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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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°F (85°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^{o}F (51.7^{o}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^{o}F (85^{o}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		

		Monomer - lbs. Crylcon EP - 3009	Powder - lbs. Crylcon EP - 3020	Aggregate - lbs. 3/4" - 1/2"	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

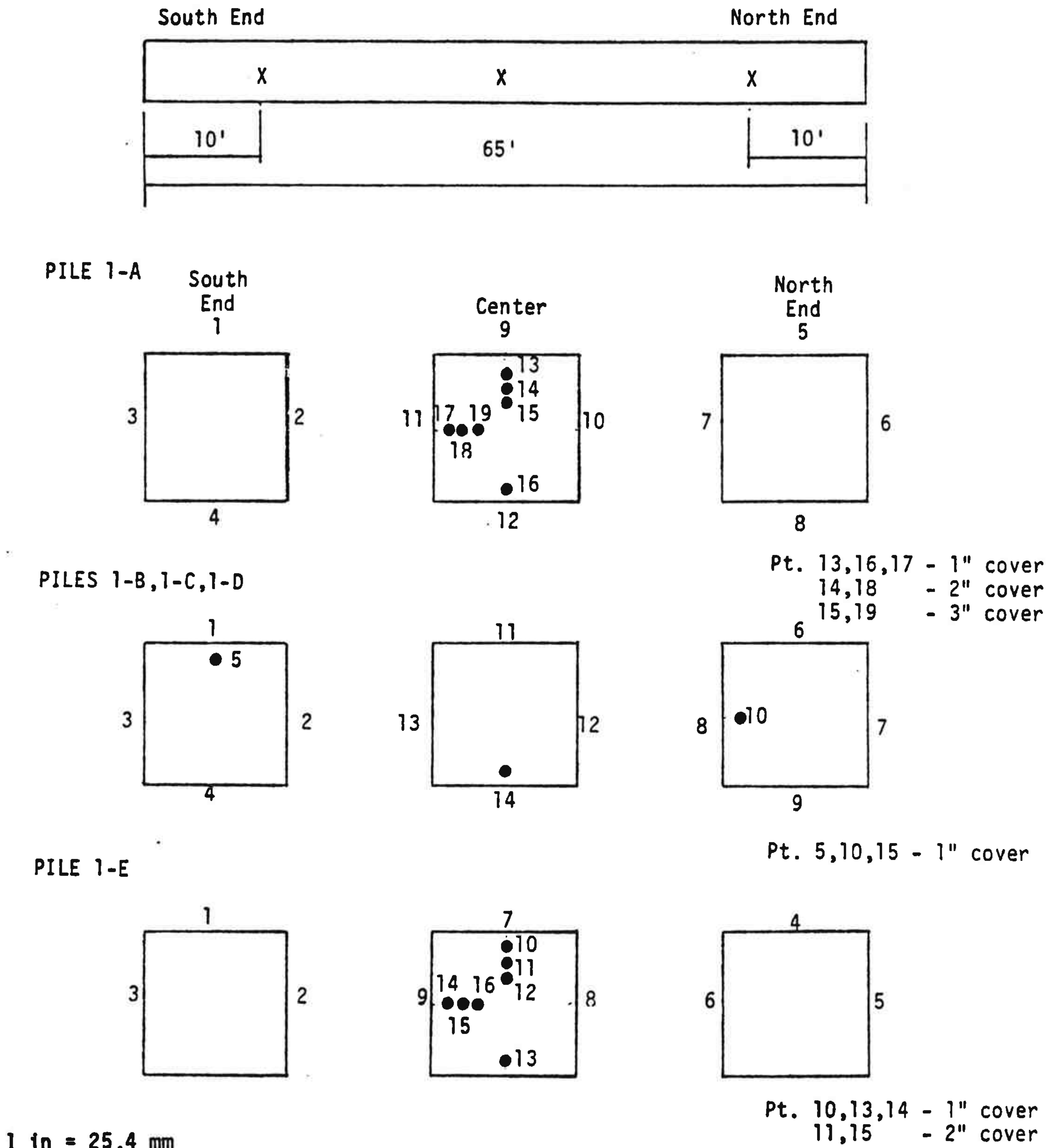


FIGURE 3-1

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^{o}F (121.1^{o}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^{o}F/hour (55.6^{o}C/hour) to a maximum surface temperature of between 260^{o} and 300^{o}F (126.6^{o} and 148.8^{o}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.

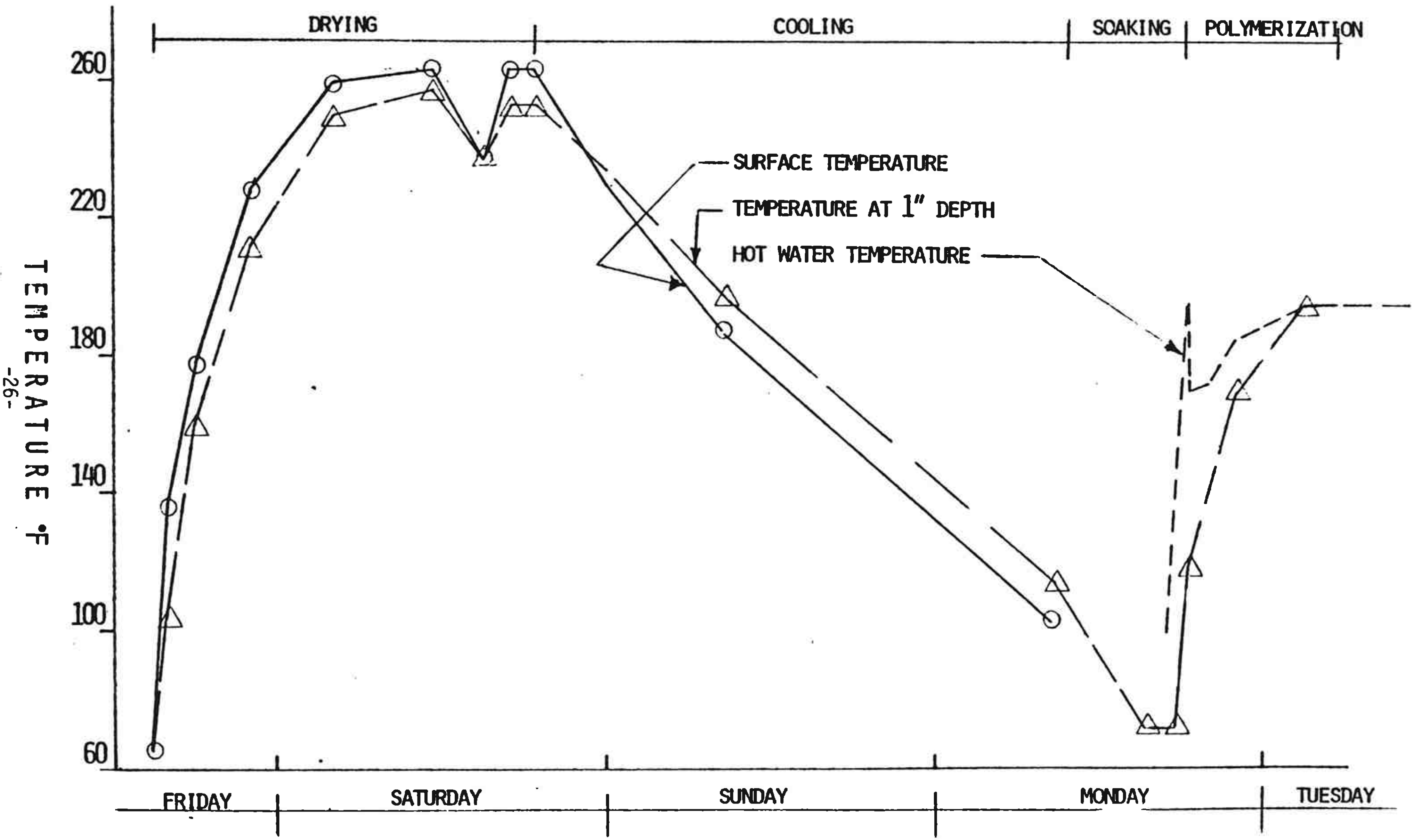
The first pile to undergo the drying process had to be heated over a 2-day period in order to meet the 10-hour drying requirements. The temperature hitory of the pile during the entire impregnation process is plotted in Figure 3-2. After the 10-hour requirement was satisfied the pile was allowed to slowly 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

PILE 1A

POLYMER IMPREGNATION CYCLE



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

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

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

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

Compressive Strength After Impregnation (lbs/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.

<u>Internally Sealed Concrete</u>

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

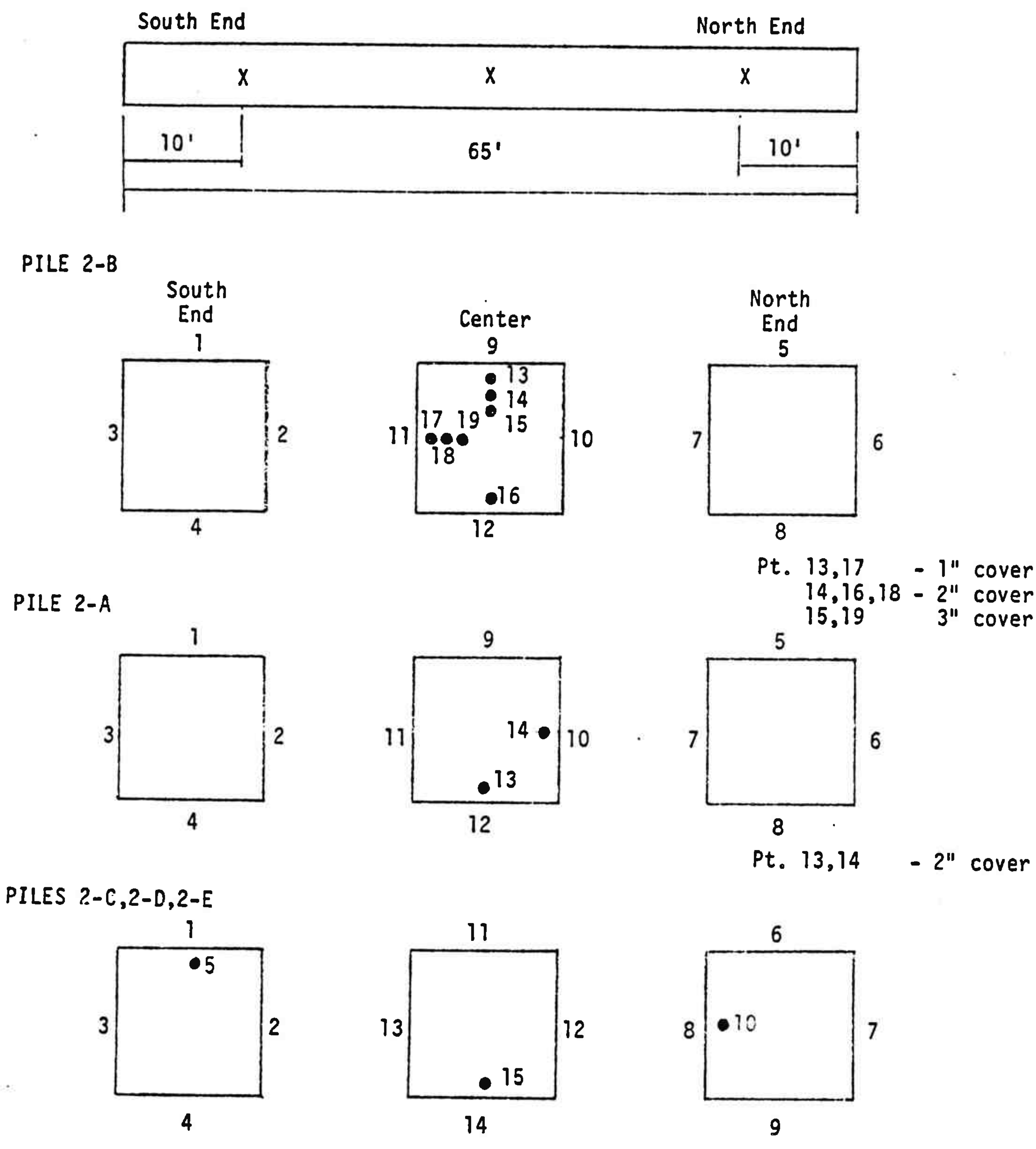
Date Cast	Compressive Strength (lbs/in^2) Test A			Test B		Test C		Modulus of Elasticity $lbs/in^2 \times 10^6$
	Age of 6" x 12" Cylinders							
	1 d		28 d	7 d	28 d	7 d	28 d	
03/10/80	4350		7003	6435	7325	4825[1]	6335[2]	[1]2.7
	4262		6331		7670	5000	6725	[2]3.5
					7625[3]			[3]3.6
					7465			
	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

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

Compressive Strength After Melting Wax Beads (lbs/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



Pt. 5,10,15 - 2" cover

1" = 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.

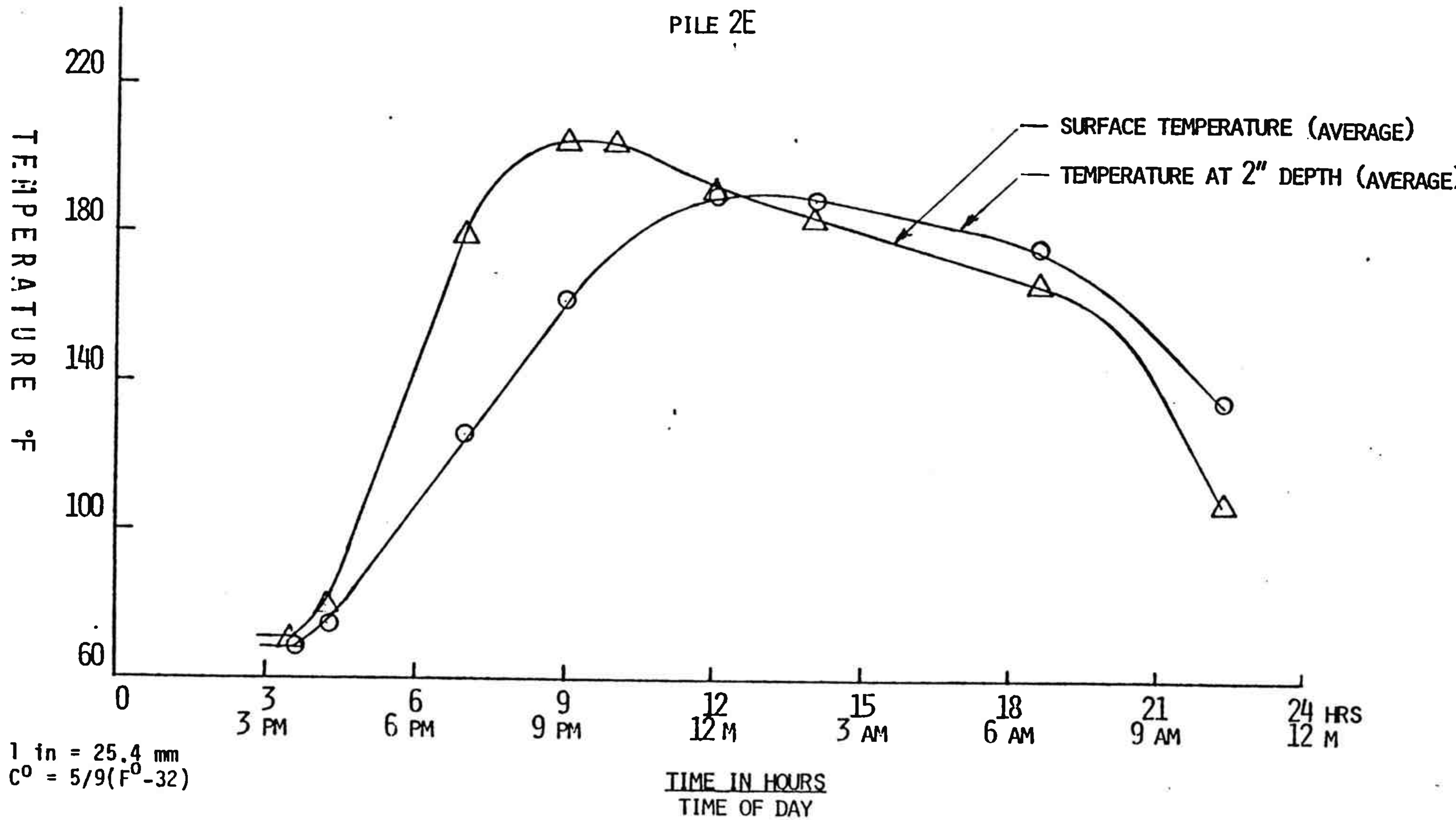
An investigation was conducted to determine the reason for the high slump, since a water/cement ratio of 0.30 was specified. One possible explanation was the occurrence of a heavy rain when the concrete was being transported to the casting bed. The rain lasted only a few minutes, but since the

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^{o}F (68.3^{o}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

Date Cast	Compressive Strength (lbs/in^2)							Modulus of Elasticity psi
	Test A		Test B		Test C		Test D	
	3 day	28 day	7 day	28 day	7 day	28 day	7 day	
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
	Test A			Test B		Test C		
	1 day	4 day	28 day	7 day	28 day	7 day	28 day	
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°F (4.4° to 7.2°C) ambient temperature. When the epoxy supplied with the strain gage kit failed to bond the strain gages on subsequent piles, a household epoxy was purchased from a local hardware store. This epoxy, called "5 Minute Epoxy", successfully bonded the strain gages to Piles 1A, 1E, 2A, 2C and 2D. Once the gages were applied they were protected by a multi-layer system consisting of a butyl rubber sealant, a neoprene pad, an aluminum tape and top coated with a nitrate rubber coating.

Readings were then recorded on each pile for a period of two weeks during which times the values were extremely inconsistent. Both tensile and compressive strains were often indicated on the same gages during subsequent readings. After examining the results, the strain gage method for determining strain was abandoned. A far less sophisticated method of embedding two nails into the piles and measuring the distance between them was substituted for the strain gages. The nails were placed into the top surface just after the pile was finished. The first measurement was taken approximately two hours after casting and a gage length of over 50 feet (15.2 m) was used in all but one pile. The second measurement was made on the next day just prior to the release of the prestressing strands. The third measurement was made within minutes after the strands were released. The modulus of elasticity was calculated from the measurement made due to elastic shortening. Additional measurements were then taken for up to 45 days after the piles were placed in storage. The strain for the polymer concrete, latex modified concrete and conventional concrete piles is found in Table 4-2. The results of this work 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

1×10^6 psi = 6.895 GPa