Use of Improved Structural Materials

Systems in Marine Piling

by

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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 evaluation of the two-year performance of the various structural concretes. Only the polymer concrete piles were rated unsatisfactory after the first two years.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES - Continued

SECTION I

INTRODUCTION

There were two main objectives in conducting this study and they were 1) to evaluate the use of newly developed structural concrete in reducing or eliminating corrosion of reinforcing steel in marine piling and 2) to evaluate the feasibility of using the materials in the commercial fabrication of precast prestressed elements. The materials selected for use had low permeability and absorbtion properties and were originally developed to combat the deterioration of concrete bridge decks caused by deicing salts. The special materials evaluated in this study are internally sealed concrete, latex modified concrete, polymer concrete and polymer impregnated concrete. Five 12 inch (.30 mm) square by 65 feet (19.8 m) long prestressed piles were fabricated using each material. In addition three conventional prestressed concrete piles and six miniature piles (8" x 8" x 20 ft.) (20.3 mm x 20.3 mm x 6.2 m) containing epoxy coated rebars were also fabricated for comparison purposes. The technique used to produce each special concrete varied greatly and this added to the complexity of the study.

The marine pile study was conducted in three phases. The first phase consisted of preparing plans and specifications for the manufacture and placement of the piles. This was accomplished after an extensive literature search and in-house laboratory work which was performed by Oregon State Highway Division personnel. The second phase consisted of evaluating the commercial manufacture, handling, and installation of twenty-three 65-foot (19.8 m) long precast prestressed concrete piles. This was accomplished after a contract was awarded following competitive bids. The third and final phase consisted of evaluating the performance of the materials during a 2 year period.

An interim report prepared in August 1981 described in detail the first two phases of this study. A summary of this work is included in the final report along with 2 year performance data and evaluation.

During the search for the most up to date information on the various special materials, very little data was found on their use in precast prestressed concrete construction. Their original use was predominantly for bridge deck overlays. Upon a close examination, many of the methods and techniques used to produce the special materials were not applicable in fabricating prestressed concrete members. An accelerated laboratory study was initiated to modify the existing technology to meet the constraints of casting prestressed concrete members. Only the epoxy coated rebars were omitted from the laboratory study since 17 products were already approved for highway construction.

As part of the laboratory study, personnel from the Oregon DOT visited the Florida State Highway Department's Office of Research and Development to learn about their work with internally sealed concrete. The major portion of the visit was spent in discussing Florida's method of melting the wax beads by an internal heating system. Although their laboratory results appeared very promising, the concept was not developed sufficiently to be used in the marine pile project. Oregon DOT personnel also visited the Bureau of Reclamation in Denver, Colorado to review their work with both polymer concrete and polymer impregnated concrete. 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 the precast prestressed pile construction.

Before reviewing the laboratory work performed by Oregon on the four special concretes a general description of their composition is appropriate.

Latex Modified Concrete is produced by adding a prescribed amount of styrene-butadiene latex modifier to a conventional concrete during mixing. The total water content is comprised of the surplus water in the latex emulsion; the moisture on the aggregate and the added mixing water. The mixing, placing and finishing are done with conventional equipment. Normally, latex modified concrete is 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 produced by adding a specified quantity of wax beads, usually 3 percent by weight of the mix, into a conventional non-air-entrained concrete during batching. 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 for a minimum of 14 days it is heated to melt the wax beads. The heating requirements usually specify a minimum temperature of 180°F (82.2°C) be attained at the 2-inch (50.8 mm) depth inside the concrete. The rate of heating and cooling of the concrete is very critical and has to be controlled to prevent thermal cracking.

Crylcon Polymer Concrete is produced by blending a proprietary acrylic mortar with dry, coarse aggregate. The acrylic mortar is composed of two components, a specially formulated powder consisting of selected resins, fillers and graded sands and a low viscosity methyl methacrylate based liquid. Crylcon polymer concrete can be mixed in a conventional mixer, but exact proportioning of the chemical components is extremely critical. Extra care is required during handling and storage of the liquid because it is flammable. Finally, all work must be completed within 20 minutes after mixing because of the short pot life of the polymer concrete system.

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.

SECTION II

This section provides a summary of the laboratory work that was performed with each material to make it better suitable for prestressed concrete construction.

Internally Sealed Concrete

There were four major objectives in testing internally sealed concrete in the laboratory. These were (1) to evaluate several 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 determine the effects of melting the wax beads on concrete strength.

The internally sealed concrete mix design used in this work was the FHWA recommended formulation for bridge deck overlay work and is found in Table 2-1 shown below:

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

It was a non-air-entrained mixture 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 total mix. The wax beads were mixed with the dry ingredients for approximately two minutes before the mixing water was added to ensure a good bead distribution throughout the concrete. Several small samples were removed from different portions of the concrete after mixing to examine bead distribution. In every case the beads appeared to be well distributed throughout the mix.

For testing purpose 6" x 12" (152 x 305 mm) cylinders and 6" x 6" x 12" (152 x 152 x 305 mm) blocks were cast. The cylinders were used to determine compressive strength and the blocks were used in the melting study.

Before any physical testing began a hot water bath/steam curing chamber was constructed using a 55 gallon (207 l) drum and two 4000 watt electric heating elements. A rack was built 15 inches (38.1 mm) below the top of the barrel to support the test specimens and by adjusting the temperatures and depth of the water the drum was operated very satisfactorily as a hot water bath or a steam curing chamber.

Only four methods for melting the wax beads in the concrete 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 results of the melting study show each system is capable of melting the wax beads at a 2" (50.8 mm) depth within the concrete but the rate of heating and the efficiency of the methods is quite different.

Heating in a 1400 watt MacAlaster Bicknell electic oven for 3-1/2 hours produced a uniform melting zone of 2 inches (50.8 mm) on all four sides of the test block while it requires only 3 hours to melt the beads in a 200,000 BTU/hr propane-fired hot air oven. The efficiency of this system was diminished by the fact that melting was achieved on only 3 sides of the test block. There was virtually no melting on the bottom side of the block.

It required 8 hours to melt the wax beads at the 2" (50.8 mm) depth with the electric blanket system because of its low output power of 130 watts per square foot at 115 volts. Furthermore only the surface directly beneath the blanket exhibited melting of the wax beads.

Finally it required 6 hours to attain a temperature of 185^{o}F (85^{o}C) at the 2 inch (50.8 mm) depth with the four 1800 watt electric infrared heaters. When the blocks were opened for examination there was complete melting within

2-1/2" (63.5 mm) of the top surface and a varying degree of melting on the vertical sides. The bottom side of the blocks had no visible melting of the wax beads.

The results of the steam curing tests indicated it was an acceptable method of curing the internally sealed concrete provided it did not melt the wax beads. Specifications were written to limit the temperature within the steam curing tent to a maximum of 125°F (51.7°C).

A loss of approximately 20% of 7 day ultimate compressive strength was recorded for concrete mixes containing a wax bead content of 3% by weight when compared to non-air-entrained mixes. Research work in Florida produced similar results.

Finally the effects of heating the internally sealed concrete cylinders to 185°F (85°C) at the 2 inch (50.8 mm) depth was insignificant. The 7 day cylinder breaks indicated a 6% loss in strength occurred when the beads were melted one day after casting and steam curing. The results of the compressive strength study are shown in Table 2-2.

Latex Modified Concrete

The purpose of testing latex modified concrete was to examine the effects of steam curing on compressive strength and to compare three different proprietary latex modifiers. The investigation began after a literature search failed to provide sufficient data and information.

The same mix design formulation was used in all tests and the latex content was kept constant at 3.5 gallons/sack (13.2 l/sack). Table 2-3 presents the mix proportions.

TABLE 2-2

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 2-2 (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 2-3

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
	27.00

1 cf = 0.0283 m^3

Three latex modifiers were examined in the laboratory and they were (1) ARCO's Dylex 1186, (2) Dow Chemical Company's Modifier A, and (3) Dow Chemical Company's Saran. The results of compression strength testing indicated Dylex 1186 and Dow Modifier A were very similar but the concrete made with the Saran latex was 24 percent stronger. Saran was not permitted to be used in manufacturing the precast prestressed concrete piles, however, because of reported chlorides in the modifier.

Four curing techniques were also compared during the study and 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. The steam curing was conducted in the steam chamber at a temperature range of 140° to 160°F (60° to 71°C). Of the four methods examined, curing in a moist room for one day followed by curing in air produced the highest 7 day strengths.

The results of the compressive strength study which are shown in Table 2-4 indicated steam cured latex modified concrete could gain sufficient strength in 24 hours to allow prestressing of the piling to occur at that time.

TABLE 2-4 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

Polymer-Impregnated Concrete

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

The selection of the initiator 2-t-Butylazo-2 cyano-propane (Luazo 79) was made after consultation with Penwalt Chemical Company and the testing of three different initiators. The quick setting relatively unstable initiators that were commonly used in the impregnation of concrete bridge decks were unsuitable for the impregnation of precast prestressed concrete piles. Luazo 79 appears to be very stable in the monomer system with temperatures up to 90°F (32.2°C) provided it was protected from direct ultraviolet sun rays.

A series of 16 tests was conducted to examine various methods of drying concrete specimens and to ascertain minimum soaking periods to obtain a desired monomer penetration of 1-1/2" (38.1 mm). The drying methods examined were (1) an electric oven, (2) a hot air oven and (3) electric infrared heaters.

The first series of tests were conducted in a 1400 watt electric oven for periods of over 72 hours and at temperatures exceeding 225°F (107°C). At the completion of the drying cycle, the 6" x 6" x 12" (152 mm x 152 mm x 305 mm) concrete block specimens were allowed to cool for over 12 hours. During this time the temperature of the blocks fell from 230°F (110°C) to 65°F (18.3°C). The temperature of the blocks was monitored by means of thermocouples which were embedded at the 1-1/2" and 2" (38.1 and 50.8 mm) depths. After cooling the blocks were immersed in a resin bath consisting of a blend of 95% methyl methacrylate (MMA) and 5% trimethylalpropane trimethacrylate (TMPTMA). By varying the monomer soaking time of the thoroughly dried concrete blocks eight hours was found to be sufficient to obtain a 1-1/2" (38.1 mm) uniform penetration. Within minutes after being removed from the monomer soaking tank, the concrete blocks were placed into a hot water bath (170^{o}F (76.7^{o}C)) to polymerize the monomer. Here they remained for 7 hours. When the blocks were removed from the hot water bath and opened, the impregnated monomer was found to be fully polymerized. Continuing the drying and impregnation study additional blocks were dried in an electric oven at various temperatures and for different durations. The results of this work indicated adequate drying could be achieved by heating the concrete above 250^{o}F (121^{o}C) for periods exceeding 8 hours.

In addition to drying the concrete blocks in an electric oven, a hot air oven and an electric infrared heater system were also examined. The hot air oven was heated by a 200,000 BTU/hr propane-fired heater while four 1800 watt elements comprised the infrared system. The results of the trying to dry a block with a hot air system clearly demonstrated the importance of good air circulation around the specimen. The three sides exposed to the moving air had a 3/4" (19 mm) resin penetration while the side that rested on a pedestal had only a 1/4" (6.3 mm) resin penetration.

The results of drying concrete blocks with infrared heaters were equally dramatic. The surface of the blocks closest to the heater had significantly better resin penetration than the other sides. The bottom of the blocks exhibited only a trace of resin while the resin penetration diminished noticeably from top to bottom. This demonstrated the need to heat the surface

TABLE 2-5 Polymer Impregnation Data

Block	Method	Maximum Drying Temp(°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

directly with the infrared elements if adequate and uniform drying was to be achieved. The results of the polymer impregnation study are presented in Table 2-5.

Polymer Concrete

The laboratory work to develop a suitable polyester styrene polymer concrete formulation for use in manufacturing precast prestressed concrete piles began with an examination of aggregate gradations and various monomer and resin blends. Although some progress was made in formulating a suitable polyester styrene mixture for precast prestressed piles, the laboratory work was redirected to reusing the methyl methacrylate monomer which would remain after the polymer impregnation treatment was concluded.

A literature review was made and as a result two methyl methacrylate formulations were selected for trial batches. These formulations were found to provide a 30 minute work time at room temperature (68°F (20°C)) and are shown in Table 2-6 below:

Table 2-6

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

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 left an undesirable finish. When the surface of the cylinders was covered to prevent monomer evaporation during curing, excellent quality concrete was obtained. The average compressive strength of cylinders that were tested in 6 hours was 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 using Formulation A. By adding a polymethyl methacrylate (PMMA) in powder form to Formulation A a reduction in evaporation and shrinkage was clearly obtained.

During the final phase of the laboratory work with polymer concrete, four proprietary acrylic mortars became commercially available to produce a MMA polymer concrete. These products were Concresive 2020, Crylcon 3020, Plexicrete and Silikal. After obtaining samples of each product, trial batches were prepared and tested. Each material had excellent workability and the allowable work time was estimated to be about 20 minutes at 68^{o}F (20^{o}C). No evaporation or shrinkage problems were encountered when 2' x 2' x 1-1/2" (.61 m x .61 m x .38 mm) slabs were fabricated. Cylinders were also cast for determining 24-hour compressive strength and the modulus of elasticity. The results of this testing are presented in Table 2-7.

Because the Crylcon had a slightly higher ultimate compressive strength and higher modulus of elasticity, it appeared to be more suitable for precast prestressed concrete work. To further examine the crylcon polymer concrete, three additional cylinders were fabricated. Two of the cylinders were tested after a 9-hour cure and one was tested after 24 hours. Although the polymer

Table 2-7

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

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 MPa) at a stress level of 3,000 psi (20.7 MPa).

The formulation used to make the cylinders 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)

After analyzing the satisfactory results obtained with Crylcon it was selected for use in manufacturing the polymer concrete piles.

SECTION III

Fabrication

It required 3-1/2 months of accelerated laboratory work before plans and specifications were prepared for the experimental piles. One noteworthy item which surfaced during the literature review was the effects of heating the concrete and prestressing strands to temperatures exceeding 230°F (110°C) during the impregnation drying process. Work performed by the Bureau of Reclamation indicated a prestress loss of 8 to 10% could be expected due to strand relaxation at the elevated temperature. To make up for this loss, one additional strand was added to the conventional six strand pattern. The seven strand pattern was used in all of the piles in order to better compare the performance of the materials.

There were four major categories of work listed in the specifications. They 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 a monitoring system, and (4) perform all testing and incidental work as called for in the specifications and plans. The testing and incidental work included strain measurements, coring, temperature monitoring and the fabrication of many test cylinders and blocks.

On October 24, 1979 the contract documents were completed and the project was advertised. Although a three-week bid submittal period was allowed only two bids were received. 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 presented 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.

After careful deliberation, a decision was made to award the contract to the low bidder. On January 9, 1980, a notice to proceed was issued to Coast Marine Construction and immediately thereafter they awarded a subcontract to Morse Bros. Prestress, Inc., of Harrisburg, Oregon, for the fabrication of the piles.

Before any work began, 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. Once the requirements were understood, 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

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

that time a formal request was made by Morse Bros. to construct a special heating chamber for drying the polymer impregnated concrete piles and melting the wax beads in the internally sealed concrete piles. The proposed system utilized super heated steam in four radiator pipes. Although this method differed from the three allowed in the specifications, conditional approval was granted with the provision the heating chamber would have to be successfully tested. After a review of the work schedule and the testing procedure report was made, approval to begin work was granted.

The following paragraphs describe the fabrication techniques that were used to construct and process the prestressed concrete piles. A more detailed discussion was presented in the interim report. The ingredients used to manufacture the piles are listed in Table 3-2.

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 fabricated using a conventional air-entrained Class 5000-1 concrete and were similar to the three control piles. Before casting, however, thermocouples were placed at various locations within the piles in order to monitor the drying, cooling, and polymerization temperatures. The location of the thermocouples within the piles are presented in Figure 3-1. The concrete was batched in a 4-cubic yard (3 m) drum mixer and transported to the prestressing beds in agitator-type mobile buckets. 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. Just before the piles were subjected to the impregnation process each was sandblasted to remove surface contaminants

Table 3-2

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]
3A,3C	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]
Reject	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]
1A,1E	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]
1C,1D	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
1B,3B	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]
2B,2E	Intern. Sealed	705	1,075	945	725	26.5	35.2	114.0[3]
3-13-80	Intern. Sealed	Cement	1,075	945	725	26.5	35.2	114.0[3]
2A,2D	Intern. Sealed	not Recorded	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]
Rej.,2C	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]
Reject	Latex Modified	705	1,170	1,170	540	1.36	35.2	220.5[2]
4-17-80 5D	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]
5C,5E	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]
5A,5B	Latex Modified	705	1,170	1,135	525	3.64		

Date Cast	Concrete Type	Monomer - lbs. Crylcon EP - 3009	Powder - lbs. Crylcon EP - 3020	Aggregate - lbs. 3/4" - 1/2"	Aggregate - lbs. 1/2" - #4
4- 9-80 4B	Polymer	175.5	1,980	700	1,050
4-10-80 4A,4D	Polymer	195.0	1,980	700	1,050
4-11-80 4C,4E	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

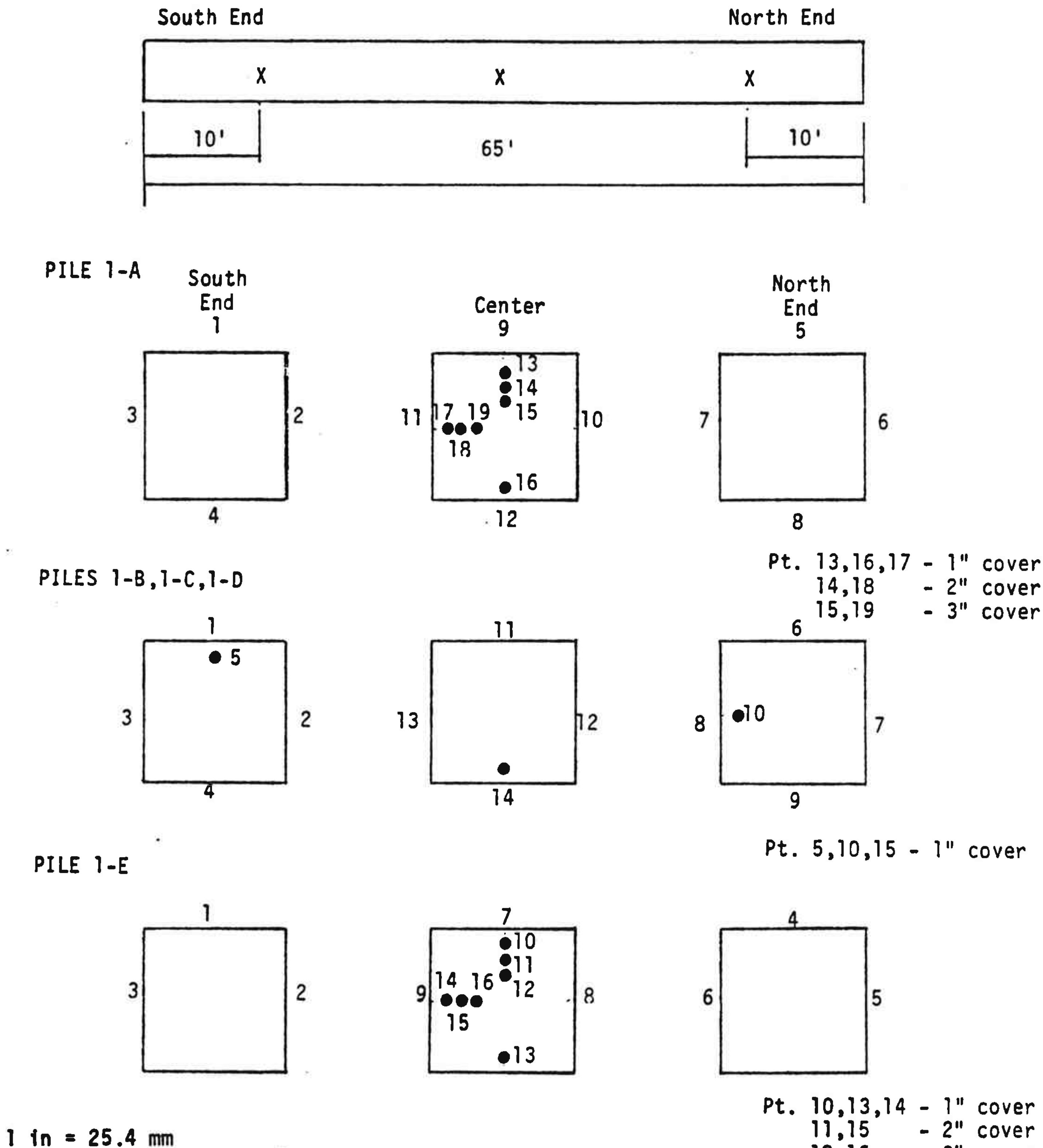


FIGURE 3-1

Location of Thermocouples
in Polymer Impregnated Concrete Piles

such as form release oil or curing compounds. The sandblasting was found to be beneficial for monomer penetration in the laboratory study.

While the polymer-impregnated piles were in storage, a heating chamber was constructed using plywood sheeting and 6" (152 mm) thick foil backed insulation. Steam pipes with 4" (102 mm) fins were placed in each corner to provide uniform heating throughout the oven. Super heated steam, which was used for steam curing, was utilized as the heat source. When drying the concrete pile the moisture laden hot air was evacuated from the oven 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.

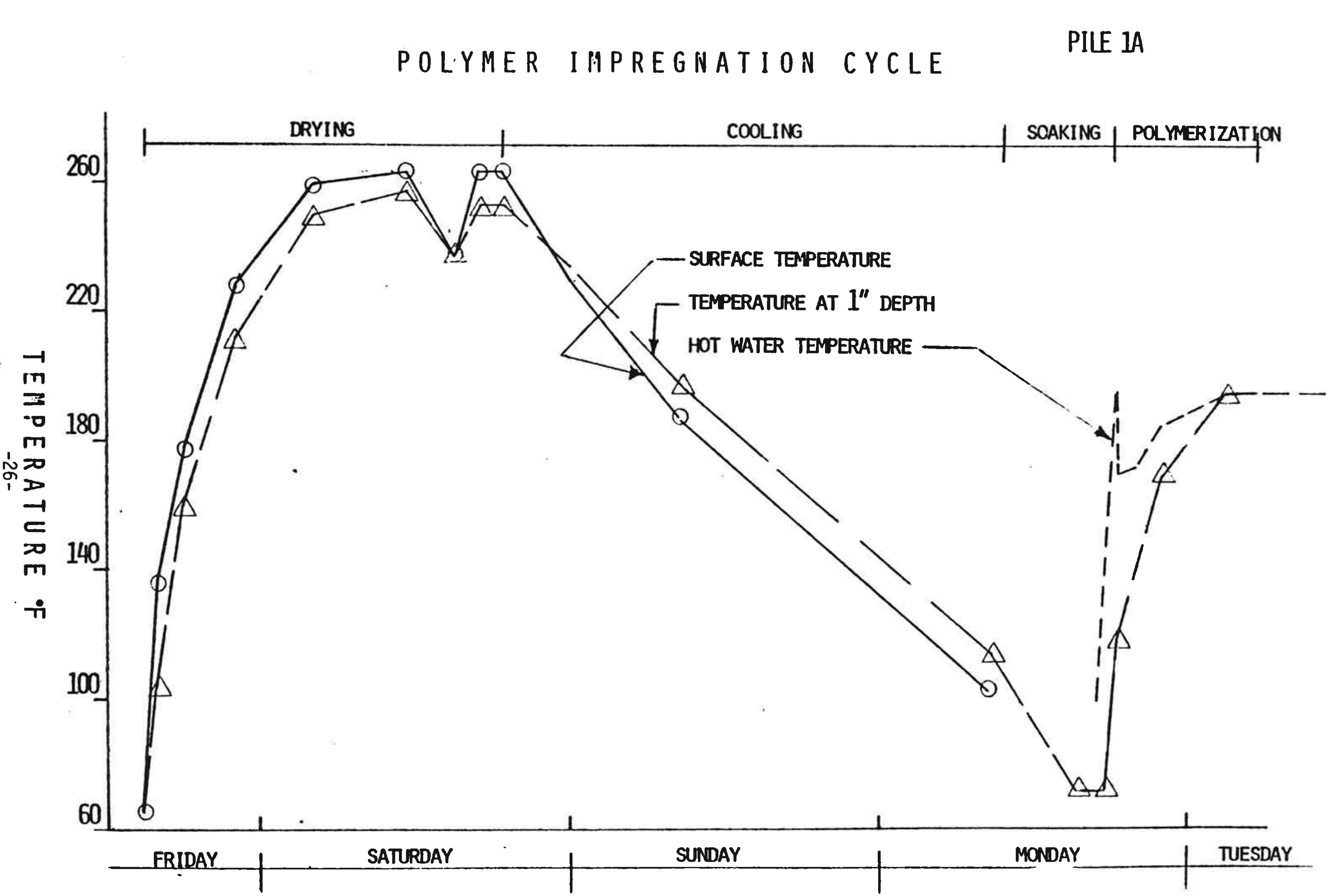
After the heating chamber was constructed and tested for leaks, a pile with 19 thermocouples was placed inside for a trial run. The thermocouples were strategically located at both ends and at the middle of the pile. Some of the thermocouples were embedded into the pile at the 1", 2" and 3" (25.4, 50.8 and 76.2 mm) depths to determine the temperature gradient within the pile.

During the preliminary heating test 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 some consideration 10 hours of heating above 250°F was selected for the steam heated oven which was similar to the hot air heating system requirements. A cooling rate of the concrete surface was also limited to a maximum decline of 100°F (37.7°C) per hour in order to reduce the amount of surface cracking.

The first pile to undergo the drying process had to be heated over a 2-day period in order to meet the 10-hour drying requirements. The temperature hitory of the pile during the entire impregnation process is plotted in Figure 3-2. After the 10-hour requirement was satisfied the pile was allowed to slowly cool to below 100°F (37.8°C) before it was placed into a tank of monomer to begin the impregnation cycle. In spite of the slow cooling longitudinal cracks were present on all four faces of the pile.

The immersion tank used to hold the momomer was constructed by modifying a 16" (406 mm) square steel form. The form was lined with plastic sheeting to ensure 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. The form was also grounded to eliminate sparking from static electricity.

Although much of the impregnation work that was conducted in the laboratory used a blend of 95% methyl methacrylate (MMA) and 5% trimethylolpropane trimethacrylate (TMPTMA) only methyl methacrylate was used to impregnate the prestressed concrete piles. A greater momomer penetration was achieved with the pure MMA system. The monomer was initiated with 2-t-Butylazo-2-cyanopropane (Luazo 79) at a rate of 0.5% by weight. The specifications stated all soaking of the piles had to be performed between sunset and sunrise unless



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

FIGURE 3-2

the fabricator provided an acceptable shielding system to protect the monomer from the polymerization effects of direct and indirect solar radiation. Because of the work scheduling the fabricator found it desirable to soak the piles during daylight hours and a portable roof system was provided to protect the impregnation tank. Once the pile was placed into the tank, a plastic sheet was used to prevent monomer evaporation.

The first impregnation pile (Pile 1A) was soaked in the monomer bath for 8 hours before it was removed and placed into a tank of hot water to cause polymerization. To ensure complete polymerization of the impregnated resin, the pile remained in the hot water bath for 8 hours. Like the monomer soaking tank, the hot water tank was also fabricated from a surplus steel casting form. Additional work was necessary however to provide a method for heating the water. The tank was retrofitted with two separate heating systems to ensure adequate heating capability. The primary system was a large electric boiler and the secondary system consisted of two steam pipes which ran the full length of the tank. Before the impregnation work began, the hot water tank was also tested to ensure that it was capable of producing sufficient heat to maintain the necessary 170^{o}F to 185^{o}F (76.6^{o} to 85^{o}C) water temperature. A portable insulated plywood enclosure had to be fabricated to fit over the tank to reduce heat loss. During the initial trial run it was found desirable to preheat the water to a temperature higher than that stated in the specifications. Original fears that an initial water temperature of 195^{o}F (90.6^{o}C) would cause an accelerated depletion of surface monomer did not happen.

In order to monitor the effectiveness of the impregnation treatment, 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 the first pile through the complete process. When the blocks were opened at the conclusion of the treatment, a dark 1" (25.4 mm) polymer penetration was clearly visible on all surfaces. Cores later removed from the pile confirmed the successful 1" (25.4 mm) impregnation.

At the conclusion of the treatment the general appearance of the polymer impregnated concrete pile was very good. The small surface defects which are common to all precast units and the cracks caused by heating and cooling were sealed with the resin. The compressive strengths of the conventional concrete and the polymer impregnated concrete after treatment are presented in Table 3-3. A 23 percent gain in compressive strength was achieved when a 1 inch resin penetration was obtained in Pile 1A.

The second and third polymer impregnated piles (1B and 1C) were treated without incident and a 3/4" to 7/8" polymer penetration was achieved.

Trouble in processing the fourth pile (1D) occurred, however, after the pile was placed into the hot water bath to polymerize the monomer. A malfunction in the recirculating system allowed the water level to fall 1-1/2" (38.1 mm) below the top surface of the pile. When cold water was added to the tank, the bath water temperature dropped from 190°F (87.8°C) to below 160°F (71°C). Although the malfunction was discovered about one hour after the pile entered the bath, attempts to repair the system were not successful for several hours. 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). When the bath system became operational again both heating systems were used to reheat the water. The fourth pile remained in the hot water bath for over 10 hours after the 170°F (76.7°C) temperature was reached.

Table 3-3

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

Date Cast	Compressive Strength (lbs/in^2) Test A, Age of 6" x 12" Cylinders: 1 day	Test A: 28 day	Test B: 7 day	Test B: 28 day	Test C: 7 day	Test C: 28 day	Modulus of Elasticity $lbs/in^2 \times 10^6$
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/in^2)

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

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.

The fifth polymer impregnated pile (Pile 1E) also did not receive a full treatment due to a fabrication error. After being dried and allowed to cool the pile was then placed into the monomer soaking tank for impregnation. After soaking for only 4 hours the monomer in the tank began to solidify. Due to an oversight by the fabricator, the roof system was not replaced over the soaking tank after the pile was inserted and solar radiation caused the monomer to polymerize violently. After much prying the pile was forcibly extracted from the soaking tank and placed into the hot water bath to complete the polymerization of the impregnated resin. When Pile 1E was finally placed in storage, it required several hours of chipping and scraping to remove the unsightly plastic coating on the top surface of the pile. Several cores were taken from Pile 1E to determine the amount of resin penetration that was achieved. The results were unsatisfactory as only a light 3/8" (19 mm) penetration was noted.

Because the fabricator failed to follow the specifications, Piles 1D and 1E were purchased at the bid price of conventional concrete.

Internally Sealed Concrete

The first two internally sealed concrete piles were fabricated on March 10, 1980. The concrete was batched automatically in a four cubic yard mixer. The wax beads were added by hand into the mixer with just the dry ingredients for a two minute premixing period. After the beads were distributed throughout the mix, 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. The mixing, placing and finishing of the internally sealed concrete were similar to conventional concrete.

Two hours after casting, the piles were steam cured for 8 hours. During the steaming, the air temperature under the tent reached 138°F (58.9°C) for a brief time but was quickly lowered to the 125°F 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), no premature melting of the wax beads was found when a 6" x 6" x 12" (152 x 152 x 305 mm) test block was opened immediately after steam curing.

Approximately 18 hours after casting, two cylinders were tested at the fabrication plant to determine if the concrete had gained sufficient strength to allow the piles to be prestressed. Because both cylinders failed above 4,000 psi (27.6 MPa), prestressing was allowed. The piles were removed from the casting beds and placed in storage. A plastic sheet was used to cover the piles to permit a dry cure. The ultimate compressive strength of the internally sealed test cylinders is presented in Table 3-4.

Thermocouples were cast in various locations within the internally sealed concrete piles to monitor the melting of the wax beads. Many of the thermocouples were placed at a depth of 1/16 inch while others were located at a depth of 1, 2 and 3 inches (25.4, 50.8, and 76.2 mm). The locations of the thermocouples are presented in Figure 3-3.

Table 3-4

Compressive Strength and Modulus of Elasticity of Internally Sealed Concrete

Date Cast	Compressive Strength (lbs/in^2) Test A			Test B		Test C		Modulus of Elasticity
	Age of 6" x 12" Cylinders							$lbs/in^2 \times 10^6$
	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/in^2)

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

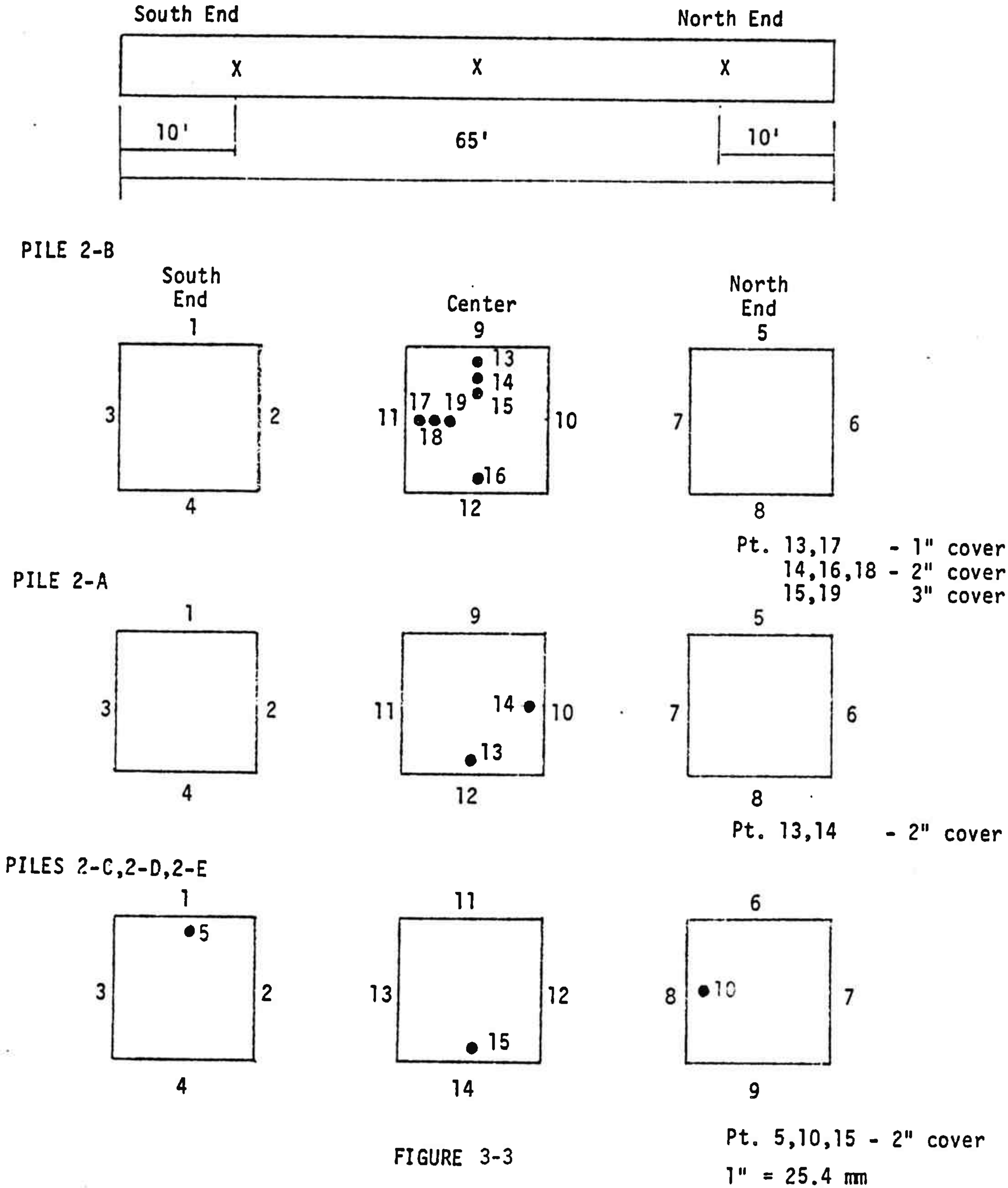


FIGURE 3-3

Location of Thermocouples
in Internally Sealed Concrete Piles

When the other three internally sealed concrete piles were cast on March 10 and 18 they failed to gain sufficient strength after being steam cured at 125°F (51.7°C) to be prestressed the following day. After additional steam curing at 125°F (51.7°C) the concrete breaks were above 4,000 psi and prestressing was allowed. The piles were removed from their casting beds and placed in dry storage.

The first internally sealed concrete pile to undergo the melting process was placed into the heating oven on April 22 after a 34 day dry cure. This pile, designated Pile 2B, had 19 thermocouples to help monitor the heating characteristics and to guarantee the wax beads were melted uniformly. Approximately 7-1/2 hours after heating began, all three thermocouples at the 2 inch (50.8 mm) depth registered temperatures over 180°F (85°C). Heating was then terminated and the pile was allowed to cool slowly within the oven.

In order to evaluate the effectiveness of the heating system and to reexamine the effects of melting the wax beads on strength, two blocks of internally sealed concrete and one cylinder accompanied the pile through the melting cycle. Before the pile was removed from the oven the blocks were opened to determine the depth of bead melting. The outer 2-1/2 inch (63.5 mm) zone around the blocks was found to have complete melting of the beads. Cores later removed from the pile confirmed the satisfactory results. An examination of the pile was made at the completion of the melting process and tight longitudinal cracks were found on all four faces. The cracks appeared to have been sealed by the melted wax, however. The cores also revealed the heating related cracks were only 1-1/2" (12.7 mm) deep. The results of testing one internally sealed concrete cylinder 3 days after the beads were melted showed only a slight reduction in compressive strength.

The melting of the wax beads in piles 2A, 2C, 2D and 2E was accomplished without difficulty. Pile 2A underwent 5 additional hours of heating after it had reached a temperature of 190 °F (87.7 °C) at the 2" (50.4 mm) depth. An oversight at the fabrication plant allowed the surface temperature of the pile to reach 230°F (110°C) and a temperature of 212°F (100°C) at the 2" (50.4 mm) depth. When the 6" x 6" x 12" (152 x 152 x 305 mm) test block was opened the wax beads were all found to be completely melted. The temperature profile during the melting of the wax beads in Pile 2E is plotted in Figure 3-4.

Latex Modified Concrete

The first two latex modified concrete (LMC) piles were cast on February 29, 1980. The fabrication was very similar to that of conventional concrete except the latex emulsion was added to the mixer after the other ingredients. Although 3 proprietary latex modifiers were listed in the specifications, the fabricator chose Dow Chemical Company's Modifier A. The latex modified concrete was mixed for 3 minutes before it was discharged into an agitator type mobile bucket. Within five minutes after mixing, placement of the concrete began. Several times during casting the concrete slump was measured and each time it was slightly greater than 9" (228 mm). The general appearance of the LMC mix was poor and some minor segregation was noted during consolidation. Although each pile was cast within 20 minutes, it was difficult to finish them by hand. The latex film which formed on the top surface was very sticky and it tore when troweled.

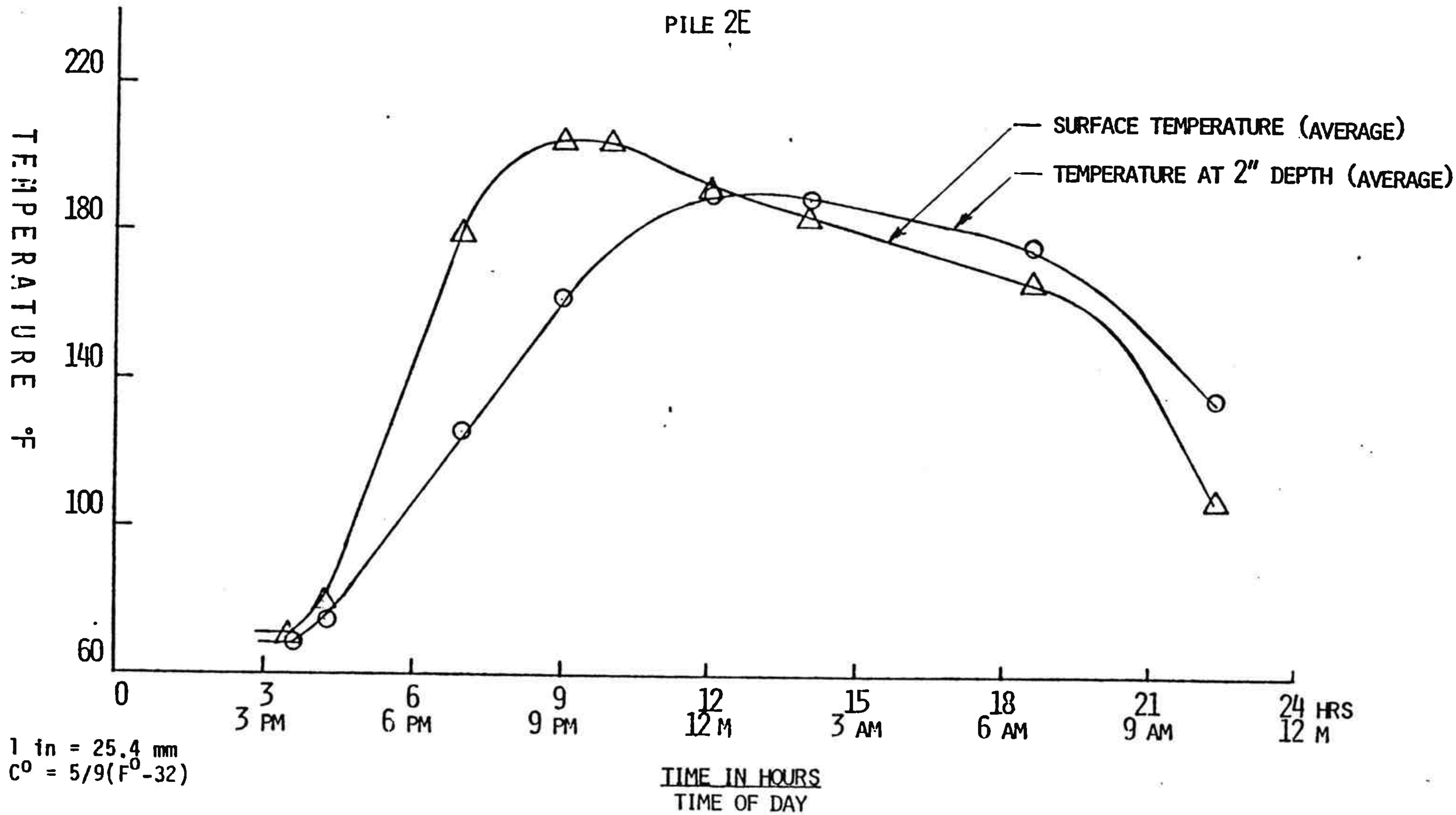
An investigation was conducted to determine the reason for the high slump, since a water/cement ratio of 0.30 was specified. One possible explanation was the occurrence of a heavy rain when the concrete was being transported to the casting bed. The rain lasted only a few minutes, but since the

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 3-4

mobile bucket had an open top, some rain water was incorporated into the mix. The temperature during fabrication was 52°F (11.1°C).

The piles were steam cured within 3 hours after casting. The steam was maintained for a total of 6 hours, three of which were above 140°F (60°C). Since casting occurred on a Friday, the piles were allowed to further cure undisturbed until Monday morning. At that time two cylinders were tested at the prestress concrete plant to determine compressive strength. The average cylinder break was only 4,130 psi (28.5 MPa). This was lower than expected but sufficient to allow the piles to be prestressed.

After the first two LMC piles were placed in storage, an attempt was made to attach strain gages to them. The attempt was not successful because the bonding epoxy would not set at the low ambient temperatures. Shrinkage and creep measurements were therefore not made on these piles.

The next latex modified concrete pile was fabricated with one internally sealed concrete pile on March 18, 1980. As before, the LMC was very sloppy and wet when it was deposited into the form. In spite of the 0.30 water/cement ratio, an 8-3/4" (222 mm) slump was measured twice during casting. The formation of the latex film on the top surface of the pile within 20 minutes after mixing made the finishing very difficult and uneven. Due to the presence of the internally sealed concrete pile in the adjacent casting bed, both piles had to be subjected to the same low temperature steam cure. Steam was applied to both piles for 14 hours within the 125°F (51.7°C) range. On the following morning, the LMC cylinder crumbled as it was placed into the testing machine, while the internally sealed concrete had a compressive strength of slightly over 3,300 psi (22.7 MPa). Both piles were allowed to remain in the casting beds for one additional day and were again subjected to steam for 15 hours. On the second day after casting the LMC cylinders failed at an average compressive strength of only 3,042 psi (21 MPa). Despite the apparent low strength the fabricator decided to release the prestressing stands. When the strands were released, they immediately disappeared into the pile due to a lack of bond. When the LMC pile was removed from the casting bed it deflected and cracked very badly. The pile was rejected by the fabricator.

Using the same mix design as the other latex modified concrete piles two more LMC piles were fabricated on March 20, 1980. Once again a 9" (228 mm) slump was measured even though a water/cement ratio of 0.28 was used. The same finishing problems occurred as described previously with the other LMC piles. After the piles were fabricated they were steam cured for 10 hours. During the last six hours the steam temperature remained above 150°F (65.6°C). When two cylinders were tested on the following morning the results were disappointing. The average compressive strength was only 2,025 psi (14 MPa). The piles were resteamed and allowed to remain in the casting beds over a weekend. On Monday morning, two more cylinders were tested and they were found to be not much stronger than the previous ones. A decision was made to release the prestressing strands. Upon release the strands retracted into the concrete piles. When the piles were removed from the casting beds, both deflected excessively and this resulted in extensive cracking. Both piles were rejected by the fabricator.

During a thorough examination of the mix ingredients it was discovered that a water-reducer set-retarding agent (Pozzolith 100-XR) was introduced into the latex modified concrete. Since this agent was not used in the preliminary work its effect on the concrete properties was questionable. Two small trial batches of latex modified concrete were then prepared at the prestressed concrete plant. The first batch contained the water-reducer set-retarding agent while it was omitted from the second batch. Using the same water/cement ratio 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). When the cylinders were tested the next day the concrete with the admixture failed at an average compressive stress of 1,875 psi (12.9 MPa) while the concrete without the water-reducer set-retarder failed at 3,775 psi (26 MPa). This result indicates the admixture and the latex emulsion were not compatible. Since the first two latex modified concrete piles contained Pozzolith 100-XR and their strength tests were erratic, they were also rejected.

Before additional LMC piles could be fabricated a new supply of latex emulsion had to be acquired. This delayed the refabrication until mid-April. When the next set of LMC piles were constructed a representative from Dow Chemical Company was present to provide technical assistance.

On April 17, 1980 one LMC pile was constructed with two changes in the mix design. First, the Pozzolith 100-XR was omitted 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). When the latex modified concrete was placed in the form no segregation was noted and the concrete slump was measured at 5-1/4" (133 mm). After the pile was cast it was steam cured for 14 hours and the steam temperature was above 150°F (65.6°C) for eleven of those hours. When the two cylinders were tested on the next morning their average ultimate compressive strength was only 3,550 psi (24.5 MPa). This was not high enough to permit prestressing so the pile was resteamed on the second night for an additional

10 hours and allowed to further cure over a weekend. On Monday the pile was finally prestressed when the cylinders indicated an average compressive strength of 5,720 psi (39.4 MPa). The pile was removed from the casting bed and placed in storage without incident.

The next two LMC piles were cast on April 22, 1980. The fabrication went very well although the concrete had a 9" slump. Both piles were steam cured for 12 hours during the first night at a temperature of 155°F (68.3°C). When the cylinders were tested on the next day the average breaking strength was only 3,490 psi (24 MPa) so the piles were subjected to an additional steam curing for 12 hours. On the second day after casting the compressive strength of the cylinders was slightly above 4,000 psi (27.6 MPa) and the piles were prestressed.

The last two LMC piles were cast on April 24, 1980 and like the previous piles did not attain sufficient strength after steam curing during the first night. The piles were resteamed for 10 hours and then allowed to further cure over a weekend. On Monday, the cylinders indicated an average compressive strength of 5,420 psi (37.4 MPa) was attained which allowed the piles to be prestressed. By omitting the water-reducer set-retarding agent a group of 5 latex modified concrete piles was fabricated satisfactorily except for the slightly rough surface that was produced by hand finishing. The extended curing time disrupted the fabricating schedule but it did not cause any major problems. The compressive strength of the various latex modified concrete piles is presented in Table 3-5.

Table 3-5

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 4173	4545 4775	5145	6600 6720	2740 3120 4250[2] 4105	4995 3145	7180[1] 7075 7945	[1]3.0×10^6 [2]2.0×10^6

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 3643	5787 5694	7463 7498	- -	- -	5680[1]	6580 6600	[1]3.7×10^6
	1 day	2 day	28 day	7 day	28 day	7 day	28 day	
04-22-80	3448 3537	4067 4156	6750 6950	5270	6600 6670[2]	5305[1] 5340	6105 5765 6070[3]	[1]3.3×10^6 [2]3.6×10^6 [3]3.4×10^6
	1 day	4 day	28 day	7 day	28 day	7 day	28 day	
04-24-80	3360 3537	5287 5553	7356 7335	6065	6910 6890[3]	5790[1] 5730[2]	5990 6420 6505[4]	[1]3.4×10^6 [2]3.5×10^6 [3]3.5×10^6 [4]3.6×10^6

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

Polymer Concrete

The methyl methacrylate polymer concrete piles were fabricated on April 9, 10 and 11, 1980. Unlike the other systems the polymer concrete requires the use of dry coarse aggregate. Two weeks prior to fabrication the coarse aggregate was heated in an asphalt concrete plant at 425°F (218.3°C) to reduce the moisture content to below 0.5 percent. Once dried, the aggregate was stored in covered hoppers where it cooled to ambient temperature. The desired coarse aggregate gradation is presented in Table 3-6 shown below.

Table 3-6

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

Only one polymer concrete pile was fabricated on the first day in order for the fabricator to gain experience with the materials. Before beginning the construction the casting bed received a light coating of axle grease in lieu of the form oil. This was done to reduce the potential bonding of the polymer concrete to the steel form. Special care was taken to ensure the prestressing strands were not contaminated by the grease.

The mix design used for the first polymer concrete pile was altered from the one in the specifications because trial batches made with the Morse Bros. aggregate appeared to be too wet. After reducing the resin content several times a 4.5 percent concentration was found to produce a workable mix. Technical representatives from DuPont, the supplier of the polymer materials, were present and agreed to the change in formulation.

Unlike the other experimental concretes, the polymer concrete was mixed in a one cubic yard pan-type mixer. This mixer was selected for two reasons. First, it was easier to load the two polymer components into the mixer by hand and secondly, it was easier to clean. The batching sequence consisted of first placing the aggregate and a small quantity of monomer into the mixer to wet the surface of the stones. When the mixer was operated briefly for this purpose, sparks were produced in the pan. Because the monomer vapors are flammable this was somewhat hazardous. After the aggregate was wetted, Crylcon powder EP 3020 and Crylcon monomer EP 3009 were added to the mixer and all ingredients were mixed for 5 minutes.

A total of eleven workers were needed to mix, transport, place and finish each batch of polymer concrete within the 20 minute allowable work time. This compares unfavorably to manufacturing a conventional concrete pile when only 4 workers are required.

The first one cubic yard batch of polymer concrete appeared to be slightly dry but no change was made in the formulation of the last 2 batches. The top surface of the pile was moderately difficult to finish. Three hours after the polymer concrete was mixed a cylinder was tested to determine compressive strength. The cylinder failed at 6,295 psi (43.4 MPa). On the following morning two additional cylinders were tested and they failed at an average compressive stress of 6,845 psi (47.2 MPa). Because of these results the polymer concrete pile was prestressed and removed from the casting bed.

No bonding problems were encountered due to the grease film application. When the pile was placed in temporary storage, three major rock pockets were discovered. These defects were later patched by flooding the voids with monomer.

A decision was made to increase the monomer content to 5 percent for the next two polymer concrete piles in order to increase workability. This change greatly improved the mix and the new formulation was adopted for the last four polymer concrete piles. The polymer concrete mix designs are presented below in Table 3-7.

Table 3-7

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

The compressive strengths of the various mixes are found in Table 3-8.

On April 10 two more polymer concrete piles were successfully cast using the new formulation. Improved communications between the batching area and the casting bed greatly improved the efficiency of manufacturing the pile. Eleven workers were still needed, however, to provide a continuous supply of polymer concrete and to place and finish each 1 cubic yard batch of polymer concrete within the 20 minute allowable work time.

Table 3-8

Compressive Strength and Modulus of Elasticity
of Polymer Concrete

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

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 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

Table 4-1

Maximum Horizontal Bow in Piles

Pile Group	Pile Inches/Date Cast/Casting Bed 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

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 3-1/8" (79.3 mm) was recorded for Pile 4E. 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" (50.8 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 $45^{\circ}F$ (4.4° to $7.2^{\circ}C$) 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 indicate 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.

SECTION V

Installation and In Situ Testing 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

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
	Latex Modified		
5A	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 x 10^6 psi = 6.895 GPa

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 5-1 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.

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 foot

Table 5-1

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

(5.5 to 9.1 m) 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 pènetration 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 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 over-mixing. 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. 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 the chloride ion testing for select piles 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. 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 5-3. 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

Table 5-2

Average Chloride Ion Concentrations in Select Piles
(lbs chloride ion/c.y. concrete)

Sample Depth 1/8" to 1"
Average Original Ion Concentration 0.18 lb/c.y.

		Date Tested				
	Pile	8/26/80	2/18/81	8/19/81	2/3/82	9/8/82
Polymer Impregnated Concrete	1B	1.36	1.50	1.17	3.3	3.3
	1C	0.80	1.70	1.14	2.0	3.2
Internally Sealed Concrete	2D	.20	.86	.17	.60	.40
	2E	.18	.40	.14	.90	.30
Conventional Concrete	3B	2.36	.89	3.15	3.9	2.6
	3b	1.65	-	-	1.8	2.0
Polymer Concrete	4A	.49	0.55	.89	.2	1.6
	4B	1.39	-	-	.2	1.5
Latex Modified Concrete	5B	.30	1.20	2.1	.9	1.4
	5E	1.05	.94	1.2	1.4	1.5

Table 5-3

Half-Cell Potential Readings in Volts
Copper - Copper Sulfate
Date Tested September 9, 1980
Ambient Temperature 65°

Group	Elevation* feet	Pile A	Pile B	Pile C	Pile D	Pile E
1	5	.10	.11	.10		.09
	4	.10	.12	.11		.11
Polymer	3	.13	.16	.14		.11
Impregnated	2	.20	.19	.19		.17
Concrete	1	.50	.30	.25		.24
	-.5	.58	.48	.58		.43
2	5	.35	.30		.21	.21
	4	.37	.35		.20	.23
Internally	3	.50	.40		.30	.26
Sealed	2	.58	.49		.38	.30
Concrete	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	3	.46	.44	.21		.30
Modified	2	.54	.50	.27		.38
Concrete	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.

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.

During four subsequent inspections at approximately six month intervals, half-cell testing was performed on several piles within each group while chloride ion samples were removed from only two piles within each group. When the last inspection was made on September 8, 1982, chloride ion samples were taken from 18 of the 22 piles and 2 of the 6 blocks. Each sample was composed of material from two sample holes.

The half-cell potential readings made after the piles were installed were fairly consistent over the two-year testing period. There were some slight fluctuations in the magnitude of the readings but individual piles and groups that had low initial readings continued to have low readings. During each inspection random half-cell readings were taken on two or more faces of the same pile and in almost all cases the potential readings were extremely close. The half-cell potential readings taken during the 4 inspections are presented in Tables 5-4 through 5-7.

Table 5-4

Half-Cell Potential Readings in Volts
Copper - Copper Sulfate
Date Tested February 10, 1981
Ambient Temperature 32° F

Group	Elevation* feet	Pile A	Pile B	Pile C	Pile D	Pile E
1	5	.08	.04	.02		.02
	4	.10	.10	.05		.04
Polymer	3	.17	.19	.16		.12
Impregnated	2	.23	.23	.24		.23
Concrete	1	.48	.33			
2	5	.13	.22		.16	.16
Internally	4	.18	.28		.19	.21
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	3	.43	.45	.24		.24
Modified	2	.53	.56	.31		.29
Concrete	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 5-5

Half-Cell Readings in Volts
Copper - Copper Sulfate
Date Tested August 19, 1981
Ambient Temperature 67° F

Group	Elevation* feet	Pile A	B	C	D	E
1	5	.08	.07			.13
	4	.17	.05			.09
Polymer	3	.20	.09			.03
Impregnated	2	.25	.16			.13
Concrete	1	.30	.14			.42
	0					.52
2	5	.08	.17		.07	.08
	4	.11	.23		.05	.11
Internally	3	.16	.29		.11	.16
Sealed	2	.21	.38		.18	.21
Concrete	1	.31	.42		.23	.31
	0				.33	
3	5	.01	.06			
	4	.07	.07			
Conventional	3	.11	.10			
Concrete	2	.17	.16			
	1	.21	.18			
	0	.21	.18			
4	5	.58	.08	.69		
	4	.65	.05	.73		
Polymer	3	.66	.66	.74		
Concrete	2	.64	.62	.73		
	1	.67	.67	.75		
5	5		.16	.10		.15
	4		.30	.18		.26
Latex	3		.37	.23		.32
Modified	2		.42	.25		.40
Concrete	1		.50			.43

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

Table 5-6

Marine Pile

Half-Cell Readings in Volts
Copper - Copper Sulfate
Date Tested February 3, 1982

Group	Elevation* feet	Pile A	Pile B	Pile C	Pile D	Pile E
1	5.00	.05	.01	.03	.02	.02
Polymer	4.25	.08	.07	.06	.05	.02
Impregnated	3.50	.11	.09	.08	.10	.06
Concrete	2.75	.16	.16	.12	.15	.19
	2.00	.21	.24	.18	.18	.45
	1.25	.29	.31	.26	.33	.52
	0.50	.39	---	---	.40	---
2	5.00	.09	.21	.08	.10	.09
	4.25	.12	.28	.10	.11	.09
Internally	3.50	.16	.35	.18	.18	.14
Sealed	2.75	.21	.44	.20	.21	.18
Concrete	2.00	.30	.52	.26	.33	.27
	1.25	.43	.58	---	.42	.42
	0.50	.52	.60	---	---	---
3	5.00	.08	.08	N/A	N/A	N/A
	4.25	.10	.14			
Conventional	3.50	.10	.19			
Concrete	2.75	.19	.30			
	2.00	.21	.32			
	1.25	---	---			
4	5.00	.60	.74	.60	---	.50
	4.25	.63	.80	.65	---	.62
Polymer	3.50	.64	.76	.67	---	.66
Concrete	2.75	.64	.85	.67	---	---
	2.00	.64	.90	.67	---	---
	1.25	.64	---	---	---	---
5	5.00	.18	.17	.09	N/A	.05
	4.25	.25	.20	.16		.09
Latex	3.50	.42	.34	.25		.28
Modified	2.75	.50	.46	.30		.30
Concrete	2.00	.53	.52	.38		.41
	1.25	---	.67	.54		---
		A-I	A-O	B-I	C-I	C-O
Blocks	5.00	0	0	.01	0	.02
	4.25	.05	0	.01	0	.11
	3.50	.06	0	.02	0	.17
	2.75	.12	.04	.06	0	.21
	2.00	.20	.10	.10	---	.29
	1.25	---	---	---	---	.40

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

Table 5-7

Half-Cell Potential Readings in Volts
Copper - Copper Sulfate
Date Tested 9/8/82
Ambient Temperature 65°F

Group	Elevation* Feet	Pile A	Pile B	Pile C	Pile D	Pile E
1	5	0.08	.06	.09	-	.05
Polymer	4	.10	.07	.08	-	.05
Impregnated	3	.16	.08	.10	-	.08
Concrete	2	.19	.12	.13	-	.11
	1.5	.25	.16	.17	-	.15
	1.0	.19	.21	.24	-	.26
	0.75	-	-	-	-	-
2	5	.10	.13	-	.11	.12
Internally	4	.11	.17	-	.12	.18
Sealed	3	.13	.24	-	.14	.16
Concrete	2	.18	.37	-	.20	.23
	1.5	.25	.37	-	.24	.25
	1.0	.33	.46	-	.30	.30
	0.75	-	-	-	.46	-
3	5	.09	.17	-		
Conventional	4	.05	.14	-		
Concrete	3	.18	.18	-		
	2	.19	.23	-		
	1.5	.27	.29	-		
	1.0	.29	.34	-		
	0.75	.46	-	-		
4	5	.33	.27	.41	-	0
Polymer	4	.55	.30	.55	-	.01
Concrete	3	.53	.53	.68	-	.02
	2	.67	.69	.70	-	.56
	1.5	.68	.69	.71	-	.70
	1.0	.66	.70	.71	-	.70
	0.75	.69	-	-	-	.69
5	5	.06	.06	.03	N/A	.07
Latex	4	.07	.12	.10		.08
Modified	3	.08	.16	.12		.12
Concrete	2	.15	.20	.14		.16
	1.5	.28	.26	.23		.22
	1.0	.40	.37	.30		.34
	0.75	.54	.47	.42		.40
Blocks		A-I	A-O	B-I	C-I	
Conventional	5	.12	.12	.08	.10	
Concrete	4	.08	.10	.03	.10	
	3	.14	.10	.04	.10	
	2	.13	.03	.08	.03	
	1.5	.02	.03	.10	.04	
	1.0		.09	.13	.03	

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

There appears to be a discrepancy between the chloride ion concentration and the half-cell potentials recorded in several instances. A number of researchers have suggested that a concentration of between 1.5 to 2 lbs (.52 to .69 kg/m^3) of chloride ion per cubic yard of concrete at the rebar depth is necessary to initiate corrosion of steel in concrete. The apparent low chloride ion content in the internally sealed concrete did not support the high half-cell readings in pile 2B. It is possible, however, that an extremely small crack may be permitting the salt water to penetrate the otherwise sealed concrete.

The high half-cell potential readings recorded in all of the polymer concrete piles were not supported by high chloride ion content either, but the rust spots that have appeared on the surface of 4 piles has attested to the presence of corrosion.

The absence of high half-cell potential readings on the conventional concrete piles indicated no corrosion was occurring to date. The epoxy-coated rebars within the blocks constructed with conventional concrete also had very low half-cell potential readings.

Table 5-8 presents the results of the final inspection and includes remarks concerning manufacturing errors that may have affected performance.

SECTION VI

Final Evaluation and Comments

The complexity and difficulty in fabricating 65-foot (19.8 m) 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

Table 5-8

Final Inspection Report

Material	Pile	Average Chloride Ion Content lbs Cl-/cu yd (1 lb/cy = .35 kg/m^3)	Half-Cell Reading at El. 2' in Volts
Polymer Impregnated Concrete	1A	3.2	0.19
	Remarks - No distress was noted except tight longitudinal cracks due to heating. Pile had 1" dark resin impregnation and cracks appeared sealed.		
	1B	3.3	0.12
	Remarks - No distress was noted except tight longitudinal cracks due to heating. Pile had 3/4" to 7/8" dark resin impregnation and cracks appeared sealed.		
	1C	3.2	0.13
	Remarks - No distress was noted except tight longitudinal cracks due to heating. Pile had 3/4" resin impregnation and cracks appeared sealed.		
	1D	-	-
	Remarks - Pile 1D was not tested because of the swift tidal current. No distress was noted except tight longitudinal cracks due to heating. Pile had only a light 3/8" resin penetration due to a manufacturing error.		
	1E	2.8	0.11
	Remarks - No distress was noted except tight longitudinal cracks due to heating. Unsightly plastic coating visible on one face. Pile had only a 3/8" light resin penetration due to premature polymerization but cracks appeared sealed.		
Internally Sealed Concrete	2A	1.5	0.18
	Remarks - No distress was noted except tight superficial map cracks due to heating. The cracks appeared to be sealed with melted wax. Pile 2A was overheated for five hours. One face had tiny holes that were once occupied by wax beads.		

Table 5-8 (Continued)
Final Inspection Report

Material	Pile	Average Chloride Ion Content lbs Cl-/cu yd (1 lb/cy = .35 kg/m^3)	Half-Cell Reading at El. 2' in Volts
Internally Sealed Concrete (Cont.)	2B	0.7	.37
	Remarks - No distress was noted except tight superficial map cracks due to heating. Cracks appeared to be sealed with melted wax.		
	2C	-	-
	Remarks - Pile 2C was not tested because of the swift tidal current. No distress was noted except tight superficial map cracks due to heating. Cracks appeared to be sealed with melted wax.		
	2D	0.4	0.20
	Remarks - No distress was noted except tight superficial map cracks due to heating. Cracks appeared to be sealed with melted wax. Pile 2D had to be patched after a small area of soft concrete was found on one face before installation.		
	2E	0.3	0.23
	Remarks - No distress was noted except tight superficial map cracks due to heating. Cracks appeared to be sealed with melted wax.		
Conventional Concrete	3A	2.6	0.19
	Remarks - No distress was noted.		
	3B	2.6	0.23
	Remarks - No distress was noted.		
	3C	-	-
	Remarks - No distress was noted.		
Block	3AO	1.8	0.13
	Remarks - Block has developed random horizontal cracks between supporting bolts. No corrosion problems were noted with epoxy-coated rebars.		

Table 5-8 (Continued)
Final Inspection Report

Material	Pile	Average Chloride Ion Content lbs Cl-/cu yd (1 lb/cy = .35 kg/m^3)	Half-Cell Reading at El. 2' in Volts
Block	3BI	2.2	0.08
	Remarks - Block has developed random horizontal cracks between supporting bolts. No corrosion problems were noted with epoxy-coated rebars.		
Polymer Concrete	4A	1.6	0.67
	Remarks - Rust spots were found on two faces and corner spall was noted in several locations. The half-cell readings were very high within the tidal zone.		
	4B	1.5	0.69
	Remarks - The appearance of Pile 4B was very poor. There was serious corner spall at several locations and the rock pockets that were patched were unattractive. The high half-cell reading indicated active corrosion was occurring throughout the pile. Pile 4B was constructed with a 4-1/2 percent resin content.		
	4C	1.3	0.70
	Remarks - Rust spots were found on one face and the surface of one face appeared to be very porous. Very high half-cell readings were recorded within the tidal zone. Corner spall was noted at one edge.		
	4D	-	-
	Remarks - No testing was performed on Pile 4D due to the swift tidal current. Rust spots were found on two faces and minor corner spall was observed at one location. Very high half-cell readings were recorded within the tidal zone.		
	4E	1.5	0.56
	Remarks - Rust spots were found on one face and corner spall was noted in three locations. One face appeared to be porous.		

Table 5-8 (Continued)
Final Inspection Report

Material	Pile	Average Chloride Ion Content lbs Cl-/cu yd (1 lb/cy = .35 kg/m^3)	Half-Cell Reading at El. 2' in Volts
Latex Modified Concrete	5A	1.9	0.27
	Remarks - No distress was noted.		
	5B	1.4	0.29
	Remarks - A tight longitudinal crack was noted on one face.		
	5C	1.2	0.25
	Remarks - No distress was noted except some minor abrasion on one face.		
	5D	-	-
	Remarks - Pile 5D was damaged during installation and was removed.		
	5E	1.5	0.22
	Remarks - A tight longitudinal crack was noted on one face.		

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. During the final inspection longitudinal cracks were found in 2 of the 4 piles and some minor surface abrasion was found on the face of pile 5C. The average chloride ion content was slightly less than the conventional concrete and the half-cell potential readings were below the threshold of corrosion. Overall, the short term performance of the latex modified concrete is satisfactory and it is recommended for further use in prestressed members in a marine environment.

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^{o}F (51.7^{o}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 physical condition of the internally sealed concrete piles was very good after a 2-year period. The chloride ion penetration was the lowest for the materials tested and only one pile had half-cell potential readings greater than 0.30 volts at the two foot reference elevation. For some unexplained reason, the initial half-cell potential readings in piles 2A, 2B, 2D and 2E were relatively high even before they were installed. The short term performance of the internally sealed concrete is satisfactory and it is recommended for further application in marine 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 (20 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 performance of the polymer concrete piles is unsatisfactory after only 2 years. Rust spots were noted on four piles and some corner spalling was beginning to occur on all 5 piles. Very high half-cell potential readings were recorded consistently in the polymer concrete piles. This indicated corrosion was occurring. Polymer concrete should still be considered experimental and is not recommended for routine use.

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 2 year performance of the polymer impregnated concrete piles is questionable. Although no environment-caused distress was found, high chloride ion content at the 0" to 1" (0 to 25.4 mm) depth indicated the material to be permeable. The low half-cell potential readings in each pile indicated no corrosion was occurring but if further chloride ion penetration occurs a rapid deterioration problem could be expected.

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.

The performance of the epoxy coated rebars is excellent after a 2 year period in spite of the fact there were numerous horizontal cracks in the miniature concrete piles. The continued use of epoxy coated rebars is recommended in a marine environment.

THE END

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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, September 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, October 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.

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 pilings in each group. The engineer will review this report and approve or disapprove of 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 6 percent of the beads shall have discernible voids.

The average void volume and the percentage of beads with discernible 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 breaks on 6" x 12" 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" x 6" 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.)

Construction - (Continued)

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.

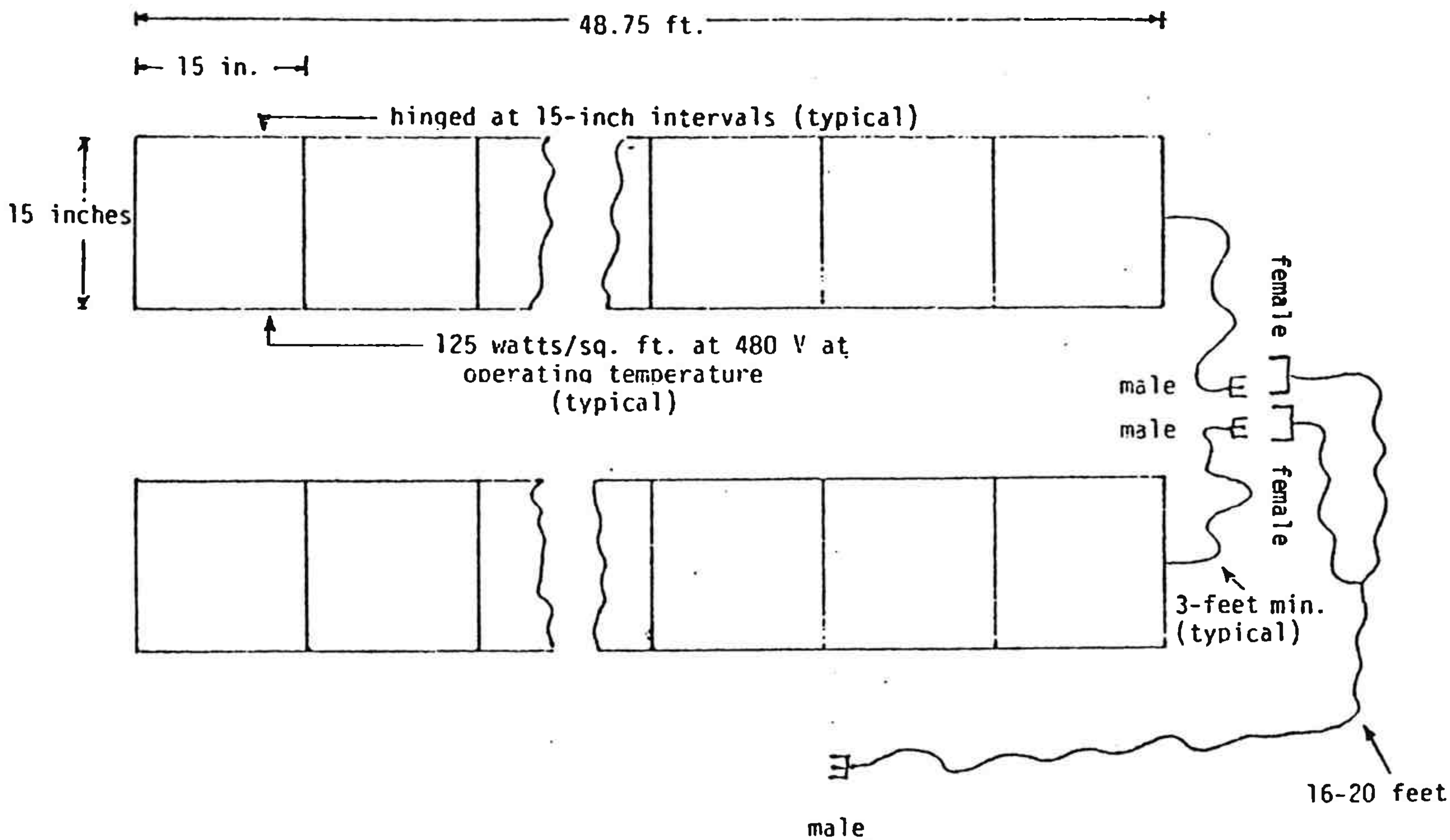
Thermal Output - The thermal output of the electrical heating blankets is dependent upon the heating element resistance which is a direct function of the element temperature. The blankets shall be designed for 125 watts per square foot output at design operating temperature. Ambient temperature, moisture, 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 generator 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:	± 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 hot-air 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 ± 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 heat 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	$CH_2=C(CH_3)COOCH_3$
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	13°C (55°F)
(Tag, ASTM D1310)	

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 ± 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 $\pm$ 30 percent or $\pm$ 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, cracks, contamination 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 $20^{o}C$ and $30^{o}C$.

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-metallic 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.

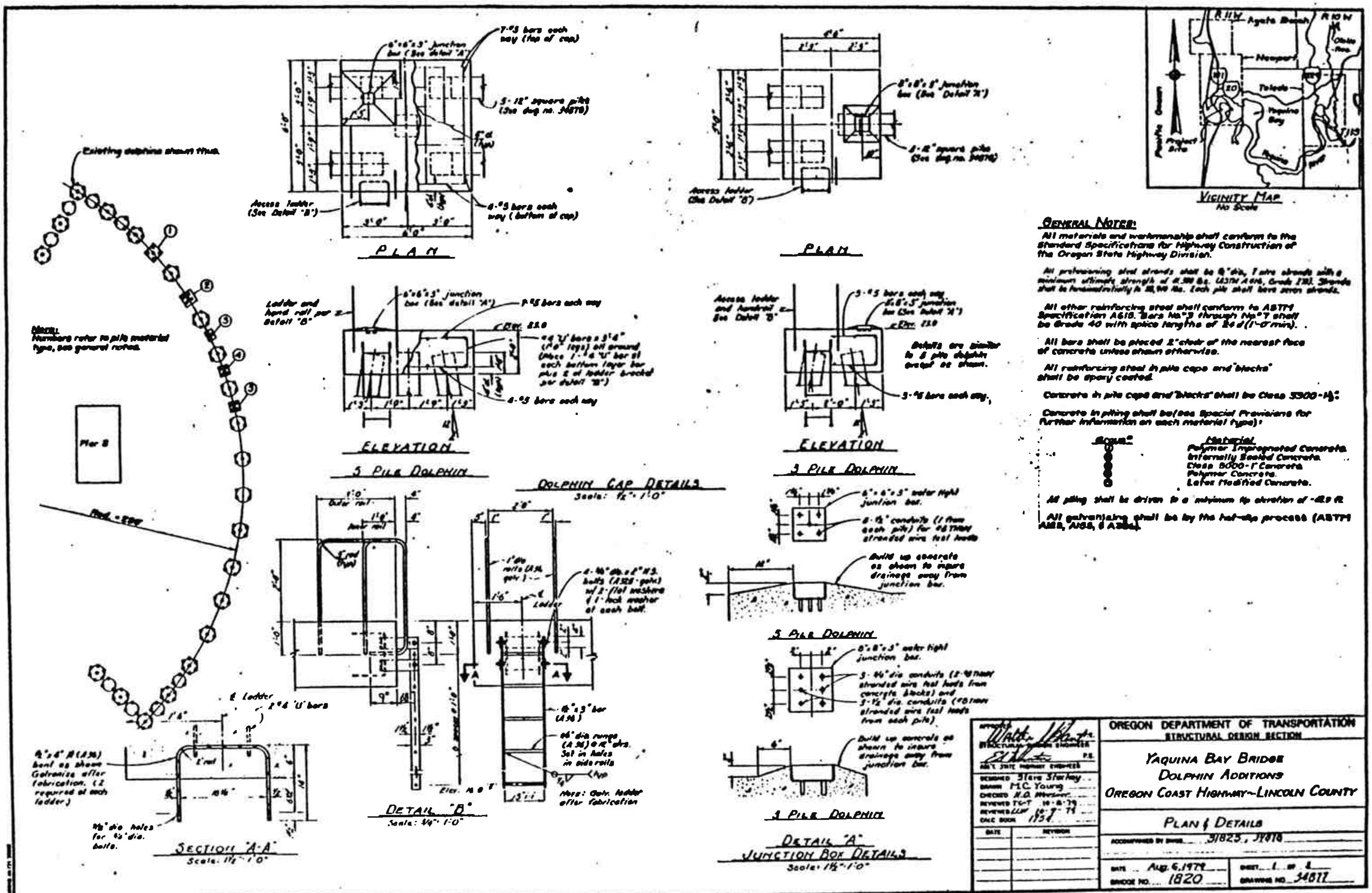
MONITORING EQUIPMENT

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.

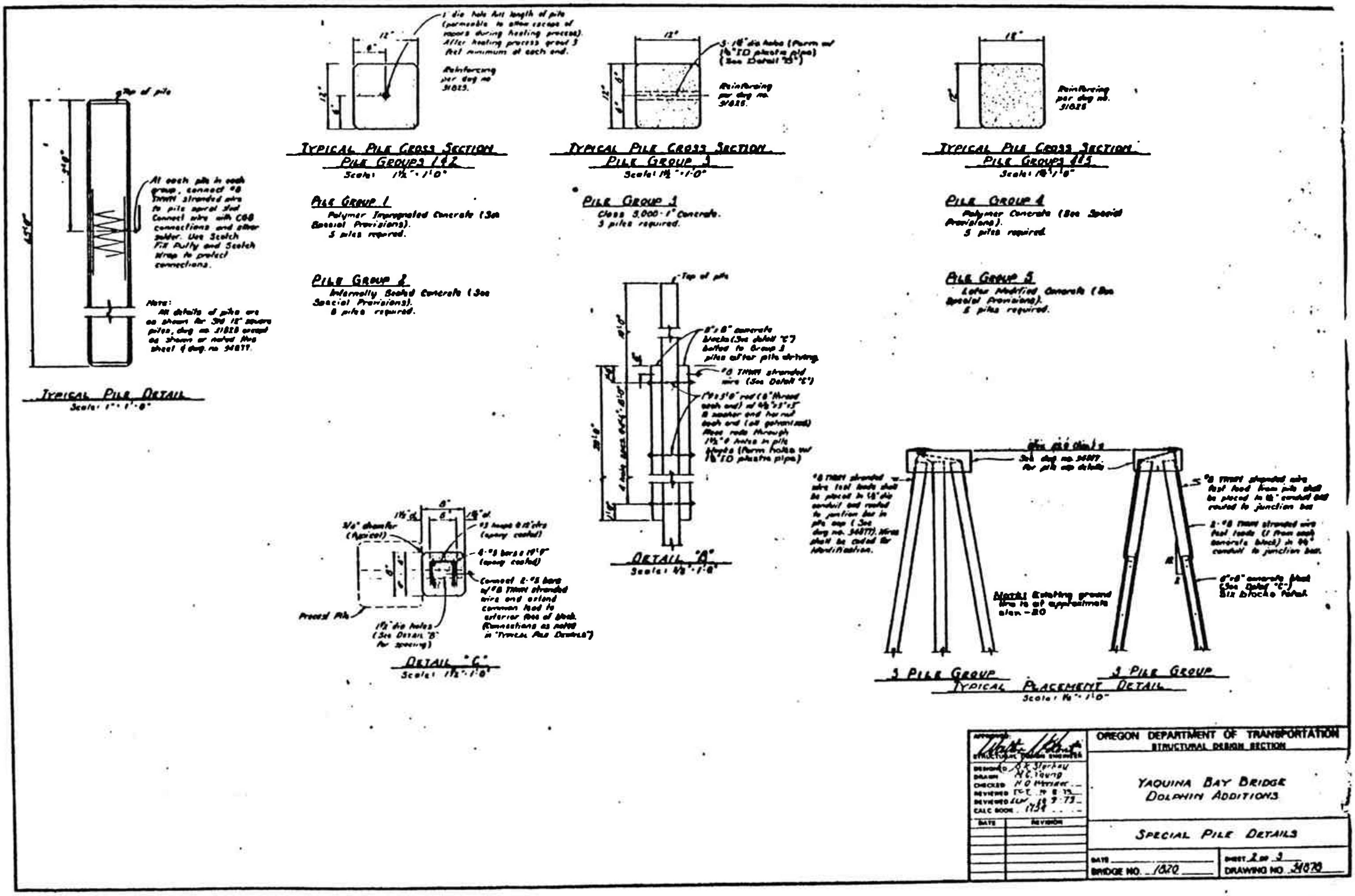
Materials - All materials and installation shall conform to the requirements of NEMA and NEC.

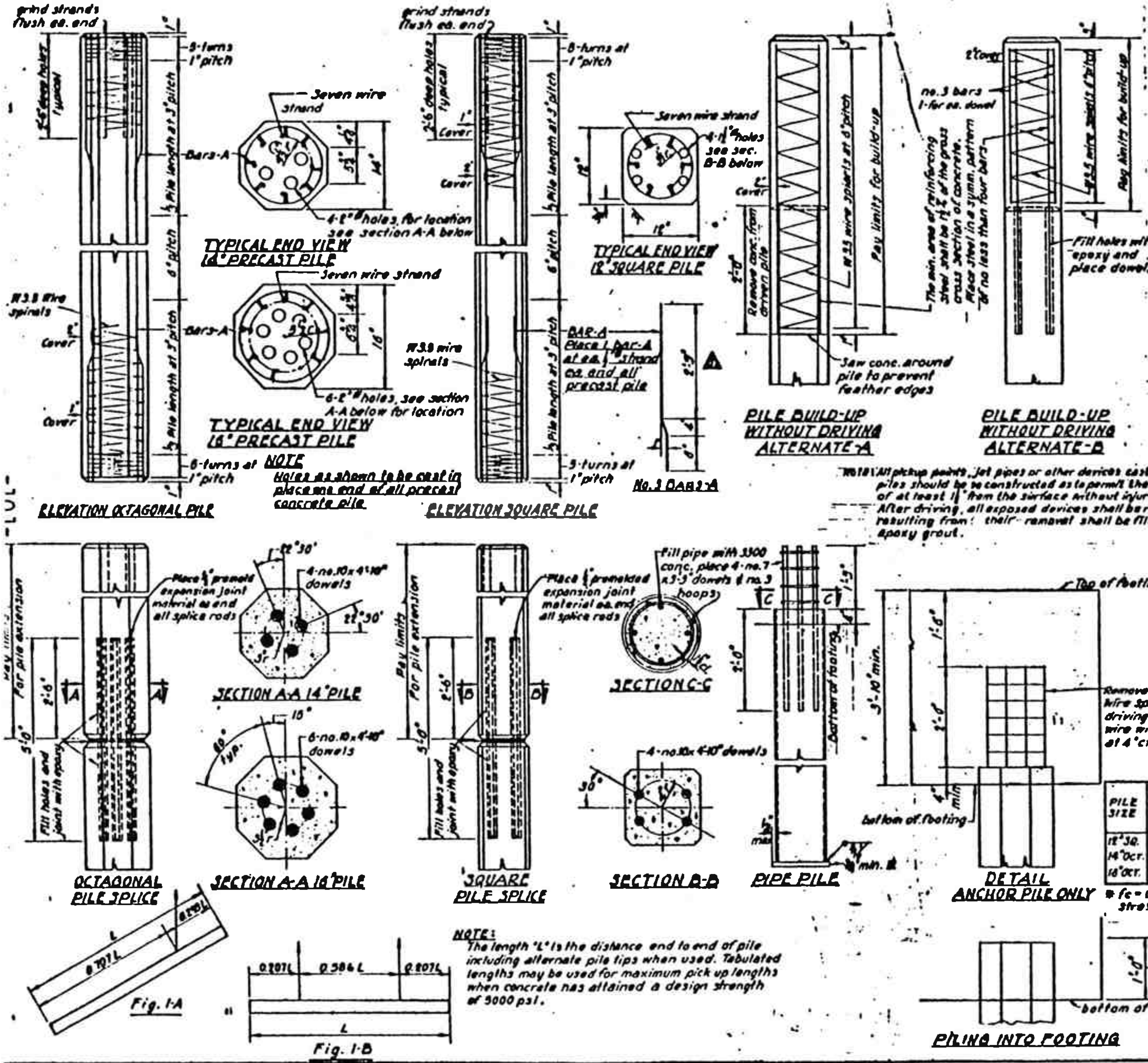
Measurement - There will be no measurement of the above work.

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 8
PLAN
ELEVATION
5 PILE DOLPHIN
PLAN
ELEVATION
3 PILE DOLPHIN
DOLPHIN CAP DETAILS
Scale: 1/2" = 1'-0"
SECTION "A-A"
Scale: 1 1/2" = 1'-0"
DETAIL "B"
Scale: 3/4" = 1'-0"
5 PILE DOLPHIN
3 PILE DOLPHIN
DETAIL "A"
JUNCTION BOX DETAILS
Scale: 1 1/2" = 1'-0"
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 5300-1 1/2".
Concrete in piling shall be (See Special Provisions for further information on each material type):
Group
Material
Polymer Impregnated Concrete.
Internally Sealed Concrete.
Class 8000-1" Concrete.
Polymer Concrete.
Latex Modified Concrete.
All galvanizing shall be by the hot-dip process (ASTM
OREGON DEPARTMENT OF TRANSPORTATION
STRUCTURAL DESIGN SECTION
YAQUINA BAY BRIDGE
DOLPHIN ADDITIONS
OREGON COAST HIGHWAY~LINCOLN COUNTY
PLAN & DETAILS
DESIGNED Steve Starkey
DRAWN M.C. Young
CALC BOOK 1854
DATE Aug. 6, 1979
BRIDGE NO. 1820
DRAWING NO. 34877

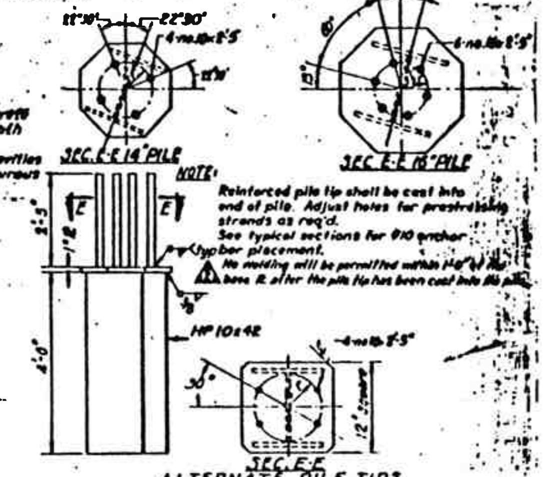

TYPICAL PILE DETAIL
Scale: 1" = 1'-0"
TYPICAL PILE CROSS SECTION
PILE GROUPS 1 & 2
Scale: 1½" = 1'-0"
PILE GROUP 1
Polymer Impregnated Concrete (See Special Provisions).
5 piles required.
PILE GROUP 2
Internally Sealed Concrete (See Special Provisions).
8 piles required.
TYPICAL PILE CROSS SECTION
PILE GROUP 3
Scale: 1½" = 1'-0"
PILE GROUP 3
Class 5,000-1" Concrete.
3 piles required.
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.
DETAIL "B"
Scale: ½" = 1'-0"
DETAIL "C"
Scale: 1½" = 1'-0"
5 PILE GROUP
3 PILE GROUP
TYPICAL PLACEMENT DETAIL
OREGON DEPARTMENT OF TRANSPORTATION
STRUCTURAL DESIGN SECTION
YAQUINA BAY BRIDGE
DOLPHIN ADDITIONS
SPECIAL PILE DETAILS
BRIDGE NO. 1820
SHEET 2 OF 3
DRAWING NO. 34878



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 40', or 3/16" x (total length in feet) ÷ 30 feet.

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



ALTERNATE PILE TIPS

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'-3"	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

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

DATE	REVISION
	Revised Dimension
	Added no. welding note
	Revised conc. note

OREGON STATE HIGHWAY DIVISION

CONCRETE PILE DETAILS
PRECAST PRESTRESSED AND PIPE PILE

STANDARD

DATE 8-2-77
BRIDGE NO
SHEET 1 OF 1
DRAWING NO. 31825