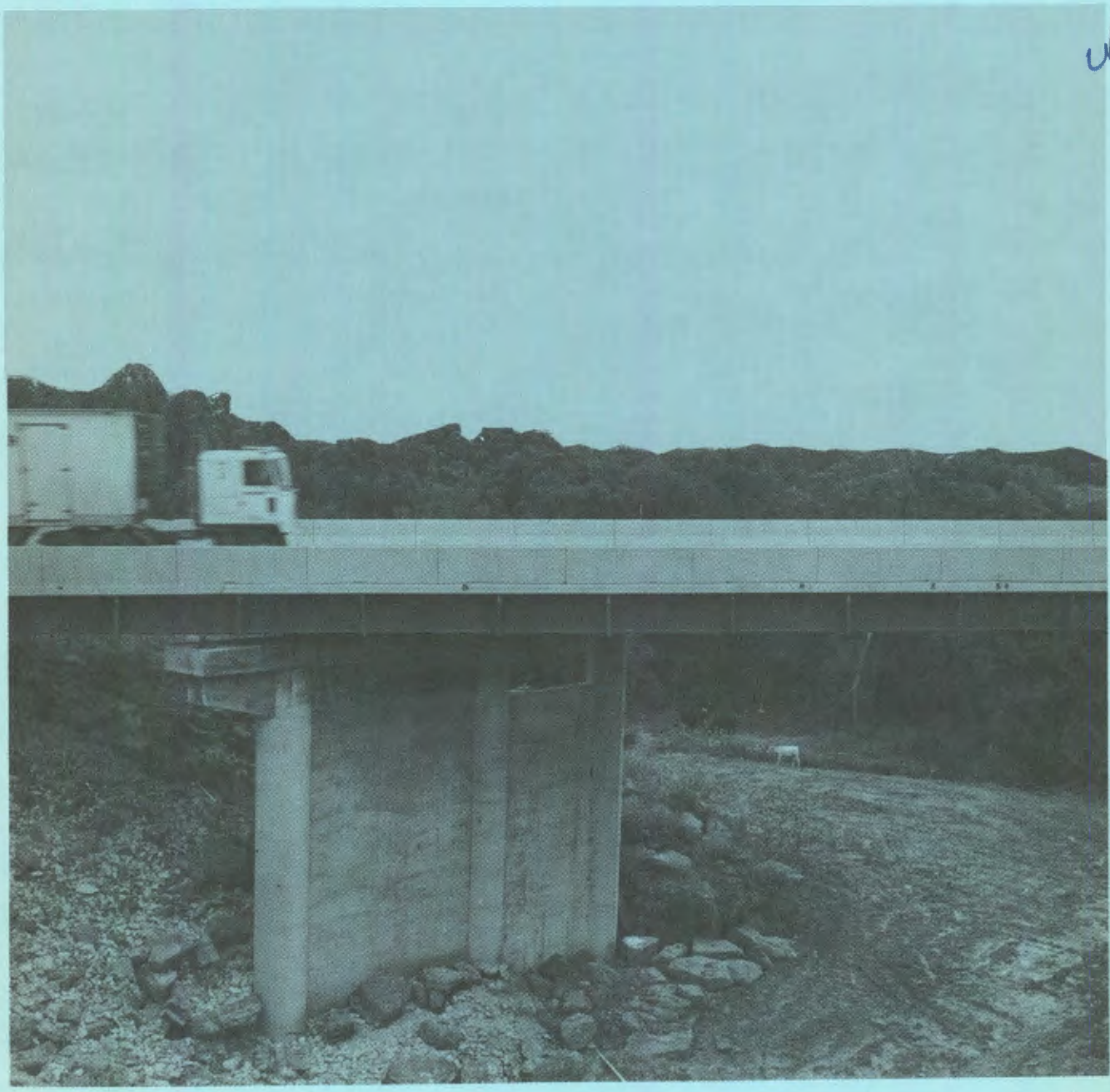
Internally Sealed Concrete - Cow Creek

Perry, Oklahoma

dp Demonstration Project No. 49
Report No. FHWA-DP-49-1
Interim Report
August 1981

U.S. Department of Transportation
Federal Highway Administration
Eastern Direct Federal Division
Demonstration Projects Program



The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Oklahoma Department of Transportation or the Federal Highway Administration. This report does not constitute a Standard, Specification, or Regulation.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OK-81/1		

4. Title and Subtitle	5. Report Date
Internally Sealed Concrete at Cow Creek, Oklahoma	August 1981
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Jack C. Stewart and Ghasem Pourkhosrow	79-05-1, Item No. 403

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Oklahoma Department of Transportation Research and Development Division 200 N.E. 21st Street Oklahoma City, OK 73105	I-FI-35-4(94)184
	11. Contract or Grant No. DOT-FH-15-316
	13. Type of Report and Period Covered Interim Report July 1979 thru January 1981
12. Sponsoring Agency Name and Address Federal Highway Administration Demonstration Projects Division, EDFD 1000 N. Glebe Road Arlington, Virginia 22201	14. Sponsoring Agency Code HDP-15

15. Supplementary Notes

Prepared in cooperation with the Federal Highway Administration
Darrell E. Maret, Project Manager

16. Abstract

This report discusses Oklahoma's second experimental internally sealed concrete bridge deck. It differed from the first one in that it contained wax beads only in the top two inches as opposed to full depth, and it covered the entire deck instead of just one span. The objective of this study was to gain experience in placing and heating a wax impregnated concrete bridge deck on a full-scale basis. Work was performed on an existing Interstate bridge that needed widening and redecking. The bridge's maintenance history is included. The project design and construction phases are described in detail. The deck was placed with two pours instead of a monolithic pour as originally planned. A petrographic classification was made of the aggregates. The mix design detailing the conversion from conventional bridge deck concrete to wax bead concrete is explained. A trial mix was made prior to pouring the wax bead overlay to insure good bead distribution.

The heat blankets and heat treating method used to internally seal the deck are described. Tests to determine the effectiveness of the wax seal are discussed. These included: (1) A "before" and "after" heating crack survey, (2) 24 hour absorption, (3) Dye penetration, (4) skid resistance, (5) half-cell potential, (6) compressive and flexural strength, and (7) a chloride analysis. All of the tests showed good results. This method deserves serious consideration in the bridge design process.

17. Key Words	18. Distribution Statement
Internally Sealed Concrete, Wax Beads, Heat Blankets, Bridge Deck Concrete, Concrete Heating, Cow Creek, Oklahoma.	No restrictions. This publication is available from the Research and Development Division, Oklahoma Department of Transportation

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	91	

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Objective	1
Background	1
Test Procedures	4
Bridge History	4
Geometric Description and Traffic	6
CONSTRUCTION	7
Design Background	7
Methodology	7
Mix Design	9
Bottom Lift	11
Trial Mix	11
Placement of Wax Bead Overlay	12
INTERNALLY SEALING	15
Electric Blankets	15
Heat Treating	15
Cost Analysis	21
TESTS RUN	23
Crack Survey	23
Penetration	25
Absorption	25
Skid Test	25
Half-Cell	25
Compressive Strength	26
Flexural Strength	27
Chloride Penetration	27
Core Hole Patching	29
SUMMARY AND CONCLUSIONS	32
REFERENCES	34
APPENDIX A	
Photograph 1. Concrete batch plant used to produce the base lift and the wax bead concrete.	A-1

Photograph 2.	Inspecting the wax beads.	A-1
Photograph 3.	Wax beads being manually added to the drum mixer.	A-2
Photograph 4.	Water was used to wash all of the beads into the drum.	A-2
Photograph 5.	Cylinders and beams were made from a trial mix of the wax bead concrete.	A-3
Photograph 6.	Slump tests were run on the trial mix.	A-3
Photograph 7.	The bottom course was placed to 0-1/2 inch above the reinforcing bars.	A-4
Photograph 8.	A sand-cement grout was broomed on the bottom course immediately before the wax bead overlay was placed.	A-4
Photograph 9.	The wax bead concrete overlay was placed and finished 28 days after the bottom course.	A-5
Photograph 10.	Wet burlap was used for curing the concrete.	A-5
Photograph 11.	The generator used to supply power to the heat blankets.	A-6
Photograph 12.	Display gauges on the generator. This type of instrumentation was necessary for effective control of power. This generator also has an excitor switch and a wide range rheostat which are highly desirable.	A-6
Photograph 13.	Transformer with the fuse box and generator in the background.	A-7
Photograph 14.	Power cable used to connect the control console to the transformer.	A-7
Photograph 15. and Photograph 16.	Control console. Flashing red light would come on automatically if any of the circuits broke.	A-8
Photograph 17.	Each breaker switch controls two heat blankets.	A-9
Photograph 18.	A partial heat zone (no insulation) is set up around the perimeter of each heat run.	A-9

Photograph 19. and Photograph 20. Three sets of thermocouples (2 inch level) and hockey puck (surface) were placed under each heat run. They were wired into a central temperature monitor. A-10

Photograph 21. and Photograph 22. Blankets and insulation were placed and covered with mesh netting and weights to prevent wind disturbance. Portable flood lights were used for night operations. A-11

Photograph 23. and Photograph 24. The blankets were handled with care when carried from one heat run to the next. A-12

Photograph 25. and Photograph 26. Crack surveys were run on the deck both before and after heat treating. A-13

Photograph 27. and Photograph 28. Several cores were taken from the deck to determine the sealing effectiveness after heating. The holes were patched and sealed. A-14.

APPENDIX B

Special Provisions B-1

APPENDIX C

Mix Designs C-1

APPENDIX D

FHWA Heat Treating Guidelines D-1

APPENDIX E

FHWA Test Procedures E-1

LIST OF FIGURES

		Page
Figure 1.	Typical Heating Sequence.	18
Figure 2.	Typical heat runs showing the temperature versus time effects of the heating blankets at a depth of two inches in the deck.	20
Figure 3.	Crack Survey and Core Locations	24

LIST OF TABLES

Table 1.	Properties of Wax Beads	3
Table 2.	Cost Analysis	22
Table 3.	Chloride Analysis	30

INTRODUCTION

One of the most severe problems facing the highway industry is corrosion of the bridge deck reinforcing steel. This is caused by a chloride solution which results from the application of salts (NaCl and $CaCl_2$) on icy roads. The continuous network of capillaries or bleed channels, voids, and shrinkage cracks formed in the concrete during cure makes it vulnerable to water and chloride solution penetration. Since a high accident rate would prevail without the application of salt, a system to prevent the salt from penetrating to the reinforcing steel is needed.

Objective

The objective of this study was to place, heat, and evaluate a wax impregnated concrete bridge deck overlay on a full-scale basis to gain further experience with the procedure. The wax bead project is part of the Federal Highway Administration's (FHWA) Technology Transfer Program. Demonstration Project No. 49, Internally Sealed Concrete, was administered by FHWA, Demonstration Projects Division Region 15, Arlington, Virginia.

Background

Oklahoma installed one internally sealed bridge deck span in 1976 and has been very pleased with the sealing ability that it exhibited. The bridge is located east of Shawnee on SH 3 over the North Canadian River. However, only one span was placed using the wax beads and it was poured with the wax beads full depth. On the Cow Creek project, completed in the autumn of 1979 , the beads were placed in only the top two inches (51 mm) of the slab as an overlay.

Many systems for sealing bridge decks against salt penetration have

proven inadequate in reducing the corrosion of the steel in the bridge deck. Others reduce the salt penetration but do not completely seal the bridge deck.

The internal sealing system was devised by the Monsanto Research Company under a contract with the FHWA, Office of Research, between 1972 and 1974, using wax beads as the sealant. This system consists of adding small spheres of wax, varying in diameter from 0.007 to 0.033 inch (0.18 to 0.84 mm), replacing an equal volume of sand, to a plastic non-air entrained concrete mix. After a curing period, the deck was heated causing liquified wax to flow into the pores and capillaries thus impregnating the concrete. Upon removal of the heat, the wax cools and solidifies, blocking the passage ways. The capillary network thereby becomes a discontinuous, closed system effectively blocking penetration by water and chloride solutions.(1)

The wax beads were produced by American Lignite Products Company in Ione, California. They consisted of 25 $\pm$ 5 percent Montan wax and 75 $\pm$ 5 percent paraffin. Montan wax is a naturally occurring, polar mineral wax which is found in low grade lignite, or brown coal, formations used largely to make carbon paper. Paraffin is a waxy, crystalline, hydrocarbon material which is obtained from distillates of petroleum. The paraffin used had a melting point of $149^{o}\pm 2^{o}F$ ($65^{o}\pm 1^{o}C$). The wax beads had an average specific gravity of 0.845 and an approximate unit weight of 53 pounds per cubic foot (849 kg/m^3) as determined by the solid volume method. Wax bead properties are shown in Table 1.

Internal sealing was not accomplished until the heat treating had been completed. This required heating the deck to $185^{o}F$ ($85^{o}C$) down to the two inch (51 mm) level. Heating of the deck was done by an electric blanket heating system. The electric blankets, developed by FHWA, were transported to the project in a FHWA vehicle. FHWA demonstration projects personnel advised

PROPERTIES OF WAX BEADS

Material:	Montan Wax %	25.2
	Paraffin Wax %	74.8
Melting Point		150°F
Specific Gravity		0.845
Void Volume %		9.2
Beads with discernible voids %		95.7
Screen Analysis		
	Passing 16 mesh, wt. %	100.0
	Passing 20 mesh, wt. %	100.0
	Passing 80 mesh, wt. %	3.8

TABLE 1. Properties of Wax Beads

during the heating operation which was funded under the Demonstration Projects program.

Test Procedures

Dye penetration, resistance of concrete to chloride ion penetration, total chloride ion in the concrete, 24 hour absorption, compressive and flexural strength tests were run on core samples in the lab. The first three tests are FHWA test procedures and are found in Appendix E. The absorption test involved weighing a core sample then drying in a forced air oven at $230^{o}F$ ($110^{o}C$) for 72 hours and weighing again. This high temperature remobilizes the wax, therefore the sample was no longer representative of the deck as far as field conditions are concerned. Next it was placed in water for 24 hours, then removed and reweighed. Calculations involving these various weights give percent moisture as received and percent absorption in a saturated surface dry condition. Compressive strength tests were performed on molded concrete cylinders following the AASHTO T 22-74 test procedures. ASTM procedure C 78 was followed in performing tests on molded beams.

Field tests on the bridge deck included: (1) half-cell measurements using a $Cu/CuSO_4$ electrode as a reference; (2) crack surveys made by visual inspection both before and after the deck was heated; (3) skid tests following the ASTM E-274-70 test designation; and (4) delamination soundings made by the audio chain-drag method.

The bridge will be monitored annually for the next several years.

Bridge History

The Cow Creek Bridge was originally built in 1959 as Project No. I-35-4(23). It was built with continuous wide flange beam spans on a 2.8 percent

grade with the south end being higher and in a 0^{o} - 24' circular curve. It was 273.2 feet (83.3 m) long and had a clear roadway of 30 feet (9.1m).

However, since construction the concrete deck had deteriorated badly as a result of age and many winter deicing treatments. Inspection records indicate the following:

1964. Some spalling was observed in 75 percent of the floor.

1967. The deck was armor coated and the curbs were treated with linseed oil.

1969. The deck was freshly overlaid with asphalt.

1973. Salt had penetrated the slab and was leaching through the bottom of the deck in several small areas.

1974. Span No. 1. Moisture had seeped through the concrete slab to the bottom side of the deck in several areas under the west gutter line. There were also similar areas at mid-span and along the bottom side of the east gutter line. The underside of the deck was leaking moisture which caused several diaphrams to rust. The curbs and asphalt overlay were cracked.

Span No. 2. There were seep areas on the bottom side of the deck in the west gutter adjacent to Pier No. 1.

Span No. 3. There was evidence that at least one third of the span was seeping badly. It was also cracking and leaching through the bottom.

The spans are numbered from south to north.

The estimated cost to redeck and widen was $183,000.

1975. Salt solutions had penetrated through the floor in numerous places. The east gutter of the north span was the worst area.

1978. The deck was overlaid.

1979. The bridge was widened and redecked with wax bead concrete.

During the summer of 1979, the wax bead rehabilitation occurred as part of construction Project No. I-FI-35-4(94)184. Upon removal of the original concrete bridge deck, a visual inspection of the old steel was made. It was good steel with some localized areas of severe rust.

Geometric Description and Traffic

The wax bead process was utilized on the Cow Creek bridge in Noble County. The bridge is located 1.5 miles (2.4 km) south of Perry on I-35 in the southbound lanes. The bridge is constructed with three continuous spans using steel wide flange beams. It is 273.2 feet (83.3 m) long and 40 feet (12.2 m) wide with concrete parapet walls. The ends are at a 45 degree skew.

The bridge was widened from 30 feet (9.1 m) to 37 feet (11.3 m) of clear roadway to meet interstate standards. The average daily traffic (ADT) volume presently averages 10,000 vehicles with an estimated ADT of 16,000 by the year 2000 A.D. The truck factor is 20 percent.

CONSTRUCTION

Design Background

Rehabilitation plans for this bridge included widening and replacing the deck. The widening included adding one pier each to the west side in line with the two existing ones connected with a cross strut. A plate girder was placed on top seven feet (2.1 m) from and parallel with the closest existing wide flange beam.

It was decided to incorporate wax beads for internally sealing the concrete deck. The first, or bottom, lift would just cover the reinforcing steel and be approximately 6.5 inches (165 mm) thick. The second lift, containing the wax beads would be two inches (50 mm) thick. However, it was decided later that two separate placements would be better. The two lifts used were the same thickness as if the deck had been poured monolithically.

Methodology

The ingredients for a one cubic yard (0.8 m^3) Class AA wax bead trial mix were Type I cement, Ada, Oklahoma; fine aggregate, Blackburn Sand Co., Blackburn, Oklahoma; No. 7 coarse aggregate, Standard Industries, Tulsa, Oklahoma; wax beads, American Lignite Products Co., Ione, California; set retarder, Master Builders; and water from the city of Perry, Oklahoma.

A petrographic examination was made of the aggregates. It showed that the fine aggregate consisted of subangular to subrounded grains of quartz with very little feldspar or other constituents. It was well graded.

The coarse aggregate was found to be a hard, fossiliferous limestone. It did not contain any deleterious partings or fractures. A physical and chemical analysis indicated the following:[2]

Physical Data

L.A. Abrasion 100 rev. %	L.A. Abrasion 500 rev. %	Absorption %	Bulk Specific Gravity
6.8	31.8	1.8	2.64

Chemical Analysis (%)

$CaCO_3$	$MgCO_3$	CO_2	SiO_2	Al_2O_3	FeO	P_2O_5	K_2O	Na_2O	S	H_2O	Insol. residue
94.43	2.19	42.63	1.74	0.94	0.32	.05	.09	.07	.07	none	2.70

The original design plans called for pouring the entire deck as a single monolithic pour; however, after extensive conferences between the Oklahoma Department of Transportation (ODOT) engineers, the contractor, and the owner of the concrete batch plant, it was decided to pour the deck in two lifts instead.

To have poured the deck monolithically almost would have required having a portable concrete plant located at the job site. Concern was expressed by all parties about the 30 minute time limit for placing the top layer over the bottom layer. It was felt that this time limit would be the minimum time between placements instead of the maximum, as required. Also, there was a mix-up in ordering the wax beads. The quantity ordered had been based on bulk weight as opposed to the absolute volume method. For that reason, more beads had to be ordered before the top lift could be placed. At this time a change-in-plan was made. Since the contractor was facing down time until the new shipment of beads arrived, and the planned monolithic pour was questionable at best; it was decided to change the deck placement to two separate pours. This would require time for the bottom lift to gain strength before the top, wax bead lift

could be placed. During this period the contractor was allowed to pour the parapet walls. No problems were experienced during either of the two pours other than those encountered during typical construction; primarily weather and machinery.

Normally, placing the parapet walls before the deck has been heated is not advisable. The possibility exists of thermal cracks being formed along the wall's base during the heating operations. However, great care was used in this area at the time of heating. The parapet walls escaped with very little to no cracking. This is discussed further in the Heat Treating section.

Mix Design

The concrete mix for overlay differed from a standard Class AA, 658 lbs per yd^3 (390 kg per m^3) non-air entrained mix primarily in that two cubic feet (0.06 m^3) of sand were replaced by an equal volume of wax beads, or approximately three percent by weight of concrete. It is important to note that the weight of wax beads required to replace the fine aggregate should be calculated by the absolute volume method rather than by bulk weight. The computations for this are shown in Appendix C.

In Oklahoma concrete designs are formulated from a computer program. The input variables include: (1) number of sacks of cement and gallons of water per cubic yard of concrete; (2) the specific gravities of the sand, rock, and cement involved; and (3) the percent, if any, of the air entraining agent involved. The computer output produces a table of batch quantities, based upon varying ratios of sand and rock, that may be chosen. Since the same aggregate sources were used to produce the concrete for both the bottom lift and the overlay, the specific gravities did not change. Both courses also maintained the same cement factor and water-cement ratio. The variable that did change

however was the percent of air entrainment. The two printouts can be seen in Appendix C. A six percent air entrainment was designed into the bottom lift and zero percent in the wax bead overlay. The slump for either lift was to be from one to three inches (50 - 150 mm).

A 37/63 sand-rock ratio was chosen for the lower portion of the deck. However, it was felt that this gradation had too high a percentage of coarse aggregate for the two inch (51 mm) overlay; so the design was changed to a 40/60 ratio. The AASHTO M 43, size No. 7 aggregate was used. The 0.5 inch (13 mm) size for a two inch (51 mm) overlay was the maximum allowable. A set retarding chemical admixture was used in both lifts since the temperature was above $75^{o}F$ ($24^{o}C$).

The batch weights per cubic yard for the wax bead overlay were computed as follows:

1. Using the 40/60 ratio, 1,235 pounds (560 kg) of sand would normally be used. Replace 2 cubic feet (0.06 m^3) of sand with 2 cubic feet (0.06 m^3) of wax beads per cubic yard (0.8 m^3).
2. Designing by the absolute solid volume method knowing the specific gravity of sand to be 2.607 and that of the wax beads to be 0.845, the following adjustments were obtained:

   Sand

   2.607 x 62.4 lbs/ft^3 x 2 ft^3 = 325 lbs removed.

   1235 lbs - 325 lbs = 910 lbs of sand per yd^3.

   Wax Beads

   0.845 x 62.4 lbs/ft^3 x 2 ft^3 = 105.46 lbs of beads added per yd^3.
3. After additional computations were completed, as shown in Appendix C, taking the moisture in the rock and sand into consideration and the absorption factor of the rock, the final batch weights per cubic yard were:

Material	Quantity
Sand	937 pounds
Rock	1821 pounds
Cement	658 pounds
Water	34 gallons
Set Retarder	20 ounces
Wax Beads	105 pounds

Bottom Lift

The bottom 6.5 inches (165 mm) of the deck were poured in three days; from July 23 through July 26, 1979. The concrete was a conventional Class AA type containing air entraining and retarding agents. Morrow Service Company batched the mix into 8.5 cubic yard (6.5 m^3) transit mixers at their plant in Perry and then hauled it to the bridge site. The plastic concrete was placed in the forms by use of a one cubic yard (0.8 m^3) bucket attached to a crane. It was then vibrated with a power vibrator and smoothed with a Gomaco finishing apparatus.

Trial Mix

A one cubic yard (0.8 m^3) trial mix was made incorporating the wax beads in the same manner that the mix would be produced for the two inch (50 mm) wax bead overlay. It was determined from discussion with the concrete plant personnel that all of the dry mix could not be added to the truck before any water as the drums would not turn 8.5 cubic yards (6.5 m^3) dry. There would have to be some degree of fluidity in the mix for the drum to turn. For this reason most of the water would be added simultaneously with the aggregates and cement. The wax beads had a tendency to adhere to the wetted sides of the mixer. Therefore, the remaining water was sprayed in with a hose after all of

the other ingredients had been added. This method seemed to work quite well as far as the mixing was concerned. This was a trial mix to determine a mix method of achieving good bead distribution. Another method might have been needed if tests showed that good bead distribution was not achieved.

Slump and air tests were performed. Although no air entrainment was added, the air meter indicated about 2.4 percent air in the mixture. This was fairly normal. The slump was 1.5 inches (38 mm). Seven-6 inch x 12 inch (150 mm x 300 mm) cylinders and three-6 inch x 6 inch x 18 inch (150 mm x 150 mm x 460 mm) beams were cast from the one cubic yard (0.8 m^3) trial mix for testing purposes.

Thirty eight hours after making the cylinders and beams, the first beam was broken flexurally according to ASTM Procedure C 78 using third-point loading. The beam had a flexural strength of 475 psi (3.3 MPa). The broken surfaces were then studied under a magnifying glass. The wax beads were very evenly distributed on both surfaces. The broken beam was again broken at two new points for the purpose of checking bead distribution in different areas. After studying the new break points, it was determined that bead distribution was adequate. Therefore, the method of mix was acceptable. It was agreed however, that as much water as possible would be held out while the dry ingredients were being added. This detained water would then be sprayed into the mixing drum with a hose to wash any wax beads into the mix that had adhered to the side wall.

Placement of Wax Bead Overlay

Twenty eight days after the lower portion of the deck had been poured it was sand blasted and cleaned in preparation for the wax bead concrete overlay. The contractor began about 7:00 a.m. and finished at 4:30 p.m.

The temperature in the morning was approximately 70°F (21°C) with a relative humidity of 75 percent and no wind. During the afternoon the temperature rose substantially to the point that the bonding grout was getting stiff too quickly. The overlay was approximately 50 percent complete at 1:30 p.m. when the temperature reached 92°F (33°C). From this point forward the deck was wetted before applying the bonding grout. The grout was a sand, cement mixture placed on the deck in a wet condition prior to the overlay. The concrete was placed on the deck initially by a conveyor-belt system. However, one of the belt machines developed motor trouble, so the conveyor belt system was discarded by 10:00 a.m. The concrete trucks then backed up in front of the finishing machine and deposited the concrete on the deck. Sheets of "burline" were placed on the deck in order to catch any oil or grease spills from the trucks. As the pour proceeded, the burline mats were rolled up.

The finishing machine was the same Gomaco used to place the bottom lift. It consisted of a rotating auger, a horizontal cylinder with a vibrating pan float in front and a pan float in back. The vibrating front float provided the necessary vibration for the concrete. The trailing float provided the finish on the concrete. The metal, cylindrical roller could be used only because of the relatively low slump concrete. Some hand finishing was necessary in the gutter line, but it was minimal. Initial set took approximately 2.5 hours for the concrete poured in the morning and was averaging about 2 hours for that placed in the afternoon. Also, during the morning damp burlap was placed over the wax bead concrete approximately one hour after the pour. In the afternoon placement occurred thirty minutes after the pour. Rewetting of the burlap took place some twenty minutes after it had been spread. It should be pointed out that membrane forming compounds cannot be used for curing because the membrane interferes with moisture vapor removal prior to and during

heating.[1] Later in the day, burline sheets were placed over the wet burlap mats and weighted down with boards. At one point during the afternoon, however, a large section of wet burlap that had been placed during the morning was disturbed by gusty winds without being noticed for quite some time. By the time it was discovered, many shrinkage cracks had already begun to develop. See Photo 25. This occurred in the east shoulder area approximately 100 feet (30.5 m) from the south end of the bridge.

The wax bead concrete was mixed in four cubic yard (3.2 m^3) batches at the Morrow Service Co. plant in Perry. The wax beads were preweighed for each mix and manually dumped into the ready mix trucks after all of the other ingredients and most of the water had been placed. Mixing was accomplished with 85 revolutions of the drum, 60 at the plant and the remainder enroute to or at the job site. This procedure worked very well. Wax bead content tests were run at the bridge site throughout the day with a Chase air indicator using a sodium chloride solution. (This procedure is given in Appendix E.) The test results ranged from 7.3 percent to 7.8 percent wax bead content. This indicates a uniform dispersion of the wax beads. Air entraining admixture was not included in the wax bead overlay; however, set retarder was. Seven slump tests were run throughout the day with values ranging from 2.5 to 3.25 inches (64 to 83 mm) with the specification being from 2.0 to 4.0 inches (50 to 100 mm).

After the seventy-two hour curing period, the deck was tested by the chain drag method to insure that all of the two inch (51 mm) lift had properly adhered to the deck. The test showed the overlay to be satisfactorily bonded. No delaminations were discovered.

INTERNALLY SEALING

The bridge was ready to be heat treated after the wax bead overlay had cured for 28 days. Compressive strength tests performed on test cylinders indicated strengths of at least 5,000 psi (34.5 MPa). Just prior to heating, the entire bridge was cleaned by sweeping it with a power broom and then washing it with water.

Electric Blankets

The heating equipment consisted of 18 blankets each being 15 inches (381 mm) wide and 48.75 feet (14.86 m) long as shown in Photo 17. The blankets are constructed of metal heating elements and electrical insulating materials. An electrically continuous stainless steel outer sheath covers both sides, including stainless steel covers over the hinges. Hinges occur every 15 inches to 24 inches (381 to 610 mm). The stainless steel sheathing on the underside of the blankets is blackened to maximize radiant heat transfer. The continuous stainless steel sheathing is utilized as a positive grounding system. The blankets have a constant power, (at a constant voltage of 480) of 142 watts/ft^2 (1.53 kw/m^2) at 350°F (177°C) element temperature in all areas except on a 15 inch (381 mm) panel at the input end.

Heat Treating

Heating was begun at the south end of the bridge. Power was supplied to the blankets by a diesel powered Caterpillar 3408 generator shown in Photo 11. It provided a nominal 480 volts with an output capacity of 275 kw through three phases. The generator had a rheostat which allowed the voltage to be varied.

Lower voltages were used to stay within the limits specified by FHWA Office of Research for the first 1 1/2 hours of heating. Higher voltages were beneficial when the wind became stronger and during the cool nights.

The remaining portion of the electrical system consisted of a fuse box, transformers, feeder cables, a control console made up of breaker switches, and finally the blankets themselves. Other miscellaneous equipment required to complete this project included: (1) 32 rolls of R-19, 6 inch x 23 inch (150 mm x 585 mm) unfaced fiberglass insulation; (2) plastic mesh netting and steel bars to hold the insulation in place in the wind; (3) large sheets of plastic to be used only in case of rain; (4) portable generators; (5) electric drill; and (6) a set of three flood lights for night time activities.

Before any of the blankets were placed, the deck was marked with chalk by FHWA's Demonstration Projects engineers to indicate where the blankets should be located. From their calculations, it was found that 14 heat runs would be required, seven along each side of the bridge, and that 18 blankets would be needed for each heat run. Since the ends of the bridge are constructed at 45 degree skews, the blankets in each run were placed to take this into account.

Six sensors were used under each heat run to monitor deck heating activity. Three depth probe thermocouples and three surface temperature thermocouples, called "hockey pucks" because of their resemblance to real pucks, were placed on a diagonal axis under each heat run. The six thermocouples plus one ambient temperature thermocouple were wired into a single temperature monitor. The temperature probes were placed in 0.5 inch (13 mm) diameter holes to monitor concrete temperature at the two inch (51 mm) depth. The hole and probe were packed with drilling dust to provide good contact with the deck. The "hockey pucks" were placed on the surface adjacent to the probes. They were calibrated and a conversion table used to indicate the concrete temperature at a 1/16 inch (2 mm) depth.

The placement of the blankets for one heat run included 17 on the deck itself and one placed against the lower portion of the parapet wall. Placing the blanket on the wall was an attempt to prevent cracking by reducing the thermal shock created by the temperature gradient between the fully heated slab and the non-heated wall.

Six inches (150 mm) of unbacked fiberglass insulation placed over the heated blankets created a "full-heat" area. No insulation on top of a heated blanket created what was referred to as a "partial heat area." The full heat areas overlapped adjacent full heat areas a minimum of one foot (0.32 m) to assure complete sealing. All sections of the deck were covered by the blankets in succession and were fully heated. Figure 1 shows the heating sequence used on the bridge. Only one heat run and one cool-down area were done at once. However, Figure 1 shows two heat runs only for the purpose of illustrating the overlapping method. Each of the 14 heat runs had a partial heating zone created along the outer edges to taper the heat flow in these areas. The unbacked insulation was required to allow any moisture in the deck to escape. This fiberglass insulation was probably the single largest problem incurred during the heating phase. Wind blew fiberglass particles into the air during transfer from one heat run to the next. These particles managed to get under the clothes and gloves of the men moving the insulation causing skin irritation.

Controlled heating from the blankets provided enough time for moisture removal regardless of the concrete moisture content. This was accomplished by either of two methods: (1) voltage was regulated at the generator by the rheostat or (2) by manually turning breaker switches "off" or "on" at the control console. Each switch controlled two blankets. FHWA guidelines were followed by engineers in controlling heat treating of the wax bead concrete. This information may be seen in Appendix D.

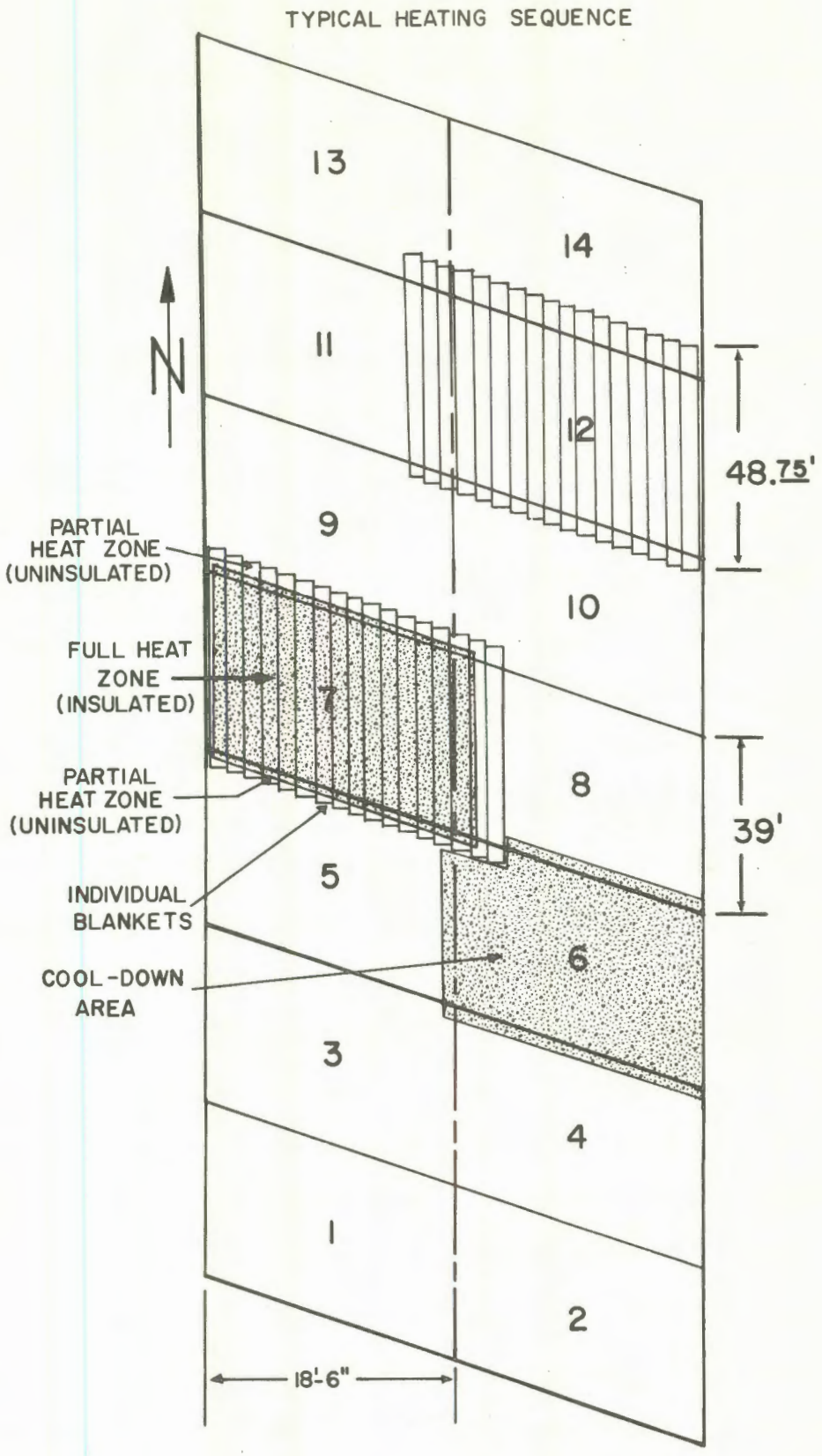


Figure 1. Plan view of the bridge deck showing the heating sequence. Blankets on Heat Run 12 demonstrate how heating areas overlapped the longitudinal center line.

Heating of the deck was begun at 6:30 p.m., Monday, September 17, 1979, and completed at 5:30 p.m. the following Saturday. Work proceeded on a 24 hour a day schedule during this week. Approximately 12 hours were lost due to a generator breakdown. This was the only system failure during the heating operation. The 14 heat runs averaged six hours each with the shortest being 5.25 hours and the longest requiring 9.0 hours. The shortest run time was probably achieved because heating was begun at 2 p.m. and the ambient temperature reached 86°F (30°C) that afternoon. The longest heating period required was begun at 1 a.m. with the ambient temperature averaging 57°F (14°C) throughout the night. Fourteen of the eighteen blankets were turned off at 7:30 a.m., or after 6.5 hours. However, the remaining four blankets did not achieve the required temperature until 10 a.m.

FHWA studies show the primary factors affecting blanket heating times are: (1) ambient temperature; (2) wind; (3) moisture in the deck; (4) blanket thermal stability; and (5) rain.[1] It was felt that this project was very fortunate in each of these aspects. Heating during the summer months would naturally have been more desireable with higher ambient temperatures available. Wind was not a factor with only a slight breeze during the daytime and calm at night. Also, no rain fell during the entire week.

The six heat runs begun during the day time averaged 5.7 hours each. The two heat runs begun during the early evening hours averaged 5.8 hours, and the 6 runs made at night averaged 6.5 hours. Figure 2 gives a graphic view of this heating process on a temperature versus time graph. It took approximately 1.3 hours to change the blankets from one heat location to the next using six men, or a total of 7.8 man hours. However, the first thirty minutes after full heat had been reached, and the power turned off, was used as a cool down period. During this period, the blankets were too hot to handle. Even after this period, the blankets remained very warm.

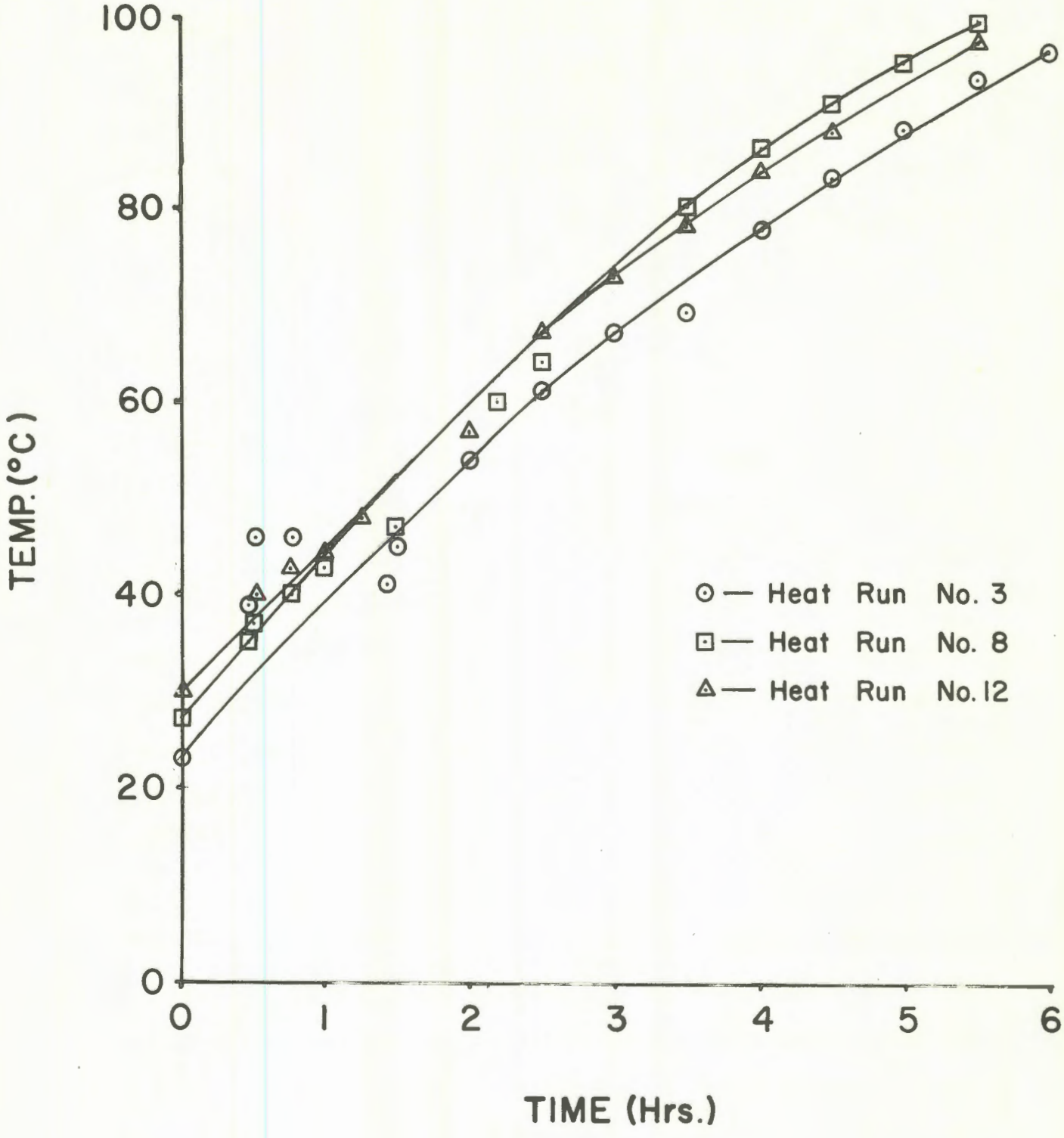


Figure 2. Typical heat runs showing the Temperature vs. Time effects of the heating blankets at a depth of two inches in the deck.

The heat runs were made in a stair-step fashion. The first heat run was made on the west side of the bridge beginning at the south end. The second run was made adjacent to the first one on the east side. The full heat areas overlapped at least one foot (0.3 m) along the longitudinal heating joints. The third run was made back on the west side of the bridge with the full heat transverse side overlapping that of the first heat run by one foot (0.3 m). This procedure was followed until the fourteenth or last heat run was made on the far northeast corner of the deck on September 22.

As full heating was completed on a particular run and the blankets moved to the next location, insulation was placed directly over the still hot deck. By going back and forth across the bridge no thermal gradient was set up along the bridge centerline.

FHWA and ODOT personnel were at the bridge site 24 hours a day during the heating phase. FHWA's project manager and two engineering technicians provided technical expertise and recorded technical data. With their advice and willing spirit, the job was made easy. All procedures went according to plan. This was, however, a direct result of organizing and coordinating prior to the actual heating period.

Cost Analysis

Table 2 shows most of the costs incurred as a result of internally sealing the deck. These are in addition to those incurred during construction of a traditional deck. It must be remembered that these costs are generated only as a result of this particular project constructed in 1979. The two concrete prices are those bid for the given quantitites. Personnel costs and some miscellaneous expenses are not shown. The number of man hours and machine hours are discussed in this report. Any agency that is considering doing an internally sealed concrete project could use the procedures in this report to develop a cost estimate for their individual situation.

COST ANALYSIS

MATERIAL	Quantity	Unit Price	Amount
Class "AA" Concrete	269.95 C.Y.	$170.00	$45,891.50
Class "AA" Internally Sealed Wax Bead Conc.	62.45 C.Y.	$300.00	$18,735.00
Cost of Wax Bead Concrete above that of conventional Class "AA" Concrete:		($300 - $170)(62.45 C.Y.) =	$ 8,118.50
Generator	7 days	$143.00	$ 1,001.00
Diesel Fuel	1059 gallons	$ 0.80	$ 847.20
Insulation	32 rolls	$ 13.14	$ 420.48
Plastic Sheets			$ 50.00
Electric Heat Blankets, Mesh Netting, and FHWA personnel costs not included.			$ 0.00
Two small portable generators, portable flood lights, personnel costs and expenses not included.			$ 0.00
		Total	$10,437.18 *

* This represents materials and equipment costs of $1.03 per square foot above that of a conventional deck, but does not include labor which would be roughly equal in cost.

TABLE 2. Cost Analysis

TESTS RUN

Crack Survey

A preheat crack survey was run when the wax bead deck was 23 days old, or 4 days before heating was to begin. The cracks found were predominately the very narrow shrinkage crack type and the majority fell within nine feet (2.7 m) of the east parapet wall. They primarily developed in groups with the cracks in each group being four to six feet (1.2 to 1.8 m) long and approximately a foot apart (0.3 m). Going from south to north along the bridge, the first group occurred from the 80 foot (24 m) to the 135 foot (41 m) mark. A second group, that was far less severe, was located from the 135 foot (41 m) to the 190 foot (58 m) mark. These were very small shrinkage cracks occurring far less frequently. Figure 3 gives a sketch of the deck showing the crack survey.

It was in these two areas that the burlap used during the initial cure had been disturbed by the wind. The plastic concrete was exposed approximately one hour. One interesting phenomenon about these cracks was that they were oriented from southwest to northeast. It was theorized that they followed this inclination because the wind had been blowing in this direction during the state of initial set and cure. Also, the maximum slope was perpendicular to the cracks. Pouring uphill would have reduced the tension stresses in the fresh concrete.

The post-heat crack survey was run three days after heat treating was completed. No new cracks were discovered as a result of the heating operation. However, something noteworthy did occur as the deck was wetted in preparation for running the survey. The entire deck "beaded-up." The previous

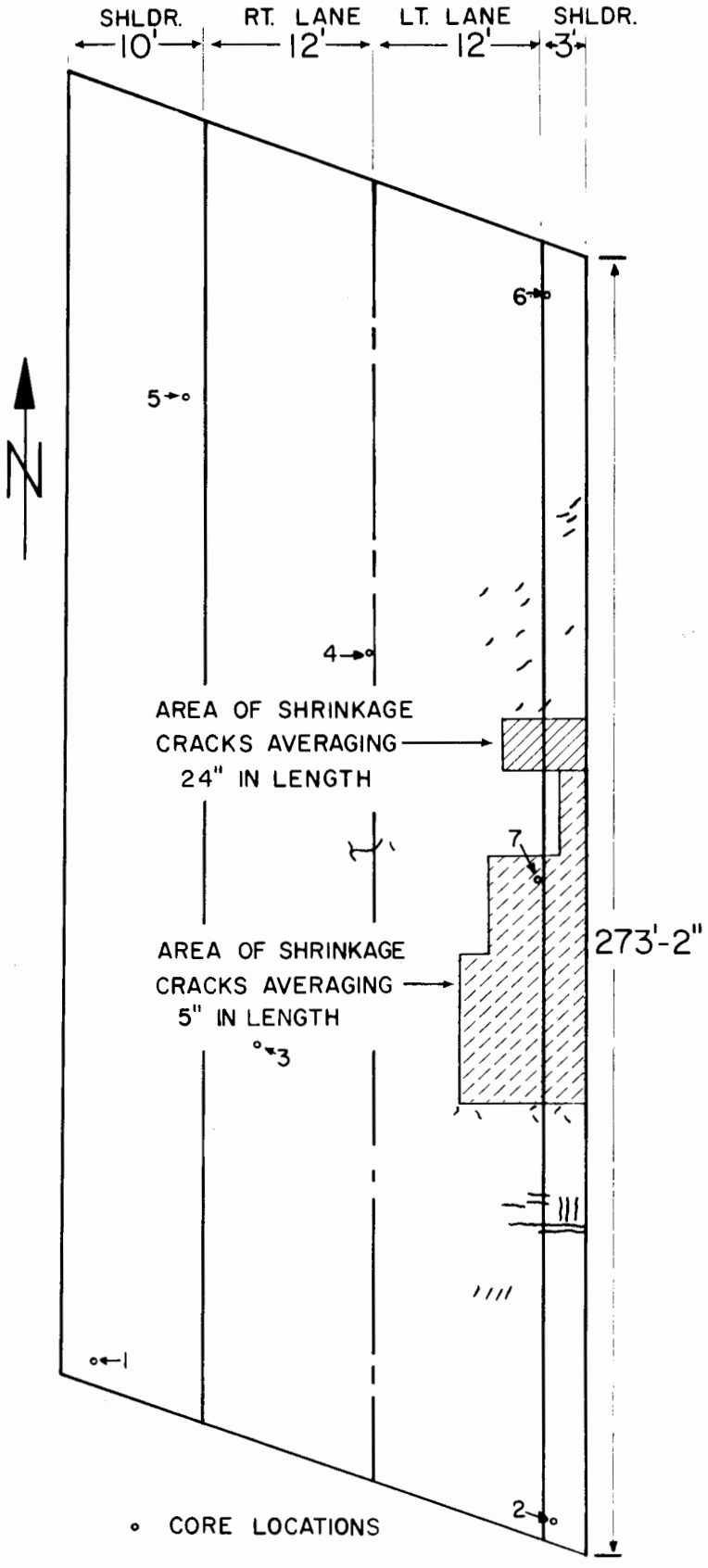


Figure 3. Crack Survey & Core Locations.

cracks had been sealed and appeared smaller. As the deck dried, water did not stay over the cracks as it had done on the previous survey.

Penetration

Three cores were taken from the heated bridge deck two days after heating was completed. The samples were split in half and placed in an air-circulating oven at 100°F (38°C) for 14 days. The dried cores were soaked in water containing red dye and a wetting agent, Calgon, for 14 days. They were then split and the dye penetration was observed. There was no significant penetration of the cores.

Absorption

Absorption tests were run on concrete core samples that were taken from the deck approximately ten months after it had been heat treated. A 24 hour absorption test, as described previously, was run on the top two inches (50 mm) of a core taken from the southbound lane of the deck and resulted in a 1.2 percent absorption by dry weight.

Skid Test

Skid tests were run on the bridge deck approximately two days after the deck had been heated. Testing was done at the standard operating speed of 40 miles/hour (64.4 km/hour). Results of the test showed that the outside lane had a skid number of 55 and the inside lane had a skid number of 46. These results are within the range of values found on normal concrete surfaces under similar conditions.

Half-Cell

Reinforcing steel imbedded in sound, uncontaminated concrete does not

normally corrode. However, when a metal does begin to corrode it goes from what is referred to as a passive state to an active state. Researchers in the field of reinforced concrete have found that when imbedded steel becomes passivated and begins to corrode, its half-cell potential becomes more negative when using a $Cu/CuSO_4$ electrode as a reference. That is to say that more active metals exhibit larger negative half-cell potentials than less active metals or depassivated ones. Normally passivated reinforcing steel will have a half-cell potential of 100 to 250 mV negative to the $Cu/CuSO_4$ electrode. With the addition of sufficient quantitites of chloride salts the imbedded steel will become active and begin to corrode. The potential will climb above 300 mV and may exceed 600 mV.[3]

From a half-cell survey run on the bridge deck four days after heating, it was determined that the rebar was not corroding. All of the readings were exceptionally low with the highest being 167 mV. These readings will be used as base values.

Compressive Strength

The compressive strengths of the wax bead concrete cylinders were tested 28 days after placement. The cylinders were first covered with wet burlap mats for 24 hours and then were placed in lime water. The test showed that all of the cylinders had strength above the desired 4000 psi (27.6 MPa) level and had an average strength of 5552 psi (38.28 MPa). The lowest cylinder strength was 5100 psi (35.2 MPa) and the highest was 6010 psi (41.44 MPa).

A cylinder containing wax beads was tested approximately one year later. The result was a compressive strength of 5940 psi (40.96 MPa).

Another wax bead cylinder was heated in the laboratory one year and eight months after casting. The heating was controlled. It was heated at the same rate as the bridge deck had been. Upon obtaining full heat, the cylinder

was allowed to cool at a controlled rate. Six days were allowed for the cylinder to achieve thermal stability before being subjected to a compressive strength test.

The heated wax bead cylinder had a compressive strength of 4460 psi (30.75 MPa) which is 10 percent in excess of design strength. This is approximately 20 percent less than the average strength of 28 day unheated wax bead concrete. These tests indicate that there should be no significant problems with the strength of internally sealed concrete.

Flexural Strength

The flexural strength of concrete for the bridge deck was determined by means of bonding tests on 6 x 6 inch (150 x 150 mm) beams. Tests showed that the concrete beams had 666 psi (4.6 MPa) modulus of rupture after 7 days and 733 psi (5.1 MPa) after 14 days of age. This exceeded the desired 550 psi (3.8 MPa) for 28 days.

Chloride Penetration

Four core samples were taken from the internally sealed deck two days after heating was completed. Chloride penetration tests were run to determine the sealing effectiveness of the wax. The cores were each four inches in diameter by four inches long (100 mm x 100 mm) and were taken from the following sites:

Site 1. 5'-3" (1.60 m) from south end and 2'-3" (0.69 m) from west side.

Site 3. 83'-8" (25.50 m) from south end and 2'-4" (0.71 m) from east side.

Site 5. 58'-8" (17.88 m) from north end and 8'-2" (2.49 m) from west side.

Site 7. 136'-9" (41.71 m) from south end and 3'-3" (0.99 m) from east side.

These sites can be seen on Figure 3.

Core No. 1 was used as a control sample while the other three were ponded with a three percent sodium chloride solution for 90 days, as outlined in Attachment B of Appendix E. After this time period, the ponding solution was removed and three samples were taken from each core at the following depths:

"A" layer. 0.063 in. to 0.500 in. (1.6 mm to 13 mm).

"B" layer. 0.500 in. to 1.000 in. (13 mm to 25 mm).

"C" layer. 1.000 in. to 1.500 in. (25 mm to 38 mm).

The chloride content (pounds per cubic yard) of each sample was determined in accordance with the procedures described in Attachment C of Appendix E. The results can be seen in Table 3. Please note that the chloride content obtained on sample 7C appears to be in error. (See paragraph 4.3.7 in Appendix E.)

The test results show that the chloride content was confined at or above the 0.50 inch (13 mm) depth. The average reading for the "A" layer was 4.18 lbs/yd^3 as compared to 0.41 lbs/yd^3 on the control core. The "B" layer averaged 0.35 lbs/yd^3 as compared to 0.16 lbs/yd^3 in the control core. The "C" layer averaged 0.12 lbs/yd^3, disregarding the apparently erroneous value found for that of the No. 7 core, as opposed to 0.06 lbs/yd^3 in the "C" layer of the control. After the 90 day ponding test, the "B" and "C" layers showed a doubling in the amount of chloride. However, this value is insignificant when compared to the amount of chloride required to harm the steel.

A value of 1.50 pounds of chloride per cubic yard (0.89 kg/m^3) of concrete is generally considered as the maximum allowable before corrosion of the bars sets in. At any value below 1.5 lbs/yd^3, it is conservative to say that the reinforcing steel is not corroding.

The "C" layer, which is a minimum of 0.50 inches (13 mm) above the top of the steel, contains only eight percent of the chloride content that is

considered harmful. It is therefore concluded that internally sealing the concrete deck with wax beads has for all practical purposes stopped the ingress of the chloride solution.

Core Hole Patching

As a result of temperature probe holes and test cores the concrete deck had numerous holes. If future tests were to be of any relevance, these holes had to be filled and sealed in a manner that would assure that they were as water tight as the internally sealed deck itself. This was accomplsihed by first spraying the inside of the holes with a liquid sealing product, Chem-Trete. The holes were then filled with a cement grout and struck off flush. Once the grout had set up, Chem-Trete was brushed over the top to complete the sealing.

****
* OKLAHOMA DEPARTMENT OF HIGHWAYS *
* MATERIALS DIVISION *
* CHLORIDE ANALYSIS *
****

PROJECT NO.: I-35-4(94)184 REPORT DATE ...12-08-80
DATE RECEIVED : 0-00-80
DATE SAMPLED : 6-10-80
COUNTY : NOBLE
BRIDGE : 01-CB0001
COMMENTS : I-35-4(94)184-NOBLE COUNTY-(COW CREEK BRIDGE)

% LOSS(<.625) = 4.015 % LOSS(>0.625) = 4.220 % LOSS(ALL DEPTHS) = 4.150

SAMPLE (1)	STA.	LANE (2)	HALF CELL	SAMPLE DEPTH	STEEL DEPTH	% CL- (RECD)	% CL- (DRY)	% H2O	% LOSS	ADJ. % CL- (3)	CL-LBS. / CU.YD. (3)
1A	0+ 0	0	0	0.063 TO 0.500	0.0	0.0113	0.0115	2.043	4.61	0.0106	0.4134
1B	0+ 0	0	0	0.500 TO 1.000	0.0	0.0043	0.0044	1.433	4.58	0.0040	0.1574
1C	0+ 0	0	0	1.000 TO 1.500	0.0	0.0015	0.0015	1.347	4.16	0.0015	0.0574
3A	0+ 0	0	0	0.063 TO 0.500	0.0	0.1630	0.1660	1.856	4.50	0.1556	6.0914
3B	0+ 0	0	0	0.500 TO 1.000	0.0	0.0181	0.0184	1.933	4.59	0.0170	0.6637
3C	0+ 0	0	0	1.000 TO 1.500	0.0	0.0045	0.0046	1.657	4.00	0.0046	0.1797
5A	0+ 0	0	0	0.063 TO 0.500	0.0	0.0737	0.0749	1.597	4.25	0.0744	2.9122
5B	0+ 0	0	0	0.500 TO 1.000	0.0	0.0069	0.0070	1.828	4.50	0.0066	0.2578
5C	0+ 0	0	0	1.000 TO 1.500	0.0	0.0014	0.0014	2.541	4.24	0.0014	0.0532
7A	0+ 0	0	0	0.063 TO 0.500	0.0	0.0998	0.1018	2.014	4.75	0.0904	3.5383

(1) THE NUMBER IS THE HOLE FROM WHICH THE SAMPLE WAS TAKEN. THE LETTER IS THE POSITION WITHIN THE HOLE. A=TOP OR FIRST. B=SECOND ETC.
(2) LANES ARE NUMBERED FROM LEFT TO RIGHT FACING IN THE DIRECTION OF STATIONING.
(3) THE VALUES ARE ADJUSTED FOR DIFFERENCES IN THE AMOUNT OF AGGREGATES IN INDIVIDUAL SAMPLES.

TABLE 3. Chloride Analysis

REPORT DATE . . .12-08-80 PROJECT NO. . .I-35-4(94)184 PAGE . . . 2

% LOSS(<.625) = 4.015 % LOSS(>0.625) = 4.220 % LOSS(ALL DEPTHS) = 4.150

SAMPLE (1)	STA.	LANE (2)	HALF CELL	SAMPLE DEPTH	STEEL DEPTH	% CL- (RECD)	% CL- (DRY)	% H2O	% LOSS	ADJ. % CL- (3)	CL-LBS. / CU.YD. (3)
7B	0+ 0	0	0	0.500 TO 1.000	0.0	0.0032	0.0033	2.258	4.55	0.0030	0.1189
7C	0+ 0	0	0	1.000 TO 1.500	0.0	0.1089	0.1106	1.572	4.51	0.0984	3.8514
11S	0+ 0	0	0	0.063 TO 0.500	0.0	0.0054	0.0055	1.439	4.77	0.0048	0.1898

(1) THE NUMBER IS THE HOLE FROM WHICH THE SAMPLE WAS TAKEN. THE LETTER IS THE POSITION WITHIN THE HDLE. A=TOP OR FIRST. B=SECOND ETC.
(2) LANES ARE NUMBERED FROM LEFT TO RIGHT FACING IN THE DIRECTION OF STATIONING.
(3) THE VALUES ARE ADJUSTED FOR DIFFERENCES IN THE AMOUNT OF AGGREGATES IN INDIVIDUAL SAMPLES.

TABLE 3. Chloride Analysis (continued)

SUMMARY AND CONCLUSIONS

The objective of this study was to pour and heat a wax impregnated concrete bridge deck on a full-scale basis to gain further experience with the procedure. It is felt that the results of this objective were very successful.

Several tests run on the bridge deck after it had been internally sealed indicated that a successful project had been accomplished:

1. A crack survey revealed that no new cracks could be observed as a result of the heating operation.
2. Twenty four hour absorption tests performed on core samples taken from the deck showed a 1.2 percent absorption by dry weight. This value is considerably lower than that of normal Type AA concrete. It was theorized that part of this absorption was taking place through the surface aggregate.
3. Dye penetration tests revealed no significant penetration after soaking for 14 days. Upon breaking the cores, dye could not even be detected at the 1/32 inch (0.8 m) depth.
4. Results of tests to measure the skid resistance of the internally sealed surface after the wax had been melted were no lower than what may have been expected on normal concrete surfaces under similar conditions.
5. Half-cell potential tests run on the deck using $Cu/CuSO_4$ as the base electrode showed low potential readings, indicating no corrosion, as expected. These initial values will serve as reference data for future observations.

6. Compressive and flexural strength tests indicated that the wax beads had no detrimental effects on the concrete. It was as strong as conventional Class AA bridge deck concrete.
7. Laboratory ponding test results with three percent sodium chloride solutions indicated that internally sealing the concrete limited the harmful amounts of chloride above the 0.5 inch (13 mm) depth. This is well above the top of the steel level which is two inches (50 mm).
8. Delamination soundings were made by the audio chain-drag method in an attempt to locate any unsound or poorly bonded areas. None were found.

Internally sealing bridge deck concrete with melted wax beads is a reasonably simple method to perform in the field. The method does not adversely affect the strength of the concrete or the surface properties. Based solely upon the prices bid on this project, plus equipment and materials to heat the deck, it cost \$1.03 per square foot (\$11.09/m^2) more to construct the deck of internally sealed concrete than with standard concrete. The additional labor is not included in this price. Table 2 shows the cost breakdown. It is felt that sealing bridge decks by the wax bead method should be at least considered as a viable option in the bridge design process with the other available alternatives.

REFERENCES

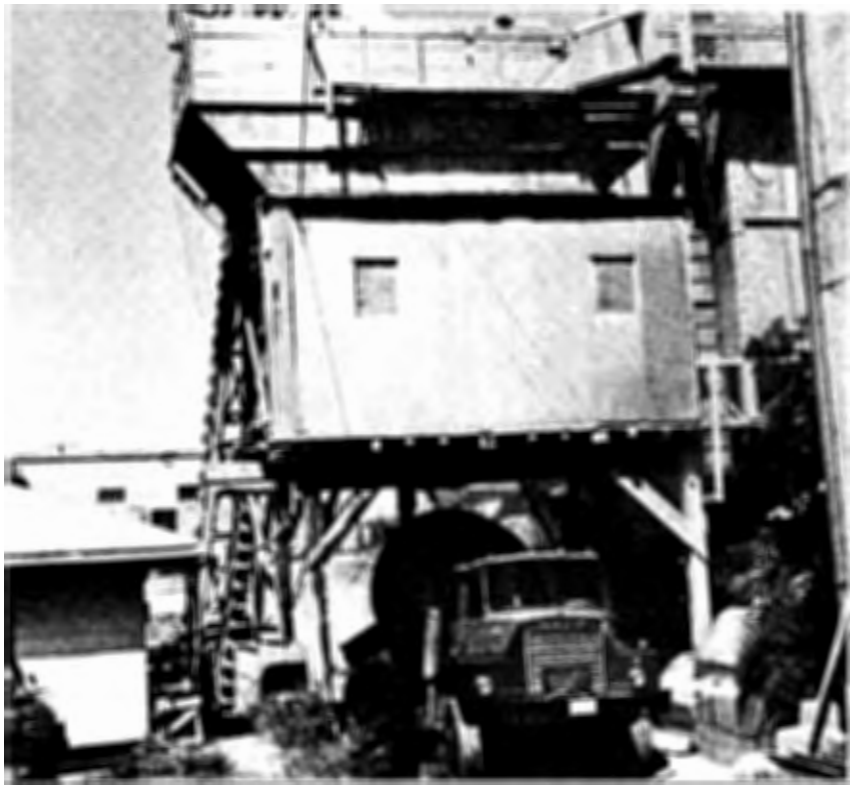
1. Implementation Package 77-9, "Internally Sealed Concrete - Guide to Construction and Heat Treatment", U.S. Department of Transportation, Offices of Research and Development, Implementation Division, April 1977.

2. "Oklahoma Geology Notes", Oklahoma Geological Survey, University of Oklahoma, Norman, Oklahoma, Vol. 32, No. 5, October 1971.

3. Ward, Phil, "Bridge Deck Rehabilitation: Methods and Materials", Oklahoma Department of Transportation, Research and Development Division, Part I, August, 1977.

APPENDIX A

PHOTOGRAPHS



Photograph 1: Concrete batch plant used to produce the base lift and the wax bead concrete.

Photograph 2: Inspecting the wax beads.

Photograph 3: Wax beads being manually added to the drum mixer.

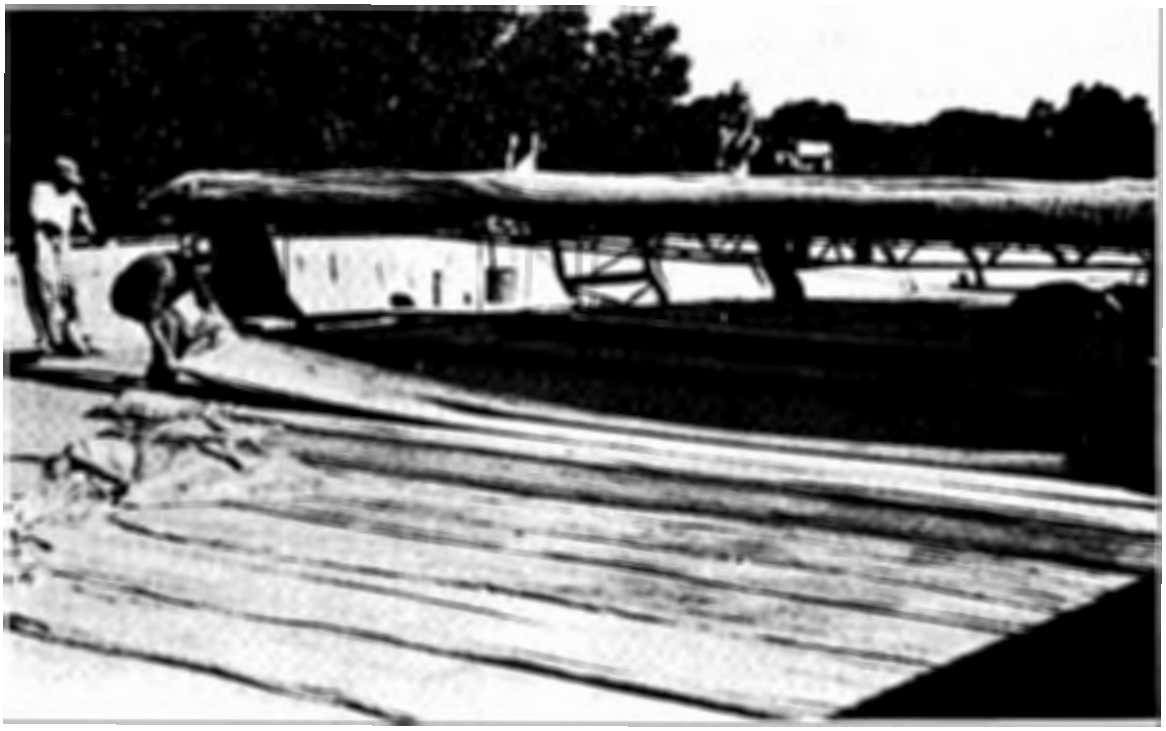
Photograph 4: Water was used to wash all of the beads into the drum.

Photograph 5: Cylinders and beams were made from a trial mix of the wax bead concrete.

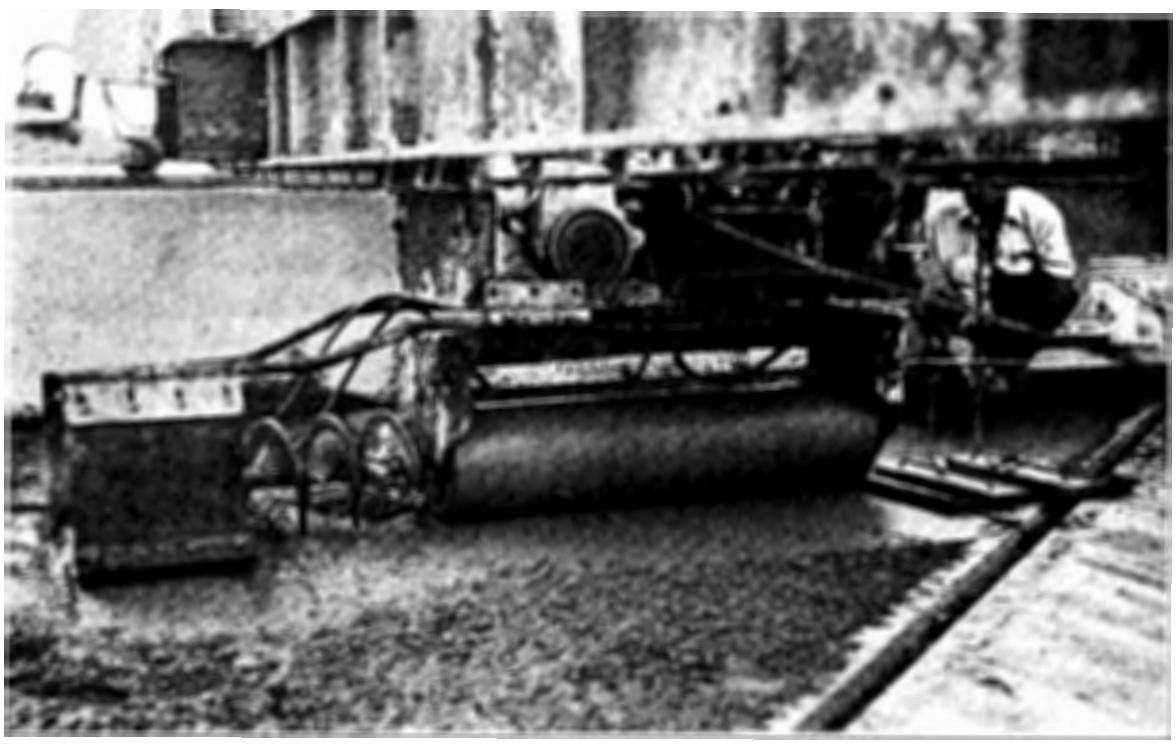
Photograph 6: Slump tests were run on the trial mix.

Photograph 7: The bottom course was placed to 0-1/2 inch above the reinforcing bars.

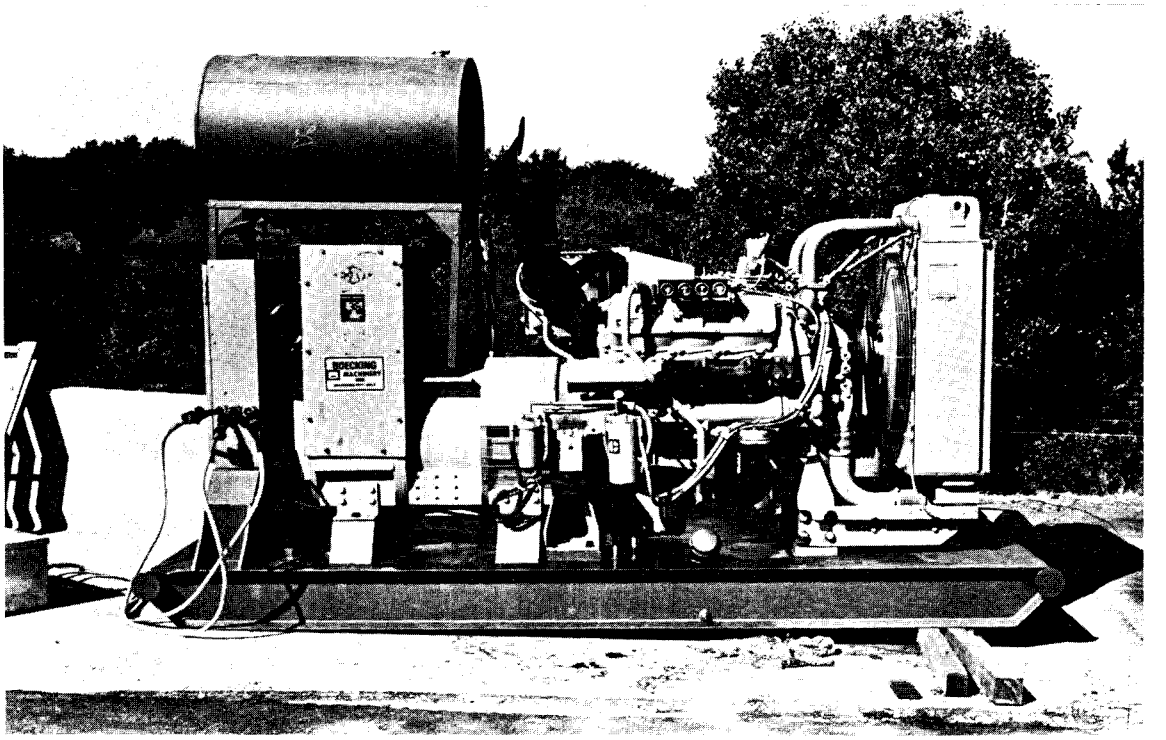
Photograph 8: A sand-cement grout was broomed on the bottom course immediately before the wax bead overlay was placed.



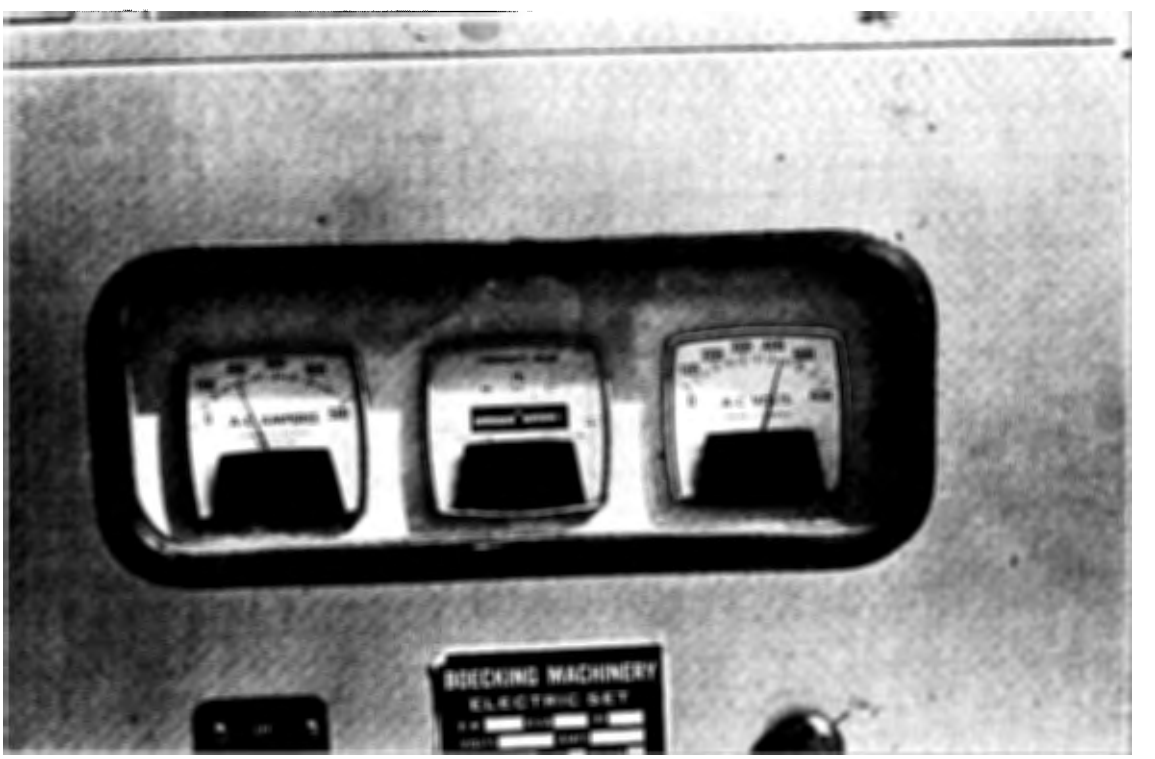
Photograph 9: The wax bead concrete overlay was placed and finished 28 days after the bottom course.



Photograph 10: Wet burlap was used for curing the concrete.



Photograph 11: The generator used to supply power to the heat blankets.

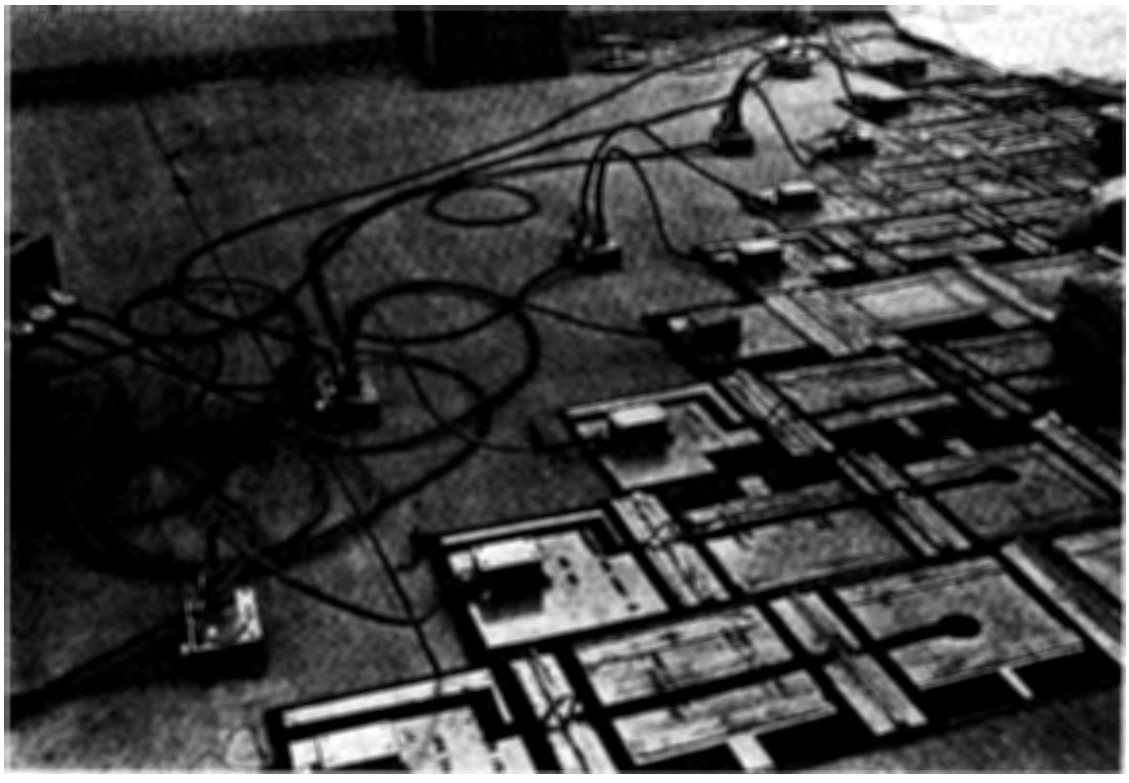


Photograph 12: Display gauges on the generator. This type of instrumentation was necessary for effective control of power. This generator also has an excitor switch and a wide range rheostat which are highly desirable.

Photograph 13: Transformer with the fuse box and generator in the background.

Photograph 14: Power cable used to connect the control console to the transformer.

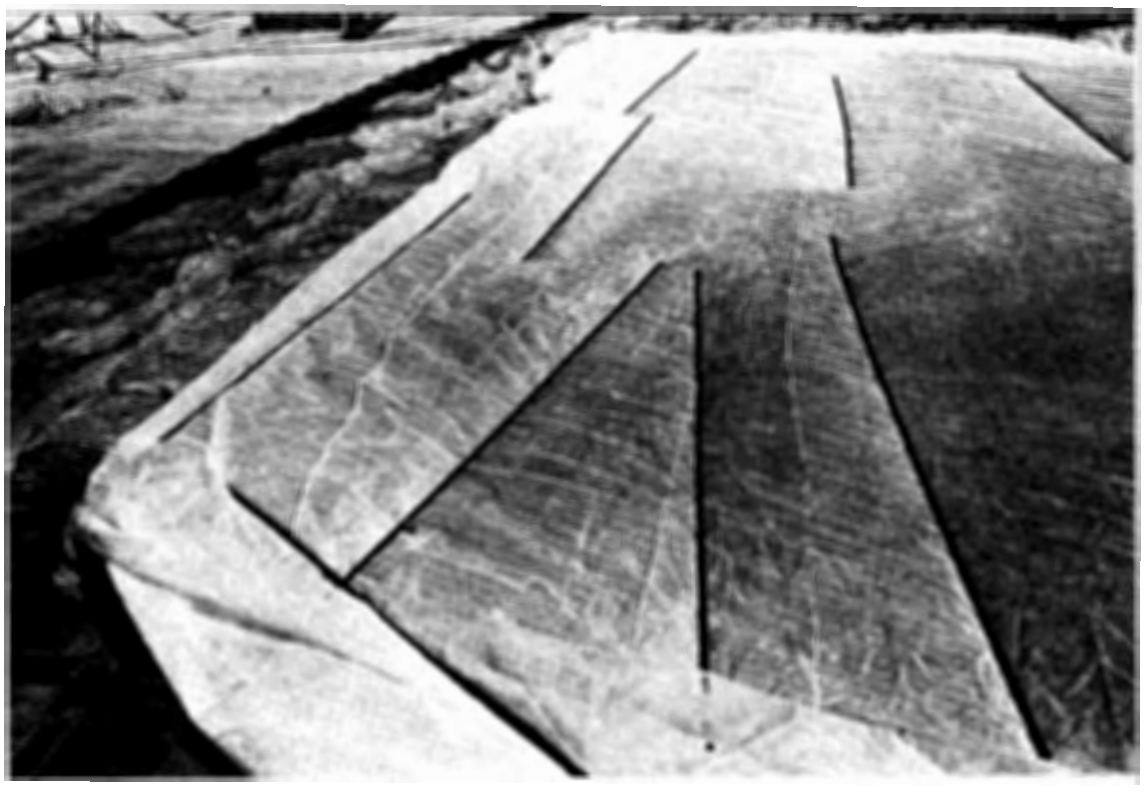
Photographs 15 & 16: Control console. Flashing red light would come on automatically if any of the circuits broke.



Photograph 17: Each breaker switch controls two heat blankets.

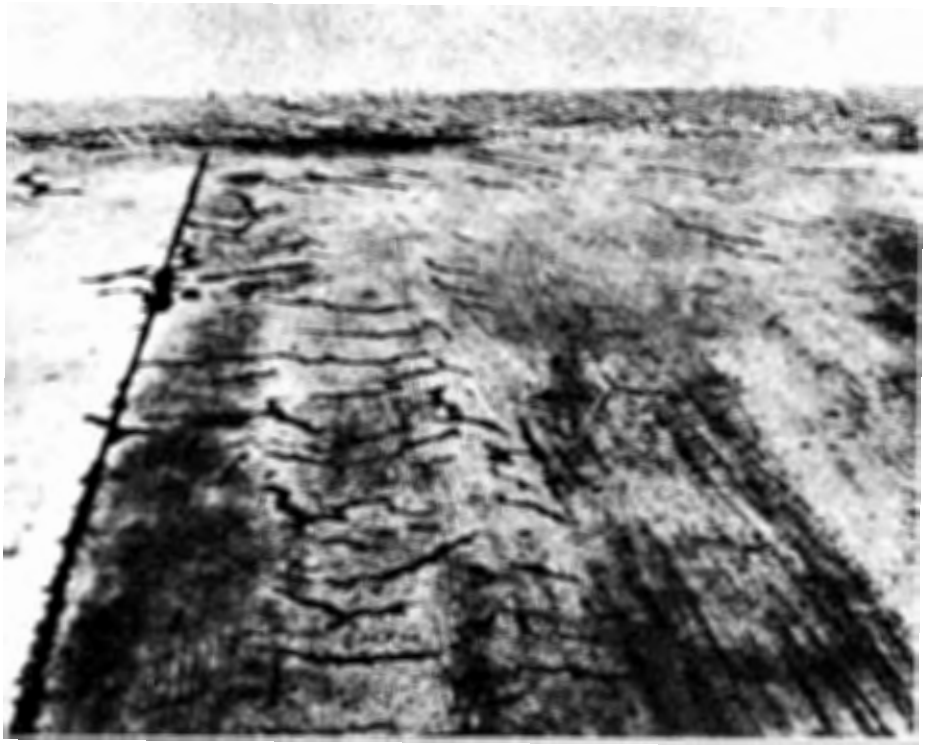
Photograph 18: A partial heat zone (no insulation) is set up around the perimeter of each heat run.

Photographs 19 & 20: Three sets of thermocouples (2 inch level) and hockey puck (surface) were placed under each heat run. They were wired into a central temperature monitor.



Photographs 21 & 22: Blankets and insulation were placed and covered with mesh netting and weights to prevent wind disturbance. Portable flood lights were used for night operations.

Photographs 23 & 24: The blankets were handled with care when carried from one heat run to the next.



Photographs 25 & 26: Crack surveys were run on the deck both before and after heat treating.

Photographs 27 & 28: Several cores were taken from the deck to determine the sealing effectiveness after heating. The holes were patched and sealed.

APPENDIX B

SPECIAL PROVISIONS

OKLAHOMA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION
FOR
INTERNALLY WAX SEALED CONCRETE BRIDGE FLOOR

These Special Provisions revise, amend, and where in conflict, supersede applicable Sections of Standard Specifications for Highway Construction, Edition of 1976.

504.01. DESCRIPTION. This work shall consist of the construction of an Experimental Internally Wax Sealed Concrete Bridge Deck in accordance with these Specifications or as established by the Engineer.

504.02. MATERIALS. The wax beads shall consist of a physical blend of 75 ± 5 percent Paraffin Wax, melt point of 149° F ± 2° F (65° ± 1.1° C) and 25 ± 5 percent crude grade Montan wax.

The wax beads size shall be as follows:

Sieve Size	(mm)	Percent Passing
No. 20	(0.85)	99-100
No. 80	(0.18)	0-5

Wax beads shall be spherical in shape and have a specific gravity of 0.845 ± 0.020 with a void volume of 8.0 to 12.0 percent. Further, a minimum of 60 percent of the beads shall have discernible voids.

The wax beads shall be packaged in containers not to exceed 250 lbs (113.4 kg) and in such a way as to prevent sintering and moisture ingress during shipment and storage. Maximum temperature indicators shall be placed in two of the wax beads containers and plainly marked.

The Contractor shall furnish a type "A" certification for each lot of material furnished to the project.

The Internally Wax-Sealed concrete shall be Class AA concrete as specified in Section 701 except that it shall be non-air entrained and 2 cu ft per cu yd (0.074 cu M/cu M) of the fine aggregate shall be replaced with the wax beads.

504.04. CONSTRUCTION METHODS. The wax beads shall be shipped and stored in such a manner that they are not exposed to temperatures in excess of 120° F (49° C). All containers shall be shipped and stored in the same environment.

On delivery the Contractor shall notify the Research and Development Division so that the maximum shipping temperature may be recorded.

The reinforced concrete in the bridge deck shall be placed in two layers. The bottom layer shall be Class AA concrete meeting the requirements of Section 701. The bottom layer shall be placed, consolidated and struck off without excessive manipulation to 1/2 inch (12.7 mm) above the top mat of reinforcing steel. The Contractor shall notify the Research & Development Division after the reinforcing steel has been placed so the Research & Development Division can install Thermocouples on the steel prior to the placement of the concrete in the bottom layer.

Any portion of the bottom layer of concrete which has been placed more than 30 minutes without being covered with the top layer shall be removed and replaced with freshly mixed concrete at the Contractor's expense.

The surface course shall be Internally Wax Sealed concrete meeting the requirements specified above. It shall have a minimum finished thickness of 2 inches (5.1 cm) and shall be finished in accordance with Section 504.04(e). Care should be taken in the finishing operation to prevent the wax beads from floating to the surface.

The deck shall be covered with wet burlap and polyethylene sheet or a similar approved wet curing process, as soon as finishing is completed. The covering shall be placed and lapped so no moisture will be lost in the concrete through the surface until the curing period has ended. The concrete shall be cured for a minimum of seven days or as otherwise directed by the Engineer.

This system requires the wax in the wax-impregnated bridge deck concrete be melted after the deck has been cured. Heat treatment will be performed by the Research & Development Division anytime after the bridge deck is 28 days old and before opening to traffic.

504.05. METHOD OF MEASUREMENT. The Internally Wax-Sealed concrete shall be measured by the cubic yard of Class AA Internally Wax-Sealed concrete calculated on a theoretical basis according to the dimensions shown on the Plans and the 2 in (5.1 cm) thickness of the surface course placed and accepted.

504.06. BASIS OF PAYMENT. The Internally Wax-Sealed concrete, as measured above will be paid for at the contract unit price

(B)SP CLASS "AA" INTERNALLY WAX-SEALED CONCRETE CU.YD.

which shall be full compensation for furnishing all materials, equipment, labor and incidentals to complete the work as specified.

APPENDIX C

MIX DESIGNS

CONCRETE DESIGN DATE: 04-23-79 TIME: 08.24.40

PROJECT: I-FI-35-4(94)184 BRIDGE JOB MORROW SERVICE CO. PERRY, OK

CLASS AA(AE) CONCRETE. DESIGN RUN BY: MARVIN BEIER

MATERIAL	SPECIFIC GRAVITY	SOURCE
SAND	2.607	BLACKBURN SAND, BLACKBURN, OK
ROCK	2.524	STD. IND., INC. (PEEL) KAW CITY, OK
CEMENT	3.150	IDEAL CEMENT, ADA, OKLAHOMA

USING 658 POUNDS OF CEMENT AND 35.00 GALLONS OF WATER PER CUBIC YARD, WHICH GIVES A WATER TO CEMENT RATIO OF 0.44.

WITH 6.00 % AIR ENTRAINING.

PERCENT		POUNDS/CUBIC YARD			ABSOLUTE VOLUME (CUBIC FEET/CUBIC YARD)				
SAND	ROCK	SAND	ROCK	CEMENT	SAND	ROCK	CEMENT	WATER	AIR
35	65	989	1778	658	6.0780	11.2877	3.3476	4.6667	1.6200
36	64	1017	1750	658	6.2517	11.1141	3.3476	4.6667	1.6200
37	63	1045	1723	658	6.4253	10.9404	3.3476	4.6667	1.6200
38	62	1074	1696	658	6.5990	10.7668	3.3476	4.6667	1.6200
39	61	1102	1668	658	6.7726	10.5931	3.3476	4.6667	1.6200
40	60	1130	1641	658	6.9463	10.4194	3.3476	4.6667	1.6200

WITH 0.0 % AIR ENTRAINING.

PERCENT		POUNDS/CUBIC YARD			ABSOLUTE VOLUME (CUBIC FEET/CUBIC YARD)				
SAND	ROCK	SAND	ROCK	CEMENT	SAND	ROCK	CEMENT	WATER	AIR
35	65	1081	1944	658	6.6450	12.3407	3.3476	4.6667	0.0
36	64	1112	1914	658	6.8349	12.1509	3.3476	4.6667	0.0
37	63	1143	1884	658	7.0247	11.9610	3.3476	4.6667	0.0
38	62	1174	1854	658	7.2146	11.7712	3.3476	4.6667	0.0
39	61	1205	1824	658	7.4044	11.5813	3.3476	4.6667	0.0
40	60	1235	1794	658	7.5943	11.3914	3.3476	4.6667	0.0

AIR ENTRAINED CONVENTIONAL MIX

Material	Cubic Feet of Solid per Cubic Yard	Design Weights per Cubic Yard (lbs)
Air	1.62	0
Cement (C.F. = 7.0)	3.34 (S.G. = 3.15)	658
Water (W/C = 0.44)	4.67	290
Fine Aggregate (37% of total aggregate)	6.43 (S.G. = 2.61)	1045
Coarse Aggregate (63% of total aggregate)	10.94 (S.G. = 2.52)	1723
TOTAL	27.00	3716 (or 137.6 lbs/ft^3)

CONVERSION TO INTERNALLY SEALED CONCRETE

Before any conversions were made, the mix design was changed due to different percentages of air entrainment and differences in the sand/rock ratio requirements. The conversion to the wax bead concrete from the conventional mix was then based on the revised mix design. The conversion was made by replacing 2.0 ft^3 per yd^3 of fine aggregate with 2.0 ft^3 per yd^3 of wax beads on an absolute volume basis.

The following calculations were made:

1. Amount of Fine Aggregate removed: $(2\ ft^3/yd^3)(2.607)(62.4\ lbs/ft^3)=325\ lbs/yd^3$
2. Amount of Wax Beads added: $(2\ ft^3/yd^3)(0.845)(62.4\ lbs/ft^3)=105.5\ lbs/yd^3$

NEW MIX DESIGN (lbs/yd^3)

1.	Fine Aggregate. 1235 - 325 =	910
2.	Coarse Aggregate.	1794
3.	Cement.	658
4.	Wax Beads.	105.5
5.	Water.	290
	TOTAL	3757.5

(or 139.2 lbs/ft^3)

MOISTURE

Moisture content and absorption tests were performed on the aggregate just prior to batching. The results were as follows:

A. Moisture Content of the Sand: 2.9%
B. Moisture Content of the Rock: 1.5%
C. Absorption Factor of the Rock: 2.7%

Batch Design Moisture Calculations:

A. The mix design calls for 910 lbs of sand. It contains 2.9% moisture.
Therefore; (100% - 2.9%)(X) = 910; $X = \frac{910}{.971}$ = 937.18 lbs of bulk sand
- 910.00 lbs of pure sand
27.18 lbs of moisture

B. The mix design calls for 1794 lbs of rock. The rock contains 1.5% moisture.
Therefore; (100% - 1.5%)(X) = 1794; $X = \frac{1794}{.985}$ = 1821.32 lbs of bulk rock
- 1794.00 lbs of pure rock
27.32 lbs of moisture

C. The rock was found to have an absorptive factor of 2.7%.
(1794 lbs of rock) (2.7%) = 48.44 lbs of moisture absorbed.

Moisture In the Mix Due to the Aggregates:

27.18 lbs of moisture in the sand
+ 27.32 lbs of moisture in the rock
54.50 lbs of moisture in the aggregate
- 48.44 lbs of moisture absorbed by the rock
6.06 lbs of excess moisture

Batch Water Requirements:

(6.06 lbs) (1 gal/8.33 lbs) = 0.73 gallons

35.00 gallons - 0.73 gallons = 34.27 gallons of water required to be batched into the wax bead mix.

DESIGN PROCESS FOR INTERNALLY SEALED CONCRETE

Material	Conventional Concrete Mix Design (lbs/yd^3)	Conversion to Wax Bead Concrete (lbs/yd^3)	Batch Weights after Moisture Corrections (lbs/yd^3)
Air	0	0	0
Cement (C.F. = 7.0)	658	658	658
Water (W/C = 0.44)	292	292	286
Fine Aggregate (40% of Total Aggregate)	1235	910	937
Coarse Aggregate (60% of Total Aggregate)	1794	1794	1821
Wax Beads	0	105.46	105.46
Set Retarder	20 oz.	20 oz.	20 oz.
	3980.25	3760.71	3808.71
or	147.4 lbs/ft^3	139.3 lbs/ft^3	141.1 lbs/ft^3

The wax bead concrete is a lighter material than the conventional concrete due to replacing some of the fine aggregate with the lower specific gravity wax beads.

APPENDIX D

FHWA HEAT TREATING GUIDELINES

GUIDELINES AND FIELD OPERATIONS
CHECKLIST FOR
HEAT TREATING INTERNALLY SEALED CONCRETE

HEATING PARAMETERS

Limit surface temperature (at 1/16 inch depth) to maximum of 160°F in first 1.3 hours of the heat run. This limitation or precaution permits potentially damaging quantities of moisture vapor to escape before the wax starts to block capillaries and causing pressure buildup.

In addition to the above, the following limitations are applicable:

1. Limit surface temperature (at 1/16 inch depth) during initial 0.5 hour of heating, to not more than 145°F, nor less than 30°F above the ambient air temperature. These precautions are to insure removal of moisture to the extent necessary.

2. A temperature of 320°F is the maximum permitted, as a precaution against damage to the concrete due to excessive temperatures. These are monitored at equivalent 1/16 inch depth surface temperature.

Heat treating is complete when the concrete has reached 185°F at a 2-inch depth in all areas being heat treated, but shall not be attained in less than 5 hours.

The thermocouples monitoring the heat applied to the concrete during heat treatments have been calibrated, and the following limitations will apply:

Time Hours	Depth	Monitor Reading °C	Corrected °C	Monitor Reading °F	Corrected °F	
0 - 0.5	Surface	80	63	176	145	Maximum
0.5 - 1.3	Surface	87	71	188.6	160	Maximum
After 1.3	Surface	166	160	330.8	320	Maximum
Heat Required	2 inches	93	85	199.4	185	Minimum

APPENDIX E

FHWA TEST PROCEDURES

ATTACHMENT A

DYE PENETRATION TEST TO DETERMINE SEALING EFFECTIVENESS OF THE INTERNALLY SEALED CONCRETE

1. Take three 2-inch diameter by 4-inch-deep cores from the bridge deck after heat-treatment.
2. Split cores in half.
3. Place cores in an air-circulating oven at 100°F. for 14 days.
4. Immerse cores in water containing red dye (recorder ink) and a wetting agent (calgon).
5. Soak for 14 days.
6. Then split again.
7. Observe dye penetration.

ATTACHMENT B

Resistance of Concrete to Chloride Ion Penetration

1. Scope

1.1 This method covers the determination of the resistance of internally sealed concrete specimens to the penetration of chloride ion. It is intended for use in determining the effect of variations in the properties of the concrete on the resistance of the concrete to chloride ion penetration. This test method is not intended to provide a quantitative measure of the length of service that may be expected from a specific type of concrete.

2. Test Specimens

2.1 The specimens for use in this test shall be 4-inch or greater diameter cores taken from the internally sealed concrete bridge deck after the heat-treating process has been completed.

> Note 1 - This method contemplates the use of a minimum of four specimens for each evaluation with each core not less than 3 inches (76 mm) thick and 4 inches (102 mm) in diameter. Ponding and chloride determination procedures will be difficult to perform on smaller specimens.

2.2 Since a 21-day wet cure will have been achieved prior to the heat-treating, chloride penetration analyses shall proceed as specified in item 3.

3. Procedure

3.1 The cores shall be abraded for 0.125 inch (3.2 mm) $\pm$ 0.0625 inch (1.6 mm) from the finished surface using grinding or sandblasting techniques. No water shall be used in the abrading process and the process shall not heat any portion of the concrete to more than 100°F.

3.2 Place 0.75 inch (19 mm) high by 0.50 inch (13 mm) wide dams around the top edge of all cores except one, which will then become the control core.

3.3 All cores shall be placed in a drying room of the type specified by AASHTO: T-160, "Length Change of Cement Mortar and Concrete" at a temperature of 100°F for a period of 6 days. After drying, the cores with dams will be subjected to continuous ponding with a 0.50 inch (13 mm) deep 3 percent sodium chloride solution for 90 days. Glass plates shall be placed over the ponded solutions to retard evaporation of the solution. Additional solution shall be added if necessary to maintain the 0.50 inch depth.

3.4 After 90 days of exposure the solution shall be removed from the cores. The cores shall be allowed to dry and then the surfaces shall be wire brushed until all salt crystal buildup is completely removed.

3.5 Samples for chloride ion analysis shall then be taken from all cores in accordance with the rotary hammer procedure described in report FHWA-RD-74-5 or by dry coring (1.5 inch (38 mm) minimum diameter cores) and dry sawing. Three samples shall be obtained from each core at each of the following depths:

1/16 inch (1.6 mm) to 0.5 inch (13 mm)
0.5 inch (13 mm) to 1.0 inch (25 mm)
1.0 inch (25 mm) to 1.5 inch (38 mm)

The chloride content (parts per million by weight) of each sample shall be determined in accordance with the procedures described in attachment C.

4. Calculations

4.1 The baseline chloride ion content for the test specimens shall be determined as the average chloride ion content of samples obtained from the 1/16 inch (1.6 mm) to 0.5 inch (13 mm), 0.5 inch (13 mm) to 1.0 inch (25 mm), and 1.0 inch (25 mm) to 1.5 inch (38 mm) depths within the core that was not ponded with 3 percent NaCl solution.

4.2 The absorbed chloride ion content of each sample from the ponded cores shall be determined as the difference between the total chloride ion content of that sample and the baseline value calculated in Section 4.1. If the result is less than zero, the result shall be reported as zero. The average chloride ion absorbed at each sampling depth shall be calculated.

5. Report

5.1 Reporting shall include: (1) each total chloride ion value determined in Section 3.5; (2) the average and maximum baseline chloride ion (Section 4.1); (3) each calculated absorbed chloride ion value determined in Section 4.2; and (4) the average and maximum absorbed chloride ion values calculated in Section 4.2 for each depth.

ATTACHMENT C

STANDARD METHOD OF SAMPLING AND TESTING FOR TOTAL CHLORIDE ION IN CONCRETE

1. Scope

1.1 This method covers a procedure for the determination of the total chloride ion content of aggregates, portland cement, mortar, or concrete. The method is limited to material that does not contain sulfides, but the extraction procedure, paragraphs 5.1 through 5.6, may be used for all such materials.

2. Apparatus

2.1 Samples may be obtained by one of two methods, 2.1.1 or 2.1.2

2.1.1 Core drill.

2.1.2 Rotary impact type drill with a depth indicator and drill or pulverizing bits of sufficient diameter to provide a representative sample of sufficient size for testing.

2.1.2.1 Sample container capable of maintaining the sample in an uncontaminated state.

2.1.2.2 Spoons of adequate size to collect the sample from the drilled holes.

2.1.2.3 A "blow out" bulb or other suitable means or removing excess pulverized material from the hole prior to redrilling operations.

2.1.2.4 A pachometer capable of determining the location and depth of steel reinforcement to $\pm$ 1/8 inch ($\pm$3 mm).

2.2 Testing

2.2.1 Chloride ion or silver/sulfide ion selective electrode and manufacturer-recommended filling solutions.

Note: Suggested electrodes are the Orion 96-17 Combination Chloride Electrode or the Orion 94-6 Silver/Sulfide Electrode or

equivalents. The Silver/Sulfide electrode requires use of an appropriate reference electrode (Orion 90-92 or equivalent).

2.2.2 A millivoltmeter compatible with the ion electrode.

Note: Suggested millivoltmeter is the Orion Model 701A Digital pH/m_V meter or equivalent.

2.2.3 Magnetic stirrer and teflon stirring bars.

2.2.4 Burette with 0.1 mL graduations.

2.2.5 Balance sensitive to 0.0001 gram with minimum capacity of 100 grams.

2.2.6 Balance sensitive to 0.1 gram with minimum capacity of 1 Kg.

2.2.7 Hot plate, 250° to 400°C heating surface temperature.

2.2.8 Glassware - 100 to 250 mL beakers, filter funnels, stirring rods, watch glasses, dropper; mortar and pestle; wash bottles.

2.2.9 Sieve, U.S. Standard 50 mesh.

2.2.10 Whatman No. 40 and No. 41 filter papers (or equivalent)

Note: If equivalent filter papers are used, they should be checked to confirm that they do not contain chloride which will contaminate the sample.

3. Reagents

3.1 Concentrated HNO_3 (sp. gr. 1.42)

3.2 Sodium chloride, NaCl, reagent grade (primary standard).

3.3 Standard 0.0100 N NaCl solution. Dry reagent grade NaCl in an oven at 105°C. Cool, in a desicator, weigh out 0.5844 gram, dissolve in distilled H_2O, and transfer to a 1-liter volumetric flask. Make up to the mark with distilled H_2O and mix.

3.4 Standard 0.01 N $AgNO_3$. Weigh 1.7 grams of reagent grade $AgNO_3$, dissolve in distilled H_2O, filter into a 1-liter brown grass bottle, fill, and mix thoroughly. Standardize against 25.00 mL of the NaCl solution by the titration method given in paragraph 5.7.

3.5 Distilled water.

3.6 Methyl orange indicator.

3.7 Ethyl alcohol, technical grade.

4. Method of Sampling

4.1 Determine the depth within the concrete for which the chloride content is desired. Use the pachometer to determine reinforcement bar location and depth.

4.2 Core Method - Drill the core to chosen depth and retrieve.

4.2.1 When samples are received in the laboratory in other than pulverized condition, the sample shall be crushed and ground to a powder. All sawing or crushing shall be done dry (i.e. without water). All material shall pass a No. 50 mesh sieve. All pulverizing tools and sieves shall be washed with ethyl alcohol or distilled water and shall be dry before use with each separate sample (see note para. 4.3.7).

4.3 Pulverizing Method

4.3.1 Set the rotary hammer depth indicator so that it will drill to 1/4 inch (6 mm) above the desired depth.

4.3.2 Using a drill or pulverizing bit, drill until the depth indicator seats itself on the concrete surface.

4.3.3 Thoroughly clean the drilled hole and surrounding area utilizing the "blow out" bulb or other suitable means.

4.3.4 Reset the depth indicator to permit 1/2 inch (13 mm) additional drilling.

4.3.5 Pulverize the concrete until the depth indicator again seats itself on the concrete.

Note: Care must be exercised during this pulverizing operation to prevent the drill bit from abrading concrete from the sides of the hole above the sampling depth. To insure against this, some users utilize an 0.25 inch (6 mm) smaller diameter bit in this step than that used in para. 4.3.2.

4.3.6 Collect at least 10 grams of the material remaining in the hole using a spoon and place in the sample container.

4.3.7 If the sample, as collected, does not completely pass a 50 mesh screen, additional pulverizing shall be performed until the entire sample is finer than 50 mesh.

Note: During sample collection and pulverizing, personnel shall use caution to prevent contact of the sample with hands, or other sources of body perspiration or contamination. Further, all sampling tools (drill bits, spoons, bottles, sieves, etc.) shall be washed with ethyl alcohol or distilled water and shall be dry prior to use on each separate sample. Ethyl alcohol is normally perferred for washing because of the rapid drying which naturally occurs.

5. Procedure

5.1 Weigh to the nearest milligram a 3 gram powdered sample representative of the material under test.

Note: Some users dry the sample to constant weight in a 105°C oven and determine the dry sample weight prior to analysis. This optional procedure provides a constant base for comparison of all results by eliminating moisture content as a variable. It is generally believed that drying is only necessary when very high accuracy is desired (see Reference 1 for data in this area).

Transfer the sample quantitatively to a mortar; add 10 mL of hot (90° to 100°C) distilled H_2O to the mortar, swirling to bring the powder into suspension.

Carefully grind the slurry with a pestle until all lumps are gone. Very little grinding will be necessary for soft aggregates, but considerable effort will be required for samples containing hard aggregates.

Note: Sample particle size after grinding should be such that it will pass a 100 mesh screen. Further, about 75 percent of a properly ground sample will pass a 200 mesh screen. It is suggested that the analyst grind several trial samples, in accordance with the above procedure and then dry the samples and determine the particle size as a means of defining the grinding required for actual samples.

5.2 Transfer the slurry quantitatively from the mortar through a funnel into a 100 mL beaker, rinsing the funnel lightly with hot distilled H_2O. Add 3 mL concentrated HNO_3 to the mortar and stir with the pestle to completely dissolve any cement left in the mortar. Transfer the contents of the mortar through the funnel while continuously stirring the beaker with a glass stirring rod. Rinse the mortar, pestle, inside of the funnel and the tip of the funnel with hot distilled H_2O.

Note: Too rapid transfer of the acid into the 100 mL beaker will cause excessive foaming or frothing of samples with calcareous aggregates or organic components and resultant risk of sample loss.

5.3 Make up the solution in the 100 mL beaker to approximately 50 mL with hot distilled H_2O. Stir thoroughly to ensure complete sample digestion. Add five drops of methyl orange indicator and stir. If yellow to yellow-orange color appears solution is not sufficiently acidic. Add additional concentrated HNO_3 dropwise with continuous stirring until a faint pink or red color persists in the solution. Cover with a watch glass, retaining the stirring rod in the beaker.

Note: Due to the presence of relatively insoluble materials in the sample, the solution generally will have a strong gray color, making the detection of the indicator color difficult at times. Running of several trial samples is suggested to give the analyst practice in detecting the indicator color.

5.4 Bring the solution in the covered 100 mL beaker to a boil on a medium heat (250 to 400°C) hot plate, and then boil for a full minute with care to avoid frothing and spillovers. Remove from heat.

Note: The analysis can be stopped at this point and the sample allowed to cool in an HCl fume-free area if it is necessary. Before proceeding to the next step, however, the solution must again be brought to a boil.

5.5 Prepare a funnel fitted with double filter paper (Whatman No. 41 over No. 40 filter paper or equivalents) and a 250 mL beaker to receive the filtrate. Carefully lift the watch glass from the 100 mL beaker without tilting it, and wash any adhering drops into the filter paper with hot distilled water. Then filter the hot solution into the 250 mL beaker. Proceed carefully, employing the stirring rod to aid quantitative transfer of the solution into the filter funnel. Wash the inside of the 100 mL beaker and the stirring rod twice with hot distilled H_2O. Transfer the washings through the filter into the 250 mL beaker. Finally, carefully wash the outside of the pouring lip of the 100 mL beaker with hot distilled H_20 into the filter.

5.6 Wash the filter paper five to ten times with hot distilled H_2O, being careful not to lift the paper away from the funnel surface. Finally, lift the filter paper carefully from the funnel and wash the outside surface of the paper with hot distilled H_20; then wash the tip of the funnel. The final volume of the filtered solution should be 125 to 150 mL. Cover with a watch glass and allow to cool to room temperature in an HCl fume-free atmosphere.

5.7 Two alternate methods are available to determine the Cl- content of the solution. Both methods utilize an ion selective electode (Cl- or Ag+) and both methods for the purpose of this analysis give results of essentially equal accuracy and precision. However, Method II offers a substantial decrease in time required for analysis over Method I.

5.7.1 Alternate Method I: Potentiometric Titration

Fill the Cl- or the Ag+ electode with the solution(s) recommended by the manufacturer, plug it into the millovoltmeter (preferably the type with a digital rather than a dial readout), and determine the approximate equivalence point by immersing the electrode in a beaker of distilled H_2O. Note the approximate millivoltmeter reading (which may be unsteady in H_2O.

Take the cooled sample beaker from 5.6 and carefully add 4.00 mL of 0.01 N NaCl, swirling gently. Remove the beaker of distilled H_2O from the electrode, wipe the electrode with absorbent paper, and immerse the electrode in the sample solution. Place the entire beaker-electrode assembly on a magnetic stirrer and begin gentle stirring.

Using a calibrated buret, add gradually and record the amount of standard 0.01 N $AgNO_3$ solution necessary to bring the millivoltmeter reading to -40 mv of the equivalence point determined in distilled H_2O. Then add standard 0.01 N $AgNO_3$ solution in 0.10 mL increments recording the millivoltmeter reading after each addition.

As the equivalence point is approached, the equal additions of $AgNO_3$ solution will cause larger and larger changes in the millivoltmeter reading. Past the equivalence point, the changes per unit volume will again decrease. Continue the titration until the millivoltmeter reading is at least 40 mv past the approximate equivalence point.

The endpoint of the titration usually is near the approximate equivalence point in distilled water and may be determined by (1) plotting the volume of $AgNO_3$ solution added versus the millivoltmeter readings. The endpoint will correspond to the point of inflection of the resultant smooth curve, or (2) calculating the differences in millivoltmeter readings between successive $AgNo_3$ additions and calculating the total volume of $AgNO_3$ which corresponds with each difference (i.e., the midpoints between successive additions).

Example:

Raw Data		Difference	
Titrant Volume	Millivolt Reading	Titrant Midpoints	Millivolt Differences
4.2 mL	130.0	4.25 mL	5.0
4.3 mL	135.0	4.35 mL	7.0
4.4 mL	142.0	4.45 mL	10.0
4.5 mL	152.0	etc.	
etc.			

The endpoint will be near the midpoint which produced the largest change in millivoltmeter reading. It may be determined by plotting midpoints versus differences and defining the $AgNO_3$ volume which corresponds to the maximum difference on a smooth, symmetrical curve drawn through the points. However, it can usually be estimated accurately without plotting the curve by choosing the midpoint which corresponds to the maximum difference and adjusting for asymmetry, if any. In other words, if the differences on each side of the largest difference are not symmetrical, adjust the endpoint mathematically in the direction of the larger differences. Detailed examples of this adjustment are contained in Reference 1.

5.7.2 Alternate Method II: Gran Plot Method

This method is comparable with either a Cl- or Ag+ ion-selective electrode. Attach the electrode of choice to a compatible digital millivoltmeter after filling with required solutions as per the electrode manufacturer's instructions. Clean the electrode with distilled H_2O and pat dry with absorbent paper.

Weigh the cooled sample and beaker from 5.6 without the watch glass and record the weight. Using a calibrated buret, titrate the sample to 225 mv $\pm$ 5 mv (Cl- electrode) or 310 $\pm$ 5 mv (Ag+ electrode) with standard 0.01N $AgNO_3$ solution. Record the volume added and the millivoltmeter reading.

Continue to titrate in 0.50 mL increments recording the volume added and the millivoltmeter reading for each increment. Add and record the data for at least five increments. Empty, clean, dry, and weigh the beaker. Subtract beaker weight from beaker + solution weight determined above to define solution weight.

Additional information on the Gran Plot Method is given in Reference 2.

6. Calculations

6.1 Alternate Method I - Potentiometric Titration

Determine the endpoint of the titration as described in para. 5.7.1 by either plotting a curve or estimating from the numerical data. Calculate the percent Cl- ion from the equation:

$$\% \text{ Cl} = 3.5453 \left(\frac{V_1 N_1 - V_2 N_2}{W} \right)$$

Where:

V_1 = endpoint in mL

V_2 = Volume of NaCl solution added, in mL

N_1 = normality of AgNO

N_2 = Normality of NaCl solution

W = Weight of original concrete sample in grams.

6.2 Alternate Method II - Gran Plot Method

Calculate corrected values for each of the volumes recorded in 5.7.2 by the equation:

$$V_{correct} = \frac{V \text{ record}}{W/100}$$

Where:

W = original solution weight in grams

V record = Volumes recored in mL

If any of the V correct values are greater than 10, see para. 6.3. If less than 10, plot these corrected values versus the corresponding millivolt readings on Orion Gran Plot Paper (10 percent volume corrected type with each major vertical scale division equal to 5 millivolts) or equivalent. Draw the best straight line through the points and read the endpoint at the intersection of the line with the horizontal axis of the graph. Calculate the actual endpoint by the equation:

$$E_a, \text{ ACTUAL ENDPOINT} = E_g \left(\frac{W}{100} \right)$$

Where:

E_g = Endpoint determined from graph in mL

W = Weight of solution in grams

Then

$$\% \text{ Cl-} = \frac{3.5453}{Wc} E_a N$$

Where:

E_a = Actual endpoint, in mL

N^a = Normality of $AgNO_3$

W_c = Concrete sample weight in grams

6.3 Supplementary Gran Method Calculations:

When the V correct volumes determined in 6.2 are greater than 10, discard the values and follow the following procedure.

Choose a constant which, when subtracted from all V record volumes, yields values less than 10 ml.

Note: This constant, designated as X in the formulas below, is normally assigned an even value such as 5, 10, 15, 20, etc.

Calculate a revised solution weight W_r

$$W_r = W + X$$

Where: W = original solution weight in grams
X = the constant

Then calculate corrected volumes for each recorded volume as:

$$V \text{ corrected} = \frac{V \text{ record} - X}{W_{r/100}}$$

Plot these values and determine the graph endpoint E_g as described in para. 6.2. The actual endpoint, E_a is then:

$$E_a = E_g \left(\frac{W_r}{}\right) + X$$

Where: E_a = actual endpoint in ml
E_g = endpoint from graph in ml
W_r = revised solution weight in grams
X = the constant chosen above

Calculate the chloride content using the formula given in para. 6.2.

6.4 The percent chloride may be converted to pounds of Cl- per cubic yard of concrete as follows:

$$\text{lbs. Cl-/yd}^3 = \%Cl = \left(\frac{UW}{100}\right)$$

Where:

UW = Unit weight of concrete per cubic yard.

Note: A unit weight of 3915 lbs/yd^3 is often assumed for normal structural weight concrete when the actual unit weight is unknown.

7. References

1. Clear, K. C., "Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair," Federal Highway Administration, Report FHWA-RD-74-5, February 1974. National Technical Information Service PB 232-604/AS.

2. Clemena, G. C., Reynolds, J. W., and McCormick, R. M., "Comparative Studies of Chloride in Hardened Concrete," Virginia Highway and Transportation Research Council, Report 77-R7, August 1976. This report is available from the National Technical Information Service, Springfield, Virginia 22161.

ATTACHMENT D

Procedure for Determining Percent Wax Beads by Volume in Plastic Concrete

1. Equipment Required:

   a. Chace Air Meter (Calibrated as per attachment).
   b. Squeeze bottle of saturated NaCl solution
   c. Squeeze bottle of H_2O
   d. Screen: #4 mesh

2. Since wax beads have a lower specific gravity than the saturated NaCl solution, they will float. Due to this fact, the Chace Air Meter can be utilized to determine the percent wax beads by volume in plastic concrete.

3. Procedure:

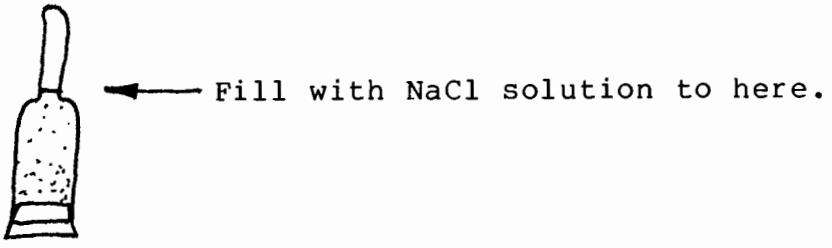
   a. Screen a sample (approximately 1 lb.) of the plastic concrete through a #4 mesh screen to remove the coarse aggregate.

   b. Fill the sample cup of the Chace Air Meter with a sample of the screened plastic concrete.

   c. Remove the excess plastic concrete from the sides of the sample cup and stopper with a squeeze bottle of H_2O (i.e., rinse the <u>outside</u> of the sample cup and stopper with water).

   d. Place the sample cup containing the concrete sample inside the Chace Air Meter. Make sure that the stopper is in tightly.

   e. Fill the meter through the narrow neck with saturated NaCl solution until the solution level reaches the bottom of the <u>narrow</u> neck on the meter.



   f. Holding the opening at the top of the meter closed (with thumb or forefinger), vigorously shake the meter for 30 seconds separating the wax beads from the plastic concrete.

g. Add NaCl solution through the neck of the meter until the top of the wax bead column is even with the top mark on the neck of the meter. (Meter must be vertical.)

h. Holding the meter vertically, gently tap the rubber stopper against a solid surface for a period of 15 seconds. This will cause any stray beads to float up into the neck of the meter.

i. Allow the meter to set on flat surface for a period of 1 minute (note: meter must be setting on its rubber stopper in the vertical position).

j. Determine the height of the bead column to the nearest 1/10 of a division by counting the number of divisions that the column occupies in the neck of the meter.

k. To determine the percent wax beads by volume in the mix, simply convert the meter column height reading to percent wax beads by using your calibration curve.

l. Note: In order to obtain an accurate percent wax bead value, it is necessary to run three samples using the average of the three as the actual percent wax beads in the concrete mixture.

Calibration of Chace Air Meter to Read Percent Wax Beads by Volume

1. Since all Chace Meters do not yield the results for the same sample mix, it is necessary to calibrate the meter that will be used for wax bead volume determinations. Also, since the calibration procedure is time-consuming (approximately 3 hours), it is suggested that 1 meter be set aside and used exclusively for wax bead volume determinations (Note: This eliminates the need for continual recalibration because the same meter will be used each time.)

2. To calibrate the meter, four mix designs are needed: 5 percent wax beads by volume, 6 percent wax beads by volume, 8 percent wax beads by volume, and 10 percent wax beads by volume. Also, a total mix weight of approximately 2600 grams is desirable to facilitate hand mixing. Use the following table to design those mixes. (Note: The table is based on: CF = 7 bags/yd^3, w/c = 0.55, air = 3 percent.)

Solid Volumes in $ft.^3/yd^3$

Percent Wax	5	6	8	10
Cement	3.35	3.35	3.35	3.35
Air	0.81	0.81	0.81	0.81
Water	5.80	5.80	5.80	5.80
Fine Aggregate	8.22	7.95	7.41	6.87
Coarse Aggregate	7.47	7.47	7.47	7.47
Wax Beads	1.35	1.62	2.16	2.70

To obtain the S.S.D. weight of each material for a small (2600± grams) batch that can be hand mixed easily, multiply each volume in the table by the following:

S.S.D. weight of material in grams = (43.00)x(S.G.)x(Volume from table)

Constant ↑

Where:

S.G. = Specific gravity of material
Volume from table = Volume of that material for the percent wax beads desired. (Example: For a 4 percent wax bead mix, the cement volume is 3.35 ft.^{3}).

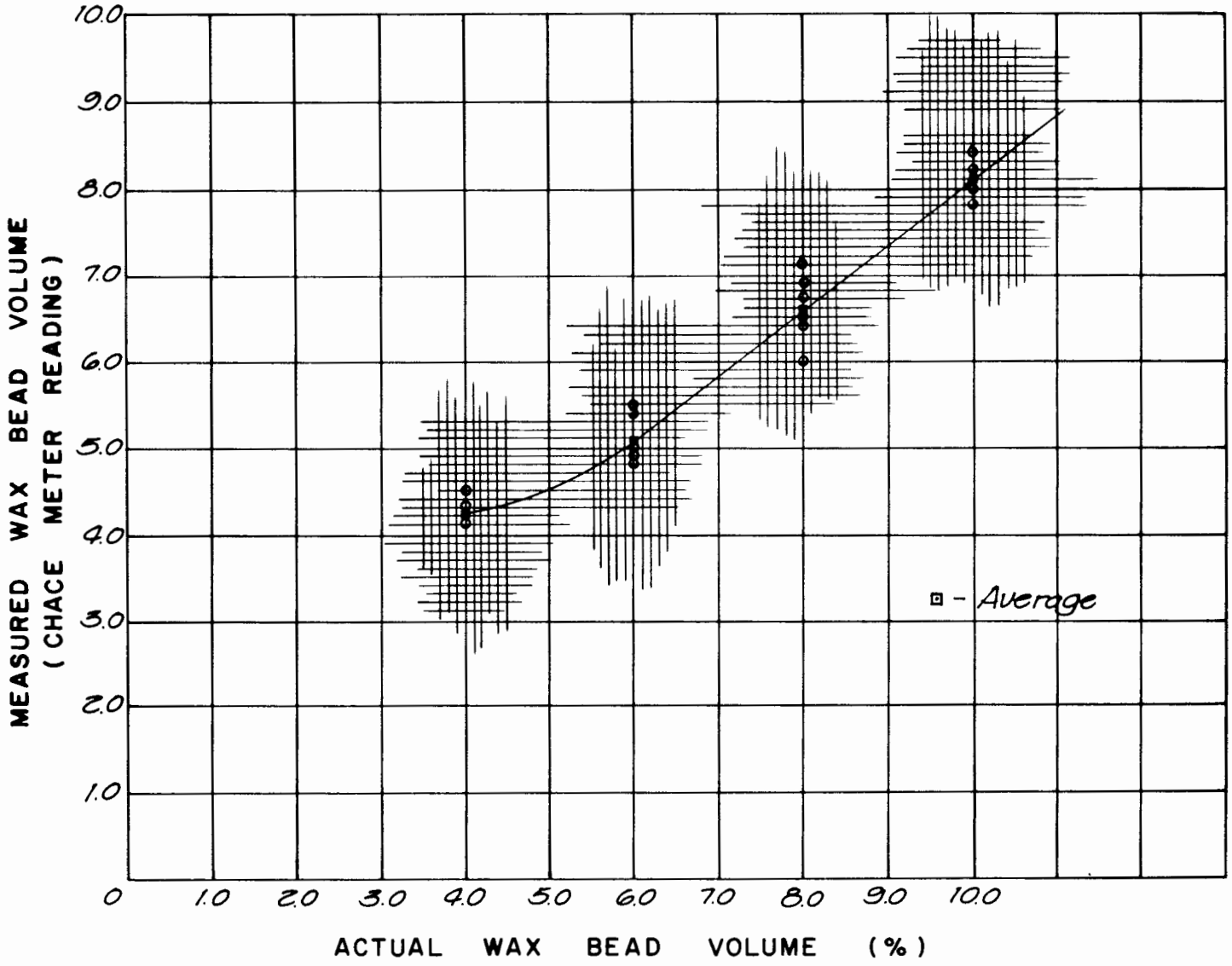
Next, obtain the batch weights and adjust for moisture in the aggregates as necessary to obtain final mix weights.

*Note: A sample for a 5 percent by volume wax bead mix is attached. Do not use this as a standard mix, it is only for reference.

3. Calibration Procedure:

a. Prepare the first mix (5 percent wax beads by volume).
b. Follow the instructions, (Attachment D.3. - "Procedure for Determining Percent Wax Beads by Volume in Plastic Concrete") through step J. (Note: Do the procedure four times to obtain four readings.)
c. Follow steps a and b for the other three mixes (i.e., 6 percent, 8 percent, 10 percent).
d. Average the four readings for each mix.
e. Plot the average readings against the actual percent wax beads in each mix to obtain the calibration curve.
f. Make up a conversion sheet that can be kept with the meter for field use.
g. Samples of the calibration curve and conversion sheet follow.

4. Once the meter has been calibrated, it may be used in the field to monitor wax bead content (percent by volume) while the concrete is being placed.


MEASURED WAX BEAD VOLUME
(CHACE METER READING)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
ACTUAL WAX BEAD VOLUME (%)
⊡ - Average

WAX BEAD VOLUME CONVERSION

Chace Meter Column Height	Actual Percent Wax Bead Volume
4.10	4.75
4.29	5.00
4.49	5.25
4.68	5.50
4.87	5.75
5.06	6.00
5.25	6.25
5.43	6.50
5.64	6.75
5.82	7.00
6.02	7.25
6.20	7.50
6.40	7.75
6.59	8.00
6.77	8.25
6.96	8.50
7.15	8.75
7.34	9.00
7.54	9.25
7.72	9.50
7.91	9.75
8.10	10.00

Sample 5 Percent by Volume Wax Bead Mix

C.F. = 7 bags/yd^3 W/C = 0.55 percent 3 percent Air No Admixture
3 percent total moisture in sand 0 percent absorption in sand 3 percent free H_2O in sand

0.5 total moisture in stone 0.5 percent absorption in stone 0.0 percent free H_2O in stone

Specific Gravities: Cement = 3.15, Sand (F.A.) = 2.65, Stone (C.A.) = 2.77, Wax Beads = 0.84

SSD Weights (Grams)

Cement	= 453.76
Air	= -
Water	= 249.4
Fine Aggregates	= 936.67
Coarse Aggregates	= 889.75
Was Beads	= 48.76
TOTAL WT.	2578.34

Final Batch Weights (Grams)

Cement	= 453.76		
Air	= -		
Water	= 225.98	-----	[249.4 - (960.09 - 936.67)]
Fine Aggregate	= 960.09	-----	[(936.67)(1.025)]
Coarse Aggregate	= 889.75		
Wax Beads	= 48.76		
TOTAL WT.	2578.34		

HDP-15/8-81(500)