Internally Sealed Concrete Using Wax Beads

Final Report
WA-RD 132.1

October 1987

Washington State Department of Transportation
Planning, Research and Public Transportation Division

in cooperation with the
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16. ABSTRACT

The use of wax beads to internally seal a concrete bridge deck to reduce the intrusion of chloride for the protection of the reinforcing steel is reported. Test panels of the internally sealed concrete were constructed to determine the best heating method and amount of time required to melt the wax beads. The test panel and bridge deck mix design, construction, heating, and evaluations are documented. The low chloride content test and low half cell potential tests indicate that the Internally Sealed, Wax Bead, Concrete is performing as designed.

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For
Washington State Transportation Commission
Department of Transportation

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INTRODUCTION

In an attempt to curb bridge deck deterioration caused by chloride intrusion, the Washington State Department of Transportation (WSDOT) has investigated and constructed various types of protective systems with varying success. As new systems emerge, WSDOT evaluates them in an attempt to identify those that hold promise for field testing on a bridge construction project.

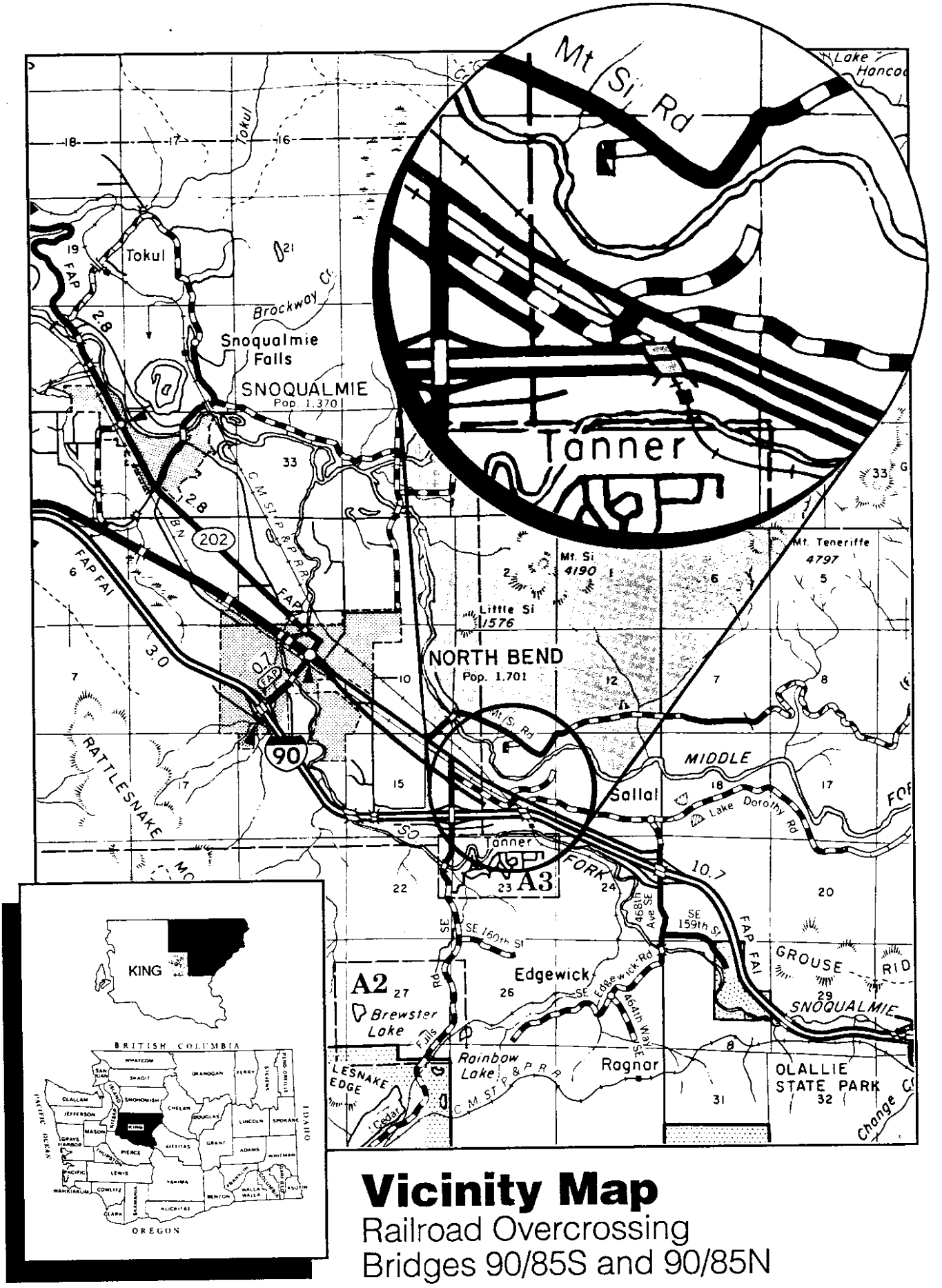
Internally sealed concrete using wax beads was a protection method developed by the Monsanto Research Corporation, under contract to the Federal Highway Administration (FHWA). This method of protecting bridge deck reinforcing steel appeared to be a practical solution to chloride induced corrosion problems, and led to WSDOT participating in FHWA Demonstration Project No. 49 on the use of internally sealed concrete for new bridges.

Objective

The objective of this demonstration project was to build a test bridge deck containing a quantity of wax sufficient to fill all pores (or capillaries) in the top 2 inches (51 mm) layer of concrete, and thus prevent the entry of corrosion-causing chemicals. This would, in turn, eliminate or reduce the corrosion of the reinforcing steel in the bridge deck and prolong the service life of the bridge.

Study Site

WSDOT chose twin structures that were being built on I-90, 2 miles east of the town of North Bend (see Vicinity Map) as the site for the internally sealed concrete installation. One of the structures would be built with the deck containing wax beads and the other structure would be built using standard AX concrete to serve as a control for the long term performance measurements.



Vicinity Map

Railroad Overcrossing
Bridges 90/85S and 90/85N

CONSTRUCTION SUMMARY

Prior to constructing the bridge deck, the contractor constructed test panels to identify the most efficient procedures for mixing, handling, placing, finishing, and heating the internally sealed concrete. The work on the test panels was representative of the full-size bridge deck scaled down, with the contractor being allowed several options in construction procedures and methods of heating. The experience gained from these tests by the contractor and the WSDOT Project Engineer was the basis for a firm set of specifications for the work on the bridge deck. A summary of the test panel construction is described below (1).

Test Panels

Four test panels were constructed to evaluate the various options available for two layer bridge deck construction and concrete heating. The options were:

1. Place, by bucket, 5 inch (129 mm) standard Class AX concrete, wait one hour and place 2 inch (51 mm) wax bead concrete.

2. Place by bucket, 5 inch standard Class AX concrete, let cure 24 hours, clean surface with water jet (1200 psi) dry surface, place cement-sand slurry, and place 2 inch (51 mm) wax bead concrete.

3. Same as No. 2 except cleaning to be done by water jet with sand injection.

4. Place 5 inch (129 mm) wax bead concrete, wait 30 minutes, then place 2 inch (51 mm) wax bead concrete.

The test panels were cast in September 1975. The ambient temperature during placement was 65 degrees F (18 degrees C).

Test Panel Construction

The test panels were 8 feet (2.4 m) wide and 12 feet (3.7 m) long with the same thickness and reinforcing steel design specified for the bridge deck. Nonair-entrained (WSDOT specification) Class AX concrete with a designed compressive strength of 4,000 lbs/square in. (27.6 MPa) was used for each of the two concrete layers. The wax beads were added, by weight, to replace an equal amount of sand in the Class AX concrete and mixed at the construction site. The following mix designs were used:

ITEM	Standard Class AX Concrete	Class AX Concrete With Wax Beads
Cement, kg	276.6	276.6
Fine aggregate, kg	642.2	496.1
Coarse aggregate, kg	815.4	815.4
Wax beads, kg	---	53.5
Total water, L	113.6	113.6

The sand used a fineness modulus of about 3.2; the grading for Washington State No. 5 coarse aggregate is as follows:

	Percent Passing by Weight	
Sieve	Minimum	Maximum
1 in (25 mm)	100	--
3/4 in (19 mm)	80	100
3/8 in (10 mm)	10	40
No. 4 (4.8 mm)	0	4

A Gomaco 350 finishing machine was used for finishing the panels. No attempt was made to smooth the surface of the first concrete course (to the top of the reinforcing steel) prior to placement of the second course. Panel 2 was cleaned with a water jet prior

to placement of the second course. Panel 3 was cleaned with water jet with sand injection. The sand was removed with brooming and compressed air. Panels 1 and 4 had no surface treatment prior to the placement of the second course.

The first concrete course on panels 2 and 3 were coated with a cement-sand slurry (1:1 mixture) prior to placement of the wax bead concrete. A portion of panels 2 and 3 and both courses of panel 4 were placed using a Thompson 4-inch (102 mm) piston-type concrete pump. The other concrete pours were placed by bucket. Internal vibration was used to consolidate the concrete, in all test panels.

All of the panels were covered overnight with plastic sheeting. The next day the plastic sheeting was removed and replaced with burlap, which was kept wet for a ten-day curing period. No curing compounds were used.

The pouring of the first course of the concrete test panels, slab cleaning, and wax bead concrete pour were accomplished without major problems. The application of the cement-sand slurry by brushing was done as specified. No problems occurred during the pouring of the second course.

Test Panel Heat Treatment

The test panels were heated by using four methods: 1) very hot air; 2) gas-fired infrared; 3) electric infrared; and 4) electric blankets. The three high-intensity heating methods caused many spalls, approximately .75 inches (19 mm) deep. The slower electric blanket heating did not cause spalling.

It took five hours to heat the wax bead concrete to the required 185°F (85°C) at the 2 inch (51 mm) depth using the heating blankets covered with fiberglass insulation.

Test Panel Materials Testing

Four-inch (102 mm) diameter cores were removed from each panel prior to and following the heat treatment. The cores were tested by WSDOT Materials laboratory for tensile bond between the first and second concrete course. Tensile breaks on all the cores occurred in the wax bead overlay, above the bond line. Following are the results of the tensile bond tests:

Panel Number	Two-Course Procedure	Direct Tensile Bond (MPa)	Location of Break
1	Wax bead overlay placed on fresh, Class AX Concrete after one hour delay	1.34	1.3 cm above bond line
2	Wax bead overlay placed on hardened lower course after water blast and portland cement grout	0.69	Slightly above bond line
3	Wax bead overlay placed on hardened lower course after water-and-sand-blast and portland cement grout	1.69	1.3 cm above bond line
4	Wax bead overlay on fresh, wax bead lower course after 30 to 45 minute delay	1.52	2.5 cm above bond line

Notes: 1 MPa = 145 lbs/in 2 1 cm = 0.39 in.

Test Panel Problems

The surface of panels receiving high-intensity heating had major spalling of the concrete.

Recommended Methods and Procedures for Bridge Deck Construction

Two methods of construction of the bridge deck panels were identified, based on the magnitude of the tensile break values. They were the (1) wax bead overlay on the Class AX concrete with water jet/sand cleaning bridge deck slabs surface, and (2) wax bead overlay placed on the fresh first Class AX concrete course after a 30 minute to 1 hour delay. Due to the ease of placement, the contractor elected to place both concrete courses on the same day (method 2 above).

Bridge Deck Concrete Mix

The specifications for the westbound structure were modified to provide for two concrete courses: (1) Class AX (WSDOT spec.) and (2) wax bead modified Class AX (with wax beads replacing some of the sand on a 1:1 by weight basis). The mix design was the same as used in the test panels (see page 6).

Bridge Deck Concrete Placement

The bridge deck concrete was placed on November 11, 1975. The contractor used two concrete pump trucks. One truck pumped the Class AX concrete and the other truck pumped the wax bead concrete. The wax bead concrete pour started approximately 30 feet (9.1 m) behind the Class AX concrete pour. The distance between pours was reduced to 15 feet (4.5 m) with no noticeable displacement of the Class AX concrete during the placement of the wax bead concrete.

The placement and finishing, (Bidwell finishing machine was used), of the bridge deck was completed in eight hours. There was 195 cubic yards (149 cubic meters) of Class AX concrete and 80 cubic yards (61 cubic meters) of wax bead concrete used. The temperature during the concrete placement operation was $\pm$ 60 degrees F ($\pm$ 10 degrees C). The weather was overcast with light rain showers in the morning and afternoon.

Bridge Deck Heating

Due to cool, damp weather, the contractor erected a polyethylene air bubble that covered the entire bridge deck. The bubble provided a more suitable environment for heating the concrete to the required temperature. The bridge deck was heated with heating blankets, covered with insulation, to the specified temperature of 185° to 93°C). The contractor started the heating process on April 1, 1976, and it was completed on April 9, 1976. The heating was interrupted twice due to the bubble deflating during high winds.

Bridge Deck Problems

The construction of the wax bead bridge deck went as planned. There were no major problems.

Bridge Deck Construction Summary Conclusions

1. The use of two concrete pump trucks allowed the contractor to control the paving of the panels so the wax bead concrete could be placed 15 feet behind the Class AX.

2. The use of heating blankets with an insulation cover appeared to provide the required heat for melting the wax beads.

3. The use of the polyethylene air bubble protected the heat blankets from rain.

EVALUATION

Internally Sealed, Wax Bead, Concrete Bridge Deck Evaluation

The bridge with the internally sealed, wax bead, concrete, and the Class AX concrete decks were opened to traffic in September 1976. The only post construction tests performed on the bridge deck were friction resistance skid tests. The friction numbers varied from 51.6 to 54.4, with an average of 53.4. The bridge deck was visually monitored, annually, for nine years.

In 1978, the wax bead concrete deck appeared to be performing satisfactorily. Transverse cracks at each end of the bridge showed no change from the date of first reporting, which was shortly after the structure was opened to traffic. These cracks were caused by settlement of the end piers. Pier 1 settled approximately .07 feet (.02 m) and Pier 4 settled .12 feet (.04 m). In addition to the transverse cracks, roadmap cracking (plastic shrinkage cracks) were noted on the deck surface.

In 1981 concrete samples were removed from both the westbound internally sealed concrete bridge deck (90/85N) and the eastbound Class AX concrete deck (90/85S). The samples were tested by the WSDOT Materials Laboratory for chloride content. The test results were as follows:

Wax Bead
Bridge Deck (90/85N)

Test	Chloride, lb/CY
1	0.94 (crack)
2	0.33
3	0.21
4	1.09 (crack)
5	0.27 (crack)
6	0.96
7	0.95
8	0.30 (crack)

Average = 0.63 lbs/CY

Class AX
Bridge Deck (90/85S)

Test	Chloride, lb/CY
1	0.27
2	0.18
3	0.51
4	0.27
5	0.51
6	0.17
7	0.19
8	0.27

Average = 0.30 lbs/CY

The chloride content of the concrete samples from the internally sealed bridge deck were slightly higher on the average (0.63 lbs/CY) than the Class AX bridge deck (0.30 lbs/CY).

Prior to the removal of the concrete samples for chloride content determination, a chain drag was used on both bridges. What appeared to be a small delamination was detected over one of the pier caps of the internally sealed structure (90/85N). The location was recorded for future inspection.

In 1985, additional concrete samples were tested for chloride content. The samples were removed as close as possible to the location of the 1981 sampling. The test results from the two sample periods are shown side by side below:

Wax Bead Bridge Deck			Class AX Bridge Deck		
Test	Chloride lb/CY		Test	Chloride lb/CY	
	1985	1981		1985	1981
1	1.14	0.94 (crack)	1	0.45	0.27
2	0.49	0.33	2	0.46	0.18
3	0.24	0.21	3	0.74	0.51
4	0.56	1.09 (crack)	4	0.17	0.27
5	1.02	0.27 (crack)	5	0.23	0.51
6	0.22	0.96	6	0.32	0.17
Average =	0.62	0.63	Average =	0.40	0.32

The 1985 results again show a slightly higher concentration of chloride, on the average, in the internally sealed bridge deck.

Twelve random electric Half Cell potential readings were recorded on the outside lane of the internally sealed bridge (90/85N).

The readings ranged from +0.025 to -0.025. Readings on the Class AX bridge (90/85S) ranged from +0.050 to +0.070. These low readings indicate zero corrosion activity in either bridge.

Literature Review

A review of reports from states (2)(3)(4)(5) that constructed internally sealed bridge decks using wax beads was conducted to access their experiences. A copy of each state's conclusions (Idaho, Oklahoma, Pennsylvania, and Texas) is included as Appendix A.

CONCLUSIONS

1. The low chloride content test results indicate the internally sealed, wax bead, concrete has performed as designed.

2. The very low Half Cell potential readings are an indicator that the reinforcing steel is not corroding in the internally sealed bridge or the control bridge.

3. Chloride content test results indicate that the hairline cracking of the internally sealed deck is allowing slightly more chloride ion intrusion into the concrete than the uncracked AX concrete deck used as a control.

4. The internally sealed, wax bead, concrete bridge deck costs more to construct than the WSDOT Standard Concrete bridge deck.

RECOMMENDATIONS

1. WSDOT should continue to monitor developments in internally sealed bridge deck technology for solutions to the concrete cracking problems and the high construction costs.

2. WSDOT should continue to monitor and conduct chloride content tests on the internally sealed, wax bead, bridge deck as part of the bridge inspection program.

3. WSDOT should continue its policy of not allowing internally sealed, wax bead bridge decks.

REFERENCES

1. "Construction and Quality Control of Pavement and Structures," Transportation Research Record 652, Transportation Research Board, National Academy of Sciences, 1977 Report Title "Two-Course Construction of An Internally Sealed Concrete Bridge Deck."

2. "Internally Sealed (Wax Bead) Concrete for Bridge Decks," Idaho Transportation Department, Research Section, Final Report, September 1982.

3. "Wax Bead Concrete Bridge Deck," Commonwealth of Pennsylvania, Department of Transportation, Bureau of Bridge and Roadway Technology, Final Report, August 1985.

4. "Internally Sealed Concrete at Cow Creek, Oklahoma," Oklahoma Department of Transportation, Research and Development Division, Interim Report, August 1981.

5. "Internally Sealed Concrete, Monahans, Texas," Texas State Department of Highways and Public Transportation, Interim Report, January 1982.

Note:

The conclusions have been extracted from Numbers 2, 3, 4, & 5, and are incorporated in this document as Appendix A.

APPENDIX A

EXPERIENCE OF OTHER STATES

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.

SUMMARY AND CONCLUSIONS

The objective of this study was to construct a bridge deck impregnated with wax beads and evaluate its performance under service conditions. Heat treatment of the deck was completed in late October, 1980. The bridge, however, has not been opened to traffic as of the writing of this report.

Based on the tests conducted on a small test slab and the completed bridge deck, the following statements and conclusions are made:

1. None of the cracking observed during the crack survey can be attributed to the heat treatment.

2. The dye penetration test did not show any variation in the absorption rate of the heated zone over the unheated zone or the unheated slab concrete.

3. The freeze-thaw durability of the heat treated concrete was better than the unheated sublayers and much better than the unheated test slab concrete.

4. The chloride penetration of the heated bridge deck concrete was improved over the unheated test slab concrete, especially in the top one-half inch.

5. The corrosion potential survey showed no evidence of reinforcing steel corrosion. This is as expected since there has been no salt applied to the deck.

6. The wax beads in the concrete caused no apparent reduction in concrete strengths. The measured strengths were equal to or greater than required for normal Class "C" bridge slab concrete.

SUMMARY AND CONCLUSIONS

The objective of this study was to place and heat a wax impregnated concrete to 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 the project was accomplished, but the seal was not obtained.

1. The crack surveys show an increase in cracking with every survey. There are two types of cracks, those that could be associated with the heating and some full depth cracks that appear to be shrinkage or temperature associated. The surface cracks are no problem. The full depth cracks will require sealing.

2. The dye tests show no penetration.

3. Half cell potential tests run on the deck using $CU/CuSO_4$ as the base electrode show low potential readings, indicating no corrosion.

4. Compressive tests indicate that the wax beads had no detrimental effects on the concrete strength.

5. Chain drag tests show no delamination.

6. 90 day soak tests show very little to no salt penetration.

Internally sealing bridge deck concrete with melted wax beads is a reasonably simple method to specify and construct, provided the FHWA supplies the heating equipment and supervises the heating operations. This heating of the bridge deck appears to cause surface cracking.

Based solely on bid prices, wax bead protection cost twice Idaho's standard bridge deck protection system of expoxy coating the top layer of reinforcing steel with 2½" minimum concrete cover.

Idaho will not continue internally sealing bridge deck concrete because of the surface cracking and cost.

Because the full depth cracking some repair or treatment should be made to protect the exposed steel.

CONCLUSIONS AND RECOMMENDATIONS

1) Advanced planning should be done to insure that the proper number and lengths of blankets are available before heating begins. The arrangement of the blankets should minimize overlapping and dead air space.

2) Additional studies pertaining to maximum temperatures necessary to melt the wax beads to a 2-inch depth should be conducted.

3) Heating should not be conducted if there is any chance of rain.

4) The transverse and diagonal cracking of the wax bead concrete could be referred to as "thermal cracking" based on similiar reports from several other states DOT's.

From the Virginia Highway and Transportation Research Council, an interim report dated October 1981 stated that "cracks were noticed during and after the heat treatment. These cracks were due to the heating and cooling process and were referred to as "thermal cracks." A few cracks were noted on a control deck, but these were reported due to "plastic and drying shrinkage" (6).

In a report from the Idaho Transportation Department dated September 1982, based on information from several inspections of the test bridge decks, it was stated that there was "an increase in cracking with every survey." All other tests showed favorable results, i.e. Dye test, Half-cell potential, but Idaho discontinued the use of wax impregnated concrete for bridge decks because of the cracking and high cost of construction (7).

The New Jersey Department of Transportation disclaimed the "thermal crack" theory. Cracks appeared in test decks a few months after construction, but these were not considered due to the heating process since similar cracks have appeared on other bridges throughout the state (8).

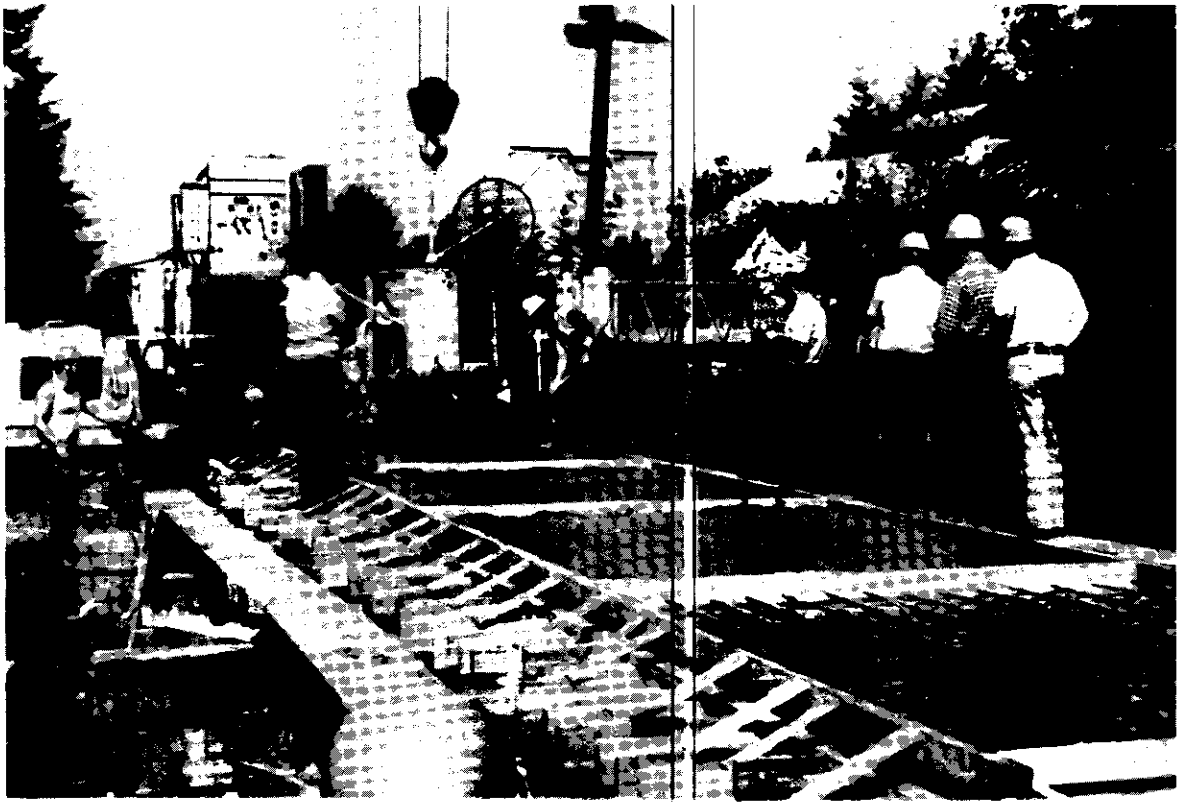
One possible explanation for cracks occuring over the transverse stringers is that the box beams acted like a heat-sink. The heat from the blankets was drawn to the box beams, passing through the concrete above them. The result is that the concrete above the box beams dries out in a short period of time (8 to 10 hours) relative to the concrete between the beams, causing shrinkage cracks. This is the same result as when proper hydration is not maintained during the normal curing period (9).

5) After the heating operation, compressive strength tests should be run. The cracks will have some detrimental affect on the compressive strength, and the extent of this affect should be known.

6) Because the technology has not advanced far enough yet, the method of heat-treating the concrete to melt the wax beads is very costly. Since cracking frequently occurs leaving the rebar susceptible to corrosion, the entire purpose for internally sealing the concrete is defeated. Therefore, wax bead impregnation of concrete bridge decks is not feasible at this time.

APPENDIX B

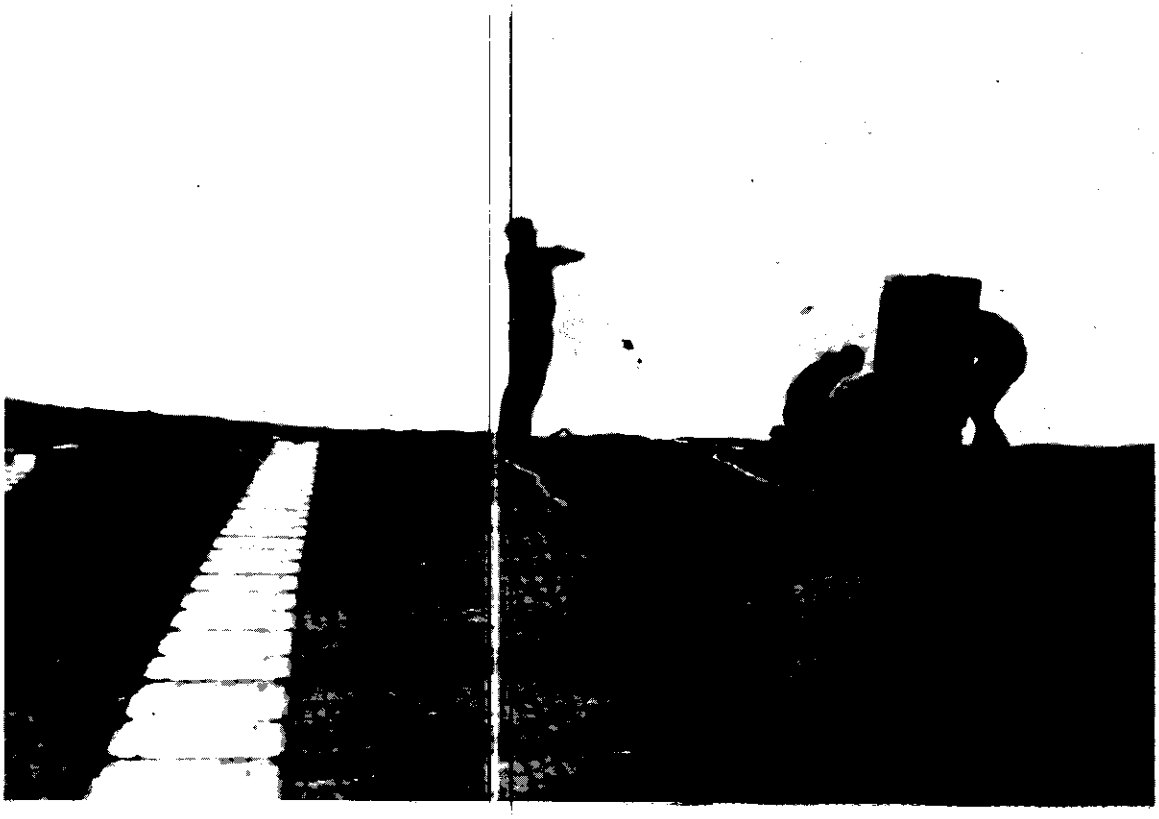
PHOTOGRAPHS



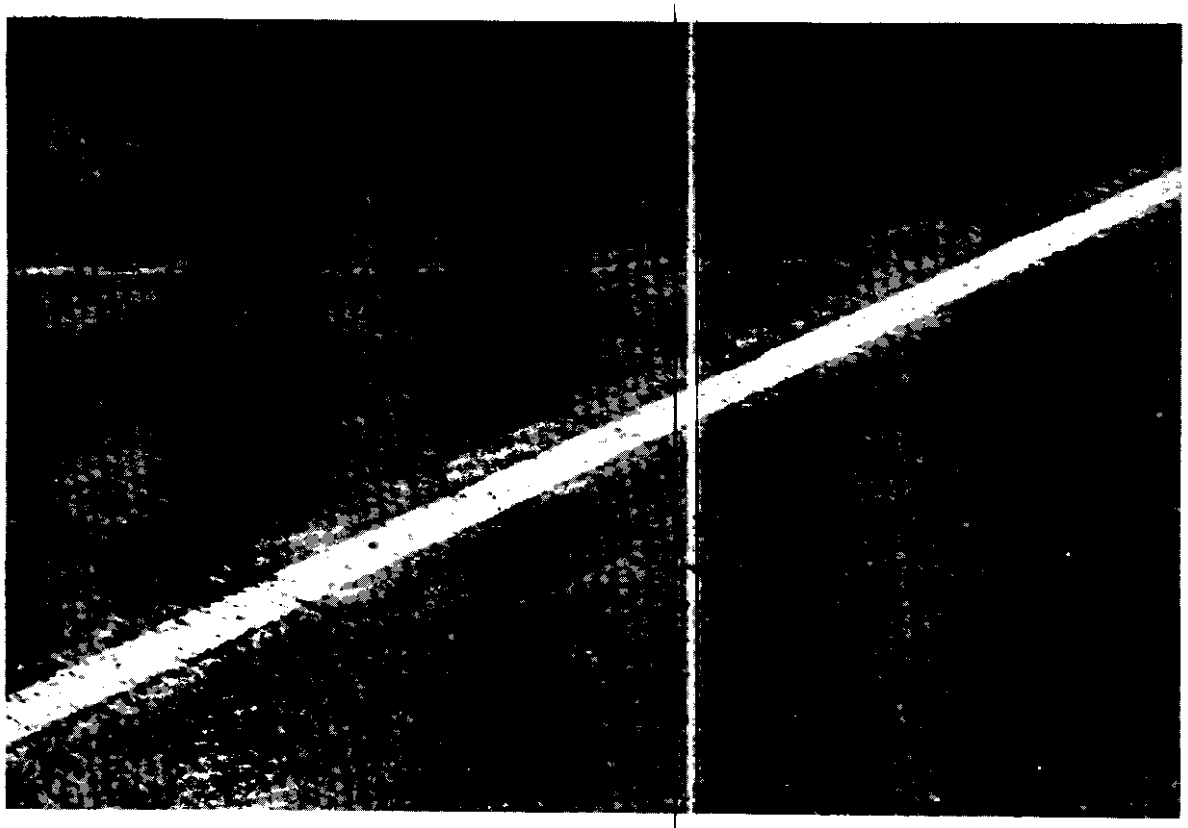
Concrete Placement at Test Site

Heating Blankets at Test Site

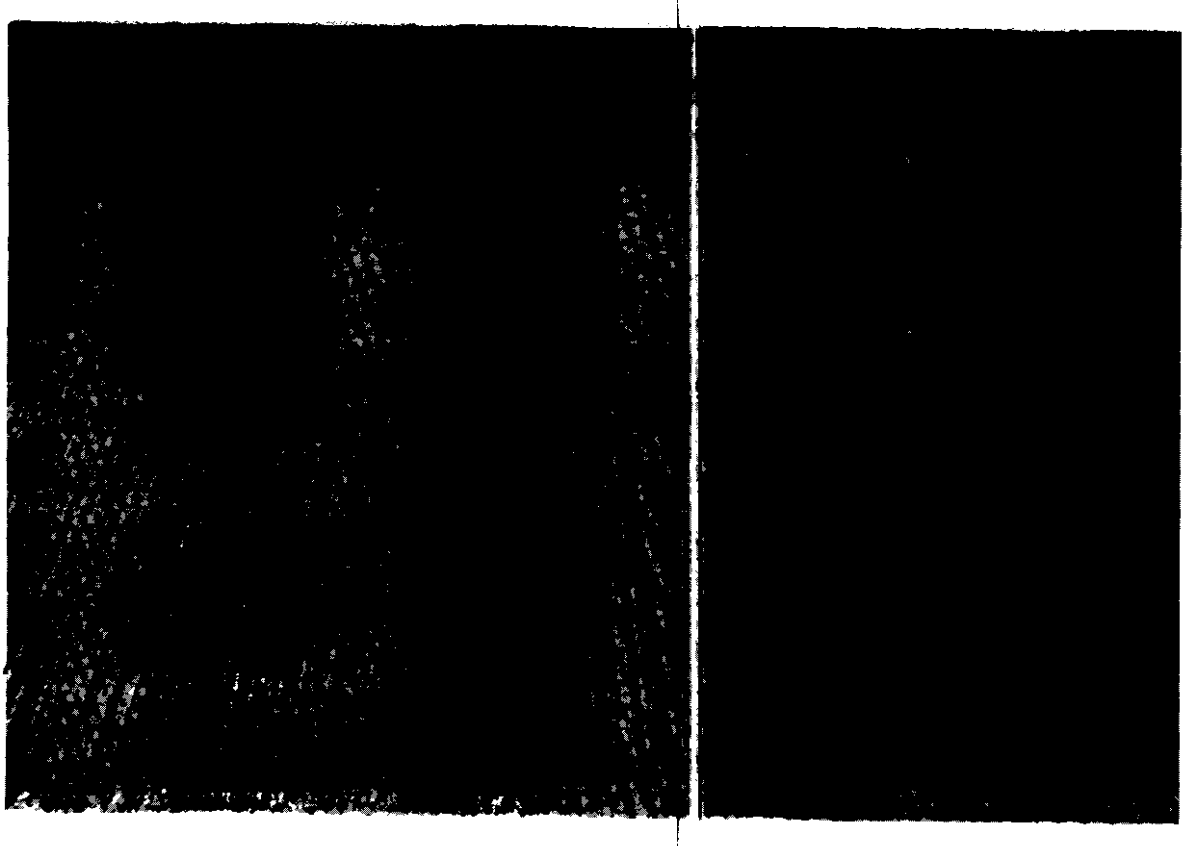
Plastic Cover over Bridge Deck



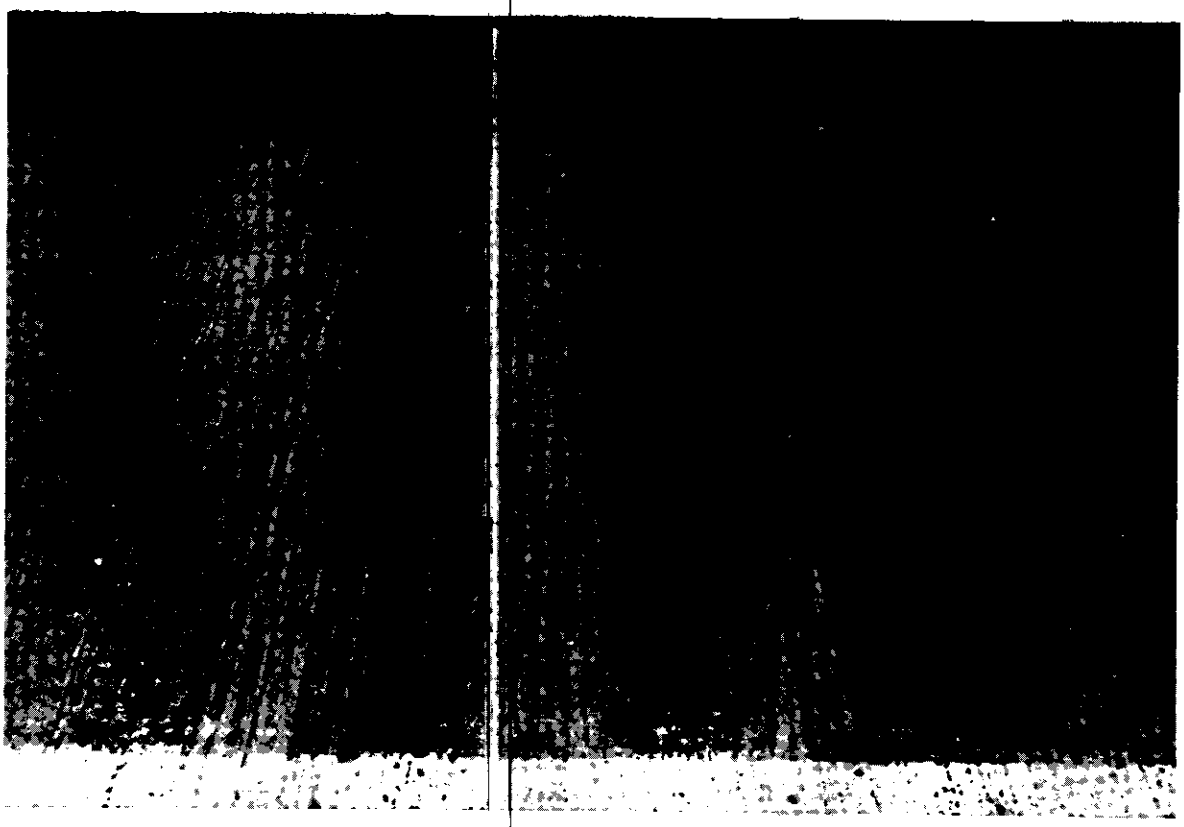
Heating Blankets on Bridge Deck
Under Plastic Cover



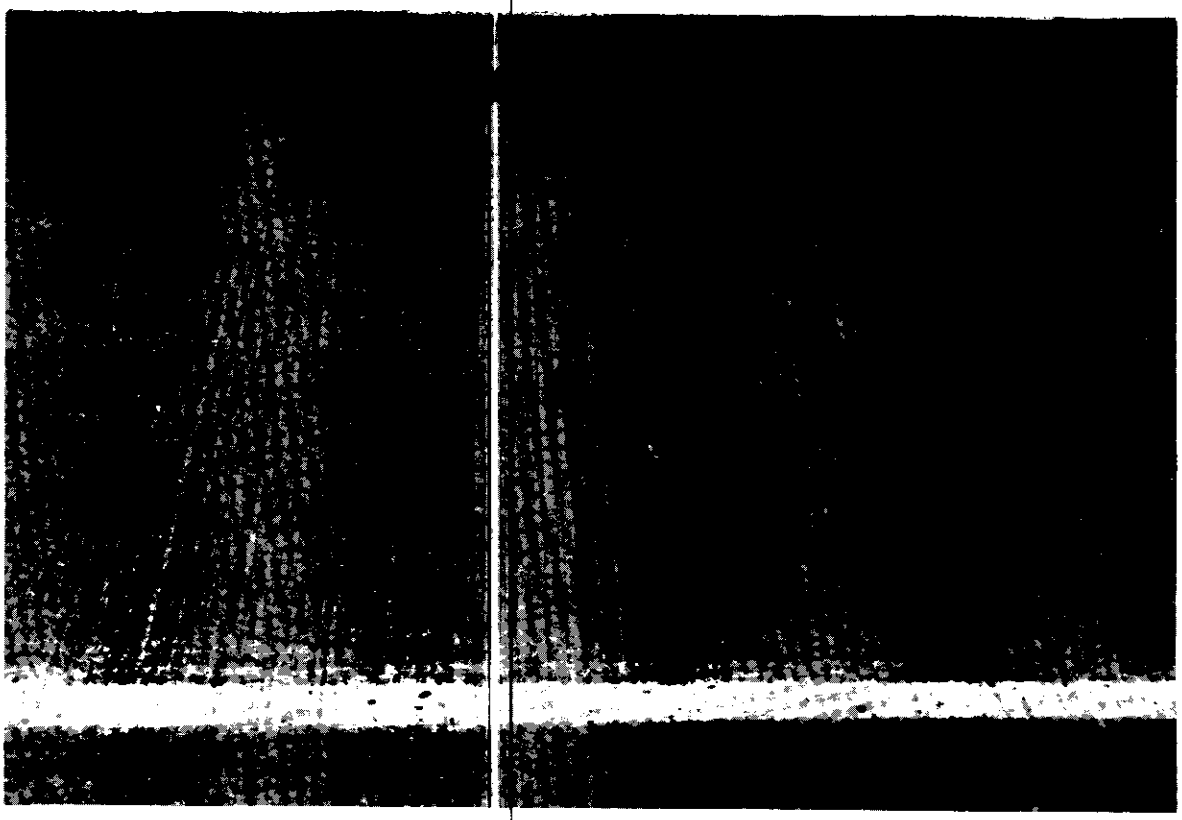
Wax Bead Bridge Deck Cracks



Wax Bead Bridge Deck Cracks



Wax Bead Bridge Deck Cracks



Wax Bead Bridge Deck Cracks