Use of Improved Structural Materials Systems in Marine Piling

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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^{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°F (76.7°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°F (121°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	ABORTED						
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 not Recorded	1,075	945	725	26.5	35.2	114.0[3]
2A,2D	Intern. Sealed		1,085	945	725	25.5	35.2	114.0[3]
3-18-80	Latex Modified	705	1,170	1,170	540	4.4	35.2	220.5[2]
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	Latex Modified	705	1,170	1,135	525	5.45	--	206.0[2]
5D								
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.	Powder - lbs.	Aggregate - lbs.	
		Crylcon EP - 3009	Crylcon EP - 3020	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

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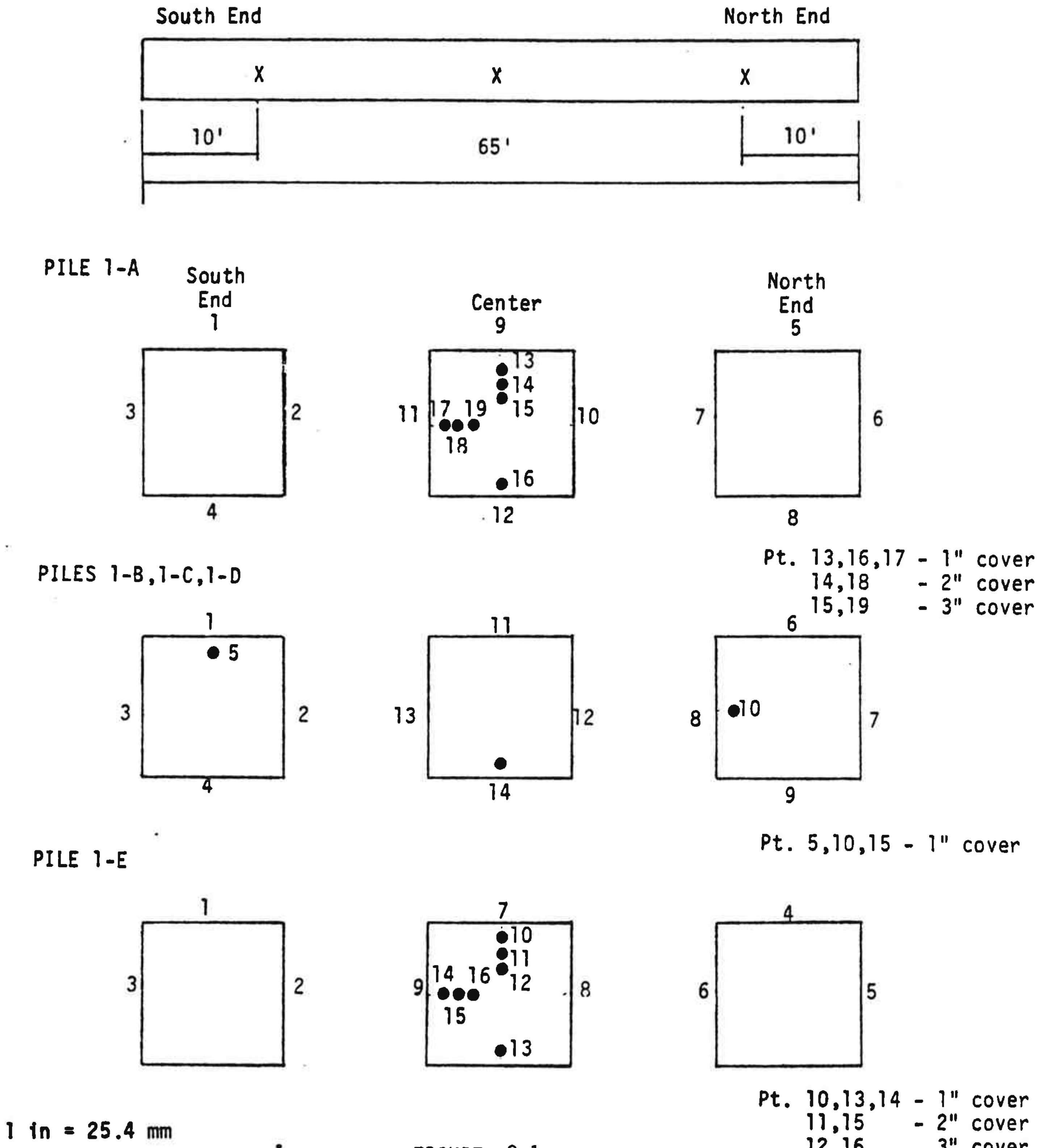
[1] Air Entraining Agent (oz.)
[2] Latex Modifier (lbs)
[3] Wax Beads (lbs)

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



Pt. 13,16,17 - 1" cover
14,18 - 2" cover
15,19 - 3" cover

Pt. 5,10,15 - 1" cover

Pt. 10,13,14 - 1" cover
11,15 - 2" cover
12,16 3" cover

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-cyano-propane (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