USE OF IMPROVED STRUCTURAL MATERIALS SYSTEMS IN MARINE PILING

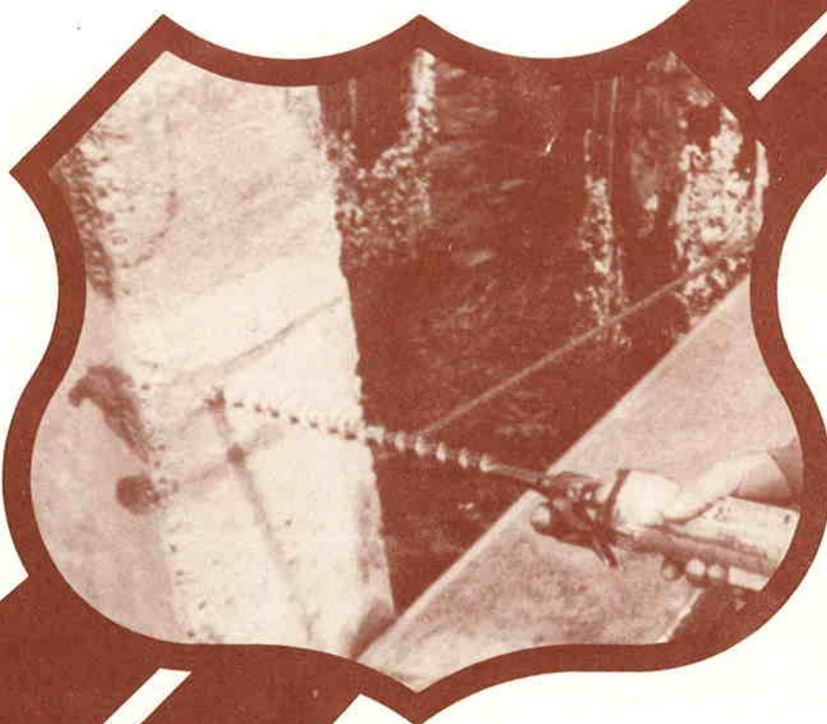
U.S. Department
of Transportation

Federal Highway Administration

Offices of Research
and Development
Washington, D.C. 20590

Report No.
FHWA/RD-82/113

Interim Report
September 1982



FOREWORD

This report contains the results of a study to evaluate the feasibility of fabricating precast prestressed concrete piles using low permeability materials that were developed mainly for the protection and rehabilitation of bridge decks. The report describes promising techniques that can be used for the commercial manufacture of marine piles made from polymer concrete, polymer-impregnated concrete, internally sealed concrete, and latex modified concrete.

Sufficient copies of the report are being distributed by FHWA Bulletin to provide a minimum of one copy to each FHWA regional office, one copy to each FHWA division office, and two copies to each State highway agency. Direct distribution is being made to the division offices.

Richard E. Hay
Director, Office of Engineering and
Highway Operations Research
and Development

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-82/113		

4. Title and Subtitle

USE OF IMPROVED STRUCTURAL MATERIALS SYSTEMS IN MARINE PILING

5. Report Date
September 1982

6. Performing Organization Code

8. Performing Organization Report No.

7. Author(s)
William J. Quinn

9. Performing Organization Name and Address

Oregon State Highway Division
State Transportation Building
Salem, Oregon 97310

10. Work Unit No. (TRAIS)
FCP 34K3073

11. Contract or Grant No.
DOT-FH-11-9587

12. Sponsoring Agency Name and Address

Office of Research, Materials Division
Fairbank Highway Research Station, HRS-22
Federal Highway Administration
Washington, D.C. 20590

13. Type of Report and Period Covered

Interim Report
4/79 to 2/81

14. Sponsoring Agency Code
M/0805

15. Supplementary Notes

Contract Manager: Peter A. Kopac

16. Abstract

This report contains the results of a study to evaluate the feasibility of manufacturing precast, prestressed marine piles from polymer concrete, polymer impregnated concrete, internally sealed concrete and latex modified concrete. Included in the report are (1) a description of the laboratory work that preceded the preparation of the specifications, (2) a description of the manufacturing process and problems with each system, and (3) the initial results of the short term performance of the various structural concretes.

17. Key Words	18. Distribution Statement
Marine Piling, Polymer Concrete, Polymer Impregnated Concrete, Internally Sealed Concrete, Latex Modified Concrete, Prestressed Concrete Piles	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	107	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

	Page
List of Figures	iii
List of Tables	iv
Section I - Introduction	1
Section II - Laboratory Work	2
Internally Sealed Concrete	2
Latex Modified Concrete	7
Polymer-Impregnated Concrete	11
Polymer Concrete	22
Section III - Fabrication	25
Polymer-Impregnated Concrete	29
Internally Sealed Concrete	39
Latex Modified Concrete	48
Polymer Concrete	56
Epoxy-Coated Reinforcing Steel	61
Section IV - Problems During Manufacturing	61
Horizontal Bending	61
Creep and Shrinkage Measurements	63
Section V - Installation and Testing	66
Section VI - Initial Evaluation and Comments	73
References	75
Appendix	76

LIST OF FIGURES

Number	Title	Page
3-1	Placing Concrete Pile into Drying Oven	32
3-2	Location of Thermocouples in Polymer-Impregnated Concrete Piles	33
3-3	Polymer Impregnation Cycle for Pile 1A	36
3-4	Pile Being Placed in Monomer Soaking Tank for Impregnation . .	37
3-5	Pile Being Placed in Hot Water Bath	37
3-6	Wax Beads Added to Mixer	46
3-7	Placing Internally Sealed Concrete Pile into Melting Oven . .	46
3-8	Location of Thermocouples in Internally Sealed Concrete Piles	47
3-9	Internally Sealed Concrete Temperature vs. Time for Pile 2E	51
3-10	Latex Modifier Added to Mixer	52
3-11	Slump Test for Latex Modified Concrete	52
3-12	Polymer Concrete Exotherm	58
4-1	Horizontal Curvature of Polymer Concrete Pile	64
5-1	Pile Installation Site at Yaquina Bay	64
5-2	Chloride Ion Sample Being Removed From Pile	72
5-3	Measuring Half-Cell Potential	72

LIST OF TABLES

Number	Title	Page
2-1	Calculated Mix Design for Internally Sealed Concrete	5
2-2	Internally Sealed Concrete Temperatures During Wax Bead Melting	5
2-2a	Electric Oven Heater	5
2-2b	Electric Blanket Heater	5
2-2c	Electric Infrared Heater	6
2-2d	Hot Air Heater	6
2-3	Compressive Strength Study of Internally Sealed Concrete . .	8
2-4	Calculated Mix Design Latex Modified Concrete	10
2-5	Compressive Strength Study of Latex Modified Concrete	10
2-6	Polymer-Impregation Data	12
2-7	Impregnation of Block A, Electric Oven Method	13
2-8	Impregnation of Block B, Electric Oven Method	13
2-9	Impregnation of Block C, Electric Oven Method	14
2-10	Impregnation of Block E, Electric Oven Method	14
2-11	Impregnation of Block F, Electric Oven Method	15
2-12	Impregnation of Block G, Electric Oven Method	15
2-13	Impregnation of Block H, Hot Air Oven Method	16
2-14	Impregnation of Block I, Electric Oven Method	16
2-15	Impregnation of Block J, Electric Oven Method	17
2-16	Impregnation of Block K, Electric Oven Method	17
2-17	Impregnation of Block L, Infrared Heating Method	18
2-18	Impregnation of Block M, Infrared Heating Method	18
2-19	Impregnation of Block N, Infrared Heating Method	19

LIST OF TABLES - Continued

Number	Title	Page
2-20	Impregnation of Block O, Electric Oven Method	19
2-21	Impregnation of Block P, Electric Oven Method	20
2-22	Polymer Concrete Formulations	23
2-23	Aggregate Gradation for Polymer Concrete	23
2-24	Compressive Strength Study of Polymer Concrete	24
3-1	Bid Schedule	27
3-2	Pile Manufacture Sequence	28
3-3	Concrete Mix Ingredients	30
3-4	Compressive Strength and Modulus of Elasticity of Conventional Concrete and Polymer Impregnated Concrete. . .	31
3-5A	Concrete and Water Temperature During Impregnation of Pile A.	34
3-5B	Concrete and Water Temperature During Impregnation of Pile B.	40
3-5C	Concrete and Water Temperature During Impregnation of Pile C.	41
3-5D	Concrete and Water Temperature During Impregnation of Pile D.	42
3-5E	Concrete and Water Temperature During Impregnation of Pile E.	43
3-6	Compressive Strength and Modulus of Elasticity of Internally Sealed Concrete	45
3-7A	Concrete Temperature During Melting of Wax Beads Pile 2A. . .	49
3-7B	Concrete Temperature During Melting of Wax Beads Pile 2B. . .	49
3-7C	Concrete Temperature During Melting of Wax Beads Pile 2C. . .	50
3-7D	Concrete Temperature During Melting of Wax Beads Pile 2D. . .	50
3-7E	Concrete Temperature During Melting of Wax Beads Pile 2E. . .	50
3-8	Compressive Strength and Modulus of Elasticity of Latex Modified Concrete	54

LIST OF TABLES - Continued

Number	Title	Page
3-9	Polymer Concrete Coarse Aggregate Gradation	57
3-10	Polymer Concrete Formulations	57
3-11	Compressive Strength and Modulus of Elasticity of Polymer Concrete	60
4-1	Maximum Horizontal Bow in Piles	62
4-2	Strain and Modulus of Elasticity for Select Piles	65
5-1A	Half-Cell Potential Readings in Volts	67
5-1B	Half-Cell Potential Readings in Volts	69
5-1C	Half-Cell Potential Readings in Volts	70
5-2	Chloride Ion Concentrations	71

SECTION 1

INTRODUCTION

The purpose of this study was to evaluate the use of newly developed improved structural concretes in marine piling. Generally, these materials have low permeability and were developed to eliminate premature deterioration of concrete bridge decks caused by penetrating deicing salts. Because similar problems were experienced with concrete piles in a marine environment, the implementation of the special concrete materials appeared highly desirable. The technique used in the production of each material varies greatly and this added to the complexity of the study. The special concretes investigated in this study include internally sealed concrete, latex modified concrete, polymer concrete, and polymer-impregnated concrete. Five piles were fabricated using each material. In addition, six miniature piles containing epoxy coated rebar were included for analysis. Three conventional concrete piles were also fabricated for comparison purposes. During the project, 23 piles measuring 12" x 12" x 65' (.30 x .30 x 19.8 m) were fabricated and placed in dolphins for pier protection in Yaquina Bay at Newport, Oregon. The miniature piles measured 8" x 8" x 20' (.20 x .20 x 6.1 m), and they were attached to the conventional piles so as to be exposed to the tidal action.

The project was conducted in three phases. The first phase consisted of preparing plans and specifications for the manufacture and placement of the piles. (See Appendix for specifications). The second phase consisted of evaluating the commercial manufacture, handling, and installation of the piles. The third phase was the evaluation of the performance of the piles for a two-year period.

Before writing the specifications, a literature search was conducted to gain the latest information on each of the experimental concrete materials. The findings of the search indicated most of the previous work was performed for bridge deck protection and very little information was available for precast prestressed concrete construction. Because each of the experimental protective materials had to be modified for prestressed concrete work, an accelerated laboratory study was initiated. Only the epoxy coated rebars were omitted from the laboratory study since 17 products were already approved for highway construction.

During the literature search, personnel from ODOT visited the Office of Research and Materials of the Florida State Highway Department to learn about their work with internally sealed concrete. Much of the discussion with the Florida researchers centered on their experiments in developing a method of melting the wax beads by an internal heating system. The preliminary results of their laboratory work appeared very promising, but the concept was not far enough advanced to be used in the marine pile project. The Florida visit concluded with a tour of the laboratory facilities.

Next, ODOT personnel visited the Bureau of Reclamation in Denver, Colorado to review their work with both polymer concrete and polymer impregnated concrete. Several meetings were held with key technical personnel closely associated with the development and testing of methyl methacrylate polymer concretes. During the visit, the impregnation facilities were inspected and a vinyl ester polymer concrete overlay was observed being placed. The method of polymerizing fully impregnated polymer concrete test slabs utilizing a hot water bath was of particular interest and appeared to be applicable for use in marine pile work.

Before Oregon's laboratory work commenced, material, supplies, and equipment had to be obtained. Because monitoring of the temperature within the concrete was crucial during the drying and heating cycles for the polymer-impregnated concrete and internally sealed concrete treatments, a thermocouple thermometer was purchased. To increase the monitoring capabilities a twelve unit selector switch was connected to the thermometer.

A hot water bath/steam curing chamber was also constructed during the preparation time. The unit was made by retro-fitting a 55 gallon (209 l) drum with two 4,000 watt electric heating elements. Separate thermostats were attached to each heating element and a removable rack was built 15" (.38 m) below the top of the barrel to support test samples. By regulating the depth of the water and the water temperature, the drum could be operated as a hot water bath or a steam curing chamber.

A brief description of the general production techniques for the experimental material follows:

Latex Modified Concrete is produced by adding an appropriate amount of styrene-butadiene latex modifier to a conventional concrete during mixing. The mix design is adjusted to account for the surplus water found in the latex emulsion. The mixing, placing and finishing are done with conventional equipment. Latex modified concrete is normally cured in two steps. A moist cure is required during the first 24 hours and this is followed by 72 hours of curing in air.

The Internally Sealed Concrete is made by adding a specified quantity of wax beads, usually 3 percent by weight of the mix, into a conventional non-air-entrained concrete during mixing. The beads are a blend of 75 percent paraffin and 25 percent montan wax and range in size from #20 to #80 mesh. The concrete is mixed, placed, finished and cured using conventional methods and equipment. After the concrete has cured, it is heated to melt the wax beads. The heating requirement usually specifies a minimum temperature of 180°F (82.2°C) be attained at the 2-inch depth inside the concrete. The rate of heating and cooling of the concrete is very critical and has to be controlled to prevent cracking.

The manufacture of Crylcon Polymer Concrete consists of blending a proprietary acrylic mortar with a dry, coarse aggregate. The acrylic mortar is composed of two components, a special powder and a liquid monomer. Since the monomer is flammable, extra care is required during handling. Crylcon polymer concrete can be mixed in a conventional mixer, but proportioning the chemical components is extremely critical. Because crylcon polymer concrete is a rapid setting mixture generally all work has to be completed within 20 minutes after mixing.

The Polymer-Impregnated Concrete system consists of five major steps. First, a concrete element is cast and cured for a minimum of 21 days. Second, the concrete is dried by subjecting it to temperatures above 250°F (121.1°C) for a period of time exceeding eight hours. Third, the concrete is allowed to cool slowly to below 100°F (37.7°C). Fourth, a low viscosity liquid monomer is allowed to penetrate the concrete by ponding or soaking techniques which last for several hours. And fifth, the monomer is converted into a hardened plastic within the concrete by the application of heat. Of the four experimental systems, the production of polymer impregnated concrete is the most complicated.

The laboratory work which is described in the following section was performed to examine the changes in the production of the experimental concretes that were necessary for precast prestressed concrete fabrication.

SECTION II

The following sections provide a description of laboratory work performed by Oregon State Highway Division personnel on four experimental concrete materials. Included in this section are the results of compressive strength studies of the different materials and results of heating studies conducted on various methods for drying concrete specimens and melting wax beads.

Internally Sealed Concrete

There were four objectives in testing internally sealed concrete in the laboratory. These were (1) to evaluate various methods of melting the wax beads, (2) to examine the effects of the wax beads on concrete strength, (3) to investigate the effects of steam curing internally sealed concrete, and (4) to evaluate the effects of melting the wax beads on concrete strength.

The study began when several batches of internally sealed concrete were made for casting 6" x 12" (152 x 305 mm) cylinders and

6" x 6" x 12" (152 x 152 x 305 mm) blocks. The mix design used in this work was the FHWA formulation recommended for bridge deck overlays and is found in Table 2-1. This was a non-air-entrained mix with a 7-1/2 sack/cy (9.8 sack/m^3) cement factor and contained a wax bead content of approximately 3 percent by weight of the concrete. A Hobart pan-type mixer was used to prepare the internally sealed concrete. The wax beads were mixed with the dry ingredients for approximately two minutes before mixing water was added to the mixer. Several small samples of concrete were removed from the mixer during batching to examine bead distribution. Results from this sampling indicated the beads were well dispersed throughout the mix.

After casting, the test specimens were cured by either of two methods. The first method was in accordance with AASHTO T 126-76, a conventional 7 day moist-room method. The second method consisted of a short steam cure followed by curing in the moist-room. Before the cylinders were placed into the steam chamber the concrete was allowed to take an initial set for 2 to 2-1/2 hours. Then steam was applied for approximately 6 hours. In order to avoid the possibility of melting the wax beads prematurely, the temperature within the steam chamber was maintained between 120°F and 140°F (48.8°C and 60°C). Normally the cylinders were tested in 7 days.

The cylinders manufactured for Test 44 were fabricated at Morse Bros. Prestressed Concrete plant. Here the cylinders were steam cured during a normal steaming operation at 150°F (65.5°C). Although these cylinders were not subjected to additional heating, some minor bead melting was detected in the outer shell of the cylinders when they were opened.

Only four methods for melting the wax beads were examined in this study. They were (1) an electric oven, (2) electric blankets, (3) electric infrared heaters, and (4) a hot air propane-fired oven. During each test, the temperature within the 6" x 6" x 12" (152 x 152 x 305 mm) test blocks was monitored periodically by thermocouples embedded in the blocks at various depths. The heating history of the various methods are found in the accompanying Tables 2-2(a) - 2-2(d).

The first two internally sealed concrete blocks were heated in a 1400 watt MacAlaster Bicknell electic oven. Thermocouples were attached to the surface and embedded at the 1-1/2" and 2" (38.1 and 50.8 mm) depth. When the blocks were first placed into the oven the thermostat was set at 150°F (65.5°C) for a two hour warm up period. Then the thermostat setting was increased to 225°F (107.2°C) for the remainder of the melting cycle. Using this heating sequence it required 3-1/2 hours to reach the desired 185°F (85°C) at the 2" (50.8 mm) depth within the blocks (see Table 2-2(a) for the temperatures recorded during this test.) At this point the heating was terminated and the blocks were allowed to cool slowly in the oven. When the blocks were opened on the following day, the wax beads were found to be completely melted in the outer 2" (50.8 mm) shell of the blocks.

Next an electric blanket system with an output power of 130 watts per square foot at 115 volts was used to heat nine internally sealed concrete blocks. The blankets were borrowed from the FHWA Fairbank Laboratory where they were used during the original development of internally sealed concrete. During this testing, three 6" x 6" x 12" (152 x 152 x 305 mm) blocks were placed under each of the three 15" x 15" (381 x 381 mm) sections of blanket. The interior blocks under each section had thermocouples embedded at 1-1/2" and 3" (38.1 and 76.2 mm) depths. The blanket was placed directly on the blocks and both were covered with 3-1/2" (88.9 mm) thick insulation to prevent heat loss. After 8 hours of heating, the average temperature at the 1-1/2" (38.1 mm) depth was 206°F (96.6°C), while the average temperature at the 3" (76.2 mm) depth was 151°F (66.1°C). At this time, the heating was terminated and the blocks allowed to cool. When the blocks were opened, complete melting of the wax beads was observed to a depth of 2" (50.8 mm). Going deeper into the block the amount of melting diminished. The temperatures recorded within the three interior blocks are found in Table 2-2(b). Two other blocks were subjected to heating with the electric blanket. One block was heated for 8 hours on each of two sides while the other block was heated for 8 hours on each of four sides. When the blocks were opened, a thorough 2-1/2" (63.5 mm) melting zone was found beneath the heated surface.

Two internally sealed concrete blocks were also heated with four 1800 watt electric infrared heaters. The heating elements were supported on an aluminum frame that was 36" (.91 m) tall. An enclosure was made over the frame consisting of a 3-1/2" (88.9 mm) layer of insulation and plastic sheeting. After some initial testing, it was found necessary to place the blocks approximately 18" (.45 m) from the heaters in order to achieve a reasonably fast melting of the wax beads. With this arrangement it required approximately 4-1/2 hours to attain a temperature of 185°F (85°C) at the 1-1/2" (38.1 mm) depth and 6 hours at the 2" (50.8 mm) depth. See Table 2-2(c) for the temperature gradients in blocks 6 and 7.

When the blocks were opened the wax beads were found to be completely melted within a depth of 2-1/2" (63.5 mm) from the top surface. The vertical sides of the blocks, however, exhibited varying degrees of melting depending on the distance from the heaters. The bottom surface of the blocks had no visible melting.

Finally, the wax beads in two internally sealed concrete blocks were melted in a specially fabricated hot air heating oven. The oven measuring 2' x 2.5' x 3.0' (.6 x .76 x .91 m) was constructed of plywood, and aluminum sheets and had a 3-1/2" (88.9 mm) layer of fiberglass insulation. A 200,000 BTU/hr propane-fired heater was obtained as the heat source. Vent holes were provided at the rear of the oven for the forced air to escape. Because of the intense heat at the discharge of the hot air blower a four foot long aluminum extension was made to increase the distance between the blocks and the heater. This arrangement provided a suitable method for melting the wax beads within the blocks. Two blocks were mounted on a small pedestal in the middle of the oven and each contained three thermocouples. The thermocouples were located on the surface and at the 1" and 2" (25.4 and 50.8 mm) depths. The time required to reach a temperature of 185°F (85°C) at the 2" (50.8 mm) depth was approximately 3 hours (see Table 2-2(d)). When the blocks were opened, the melting was found on only three surfaces, namely the top and vertical sides. Because of poor air circulation, the bottom side had only a very slight melting. The results of this testing indicated good air movement around the entire specimen was necessary if uniform melting was to be obtained. The possible difficulty in obtaining uniform heating along the 65 foot (19.8 m) long piles mandated a specification requiring the surface temperature to be measured by thermocouples on each surface of the pile at a maximum spacing of 30 (9.1 m) feet during the melting activity.

The results of testing the compressive strength of conventional and internally sealed concretes are shown in Table 2-3. In Test 41, a conventional concrete containing no entrained air was used to make four cylinders. Two cylinders received a conventional moist-room cure while two were steam cured. This test was repeated in Test 42, but this time an air-entraining agent was added to the mix. The remainder of the concrete mixes in this series contained a 3% (by weight) wax bead content.

From a comparison of the test results it appears that a 3% (by weight) content of unmelted wax beads reduced the compressive strength by approximately 20% in cylinders that were only moist cured. Similar results were reported after an extensive study by the Florida Highway Department researchers.

The effects of steam curing both conventional and internally sealed concrete were indicated in Tests 42, 43, 52, and 54. The average reduction in 7-day compressive strength for the conventional concrete was near 28% and approximately 15% for the internally sealed concrete.

The wax beads in Test 47 were melted by heating the two cylinders in an electric oven after a 6-day cure. The melting technique was similar to that already described for the internally sealed concrete blocks. It required approximately 3-1/2 hours to obtain a temperature of 185°F (85°C) at a 2" (50.8 mm) depth within the cylinder. On the 7th day after casting, two cylinders containing unmelted wax beads and two with melted beads

TABLE 2-1

Calculated Mix Design for Internally Sealed Concrete

	$FT.^3$	S.G.
Cement	3.61	3.14
Sand	6.16	2.57
3/4 - 1/2	4.01	2.62
1/2 - 1/4	5.80	2.42
Water	4.72	1.00
Air	.54	--
Wax Beads	2.16	0.86
	27.00	

1 cf = 0.0283 m^3

TABLE 2-2

Internally Sealed Concrete Temperatures During Wax Bead Melting

Table 2-2(a): Electric Oven Heater

	Block 1			Block 2		
Time	Surface Temp °F	1-1/2" Temp °F	2" Temp °F	Surface Temp °F	1-1/2" Temp °F	2" Temp °F
8:10 a.m.	68	68	66	68	66	66
8:35 a.m.	130	82	75	130	82	73
10:00 a.m.	150	125	125	150	127	125
11:35 a.m.	225	189	189	225	190	187

Table 2-2(b): Electric Blankets Heater

	Block 3		Block 4		Block 5	
Time	1-1/2" Temp °F	3" Temp °F	1-1/2" Temp °F	3" Temp °F	1-1/2" Temp °F	3" Temp °F
9:00 a.m.	63	61	63	63	63	63
10:05 a.m.	122	75	126	77	118	74
11:00 a.m.	149	95	154	99	147	97
11:55 a.m.	162	102	167	104	158	102
1:05 p.m.	172	113	178	118	169	116
2:00 p.m.	178	127	183	133	178	131
3:00 p.m.	185	140	190	145	187	142
4:10 p.m.	194	144	201	149	199	145
5:00 p.m.	203	149	203	154	208	151

$C^o = 5/9(F^o-32)$ 1 in = 25.4 mm

Internally Sealed Concrete Temperatures During Wax Bead Melting

Table 2-2(c): Electric Infrared Heater

	Block 6			Block 7		
Time	Surface Temp °F	1-1/2" Temp °F	2" Temp °F	Surface Temp °F	1-1/2" Temp °F	2" Temp °F
8:30 a.m.	68	68	68	68	66	68
9:30 a.m.	142	100	88	138	98	86
10:35 a.m.	183	148	133	181	143	133
11:30 a.m.	198	165	149	198	163	147
1:05 p.m.	230	185	171	226	185	169
2:30 p.m.	252	207	189	248	205	185

Table 2-2(d): Hot Air Heater

	Block 8			Block 9		
Time	Surface Temp °F	1" Temp °F	2" Temp °F	Surface Temp °F	1" Temp °F	2" Temp °F
10:00 a.m.	65	65	63	65	63	63
10:30 a.m.	149	108	84	151	108	84
11:05 a.m.	172	144	122	172	146	124
11:30 a.m.	194	172	158	192	174	158
12:00 noon	207	185	172	209	187	174
1:15 p.m.	226	205	190	228	205	190

$C^{o} = 5/9(F^{o}-32)$ 1 in = 25.4 mm

were tested. The results of this work indicated only a 6% reduction occurred in compressive strength due to melting the beads. The 28-day strength of two other cylinders that were heated 27 days after casting showed a slightly higher value than the 7-day unmelted cylinder break. No thermal cracking was detected in the cylinders before the compression tests.

In Test 43, six cylinders were cast and steam cured for six hours. Two cylinders were allowed to cool and then placed into the moist room for seven days. Two other cylinders were taken directly from the steam chamber and placed into an electric oven to melt the wax beads. The remaining two cylinders were allowed to cool overnight in air before being also placed into the oven. The 7-day cylinder breaks indicated a 6% loss in strength occurred when the beads were melted one day after steam curing and a 15% strength loss occurred when the beads were melted directly after steam curing.

The results of testing the internally sealed concrete indicated steam curing would be an acceptable method of curing the prestressed concrete piles provided the temperature within the steam chamber did not cause the beads to melt. For this reason, a maximum steam temperature of 125°F (51.7°C) was specified during the fabrication of the internally sealed concrete piles. Additional findings indicate that there was a substantial loss in compressive strength when a 3% by weight wax bead content was used, but the residual strength was sufficient for prestressed concrete work.

Although there was an additional strength loss due to heating the concrete high enough to melt the wax beads, the loss was tolerable and no noticeable damage was done if the heating and cooling cycle was controlled.

Latex Modified Concrete

The purpose for testing latex modified concrete was to examine the effects of various curing methods on compressive strength. Product information from the manufacturers of the latex modifiers indicated an initial 24 hour moist cure followed by a 72 hour dry cure was preferable for the latex modified system. Since the literature search failed to provide information on steam curing of latex modified concrete to attain high early strength, an investigation was begun. During the laboratory study, four curing techniques were examined. They were (1) curing in a moist room, (2) steam curing for 6 hours followed by curing in a moist room, (3) steam curing for 6 hours followed by curing in air, and (4) curing in a moist room for 1 day followed by curing in air.

All steam curing was conducted in the steam chamber at temperatures between 140° and 160°F (60° and 71°C). Besides investigating curing methods, a comparison of three latex modifiers was made during the study. The modifiers were ARCO's Dylex 1186, Dow Chemical Company's Modifier A, and Dow Chemical Company's Saran. The same mix design formulation was used in all testing. This formulation was similar to that commonly used in bridge deck overlay work except a larger aggregate size was permitted. The mix design specified a latex modifier content of 3.5 gal/sack (13.2 l/sack) of cement. Because the modifier was composed of approximately 50 percent water, an appropriate amount of mixing water was omitted from the design. The quantities used to produce a cubic yard of latex modified concrete are found in Table 2-4.

Four batches of latex modified concrete were used to fabricate 6" x 12" (152 x 305 mm) test cylinders. Dow Modifier A was used in two mixes, while ARCO's Dylex 1186 and Dow's Saran modifiers were used in the others. The latex modifier was added directly into the mixer during batching and all mixing was performed in a Hobart pan-type mixer. After mixing, the slump, air content and unit weight of the concrete was measured before the cylinders were made.

The results of the compressive strength study of latex modified concrete appear in Table 2-5. Most of the testing was performed after a 7-day cure, except four cylinders were tested after 24 hours. The results from Tests 55 and 56 indicated that a steam cured latex modified concrete could gain sufficient strength

TABLE 2-3:

Compressive Strength Study of Internally Sealed Concrete

Test No.	Cement Factor sacks/cy	Total Air Content %	Slump inches	Unit Weight lbs/cf	Cure[1]	Wax Content % by wt	Method of Melting Wax	7 Day Break Ultimate Compressive Strength(fc) psi
41-1	7.5	2.0	3.0	146.7	A	0.0	none	6770
41-2	7.5	2.0	3.0	146.7	A	0.0	none	6455
41-3	7.5	2.0	3.0	146.7	B	0.0	none	5250
41-4	7.5	2.0	3.0	146.7	B	0.0	none	4950
42-1	7.5	3.7	3.25	144.9	A	0.0	none	6315
42-2	7.5	3.7	3.25	144.9	A	0.0	none	6245
42-3	7.5	3.7	3.25	144.9	B	0.0	none	4310
42-4	7.5	3.7	3.25	144.9	B	0.0	none	4265
43-1	7.5	2.1	3.0	137.3	B	3.0	none	4400
43-2	7.5	2.1	3.0	137.3	B	3.0	none	4355
43-3	7.5	2.1	3.0	137.3	B	3.0	oven	3715
43-4	7.5	2.1	3.0	137.3	B	3.0	oven	3730
43-5	7.5	2.1	3.0	137.3	B	3.0	oven	4030
43-6	7.5	2.1	3.0	137.3	B	3.0	oven	4180
44-1	7.5	2.1	3.0	138.2	B	3.0	none	4055
44-2	7.5	2.1	3.0	138.2	B	3.0	none	4160
44-3	7.5	2.1	3.0	138.2	B	3.0	none	4440
44-4	7.5	2.1	3.0	138.2	B	3.0	none	4605
47-1	7.5	2.5	3.25	137.3	A	3.0	none	5075
47-2	7.5	2.5	3.25	137.3	A	3.0	none	5220
47-3	7.5	2.5	3.25	137.3	A	3.0	oven	4830
47-4	7.5	2.5	3.25	137.3	A	3.0	oven	4865
47-5	7.5	2.5	3.25	137.3	A	3.0	oven	5235**
47-6	7.5	2.5	3.25	137.3	A	3.0	oven	5275**
52-1	7.5	2.4	3.75	137.8	A	3.0	none	4560
52-2	7.5	2.4	3.75	137.8	A	3.0	none	4730
52-3	7.5	2.4	3.75	137.8	B	3.0	none	4485

1 cy = 0.764 m^3 1 lb/cf = 16.02 kg/m^3
1 in = 25.4 mm 1000 psi = 6.895 MPa

TABLE 2-3: (Continued)

Compressive Strength Study of Internally Sealed Concrete

Test No.	Cement Factor sacks/cy	Total Air Content %	Slump inches	Unit Weight lbs/cf	Cure[1]	Wax Content % by wt	Method of Melting Wax	7 Day Break Ultimate Compressive Strength(fc) psi
52-4	7.5	2.4	3.75	137.8	B	3.0	none	4465
52-5	7.5	2.4	3.75	137.8	B	3.0	oven	4915***
52-6	7.5	2.4	3.75	137.8	B	3.0	oven	4840***
54-1	7.5	2.0	3.0	138.6	A	3.0	none	4815
54-2	7.5	2.0	3.0	138.6	A	3.0	none	4825
54-3	7.5	2.0	3.0	138.6	B	3.0	none	3670
54-4	7.5	2.0	3.0	138.6	B	3.0	none	3655
54-5	7.5	2.0	3.0	138.6	B	3.0	none	3615
54-6	7.5	2.0	3.0	138.6	B	3.0	none	3670

1 cy = 0.764 m^3 1 lb/cf = 16.02 kg/m^3 $C^o = 5/9(F^o-32)$
1 in = 25.4 mm 1000 psi = 6.855 MPa

[1]A Cure in moist room only
B Steam cure for 6 hours then place in moist room.

Remarks:

43-3,4 - Specimens were taken immediately from the steam chamber and placed in an oven at 90°C for 6 hours.

43-5,6 - Specimens were allowed to cool for 15 hours before being placed in oven at 90°C for 6 hours.

44-1,2 3,4 - All cylinders were manufactured and cured at Morse Bros. Prestressed Concrete Plant.

47-3,4 - Cylinders were moist cured for 5 days and allowed to dry in air overnight. The cylinders were placed in an oven at 90°C for 6 hours.

**47-5,6 - Cylinders were moist cured for 7 days and allowed to air cure for 19 days. The cylinders were placed in an oven at 90°C for 6 hours on the 27th day. 28 day breaks are recorded.

***52-5,6 - Cylinders were steam cured for 6 hours then air cured for 27 days. The beads were melted during the 27th day and the cylinder tested on the 28th day.

TABLE 2-4: Calculated Mix Design Latex Modified Concrete

	cu. ft.
Cement	3.58
Sand	7.04
3/4 - 1/2	4.42
1/2 - 1/4	6.67
Water	.96
Air	.81
Latex	3.52
1 cf = 0.0283 m^3	27.00

TABLE 2-5: Compressive Strength Study of Latex Modified Concrete

Test No.	Cement Factor sacks/cy	Total Air Content %	Slump inches	Unit Weight lbs/cf	Cure	Latex Type	Latex Quantity gal/sack	7 Day Ultimate Compressive Strength(fc) psi
48-1	7.5	8.0	2.25	135.1	A	ARCO	3.5	4850
48-2	7.5	8.0	2.25	135.1	A	ARCO	3.5	4820
48-3	7.5	8.0	2.25	135.1	A	ARCO	3.5	4450
48-4	7.5	8.0	2.25	135.1	A	ARCO	3.5	4555
53-1	7.5	3.2	6.25	145.1	A	Dow "A"	3.5	4725
53-2	7.5	3.2	6.25	145.1	A	Dow "A"	3.5	4830
53-3	7.5	3.2	6.25	145.1	B	Dow "A"	3.5	4265
53-4	7.5	3.2	6.25	145.1	B	Dow "A"	3.5	4270
53-5	7.5	3.2	6.25	145.1	C	Dow "A"	3.5	4515
53-6	7.5	3.2	6.25	145.1	C	Dow "A"	3.5	4570
55-1	7.5	3.0	1.0	145.2	B	Dow "A"	3.5	4420**
55-2	7.5	3.0	1.0	145.2	B	Dow "A"	3.5	4480**
55-3	7.5	3.0	1.0	145.2	D	Dow "A"	3.5	5850
55-4	7.5	3.0	1.0	145.2	D	Dow "A"	3.5	6095
56-1	7.5	2.6	4.0	148.1	B	Dow Saran	3.5	6040**
56-2	7.5	2.6	4.0	148.1	B	Dow Saran	3.5	5925**
56-3	7.5	2.6	4.0	148.1	D	Dow Saran	3.5	7975
56-4	7.5	2.6	4.0	148.1	D	Dow Saran	3.5	7930

* A Cured in Moist Room
B Steam cured for 6 hours then placed in moist room.
C Steam cured for 6 hours then air cured.
D Moist cured for 1 day then air cured.
** 24 hour break

1 cy = 0.764 m^3 1 lb/cf = 16.02 kg/m^3 1 gal = 3.78 l
1 in = 25.4 mm 1000 psi = 6.895 MPa

in 24 hours to allow the piles to be prestressed at that time.

A comparison of the results obtained in Tests 55 and 56 also indicate the concrete modified with Saran to be 24% stronger then the concrete containing Dow Modifier A. Unfortunately the unanswered questions concerning the presence of chlorides in Saran prohibited its use in the marine piles.

The results of Tests 48 and 53 indicated the concretes modified with Arco's Dylex 1186 and Dow Modifier A to have approximately the same compressive strength after similar cures.

Polymer-Impregnated Concrete

There were four major problem areas that required laboratory study before specifications could be written for the polymer impregnation piles. These areas were (1) determining an appropriate initiator, (2) determining suitable drying techniques for 65 foot (19.8 m) long concrete piles, (3) determining a minimum soaking time to obtain a 1-1/2" (38.1 mm) penetration, and (4) determining a suitable polymerization technique.

Although a polymer impregnation system had been used successfully for bridge deck treatments in the past, the prescribed technique was not applicable for the impregnation of precast prestressed concrete piles. One of the main problems was the initiator requirements. In bridge deck work, a quick acting relatively unstable initiator is desirable while a stable initiator is mandatory for the impregnation of the piles to prevent a premature polymerization. After consulting with the Pennwalt Chemical Company, they supplied three different initiators for testing. After performing experiments in the chemistry laboratory, 2-t-Butylazo-2-cyano-propane (Luazo 79) was chosen for trial impregnations. This initiator appeared quite stable in the resin system with temperatures up to 90°F (32.2°C), provided it was protected from the sun's ultraviolet rays.

Before the impregnation study began 6" x 6" x 12" (152 x 152 x 305 mm) blocks were fabricated using 5,000 psi (34.5 MPa) air-entrained concrete. While the blocks were curing, thermocouples were embedded at the 1-1/2" and 2" (38.1 and 50.8 mm) depths in order to monitor the temperature during the drying studies.

The first series of tests were conducted to study the length of monomer soaking time required to obtain a 1-1/2" (38.1 mm) polymer penetration. Blocks A & B were heated in a 1400 watt electric oven for 96 hours at a maximum temperature of 230°F (110°C). At the completion of the drying period, the blocks were allowed to cool for 16 hours during which time the temperature within the blocks fell to 65°F (18.3°C). The blocks were then immersed in a bath consisting of a blend of 95% methyl methacrylate (MMA) and 5% trimethylalpropane trimethacrylate (TMPTMA). The monomer was initiated with Luazo 79 at a concentration of 0.5%. Block A was impregnated for 5 hours while Block B was allowed to soak for 7 hours. Within minutes after being removed from the soaking tank, the blocks were placed into a hot water bath (170°F (76.7°C)) to polymerize the monomer system. After 7 hours in the hot water bath the blocks were removed and allowed to cool. When the blocks were opened, Block A had a uniform 1" (25.4 mm) polymer penetation while Block B had a uniform 1-1/4" (31.7 mm) penetration. The complete results of the penetration study are found in Table 2-6, while the temperatures which were monitored throughout the impregnation study appear in Tables 2-7 thru 2-21.

Blocks C & D underwent similar impregnation techniques as Blocks A and B, but this time the drying period was reduced to 72 hours. Block C was soaked for 8 hours in the monomer bath while Block D was scheduled to receive a 10 hour soaking, but a leak developed in its soaking tank causing that test to be aborted. A 1-1/2" (38.1 mm) polymer penetration was achieved in Block C after an 8 hour soaking period was provided.

Continuing the drying and impregnation study, Blocks E, F, G, I, J, K, O, and P were also dried in an electric oven at various temperatures and for different durations. From this work it became apparent that adequate drying could be achieved by heating the concrete above 250°F (121°C) for periods exceeding 8 hours. The results of drying Block O in an

TABLE 2-6: Polymer Impregnation Data

Block	Method	Maximum Drying Temp(^{o}F)	Total Drying Time(hr)	Cooling Time(hr)	Soaking Time	Polymerization Heating Time(hr)	Monomer Penetration(")
A	Electric Oven	230	96	16	5.0	7.0	1.0
B	Electric Oven	230	96	16	7.0	7.0	1.25
C	Electric Oven	230	69	12	8.0	7.0	1.50
D	- A B O R T E D -						
E	Electric Oven	230	9	15	8.0	5.5	0.375
F	Electric Oven	230	14	11	8.0	5.5	0.25
G	Electric Oven	240	10	12	8.0	8.0	0.75
H	Hot Air Oven	250	10	13	8.0	8.0	0.75
I	Electric Oven	240	10	12	8.5	5.5	0.375
J	Electric Oven	240	57	14	8.0	6.0	1.25-1.50
K	Electric Oven	240	57	14	8.0	6.0	1.25-1.50
L	Infrared	320	12	12	8.0	6.0	1.50
M	Infrared	280	12	12	8.0	6.0	1.375
N	Infrared	300	8.5	12	7.0	4.0	0.75
O	Electric Oven	300	10	14	8.0	4.0	2.5
P	Electric Oven	300	16	14	8.0	4.0	3.0

$C^{o} = 5/9(F^{o}-32)$
1 in = 25.4 mm

TABLE 2-7

Impregnation of Block A
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
05/24	2:30 pm	150	67	68	-
	3:35 pm	220	111	111	-
05/25	10:00 am	225	213	208	-
	1:00 pm	228	217	210	-
	3:00 pm	225	218	212	-
05/28	11:00 am	230	219	212	-
	2:30 pm	228	226	220	-

Block cooled for 16 hours. Block soaked in monomer bath for 5 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
05/29	11:30 am	-	66	66	185
	11:45 am	-	88	88	174
	12:15 pm	-	150	150	172
	12:30 pm	-	161	161	170
	1:45 pm	-	176	174	178
	3:35 pm	-	182	181	180
	5:30 pm	-	169	168	167
	6:30 pm	-	162	162	162

Resulted in 1" penetration.

TABLE 2-8

Impregnation of Block B
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
05/24	2:30 pm	150	67	68	-
	3:35 pm	220	111	111	-
05/25	10:00 am	225	213	208	-
	1:00 pm	228	216	210	-
	3:00 pm	225	218	212	-
05/28	11:00 am	230	219	212	-
	2:30 pm	228	226	220	-

Block cooled for 16 hours. Block soaked in monomer bath for 7 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
05/29	1:45 pm	-	68	68	178
	3:35 pm	-	178	178	180
	5:30 pm	-	167	168	167
	6:30 pm	-	163	163	162
	8:30 pm	-	174	174	174

Resulted in 1-1/4" penetration.

$C^o = 5/9(F^o-32)$
1 in = 25.4 mm

TABLE 2-9

Impregnation of Block C
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
05/28	2:00 pm	125	67	67	-
	5:00 pm	210	130	125	-
05/29	6:30 am	208	206	204	-
	10:30 am	228	223	214	-
	12:30 pm	226	225	216	-
	5:30 pm	208	217	210	-
05/30	11:00 am	228	225	219	-
	3:30 pm	228	226	221	-
05/31	8:00 am	230	230	225	-
	11:00 am	230	230	228	-

Block cooled for 12 hours. Block soaked in monomer bath for 8 hours

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
06/01	7:00 am	-	72	72	180
	8:00 am	-	150	148	170
	9:00 am	-	178	178	176
	12:00 noon	-	178	178	180
	1:00 pm	-	174	173	176
	2:00 pm	-	178	177	176

Resulted in 1-1/2" penetration.

TABLE 2-10

Impregnation of Block E
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
06/04	7:30 am	-	20	20	-
	11:00 am	200	158	158	-
	12:30 pm	221	185	185	-
	2:30 pm	226	196	195	-
	4:00 pm	226	208	207	-
	4:30 pm	230	210	207	-

Block cooled for 15 hours. Block soaked in monomer bath for 8 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
06/05	3:30 pm	-	71	71	171
	4:15 pm	-	169	169	186
	5:00 pm	-	179	179	183
	9:00 pm	-	183	183	183

Resulted in 3/8" penetration.

$C^{o} = 5/9(F^{o}-32)$
1 in = 25.4 mm

TABLE 2-11

Impregnation of Block F
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
06/12	6:15 am	170	66	66	-
	7:30 am	199	115	111	-
	8:30 am	207	140	136	-
	9:30 am	207	163	158	-
	10:30 am	212	180	176	-
	12:30 pm	223	196	194	-
	3:30 pm	223	196	196	-
	5:30 pm	230	215	212	-
	8:15 pm	232	219	219	-

Block cooled for 11 hours then soaked in monomer bath for 8 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
06/13	3:30 pm	-	70	68	170
	3:50 pm	-	134	124	178
	4:30 pm	-	168	164	192
	7:00 pm	-	179	178	187
	9:00 pm	-	181	181	183

Resulted in 1/4" penetration.

TABLE 2-12

Impregnation of Block G
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
06/18	10:00 am	230	58	58	-
	11:00 am	-	122	120	-
	12:00 N	235	170	167	-
	2:00 pm	240	203	202	-
	4:00 pm	238	212	210	-
	5:30 pm	240	219	217	-
	7:00 pm	241	223	220	-
	8:00 pm	238	223	220	-

Block cooled for 12 hours and then soaked for 8 hours in monomer bath.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
06/19	4:00 pm	-	61	60	178
	4:30 pm	-	120	121	181
	5:00 pm	-	177	176	177
	7:00 pm	-	167	166	165
	10:00 pm	-	171	171	170
	12:00 M	-	171	171	176

Resulted in 3/4" penetration.

$C^o = 5/9(F^o - 32)$
1 in = 25.4 mm

TABLE 2-13

Impregnation of Block H
Hot Air Oven Method

Date	Time	Surface Temp F	Block Temp F 1-1/2"	2"	Hot Water Bath Temp F
06/18	9:00 am	55	55	55	-
	9:30 am	152	115	93	-
	10:00 am	177	147	132	-
	11:30 am	240	213	200	-
	1:00 pm	240	230	222	-
	4:00 pm	250	237	230	-
	5:30 pm	250	234	232	-
	7:00 pm	248	237	240	-

Block cooled for 13 hours then soaked in monomer bath for 8 hours.

Date	Time	Surface Temp F	Block Temp F 1-1/2"	2"	Hot Water Bath Temp F
06/19	4:00 pm	-	61	61	170
	4:15 pm	-	99	75	165
	5:00 pm	-	180	169	187
	5:30 pm	-	185	180	181
	6:00 pm	-	178	175	178
	7:00 pm	-	171	171	172
	9:00 pm	-	180	180	180
	10:00 pm	-	177	178	175
	12:00 pm	-	176	177	177

Resulted in 3/4" penetration.

TABLE 2-14

Impregnation of Block I
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	2"	Hot Water Bath Temp F
07/09	9:00 am	210	70	70	-
	10:00 am	210	114	112	-
	11:00 am	210	140	136	-
	1:00 pm	210	167	165	-
	4:00 pm	240	210	204	-
	7:00 pm	240	223	221	-

Block cooled for 12 hours then soaked for 8.5 hours in monomer bath.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	2"	Hot Water Bath Temp F
07/10	3:30 pm	-	65	65	183
	4:00 pm	-	105	102	176
	5:00 pm	-	176	174	178
	7:00 pm	-	175	176	174
	9:00 pm	-	180	179	180

Resulted in 3/8" penetration.

$C^o = 5/9(F^o - 32)$
1 in - 25.4 mm

TABLE 2-15

Impregnation of Block J
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/18	10:00 am	150	67	67	-
	1:00 pm	200	115	111	-
	3:00 pm	225	187	180	-
07/19	8:00 am	240	238	238	-
	2:00 pm	241	240	240	-
07/20	8:00 am	238	239	240	-
	11:00 am	240	240	241	-
	3:00 pm	241	239	239	-
	7:00 pm	239	238	239	-

Block cooled for 14 hours then soaked in monomer bath for 8 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/21	5:00 pm	-	65	65	176
	5:30 pm	-	162	158	173
	6:00 pm	-	178	176	181
	8:00 pm	-	178	178	178
	10:00 pm	-	176	177	175
	11:00 pm	-	179	178	180

Resulted in 1-1/4" to 1-1/2" penetration.

$C^o = 5/9(F^o-32)$
1 in = 25.4 mm

TABLE 2-16

Impregnation of Block K
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/18	10:00 am	150	69	68	-
	1:00 pm	200	117	111	-
	3:00 pm	225	188	179	-
07/19	8:00 am	240	241	238	-
	2:00 pm	241	241	240	-
07/20	8:00 am	238	239	239	-
	11;00 am	240	241	240	-
	3:00 pm	241	240	239	-
	7:00 pm	239	239	240	-

Block cooled for 14 hours then soaked in monomer bath for 8 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/21	5:00 pm	-	65	66	176
	5:30 pm	-	163	158	173
	6:00 pm	-	179	176	181
	8:00 pm	-	178	179	178
	10:00 pm	-	177	176	175
	11:00 pm	-	179	179	180

Resulted in 1-1/4" to 1-1/2" penetration.

TABLE 2-17

Impregnation of Block L
Infrared Heating Method

Date	Time	Surface Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/25	8:30 am	68	67	68	-
	9:30 am	140	98	90	-
	10:30 am	175	145	138	-
	11:30 am	191	170	165	-
	1:00 pm	245	222	216	-
	3:00 pm	279	261	255	-
	8:30 pm	320	311	308	-

Block cooled for 12 hours and then soaked in monomer bath for 8 hours.

Date	Time	Surface Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/26	4:30 pm	-	67	68	178
	5:00 pm	-	157	151	172
	5:30 pm	-	170	163	180
	6:30 pm	-	182	180	185
	7:30 pm	-	189	187	192
	10:30 pm	-	190	188	194

Resulted in 1-1/2" penetration.

TABLE 2-18

Impregnation of Block M
Infrared Heating Method

Date	Time	Surface Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/25	8:30 am	68	68	67	-
	9:30 am	136	97	90	-
	10:30 am	167	140	132	-
	11:30 am	180	162	155	-
	1:00 pm	230	210	202	-
	3:00 pm	255	237	233	-
	8:30 pm	280	272	267	-

Block cooled for 12 hours then soaked in monomer bath for 8 hours.

Date	Time	Surface Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
07/26	4:30 pm	-	68	68	178
	5:00 pm	-	158	150	172
	5:30 pm	-	170	162	180
	6:30 pm	-	183	180	185
	7:30 pm	-	189	187	192
	10:30 pm	-	190	189	194

Resulted in 1-3/8" penetration.

$C^o = 5/9(F^o-32)$
1 in = 25.4 mm

TABLE 2-19

Impregnation of Block N
Infrared Heating Method

Date	Time	Surface Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
08/02	9:00 am	66	66	65	-
	10:00 am	188	164	157	-
	11:00 am	217	196	188	-
	12:00 N	238	220	211	-
	1:00 pm	264	240	228	-
	3:00 pm	285	268	257	-
	5:00 pm	294	280	271	-
	5:30 pm	300	284	273	-

Block cooled for 12 hours and then soaked in monomer bath for 7 hours.

Date	Time	Surface Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
08/03	12:30 pm	-	67	66	185
	1:00 pm	-	160	155	180
	2:30 pm	-	181	178	185
	4:30 pm	-	180	177	182

Resulted in 3/4" penetration.

TABLE 2-20

Impregnation of Block O
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
08/07	7:30 am	295	64	64	-
	8:30 am	302	129	124	-
	9:30 am	300	183	177	-
	10:30 am	300	225	220	-
	12:30 pm	297	252	247	-
	3:30 pm	302	279	273	-
	5:30 pm	304	286	283	-

Block cooled for 14 hours and then soaked in monomer bath for 8 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
08/08	3:30 pm	-	65	65	186
	4:30 pm	-	152	148	196
	5:30 pm	-	186	185	192
	6:30 pm	-	183	182	189
	7:30 pm	-	180	180	182

Resulted in 2-1/2" penetration.

$C^o = 5/9(F^o-32)$
1 in = 25.4 mm

TABLE 2-21

Impregnation of Block P
Electric Oven Method

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
10/25	6:00 pm	297	61	61	-
	6:15 pm	300	70	66	-
	6:30 pm	300	84	79	-
10/26	7:30 am	300	273	262	-
	8:30 am	302	284	273	-
	9:30 am	297	290	277	-
	10:00 am	300	297	285	-

Block cooled for 14 hours and then soaked in monomer bath for 8 hours.

Date	Time	Oven Temp F	Block Temp F 1-1/2"	Block Temp F 2"	Hot Water Bath Temp F
10/27	8:00 am	-	57	57	165
	8:30 am	-	102	90	170
	9:00 am	-	150	145	176
	10:00 am	-	181	180	179
	11:00 am	-	180	180	180
	12:00 am	-	172	172	180

Resulted in 3" penetration.

$C^o = 5/9(F^o-32)$
1 in = 25.4 mm

electric oven at 300°F (148.9°C) for 10 hours in combination with an 8 hour monomer soaking period indicated a 2-1/2" (63.5 mm) penetration was obtainable.

In addition to drying the concrete blocks in an electric oven, two other methods were examined. They were a propane gas-fired hot air heating system and an electric infrared heater system. Both systems were described in detail in the internally sealed concrete section.

Block H was heated in the specially constructed hot air oven which utilized a 200,000 BTU/hr propane-fired heater. The block was set on a pedestal in the middle of the oven for a 10 hour drying period. A maximum surface temperature of 250°F (121.1°C) was reached after 7 hours of heating. Block H was allowed to cool for 13 hours before being placed into a resin bath for 8 hours. When the block was opened, a 3/4" (19 mm) penetration was found on only three sides. The bottom side had only a 1/4" (6.3 mm) resin penetration which was attributed to inadequate drying due to poor air circulation. Since the concrete surface temperature was maintained at 250°F (121.1°C) for only three hours, a greater penetration could have been achieved if the drying time was extended. The importance of good air circulation around the concrete was very apparent.

Three blocks, L, M, and N, were dried with an electric infrared heating system which was composed of four 1800 watt elements. Blocks L and M were placed within the infrared heating enclosure at the same time, but in different positions. Both were located 18" (457 mm) below the heating elements. Block L was placed directly beneath one element while Block M was placed equidistant between two elements. Both blocks were heated for 12 hours during which time Block L reached a maximum surface temperature of 320°F (160°C) while Block M had a maximum surface temperature of 280°F (137.8°C). Each block was permitted to cool for 12 hours before being placed in a monomer soaking tank for 8 hours. At the completion of the impregnation cycle, both blocks were placed into a hot water bath (170°F (76.7°C)) for a 6 hour polymerization phase. When Block L was opened, a 1-1/2" (38.1 mm) polymer penetration was found on the top surface, while the penetration on the vertical sides varied from 1-1/2" (38.1 mm) at the top to 3/8" (9.5 mm) at the bottom. The bottom surface of Block L exhibited only a trace of polymer. A similar pattern was found when Block M was opened except the maximum polymer penetration was only 1-3/8" (34.9 mm).

Block N was placed 15" (381 mm) below and directly under one of the infrared heating elements for an 8-1/2 hour drying period during which time a maximum surface temperature of 300°F (131°C) was attained. The block was allowed to cool for 12 hours before being placed into the monomer soaking tank for a 7 hour impregnation period. Only a 3/4" (19 mm) maximum polymer penetration was obtained on the top surface of Block N due to the reduced drying time and the reduced soaking period. The polymer penetration on the vertical sides of the block diminished noticeably from top to bottom.

The results of the laboratory testing indicated Luazo 79 was a suitable initiator for use in the impregnation of precast prestressed concrete piles by providing a relatively stable monomer bath system. The polymerization technique of immersing the impregnated concrete into a hot water bath and maintaining a water temperature above 170°F (76.7°C) for a minimum of 6 hours was successful.

The electric infrared heater system provided an acceptable drying method, but was only effective on the sides of the concrete facing the heating elements.

The hot air heating system did not provide sufficient drying to allow a uniform 1" (25.4 mm) polymer penetration, but it appeared capable of doing so if the length of drying time was increased and if adequate air circulation was provided around the concrete surface.

Finally a 1-1/2" (38.1 mm) polymer impregnation was achieved after an 8 hour soaking period when the concrete was dryed sufficiently.

Polymer Concrete

The laboratory study to develop a suitable polymer concrete formulation for use in manufacturing precast prestressed piles began with an examination of aggregate gradations and various monomer and resin blends. Using knowledge gained in previous studies of polyester styrene polymer concrete for bridge deck overlays, cylinders and small beams were fabricated and tested. Although some progress was made in designing a usable polyester styrene mixture for precast elements, the laboratory work was re-directed toward using methyl methacrylate (MMA) as the binder. The main reason for this change was economics. Since there would be hundreds of gallons of methyl methacrylate monomer remaining after the polymer impregnation treatment of the piles, it appeared highly desirable to use this resin in the polymer concrete piles.

A literature review indicated a considerable amount of laboratory and field work had been performed with methyl methacrylate polymer concrete. Most of this work was performed by the Brookhaven National Laboratory for the Federal Highway Administration. The laboratory work included an extensive study of time to gel (allowable work time) of various monomer blends and formulations. By varying the concentration of initiator and promoter, the allowable work time of some methyl methacrylate polymer concrete mixes was extended to 120 minutes, but with a delay in cure time. This testing was done at three different temperature levels also.

After studying the results found in the literature review, two methyl methacrylate formulations were selected for trial batches. These formulations, which are found in Table 2-22 provided a 30 minute work time at room temperature 68°F (20°C).

The testing of Formulation A began when several small batches of polymer concrete were mixed using different aggregate gradations. Because the resin had a low viscosity it drained badly from the aggregate of the initial batch. By adding a larger percent of material passing the #200 sieve in the form of rock flour or portland cement, the drainage problem was somewhat reduced. The final aggregate gradation selected for laboratory use is found in Table 2-23.

When 6" x 12" (152 x 305 mm) cylinders and 2' x 2' x 1-1/2" (.61 m x .61 m x .38 mm) slabs were prepared using Formulation A, excessive evaporation of the surface liquid left a weak, easily-abraded surface which was totally unacceptable. When the surface of the cylinders was covered to prevent the monomer evaporation during curing, excellent quality concrete was obtained. Cylinders that were tested in 6 hours exhibited an average ultimate compressive strength of 6,550 psi (45.2 MPa).

In addition to the evaporation problem, shrinkage was clearly noticeable when 2' x 2' x 1-1/2" (.61 m x .61 m x .38 mm) slabs were cast. A polymethyl methacrylate (PMMA) in powdered form was added to Formulation A creating Formulation B. The PMMA greatly improved the workability of the mix and reduced resin drainage, surface evaporation and some polymer concrete shrinkage.

Next a study was made to determine the effects of using a resin containing two initiators. A small quantity of MMA monomer was initiated with "Luazo 79" at the same concentration as that of the impregnation mixture. This resin was stored for a two week period before being used to simulate conditions in the field. A small batch of polymer concrete was then mixed using Formulation A. A 30 minute allowable work time was obtained, provided the mixing bowl was covered to prevent monomer evaporation. Three 3" x 6" (76 x 152 mm) cylinders were fabricated and tested in 24 hours. The average ultimate compressive strength was 7,025 psi (48.3 MPa) indicating a satisfactory cure had occurred.

At this point in time, four proprietary acrylic mortars became commercially available to produce a MMA polymer concrete. These products were Concresive 2020, Crylcon 3020, Plexicrete and Silikal. Each was a two component system consisting of a powder and a liquid. The powders contained reactive and inert fillers plus a benzoyl peroxide initiator while the liquid was composed of methyl methacrylate monomer, a plasticizer and a

TABLE 2-22

Polymer Concrete Formulations

	Formulation A	Formulation B
% Monomer Content by wt of aggregate	10%	10%
Monomer	95% MMA 5% TMPTMA	90% MMA 5% TMPTMA 5% PMMA
Initiator	2.0% BPO	2.0% BPO
Promoter	1.0% DMA	1.0% DMA

BPO - benzoyl peroxide
PMMA - polymethyl methacrylate
MMA - methyl methacrylate
TMPTMA - trimethylolpropane trimethacrylate
DMA - dimethyl aniline

Table 2-23

Aggregate Gradation For Polymer Concrete

Sieve Size		% Passing
1"	(25.4 mm)	100.0
3/4"	(19.0 mm)	99.0
1/2"	(12.7 mm)	85.0
3/8"	(9.51 mm)	74.0
1/4"	(6.35 mm)	57.0
#4	(4.76 mm)	53.0
#8	(2.38 mm)	46.0
#16	(1.19 mm)	38.0
#30	(0.59 mm)	30.0
#50	(0.30 mm)	11.0
#100	(0.15 mm)	7.0
#200	(0.074 mm)	6.0

Table 2-24

Compressive Strength Study of Polymer Concrete

Test No.	Product Name	Ultimate Compressive Strength psi	Ultimate Compressive Strength Age (hrs)	Modulus of Elasticity at 3000 psi psi ($x10^6$)	Modulus of Elasticity at 3000 psi Age (hrs)
PC1-1	Concresive 2020	7155	24	---	---
PC1-2	Concresive 2020	6985	24	2.5	24
PC2-1	Crylcon 3020	9040	24	---	---
PC2-2	Crylcon 3020	9285	24	3.3	24
PC3-1	Crylcon 3020	9250	48	3.3	24
PC4-1	Silikal	5500	24	2.2	24
PC4-2	Silikal	5970	24	---	---
PC5-1	Plexicrete	5510	24	2.5	24
PC5-2	Plexicrete	6140	24	---	---
PC6-1	Crylcon 3020	8680	9	---	---
PC6-2	Crylcon 3020	8565	9	3.3	9
PC6-3	Crylcon 3020	9495	24	3.7	24

1000 psi = 6.895 MPa

promoter. A dry coarse aggregate had to be added to produce polymer concrete. After obtaining samples of each of the materials, batches were prepared and tested. Each material had excellent workability and the allowable work time was estimated to be 20 minutes at 68°F (20°C). No evaporation or shrinkage problems were detected when 2' x 2' x 1-1/2" (.61 m x .61 m x .38 mm) slabs were made. Cylinders measuring 6" x 12" (152 x 305 mm) were also cast for determining 24-hour compressive strength and the modulus of elasticity . The results of this testing were very favorable and are found in Table 2-24. After examining the test results, it appeared Crylcon was more suitable for prestressed con crete work because of its higher strength and greater modulus of elasticity. Three additional Crylcon polymer concrete cylinders were fabricated for further testing. Two cylinders were tested after a 9-hour cure and one was tested after a 24-hour cure. Although the polymer concrete had not fully cured in 9 hours, it had an average ultimate compressive strength of 8,622 psi (59.4 MPa) and a modulus of elasticity of 3.3×10^6 psi (22.7 GPa) at a stress level of 3,000 psi (20.7 MPa). The results after a 24-hour cure indicated an ultimate compressive strength and modulus of elasticity of 9,495 psi (65.4 MPa) and 3.7×10^6 psi (25.5 GPa) respectively.

In order to further examine shrinkage of the Crylcon polymer concrete, two 3.5" x 3.5" x 8' (89 mm x 89 mm x 2.4 m) long beams were constructed in wooden molds to which a triple application of paraffin wax was used to prevent bonding. One beam contained a 3/8" (9.5 mm) diameter reinforcing rod while the other was unreinforced. The purpose of this test was (1) to see if the unreinforced polymer concrete would shrink away from the ends of the mold and (2) to see if cracking would occur along the rebar as shrinkage occurred dur ing curing. After observing the beams for three weeks, no shrinkage was detected. The formulation used for the beams was:

Crylcon 3020 (Powder)	67 lbs.	(30.4 kg)
Crylcon 3010 (Liquid)	9.3 lbs.	(4.2 kg)
Coarse Aggregate	67 lbs.	(30.4 kg)

Because of the apparent lack of problems and the satisfactory results obtained with Crylcon it was selected for use in manufactur ing the polymer concrete piles.

SECTION III

After 3-1/2 months of laboratory work, the experimental piles were designed while the plans and specifications were prepared. During the design of the piles the effects of heating the concrete and prestressing strands to temperatures above 230°F (110°C) became a major concern. After reviewing the results of testing by the Bureau of Reclamation on the effects of high temperatures on strand relaxation in prestressed members, it became apparent an additional 8 to 10% prestress loss would be experienced due to drying the concrete. To make up for this loss, one additional strand was added to the conventional six strand pattern. The seven strand pattern was subsequently used in all of the piles in order to better compare the performance of the materials.

There were four major categories of work in the specifications. These were (1) to furnish and install 23 precast prestressed concrete piles, (2) to furnish and install 6 precast concrete blocks containing epoxy coated rebars, (3) to construct concrete pile caps; furnish and install wiring for monitoring sys tem, and (4) perform all testing and incidental work as called for in the specifications and plans.

The testing and incidental work in item four included strain measurements, coring, temperature monitoring and the fabrication of many additional test cylinders and blocks.

When the plans and specifications were completed, they were submitted to FHWA for approval. To hasten their acceptance and to answer any questions directly, the principal investigator met with FHWA personnel at the Fairbank Laboratory in early September 1979. This meeting was beneficial as several changes were made in the specifications. A testing plan detailing the monitoring activities of both the state and the fabricator were also reviewed.

After the plans and specifications were revised, resubmitted and approved by FHWA, a formal contract was prepared by the Oregon State Department of General Services. On October 24, 1979 the contract documents were completed and the project was advertised. A three-week bid submittal period was then allowed before the bids were opened on November 14, 1979. Although there were several inquiries about the marine pile project from prospective bidders, only two bids were received and unfortunately both were well above the engineer's estimate. Coast Marine Construction submitted the low bid at $139,736 while the other bid was $214,232. The low bid which exceeded the engineer's estimate by approximately $65,000 is found in Table 3-1. When the bids were examined, most of the bid overrun was attributed to mobilization and the cost of the polymer concrete materials.

Because there were not sufficient funds in the original agreement with the FHWA to proceed with the work, the contract was not immediately awarded. After careful deliberation, the FHWA decided to provide the additional funding necessary to complete the project. The contract was finally awarded four weeks after the bids were opened.

On January 9, 1980, the notice to proceed was issued to Coast Marine Construction. Immediately thereafter Coast Marine Construction awarded a subcontract to Morse Bros. Prestress, Inc., of Harrisburg, Oregon, for the fabrication of the piles.

Within one week after receiving the subcontract, personnel from Morse Bros. met with the principal investigator to discuss specification requirements. In addition to fabricating the piles, the specifications required the contractor to closely monitor strain and temperatures as the piles were built and processed. Before any work began, a procedure report detailing the methods to be used to acquire this information had to be approved by the principal investigator. Shortly after the meeting, Morse Bros. began ordering the experimental materials and supplies necessary to fabricate the piles.

On February 12, a tentative work schedule and procedure report describing their testing methods were submitted by Morse Bros. for state approval. At this time Morse Bros. formally requested permission to construct a special heating chamber for drying the polymer impregnated concrete piles and melting the wax beads in the internally sealed concrete piles. Morse Bros. proposed to use super heated steam in four radiator pipes to accomplish the heating. Although three other methods were allowed in the specifications, conditional approval was granted with the provision the heating chamber would have to be successfully tested. The work schedule and procedure report were reviewed and approved within one week.

The temperature monitoring system selected by the fabricator consisted of a 24 point Esterline Angus recording potentiometer Model E1124E and 20 gage Type J thermocouple wires. This system proved to be very adequate for the project.

The proposed method for measuring shrinkage and creep of the various experimental materials with strain gages is described in detail in a later section.

On February 28, after several aborted starts, the fabrication of the piles began when two conventional concrete prestressed piles were cast. The responsibility for the manufacture and treatment of the piles was delegated to the plant quality control engineer by the plant manager because new fabrication techniques were required for the special materials. In spite of careful planning, some disruption of the plant's normal activities occurred which led to an internal conflict between production and quality control. Once the conflict was settled, the fabrication of the piles progressed at a relatively smooth pace.

The sequence in which the piles were manufactured can be found in Table 3-2.

The following sections describe the fabrication techniques that were used to construct the piles.

Table 3-1

BID SCHEDULE

Item No.	Item	Unit	Quantity	Unit Price (In Figures)	Total (In Figures)
1	Furnish Internally Sealed Concrete Piling	Each	5	$1,440.00	$ 7,200.00
2.	Furnish Latex Modified Concrete Piling	Each	5	1,670.00	8,350.00
3.	Furnish Polymer-Impregnated Concrete Piling	Each	5	2,620.00	13,100.00
4.	Furnish Polymer Concrete Piling	Each	5	5,920.00	29,600.00
5.	Furnish Portland Cement Concrete Piling	Each	3	1,140.00	3,420.00
6.	Drive Piles	Each	23	1,000.00	23,000.00
7.	Portland Cement Concrete "Blocks"	Each	6	390.00	2,340.00
8.	Concrete Pile Caps	Lump Sum	All	Lump Sum	44,226.00
9.	Monitoring Equipment	Lump Sum	All	Lump Sum	8,500.00
				Total Amount of Bid	$139,736.00

Table 3-2

Pile Manufacture Sequence

Date Cast	Type of Material	Pile Number
2-28-80	Conventional Conc.	3A 3C
2-29-80	Latex Mod. Conc. Latex Mod. Conc.	Rejected Rejected
3-5-80	Poly. Impreg. Conc. Poly. Impreg. Conc.	1A 1E
3-6-80	Poly. Impreg. Conc. Poly. Impreg. Conc.	1C 1D
3-7-80	Poly. Impreg. Conc. Conventional Conc.	1B 3B
3-10-80	Inter. Sealed Conc. Inter. Sealed Conc.	2B 2E
3-13-80	Inter. Sealed Conc. Inter. Sealed Conc.	2A 2D
3-18-80	Inter. Sealed Conc. Latex Mod. Conc.	2C Rejected
3-20-80	Latex Mod. Conc. Latex Mod. Conc.	Rejected Rejected
4-9-81	Polymer Conc.	4B
4-10-80	Polymer Conc. Polymer Conc.	4A 4D
4-11-80	Polymer Conc. Polymer Conc.	4C 4E
4-17-80	Latex Mod. Conc.	5D
4-22-80	Latex Mod. Conc. Latex Mod. Conc.	5C 5E
4-24-80	Latex Mod. Conc. Latex Mod. Conc.	5A 5B

Polymer-Impregnated Concrete

The concrete piles that were destined to become polymer-impregnated were cast on March 5, 6, and 7, 1980. These piles were constructed using a conventional air-entrained Class 5000-1 concrete. The weights of the mix ingredients for the piles are listed in Table 3-3. Before casting, thermocouples were placed at various locations within the piles in order to monitor the drying, cooling, and impregnation temperatures. The concrete was mixed in a 4-cubic yard (3 m) drum mixer and transported to the casting beds in an agitator-type mobile bucket. After the piles were cast, steam cured and prestressed, they were placed in a stockpile and covered with plastic sheeting to allow a dry cure. The piles were required to have a minimum cure in air of 21 days before undergoing the impregnation treatment. Several 6" x 12" (152 x 305 mm) test cylinders were made during the fabrication of the piles to check quality control. Some of the cylinders were tested at the fabrication plant while others were tested at the State Highway Laboratory in Salem. In addition to the compressive strength, the modulus of elasticity of several samples was also determined. Since the mix design for the polymer-impregnated concrete piles and the control piles was identical, the results of testing quality control cylinders of both are shown in Table 3-4.

Before the polymer impregnation treatment began, each of the piles was sandblasted to remove any surface contaminants such as form release oil or curing compounds. The sandblasting was found to enhance the polymer penetration in the laboratory study.

While the piles were in storage, a heating chamber was constructed using plywood sheeting and 6" (152 mm) thick foil backed insulation. The cover was made in 8-foot (2.4 m) sections so that it could be easily opened or removed. Steam pipes with 4" (102 mm) fins were placed in each corner to provide a uniform heat throughout the oven. Super heated steam, which was used for steam curing, was utilized as the heat source. When drying the concrete piles, the moisture laden hot air was evacuated from the chamber by an exhaust fan located at one end of the chamber. The outside dimensions of the heating chamber were 3' x 3' x 67' (.9 x .9 x 20.4 m) long while the inside clearance between the steam pipe fins was only 15-1/2" (394 mm). Steel angle supports were placed at 15-foot (4.6 m) centers on the floor of the oven to permit air circulation around the pile. Figure 3-1 shows a pile being lowered into the heating chamber.

After the heating chamber was constructed and tested for steam leaks, Pile 1A was placed into it for a trial run. Pile 1A had 19 thermocouples strategically placed near both ends and at the middle of the pile. In this way the heating characteristics of the oven were analyzed on a full size model. Figure 3-2 shows the location of the thermocouples in each of the polymer impregnated piles.

During the preliminary heating tests an average surface temperature of 250°F (121.1°C) was reached after an 8-hour warm up period. Because of the successful demonstration, the heating chamber was accepted as an alternate to the recommended methods listed in the specifications. The original specifications dictated the piles to be dried by raising the surface temperature at an approximately linear rate not to exceed 100°F/hour (55.6°C/hour) to a maximum surface temperature of between 260° and 300°F (126.6° and 148.8°C). This temperature range had to be maintained for a total of 8 hours if an electric infrared heating system was used and 10 hours if a hot air heating system was employed. After conferring with the FHWA Office of Implementation, drying requirements were established for the steam heated drying chamber which were similar to that for the hot air heating system.

On May 5, the first pile was placed into the heating chamber at 3:30 p.m. Within one-half hour the surface temperature rose from 65° to 125°F (18.3° to 51.7°C). The temperature was then recorded periodically during the next three days until the impregnation was completed. The temperatures recorded during this work appear in Table 3-5A and the average surface temperatures and the average temperature at the 1" depth are plotted in Figure 3-3. In comparing the temperatures around the cross-section of the pile, a higher value is

Table 3-3

Concrete Mix Ingredients (per cubic yard)

Date Cast	Concrete Type	Cement lbs.	1/2" lbs.	Sand lbs.	3/4" lbs.	Water gal.	Pozz. 100-X4 (W/R) oz.	Misc. Ingredients
2-28-80	Conventional	706	1,265	1,250	575	20	35.2	4.4[1]
	Conventional	706	1,265	1,250	585	21	35.2	4.4[1]
2-29-80	Latex Modified	710	1,165	1,185	530	4.0	35	220.5[2]
	Latex Modified	710	1,150	1,170	525	4.0	35	220.5[2]
3-5-80	Poly Impregnated	710	1,265	1,240	576	23.5	35.2	4.4[1]
	Poly Impregnated	710	1,265	1,240	585	23.5	35.2	4.4[1]
3-6-80	Poly Impregnated	705	1,265	1,230	575	26.7	35.2	4.4[1]
	Poly Impregnated	710	1,265	1,235	575	26.2	35.2	4.4[1]
3-7-80	Poly Impregnated	705	1,260	1,235	575	26.2	35.2	4.4
	Conventional	705	1,265	1,235	575	25.8	35.2	4.4
3-10-80	Intern Sealed	705	1,075	945	725	26.5	35.2	114.0[3]
	Intern Sealed	705	1,075	945	725	26.5	35.2	114.0[3]
3-13-80	Intern Sealed	Cement not Recorded	1,075	945	725	26.5	35.2	114.0[3]
	Intern Sealed		1,085	945	725	25.5	35.2	114.0[3]
3-18-80	Latex Modified	705	1,170	1,170	540	4.4	35.2	220.5[2]
	Intern Sealed	705	1,085	940	750	24.4	35.2	114.0[3]
3-20-80	Latex Modified	705	1,165	1,165	515	0.55	35.2	220.5[2]
	Latex Modified	705	1,170	1,170	540	1.36	35.2	220.5[2]
4-17-80	Latex Modified	705	1,170	1,135	525	5.45	--	206.0[2]
4-22-80	Latex Modified	705	1,165	1,130	525	4.73	--	206.0[2]
	Latex Modified	705	1,170	1,130	525	4.18		
4-24-80	Latex Modified	705	1,170	1,135	515	3.64	--	206.0[2]
	Latex Modified	705	1,170	1,135	525	3.64		

		Monomer - lbs. Crylcon EP - 3009	Powder - lbs. Crylcon EP - 3020	Aggregate - lbs. 3/4" - 1/2"	Aggregate - lbs. 1/2" - #4
4-9-80	Polymer	175.5	1,980	700	1,050
4-10-80	Polymer	195.0	1,980	700	1,050
4-11-80	Polymer	195.0	1,980	700	1,050

1 Air Entraining Agent (oz)
2 Latex Modifier (lbs)
3 Wax Beads (lbs)

1 lb = 0.45 kg
1 gal = 3.78 l
1 cy = 0.764 m^3
1 oz = 28.34 g
1 in = 25.4 mm

Table 3-4

Compressive Strength and Modulus of Elasticity of Conventional Concrete and Polymer-Impregnated Concrete

Date Cast	Compressive Strength (lbs/in²)						Modulus of Elasticity
	Test A		Test B		Test C		$lbs/in^2 \times 10^6$
	Age of 6" x 12" Cylinders						
	1 day	28 day	7 day	28 day	7 day	28 day	
02/28/80	5942	8842	8490	9795	8260	9550	
	5394	8842		9813	6880	8570	
						8310[1]	[1]4.4
						8760	
						8150	
03/05/80	5995	6508	6310	7925		7625	
	5906	6280		8275		7830	
03/06/80	4951	7321	7620	9070		7625[1]	[1]3.8
	5305	7639		8960		5530	
						4385	
						7195	
						8560	
						8625	
03/07/80	5853	8850	6575	8265		8560	
	6119	8850		8195		8625	

Test A - Cylinders tested at Morse Bros. Plant after being steam cured initially and then cured in air.

Test B - Cylinders tested at OSHD Lab without being steam cured, cured only in a moist room.

Test C - Cylinders tested at OSHD Lab after being steam cured initially and then cured in a moist room.

Compressive Strength After Impregnation (lbs/in²)

Date Cast	Date Impregnated	Pile No.	Compressive Strength	
03/05/80	05/05/80	1A	10210	10210
03/07/80	05/08/80	1B	9125	-
03/06/80	05/10/80	1C	8700	8282
03/06/80	05/12/80	1D	6515	8594
03/05/80	05/15/80	1E	-	-

1000 psi = 6.895 MPa
1×10^6 = 6.895 GPa

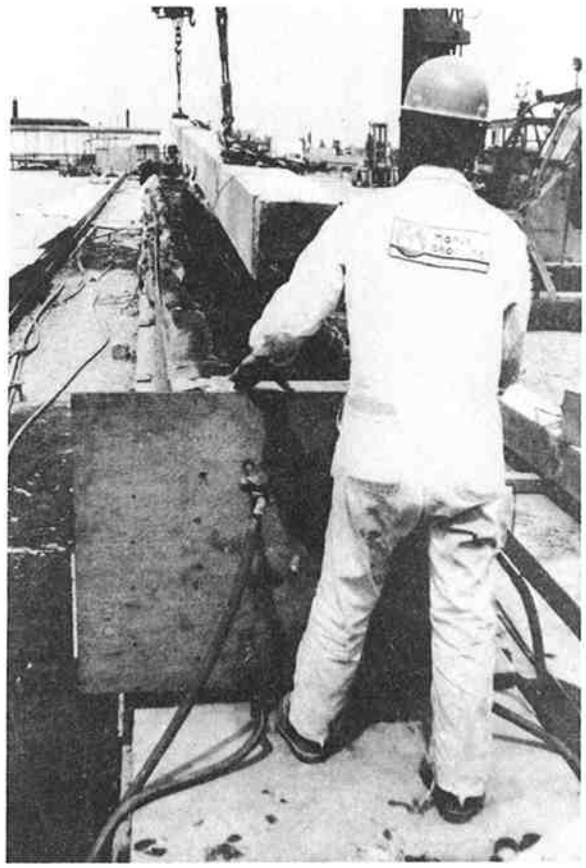


FIGURE 3-1

Placing Concrete Pile into Drying Oven

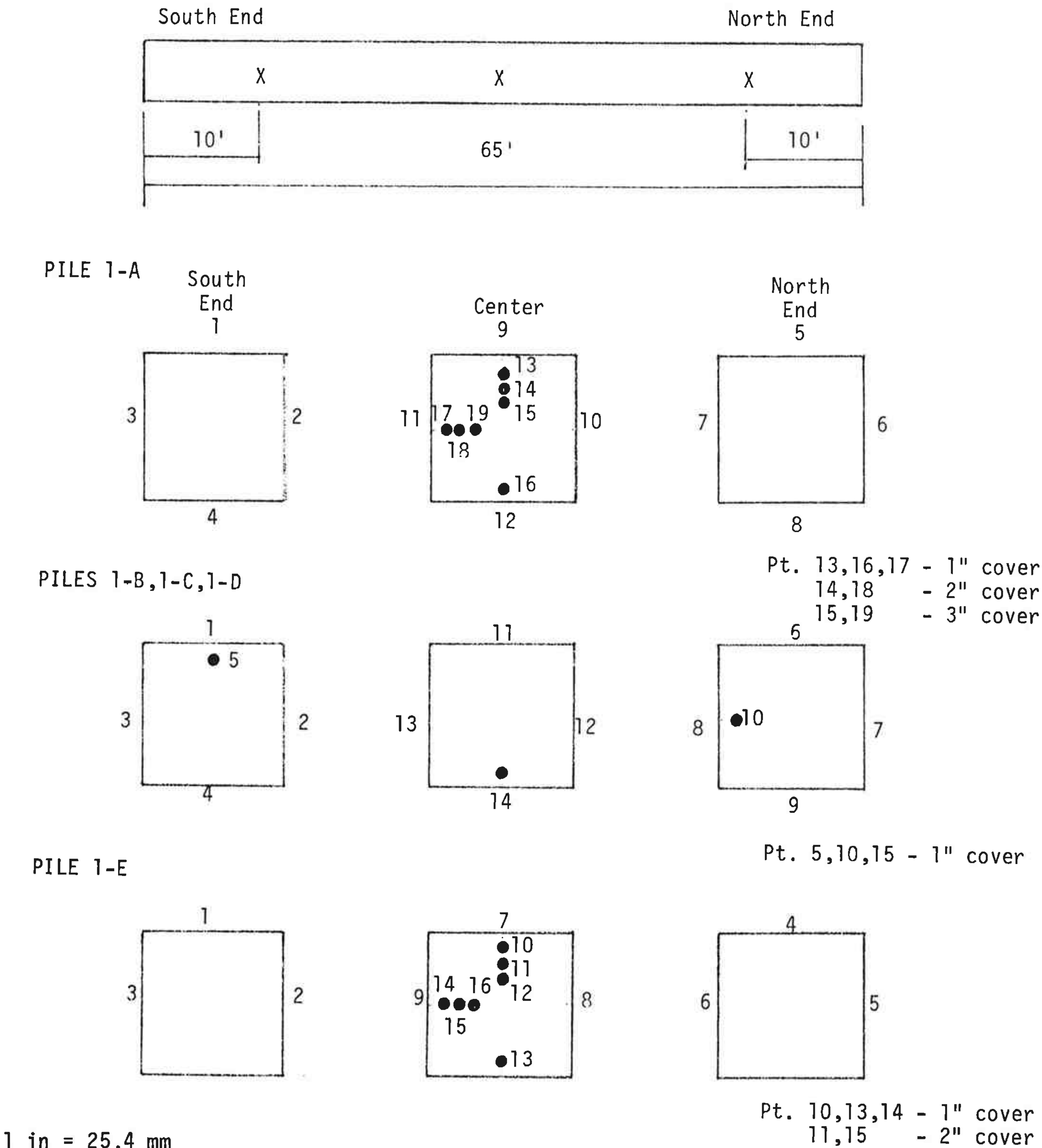


FIGURE 3-2

Location of Thermocouples
in Polymer Impregnated Concrete Piles

Table 3-5A

Concrete and Water Temperatures °F During Impregnation
Polymer Impregnated Concrete Pile 1A

Point	3:00 FRI pm	4:00 FRI pm	10:00 FRI pm	4:00 SAT am	11:30 SAT am	3:00 SAT pm	5:00 SAT pm	12:00 SUN mid	9:00 SUN am	2:30 SUN pm
1	65	120	220	258	265	240	262	236	190	173
2	65	136	225	256	264	234	262	227	182	167
3	65	125	220	255	263	234	260	226	182	167
4	65	117	214	245	255	230	250	220	175	162
5	65	120	218	255	263	240	262	235	193	172
6	65	129	217	253	260	232	260	228	185	162
7	65	130	219	255	262	233	260	227	185	158
8	65	118	210	245	255	228	250	221	180	156
9	65	132	230	262	266	241	267	236	195	180
10	65	136	228	260	264	237	264	230	188	175
11	65	142	235	262	264	234	268	228	189	173
12	65	121	217	250	255	230	254	223	184	170
13	65	94	209	249	262	243	251	238	199	182
14	65	82	204	248	257	243	247	239	200	183
15	65	75	198	243	255	243	245	240	201	184
16	65	82	204	245	255	235	248	232	191	177
17	65	104	212	250	258	238	253	234	194	175
18	65	99	205	246	257	240	249	237	198	182
19	65	78	200	244	254	241	244	238	198	182
Water	-	-	-	-	-	-	-	-	-	-

Point	7:00 MON am	11:00 MON am	7:00 MON pm	7:30 MON pm	8:00 MON pm	10:00 MON pm	3:00 TUE am	6:00 TUE am
1	98	90	-	-	-	-	-	-
2	102	91	-	-	-	-	-	-
3	102	91	-	-	-	-	-	-
4	110	92	-	-	-	-	-	-
5	94	88	-	-	-	-	-	-
6	97	89	-	-	-	-	-	-
7	96	89	-	-	-	-	-	-
8	96	88	-	-	-	-	-	-
9	96	88	72	118	140	170	190	190
10	108	97	-	-	-	-	-	-
11	103	91	-	-	-	-	-	-
12	112	98	-	-	-	-	-	-
13	115	99	-	-	-	-	-	-
14	120	100	-	-	-	-	-	-
15	125	107	-	-	-	-	-	-
16	113	102	-	-	-	-	-	-
17	115	103	72	120	140	170	191	190
18	124	104	-	-	-	-	-	-
19	126	107	-	-	-	-	-	-
Water	-	-	195	170	180	185	195	190

C° = 5/9(F° - 32)

found at the top than on the bottom, while the temperatures on both sides are very close. Also the temperature gradient along the pile appears to be very small as there was only a minor heat loss from one end of the oven to the other. The heating efficiency was substantiated by the temperatures recorded during other drying cycles.

From Figure 3-3 it is apparent the heating was terminated at approximately mid-day on Saturday after the surface temperature had reached a value of 260°F (126.6°C) for only an 8-hour duration. The heat was reapplied at 3 p.m. on Saturday for almost 5 hours in order to satisfy the 10-hour drying requirement. Pile 1A remained in the heating chamber until 7 a.m. on Monday morning. This provided a cooling period of over 39 hours. Because the roof was not removed from the oven, the rate of cooling was only approximately 5°F (2.7°C) per hour. The average surface temperature was slightly above 100°F (37.8°C) while the temperature at the 1" (25.4 mm) depth was 115°F (46.1°C) at 7 a.m. on Monday. The roof was finally removed from the oven and the pile allowed to cool in air. By 11 a.m. the average surface temperature was 90°F (32.2°C) while the temperature at the 1" (25.4 mm) depth was 100°F (37.8°C.)

Pile 1A was removed from the heating chamber and placed immediately into a tank of monomer to begin the soaking or impregnation period. The immersion tank was made by modifying a 16" (406 mm) square steel form used for casting concrete piles. The form was lined with plastic sheeting to form an impermeable enclosure. Steel supports were placed at 15-foot (4.6 m) centers on the floor of the tank to keep the pile off the bottom. Plywood panels were inserted along the sides of the frame before the plastic was applied to reduce the amount of monomer needed in the tank.

The monomer system used to impregnate the prestressed concrete piles was methyl methacrylate (MMA). Although much of laboratory impregnation work utilized a blend of 95% MMA and 5% trimethylolpropane trimethacrylate (TMPTMA) this system was not needed in the pile treatment. The monomer was initiated with 2-t-Butylazo-2-cyanopropane (Luazo 79) at a rate of 0.5% by weight. In order to protect the monomer from the polymerization effects of direct and indirect solar radiation, the specification directed all soaking of the pile be performed between sunset and sunrise unless the fabricator provided an acceptable shielding system. A portable roof system which protected the impregnation tank was approved and soaking of the piles was allowed during daylight hours.

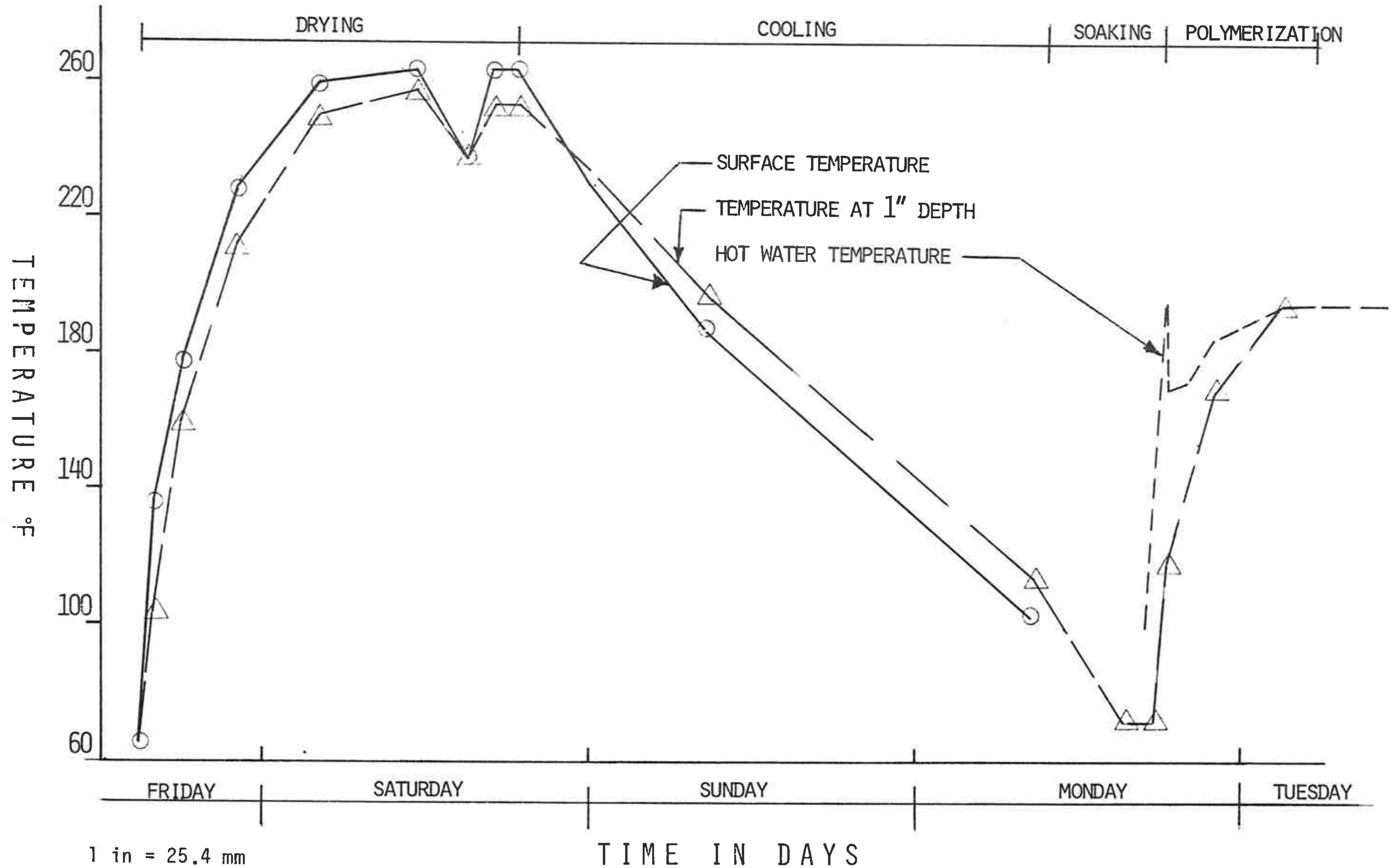
Pile 1A was inserted into the soaking tank by means of a large fork lift vehicle as seen in Figure 3-4. Once submerged, a plastic sheet was draped over the tank to reduce the evaporation of the monomer and the roof system was placed over the entire impregnation tank.

After an 8 hour soaking period, the roof system was removed and Pile 1A was lifted from the soaking tank and transported immediately to the hot water tank which was only 100 feet (30.5 m) away. Here the pile was quickly submerged into the hot water and the polymerization cycle began (see Figure 3-5).

The hot water tank was also fabricated from surplus steel casting forms, but this time extra work was needed to provide a heating system. The tank was retrofitted with two separate heating systems to ensure adequate heating capability. The primary system selected was a large electric heater boiler which was located close to the tank through which the hot water circulated. The secondary heating system consisted of two steam pipes which ran the length of the tank at the bottom. The steam used in this system came from the same oil fired boilers used to heat the drying chamber. Before beginning the impregnation, the hot water bath was also tested to ensure the system was capable of producing sufficient heat to maintain the necessary 170° to 185°F (76.6° to 85°C) water temperature. A portable insulated plywood enclosure was fabricated to fit over the hot water tank to reduce heat loss. During the first test it was found desirable to heat the water initially to a temperature higher than that specified. Original fears the higher water temperature would cause an accelerated depletion of surface monomer did not materialize.

PILE 1A

POLYMER IMPREGNATION CYCLE



1 in = 25.4 mm
$C^o = 5/9(F^o-32)$

FIGURE 3-3

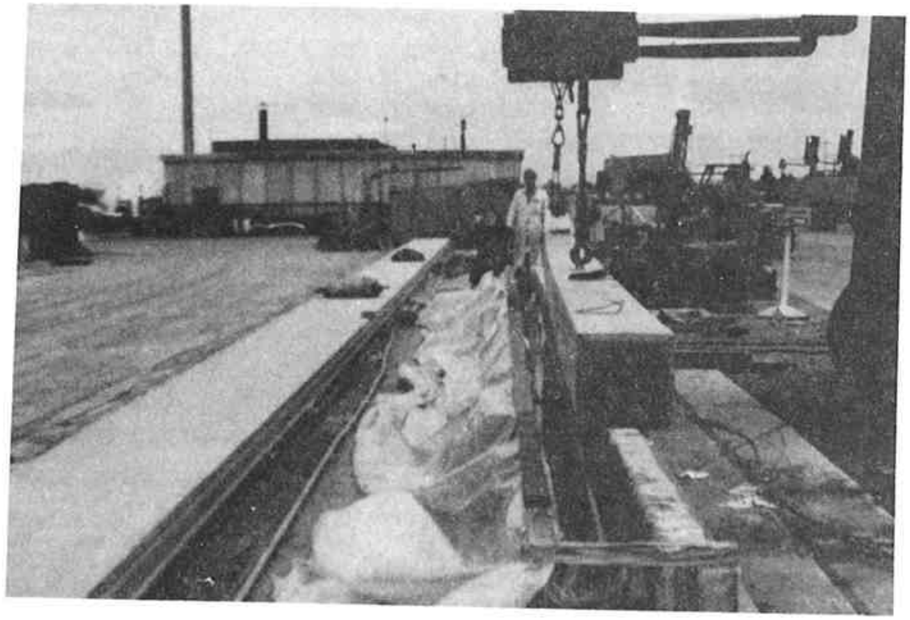


FIGURE 3-4

Pile being Placed in Monomer Soaking Tank for Impregnation

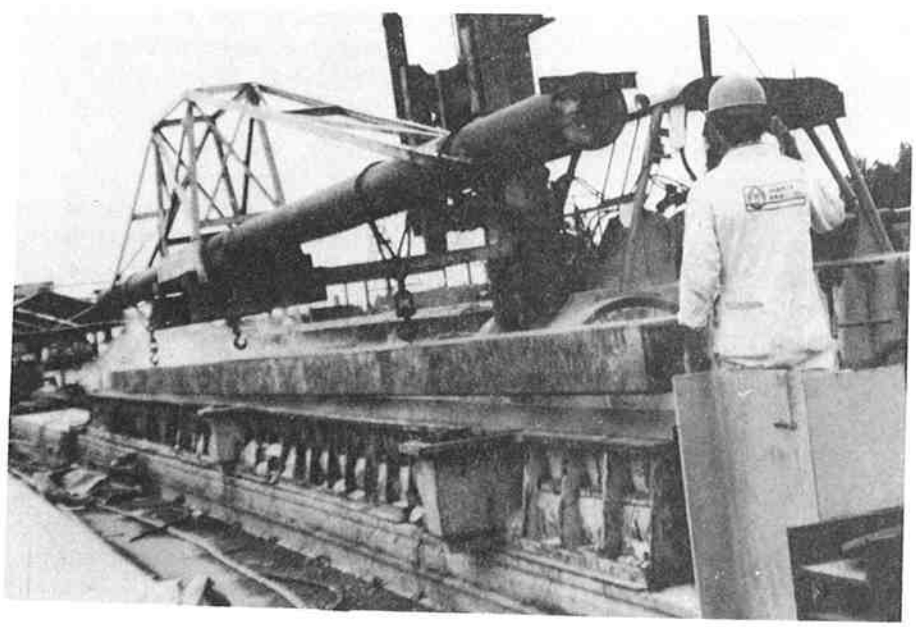


FIGURE 3-5

Pile being Placed in Hot Water Bath

Approximately two hours before Pile 1A was ready to be removed from the monomer soaking tank, the water in the polymerization tank was heated to 195°F (90.6°C). When Pile 1A was placed into the hot water bath, the water temperature dropped rapidly to 170°F (76.6°C). By running the electric boiler almost continuously, the water temperature was raised back to 195°F (90.6°C) after six hours.

Pile 1A was removed from the polymerization tank after 8 hours and placed in final storage. In spite of the complexity of the operation, everything went very smoothly.

Two 6" x 12" (152 x 305 mm) cylinders and two 6" x 6" x 12" (152 x 152 x 305 mm) concrete blocks accompanied Pile 1A through the impregnation process. When the blocks were opened at the completion of the impregnation, a dark 1" (25.4 mm) polymer penetration was clearly visible. Cores later removed from the pile confirmed the successful 1" (25.4 mm) impregnation. The cylinders were also tested on the day following the impregnation. Both cylinders failed at stresses above 10,000 psi (68.9 MPa) which indicated a 23% gain in strength over the 28 day breaks of conventional concrete.

The second pile to receive the polymer impregnation treatment was placed into the drying oven on May 8 at approximately 5 p.m. The drying tempeatures recorded for Pile 1B are found in Table 3-5B. The concrete temperature was 65°F (18.3°C) before the heating began. During the next 12 hours the surface temperature rose to a maximum of only 256°F (124.4°C) . At 6 a.m. the following morning the steam boilers were shut down, but the pile remained in the enclosed oven. Because the oven was well insulated the surface temperature on the pile fell only 50°F (10°C) during the next 9-1/2 hours. At 3:30 p.m., the steam boilers were reactivated, and by 9 p.m. the average surface temperature reached 260°F (126.6°C).

Unlike the first pile, Pile 1B had only 15 thermocouples for temperature monitoring. Besides 12 surface locations, three thermocouples were cast into the piles at a depth of 1" (25.4 mm) at three different locations. See Figure 3-2 for the exact location. As before, the temperature on the top of the pile was higher than the bottom and the temperature difference between each end of the pile was very slight.

Pile 1B was heated until 8:30 a.m. the following morning at which time the heating was stopped. A surface temperature of over 260°F (126.6°C) had been maintained for approximately 11-1/2 hours. The pile was allowed to sit undisturbed but the oven top was partially opened shortly after heating terminated. This produced a moderately fast decrease in surface temperature which was a rate of 17°F/hour (9.4°C/hour).

Pile 1B was subsequently soaked in the monomer bath for 8 hours and heated in the hot water bath for 8 hours. When the impregnation work was completed the sample blocks were opened and a polymer penetration of 7/8" (22.2 mm) was measured. As before, cores were later removed from Pile 1B and they confirmed the 7/8" (22.2 mm) polymer penetration.

Pile 1C was also successfuly impregnated after undergoing a similar process as described for Pile 1B. The polymer penetration was basically the same at 3/4 to 7/8" (19 to 22.2 mm) but the intensity of the polymer was lighter. The drying temperatures recorded for Pile 1C are found in Table 3-5C.

Pile 1D was placed into the drying oven on a Friday afternoon at 4:00 p.m. and heated continuously until 9 p.m. on Saturday. The surface temperature was above 260°F (126.6°C) for approximately 16 hours during the drying cycle (see Table 3-5D). The pile was allowed to cool until Monday morning when it was placed into the monomer soaking tank to undergo impregnation. After soaking for 8 hours, Pile 1D was removed from the impregnation tank and placed into the hot water bath. The temperature of the bath was 190°F (87.8°C) when the pile was immersed. Due to a malfunction in the recirculating system the water level fell 1-1/2" (38.1 mm) below the top surface of the pile. When cold water was added to the tank, the water temperature dropped to below 160°F (71°C) and remained at that lower temperature for several hours. Although the malfunction was discovered about one hour after the pile entered the bath, attempts to fix the recirculating system failed. The auxiliary steam pipe heating system was activated, but it did not produce sufficient heat to return the water temperature to above 170°F (76.7°C). After several hours of emergency repairs the boiler system became operational and both heating systems were used to reheat the water above 170°F (76.7°C). Pile 1D remained in the hot water tank for over 10 hours after the 170°F (76.7°C) temperature was reached. When cores were removed from Pile 1D, the total polymer penetration was found to be 3/4" (19 mm). The outer 3/8" (9.5 mm) shell around the pile however lacked the dense polymer concentration due to depletion which occurred in the hot water bath.

Pile 1E also experienced a fabricating error which prevented it from receiving the full impregnation treatment. After being heated over a two day period to attain the drying requirements, the pile was allowed to cool to below 100°F (37.8°C) (see Table 3-5E). It was then placed into the monomer soaking tank for impregnation. After only 4 hours of soaking, the monomer in the tank suddenly began to solidify. Due to an oversight by the fabricator, the roof system was not replaced over the soaking tank after the pile was immersed and solar radiation caused the upper 3" (76.2 mm) of monomer to polymerize violently. The pile was extracted from the soaking tank after the pick up stands on the top of the pile were located. The pile was then placed into the hot water bath to complete the polymerization of the impregnated pile. When the pile was finally placed in storage, an attempt was made to remove the foamlike plastic from the top of the pile. After several hours of chipping and scrapping, the workmen were successful in removing much of the plastic.

Several cores were taken from Pile 1E to determine the amount of polymer penetration. The results were unsatisfactory as only a light 3/8" (19 mm) penetration was obtained.

Because the fabricator was negligent by not following the specifications, Piles 1D and 1E were purchased at the bid price of conventional concrete.

Internally Sealed Concrete

The fabrication of the internally sealed concrete piles began on March 10, 1980 when two piles were cast. Like the polymer-impregnated piles, thermocouples were installed at designated locations within the piles to monitor the melting of the wax beads. Using the ingredients found in Table 3-3, materials for two piles were batched automatically and mixed in a four cubic yard mixer. Because a total of five cubic yards of material was needed, two batches of 2-1/2 cubic yards (1.9 m^3) each were prepared. The wax beads were added by hand into the mixer (Figure 3-6) with just the dry ingredients and then premixed for approximately two minutes to distribute the beads. After premixing, water was added and all of the ingredients were mixed for approximately three minutes. The concrete was then discharged into an agitator type mobile bucket and transported to the casting beds.

Within five minutes after mixing, concrete placement began. During casting the unit weight, air content, and concrete slump were measured. In addition, the wax bead distribution within the concrete was examined several times. The method consisted of filling a quart size glass jar one-fourth full with concrete and then filling the container with water. After shaking and stirring vigorously for 20 seconds the jar was allowed to sit for three minutes. A consistent quantity of wax beads floated to the top of the water, indicating the beads were well distributed.

The mixing, placing, and finishing of the internally sealed concrete was similar to conventional concrete.

After the top surface of the piles was finished, a canvas was placed over the beds to form a steaming tent. After a 2-1/2 hour delay, steam curing was applied for 8 hours. During the steaming, the air temperature under the tent reached 138°F (58.9°C) for a brief time but it was quickly lowered to the 125° to 130°F (51.6 to 54.4°C) range for the remainder of the steam curing period. Although the 138°F (58.9°C) temperature was in violation of the specifications which allowed a maximum air temperature of 125°F (51.7°C),

Table 3-5B

Concrete and Water Temperatures °F During Impregnation
Polymer Impregnated Concrete Pile 1B

Point	5:00 MON pm	6:00 MON pm	8:00 MON pm	11:00 MON pm	3:00 TUE am	6:00 TUE am	3:30 TUE pm	6:00 TUE pm	8:00 TUE pm	12:00 WED mid
1	66	110	169	208	238	252	203	245	258	270
2	66	116	173	210	238	251	196	245	257	267
3	66	110	166	205	236	249	197	243	254	266
4	66	109	-	202	230	242	191	237	245	-
5	66	81	148	193	228	241	202	232	245	258
6	66	114	170	209	239	231	203	248	258	268
7	66	114	171	209	238	249	195	246	254	265
8	66	120	173	209	238	249	195	245	254	265
9	66	106	159	197	228	240	139	232	244	254
10	66	82	144	190	226	240	202	230	243	255
11	66	116	173	213	244	256	205	250	260	271
12	66	116	175	213	242	253	200	248	258	269
13	66	114	169	208	238	250	200	243	248	265
14	66	-	-	-	-	-	-	-	-	-
15	66	84	144	193	231	245	210	236	248	260
Water	-	-	-	-	-	-	-	-	-	-

Point	8:30 WED am	11:30 WED am	2:30 WED pm	8:00 THU am	4:30 THU pm	5:00 THU pm	6:00 THU pm	1:00 FRI am
1	262	179	145	65	-	-	-	-
2	252	180	145	65	-	-	-	-
3	252	184	147	65	-	-	-	-
4	-	185	152	65	-	-	-	-
5	257	204	160	65	68	118	153	185
6	259	163	137	65	-	-	-	-
7	252	166	136	65	-	-	-	-
8	251	160	132	65	-	-	-	-
9	243	171	140	65	-	-	-	-
10	257	191	150	65	-	-	-	-
11	263	178	142	65	-	-	-	-
12	255	172	141	65	-	-	-	-
13	255	180	143	65	-	-	-	-
14	-	-	-	65	-	-	-	-
15	265	195	150	65	68	115	152	180
Water		-	-	-	207	174	180	195

$C° = 5/9(F° - 32)$

Table 3-5C
Concrete and Water Temperatures °F During Impregnation
Polymer Impregnated Concrete Pile 1C

Point	3:30 WED pm	4:00 WED pm	8:00 WED pm	12:00 THU mid	3:00 THU am	12:30 THU pm	3:30 THU pm	5:00 THU pm	12:00 FRI mid
1	67	128	203	232	242	206	194	252	260
2	67	114	-	-	-	-	-	-	-
3	67	118	200	228	238	198	188	250	257
4	67	-	193	-	-	-	-	-	-
5	67	89	181	219	231	204	192	237	247
6	67	121	203	232	241	209	198	255	260
7	67	121	203	233	243	205	193	253	260
8	67	114	203	230	240	203	190	252	260
9	67	108	197	226	236	200	186	244	250
10	67	90	183	219	230	209	197	240	250
11	67	125	204	230	240	210	200	205	260
12	67	125	206	234	242	205	195	205	259
13	67	122	203	228	238	204	192	202	258
14	67	100	193	226	234	198	188	245	252
15	67	94	183	220	228	212	202	240	248
Water	-	-	-	-	-	-	-	-	-

Point	8:30 FRI am	1:00 FRI pm	3:30 SAT pm	4:00 SAT pm	4:30 SAT pm	7:30 SAT pm	12:00 SUN mid
1	275	150	-	-	-	-	-
2	-	-	-	-	-	-	-
3	272	166	-	-	-	-	-
4	-	-	-	-	-	-	-
5	262	186	-	-	-	-	-
6	276	174	-	-	-	-	-
7	275	184	-	-	-	-	-
8	275	181	-	-	-	-	-
9	264	188	-	-	-	-	-
10	265	201	-	-	-	-	-
11	276	142	-	-	-	-	-
12	274	167	-	-	-	-	-
13	274	163	-	-	-	-	-
14	266	161	-	-	-	-	-
15	268	180	-	-	-	-	-
Water	-	-	188	210	175	202	192

$C° = 5/9(F° - 32)$

Table 3-5D

Concrete and Water Temperatures °F During Impregnation
Polymer Impregnated Concrete Pile 1D

Point	3:00 FRI pm	5:00 FRI pm	8:00 FRI pm	12:00 SAT mid	5:00 SAT am	11:00 SAT am	9:00 SAT pm	7:00 MON am	4:00 MON pm	4:15 MON pm
1	65	104	126	228	254	269	272	75	-	-
2	65	-	131	226	251	265	270	75	-	-
3	65	93	119	220	246	265	269	75	-	-
4	65	86	116	213	240	254	262	75	-	-
5	65	64	94	205	236	250	264	75	-	-
6	65	93	114	217	245	262	268	75	-	-
7	65	95	121	221	247	262	265	75	-	-
8	65	90	120	223	249	261	265	75	-	-
9	65	88	112	213	238	252	255	75	-	-
10	65	62	92	204	235	250	258	75	-	-
11	65	100	121	224	252	266	275	75	-	-
12	65	98	126	226	252	265	272	75	-	-
13	65	94	120	220	247	264	273	75	-	-
14	65	90	115	216	246	261	268	75	-	-
15	65	66	90	205	236	248	268	75	-	-
Water	-	-	-	-	-	-	-	-	192	168

Point	5:15 MON pm	7:00 MON pm	9:00 MON pm	10:00 MON pm	11:00 MON pm	12:00 TUE mid	4:00 TUE am	8:00 TUE am
Water	167	158	158	176	179	179	184	185

C° = 5/9(F° - 32)

Table 3-5E

Concrete and Water Temperatures °F During Impregnation
Polymer Impregnated Concrete Pile 1E

Point	3:00 MON pm	4:00 MON pm	7:00 MON pm	10:00 MON pm	12:00 TUE mid	6:30 TUE am	2:00 TUE pm	4:30 TUE pm	8:00 TUE pm	12:00 WED mid
1	56	122	188	238	250	278	226	214	257	280
2	56	133	195	240	250	275	217	206	257	278
3	56	135	195	240	250	274	216	205	257	278
4	56	128	190	225	243	272	223	211	251	273
5	56	136	196	230	247	272	213	202	252	273
6	56	133	191	225	242	268	213	202	247	269
7	56	133	199	236	255	281	233	221	265	286
8	56	142	201	236	254	280	224	211	264	284
9	56	138	196	233	251	278	224	211	260	282
10	56	90	164	214	239	270	238	226	250	275
11	56	78	153	207	231	266	239	221	248	272
12	56	69	142	200	226	263	240	228	241	268
13	56	93	163	210	232	264	225	214	243	268
14	56	95	168	215	237	269	231	230	249	274
15	56	78	152	205	229	264	235	223	243	269
16	56	70	143	199	225	263	237	225	240	267
Water	-	-	-	-	-	-	-	-	-	-

Point	7:00 WED am	11:30 WED am	6:00 THU am
1	279	228	75
2	277	222	75
3	272	221	75
4	274	214	75
5	269	205	75
6	266	206	75
7	286	241	75
8	281	230	75
9	281	230	75
10	283	243	75
11	284	254	75
12	282	255	75
13	276	236	75
14	283	242	75
15	283	250	75
16	281	253	75
Water	-	-	-

C° = 5/9(F° - 32)

no premature melting of the wax beads was found in sample blocks when they were opened. Approximately 18 hours after casting, two cylinders were tested at the fabrication plant to determine if the concrete had gained sufficient strength to allow release of the prestressed strands. Since the cylinder breaks were above 4,000 psi (27.6 MPa), the piles were prestressed. The piles were then removed from the casting beds and placed in storage. A plastic sheet was used to cover the piles to allow a dry cure. The results of testing the internally sealed concrete cylinders for compressive strength and the modulus of elasticity are found in Table 3-6.

Five extra 6" x 12" (152 x 305 mm) cylinders and several 6" x 6" x 12" (152 x 152 x 305 mm) blocks were also cast on March 10 for use in the heating chamber. One cylinder and two blocks were placed into the oven with the pile during the melting process. The cylinders were later tested to determine the effects of melting the beads. Only a small loss of strength was found to have resulted from melting the wax beads.

Two additional internally sealed concrete piles were cast on March 13. The mixing, placing, finishing and testing were similar to the other two piles but a problem developed in maintaining a constant steam temperature above 120°F (48.9°C). Cylinder breaks on the day after casting were below 4000 psi (27.6 MPa) so prestressing of the piles was not allowed. Because of the weekend, the next cylinder breaks were not scheduled until the following Monday. After a 4-day cure the compressive strength of the cylinders was above 5,000 psi (34.5 MPa) and prestressing of the piles was allowed. When prestressing was concluded, the piles were removed from the casting beds also placed in dry storage.

The last internally sealed concrete pile was fabricated on March 18. The concrete was mixed, placed and finished in approximately 20 minutes. A latex modified concrete pile was also cast at this time in an adjacent bed. Within two hours after casting, both piles were subjected to steam curing. The steam was applied for 14 hours at a temperature range of 125° to 130°F (51.7 to 54.4°C). When the internally sealed concrete cylinders were tested the following morning, they failed at an average stress of 3,350 psi (23.1 MPa), which was not sufficient to allow the pile to be prestressed. Both piles were resteamed for 15 hours at 125°F (51.7°C). When the internally sealed concrete cylinders were tested on the second day after casting, the breaks were above 4,000 psi (27.6 MPa) and the internally sealed concrete pile was prestressed at that time. As before, the pile was placed in dry storage for a minimum of 14 days before being subjected to the heating process.

The first internally sealed concrete pile to undergo the melting process was placed into the heating chamber on April 22 (see Figure 3-7). To monitor the heating characteristics of the oven and to guarantee the wax beads were melted uniformly, 19 thermocouples were placed on and in the pile. A group of seven thermocouples were cast into the pile at midspan at the 1", 2", and 3" (25.4, 50.8, and 76.2 mm) depth while 12 others were grouted onto the surface. The exact location of the thermocouples for each of the internally sealed concrete piles is shown in Figure 3-8.

When Pile 2B was placed into the heating chamber at 6:30 p.m. the concrete temperature was 65°F (18.3°C). The superheated steam was immediately activated and the melting process began. During the next 13-1/2 hours, periodic temperature readings were taken.

Approximately 7-1/2 hours after starting, all three of the thermocouples at the 2" (50.8 mm) depth registered temperatures over 185°F (85°C). At this point the heating was terminated and the pile was allowed to cool slowly in the closed chamber. At 6:30 a.m. on the following morning the top of the oven was removed to allow a more rapid cooling. In order to examine the effectiveness of the heating system before coring the pile and to reexamine the effects of melting the wax beads on strength, two blocks of internally sealed concrete and one 6" x 12" (152 x 305 mm) cylinder accompanied the pile into the heating oven during the melting cycle. Before the pile was removed from the oven the blocks were opened to determine the depth of bead

Table 3-6

Compressive Strength and Modulus of Elasticity of Internally Sealed Concrete

Date Cast	Compressive Strength (lbs/in²) Test A			Test B		Test C		Modulus of Elasticity lbs/in² x 10⁶
	Age of 6" x 12" Cylinders							
	1 d		28 d	7 d	28 d	7 d	28 d	
03/10/80	4350		7003	6435	7325	4825[1]	6335[2]	[1]2.7
	4262		6331		7670	5000	6725	[2]3.5
					7625[3]			[3]3.6
					7465			
					7540			
		4 d						
03/13/80	3113	5765	6543	5340	6375	5070	6020	
	3225	5394	6278		6170[1]		5875	[1]3.4
		2d						
03/18/80	3360	4421	4244	5245	6120	5005	5875	
	3348	4172	5570		6090		5765	

Test A - Cylinders tested at Morse Bros. Plant after being steam cured initially and then cured in air.
Test B - Cylinders tested at OSHD Lab after being cured only in a moist room.
Test C - Cylinders tested at OSHD Lab after being steam cured initially and then cured in a moist room.

Compressive Strength After Melting Wax Beads (lbs/in²)

Date Cast	Date Melted	Pile No.	Compressive Strength	Modulus of Elasticity
03/18/80	04/22/80	2B	6015	
03/13/80	04/24/80	2A	5588	
03/18/80	04/29/80	2C	6215	
03/13/80	04/30/80	2D	5985[1]	[1]3.3
03/10/80	05/01/80	2E	6275	

1000 psi = 6.895 MPa
1 in = 25.4 mm

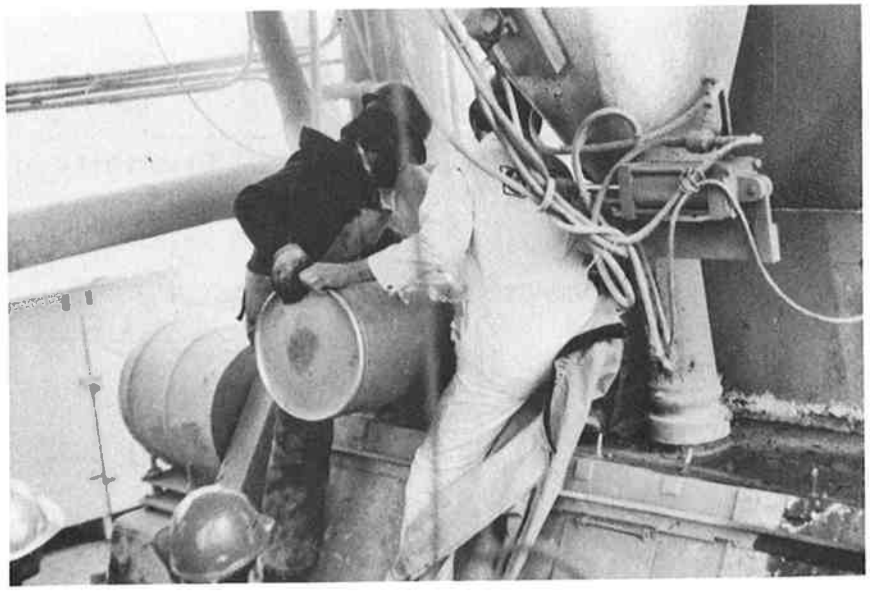
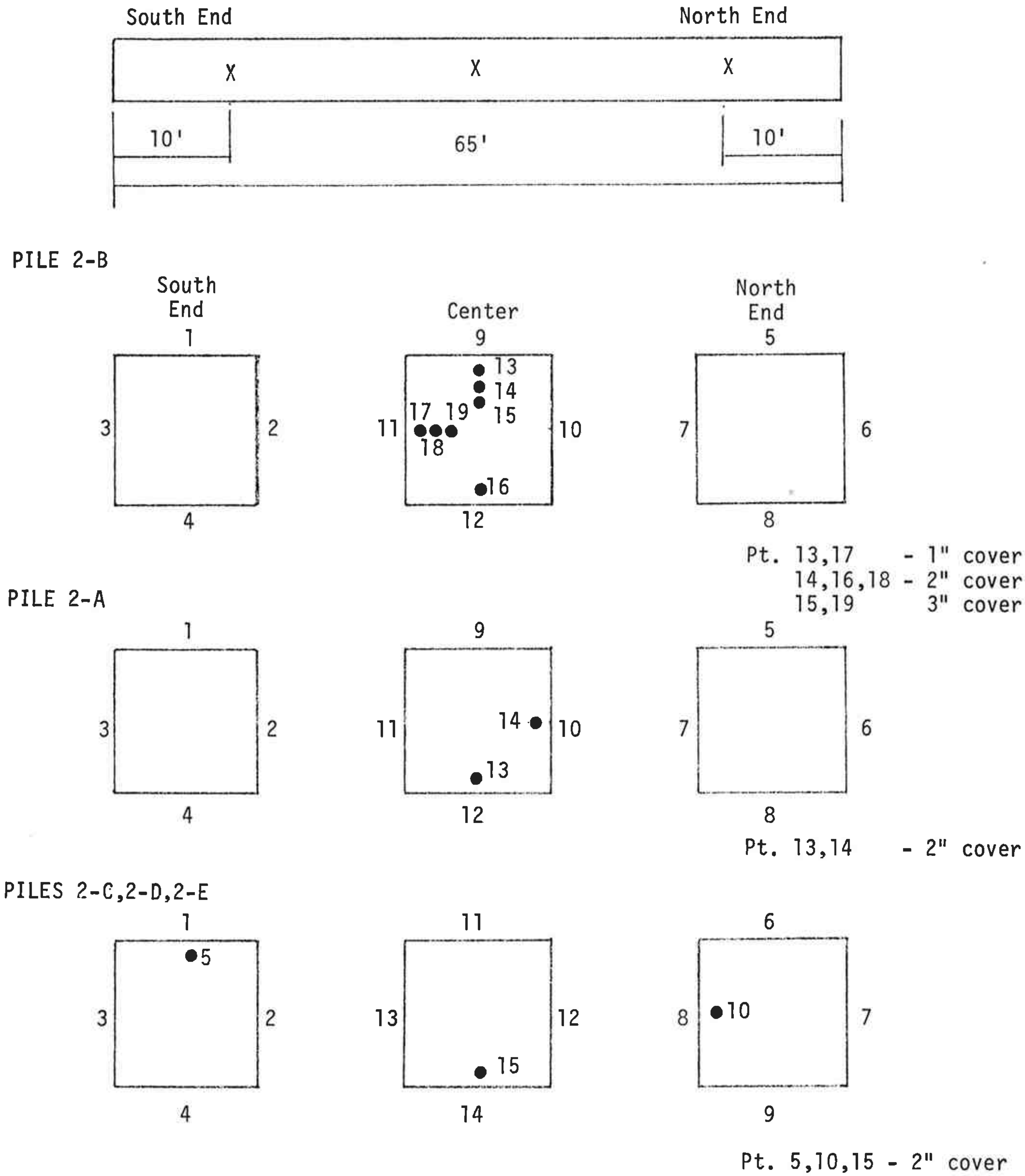


FIGURE 3-6

Wax Beads Added to Mixer

FIGURE 3-7

Placing Internally Sealed Concrete Pile into Melting Oven



1" = 25.4 mm

FIGURE 3-8

Location of Thermocouples
in Internally Sealed Concrete Piles

melting. The wax beads were found to be completely melted within the outer 2-1/2" (63.5 mm) zone.

The pile was finally removed from the heating oven shortly after 10:00 a.m. and placed in storage. Cores were later removed from the pile and they confirmed the satisfactory results. The cylinder was tested in the laboratory three days after the beads were melted. The result was satisfactory as only a minor decrease in compressive strength was detected.

The temperatures recorded during the melting process are found in Tables 3-7A thru 3-7E. The temperature readings along the length of Pile 2B appeared to be within a tolerable range but some individual readings seem to be in error. For example, point #9, which was at the midspan of the pile, was higher than the readings at either end. By excluding the questionable readings the heating chamber was found to provide a uniform method of melting the wax beads.

Pile 2A was placed into the heating chamber on April 24. Unlike the first pile, only 14 thermocouples were used to monitor the temperature. When heating began at 5:30 p.m. the concrete temperature was 67°F (19.4°C). After 7-1/2 hours of heating the thermocouples at the 2" (50.8 mm) depth indicated a temperature of 198°F (92.2°C) had been reached but for some unknown reason the heating was not terminated. The pile was heated for an additional 5 hours and this produced a surface temperature of 230°F (110°C) and a temperature of 212°F (100°C) at the 2" (50.4 mm) depth. Because of the prolonged heating the wax beads within the sample blocks were found to be completely melted when the blocks were opened.

The remaining piles, 2C, 2D, and 2E, were heated on April 29, April 30 and May 1 respectively. A plot of the surface and 2" (50.8 mm) depth temperatures for Pile 2E appears in Figure 3-9.

After the piles were heated and placed in storage, they were carefully examined and, because of the melted wax, were found to be slightly darker in appearance than conventional concrete. Several longitudinal cracks were also detected near the center of the piles on each face. These cracks were very tight and had random lengths. Cores removed from the piles indicated the cracks were approximately 1/2" (12.7 mm) deep. It was not known whether the cracks would adversely affect the durability of the concrete.

Latex Modified Concrete Piles

The first two latex modified concrete (LMC) piles were fabricated on February 29, 1980. The concrete was mixed in a conventional four cubic yard drum mixer and transported to the casting beds in an agitator type mobile bucket. Being allowed to choose between three proprietary latex modifiers listed in the specification, the fabricator selected Dow Chemical Co. Modifier A. The latex emulsion was added to the mixer by hand after it was transferred from 55 gallon (208 l) drums to 5 gallon (18.9 l) pails. See Figure 3-10. Two extra workers were needed at the automatic batcher to handle the latex during mixing. After the latex emulsion was added to the mixer, all of the ingredients were mixed for approximately three minutes. The weight of the ingredients used to produce the latex modified concrete are listed in Table 3-3.

Within five minutes after being discharged from the mixer the placement of the LMC began. Throughout the entire placement, the LMC appeared extremely sloppy and wet. The slump was measured several times during casting and each time it measured approximately 9" (228 mm) (see Figure 3-11). Because of its fluidity some minor segregation was noted during consolidation.

Although both piles were cast within 20 minutes, their surface was very difficult to finish because of the formation of a latex film. The surface was sticky and tore when troweled. An investigation was conducted to determine the reason for the large slump, but no satisfactory answer was found. From the information available, a water cement ratio of 0.295 was used during batching but a heavy rain occurred just as the concrete was being transported to the casting bed. The rain lasted only a few minutes, but since the mobile bucket did not have a cover some rain

Table 3-7A

Concrete Temperatures °F During Melting of the Wax Beads
Internally Sealed Concrete Pile 2A

Point	6:00 THU pm	8:30 THU pm	11:30 THU pm	1:00 FRI am	6:00 FRI am	12:00 FRI n
1	75	161	202	209	227	146
2	70	170	204	208	222	146
3	75	170	203	208	223	146
4	69	152	190	195	210	146
5	75	169	209	214	233	144
6	81	171	210	213	230	148
7	84	167	206	210	226	146
8	70	162	200	204	217	149
9	78	167	208	213	232	139
10	83	174	210	212	230	142
11	74	178	214	212	226	140
12	70	162	202	203	220	146
13	71	132	176	199	213	162
14	77	130	176	198	220	165

Table 3-7B

Concrete Temperatures °F During Melting of the Wax Beads
Internally Sealed Concrete Pile 2B

Point	6:00 TUE pm	7:00 TUE pm	9:00 TUE pm	12:00 WED mid	2:00 WED am	6:30 WED am	10:00 WED am
1	65	120	160	207	213	191	123
2	65	128	172	210	212	190	122
3	65	121	163	206	210	189	119
4	65	109	152	195	201	180	112
5	65	126	166	213	217	196	127
6	65	126	169	213	217	195	126
7	65	124	169	214	216	194	125
8	65	136	175	214	212	191	120
9	65	133	175	220	218	195	125
10	65	125	173	215	216	194	123
11	65	129	173	215	215	194	123
12	65	113	167	211	219	200	128
13	65	79	122	181	202	187	127
14	65	71	111	170	196	183	138
15	65	68	104	162	190	180	142
16	65	85	134	189	206	192	145
17	65	91	137	189	206	191	130
18	65	78	122	179	200	186	142
19	65	71	111	185	193	182	144

C°= 5/9(F° - 32)

Concrete Temperatures °F During Melting of the Wax Beads
Internally Sealed Concrete

Table 3-7C
Pile 2C

Table 3-7D
Pile 2D

Point	7:00 TUE pm	8:30 TUE pm	11:00 TUE pm	2:00 WED am	4:00 WED pm	5:00 WED pm	7:00 WED pm	9:00 WED pm	11:00 WED pm	1:00 THU am
1	150	171	204	215	80	129	163	197	222	210
2	168	185	212	214	73	131	171	200	223	207
3	150	171	203	209	70	131	169	201	222	205
4	128	150	180	200	-	-	-	-	-	-
5	85	121	160	200	68	84	120	159	190	198
6	143	165	199	215	80	134	170	200	223	210
7	145	167	200	214	72	130	170	200	223	207
8	150	170	201	212	69	126	165	198	222	207
9	139	158	192	203	64	114	154	190	212	200
10	89	118	158	206	68	84	121	162	191	195
11	146	168	201	217	82	139	170	200	223	210
12	147	172	201	215	60	132	172	202	223	207
13	180	200	225	219	69	139	174	205	223	207
14	151	180	207	211	67	119	158	190	213	200
15	85	121	161	203	77	83	112	150	182	195

Table 3-7E
Pile 2E

Point	4:00 THU pm	6:00 THU pm	7:00 THU pm	10:00 THU pm	12:00 FRI mid	4:00 FRI am	6:30 FRI am	10:00 FRI am
1	78	140	162	192	194	180	171	108
2	76	152	177	205	190	173	165	120
3	77	152	175	202	189	173	165	116
4	-	-	-	-	-	-	-	-
5	74	108	131	166	191	182	173	138
6	82	145	168	196	195	183	175	101
7	73	149	172	199	192	178	175	109
8	79	156	180	205	192	177	169	109
9	70	140	165	192	188	173	165	117
10	74	102	126	162	191	185	173	136
11	84	148	171	200	196	185	178	108
12	74	154	178	205	193	180	172	122
13	80	155	178	204	192	178	171	119
14	72	142	166	192	187	173	166	127
15	75	108	131	165	195	188	180	135

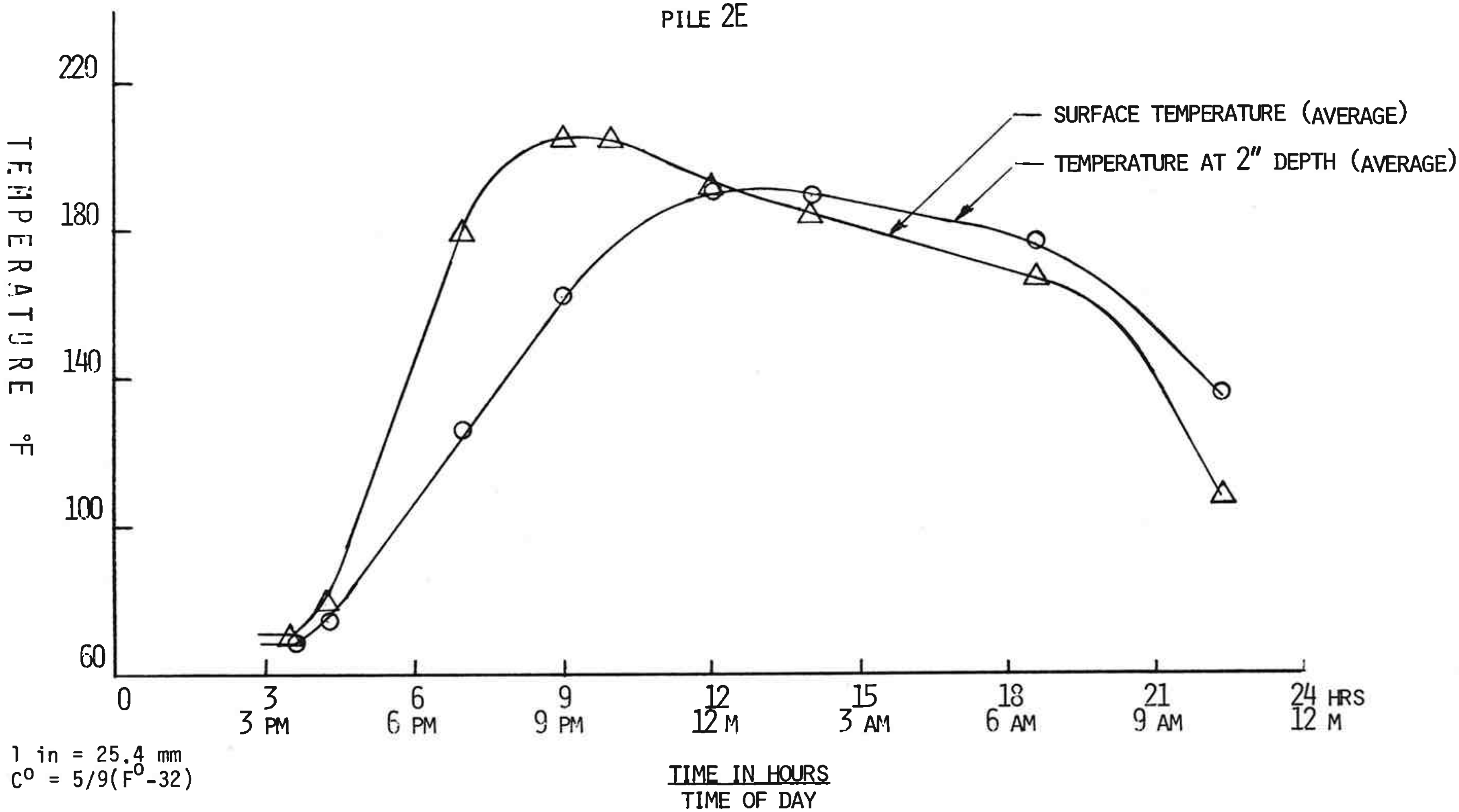
C° = 5/9(F° -32)

INTERNALLY SEALED CONCRETE

TEMPERATURE VS TIME

DURING MELTING OF WAX BEADS

PILE 2E



1 in = 25.4 mm
$C^o = 5/9(F^o-32)$

FIGURE 3-9

FIGURE 3-10

Latex Modifier Added to Mixer

FIGURE 3-11

Slump Test for Latex Modified Concrete

water was incorporated into the concrete. The temperature during the casting was 52°F (11.1°C).

When finishing was completed, the piles were quickly covered with a single layer of wet burlap before a canvas tent was installed for steam curing. Within three hours after casting the piles were subjected to steam curing. The steam was maintained for a total of 6 hours, three of which were above 140°F (60°C). Because casting occurred on Friday, the piles were allowed to cure undisturbed until Monday morning. At that time two cylinders were tested at the prestress concrete plant to determine compressive strength. After 6 hours of steam curing and three days of normal curing, the average cylinder break was only 4,129 psi (28.47 MPa). This value was lower than expected but sufficient to allow the piles to be prestressed.

After the prestressing strands were released, the piles were removed from the casting beds and placed in storage. The latex modified concrete bonded somewhat to the steel forms even though a light oil was used as a bond breaker. A double oil coating was applied for subsequent pours, and no additional bonding problems were encountered.

Immediately after the piles were placed in storage, an attempt was made to attach strain gages. The attempt failed because the bonding epoxy would not set at the low ambient temperatures. Shrinkage and creep measurements were therefore not made on the first two latex modified concrete piles.

Table 3-8 presents the results of testing cylinders that were made during the fabrication of the latex modified concrete piles. Several different methods of curing were employed and they produced very different results. For the first pile, the cylinders that were cured only in air exhibited the highest strength values. The cylinders that underwent steam curing initially and then further curing in the Highway Laboratory moist room generally had low and erratic strengths after 7 and 28 days.

The next LMC pile was not fabricated until March 18. That day, one internally sealed concrete pile was also fabricated. The same LMC mix design and mixing procedure was used as before. Once again, the LMC was very sloppy and wet when placed into the form in spite of the 0.30 water cement ratio. An 8-3/4" (222 mm) slump was measured twice during casting. Although the concrete was placed within 20 minutes, the surface was very difficult to finish due to the formation of the latex film. A single layer of wet burlap was placed over the pile when finishing was completed and before steam curing began.

Because an internally sealed concrete pile occupied the adjacent casting bed, both piles had to be subjected to a low temperature steam cure. Steam was applied to the piles for 14 hours with a maximum temperature of 125°F (51.7°C). On the next morning, the LMC cylinders were very weak and crumbled when placed into the testing machine, while the internally sealed concrete cylinders exhibited a compressive strength of slightly over 3,300 psi (22.7 MPa). Both piles remained in the casting beds for one additional day and were again subjected to steam for 15 hours. Although the LMC cylinders failed at an average compressive strength of 3,042 psi (21 MPa) on the second day after casting, the fabricator decided to release the prestressing strands. When the strands were released, they immediately disappeared into the concrete because of a lack of bond. When the LMC pile was removed from the casting bed it deflected very badly and it was immediately rejected by the fabricator.

On March 20, two more LMC piles were fabricated using the same mix design as before. Once again a 9" (228 mm) slump was measured even though a water/cement ratio of 0.28 was used. The LMC was mixed, placed, and finished within a 40-minute period. Shortly after the piles were finished they were subjected to steam curing for 10 hours. During the last six hours the steam temperature remained above 150°F (65.6°C). Two cylinders were tested on the following morning and as before the results were disappointing. The average ultimate compressive strength was only 2,025 psi (14 MPa). The piles were re-steamed and allowed to remain in the casting beds over a weekend. On Monday morning, two

Table 3-8

Compressive Strength and Modulus of Elasticity of Latex Modified Concrete

Compressive Strength (lbs/in^2)

Date Cast	Test A 3 day	Test A 28 day	Test B 7 day	Test B 28 day	Test C 7 day	Test C 28 day	Test D 7 day	Modulus of Elasticity psi
02-29-80	4085	4545	5145	6600	2740	4995	7180[1]	[1] $3.0x10^6$
	4173	4775		6720	3120	3145	7075	
					4250[2]		7945	[2] $2.0x10^6$
					4105			

Date Cast	Test A 1 day	Test A 4 day	Test A 28 day	Test B 7 day	Test B 28 day	Test C 7 day	Test C 28 day	Modulus of Elasticity psi
04-17-80	3595	5787	7463	-	-	5680[1]	6580	[1] $3.7x10^6$
	3643	5694	7498	-	-		6600	

Date Cast	1 day	2 day	28 day	7 day	28 day	7 day	28 day	Modulus of Elasticity psi
04-22-80	3448	4067	6750	5270	6600	5305[1]	6105	[1] $3.3x10^6$
	3537	4156	6950		6670[2]	5340	5765	[2] $3.6x10^6$
							6070[3]	[3] $3.4x10^6$

Date Cast	1 day	4 day	28 day	7 day	28 day	7 day	28 day	Modulus of Elasticity psi
04-24-80	3360	5287	7356	6065	6910	5790[1]	5990	[1] $3.4x10^6$
	3537	5553	7335		6890[3]	5730[2]	6420	[2] $3.5x10^6$
							6505[4]	[3] $3.5x10^6$
								[4] $3.6x10^6$

Test A - Cylinders tested at Morse Bros. Plant after being steam cured initially and then cured in air.

Test B - Cylinders tested at OSHD Lab after being cured only in a moist room.

Test C - Cylinders tested at OSHD Lab after being steam cured initially and then cured in a moist room.

Test D - Cylinders tested at OSHD Lab after being cured only in air.

1000 psi = 6.895 MPa

more cylinders were tested and they were found to be no stronger than the previous ones. When the prestressed strands were released they retracted into the concrete piles. As the piles were removed from the casting beds, both deflected badly and one suffered extensive cracking. Both piles were rejected.

At this time, two 1-1/2 cubic foot (0.04 m^3) trial batches of LMC were made at the prestressed concrete plant. The first batch was made using all of the ingredients that went into the piles. The second batch was similar except it contained no water-reducer set-retarding agent (Pozzolith 100-XR). The first batch had a 9" (228 mm) slump while the second batch had a 3-1/2" (88.9 mm) slump. Cylinders that were made from both batches were steam cured for 8 hours at 150°F (65.6°C). After one day, the concrete containing the admixture failed at an average compressive stress of 1,875 psi (12.9 MPa) while the concrete without the admixture failed at 3,775 (26 MPa) psi. This clearly demonstrated the admixture and the latex emulsion were not compatible. Because the first two piles contained the admixture and their strength tests erratic, they were also rejected.

An additional supply of latex emulsion had to be ordered from Dow Chemical Company. This delayed the refabrication of the LMC piles until April 17, 22, and 24. Due to the problems that developed during the initial fabrication, a Dow representative was sent to the processing plant to provide technical assistance.

In order to evaluate the entire manufacturing process with the least risk, only one LMC pile was fabricated on the first day. As before, the concrete was mixed in a four cubic yard drum mixer, but there were two changes made in the mix design. First, no admixtures were used and second, the latex emulsion content was reduced from 3.5 gal/sack to 3.2 gal/sack (13.2 to 12.1 l/sack). During placement no segregation was noted and a 5-1/4" (133 mm) slump was recorded. The latex film which formed on the top surface made hand finishing difficult. The single LMC pile was completely fabricated in 20 minutes.

Pile 5D was steam cured for 14 hours during the first night. The steam temperature was above 150°F (65.6°C) for eleven of those hours. On the next morning two cylinders were tested but their average ultimate compressive strength was only 3,550 psi (24.5 MPa). This was not high enough to permit the prestressing strands to be released. The pile was resteamed on the second night for an additional 10 hours. The prestressing strands were finally released after curing over a weekend when the cylinders indicated an average ultimate compressive strength of 5,720 psi (39.4 MPa). The pile was removed from the casting bed and placed in storage.

On April 22, two additional LMC piles (5C and 5E) were fabricated using a water/cement ratio of 0.28 and a latex emulsion content of 3.2 gal/sack (12.1 l/sack). The fabrication went very well, but the concrete had a 9" (228 mm) slump. The piles were steam cured for 12 hours during the first night at a steam temperature of 155°F (68.3°C). The average cylinder strength the next morning was only 3,490 psi (24 MPa) so the piles were resteamed an additional 12 hours at 155°F (68.3°C). On the second day after casting, the compressive strength of the cylinders was slightly above 4,000 psi (27.6 MPa) so the piles were prestressed and removed from the casting beds.

The last two LMC piles were cast on April 24 and like the previous two piles did not attain sufficient strength after steam curing for 13 hours to allow prestressing. The piles were resteamed for 10 hours and then allowed to further cure over a weekend. On Monday morning, the cylinder breaks indicated an average compressive strength of 5,420 psi (37.4 MPa) was attained which allowed the piles to be prestressed.

While the piles were in storage at the plant they were examined and found to be well constructed. The top surface was slightly rough due to the finishing difficulties.

Nails were embedded in the LMC piles to allowed shrinkage and creep measurements to be taken while the piles were in storage.

Polymer Concrete

The polymer concrete piles were fabricated on April 9, 10 and 11, 1980. Two weeks before fabrication began, the coarse aggregate used to produce the polymer concrete was dried in an asphalt concrete plant at 425°F (218.3°C) to reduce the moisture content to below 0.5 percent. The aggregate came from two different stockpiles which were graded 3/4" to 1/2" (19 to 12.7 mm) and 1/2" to No. 4 (12.7 to 4.7 mm). Once dried, the aggregate was stored in separate hoppers where it was allowed to cool to the ambient temperature. Before the aggregate was used, the temperature and gradation were checked and found to be satisfactory. The desired aggregate gradation after blending appears in Table 3-9.

Because the fabricator did not have experience with polymer materials, only one pile was scheduled to be built on the first day. The preparation of the casting bed was altered slightly for the polymer concrete work when a light coat of axle grease was applied in lieu of the form oil. This was done to eliminate the potential bonding of the polymer concrete to the steel form. Special care was exercised to ensure the prestressing strands were not contaminated by the grease.

The mix design used for the first piles was different from the one in the specifications as the polymer content was reduced from 7 percent to 4.5 percent. Trial batches made with the originally specified 7 percent polymer content appeared too wet when made with the Morse Bros. aggregate. After reducing the resin content in several trial batches, the 4.5 percent polymer content appeared to produce satisfactory results. Technical representatives from DuPont who were present during the work agreed to the change in formulation (see Mix A in Table 3-10).

Unlike the other experimental concretes, the polymer concrete was mixed in a one cubic yard pan-type mixer, using the following batching sequence. First, the dry aggregates were proportioned and deposited into the mixer. Next, a 5-gallon (18.9 l) can of monomer was added to the mixer to wet the surface of the stones. The mixer was then run briefly for this purpose, but in so doing, sparks were seen at the bottom of the pan as the paddles caused the aggregate to slide against the steel surface. Because the monomer vapors were flammable this was somewhat hazardous. Several fire extinguishers were available at the mixer, but fortunately they were not needed.

Once the aggregate surface was sufficiently wetted, Crylcon powder EP 3020 and Crylcon monomer EP 3009 were added to the mixer and all ingredients were mixed for 5 minutes. The monomer was added to the mixer from 5-gallon (18.9 l) cans by two workers who wore protective clothing consisting of rubber gloves, eye shields and respirators. When mixing was completed, the polymer concrete was discharged from the mixer and transported to the casting bed. Within two minutes after discharge, placement began. Four additional workers were needed to place, consolidate, and finish the concrete using conventional internal vibrators and hand tools. Each worker wore protective equipment similar to the workers at the mixer. One worker who could not wear a respirator and who could not tolerate the monomer odor had to leave the area and work on another project. The total time required to mix, place and finish the first batch was 15 minutes.

After the first batch of polymer concrete was placed a signal was sent to the mixer to begin the next load. The same mixing sequence was used as described before. Although the polymer concrete appeared to be slightly dry, no change was made in the formulation. The first polymer concrete pile was manufactured in 50 minutes with a work force which was greatly expanded to overcome the relatively short allowable work time. During casting of a conventional concrete pile only four men were needed to mix, transport, place and finish the concrete while eleven men were used for polymer concrete.

During fabrication, a thermocouple was embedded into the polymer concrete to measure exotherm during polymerization. This temperature is plotted in Figure 3-12 and indicates a peak exotherm of 99°F (37.2°C) occurred approximately one hour after mixing. Two nails were embedded into the pile to measure shrinkage, elastic shortening, and creep

Table 3-9

Polymer Concrete
Coarse Aggregate Gradation

Sieve Size	% Passing
1"	100.0
3/4"	98.9
1/2"	64.6
3/8"	31.6
1/4"	3.5
#4	0.7

1" = 25.4 mm

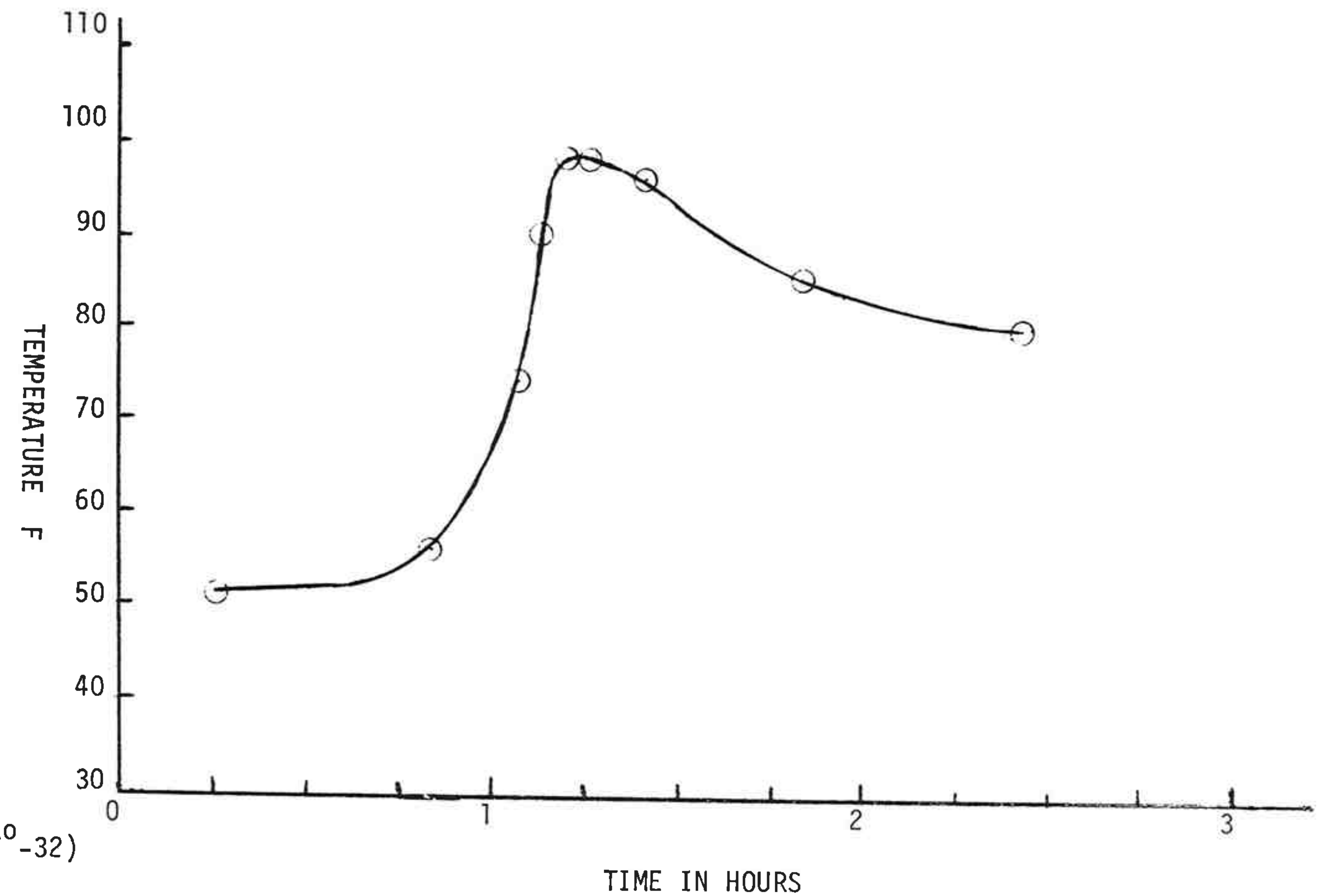
Table 3-10

Polymer Concrete Formulation
pounds per cubic yard

	Mix A lbs.	Mix B lbs.
EP 3009 Monomer	175.5	195
EP 3020 Powder	1980	1980
Coarse Aggregate	1750	1750

1 lb = 0.45 kg

Polymer Concrete Exotherm
Ambient Temperature 52 °F
Pile 4B



$C^o = 5/9(F^o - 32)$

Figure 3-12

after the surface was finished. A description of this work appears in a later section.

Three hours after the polymer concrete was mixed, a cylinder was tested to determine early compressive strength. The cylinder failed at 6,295 psi (43.4 MPa). On the following morning two additional cylinders were tested and these failed at an average compressive stress of 6,844 psi (47.2 MPa). Because of the high cylinder breaks, the polymer concrete pile was prestressed and removed from the casting bed. No bonding problems were encountered due to the grease film application. Table 3-11 presents the results of testing the polymer concrete cylinders.

When the pile was removed from the casting bed it was placed on a long steel form and supported continuously. Here it was examined and three major rock pockets were discovered. These defects were later patched by flooding the rock pockets with monomer.

The polymer concrete used to fabricate the first piles appeared slightly dry and difficult to consolidate and finish. The polymer content was therefore increased to five percent as seen in Mix B of Table 3-10. This change produced a very workable mix, and the new formulation was used to manufacture the last four polymer concrete piles.

On April 10, two more polymer concrete piles were successfully cast using the same technique as previously described. Improvements were made however in communications between the batching area and the casting bed. Several minutes before the placement of one load ended the mixing of the next one began. This small change in sequence reduced the waiting time at the bed and helped increase the efficiency of the entire operation. During the second day the workers at the casting bed chose not to wear their respirators while placing and finishing the polymer concrete.

Once again eleven workers were needed to provide a continuous supply of polymer concrete and to place and finish each batch within the 20 minute allowable work time. Only one hour and six minutes were needed to cast both piles on the second day. Immediately after casting, the piles were covered with a plastic sheet to protect them from adverse weather during polymerization.

On the following morning, two cylinders were tested at the plant. The average breaking strength was 8,528 psi (58.8 MPa) which permitted the piles to be prestressed. Both piles were quickly removed from the casting beds and placed in temporary storage adjacent to the casting area. As before, removal from the beds was uneventful due to the use of grease as a bond breaker.

The last two polymer concrete piles were cast on April 11. Using the eleven man crew the entire fabrication was completed in one hour and nine minutes. As before the piles were allowed to polymerize overnight. Both piles were prestressed on the following morning after two cylinders indicated a compressive strength of over 6,000 psi (41.4 MPa) was achieved.

The five polymer concrete piles were initially placed on steel forms and supported continuously for two weeks while undergoing shrinkage measurements and surveillance for a horizontal bowing problem. When this investigation was completed the piles were moved into another storage area where they were supported at three points. As the piles were placed on the three supports, each had large vertical deflections between supports. The maximum vertical deflection in Pile 5A was 1" (25.4 mm) while the average maximum deflection of the other polymer concrete piles was 5/8" (15.9 mm). By comparison, the deflections for the conventional and other experimental concrete piles was only 1/8" (3.1 mm). The large deflections in the polymer concrete piles were attributed to a low modulus of elasticity. Although the polymer concrete piles were more limber than the other piles, no handling problems were encountered.

The major disadvantage of the polymer concrete system was the high rate of creep. This problem is discussed more fully in Section IV. Although the polymer concrete exhibited a high early strength, the resin was not fully cured and high creep values resulted after prestressing. According to calculations, nearly 1/3 of the prestressing force was lost

Table 3-11

Compressive Strength and Modulus of Elasticity
of Polymer Concrete

Date of Casting	Compressive Strength (lbs/in²) Age of 6" x 12" Cylinders Test A 3 hour	 1 day	 Test B 4 day	 5 day	 7 day	Mod. of Elasticity lbs/in² x 10^6
04-09-80	6295	6985 6702			5445[1] 4860[1]	[1]2.2
04-10-80		8188 8864		6720[1]	6995[2] 6190[2]	[1]2.6 [2]2.4
04-11-80		6119 6348	5450[1]		5625[2] 5520[2]	[1]2.3 [2]2.3

Test A - Cylinders tested at Morse Bros. Plant after being cured only in air.

Test B - Cylinders tested at OSHD Lab after being cured only in air.

1 in = 25.4 mm
1000 psi = 6.895 MPa

to a combination of elastic shortening, shrinkage, and creep.

Epoxy-Coated Reinforcing Steel

In addition to the evaluation of the experimental concretes, epoxy-coated rebars were included in this study to analyze their performance in a marine environment. Because it was not necessary to cast full size piles, the coated rebars were used in six miniature piles measuring 8" x 8" x 20' (.2 x .2 x 6.1 m) Unlike the conventional prestressed concrete piles, a Class 3300-1 concrete was specified for the pile models. Each miniature pile contained four #5 longitudinal bars and #3 hoops at 12" (305 mm) intervals. Before the concrete was cast, two longitudinal bars in each pile model were wired to provide a ground for future half-cell testing.

The reinforcing steel was coated with Scotchkote 213 by Dura Coating Inc., of Springfield, Oregon. The coated bars were inspected and tested with a holiday detector for defects by a state inspector who performs the work routinely at the fabrication plant. The bars were found to meet the state specification and were approved for the project.

Three miniature piles were cast on May 6, 1980 while three were cast the following day. Each set of piles was steam cured for a minimum of 10 hours at temperatures over 155°F (68.3°C). The 7-day compressive strengths were 5,760 psi and 6,260 psi (39.7 and 43.2 MPa) indicating good quality concrete was used. Bolt holes were cast into the pile model so they could be attached to the conventional prestressed concrete piles after they were in place in Yaquina Bay. After casting, the miniature piles were placed in storage to await shipment to the coast.

SECTION IV

Problems During Manufacturing

Horizontal Bending

After the first ten experimental piles were cast and placed in storage, a slight bending in the horizontal plane was discovered. The piles were supported at three locations on 4" x 6" (102 x 152 mm) timbers and all but two of the piles were made with conventional concrete. A string line was used to determine the amount of bowing by placing it along the sides of each pile. A maximum bow of 1-3/4" (44 mm) was measured on Pile 1B, which was scheduled to undergo the polymer impregnation treatment, while the average bow of all piles was about 1" (25.4 mm). As time went on, additional measurements were taken and the bowing was found to have increased. After four weeks, a maximum bow of 2-1/8" (54 mm) was measured in Piles 1B and 1E. Table 4-1 presents the maximum bowing measured in each pile after a minimum 45-day cure.

When the internally sealed concrete piles were removed from the casting beds, the alignment of each pile was carefully checked and found to be straight. Within one week after casting, however, the internally sealed concrete piles began to bend horizontally. At that time the location of the prestressing strands were measured at each end of each pile to determine if an eccentricity of the prestressing force existed. The location of each strand and the center of gravity of each group of strands was found to be well within tolerable limits. The probable cause of unequal prestressing was eliminated since load cells and strand elongation were carefully checked during each prestressing to ensure the correct force was applied to each strand. Two weeks after fabrication, the maximum horizontal bending in the internally sealed concrete group was measured in Pile 2E at 2-1/4" (57.1 mm). This value increased to 3-1/8" (79.3 mm) when measured two weeks later. Three of the other internally sealed concrete piles remained almost perfectly straight while in storage.

The alignment of the polymer concrete piles was also checked immediately after they were removed from the casting beds, and all were found to be straight. Before the polymer concrete piles were placed in storage with the other piles, they were set on steel forms and supported continuously. Here, they were examined and measured for a two week period. Within a few days after casting a slight bowing was detected in each of the piles. By the end of two weeks, a maximum bowing of

Table 4-1

Maximum Horizontal Bow in Piles

	Pile Inches/Date Cast/Casting Bed				
Pile Group	A	B	C	D	E
1 Polymer-Impregnated Concrete	9/16" 03/05/80 Left	2-1/8" 03/07/80 Right	1-13/16" 03/06/80 Left	1-3/8" 03/06/80 Right	2-1/8" 03/05/80 Right
2 Internally Sealed Concrete	1/8" 03/13/80 Right	1/8" 03/10/80 Right	0" 03/18/80 Left	1-15/16" 03/13/80 Left	3-1/8" 03/10/80 Left
3 Conventional Concrete	5/8" 02/28/80 Right	1-1/2" 03/07/80 Left	1-1/16" 02/28/80 Left		
4 Polymer Concrete	2" 04/10/80 Right	1-1/4" 04/09/80 Left	1-1/8" 04/11/80 Right	1-7/16" 04/10/80 Left	5-3/8" 04/11/80 Left
5 Latex Modified Concrete	5/8" 04/24/80 Right	3/16" 04/24/80 Left	5/16" 04/22/80 Right	3/8" 04/17/80 Left	3/8" 04/22/80 Left

1 in = 25.4 mm

3-1/8" (79.3 mm) was recorded for Pile 4E (see Figure 4-1). At this point the polymer concrete piles were moved from the steel forms and placed on a three-support system with the other piles. Here the bowing continued to grow until a maximum bow of 5-3/8" (136 mm) occurred in Pile 4E.

A change in the prestress strand pattern was made during the fabrication of the latex modified concrete piles. The original pattern had all 7 strands on a 7" (177 mm) diameter circle while the new strand pattern had six strands on a 7" (177 mm) diameter circle and one strand at the center of the pile. Pile 5D had the original strand pattern while the other four latex modified concrete piles had the new pattern. The horizontal bending of the latex modified concrete piles was considerably smaller than any of the other groups of materials but this was not attributed to the change in strand pattern. The maximum bowing occurred in Pile 5A at 5/8" (1.6 mm).

After the experimental piles were fabricated, Morse Bros. Inc. built ten additional prestressed concrete piles for another state project using conventional concrete and a 7-strand on a 7" (177 mm) diameter pattern. These piles were only 55 feet (16.7 m) long, and in each case no bowing was detected after a one month period.

If the experimental piles were to have been driven or if they had been intended to carry highway loads, 13 piles would have been rejected because they failed to meet the standard straightness requirements. Since the piles were 65 feet (19.8 m) long the maximum allowable sweep was 9/16" (1.4 mm).

Creep and Shrinkage Measurements

One of the important tasks of this study was the determination of the shrinkage and creep characteristics of the experimental materials. Prior to the fabrication of the piles, the contractor was required to submit a procedure report describing his method of measuring concrete strain due to shrinkage and creep during a 15-day period immediately after prestressing. A procedure report was submitted and described the use of 2" (5 mm) long series EA strain gages manufactured by Micro Measurements. The report was reviewed and approved.

After the first two prestressed concrete piles were removed from the casting beds and placed in storage, an attempt was made to epoxy two strain gages on opposite vertical sides at each end of the piles. Unfortunately, the epoxy failed to cure at the 40° to 45°F (4.4° to 7.2°C) ambient temperature. When the epoxy supplied with the strain gage kit failed to bond the strain gages on subsequent piles, a household epoxy was purchased from a local hardware store. This epoxy called "5 Minute Epoxy", successfully bonded the strain gages to Piles 1A, 1E, 2A, 2C and 2D. Once the gages were applied they were protected by a multi-layer system consisting of a butyl rubber sealant, a neoprene pad, an aluminum tape and top coated with a nitrate rubber coating. Readings were then recorded on each pile for a period of two weeks during which times the values were extremely inconsistent. Both tensile and compressive strains were often indicated on the same gages during subsequent readings. After examining the results, the strain gage method for determining strain was abandoned. A far less sophisticated method of embedding two nails into the piles and measuring the distance between them was substituted for the strain gages. The nails were placed into the top surface just after the pile was finished. The first measurement was taken approximately two hours after casting and a gage length of over 50 feet (15.2 m) was used in all but one pile. The second measurement was made on the next day just prior to the release of the prestressing strands. The third measurement was made within minutes after the strands were released. The modulus of elasticity was calculated from the measurement made due to elastic shortening. Additional measurements were then taken for up to 45 days after the piles were placed in storage. The strain for the polymer concrete, latex modified concrete and conventional concrete piles is found in Table 4-2. The results of this work indicates the shortening due to creep and shrinkage for the polymer concrete was exceptionally high and unacceptable for prestressed concrete work. The moduli of elasticity calculated from this method were reasonably close to those recorded from test cylinders.

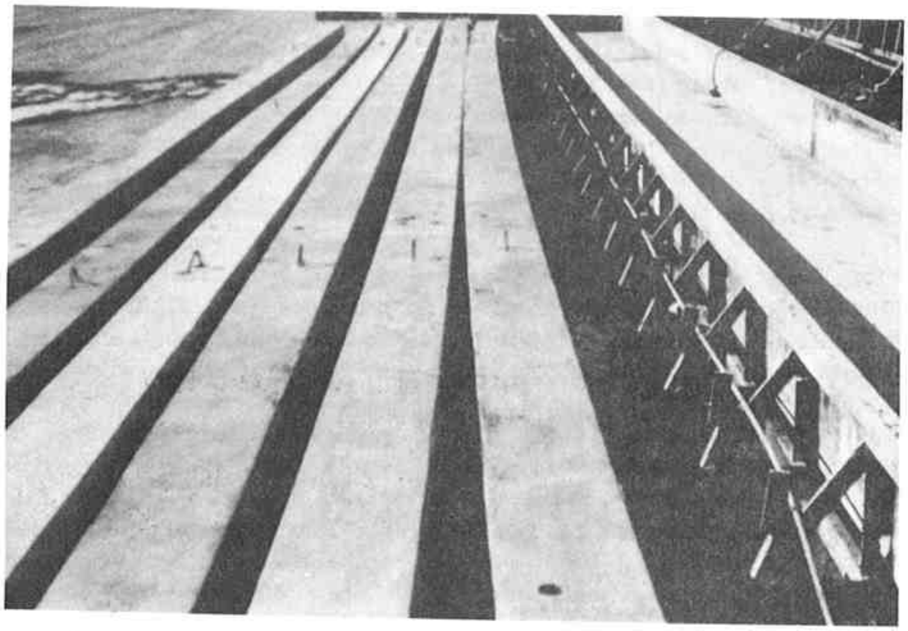


FIGURE 4-1

Horizontal Curvature of Polymer Concrete Pile

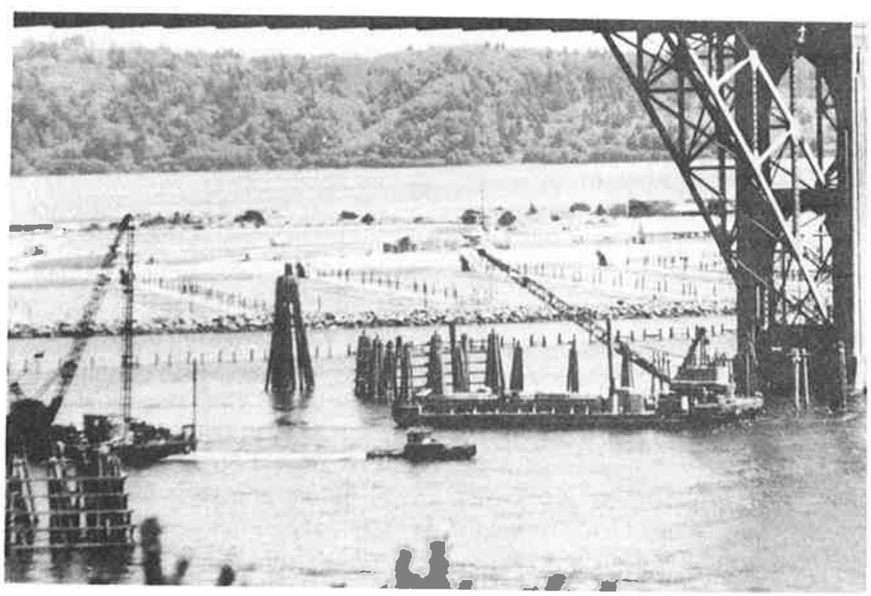


FIGURE 5-1

Pile Installation Site at Yaquina Bay

Table 4-2

Strain and Modulus of Elasticity
for Select Piles

Pile	Material	Strain "/"	Modulus of Elasticity psi x 10^6
4A	Polymer Concrete	.0010	1.7
4B		.0017	1.8
4C		.0021	2.3
4D		.0015	2.3
4E		.0022	2.3
5A	Latex Modified Concrete	.0003	3.0
5B		.0003	3.0
5C		.0008	4.0
5D		.0007	4.0
5E		.0006	4.0
1	Conventional Concrete	0.0000	3.3
2		0.0000	3.3

1×10^6 psi = 6.895 GPa

SECTION V

Installation of the Piles

After the piles were fabricated and inspected at the prestressed concrete plant, they were transported by truck to Yaquina Bay at Newport, Oregon. Here the piles were unloaded and stored briefly on a dock. While in storage, the piles were inspected for damage from handling. Although no damage was attributed to handling, a "soft spot" was found in one internally sealed concrete pile. This defect was discovered approxmately 13 feet (4 m) from the bottom of the pile on the side that was hand finished. Using a small knife, a section measuring 5" x 12" (127 x 305 mm) was removed to a maximum depth of 1/2" (12.7 mm) This area was later patched with grout. The cause of the defect is not known, but a poor distribution of the wax beads is suspected.

In addition to the visual inspection, active corrosion readings were taken using a copper-copper sulfate half cell. Because the piles were stacked in closely spaced rows, the interior piles were not accessible for testing with the electric probe. The results of the half-cell testing are found in Table 5-1A and indicate there was active corrosion occurring in the internally sealed concrete system. Three of the four internally sealed concrete piles tested had readings exceeding 0.35 volts. These high readings were generally found within the middle half of the piles. The readings taken on the other systems did not exceed 0.20 volts and no potential readings were recorded on four polymer concrete piles. When electrical resistance readings were made on each experimental concrete system, only the polymer concrete piles appeared to be impermeable as only infinite resistance readings were recorded.

Shortly after the piles were inspected and tested at dockside they were loaded onto a barge and brought to the installation site at Pier 3 of the Yaquina Bay Bridge. Figure 5-1 shows the installation site.

The experimental concrete piles were designed to be incorporated in an existing pier protection system consisting of treated timber piles. This system was comprised of groups of five or seven piles spaced at 18 to 30 (5.5 to 9.1 m) foot centers. The condition of the timber piles varied from good to bad because of a marine borer problem. The new concrete piles were arranged in five dolphins and placed alternately with the timber dolphins The elevation of the ground line at the installation site was approximately minus 27 feet (8.2 m) and the target pile tip elevation was minus 42 (12.8 m) feet. Because the foundation at the site consisted mainly of sand, the contractor was permitted to water jet the piles into position except for the last three feet (0.9 m). Each pile was driven the last three feet (0.9 m) by a 3,500 pound (1587 kg) drop hammer. The piles were placed into leads before being jetted either vertically or into their battered positions. The jet was removed when the pile reached the desired elevation and a five to ten minute waiting period was observed to allow the sand to settle back around the pile before driving began.

During the installation of the first pile group, the fall of the hammer was approximately 3.5 feet (1.1 m) and the average penetration per blow was measured at 0.36" (9.1 mm). Using the Engineering News-Record formula, the allowable pile bearing was calculated to be 26.6 tons (23.9 Mg).

All of the experimental concrete piles were successfully installed except one latex modified concrete pile, which was broken at the ground line when it was struck by the contractor's tugboat while installing an adjacent pile. Because it would have produced an unnecessary delay in the completion of the contract, the contractor was permitted to build a four pile dolphin. Since the contractor was clearly at fault no payment was made for the broken pile.

Some minor damage was sustained by each internally sealed concrete pile as they were lifted by cable from the barge and placed into the leads prior to jetting. The cable cut into the corners of the piles causing minor spalling. This damage was corrected with grout after installation. The top of the internally sealed concrete piles were reported to have crumbled slightly during driving. This did not happen with any other piles. The

Table 5-1A

Half-Cell Potential Readings in Volts
(Copper-Copper Sulfate)

Date Tested June 26, 1980

Pile No.	Rx1K[2]	Point 1[1]	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7
1B	16.0	.14	.14	.14	.16	.15	.16	.14
1C	32.0	.14	.16	.20	.20	.20	.20	.19
		.20						
2A	8.0	.20	.25	.25	.27	.32	.38	.39
2B	3.3	.21	.25	.24	.23	.25	.31	.30
2D	10.0	.22	.22	.25	.23	.20	.23	.30
2E	7.5	.23	.26	.27	.33	.40	.41	.50
3A	1.8	---	---	---	---	---	---	---
3C	0.4	.00	.00	.00	.00	.00	.00	.03
4A		.00	.00	.00	.00	.00	.00	.00
4C		.00	.00	.00	.00	.00	.00	.00
4D		.00	.00	.00	.00	.00	.00	.00
4E		.00	.00	.00	.00	.00	.00	.00
5D	3.2	.05	.08	.06	.07	.07	.08	.11
5E	1.8	.10	.11.	.11	.14	.16	.14	.17
Block 1	5.5	.05*	.01*	.01*	.02*	---	---	---
Block 2	7.5	.03*	.02*	.00*	.01*	---	---	---

	Point 8	Point 9	Point 10	Point 11	Point 12	44 feet	47 feet	50 feet
2B	.23	.28	.35	.30	.30	---	---	---
2D	.36	.39	.36	.41	.41	.30	.23	.23
2E	.49	.51	.57	.51	.51	.59	.56	.48

[1]Point 1 is 4 feet from top of pile and the other points are in 2-foot intervals.

[2]Resistance in 1000 ohms.

*Located between bolt holes.

Pile Group No. 1 - Polymer-Impregnated Concrete
Pile Group No. 2 - Internally Sealed Concrete
Pile Group No. 3 - Normal Concrete
Pile Group No. 4 - Polymer Concrete
Pile Group No. 5 - Latex Modified Concrete
Block 1 - Normal Concrete
Block 2 - Normal Concrete

damage was not too serious and no repairs were made since the top of the piles were embedded into the concrete pile caps.

After all the piles were installed, they were inspected by a three man State Highway Division underwater inspection team. No underwater damage was found during this initial inspection.

In order to provide greater stability, concrete caps were poured at each new dolphin. Epoxy-coated bars were used to reinforce the caps. The concrete was transported to the pile site in a one cubic yard bucket that was placed on a small tugboat. Only a three cubic yard load of concrete was delivered to the dock in each ready-mix truck to prevent overmixing. The placement of each three cubic yard load of concrete took a little over one hour, which was satisfactory. The caps were cast without problems.

After the concrete caps had cured a minimum of 14 days, the forms were removed and the access ladders installed. At this time the electrical testing wires that were cast into each pile were spliced with additional wire. Both were placed into PVC conduit and carried to junction boxes located in the top of the caps. The boxes provided a central grounding point at each dolphin in a location that was protected from the salt water. The details of the ladders and wiring system are shown on the construction plans in the Appendix.

The initial testing of the experimental piles began while the contractor was completing his work at the site. At this time, 20 chloride ion samples were removed from the installed piling. Four samples were taken from each special material. Figure 5-2 shows samples being removed from a pile.

The method used to obtain the samples was to drill a 3/4" (19 mm) diameter hole into the piles somewhere within the tidal zone and to carefully catch the concrete dust. The samples removed represented a depth of 1/8" to 1" (3.1 to 25.4 mm). Two samples were removed for each pile tested. The results of this testing are found in Table 5-2. A chloride ion determination was also performed on specimens made during the fabrication of the various piles. Using 11 samples, the average chloride content was 0.18 pounds chloride per cubic yard (.11 kg/m^3) concrete while the range was from 0.14 to 0.22.

The results of the initial chloride ion penetration tests indicated the internally sealed concrete was superior to the other materials in stopping chloride penetration. One latex modified concrete pile had a reasonably low value but the other pile tested was high. The control pile and the pile model containing the epoxy coated rebars had the highest chloride ion content as expected.

Within two weeks after the piles were installed, initial in-place active corrosion testing was performed by the half-cell method (see Figure 5-3). Because of the difficulty in reaching all of the piles due to the swift current, only select piles were tested from each group. A reference point was painted on one pile in each dolphin, approximately five feet above the water line. The readings were taken at the elevation of the reference point and downward at 1 foot intervals. The readings generally increased in magnitude the closer they were taken to the water line. The results of the initial half-cell testing appear in Table 5-1B. The values at elevation 2 through 5 should be used for comparison because of the unknown effects of the salt water at the lower elevation. The half-cell readings on four of the five polymer impregnated piles were well below the threshold of corrosion. The same results were found for two conventional concrete piles and three of the four miniature piles with epoxy-coated rebars. Two of the internally sealed concrete piles exhibited very high readings while two were moderately high.

All four polymer concrete piles tested had high half-cell readings indicating active corrosion was occurring. Before these piles were installed, only zero readings were reported.

Finally, during the initial testing, two latex modified concrete piles had high half-cell readings while two had moderately high readings.

Table 5-1B

Half-Cell Potential Readings in Volts
Copper - Copper Sulfate
Date Tested September 9, 1980

Group	Elevation* feet	A	B	C	D	E
		Ambient Temperature 65^{o}				
1	5	.10	.11	.10		.09
	4	.10	.12	.11		.11
Poly-Impreg.	3	.13	.16	.14		.11
Concrete	2	.20	.19	.19		.17
	1	.50	.30	.25		.24
	-.5	.58	.48	.58		.43
2	5	.35	.30		.21	.21
	4	.37	.35		.20	.23
Inter. Sealed	3	.50	.40		.30	.26
Concrete	2	.58	.49		.38	.30
	1	.60	.58		.51	.40
	-.5	.70	.65		.66	.62
3	5	.03	.16			
	4	.09	.25			
Conventional	3	.12	.25			
Concrete	2	.20	.29			
	1	.32	.39			
	-.5	.47	.56			
4	5	.30	.50	.18		---
	4	.50	.57	.10		.02
Polymer	3	.54	.58	.49		.49
Concrete	2	.56	.59	.48		.52
	1	.60	.60	.61		.58
	-.5	.64	.61	.64		.63
5	5	.32	.28	.18		.19
	4	.36	.36	.20		.26
Latex Modified	3	.46	.44	.21		.30
Concrete	2	.54	.50	.27		.38
	1	.59	.55	.40		.47
	-.5	.65	.65	.60		.63
		A-1	A-0	C-I	C-0	
Blocks	5	.03	.03	.05	.16	
	4	.08	.00	.02	.25	
Conventional	3	.10	.07	.0	.32	
Concrete	2	.16	.16	.07	.34	
	1	.26	.23	.15	.42	
	-.5	.37	.29	.24	.49	

*Elevations are from 5 feet above the water line to -.5 feet below.

Table 5-1C

Half-Cell Potential Readings in Volts
Copper - Copper Sulfate
Date Tested February 10, 1980

Group	Elevation* feet	A	B	C	D	E
		Ambient Temperature 32°				
1	5	.08	.04	.02		.02
	4	.10	.10	.05		.04
Poly-Impreg.	3	.17	.19	.16		.12
Concrete	2	.23	.23	.24		.23
	1	.48	.33			
2	5	.13	.22		.16	.16
	4	.18	.28		.19	.21
Inter. Sealed	3	.29	.36		.30	.24
Concrete	2	.50	.49		.40	.35
	1					
3	5	.15	.20			
	4	.20	.26			
Conventional	3	.24	.31			
Concrete	2	.42	.46			
	1					
4	5	.24	.44	.59		.17
	4	.69	.62	.59		.70
Polymer	3	.69	.60	.73		.70
Concrete	2	.70	.64	.73		.72
	1					
5	5	.18	.25	.10		.12
	4	.27	.39	.18		.24
Latex Modified	3	.43	.45	.24		.24
Concrete	2	.53	.56	.31		.29
	1	.56		.39		.41
		A-I	A-O	C-I	C-O	
Block	5	0.0	.08	.08	--	
	4	.08	.10	.04	--	
Conventional	3	.15	.16	.08	--	
Concrete	2	.24	.23	.16	--	
	1					

*Elevations are from 1 foot to 5 feet above the water line.

Table 5-2

Chloride Ion Concentrations
(lbs. chloride ion/c.y. concrete)

Depth 1/8" to 1"
Average Original Ion Concentration = 0.18 lbs/cy

Material	Pile	Date Sampled 8/26/80	2/18/81
Polymer-Impreg. Concrete	1-B	1.42	1.50
	1-B	1.31	--
	1-C	0.80	1.70
	1-C	0.81	--
Inter. Sealed Concrete	2-D	0.19	0.86
	2-D	0.20	--
	2-E	0.18	0.40
	2-E	0.18	--
Conventional Concrete	3-b*	1.93	--
	3-b*	1.36	--
	3-B	2.28	0.89
	3-B	2.44	--
Polymer Concrete	4-A	0.40	0.55
	4-A	0.58	--
	4-B	1.29	1.00
	4-B	1.49	--
Latex Modified Concrete	5-B	0.39	1.20
	5-B	0.19	--
	5-E	1.01	0.94
	5-E	1.12	--

*Miniature pile

1 in = 25.4 mm
1 lb/cy = 0.593 kg/m^3

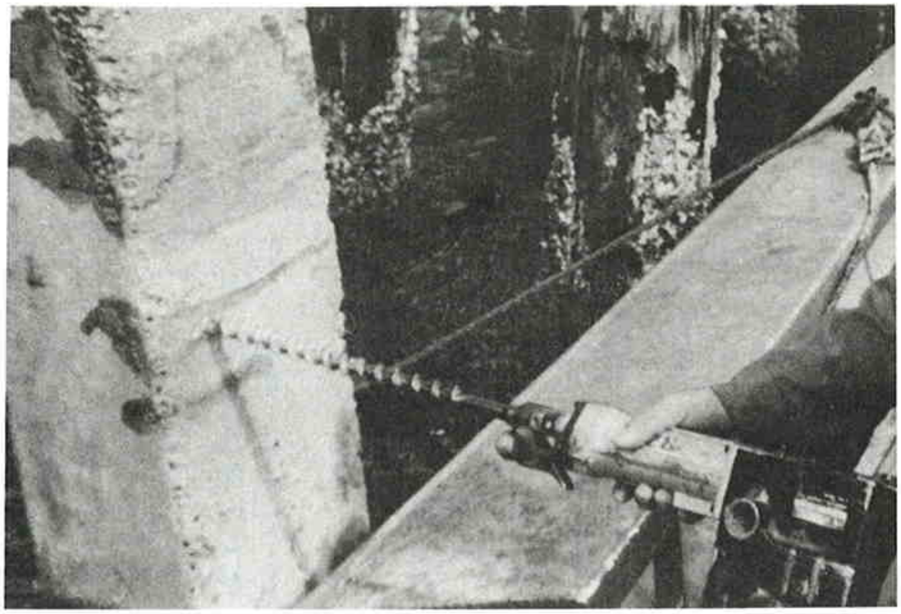


FIGURE 5-2

Chloride Ion Sample being Removed from Pile

FIGURE 5-3

Measuring Half-Cell Potential

Subsequent half-cell readings were taken six months after the piles were installed, and they appear in Table 5-1C. These values are close to the original readings and in most cases slightly lower. This may be due to a lower ambient temperature.

SECTION VI

Initial Evaluation and Comments

The complexity and difficulty in fabricating 65-foot long precast prestressed concrete piles varied greatly among the four experimental materials used. The latex modified concrete piles were considered the simplest to produce although some problems were encountered during the finishing and curing cycle for the initial piles. Extra care was required in obtaining the proper water-cement ratio to control concrete slump, and some minor problems were experienced in hand finishing the top surface of the piles because of a quick forming latex film. One undesirable feature in casting precast prestressed units with latex modified concrete was the two day curing period required to attain 4,000 psi (27.6 MPa) ultimate compressive strength even after steam curing. This prevented reuse of the casting beds in the normal 24 hour cycle. Once the latex modified concrete piles were fabricated, however, they were placed in storage where they continued to cure without additional handling. The use of latex modified concrete piling for installation in a marine environment appears to be very viable.

Internally sealed concrete was rated easy to mix, place, and finish. The wax beads were added to the concrete during mixing without problems. The tests that were performed during the casting of the piles indicated the wax beads were well distributed throughout the concrete. In order to reduce the possibility of melting the wax beads prematurely, a maximum steam temperature of 125°F (51.7°C) was specified. Because of the reduced temperature, a 48-hour cure was needed before sufficient compressive strength was attained to allow the release of the prestressing strands. As with the latex modified concrete, this was an undesirable feature because it delayed production. The melting of the wax beads in the steam heated oven was relatively easy to accomplish once the oven was built and tested. During the melting process personnel were required to monitor the temperature inside the concrete piles. The additional handling in moving the piles from storage to the oven was not a great inconvenience. After the wax beads were melted, some longitudinal cracks were found in the sides of the piles. The cracks were very tight and appeared to be filled with melted wax.

From a fabrication standpoint, the internally sealed concrete system is also a viable method for precast prestressed piles.

The fabrication of polymer concrete piles using Crylon acrylic mortar 3009-3020 was moderately difficult. Although the material was easy to consolidate and finish, it had several unfavorable features. First, the monomer was flammable and there was a danger of a flash fire while the concrete was being mixed in the pan-type mixer. Second, the polymer concrete had a relatively short pot life (30 minutes) which necessitated the use of a large work force to complete the fabrication of the piles within the allowable work time. Third, and finally, the polymer concrete exhibited an excessive amount of creep after the prestressing load was applied. Although the polymer concrete had a high early compressive strength of over 5,000 psi (34.5 MPa) in 18 hours, the binder did not fully cure until several weeks after fabrication. Nearly one third of the prestressing force was lost due to total shortening of the piles. From the limited work performed with Crylcon polymer concrete, it does not appear suitable for pretensioned prestress concrete fabrication.

The polymer-impregnated concrete system was by far the most time consuming and demanding of the four concrete systems examined. The need to build a special heating oven, a special monomer-soaking tank and a special hot water bath raised the processing cost considerably. The additional handling involved in moving the piles from one activity to another at precise times caused many disruptions in the normal production procedure within the fabrication plant. Another major disadvantage was the use of a highly volatile and flammable monomer which had an unpleasant odor. Once the monomer was initiated it had a limited pot life which was greatly affected by temperature and ultra-violet radiation. Because of the many unfavorable features associated with the polymer impregnated system, it appears highly unlikely this method will receive wide acceptance for large structural members such as piling.

The epoxy-coated rebars which were incorporated into this study were inspected after the coating was applied and found to conform to the specification. The coated rebars were subsequently used in miniature piles made with conventional concrete without problems.

After the experimental piles were fabricated, they were transported to the Oregon coast for installation in Yaquina Bay. No handling problems were encountered except for the internally sealed concrete group. While positioning these piles into the leads of the pile driver, the steel lifting cables caused some spalling at the corners of each pile. This damage was not extensive, but it indicat ed the internally, sealed concrete was slight ly abradable.

The evaluation of the performance of the piles was limited to visual inspections, chloride ion penetration analysis and active corrosion potential measurements by the half-cell method. The piles have been inspected twice since they were installed in August 1980. During both inspections all of the piles appeared to be in excellent condition and without any sign of distress. After 6 months in the salt water, a considerable amount of marine growth had attached itself to the underwater portion of each pile.

During each inspection chloride ion samples were removed from each pile group and half-cell readings were also taken. The results of this testing indicated the internally sealed concrete to be slightly superior to the other materials in preventing the intrusion of chlorides into the piles. The half-cell readings were generally lower in the polymer-impregnated concrete, internally sealed concrete and conventional concrete pile. The half-cell reading in the polymer concrete indicated active corrosion was occurring in each of the four piles tested, while two of the four latex modified concrete piles also had poor readings. The half-cell readings on the epoxy coated rebar were very low indicating no corrosion.

Additional inspections and testing will be needed to better evaluate the effectiveness of the experimental materials.

References

1) Clear, K. C. and S.W. Forster, "Internally Sealed Concrete: Material Characterization and Heat Treating Studies," Report No. FHWA-RD-77-16, Interim Report, March 1977.

2) "Internally Sealed Concrete: Guide to Construction and Heat Treatment," Implementation Package 77-9, April 1977.

3) Clifton, J. R., H. F. Beeghly, and R. C. Mathey, "Nonmetallic Coatings for Concrete Reinforcing Bars," Report No. FHWA-RD-74-18, Final Report, February 1974.

4) Clear, K. C. and Brian H. Chollar, "Styrene-Butadiene Latex Modifiers for Bridge Deck Overlay Concrete" Report No. FHWA-RD-78-35, Interim Report, April 1978.

5) Kukacka, L. E., R. Mediatone, J. Fontana, M. Steinberg, and A. Levine, "The Use of Polymer Concrete for Bridge Deck Repairs on the Major Deegan Expressway", Report No. FHWA-RD-75-513, Final Report, Jan. 1975.

6) Polymer Concrete Patching Materials, Vol. I, Users Manual, Implementation Package 77-11, April 1977.

7) Polymer Concrete Patching Materials, Vol. II, Users Manual, Implementation Package 77-11, April 1977.

8) Jenkins, J. C., G. W. Beecroft and W. J. Quinn, "Polymer Concrete Overlays", Interim User Manual Method A, Report No. FHWA-TS-78-218, December 1977.

9) Webster, R., J. Fontana, and L. E. Kukacka, "Polymer Concrete Overlays", Interim User Manual Method B, Report No. FHWA-TS-78-225, February 1978.

10) Smoak, W. G., "Polymer Impregnation of New Concrete Bridge Deck Surfaces", Revised User Manual, Report No. FHWA-RD-78-5, January 1978.

11) Smoak, W. G., "Development and Field Evaluation of a Technique for Polymer Impregnation of New Concrete Bridge Deck Surfaces," Report No. FHWA-RD-76-95, Final Report, Sept. 1976.

12) Lockman, William T., and William C. Cowan, "Polymer-Impregnated Precast Structural Concrete Bridge Deck Panels," Report No. FHWA-RD-75-121, Final Report, Oct. 1975.

APPENDIX

SPECIAL PROVISIONS

Experimental Marine Piling

WORK TO BE DONE

The work to be done under this contract consists of the following:

1. Furnish and drive 23 precast prestressed piles.

2. Furnish and install 6 precast concrete blocks.

3. Construct pile caps and furnish and install wiring for monitoring system.

4. Performance of such additional and incidental work as is called for by the specifications and plans.

APPLICABLE STANDARD SPECIFICATIONS

The Standard Specifications which are applicable to the work on this project are the 1974 edition of the "Standard Specifications for Highway Construction".

All number references in these special provisions shall be understood to refer to the Section or subsection of the Standard Specifications bearing like numbers.

Where there is a conflict between the General Provisions of Part 100 and those of the Department of General Services the provisions of the Department of General Services shall take precedence.

SECTION 107 - LEGAL RELATIONS AND RESPONSIBILITY TO PUBLIC

107.04 Minimum Wage Rates on Public Works - Delete the provisions of subsection 107.04 of the Standard Specifications in their entirety.

107.16 Federal-Aid Participation - This project is to be conducted in accordance with the regulations applying to Federal-Aid Highway Projects.

The Federal Regulations set forth in Section V, paragraph 4 of Form PR-1273 (pink sheets enclosed herewith) are hereby deleted. Form PR-47 as called for in Section VI of Form PR-1273 will not be required on projects which have a total final construction cost of less than $500,000.

SECTION 108 - PROSECUTION AND PROGRESS

108.08 Contract Time for Completion of Work - The work to be done under the contract shall be completed before the elapse of 150 calendar days.

EXPERIMENTAL PILING

Scope - This work shall consist of furnishing and driving precast prestressed piling and furnishing and attaching to piling precast "blocks" as called for on the plans and as directed by the engineer.

The kinds, number, sizes and lengths of piling and "blocks" are as follows:

Kind	Size	Length	No.	Group
Internally Sealed Concrete Piling	12"x12"	65'	5	2
Latex Modified Concrete Piling	12"x12"	65'	5	5
Polymer Impregnated Concrete Piling	12"x12"	65'	5	1
Polymer Concrete Piling	12"x12"	65'	5	4
Portland Cement Concrete Piling	12"x12"	65'	3	3
Portland Cement Concrete "Blocks"	8"x8"	20'	6	-

The piling shall conform to the details shown on Drawing Nos. 31825, 34877 and 34878.

Materials - All materials shall conform to the requirements of Section 504A of the Standard Specifications except as hereinafter modified.

Testing - The following material sampling shall be performed by the contractor:

Following completion of the surface impregnation treatment and the melting of the wax beads in the internally sealed concrete piling, the contractor shall obtain and deliver to the engineer 4 test cores from each pile in groups 1 and 2. Two cores shall be taken from each pile in groups 3, 4, and 5.

Cores shall be a minimum 2 inches in diameter and 2 inches deep. The location of the cores shall be determined by the engineer. The core holes shall be filled with a grout approved by the engineer.

The contractor shall provide the engineer with the following minimum number of 6" x 12" test cylinders at the times designated for each pile system.

Pile System	Number of Cylinders	Time
Polymer Impregnated Conc. Piling	9	After Steam Curing
Portland Cement Concrete Piling	9	After Steam Curing
Portland Cement Concrete "Blocks"	6	At Fabrication
Polymer Concrete Piling	15	At Fabrication
Internally Sealed Concrete Piling	4	At Fabrication
Internally Sealed Concrete Piling	4	After Steam Curing
Internally Sealed Concrete Piling	4	After Melting Wax Beads
Latex Modified Concrete Piling	3	At Fabrication
Latex Modified Concrete Piling	6	After Steam Curing

Material Evaluation - At least 15 days prior to beginning the prestressing of the piling, the contractor shall deliver to the engineer a written Procedure Report describing his methods of measuring concrete strains due to a combination of shrinkage, creep and strand relaxation for a period of 15 days immediately after prestressing. This measurement will be required on 2 piling in each group. The engineer will review this report and approve or disapprove the methods within 10 days of the date of receipt. The contractor shall not proceed with the prestressing of the piles until his method of testing has been approved.

The data shall be in the form of a continuous record or periodic reading recorded at 12-hour intervals for the first 48 hours and at 24-hour intervals thereafter. The technique and equipment used to obtain the information shall be described in the written Procedure Report.

Additional strain measurements will be required on the polymer impregnated piles during the drying and cooling process. This data shall be in the form of a continuous record or periodic readings recorded at 2-hour intervals.

Construction - Piling and "blocks" shall be manufactured in conformance with Section 504A of the Standard Specifications except as hereinafter modified.

All piling except internally sealed piling and polymer concrete piling shall have air entrainment of not less than 3 or more than 6 percent.

Installation - Piling shall be driven to depths which will leave the top of the piles at the elevation shown on the plans.

Driving shall be performed in conformance with the applicable provisions of Section 503 of the Standard Specifications.

A - Internally Sealed Concrete Piling

Scope - This work consists of furnishing prestressed concrete piling sealed internally with wax beads partially replacing the aggregate in the concrete.

Material - The wax beads shall conform to the following:

(a) Components - Each bead shall be a physical blend of 75±5 percent paraffin (melt point 149±2,F) and 25±5 percent crude grade montan wax.

(b) Size - Bead size shall be as follows:

Passing 16-mesh (0.047 inch) - 100 percent
Passing 20-mesh (0.033 inch) - 99 to 100 percent
Passing 80-mesh (0.007 inch) - 0 to 5 percent

All material shall be screened through a 20-mesh screen. Screening of all material through the 80-mesh shall not be required provided quality control documentation, obtained by periodic sampling, confirms that no more than 5 percent of the beads are smaller than the 80-mesh. Copies of such quality control information shall be supplied to the engineer.

(c) Shape - Bead shape shall be spherical.

(d) Voids - The beads shall, on the average, contain a void volume of not less than 8.0 percent and not more than 12.0 percent. At least 60 percent of the beads shall have discernible voids.

The average void volume and the percentage of beads with discernable voids shall be determined for each shipment in accordance with test procedures hereinafter set forth. The findings of these tests shall be reported in writing to the engineer. Also specific gravity of the beads, determined to facilitate calculation of average void volume, shall be reported in writing to the engineer.

(e) The contractor shall furnish to the engineer the manufacturer's certifications showing that the beads meet the above requirements.

(f) Wax Bead Shipping and Storage - The wax beads shall be shipped and stored in fiber drums or other moisture tight containers. The moisture content shall not exceed 1 percent at any time prior to use.

The beads shall be packaged in such a way as to prevent sintering and moisture ingress during shipment and storage for up to three months. Package shape shall be such that the beads can be easily dumped from the package into a 2-foot diameter circular opening without spillage.

The beads shall be shipped and stored in such a manner that they shall be protected from exposure to temperatures in excess of 120°F. When containers of wax beads are stored in direct sunlight they shall be covered completely with a suitable insulating blanket to avoid excessive temperatures.

Maximum temperature indicators of the permanent color change type, placed in all containers of wax beads by the producer, shall be removed and the maximum temperature recorded immediately upon delivery of the beads. If the maximum shipping temperature was 130°F or higher, and examination of the beads shows agglomeration or melting, the shipment will be rejected. If the maximum shipping temperature was 130°F or less, and no bead agglomeration or melting has occurred, the shipment shall be accepted. The indicators shall be replaced in bead containers and shall remain in the beads until the beads are added to the concrete. At that time, they shall be removed and checked. If the maximum storage temperature was 130°F or higher, and examination of the beads shows agglomeration or melting, they will be rejected.

Wax beads are supplied by the following:

American Lignite Product Co.
P.O. Box 1066
Ione, California 95040

Concrete Admixtures Corp.
P.O. Box 384
Wayne, Pennsylvania 19087

Construction:

(a) Mix Design - The internally sealed concrete shall be non-air-entrained and have a minimum cement factor of 7-1/2 sacks/cy. The bead content shall be approximately 3 percent by weight of concrete.

To determine the exact bead percent by weight, the mix shall be designed by volume. The specific gravity of the beads, supplied by the bead producer, must be confirmed. The recommended mix design involves a solid volume based design of a 1 cubic yard conventional non-air-entrained Class 5000 concrete mix and then removal of 2.10 cubic feet of sand or a combination of sand and coarse aggregate, followed by substitution of an equal volume of wax beads.

Choice of the replacement procedure (i.e. sand or a combination of sand and coarse aggregate) to be used shall be based on mix workability, consistency and ease of placement. Adjustments to the trial mix made for water, etc. should be made in the conventional manner. Bead volume shall not be changed.

The maximum size coarse aggregate shall be 1 inch for prestressed concrete piling construction.

(b) Use of Admixtures - Upon approval of the engineer, water-reducing and retarding admixtures may be used in the internally sealed concrete in accordance with prestressed concrete piling specifications provided trial mixes indicate that the resulting internally sealed concrete meets the requirements of AASHTO M 194.

(c) Compressive Strength - The minimum before heating strength of the non-air-entrained internally sealed concrete shall be not less than 4800 psi as determined by breakes on 6"x12" cylinders cured in the same manner as the piles. A minimum 14-day air curing period before heating is also required.

(d) Maximum Water to Cement Ratio - The maximum allowable water to cement ratio of the internally sealed concrete shall be 0.45 by weight.

(e) Slump - The slump of the internally sealed concrete shall not be more than 3 inches.

(f) Mixing - Mixing procedures which have been used successfully and are recommended include:

1. Addition of beads to the ribbon loaded dry ingredients followed by addition of the mix water and conventional mixing.

2. Addition of the beads to the already mixed conventional components followed by remixing for 85 revolutions.

Regardless of the mixing procedures used, adequate wax bead distribution shall be checked by visual examination of the fracture surfaces of hardened cyclinders or 6"x6" beams obtained from the beginning, half point and near the end of discharge of a one cubic yard or larger trial mix. The beads shall appear as dark specks evenly distributed throughout the lighter concrete matrix. No significant agglomeration of beads or areas without beads shall be visible on any of the fracture surfaces. If poor distribution is found, it must be corrected by modification of the mixing procedure prior to placement.

The mixing procedure shall be approved by the engineer prior to placement.

Confirmation that wax beads are in each batch of internally sealed concrete shall be determined prior to placement of the batch by the following test procedure:

Qualitative Determination of the Presence of Wax Beads in Fresh Concrete

1. Place a sample of the fresh concrete in a 400 ml or larger transparent container.

2. Fill container with water (at least 3 times as much water as volume of concrete).

3. Shake or stir vigorously for 10 seconds.

4. Allow container to sit one or two minutes; the wax beads, if present, will float and are readily visible on the surface of the water.

The weight of wax beads added to each batch of concrete shall be recorded.

Standard specification controls on concrete temperature at placement shall apply. The concrete temperature shall be recorded.

(g) Use of Concrete Pumps - The wax bead concrete may be pumped in accordance with standard specifications.

(h) Curing - A membrane forming curing compound shall not be used.

Steam curing of the internally sealed concrete will be permitted provided the ambient air temperature within the enclosure does not exceed 125°F. The temperature within the enclosure shall be monitored at 30-foot spacing either continuously or at 30-minute intervals during steam curing.

(i) Heat Treatment - The internally sealed concrete shall have attained a 4800 psi ultimate compressive strength before heat treatment.

Heat treatment may be performed at any time after the above conditions are met.

The method used to melt the wax beads may be one of the following:

1. Electric Infrared Heaters
2. Propane gas-fired Hot Air Heaters
3. Electric Blankets as Enclosure Heaters

Heat treatment shall be accomplished in such a manner that each side of the pile is heated to a minimum temperature of 185°F at the 2-inch depth. The maximum allowable temperature of any portion of the concrete shall be 280°F.

The maximum temperature variation over the heated concrete surface shall not exceed 15°F of the mean concrete surface temperature at the time the measurements are taken. At least 15 days prior to beginning the melting process the contractor shall deliver to the engineer for his review, a written procedure report describing his planned heating procedure and a detailed description of the heating enclosure. The engineer will approve or disapprove the procedure within 10 days of receiving the procedure report. The contractor shall not proceed with the melting of the wax beads until his heating procedure has been approved.

During the melting cycle, the contractor shall obtain continuous or periodic temperature (by means of thermocouples) on the concrete surface and at the 2-inch depth at the following locations:

The surface temperature shall be obtained on each side of the pile every 30 feet and at 3 locations at the 2-inch depth which will be determined by the engineer.

Surface temperature is defined as the temperature measured by a thermocouple placed at a depth of precisely 1/16 inch.

Heating procedures which utilize water vapor or steam shall not be used.

The rate of heating and cooling of the internally sealed piles shall be as follows:

Heating shall be accomplished in such a manner that the surface temperature (1/16 inch thermocouple temperature) is increased from ambient conditions to 160°F in not less than 1.3 hours. The surface temperature after 0.5 hour of heating shall not be less than 30°F above the ambient air temperature, nor more than 145°F. The time for heating to 185°F at the design sealing depth shall not be less than 5.0 hours.

The concrete shall be cooled in a manner that at no time shall the temperature at the 2-inch depth exceed the surface temperature by 20°F.

The heating systems shall be used in such a way as to permit the continuous venting of moisture vapor from the concrete during heating, especially for the hole in the center of the pile.

(j) Electric Blanket System for Heat Treating Internally Sealed Concrete - The following components are basic to the Electric Blanket Heat Treating System for Internally Sealed Concrete Piles:

Electric heating blankets
Temperature monitoring system
Power distribution console
Portable diesel fueled electric generator
Heating enclosure

(j-1) Electric heating blankets - The blankets constitute an electrical heating system for the treatment of internally sealed concrete. The blankets are shielded, hinged, primary heat sources that melt wax in the concrete.

All blankets shall be electrically, thermally and mechanically identical. Any blanket shall be capable of replacing any other blanket in the system. Blankets may operate electrically in parallel, or as series-pairs in parallel.

Material selections shall consider resistance to mechanical abrasion, weatherability, thermal stability at 400°F (operating temperature), and mechanical strength (shear, tear, and fatigue characteristics).

Mechanical:

Dimensions -	15 inches wide 48.75 feet long (hinged at 15-inch intervals) 0.200 inch thick (exclusive of bolt heads and stiffeners)
Construction -	Hinged panels approximately 15 inches by 15 inches consisting of a sandwiched lamination of stainless steel heating elements, silicon rubber and Kapton sheet electrical insultion, and stainless steel armor (grounded shielding). Blankets shall be shielded top and bottom, for both abrasion protection and personnel safety; the bottom surface shall be coated with a black

abrasion resistant material to enhance heat transfer.

The blanket shall be watertight.

All exposed metal materials shall be corrosion resistant.

Connectors - All cables shall be armored (shielded with flexible metal conduit that is electrically conductive and grounded).

All wiring shall be Teflon insulated.

All connectors shall mate in a positive-looking manner.

Connectors and associated hardware shall be weathertight and shall be constructed of corrosion resistant materials.

All cable and connector interfaces shall be stress relieved.

Current carrying capacity of connectors and cables shall meet or exceed the anticipated blanket load at maximum operation voltage.

Blankets shall have a minimum 3-foot length of cable attached to the heating elements. The cable shall terminate in a male connector.

Extension cables 16 to 20 feet long to service a blanket pair shall be provided. A cable shall be provided for each blanket pair delivered containing one end terminated in a single male connector, and the other terminated in two female connectors (to which two of the blanket male connectors will mate.)

Life expectancy - At least 500 fold/unfold, mate/unmate cycles (particularly the hinge area, and connectors).

At least 4 months of continuous operation at internal material temperature +400°F.

Electrical:

Input - 410V to 560V, 60 Hz, 3-phase

Output - Thermal; 125 watts/sq.ft. at 480V, at operating temperature (thermal stability is attained approximately two hours after power application)

Grounds -	Case (chassis) ground shall be maintained throughout the system; ground shall be continuous through cable armor, blanket armor, and connectors.

State-furnished blankets - The State will make available to the contractor ten electric blankets (See FHWA Internally Sealed Concrete Guide to Construction and Heat Treatment Manual - Implementation Package 77-9) for any mutually agreed upon two consecutive weeks between November 1 and December 31, at no cost to the contractor. The State will furnish the power distribution console, main electrical feeder cable and operator. The contractor shall furnish and pay for the enclosure, insulation, power and power sources for operation of the blankets.

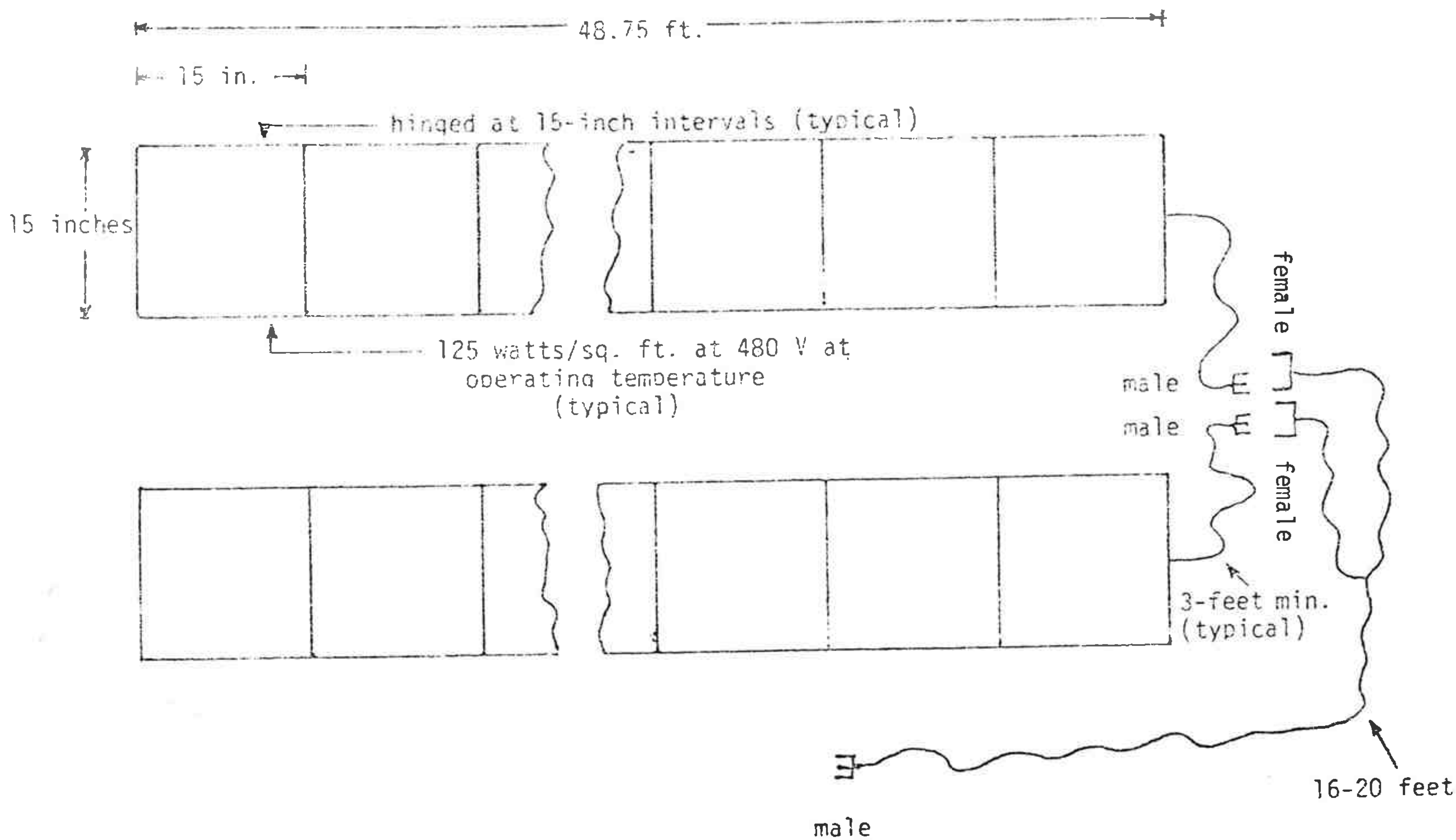
Thermal Output - The thermal output of the electrical heating blankets is dependent upon the heating element resistance which is a direct function of the element temperature. The blankets shall be designed for 125 watts per square foot output at design operating temperature. Ambient temperature, moisture, wind, etc. will tend to lower the element temperature and result in slightly higher voltage requirements.

(j-2) Portable electric generator - An electrical power source is required for using the Electric Blanket System. A portable diesel genertor has proven to be the most readily available and most economical source of electric power.

Voltage variability is required to afford the system a controllable thermal output.

When using less than the maximum 26-blanket complement, generators of proportionally lower power output may be used.

Voltage:	480 volts, 60 cycle, 3-phase
Voltage variability:	420 volts to 540 volts
Voltage regulations:	$\pm$ 5% at constant load
Power:	250,000 watts (250 KW) (a load power factor of 1.0 may be assumed)
Power Connections:	Four stud bolts - one for each phase, and one for system ground (common).
Portability:	The generator should be portable at the site; that is either truck or trailer mounted.



Design Electric Resistance Heating Blankets

B - Latex Modified Concrete Piling

Scope - This work shall consist of furnishing prestressed concrete piling using latex modified concrete.

Materials:

The portland cement shall be Type III, low alkali.

Formulated latex admixture shall be a nontoxic, filmforming, polymeric emulsion in water to which all stabilizers have been added at the point of manufacture and shall be homogenous and uniform in composition.

The latex modifier shall be one or another of the following:

Dow Modifier A
Dow Chemical Co.
Midland, Michigan

Thermoflex 8002
Reichhold Chemical Inc.
Dover, Delaware

Arco Dylex 1186
Arco Polymers Inc.
Monaca, Pennsylvania

The contractor shall submit to the engineer a test report in accordance with the Certification Program detailed in FHWA Report no. FHWA 78-35 Styrene-Butadiene Latex Modifiers for Bridge Deck Overlay Concrete.

Latex admixture to be stored shall be kept in suitable enclosures which will protect it from freezing and from prolonged exposure to temperatures in excess of 85°F.

The latex modified concrete shall be a workable mixture having the following properties or limits:

Material or Property	Latex Modified Concrete
Cement content, sacks/cu.yd.	7.5
Latex emulsion admixture, gal./sack	3.5
*Water, gal./sack	Max. 2.0
Air content, percent of plastic mix	3-6
**Slump, inches	0-3

NOTE:

*The new water added shall be adjusted to control the slump within the prescribed limits and should produce net water-cement ratios of 0.37 maximum by weight.

**The slump shall be measured 4 to 5 minutes after discharge from the mixer.

Proportioning, Mixing and Placing - No latex-modified material shall be placed at temperatures lower than 45°F. It may be placed at 45°F when rising temperature is predicted and then only if and until the prediction indicates 8 hours over 45°F for the curing period.

Latex modified concrete shall be finished within 30 minutes after mixing. The exposed surface shall be promptly covered with a single layer of clean wet burlap as soon as the surface will support it without deformation.

Adequate precautions shall be taken to protect freshly placed concrete from rain. The engineer may order removal of any concrete material damaged by rainfall.

C - Polymer Impregnated Concrete Piling

Scope - This work shall consist of furnishing portland cement concrete piling impregnated with a methyl methacrylate based monomer-catalyst system and polymerized in a hot water bath.

Materials - The concrete shall be Class 5000-1. The concrete piling shall be air cured a minimum of 21 days before beginning the drying cycle.

Concrete Surface Preparation - Concrete surfaces containing surface contaminants such as curing compounds, or form release oils, shall be cleaned by sandblasting.

Drying Cycle - The concrete surface area to be treated shall be dried sufficiently to permit polymer penetration. The equipment used to accomplish drying shall consist of a covered enclosure with an electric infrared or hot-air heat system as generally described under the heading "Enclosure and Heat Systems" or other technique as approved by the engineer.

Drying shall be accomplished by raising the concrete surface temperature at an approximately linear rate not exceeding 100°F per hour, to a minimum of 260°F, but not exceeding 300°F and maintaining that surface temperature range for 8 to 10 hours. If an electric infra-red heat system is used, the specified temperature shall be maintained for a minimum of 8 hours. If a hotair heat system is used, the specified temperature shall be maintained for a minimum of 10 hours. If a higher maximum temperature is desired, approval by the engineer shall be obtained. During the drying cycle the contractor shall obtain continuous or periodic surface temperature measurements, as hereinafter specified under the heading "Treatment Process and Quality Control Reports", at one point per side per each 30-foot of piling to assure temperature uniformity. The maximum temperature variation over the heated concrete surface shall not exceed $\pm$ 15 F of the mean concrete surface temperature at the time measurements are taken.

Enclosure and Heat Systems - It will be necessary to provide a reasonably well insulated, weather resistant enclosure over the area to be treated. The enclosure is to contain the heat and protect the concrete from rain or snow during the drying and polymerization cycles. The height of the enclosure should be kept as low possible to eliminate the need of heating an excessive air volume around the pile and to reduce heat loss from the vertical sides. It is advisable to provide the enclosure with a rigid internal frame to support the cover. It is recommended that the cover for the enclosure sides and top be formed of fiber building board, plywood, glass fiber sheets, or corrugated panels. The use of a tarpaulin or plastic membrane is discouraged.

Depending upon the area to be treated and the number and performance characteristics of the hot air sources used, care shall be taken to design a hot air distribution system that results in uniform heat distribution over the surface to be dried. Standard sheet metal heat ducts with adjustable, louvered, heat registers are acceptable. If the ducts are located on the exterior of the enclosure they should be insulated.

For hot air heating, only propane gas-fired space heaters containing electrically powered blower fans and temperature control systems are acceptable.

In addition to the above there are two basic items that shall be considered. First, temperatures within the enclosure may reach 300° to 350°F particularly at points in contact with or very near to the neat ducts. The materials chosen for constructing the enclosure shall be fire resistant and capable of withstanding exposure to these temperatures without excessive cracking, warping, or melting. Second, the pile must be removed from under the enclosure and placed in a resin soaking tank.

Cooling - After each precast prestressed concrete pile has been dried, it shall be cooled prior to monomer application. The rate of concrete surface temperature decrease during the cooling cycle shall not exceed 100°F per hour. Cooling shall continue until the maximum temperature on the surface of the concrete pile and at a depth of 1-inch is 100°F.

During the cooling and impregnation cycles, the dried pile shall be protected to prevent moisture from reentering the concrete. It may be necessary to repeat the drying and cooling cycles prior to monomer soaking should the engineer determine moisture reentered the concrete.

Impregnation - The temperature on the surface of the concrete and at the 1-inch depth shall not exceed 100°F at any time during the impregnation cycle.

Within 24 hours after the completion of the cooling cycle the pile shall be submerged into a monomer bath for a minimum of 8 hours. In order to protect the monomer from the polymerizing effects of direct and indirect solar radiation, the soaking shall occur during the time of sunset to sunrise unless the contractor provides shielding as approved by the engineer.

Polymerization - Within 15 minutes after the impregnated pile is removed from the monomer bath, polymerization shall be accomplished by uniformly heating the treated concrete pile in a non-agitating hot water bath. The water temperature when the pile is first inserted shall be between 165°F to 170°F. Within 1 hour after submersion, the water temperature shall be brought back and shall remain within a range of 170°F to 185°F for a period of 8 hours. The maximum temperature variation along the pile surface shall not exceed ± 15 F. During polymerization, the temperature of the water and at the 1-inch depth within each pile shall be monitored as hereinbefore set forth under the heading "Drying Cycle".

Monomer System - The monomer system shall be methyl methacrylate (MMA). A polymerization catalyst, 2-t-Butylazo-2-cyanopropane shall be added to this monomer at a rate of 0.5% by weight or as specified by the engineer.

Monomer Specifications - MMA shall meet the following requirements:

Formula	$CH_2C(CH_3)COOCH_3$
Inhibitor	12-25 p/m hydroquinone (HQ)
Molecular Wt.	100
Assay (Gas Chromatography), %	99.8 min.
Density	9.83 Kg/l (7.83 lb/gal)
Boiling point	100°C (212°F)
Flash point (Tag, ASTM D1310)	13°C (55°F)

As directed by the engineer the polymerization catalyst shall be 2-t-Butylazo-2-cyanopropane.

Formula $C_8H_{15}N_3$

The contractor shall provide the engineer with manufacturer's certification that the monomer and catalyst meet the above specifications. Representative samples of the monomer system shall be delivered to the engineer at least 14 days prior to use. At the engineer's option, these samples will be tested to determine specifications compliance.

Monomer system shall be used within 6 months after manufacture.

Monomer and Catalyst Storage and Handling - The monomer, MMA shall be stored in its original shipping containers or in other clean containers as approved by the engineer. Maximum monomer storage temperature shall not exceed 85°F. The storage area shall be selected to provide protection from direct sunlight, fire hazard and oxidizing chemicals. Sufficient ventilation shall be maintained in the storage area to prevent the hazardous buildup of monomer vapor concentrations in the storage air space. The polymerization catalyst shall be stored in accordance with manufacturer's recommendations but in no event shall the catalyst storage temperature be allowed to exceed 80°F. Personnel exposed to monomer or monomer vapor shall use minimum protective equipment as follows: safety eyeglasses, impervious gloves and aprons and rubber boots as required. As determined by the contractor, personnel may be required to use full face protective shields and/or self-contained respiratory equipment. All personnel handling the monomers or catalyst shall be thoroughly trained in their safe use in accordance with manufacturers' recommendations.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of monomer shall in all cases comply with the requirements of applicable Federal, state and local safety requirements and ordinances.

Monomer Handling - All monomer mixing and transfer equipment shall be of explosion proof design and provided with the electrical ground cables. Monomer transfers shall be from bottom to bottom of the vessels or through dip pipes in the vessels to prevent the buildup of static charge during transfer. Pipe fittings, valves, pump impellers or other equipment which will come into contact with monomer, shall not be made of copper or brass or of plastics attacked by the mixture. The monomer mixing area shall be free of sources of ignition and well ventilated. Spilled monomer shall be contained with absorptive material such as vermiculite or dry sawdust and removed with non-sparking equipment.

Catalyst-Monomer Mixing - The polymerization catalyst shall be mixed with the monomer system immediately prior to use. Monomer system temperature at the time of catalyst addition shall not exceed 85°F. Mixing shall be accomplished with explosion proof equipment in electrically grounded containers in a well-ventilated area.

Catalyzed monomer shall be used within 2 weeks after the addition of catalyst. The storage temperature shall be below 85°F. If a longer storage period is needed, the contractor shall demonstrate that there has been no loss of catalyst reactivity. During storage, the drum bungs shall be replaced with 2-lb/in^2 break pressure rupture disks.

Treatment Process and Quality Control Reports - At least 15 days prior to beginning the pile impregnation process the contractor shall deliver to the engineer a written Procedures Report describing his planned treatment procedures. Included in this report shall be a detailed description of the drying, impregnation, monomer mixing and storage, polymerization and quality control procedures, facilities, and equipment the contractor intends to use to treat the pile. The engineer will review this report and provide approval or disapproval of the plan within 10 days of the date of receipt. In no event shall the contractor proceed with the surface impregnation treatment until approval of his procedures, materials and equipment has been received.

During the drying, cooling, and polymerization cycles, the contractor shall obtain and supply to the engineer concrete temperature data accurate to $\pm$ 5,F from surface locations as hereinbefore specified under the heading "Drying" and from at least three points vertically spaced, 1 inch below the concrete surface at approximate 30-foot spacing at locations determined by the engineer.

This data shall be in the form of a continuous record or periodic readings recorded at the following intervals:

(a) During drying and cooling the temperature shall be recorded at 15-minute intervals during the first 3 hours and at 30-minute intervals thereafter.

(b) During polymerization the temperature shall be recorded at 15-minute intervals for the first hour or until polymerization temperature is reached and at 30-minute intervals thereafter.

The technique and equipment used to obtain temperature data shall be described in the written Procedures Report above and subject to approval by the engineer.

The contractor shall maintain and supply to the engineer monomer and catalyst records listing the dates of manufacture, storage temperatures, date of use and application rates, and quantities required for impregnation.

List of Suppliers of Monomer and Catalyst

Methyl methacrylate (MMA)	American Cyanamid Company Wayne, New Jersey 07470
	E.I. duPont de Nemours Wilmington, Delaware
	Polysciences, Inc. Paul Valley Industrial Park Warrington, Pennsylvania 18976
	Rohm and Haas Company Independence Mall West Philadelphia, Pennsylvania 19105
2-t-Butylazo-2-cyanopropane	Pennwalt-Lucidol 1740 Military Rd. Buffalo, New York 14240

D - Polymer Concrete Piling

Scope - This work consists of furnishing precast prestressed methyl methacrylate polymer concrete piles.

Materials - The binder for the polymer concrete piles shall be Crylcon EP-3010 liquid and Crylcon EP-3020 powder manufactured by DuPont or an approved equal.

The mix design shall be as follows:

Crylcon EP-3010	14 parts by weight
Crylcon EP-3020	100 parts by weight
Dry, Coarse Aggregate	100 parts by weight

The mixing procedure recommended by the manufacturer shall be followed.

The moisture content of the coarse aggregate shall be not greater than 0.5%.

The coarse aggregate shall conform to subsection 703.02 of the Standard Specifications and shall meet the following gradation:

Sieve Size	% Passing (by weight)
1"	100
3/4"	90-100
3/8"	20-50
#4	0-10
#200	0-0.6

The contractor shall follow the manufacturers recommendations for the use, storage, handling, curing of concrete, etc.

E - Portland Cement Concrete Piling

Fabrication - The three standard prestressed concrete piling shall be furnished with holes as detailed on the plans for bolting the precast "blocks" to the piling.

F - Portland Cement Concrete "Blocks"

Scope - This work consists of furnishing precast concrete "blocks" incorporating epoxy coated reinforcement as detailed on the plans.

Materials - Epoxy for use in coating reinforcing shall be one of the following products.

1. Scotchkote 202
   Minnesota Mining and Mfg. Co.
   Dover, Delaware 19901

2. Scotchkote 213
   Minnesota Mining and Mfg. Co.
   St. Paul, Minnesota 55101

3. Scotchkote 214
   Minnesota Mining and Mfg. Co.
   St. Paul, Minnesota 55101

4. Flintflex 531-6080
   E.I. DuPont de Nemours Co., Inc.
   Wynnwood, Pennsylvania 19096

5. Flintflex 531-6085
   E.I. DuPont de Nemours Co., Inc.
   Wilmington, Delaware

6. Flintflex 531-6086
   E.I. DuPont de Nemours Co., Inc.
   Wilmington, Delaware

7. Epoxy Powder 720-A-009
   Cook Paint and Varnish Co.
   Kansas City, Missouri 64141

8. CORVEL ECA - 1558-Red-27000
   Polymer Corp.
   Reading, Pennsylvania 19605

9. ECA-1440
   Polymer Corp.
   Reading, Pennsylvania 19605

10. EPOXIPLATE - 346)
11. EPOXIPLATE - 347) Armstrong Products Co.
) Warsaw, Indiana 46580
12. EPOXIPLATE - 348)
13. EPOXIPLATE R-349)

14. NAP-GARD 7-2000
    Napco Corp.
    Houston, Texas 77201

15. MOBILOX 1004-R-2
    Mobil Chemical Co.
    Cleveland, Ohio 44111

16. Fuller-O'Brien EL-704-P-9
    Fuller-O'Brien Division
    S. San Francisco, California 94056

17. Hysol's DK23-0602
    The Dextor Corp.
    Olean, New York 14760

The coating shall be applied as directed by the coating manufacturer.

The coating applicator shall supply to the engineer a representative sample of 8 ounces of the coating material used to coat each given lot bars. The sample shall be packaged in an airtight container with identification by lot number.

(a) Patching material - Patching material shall be compatible with the coating material and inert in concrete.

Patching will be done in accordance with the manufacturer's recommendations and to the prescribed thickness.

(b) Surface preparation - The surface of bars to be coated shall be prepared in accordance with the method specified by the coating supplier.

The coating shall be applied to the cleaned surface as soon as possible after cleaning and before visible oxidation of the surface occurs but in no case shall more than 8 hours elapse.

(c) Coating thickness - The film thickness after curing shall be the same as the average of the coating prequalification thickness and shall not deviate by more than ± 30 percent or ± 2 mils, whichever is less. Thickness of the film shall be measured by the method outlined in ASTM G 12.

(d) Continuity of coating - The coating shall be checked visually after cure for continuity. It shall be free from holes, voids, contamination, cracks and damaged areas. The coating shall not have more than two holidays (pinholes not visible to the naked eye) in any linear foot of the coated bars. Holiday checks shall be made with a 67-1/2 volt holiday detector in accordance with the manufacturer's instructions.

(e) Coating cure - The coating applicator shall check each production lot, shall certify that the entire production lot of coated bars supplied is in the fully-cured condition.

(f) Flexibility of coating - The flexibility of the coating shall be evaluated by bending production coated bars 120 degrees (after rebound) around a 6" diameter mandrel. The bend shall be made at a uniform rate and may take up to one minute to complete. The two longitudinal deformations may be placed in a plane perpendicular to the mandrel radius and the test specimen shall be at thermal equilibrium between 20 and 30°C.

No cracking of the coating shall be visible to the naked eye on the outside radius of the bent bar.

(g) Testing and sampling - The number and frequency of tests shall be as directed by the engineer.

Test specimens shall be provided by the applicator from production runs.

Test results shall be retained and made available as provided in Section 9.1 of AASHTO M 218.

(h) Fabrication of coated bars - Patching will not be required if the coated rebars are handled per paragraph (i) below and damage is less than noted in the following paragraphs.

Patching will be required on straight areas of the rebar only if damage exceeds 2 percent of the coated area within the total straight portion of the coated rebar. When coating repair is required, all damage shall be patched on straight areas of the rebar.

Patching will be required within each bent area of the rebar only if bond loss and damage exceed 5 percent of the coated area within each bent area. When coating repair is required, all damage within each area shall be cleaned and patched, but each bent area may be treated individually. Hairline cracks without bond loss or other damage on fabrication bends need not be patched.

Required patching shall be done as soon as possible and before visible oxidation appears. It shall be done at the fabricator's plant using the powder manufacturer's specified material.

(i) Handling - All systems for handling coated bars shall have padded contact areas for the bars wherever possible.

All bundled bands shall be padded and all bundles shall be lifted with strong back, multiple supports or a platform bridge so as to prevent bar-to-bar abrasion from sags in the bar bundle.

(j) Coated bar placement - The coated steel shall be tied using non-metalic tie wires which are inert in concrete and supported in a manner that prevents physical damage to the coated rebars during installation.

Coating repair will not be required if damage is less than 3 percent of the coated area. Where repair is required, all damaged areas will be repaired as soon as possible.

Measurement - Measurement of piling furnished and driven as specified and "blocks" furnished and attached as specified shall be the actual number of piles and "blocks" accepted.

Payment - The accepted unit pay quantities, determined as above provided, will be paid for at the applicable contract unit price per each for the pay items listed below, which price and payment shall be full compensation, in each instance, for furnishing and placing all materials, including all labor, tools, equipment, transportation and incidentals necessary to complete the work as prescribed.

Pay Item	Unit of Measurement
Furnish Internally Sealed Concrete Piling	Each
Furnish Latex Modified Concrete Piling	Each
Furnish Polymer Impregnated Concrete Piling	Each
Furnish Polymer Concrete Piling	Each
Furnish Portland Cement Concrete Piling	Each
Drive Piles	Each
Portland Cement Concrete "Blocks"	Each

PILE CAPS

Scope - This work shall consist of construction of concrete pile caps for the experimental piling to form a pile dolphin as detailed on the plans.

Materials - Concrete shall conform to the requirements of Section 504 of the Standard Specifications.

Reinforcing bars shall conform to the requirements of Section 505 of the Standard Specifications, except all bars shall be epoxy coated as hereinbefore set forth under "F - Portland Cement Concrete 'Blocks'."

Measurement - There will be no measurement of the above work.

Payment for the above work will be made at the contract lump sum amount for the item "Concrete Pile Caps" which payment shall be understood to be full and complete compensation for furnishing and placing all concrete, epoxy coated reinforcement, pipe handrail, ladders and all other materials necessary to construct the pile caps as specified.

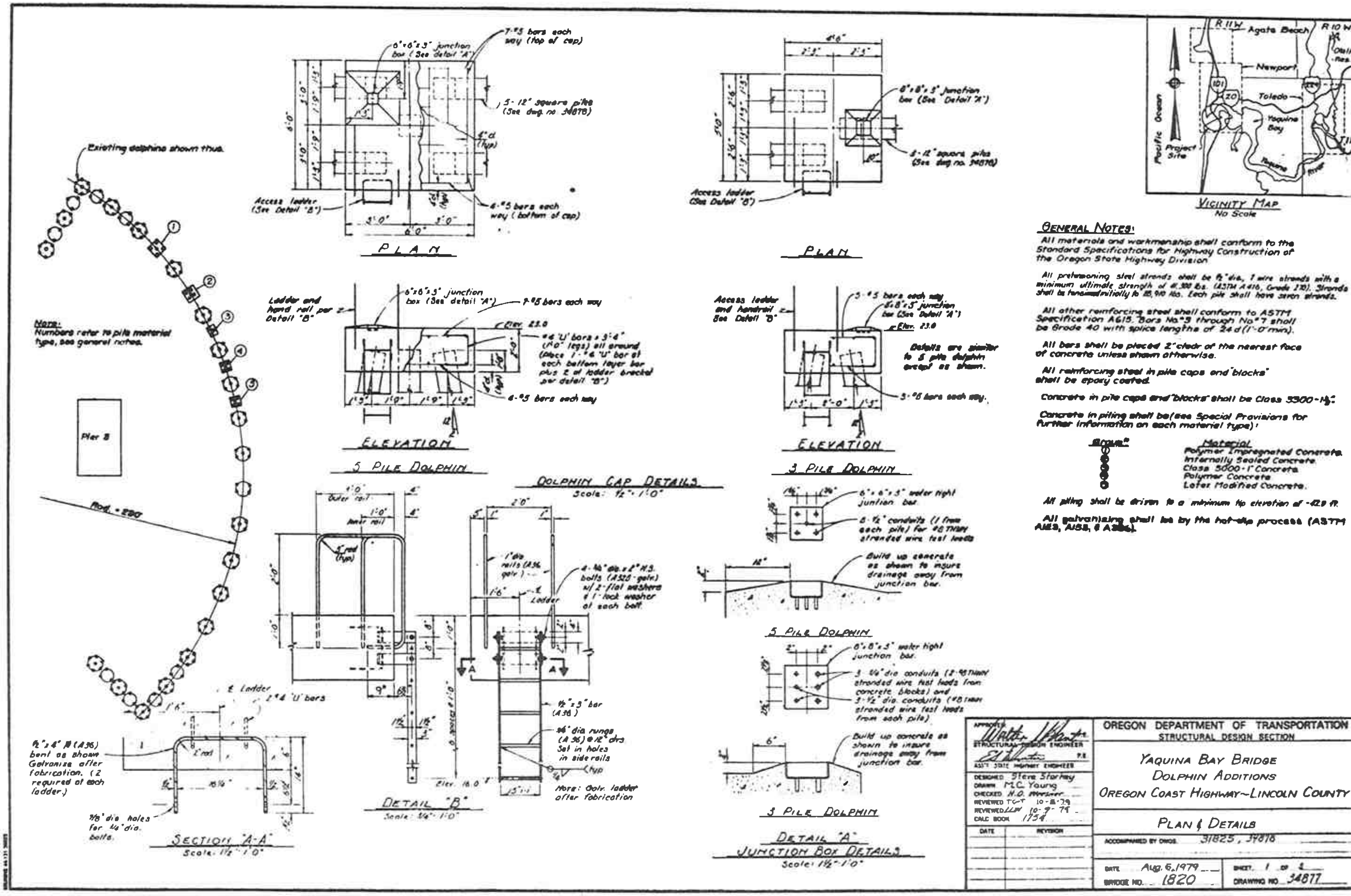
MONITORING EQUIPMENT

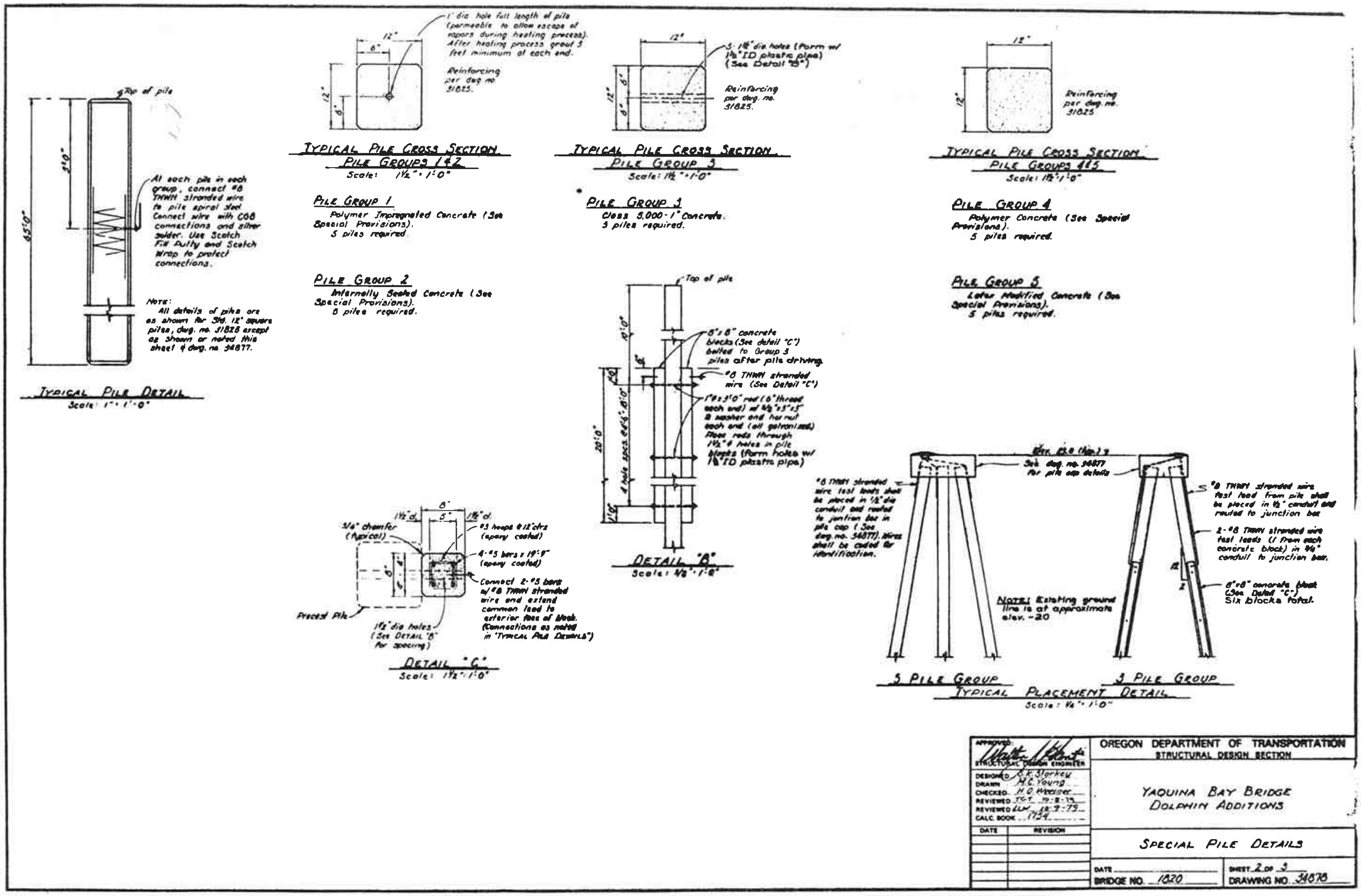
Scope - This work shall consist of furnishing and installing electrical wiring, junction boxes, conduit, etc. as called for on the plans and as directed by the engineer.

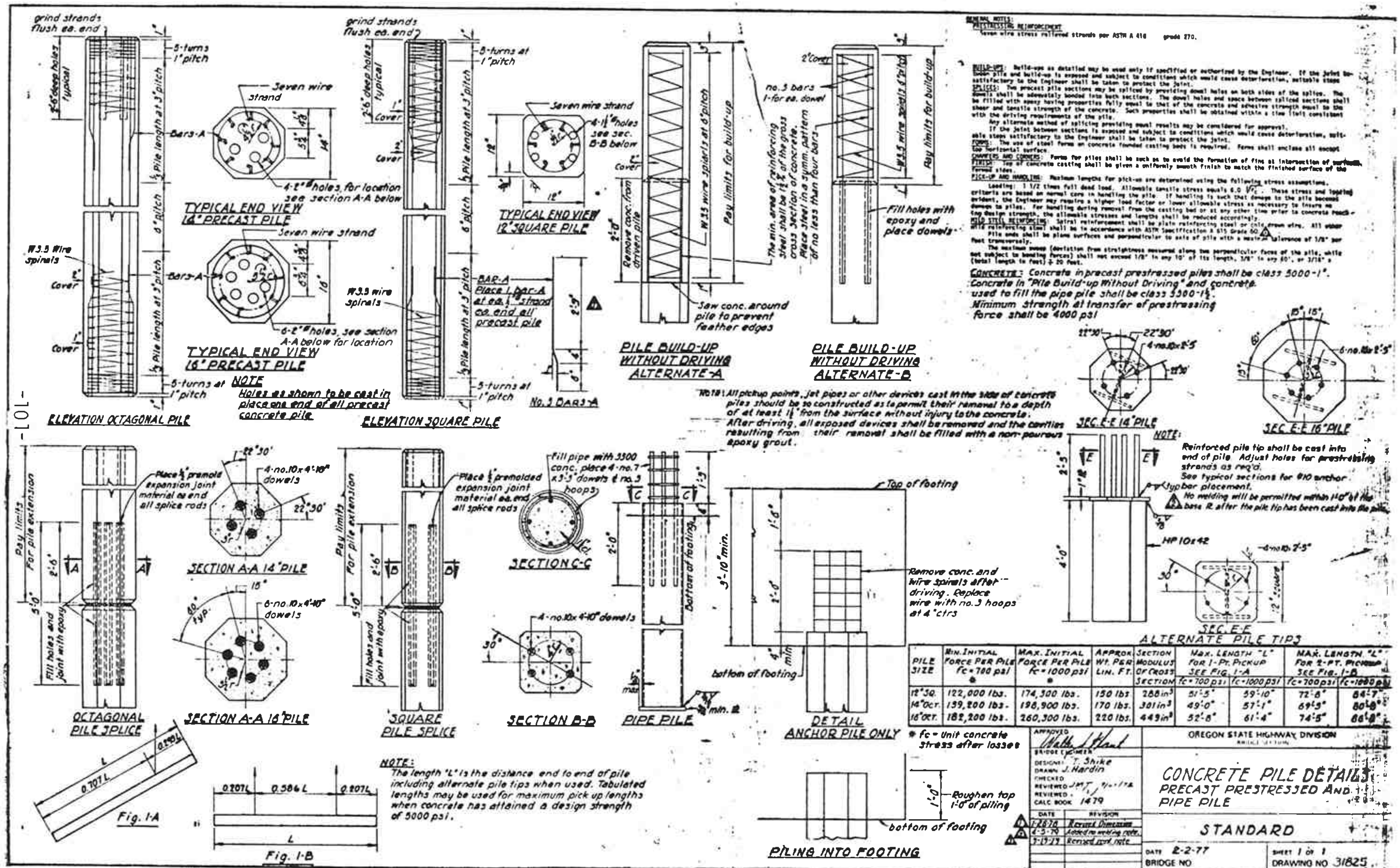
Materials - All materials and installation shall conform to the requirements of NEMA and NEC.

Measurement - There will be no measurement of the above work.

Payment - Payment for the above work will be made at the contract lump sum amount for the item "Monitoring Equipment" which payment shall be understood to be full and complete compensation for furnishing and placing all monitoring equipment and all other materials necessary for complete installation of the monitoring system as specified.


Existing dolphins shown thus.
Note:
Numbers refer to pile material type, see general notes.
Pier 3
Rad. = 280
PLAN
6"x6"x3" junction box (See detail "A")
7-#5 bars each way (top of cap)
5-12" square piles (See dwg. no. 34878)
4-#5 bars each way (bottom of cap)
Access ladder (See Detail "B")
ELEVATION
5 PILE DOLPHIN
Ladder and hand rail per Detail "B"
PLAN
8"x8"x3" junction box (See Detail "A")
3-12" square piles (See dwg. no. 34878)
Access ladder and handrail See Detail "B"
Details are similar to 5 pile dolphin except as shown.
ELEVATION
3 PILE DOLPHIN
DOLPHIN CAP DETAILS
Scale: ½" = 1'-0"
DETAIL "B"
Scale: ¾" = 1'-0"
Note: Galv. ladder after fabrication
SECTION "A-A"
Scale: 1½" = 1'-0"
DETAIL "A"
JUNCTION BOX DETAILS
Scale: 1½" = 1'-0"
Build up concrete as shown to insure drainage away from junction box.
VICINITY MAP
No Scale
Agate Beach
Newport
Toledo
Yaquina Bay
Pacific Ocean
Project Site
GENERAL NOTES:
All materials and workmanship shall conform to the Standard Specifications for Highway Construction of the Oregon State Highway Division
All other reinforcing steel shall conform to ASTM Specification A615. Bars No. 3 through No. 7 shall be Grade 40 with splice lengths of 24 d (1'-0" min).
All bars shall be placed 2" clear of the nearest face of concrete unless shown otherwise.
All reinforcing steel in pile caps and "blocks" shall be epoxy coated.
Concrete in pile caps and "blocks" shall be Class 3300-1½".
Concrete in piling shall be (see Special Provisions for further information on each material type):
Material
Polymer Impregnated Concrete
Internally Sealed Concrete
Class 5000-1" Concrete
Polymer Concrete
Latex Modified Concrete
OREGON DEPARTMENT OF TRANSPORTATION
STRUCTURAL DESIGN SECTION
STRUCTURAL DESIGN ENGINEER
ASS'T STATE HIGHWAY ENGINEER
DESIGNED Steve Starkey
DRAWN M.C. Young
CALC BOOK 1754
DATE
REVISION
YAQUINA BAY BRIDGE
DOLPHIN ADDITIONS
OREGON COAST HIGHWAY~LINCOLN COUNTY
PLAN & DETAILS
ACCOMPANIED BY DWGS. 31825, 34878
DATE Aug. 6, 1979
BRIDGE NO. 1820
DRAWING NO. 34877


Top of pile
At each pile in each group, connect #8 THWN stranded wire to pile spiral steel. Connect wire with C08 connections and silver solder. Use Scotch Fill Putty and Scotch Wrap to protect connections.
Note: All details of piles are as shown for Std. 12" square piles, dwg. no. 31828 except as shown or noted this sheet & dwg. no. 34877.
65'0"
5'0"
TYPICAL PILE DETAIL
Scale: 1" = 1'-0"
1" dia. hole full length of pile (permeable to allow escape of vapors during heating process). After heating process grout 3 feet minimum at each end.
Reinforcing per dwg. no. 31825.
TYPICAL PILE CROSS SECTION
PILE GROUPS 1 & 2
Scale: 1½" = 1'-0"
PILE GROUP 1
Polymer Impregnated Concrete (See Special Provisions).
5 piles required.
PILE GROUP 2
Internally Sealed Concrete (See Special Provisions).
5 piles required.
5-1½" dia. holes (Form w/ 1½" I.D. plastic pipe) (See Detail "B")
Reinforcing per dwg. no. 31825.
TYPICAL PILE CROSS SECTION
PILE GROUP 3
Scale: 1½" = 1'-0"
PILE GROUP 3
Class 5,000-1" Concrete.
3 piles required.
Reinforcing per dwg. no. 31825
TYPICAL PILE CROSS SECTION
PILE GROUPS 4 & 5
Scale: 1½" = 1'-0"
PILE GROUP 4
Polymer Concrete (See Special Provisions).
5 piles required.
PILE GROUP 5
Latex Modified Concrete (See Special Provisions).
5 piles required.
Top of pile
8"x8" concrete blocks (See detail "C") bolted to Group 3 piles after pile driving.
#8 THWN stranded wire (See Detail "C")
1"φx3'0" rod (6" thread each end) w/ ½"x5"x5" washer and hex nut each end (all galvanized). Place rods through 1½"φ holes in pile blocks (Form holes w/ 1½" I.D. plastic pipe)
20'0"
10'0"
4 hole spcs. @ 4'6" = 18'0"
DETAIL "B"
Scale: ⅛" = 1'-0"
3/4" chamfer (typical)
#3 hoops @ 12" ctrs (epoxy coated)
4-#5 bars x 19'9" (epoxy coated)
Connect 2-#5 bars w/ #8 THWN stranded wire and extend common lead to exterior face of block. (Connections as noted in "Typical Pile Details")
Precast Pile
1½" dia. holes (See Detail "B" for spacing)
DETAIL "C"
Scale: 1½" = 1'-0"
See dwg. no. 34877 for pile cap details
#8 THWN stranded wire test leads shall be placed in ½" dia conduit and routed to junction box in pile cap (See dwg. no. 34877). Wires shall be coded for identification.
5-#8 THWN stranded wire test lead from pile shall be placed in ½" conduit and routed to junction box
2-#8 THWN stranded wire test leads (1 from each concrete block) in ¾" conduit to junction box.
8"x8" concrete block (See Detail "C") Six blocks total.
Note: Existing ground line is at approximate elev. -20
5 PILE GROUP
3 PILE GROUP
TYPICAL PLACEMENT DETAIL
Scale: ¼" = 1'-0"
APPROVED: STRUCTURAL DESIGN ENGINEER
DESIGNED G.K. Starkey
DRAWN H.C. Young
CHECKED H.O. Weesner
REVIEWED
REVIEWED
CALC. BOOK 1454
DATE
REVISION
OREGON DEPARTMENT OF TRANSPORTATION
STRUCTURAL DESIGN SECTION
YAQUINA BAY BRIDGE
DOLPHIN ADDITIONS
SPECIAL PILE DETAILS
DATE
BRIDGE NO. 1820
SHEET 2 OF 3
DRAWING NO. 34878



NOTE: The length "L" is the distance end to end of pile including alternate pile tips when used. Tabulated lengths may be used for maximum pick up lengths when concrete has attained a design strength of 5000 psi.

NOTE: Reinforced pile tip shall be cast into end of pile. Adjust holes for prestressing strands as req'd. See typical sections for #10 anchor bar placement. No welding will be permitted within 1'-0" of the base ℞ after the pile tip has been cast into the pile.

GENERAL NOTES:

PRESTRESSING REINFORCEMENT: Seven wire stress relieved strands per ASTM A 416 grade 270.

BUILD-UPS: Build-ups as detailed may be used only if specified or authorized by the Engineer. If the joint between pile and build-up is exposed and subject to conditions which would cause deterioration, suitable steps satisfactory to the Engineer shall be taken to protect the joint.

SPLICES: Two precast pile sections may be spliced by providing dowel holes on both sides of the splice. The dowels shall be adequately bonded into both sections. The dowel holes and space between spliced sections shall be filled with epoxy having properties fully equal to that of the concrete and adhesive strength equal to the shear and tensile strength of the concrete. Such properties shall be obtained within a time limit consistent with the driving requirements of the pile.

Any alternate method of splicing providing equal results may be considered for approval.

If the joint between sections is exposed and subject to conditions which would cause deterioration, suitable steps satisfactory to the Engineer shall be taken to protect the joint.

FORMS: The use of steel forms on concrete founded casting beds is required. Forms shall enclose all except the horizontal surface.

CHAMFERS AND CORNERS: Forms for piles shall be such as to avoid the formation of fins at intersection of surfaces.

FINISH: Top of concrete casting shall be given a uniformly smooth finish to match the finished surface of the formed sides.

PICK-UP AND HANDLING: Maximum lengths for pick-up are determined using the following stress assumptions.

Loading: 1 1/2 times full dead load. Allowable tensile stress equals 6.0 $\sqrt{f'_c}$. These stress and loading criteria are based on normal care in handling the pile. If handling is such that damage to the pile becomes evident, the Engineer may require a higher load factor or lower allowable stress as necessary to insure no damage to piles. For handling during removal from the casting bed or at any other time prior to concrete reaching design strength, the allowable stresses and lengths shall be reduced accordingly.

MILD STEEL REINFORCING: Spiral reinforcement shall be plain reinforcing steel or cold drawn wire. All other mild reinforcing steel shall be in accordance with ASTM Specification A 615 Grade 60.

Pile ends shall be plane surfaces and perpendicular to axis of pile with a maximum tolerance of 1/8" per foot transversely.

The maximum sweep (deviation from straightness measured along two perpendicular faces of the pile, while not subject to bending forces) shall not exceed 1/8" in any 10' of its length, 3/8" in any 60', or 3/16" x (total length in feet) ÷ 20 feet. [illegible]

CONCRETE: Concrete in precast prestressed piles shall be class 5000-1". Concrete in "Pile Build-up Without Driving" and concrete used to fill the pipe pile shall be class 3300-1½". Minimum strength at transfer of prestressing force shall be 4000 psi

PILE SIZE	MIN. INITIAL FORCE PER PILE fc = 700 psi *	MAX. INITIAL FORCE PER PILE fc = 1000 psi *	APPROX. WT. PER LIN. FT.	SECTION MODULUS OF CROSS SECTION	MAX. LENGTH "L" FOR 1-PT. PICKUP SEE FIG. 1-A fc = 700 psi	MAX. LENGTH "L" FOR 1-PT. PICKUP SEE FIG. 1-A fc = 1000 psi	MAX. LENGTH "L" FOR 2-PT. PICKUP SEE FIG. 1-B fc = 700 psi	MAX. LENGTH "L" FOR 2-PT. PICKUP SEE FIG. 1-B fc = 1000 psi
12" SQ.	122,000 lbs.	174,300 lbs.	150 lbs	288 in³	51'-5"	59'-10"	72'-8"	84'-7"
14" OCT.	139,200 lbs.	198,900 lbs.	170 lbs.	301 in³	49'-0"	57'-1"	69'-5"	80'-8"
16" OCT.	182,200 lbs.	260,300 lbs.	220 lbs.	449 in³	52'-8"	61'-4"	74'-5"	86'-8"

* fc = Unit concrete stress after losses

OREGON STATE HIGHWAY DIVISION
BRIDGE SECTION

CONCRETE PILE DETAILS
PRECAST PRESTRESSED AND PIPE PILE

STANDARD

APPROVED: [signature] BRIDGE ENGINEER
DESIGNED: T. Shike
DRAWN: J. Hardin
CHECKED:
REVIEWED: JMT
CALC. BOOK: 1479

DATE	REVISION
1-28-78	Revised Dimensions
4-5-79	Added no welding note
3-19-79	Revised prod. note

DATE 2-2-77
BRIDGE NO
SHEET 1 OF 1
DRAWING NO 31825

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.