be used for each 100 sq ft (9.3 m<sup>2</sup>).

## 2.2 Cooling

The concrete surface should be cooled prior to monomer application with the sand left in place. The surface of the bridge deck should be protected to prevent moisture from reentering the concrete. If moisture does reenter the surface, the concrete should be redried. The surface should cool to a maximum of 100°F (38°C) prior to application of monomer. The sand should be rescreeded to provide a uniform sand cover. Temperature sensors should be replaced if damaged.

## 2.3 Monomer System

The monomer system should consist of 95 percent (weight) methyl methacrylate and 5 percent (weight) trimethylolpropane trimethacrylate. The initiator should consist of 0.5 percent (weight) 2, 2-azobis (isobutyronitrile) of the weight of the monomer system.

## 2.4 Monomer Application

Monomer should be applied as soon, and no more than 24 hours, after the slab temperature has been reduced to 100°F (55°C) or less. The monomer should be applied uniformly at a minimum rate of 0.8 lb per sq ft (4 kg per m<sup>2</sup>) to the surface. The monomer should be applied as a fine spray so as to not erode the sand cover. As the monomer is applied, the surface should be covered with polyethylene film to minimize evaporation losses. Monomer should be permitted to soak into the concrete for 4 to 6 hours. If, during the soaking period, the sand becomes dry due to evaporation loss or due to absorption into the concrete, additional monomer should be applied to the surface.

## 2.5 Polymerization

The monomer should be polymerized by heating the surface uniformly to at least 150°F (66°C) but not exceeding 190°F (88°C). The temperature should be maintained for 2 to 4 hours. The heating source should not contain an open flame or exposed high temperature elements within the enclosure. Steam heat is preferable. During polymerization, the polyethylene film should remain over the surface of the sand cover to minimize evaporation loss.

The practice of using open-flame infrared heaters should not be permitted for polymerization with or without a membrane in place. With the polyethylene removed, monomer will quickly evaporate from the sand as the temperature increases. This will likely cause evaporation of monomer from the surface of the concrete. Water sprayed on the sand only increases the time required to increase the surface temperature. With a plastic membrane in place, the monomer vapors are more concentrated beneath the membrane and the danger of fire is greatly increased. It has been learned that, in one large bridge deck impregnation in another state in which a membrane with a high melting point was used in conjunction with electric infrared heaters, many small fires occurred.

## CHAPTER 3. POST-TENSIONED POLYMER-IMPREGNATED BEAMS

Post-tensioned PIC beams were made using precast concrete I-sections 8-in. (20-cm) deep and 8-ft (2.4-m) long (8) as shown in Fig. 3.1. Unbonded tendons consisting of two to eight 0.25-in. (0.64-m) high strength wires in conduits were cast into the concrete. Two No. 2 mild steel bonded reinforcing bars were placed in the bottom flange and one No. 2 was placed in the top flange to resist temperature-induced stresses during drying and handling stresses prior to post-tensioning.

### 3.1 Fabrication of Beams

The impregnation procedure was as follows:

- (1) The beams were dried at a temperature range of 210 to 275<sup>o</sup>F (100 to 135<sup>o</sup>F) for 120 hours to remove the free water. Infrared heaters were used as the heat source.
- (2) The beams were placed in an impregnation chamber with a bolted, air-tight lid. A vacuum of ~30-in. (76-cm) of Hg was maintained for 18 hours prior to the introduction of monomer.
- (3) With the vacuum maintained, the monomer solution was introduced into the chamber. The monomer solution consisted of 95 parts (weight) of methyl methacrylate, 5 parts (weight) TMPTMA, and 0.5 part (weight) 2,2'-azobis isobutyronitrile (AIBN) initiator. The monomer was maintained at a level slightly above the top of the beam. After a 30-minute soaking period, nitrogen was injected into the chamber to provide an overpressure of 50 psi for 3 hours.
- (4) The beams were removed from the impregnation chamber and placed in a tank of pre-heated water at 176<sup>o</sup>F (80<sup>o</sup>C) for 4 to 5 hours to polymerize the monomer.

After impregnation, the prestressing wires were tensioned. Two of the beams were grouted to produce bonded tendons. Conventional portland cement grout was used in one beam; polymer grout was used in the other.

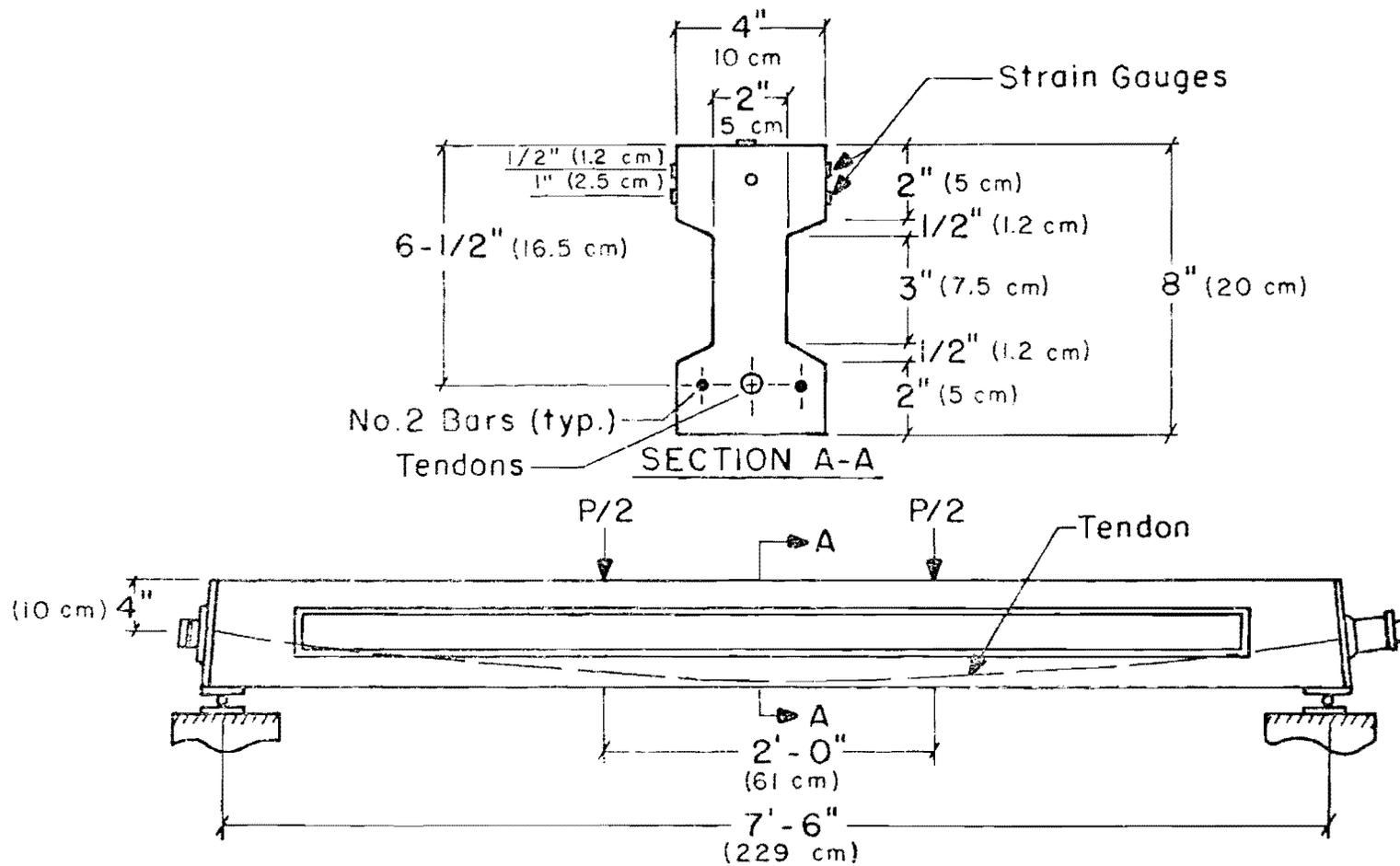


Fig. 3.1. Nominal dimensions and loading arrangement.

### 3.2 Flexural Behavior

The beams designed to investigate flexural behavior were loaded as shown in Fig. 3.1. Figure 3.2 shows the load-deflection response for four PIC beams and a control beam.

Beams PBC-2 and PBF-2 had two 0.25-in. (0.64-cm) wire tendons that corresponded to a steel ratio of 0.0038. PBF-8 had an 8-wire tendon that corresponded to a steel ratio of 0.0151. PBF-8 carried 3.2 times more load than the control, PBC-2, with about the same deflection at ultimate load. The control beam could accommodate only two wires due to the tensile stress in the top flange after post-tensioning. Deflections predicted with a computer program were in good agreement with observed deflections.

PIC beams with bonded tendons developed about the same ultimate strength as beams with unbonded tendons, but the ductility was significantly improved. The beam with polymer grouting developed about the same ultimate load as the beam with conventional grouting but had about 33 percent greater deflection.

A modified equivalent rectangular stress block was developed which permits the calculation of ultimate moments that are in good agreement with test values.

Recommended design values for compressive strength, modulus of elasticity, tensile strength, modulus of rupture, wobble coefficients, and friction coefficients may be found in Reference 8.

### 3.3 Shear Behavior

Beams were tested to determine the shear strength of PIC members. It was found that the percentage of prestressing steel has a primary influence on the shear strength. The higher the percentage of steel (which results in a higher prestressing force), the higher the shear strength. Prediction of flexural shear strength of PIC beams using American Concrete Building Code equations is conservative by about 20 percent.

### 3.4 Time-Dependent Behavior

Two beams were tested for time-dependent behavior. One, with a 4-wire tendon, was loaded to produce an initial compressive stress in the top flange equal to 16 percent of the ultimate compressive strength. The second beam,

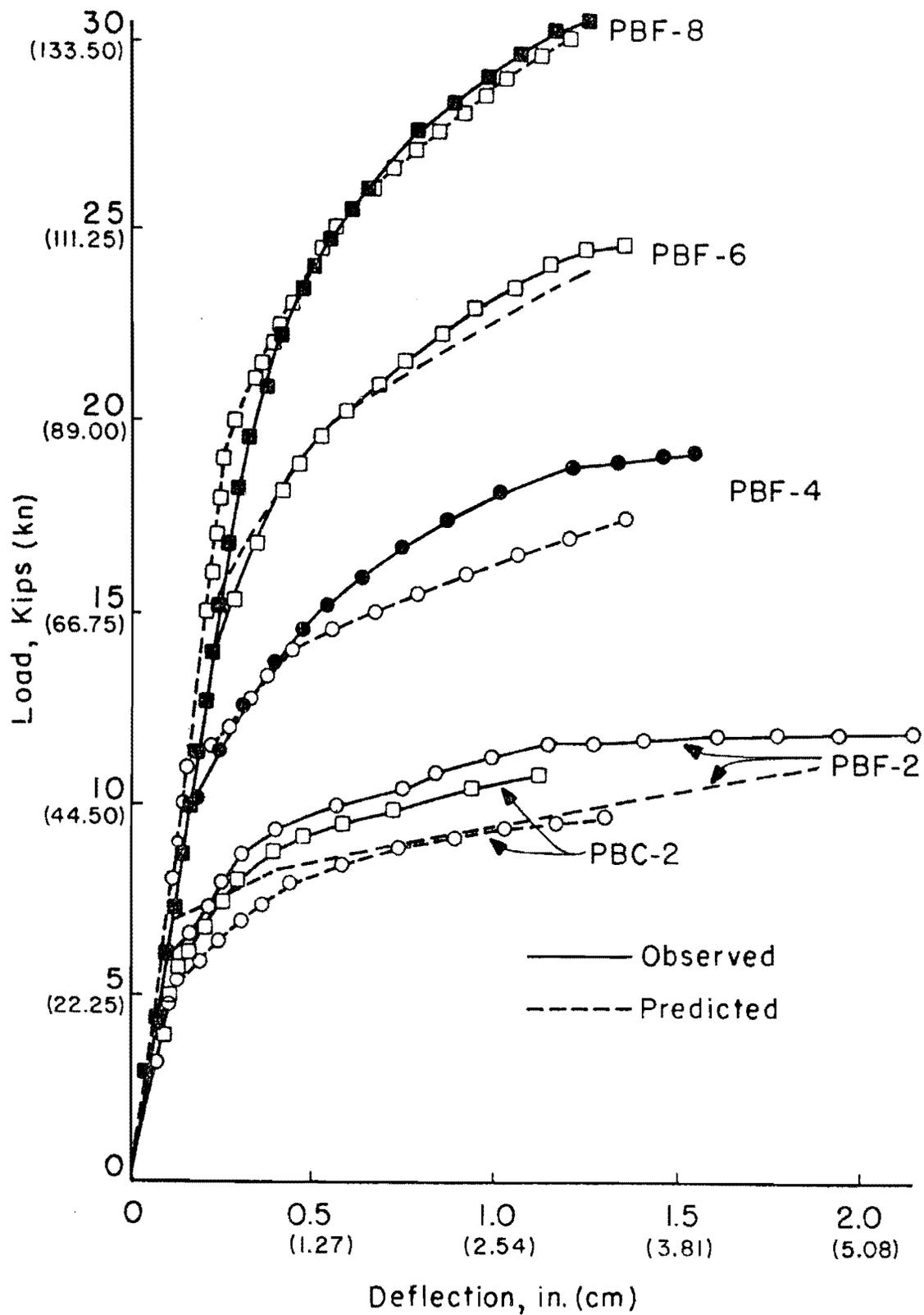


Fig. 3.2. Load-Deflection Responses for PIC and Control Beams.

with an 8-wire tendon, was loaded to produce a compressive stress of 30 percent of the ultimate in the top flange.

The unit creep was found to be a function of the stress level. The higher the initial compressive stress, the higher the creep. The creep was found to be about 1/10 to 1/13 of the creep for unimpregnated concrete. The deflections due to creep were about 1/9 to 1/16 of the deflection due to initial load. The relaxation of the wire tendons was about 2.9 percent.

## CHAPTER 4. POLYMER CONCRETE FOR REPAIR OF CONCRETE

Polymer concrete (PC) has proven to be a durable, strong material for the repair of concrete. The monomers used to make PC have a very low viscosity, approximately the same as water, and penetrate the adjacent concrete surface, which provides a very good bond. Repairs can be made quickly, which permits the area to be returned to traffic sooner. The unit cost of polymer concrete is considerably higher than that of portland cement concrete but the very short repair time and the durability of the repair make PC a cost effective repair material for highway repair.

Considerable research has been reported on PC. Several reports have been published as part of Research Study 114 (3,9,10). Other research has been reported by other investigators (11,12). A summary of the requirements for PC repairs follows.

### 4.1 Monomer Formulations

Several monomer formulations have been successfully used. Table 4.1 gives the proportions of the monomer systems used in this research. Figure 4.1 gives percentages of BzP and DMT as a function of temperature. Formulation No. 1a has been used more than any other. Butyl acrylate is used to provide more ductility in the repair. The TMPTMA has been found to reduce the surface blistering that occurs in very hot weather, especially when the monomer temperature has increased because of exposure of the storage container to direct sunlight.

### 4.2 Aggregate

Aggregate should be clean, sound, and free of organic materials. The aggregate should be as dry as possible since the monomer is not water soluble, and moisture on the aggregate will interfere with the bond. It is recommended that moisture be less than one percent by weight.

Table 4.1. 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
3a	70 to 100 (21 to 38)	88	10	2	2	4	
3b	40 to 70 (4 to 38)	88	10	2	3	6	
4	30 to 100 (-1 to 38)	88	10	2	see Fig 2.1		
5	30 to 100 (-1 to 38)	95		5	see Fig 2.1		see Fig 2.1
6	30 to 100 (-1 to 38)	98		2	see Fig 2.1		see Fig 2.1

MMA - Methyl methacrylate

BA - Butyl acrylate

TMPTMA - Trimethylolpropane trimethacrylate

LP - Lauroyl peroxide

DMT - N, N-dimethyl-p-toluidine

BzP - Benzoyl peroxide

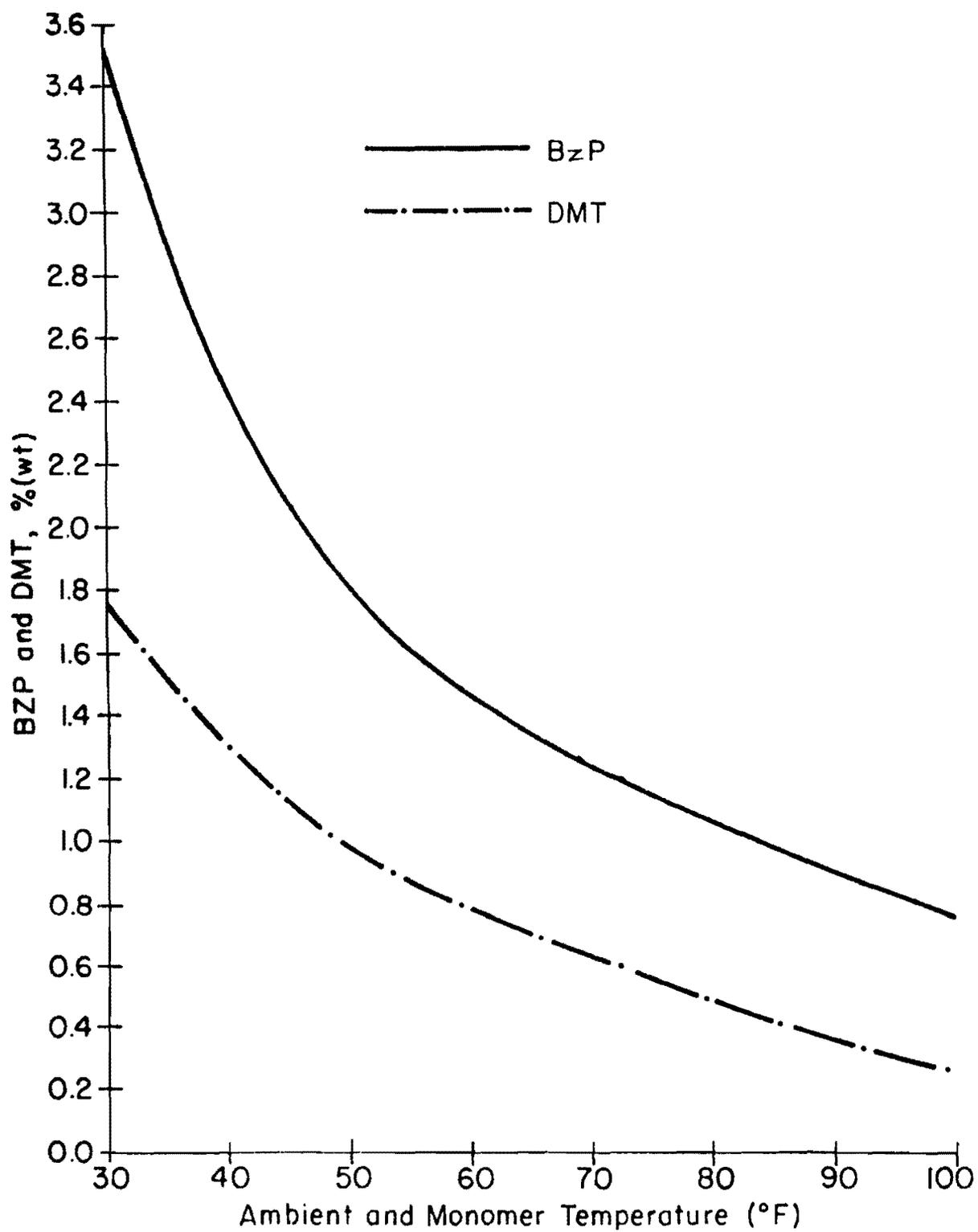


Fig. 4.1. Tentative Recommended Percentages of BzP and DMT.

The aggregate should be well-graded in order to require only the minimum amount of monomer to fill the voids. For shallow repairs, 3/4 in. (1.9 cm) or less, a well-graded concrete sand can be used. Single gradation aggregate, such as sand blast 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.

#### 4.3 Properties

The mechanical and durability properties of PC made from MMA are very good. Compressive strengths range from 4500 to 10,000 psi (31,000 to 69,000  $\text{kN/m}^2$ ).

The modulus of elasticity values are in the range of  $1 \times 10^6$  to  $3 \times 10^6$  psi ( $6.9 \times 10^6$  to  $20.7 \times 10^6$   $\text{kN/m}^2$ ). Moduli of rupture range from 1100 to 2000 psi (7600 to 13,800  $\text{kN/m}^2$ ).

#### 4.4 Preparation for Repair

All unsound concrete and any asphalt must be removed. Corrosion scale should be cleaned from the reinforcing steel. The concrete surface should be dry and clean from contaminants. Wet or damp concrete surfaces should be dried and allowed to cool before placing monomer.

Cracks in the concrete should be sealed with latex or silicone caulking compound or polyester putty to prevent leakage. Formwork should be treated with mold release agent. All joints must be water-tight.

#### 4.5 Mixing and Placement of PC

The monomer may be combined with the other liquid components except the initiator prior to the time of the repair. The initiator should be added and completely dissolved just before adding the monomer to the aggregates. In no case should the initiator and promoter be allowed to come into contact in concentrated form.

One method of placing the monomer is to put the aggregate into the repair hole and saturate the aggregate with monomer. The monomer, with initiator added, is poured or sprinkled slowly over the aggregate. The aggregate should be vibrated or tamped to insure good consolidation. The surface can be

screeded and troweled to a smooth finish. Additional sand may be required on the surface to provide a reasonably smooth surface or to absorb excess monomer. Polyethylene should be placed over the repair to minimize evaporation. Additional monomer should be added if the monomer is depleted due to leakage or evaporation.

The second method is to premix monomer and aggregate prior to placement. Mixing can be accomplished in pans or other containers; for larger quantities, a concrete mixer can be used. Reference 10 should be consulted for additional information on this method.

#### 4.6 Polymerization

The monomer formulations shown in Table 4.1 generally provide at least 20 to 30 minutes of working time prior to curing. During polymerization, the temperature on the surface may increase 50 to 100°F (10 to 38°C) above ambient, especially for repairs several inches or more in depth. Generally the repair is ready to be turned back to traffic within two hours or less after the monomer is placed.

#### 4.7 Results

Repairs made with PC in Texas have performed very well, with nearly every one still in place. In some cases the surface has eroded or worn slightly, apparently due to evaporation or leakage of monomer from the surface. A few repairs have cracked but have continued to perform well. The cost of the chemicals used to produce PC is about \$260 per cu yd (\$340 per cu m).

## CHAPTER 5. POLYMER CONCRETE OVERLAYS

The need for adequate waterproofing systems and materials for bridge decks has long been recognized. Many systems and materials have been used with varying degrees of success. Polymer impregnation of bridge decks was developed as a method for waterproofing.

A polymer concrete overlay was developed as part of Research Study 114 (13). PC overlays have several advantages that make them a very promising method for waterproofing bridge decks: (1) they are thin and lightweight; (2) they can be applied during the day between peak traffic periods and do not require closing the structure continuously for long periods of time; (3) they can be applied by maintenance forces without special equipment; (4) they provide a very good skid resistant surface; and (5) they are relatively economical.

Reference 13 should be consulted for specific details of the overlay. A summary of the procedure is presented in the following sections. These procedures are based on an overlay applied to a 40-ft x 120-ft (12.2-m x 36.6-m) bridge near Henrietta.

### 5.1 Preparation of the Surface

The surface should be cleaned by brooming. Oil, grease, asphalt, or other contaminants should be removed, preferably by sandblasting. The surface should be dry. Even if no moisture is visible, it is recommended that the surface be dried with an asphalt heater, or some other type of heater, to insure that the concrete surface is dry.

Screed guides, 0.5-in. (1.3-cm) thick wood strips with latex caulking, should be nailed to the concrete, outlining the area over which the overlay is to be applied in one application. Generally an area one lane in width by 40 ft (12.2 m) or more in length is recommended.

## 5.2 Placement of Aggregate

Well-graded, clean, dry concrete sand should be placed in the area and screeded to a depth of 0.25 in. (0.64 cm). The sand should be dried to a moisture content of less than one percent. Coarse aggregate with a diameter of  $\approx 0.375$  in. (1 cm) should be applied at a rate of 1.8 lb per ft<sup>2</sup> (8.8 kg per m<sup>2</sup>) to produce a total overlay thickness after compacting of 0.375 to 0.5 in. (1 to 1.3 cm). The coarse aggregate should be compacted with a hand roller producing light pressure. A 6-in. (15-cm) diameter concrete roller has been found to be satisfactory.

## 5.3 Monomer Formulations

Two monomer applications are used. The first monomer system is designed to provide penetration into the concrete. The second monomer system is a more viscous one to minimize run-off and more highly promoted to insure rapid polymerization. This system is a solution of polymerized MMA in unpolymerized MMA. The two monomer formulations are given in Table 5.1.

Table 5.1. Monomer Systems.

Application	Chemicals, Percent (weight)					
	MMA	MMA Syrup	TMPTMA	BA	BzP <sup>a</sup>	DMT <sup>a</sup>
First	95		5		1.35	0.7
Second	48	32	2.5	17.5	1.35	0.7

<sup>a</sup>Percentages of BzP and DMT are shown for an ambient temperature of 65°F (18°C); percentages will vary with different temperatures and may be obtained from Fig. 5.1.

## 5.4 Monomer Application

The first monomer treatment is applied with a spray bar and permitted to soak for 30 minutes. During the soak period, the area should be covered with polyethylene membrane to minimize evaporation. After 30 minutes, the second treatment is applied. Sand and/or coarse aggregate should be applied over areas where monomer ponds on the surface. The area should be covered with

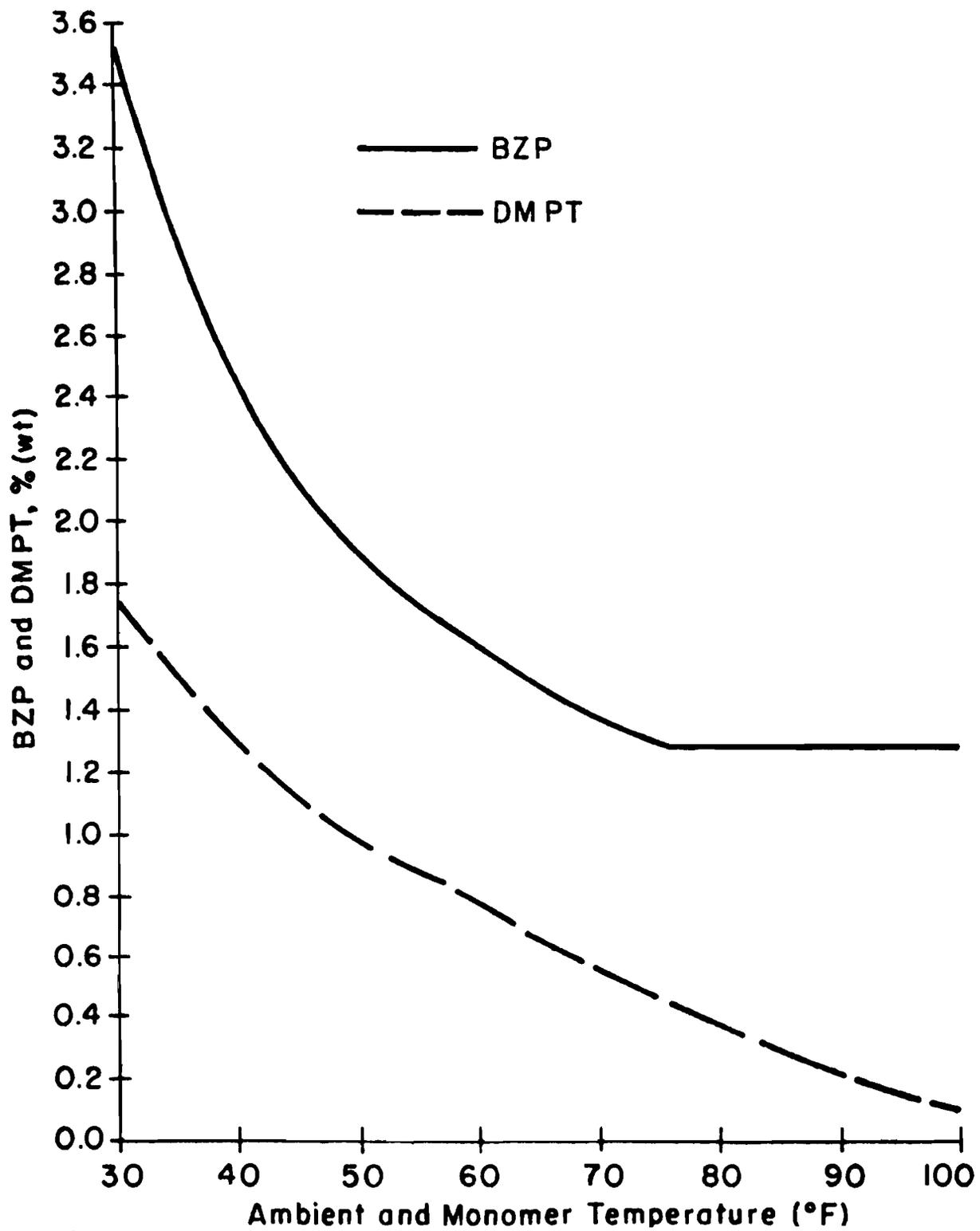


Fig. 5.1. Tentative Recommended Percentages of BzP and DMPT.

polyethylene during curing. After curing, the wood screed guides are removed and work on another area is begun.

### 5.5 Results

The chemicals for the overlay cost \$0.71 per sq ft (\$7.64 per sq m). It is estimated that a 5-man crew could apply 1200 to 2000 sq ft (110 to 185 sq m) per day. With aggregate spreaders and automated monomer applicators, the rate could be greatly increased.

The overlay shows no evidence of delaminating or cracking after exposure during a severe winter. The skid resistance measured with the British portable skid tester was significantly higher than for a concrete surface. The coarse aggregate provides good channeling for the water, which should minimize hydroplaning.

## CHAPTER 6. CONCLUSIONS

Concrete-polymer materials have excellent strength and durability properties. In Research Study 114, several applications have been identified for use in highway construction. These applications include

- (1) partial-depth polymer impregnation for bridge decks,
- (2) post-tensioned polymer-impregnated concrete beams,
- (3) polymer concrete repair of concrete, and
- (4) polymer concrete overlays for bridge decks.

All of these applications except post-tensioned PIC beams have been implemented.

## REFERENCES

1. Steinberg, M., L. Kukacka, P. Colombo, J. Kelsch, B. Monowitz, J. Dikeou, J. Backstrom, and S. Rubenstein, Concrete-Polymer Materials, First Topical Report, BNL 50134 (T-509) and USBR Ben. Rep. 41, 1968.
2. Fowler, D.W., Kukacka, L.E., Paul, D.R., Schrader, E.K., and Smoak, W.G., "Safety Aspects of Concrete-Polymer Materials", Proceedings of International Symposium on Polymers in Concrete, SP-58, American Concrete Institute, October 1976, pp. 123-138.
3. Fowler, D., T. Houston, and D. Paul, "Polymer-Impregnated Concrete for Highway Applications", Research Report 114-1, Center for Highway Research, The University of Texas at Austin, February 1973.
4. Webster, R., Fowler, D., and Paul, D., "Partial Polymer-Impregnation of Center Point Bridge", Research Report 114-5, Center for Highway Research, The University of Texas at Austin, January 1976.
5. D.W. Fowler, Donald R. Paul, and Piti Yimprasert, "Corrosion Protection of Reinforcing Steel Provided by Polymer-Impregnated Concrete", Center for Highway Research, The University of Texas at Austin, Research Report 114-2, December 1974.
6. Kennedy, Temple R., "Polymer Impregnation of New Concrete Bridge Decks", Texas Department of Highways and Public Transportation and U.S. Department of Transportation Federal Highway Administration, Research Report 508-2F, October 1977.
7. Yimprasert, P., Fowler, D.W., and Paul, Donald R., "Durability, Strength, and Method of Application of Polymer-Impregnated Concrete for Slabs", Research Report 114-4, Center for Highway Research, The University of Texas at Austin, January 1976.
8. Limsuwan, E., Fowler, D.W., and Paul, D.R., "Behavior of Post-Tensioned Polymer-Impregnated Concrete Beams", Research Report 114-6, Center for Highway Research, The University of Texas at Austin, June 1978.
9. M.M. Jaber, David W. Fowler, and Donald R. Paul, "Repair of Concrete with Polymers", Research Report 114-3, Center for Highway Research, The University of Texas at Austin, February 1975.
10. Fowler, D.W., and D.R. Paul, "Polymer Concrete Repair of Bridge Decks", Research Report 114-8, Center for Highway Research, The University of Texas at Austin, March 1979.

11. 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.
12. McNerney, Michael T., "An Investigation Into the Use of Polymer-Concrete for Rapid Repair of Airfield Pavements", Proceedings of the Second International Congress on Polymers in Concrete, Austin, Texas, October 1978, p. 431.
13. Hsu, M., Fowler, D.W., Paul, D.R., and Miller, M., "An Investigation of the Use of Polymer Concrete Overlays for Bridge Decks", Research Report 114-7, Center for Highway Research, The University of Texas at Austin, March 1979.