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THERMAL COMPATIBILITY OF BLACK PIGMENTED LOW SLUMP CONCRETE OVERLAY

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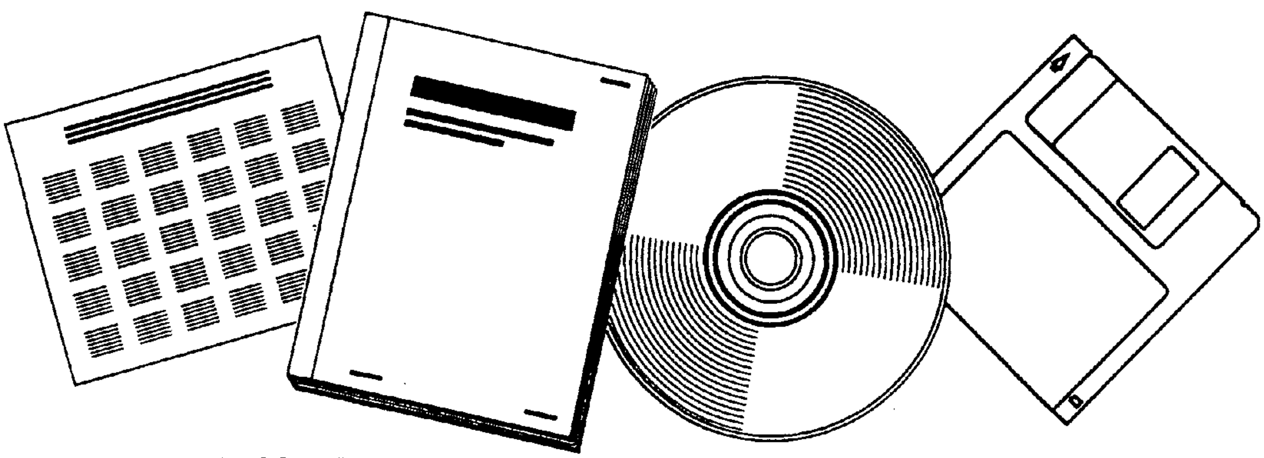

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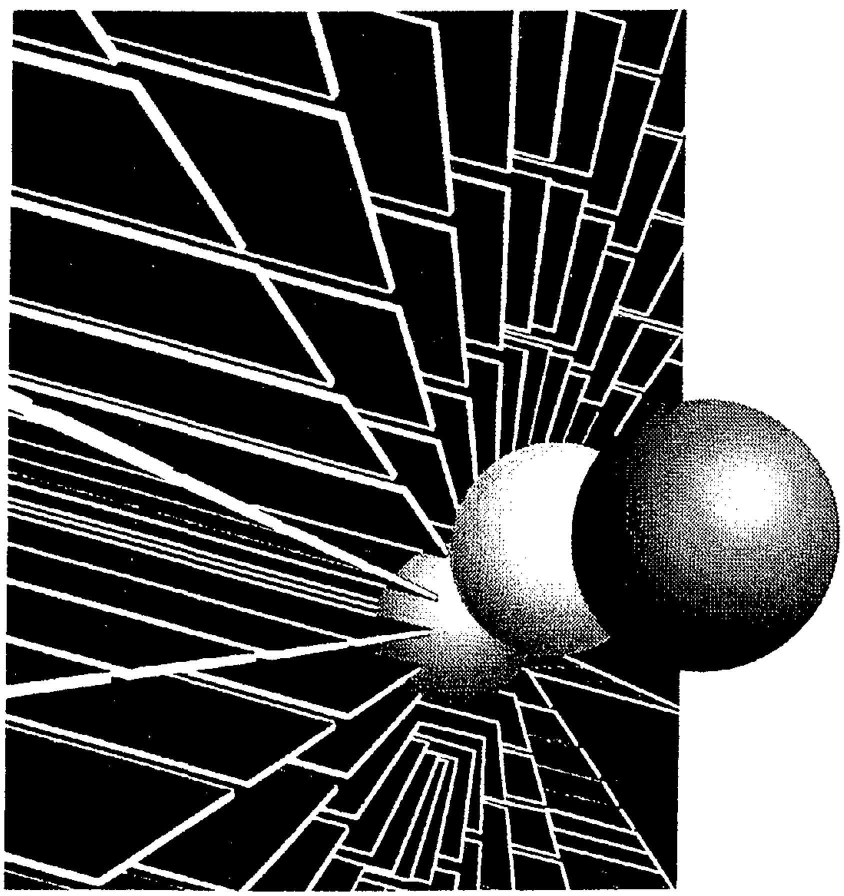
Research, Development and Technology Division

RDT 97-003

Thermal Compatibility of Black Pigmented Low Slump Concrete Overlay

Final Report



December, 1997

THERMAL COMPATIBILITY OF BLACK PIGMENTED LOW SLUMP CONCRETE OVERLAY

FINAL REPORT

RDT 97-003
Research Investigation 96-007

PREPARED BY

MISSOURI DEPARTMENT OF TRANSPORTATION

RESEARCH, DEVELOPMENT AND TECHNOLOGY DIVISION

By

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Senior Materials Research Analyst

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16. Abstract

A laboratory investigation was conducted simulating both a summer and a winter environment to determine the thermal compatibility of black pigmented low slump concrete overlay with in place bridge deck concrete. A regular low slump concrete was used as control for the evaluation.

A notebook computer controlled, data acquisition system was used to automatically turn a group of 4 heat lamps on and off at preset temperature ranges and to monitor temperatures of the concrete 1/4" below the surface of the overlay and the deck concrete.

Data indicated that both the black pigmented and the regular low slump concrete overlays were thermally compatible with the bridge deck concrete.

Additional research is warranted in the field to substantiate laboratory findings.

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Stephen C. Derendinger - A special thanks for designing and building the computer controlled, data acquisition system for maintaining and monitoring concrete surface temperatures.

Dave R. Amos - A special thanks for building and wiring an organizer unit with a separate testing bay for each concrete panel including an apparatus for suspending and adjusting each group of four heat lamps over the concrete's surface.

CONCRETE MIXING CREW

Dave R. Amos - Crew leader

Vernon W. Adams

Jonathon B. Large

Bret Lindsey

ABSTRACT

A laboratory investigation was conducted simulating both a summer and a winter environment to determine the thermal compatibility of black pigmented low slump concrete overlay with in place bridge deck concrete. A regular low slump concrete was used as control for the evaluation.

A notebook computer controlled, data acquisition system was used to automatically turn a group of 4 heat lamps on and off at preset temperature ranges and to monitor temperatures of the concrete 1/4" below the surface of the overlay and the deck concrete.

Data indicated that both the black pigmented and the regular low slump concrete overlays were thermally compatible with the bridge deck concrete.

Additional research is warranted in the field to substantiate laboratory findings.

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OBJECTIVE

This study will investigate the feasibility of using a black pigmented, low slump concrete for bridge deck overlay material. Testing will consist of determining if the dark colored concrete overlay is thermally compatible with the in place deck concrete in a laboratory simulation. The additional heat absorbed by the black surface during periods of direct sunlight would help melt the snow and ice. This would provide a safer driving surface for the motoring public and at the same time reduce the quantity of deicing salts used and subsequently reduce chloride ingress to the reinforcing steel.

INTRODUCTION

This study investigates the feasibility of using a black pigmented, low slump concrete for bridge deck overlay material. During the winter months, bridge decks in Missouri are heavily treated with deicers to help melt the snow and ice to provide a safer driving surface for the motoring public. Therefore, in order to significantly reduce the quantity of deicing salts used and subsequently reduce chloride ingress to the reinforcing steel, it has been proposed that a black pigmented, low slump concrete overlay be used. The additional heat absorbed by the black surface during periods of direct sunlight, would aid in melting snow and ice. However, because the black colored concrete may not be thermally compatible with the Class B-2 bridge deck concrete, it was decided to test the thermal compatibility of the overlay with the in place Class B-2 bridge deck concrete in a laboratory simulation. The test procedures used in this investigation was not from a "Standard Test Method", but was developed by Research, Development and Technology Division personnel.

In addition to thermal compatibility, concrete curing procedures were investigated as a separate issue of interest. Three curing methods were used. One overlaid surface was wet burlap cured, a second surface received white pigmented curing compound at a standard application rate, and a third surface was left unprotected. The purpose was to determine if any of the surfaces would develop shrinkage cracking during the first 24 hours if subjected to a hot and windy environment.

Type I Portland cement, Class A Missouri River Sand, and Cedar Valley Limestone coarse aggregate were used exclusively for both Class B-2 and Low Slump concrete mixes. All concrete was air-entrained. Type A Water-Reducer - WRDA with Hycol was used for the low slump concrete mixes. Carter Waters Ad-Aire air entraining agent was used with both designs. Both the control and the black pigmented mixtures had the same composition and were batched in the same proportions except that the pigmented mixture included the addition of iron oxide at the prescribed dosage rate of 7% by weight of cement.

INSTRUMENTATION

A notebook computer controlled, data acquisition system was used to automatically turn the heat lamps on and off at preset temperature ranges and to monitor temperatures of the concrete 1/4" below the surface of both the overlay and the base concrete. Type T thermocouple wire was placed into the fresh concrete while molding and then connected to the data acquisition system while testing. Visual Basic software was used to write the program to control the test. The following is a list of items required for assembling the data acquisition system:

- Notebook computer
- PCMCIA card DASCard 1001
- Thermocouple switching Unit
- 110 volt switching unit
- 110 volt modules (Four)
- Connecting cables

See Photo 1 for data acquisition set-up for summer environment testing. Winter environment set-up is shown in Photos 3 and 4.

INVESTIGATIVE PROCEDURES

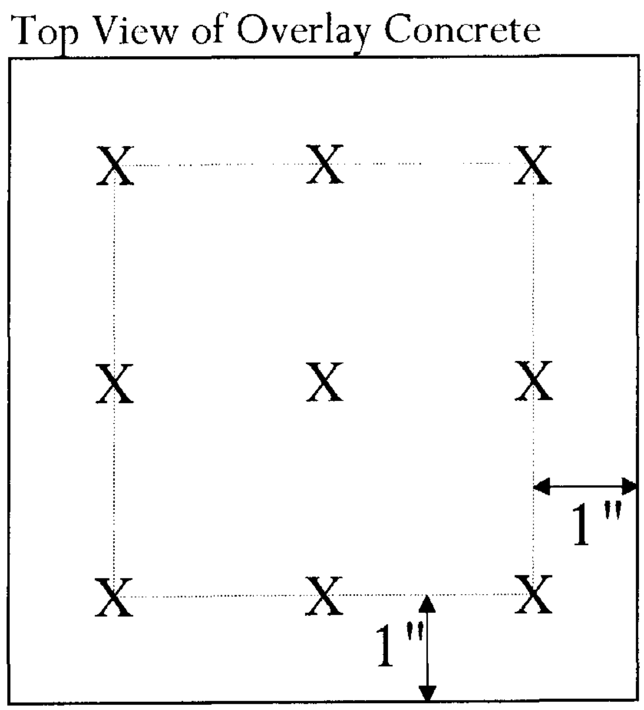
Altogether, four sets of thermal compatibility specimens were tested using both a simulated summer and a simulated winter environment. Each set consisted of one regular low slump concrete overlay for temperature control and one black pigmented low slump concrete overlay for the test panel. The computer program allowed testing and monitoring of two sets simultaneously yet independently of each other.

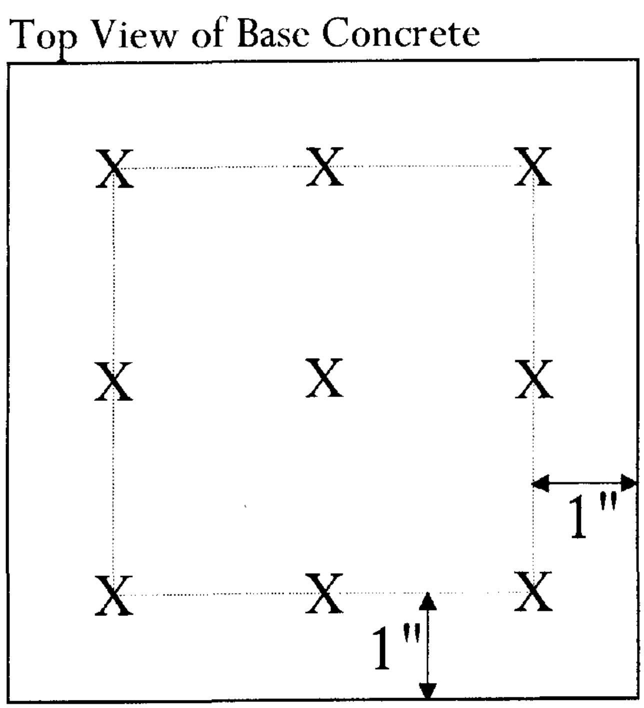
SIMULATED SUMMER ENVIRONMENT

While testing, each overlaid specimen was buried in sand to the base of the overlay to aid in creating a temperature differential between the base and the overlay concrete. Special wooden boxes were constructed to contain the sand. A 2" thick Styrofoam collar was then placed over the specimen to insulate the base concrete during the heating cycles. See Photos 5-8. A four bay organizer was constructed with plywood to house test panels while testing. Each bay was constructed so that each panel would be isolated from the effects of the others. A group of four 250 watt heat lamps were attached to a 12"x12"x 1/8" aluminum plate with the lamps spaced approximately 5 inches above the concrete's surface for each test and control panel. See Photos 1 and 2.

The number and positioning of the lamps was determined using a panel specially constructed for this purpose. This panel was made with nine thermocouples in the base and nine thermocouples in the overlay. See Figure 1 for placement of thermocouples. Temperatures

FIGURE 1: Special Concrete Overlay for Determining Heat Lamp Configuration and Spacing





'X' indicates location of thermocouple buried 1/4" below the surface.

were monitored using two ten channel dataloggers and heat lamps adjusted so that near uniform distribution of heat over the whole overlay's surface was obtained. The best configuration was the use of four heat lamps each equally centered within each 6"x6" quadrant of the 12"x12" panel and suspended approximately 5 inches above the surface of the concrete. Once this configuration was determined, all panels were set up with same lamp spacing and distance from concrete's surface.

The temperature was controlled with one thermocouple placed 1/4" deep at the center of each regular low slump overlay (control). The temperature parameters were set for a maximum temperature of 130° F and a minimum temperature of 100° F. The heat lamps on the black pigmented concrete overlay were automatically turned on and off with the regular low slump control concrete panel and on the average temperatures ran about 9° F higher throughout the heat cycles. A cycle is defined as alternately raising and lowering the temperature between 100° F to 130° F. The room temperature was controlled at 60° to accelerate cycle time. Cycles were allowed to continue for 7 days or 200 cycles whichever came first. In every case 200 cycles were reached prior to 7 days. As soon as the summer environment cycling was completed, the overlays were visually checked for cracking at the interface. Visual observations revealed no de-bonding on any of the panels. The overlays were then subjected to winter environment testing.

SIMULATED WINTER ENVIRONMENT

The temperature parameters were set for a maximum temperature of 40° F and a minimum temperature of 20° F. The walk-in freezer (set a 0° F) was used as the winter testing environment. Each overlaid panel was removed from their sand box and placed on two #8 dowel bars within each bay. See Photos 9 and 10. Zero degree air was allowed to circulate under the base concrete to help create a temperature differential between the surface of the overlay and the base concrete. Again, the heat lamps on the black pigmented concrete overlay were automatically turned on and off with the regular low slump control concrete and on the average temperatures ran about 8° F higher throughout the heat cycle. Cycles were allowed to continue for 7 days or 600 cycles whichever came first. In every case 600 cycles were reached prior to 7 days. These 600 cycles were completed in about the same length of time as the 200 cycles during the simulated summer testing. After completing the 600 cycles, each overlay was visually checked for cracking at the interface. Visual observations revealed no de-bonding of the overlay on any panel.

It was observed that the cycles were quite fast. For this study, no consideration was given to sustaining the maximum or the minimum temperatures for a few minutes to help lengthen the cycle time and perhaps provide more realistic field conditions. For future evaluations consideration should be given to lengthening the cycle time.

IOWA SHEARING STRENGTH OF BONDED CONCRETE:

The "Iowa Shear Test" was conducted to provide a quantitative means of measuring bonding quality. Three full depth 4" diameter cores were drilled through the overlay and B-2 base concrete of each overlaid panel. See Photos 11 and 12. These overlays were sheared off using the testing jig shown in Photos 13 and 14. Strength data were statistically analyzed to compare shearing bond strength of regular low slump to black pigmented concrete. Data are given in Table 1. No significant difference was found in average shearing bond strength (psi) between the black pigmented and the regular low slump concrete overlays using a 95 % level of confidence.

However, the shearing strengths of the regular low slump overlays were in most cases numerically higher than the shearing strength of the black pigmented low slump concrete. One explanation for this difference may be the addition of the 7% iron oxide by weight of cement for tinting the concrete black. See Appendix A for concrete mix designs. This probably caused the slump to be reduced from 3/4" on the regular mix to 1/2" on the black pigmented mix using the same design water. This reduction in the consistency of the concrete could have caused a slight reduction in bonding quality of the black mix as placed.

TENSION BOND TEST - TENSILE BOND STRENGTH:

In addition to the "Iowa Shearing Test" a "Tensile Bonding Test" was conducted. Three 2-inch diameter cores were drilled past the interface of the overlay and the base concrete for Tensile Bond Testing (Pull Off Method). Tensile bond tests were conducted using ACI standards. See Photos 15 and 16. Results are given in Table 1. Bond strength was statistically analyzed to compare bonding quality of regular low slump to black pigmented low slump concrete. No significant difference was found in average tensile bond strength (psi) between the black pigmented and the regular low slump concrete overlays using a 95 % level of confidence. The tensile strengths of the regular low slump overlays were in most cases numerically higher than the shearing strength of the black pigmented low slump concrete overlay. Again, as with "Iowa Shearing Test" reduction in consistency of the concrete could have slightly reduced the bonding quality of the black mix as placed.

Table 1 - CONCRETE OVERLAY BONDING STRENGTH

		Iowa Shearing Strength of Bonded Concrete		Tensile Bond Strength	
Ident.	Core	Load (psi)	Shear Strength (psi)	Load (psi)	Tensile Strength (psi)
LS-11	1	11,720	933	1,400	446
	2	10,390	827	860	274
	3	12,320	980	430	137
		Avg.	**913**		**285**
LS-12	1	11,180	890	660	210
	2	8,960	713	880	280
	3	11,080	882	930	296
		Avg.	**828**		**262**
LS-21	1	7,930	631	1,300	441
	2	12,060	960	860	274
	3	9,250	736	940	299
		Avg.	**776**		**329**
LS-22	1	11,680	929	880	280
	2	13,070	1,040	320	102
	3	8,580	683	780	248
		Avg.	**884**		**210**
LSB-11	1	9,500	756	880	280
	2	8,410	669	400	127
	3	8,730	695	640	204
		Avg.	**707**		**204**
LSB-12	1	5,500	438	720	229
	2	9,010	717	500	159
	3	10,070	801	300	95
		Avg.	**652**		**161**
LSB-21	1	7,660	610	890	283
	2	8,380	667	820	261
	3	10,170	809	730	232
		Avg.	**695**		**259**
LSB-22	1	7,160	570	740	236
	2	10,460	832	820	261
	3	11,090	883	520	166
		Avg.	**762**		**221**

LS = Regular Low Slump Concrete   LSB = Black Pigmented Low Slump Concrete

SPECIAL CONCRETE CURING TEST :

In addition to thermal compatibility testing, a special curing test was conducted on the black pigmented, low slump concrete overlay. Three concrete panels measuring 18"x18"x2", which were prepared in 1989 for an earlier investigation, were used as base concrete for the overlays. The three panels were overlaid to a depth of 2 1/2". At 30 minutes of concrete age, the surface of each overlay was wire combed. One overlay was immediately covered with wet burlap and then covered with polyethylene sheeting to reduce evaporation, a second overlay received a white pigmented curing compound at the standard application rate, and a third overlay was left unprotected. The specimens were initially placed in a hot and windy environment for 24 hours. The laboratory walk-in freezer was used to provide the testing environment for this phase of the investigation. The walk-in freezer was shut down and allowed to come to room temperature. A thermostatically controlled electric heater was then used to control the temperature in the freezer room at approximately 100° F while an electric fan was used to simultaneously blow air across the surface of each overlay.

The panels were removed from the freezer room at 24 hours of concrete age and the surfaces were observed for cracking. No cracking was observed on the surface of any of the overlays. Wet burlap with a plastic cover was then placed on the surfaces of both the "burlap cured" specimen and the "unprotected" specimen and curing continued at room temperature and humidity in the mixing room until the overlays were 96 hours old. The plastic cover and wet burlap was then removed and the specimens were allowed to continue curing in air until the concrete overlay was 28 days old at which time the surfaces were again observed for cracking. Again, no cracking was observed on the surface of these overlays.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS:

1. Test results indicate that both the black pigmented low slump and the regular low slump concrete overlays were thermally compatible with the bridge deck concrete based on a laboratory simulation of field conditions.

2. Visual inspection of the interface of the overlays on all test and control panels revealed no evidence of cracking following 200 cycles (summer environment) and 600 cycles (winter environment).

3. Consideration should be given to lengthening cycle time for future investigations. This could be done by sustaining minimum and maximum temperatures for some specified length of time.

4. No significant difference was found between average shearing bond strength of the black pigmented low slump concrete overlay and regular low slump concrete overlay at the 95% level of confidence.

5. No significant difference was found between average tensile bond strength of the black pigmented low slump concrete overlay and regular low slump concrete overlay at the 95% level of confidence.

6. The addition of black pigment to low slump concrete appears to have had no significant detrimental effect on the performance of a low slump overlay based on a laboratory evaluation.

7. No cracking developed on the surface of any of the black pigmented concrete test panels during the special curing test.

RECOMMENDATIONS:

1. It is recommended that additional research be conducted in the field to substantiate laboratory findings.

IMPLEMENTATION

It is proposed that additional research be conducted in the field to substantiate laboratory findings as results indicate that adding black pigment to low slump concrete had no detrimental effect on the performance of the bridge deck overlay. It is proposed that two bridge decks, located in close proximity to each other be selected for evaluation. One deck would be overlaid with regular low slump concrete and the other overlaid with black pigmented low slump concrete. Surface temperatures could be monitored periodically and records be maintained on performance in the winter during periods when ice and/or snow would be present. Randomly selected full depth cores would be drilled from each deck initially and following at least 5 years of service. The overlays would be sheared off using the "Iowa Shear Bonding Test" and a comparison made between bonding strength of the regular and black pigmented concrete. If the black pigmented low slump concrete performs satisfactorily under field conditions, it should then be recommended as an alternate material for overlaying bridge decks.

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Dabney, Charles M., "Impact of Color in Concrete," Concrete International, Vol. 12, December 1990, page 20.

"Colored Concrete - Last fifteen Years," Transportation Research Information Service (TRIS).

"Solomon Colors," SGS Architectural Catalog, Solomon Grind-Chem Services, Inc.

AASHTO Designation: C884-92 "Standard Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay."

AASHTO Designation: C970-82 (Reapproved 1993) "Standard Specification for Pigments in Integrally Colored Concrete.

APPENDIX A

CONCRETE MIX DESIGN DATA

Table A1

CONCRETE MIX DESIGN FACTORS
(Class B-2 Concrete)

Cement Factor (Sk/cu yd)	7.75
Water /Cement Ratio (gal/sk)	4.00
Slump (inches)	2 ½ max.
Air Content (%)	5.5±1.5

Aggregate Proportions by Absolute Volume:
- 37% Class A Missouri Sand
- 63% Gradation "D" Cedar Valley Limestone Coarse Aggregate

The mix calculations were made using oven dry weight of aggregate and allowing for moisture content of both coarse and fine aggregate.

Missouri Standard Specifications for Highway Construction, 1996

Coarse Aggregate:	Sec 1005.1 and Gradation "D" requirements of Sec 1005.1.3
Fine Aggregate:	Sec 1005.2 and Gradation requirements of Sec 1005.2.4.1

Table A2

CONCRETE MIX DESIGN FACTORS
(Low Slump Concrete)

	Non-Pigmented	Black Pigmented
Cement Factor (sk/cu yd)	8.75	8.75
Water/Cement Ratio (gal/sk)	3.70	3.70
Type A Water-Reducer (oz/sk) (WRDA with Hycol)	3.0	3.0
SGS No. 920 Black (% by Wt. of Cement)*	NA	7.0
Slump (inches)	1/2 ± 1/2	1/2 ± 1/2
Air Content (%)	5.5±1.5	5.5±1.5

* Product of Solomon Grind-Chem Services, Inc. used to tint the concrete black.

Aggregate Proportions by Absolute Volume:
50% Class A Missouri River Sand
50% Gradation "E" Cedar Valley Limestone Coarse Aggregate

The mix calculations were made using oven dry weight of aggregate and allowing for moisture content of both coarse and fine aggregate.

Missouri Standard Specifications for Highway Construction, 1996

Coarse Aggregate:	Sec 1005.1 and Gradation "E" requirements of Sec 1005.1.3
Fine Aggregate:	Sec 1005.2 and Gradation requirements of Sec 1005.2.4.1

Table A3

CHARACTERISTICS OF FRESH CONCRETE

(Class B-2 Concrete)

Cement Factor(sk/cu yd)	7.75
Water/Cement Ratio (gal/sk)	4.00
Slump (inches)	2
Air Content (%)	5.4

(Low Slump Concrete)

	Non-Pigmented	Black Pigmented
Cement Factor(sk/cu yd)	8.75	< 8.75
Water/Cement Ratio (gal/sk)	3.70	3.70
Slump (inches)	3/4	1/2 *
Air Content (%)	5.5	4.7 *
Weight of Concrete (lbs/cu ft)	143.8	147.1 *

* The addition of 7 % iron oxide by weight of cement has resulted in a significant increase in unit weight of concrete from 143.8 lbs/cu ft to 147.1 lbs/cu ft, a reduction of slump from 3/4" to 1/2", and a reduction of air content from 5.5% to 4.7%.

APPENDIX B

CONCRETE MIXING

BATCHING OF CLASS B-2 CONCRETE AND EMBEDDING OF THERMOCOUPLE WIRES

Concrete was mixed in two batches which provided enough concrete for molding nine panels measuring 12"x12"x3". Eight of these panels were used as base concrete for low slump overlays and one was used as a base for constructing a special overlaid panel for setting-up the optimum heat lamp configuration over the surface of the concrete to obtain uniformity of temperature while testing. The mix design factors are given in Table A1. Immediately after molding, a thermocouple was embedded 1/4" below the surface of the fresh concrete at the center of the tops of the specimens to be used in monitoring base concrete surface temperature while testing. The base concrete panel for the special overlaid panel was constructed with nine thermocouples embedded 1/4" below the surface and spaced as shown in Figure 1.

All coarse aggregate was in an air dry condition at the time of placing it into the mixer. Effective water was calculated according to Sec 501.6 in the Construction Manual. Mixing was done using a Lancaster SW laboratory mixer according to AASHTO T-126. Concrete was air-entrained. Slump and air content determinations were made immediately following the final mixing period. Characteristics of fresh concrete are shown in Table A3.

BATCHING OF LOW SLUMP OVERLAY CONCRETE AND EMBEDDING OF THERMOCOUPLE WIRES

Low Slump was mixed in three batches, one for non-pigmented concrete and two for black pigmented concrete in reference to MRSP-90-11B, "Low Slump Concrete Wearing Surface" and Sec 505 "Bridge Deck Concrete Wearing Surface" in the "Missouri Standard Specifications for Highway Construction, 1996. The non-pigmented concrete overlay was constructed on five B-2 base concrete panels. One of these panels was designated as a special overlaid panel and the remaining four were designated as test control panels. The second batch, a black pigmented, low slump concrete was constructed on four B-2 base concrete panels and were designated as test panels. The third batch was used to overlay the three 18"x18"x2" base concrete panels which were used for the "Special Concrete Curing Test". Prior to overlaying, the surfaces of the base concrete panels were prepared by sandblasting to remove any laitence and loose concrete material. The mix design factors are given in Table A2. Immediately after molding, a thermocouple was embedded 1/4" below the surface of the fresh concrete at the center of the tops of the specimens to be used in monitoring and controlling overlay temperature. The overlay for the special overlay was constructed with nine thermocouples embedded 1/4" below the surface and spaced as shown in Figure 1.

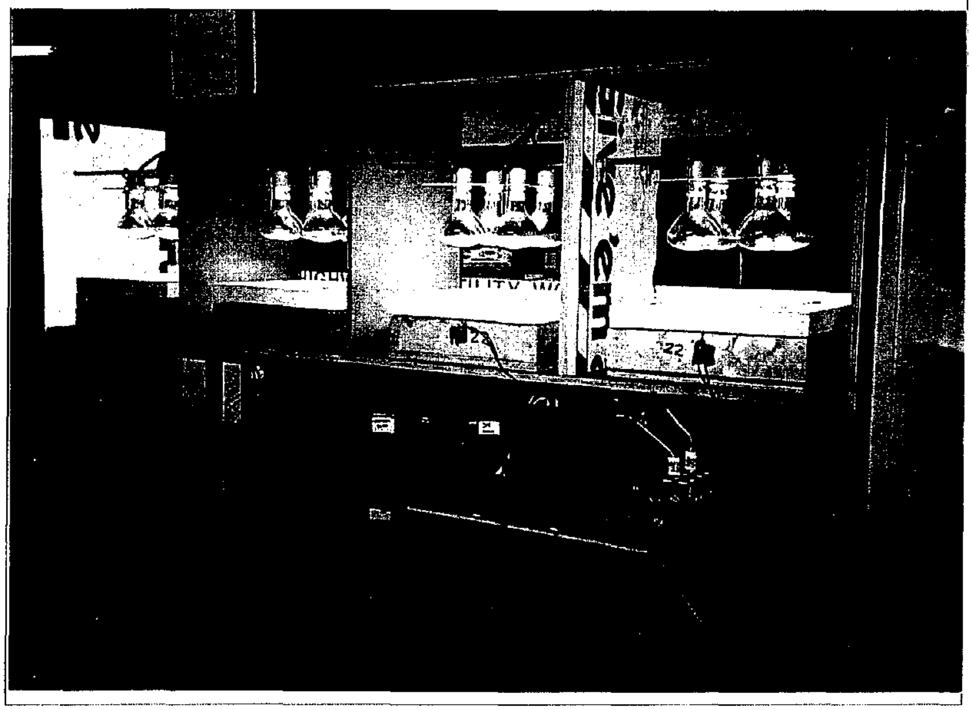
All coarse aggregate was in an air dry condition at the time of placing it into the mixer. Effective water was calculated according to Sec 501.6 in the Construction Manual. Mixing was done in a Lancaster SW laboratory mixer according to AASHTO T-126. Concrete was air-entrained. Characteristics of fresh concrete are shown in Table A3. Note that the addition of

7 % iron oxide by weight of cement resulted in a significant increase in unit weight of concrete from 143.8 to 147.1 lbs/cu ft. Also, because the water/cement ratio was held constant for both pigmented and non-pigmented mixes, the addition of iron oxide caused a reduction in slump from 3/4" to 1/2" and a subsequent reduction of air content from 5.5 % to 4.7 %. This reduction in air content complies with ASTM C979 which states that air content of pigmented concrete shall not change by more than 1.0 % as compared to uncolored concrete. Both the control mixture and the black pigmented mixture had the same composition and batched in the same proportions except that the pigmented mixture included the addition of iron oxide at the prescribed dosage rate of 7% by weight of cement. The plant representative of Solomon Grind-Chem Services, Inc. said that keeping the dosage of iron oxide under 10 % by weight of cement should not affect the concrete mix design.

APPENDIX C

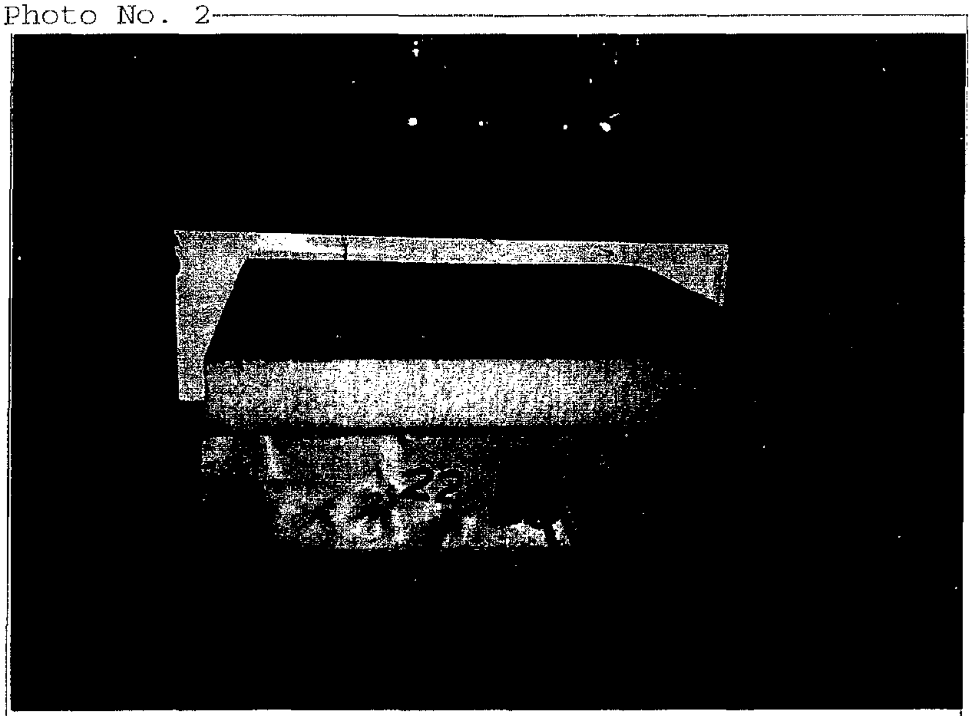
PHOTOGRAPHS

Photo No. 1



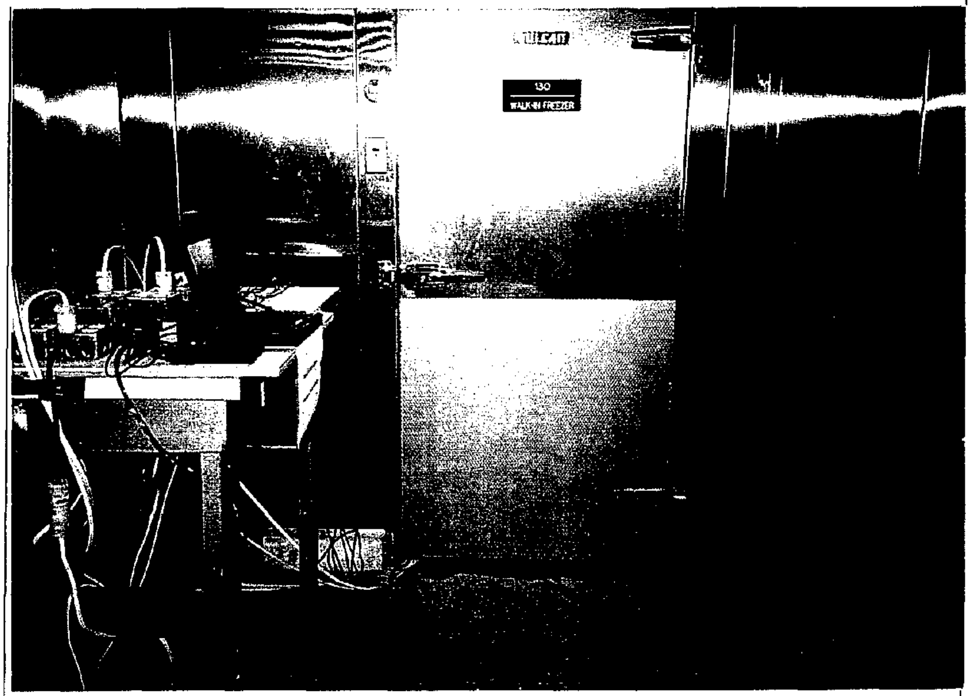
Data acquisition set-up for summer environment test

Photo No. 2



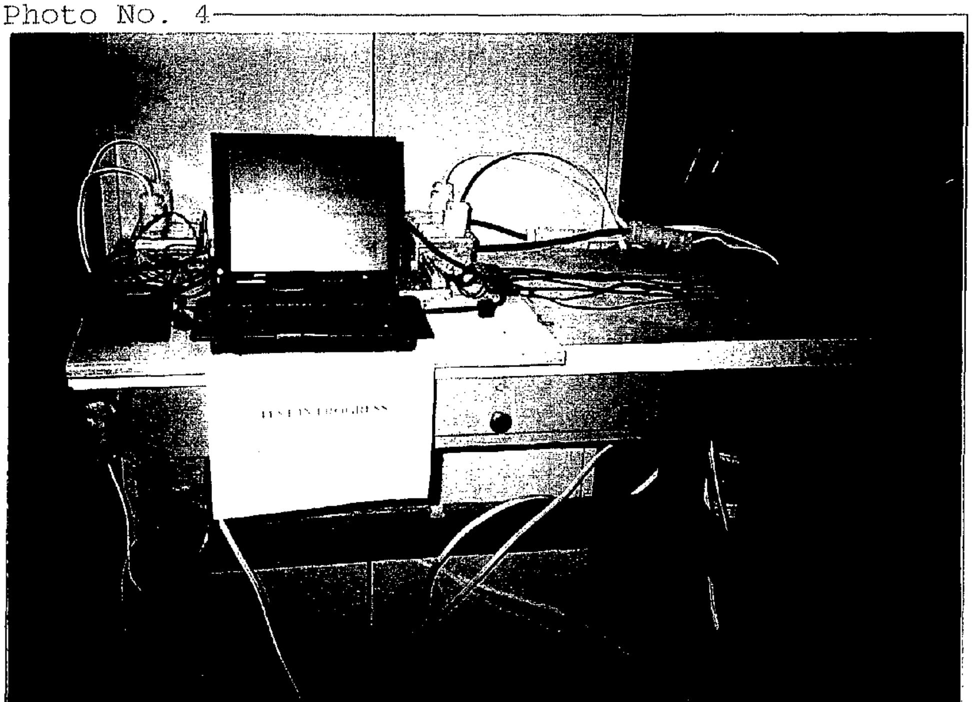
Heat lamp spacing above concrete overlay surface

Photo No. 3



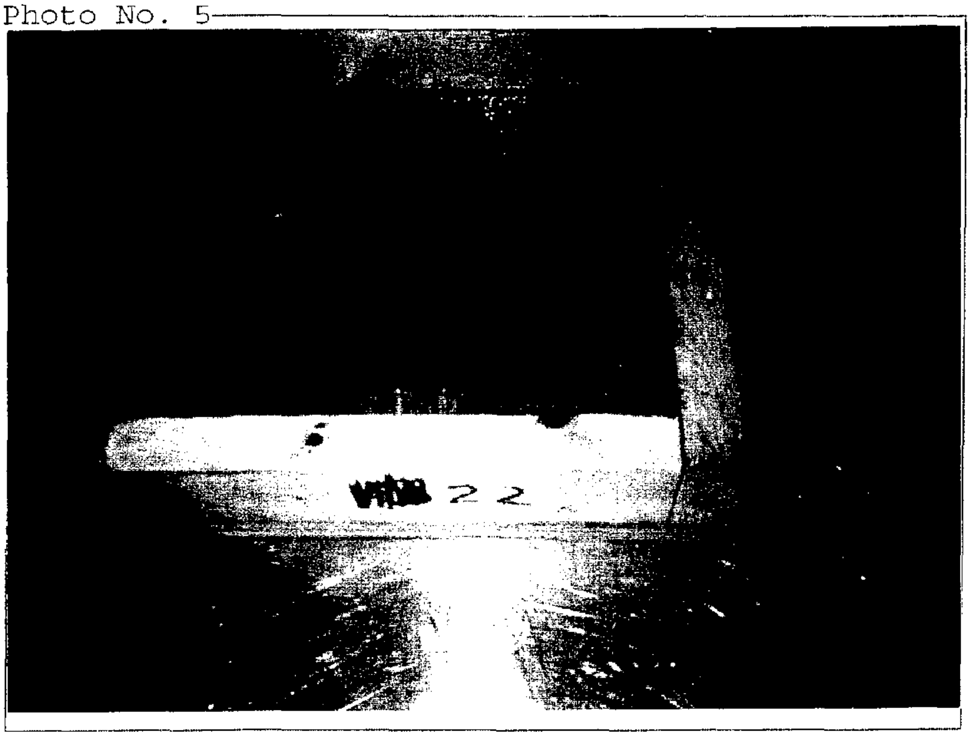
Data acquisition set-up for winter environment test

Photo No. 4



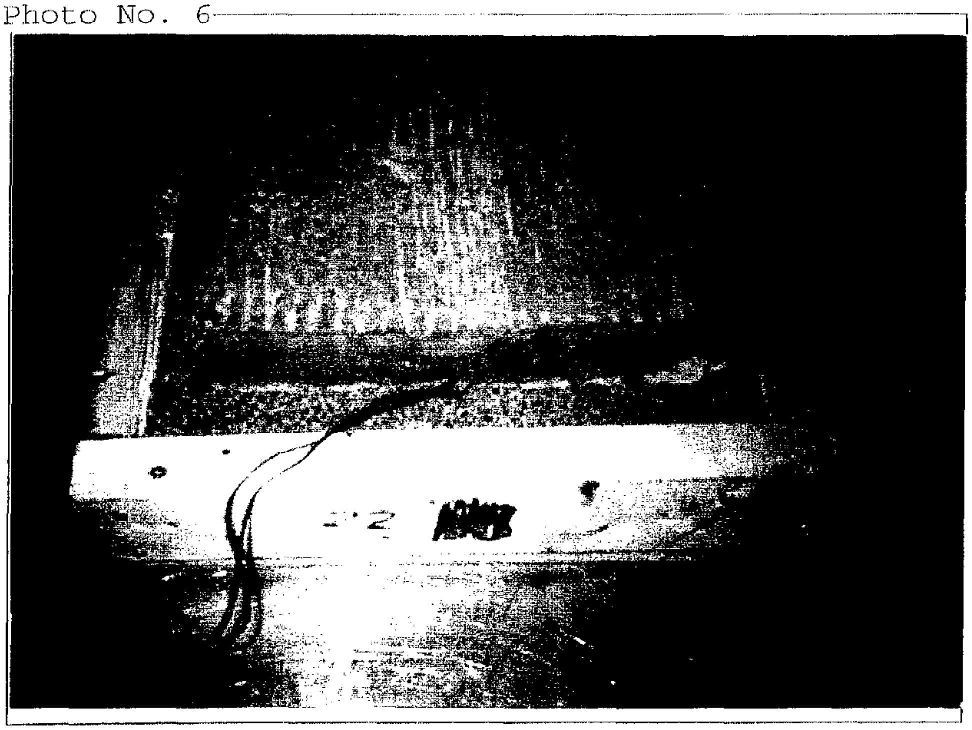
Close-up view of computer hook-up

Photo No. 5



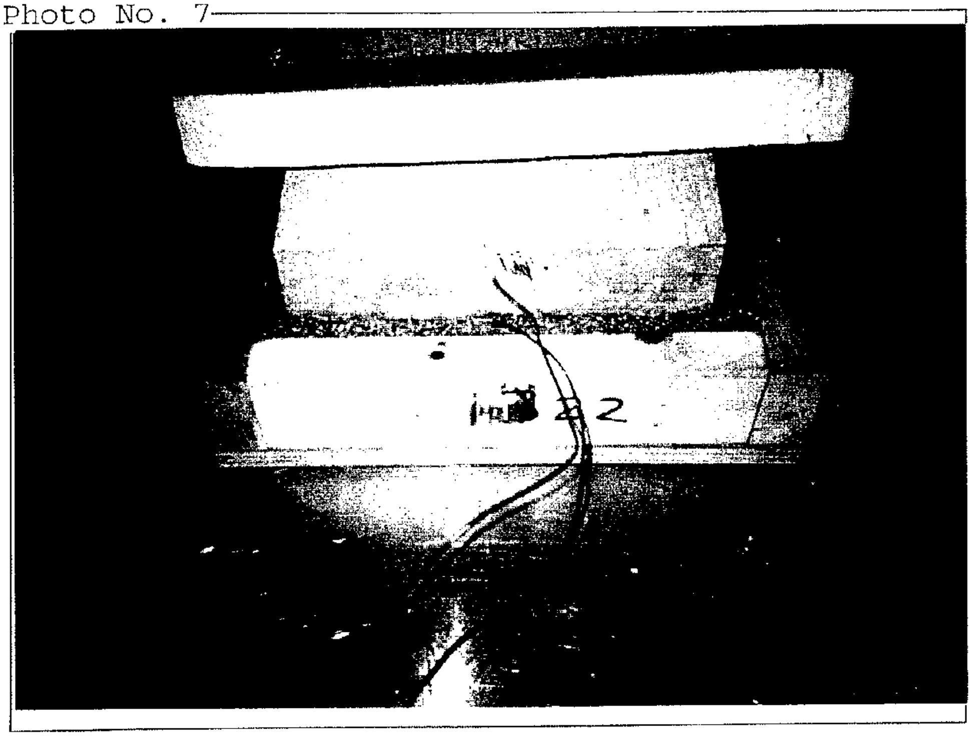
View of box used to contain sand around base of overly

Photo No. 6



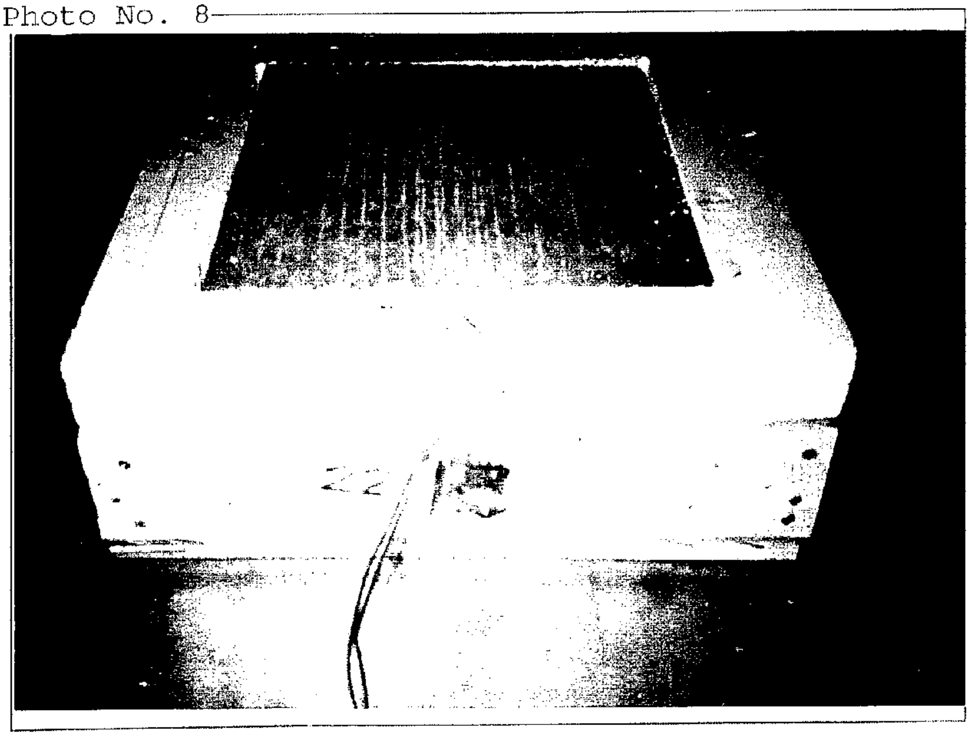
View of overlaid panel with base buried in sand

Photo No. 7



Positioning of styrofoam around overlay

Photo No. 8

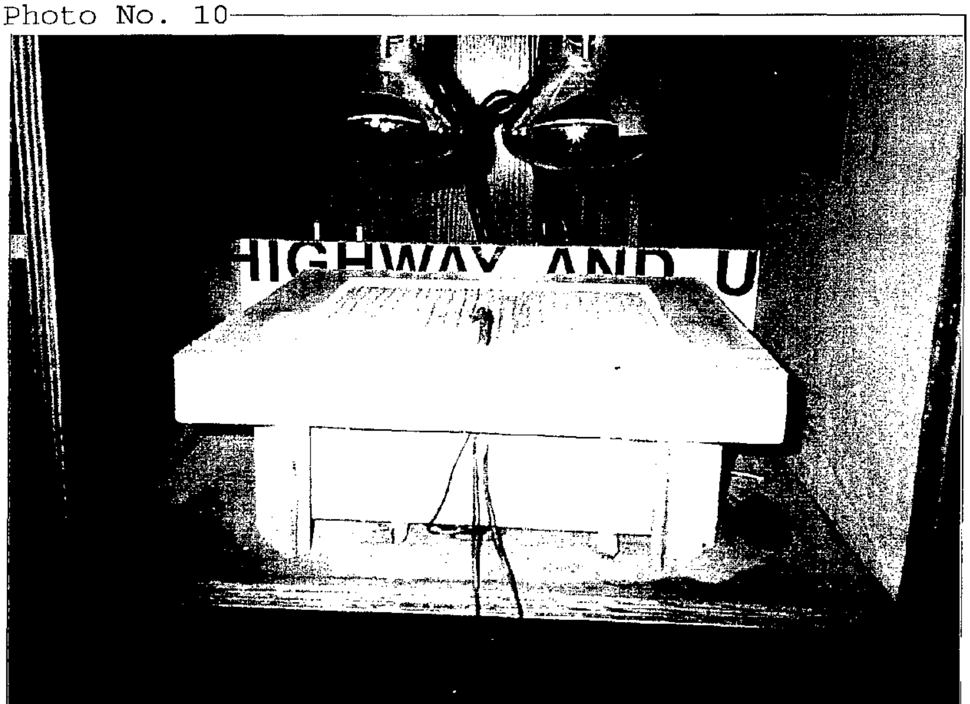


Styrofoam in place and specimen ready for testing

Photo No. 9

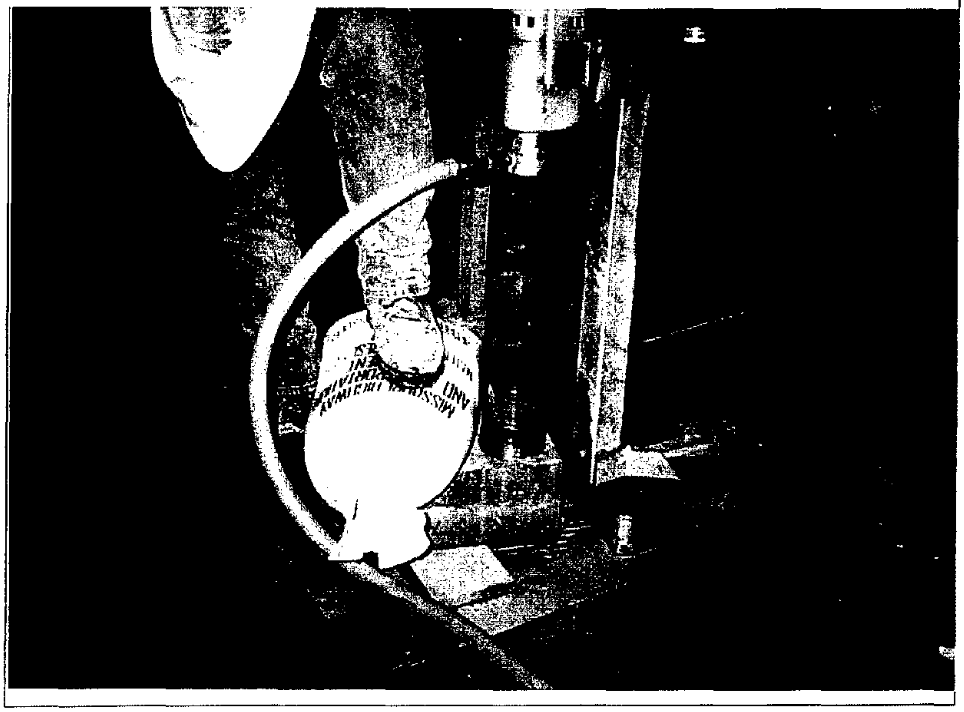
Set-up for winter environment testing

Photo No. 10



Placement and positioning of heat lamp grouping

Photo No.11

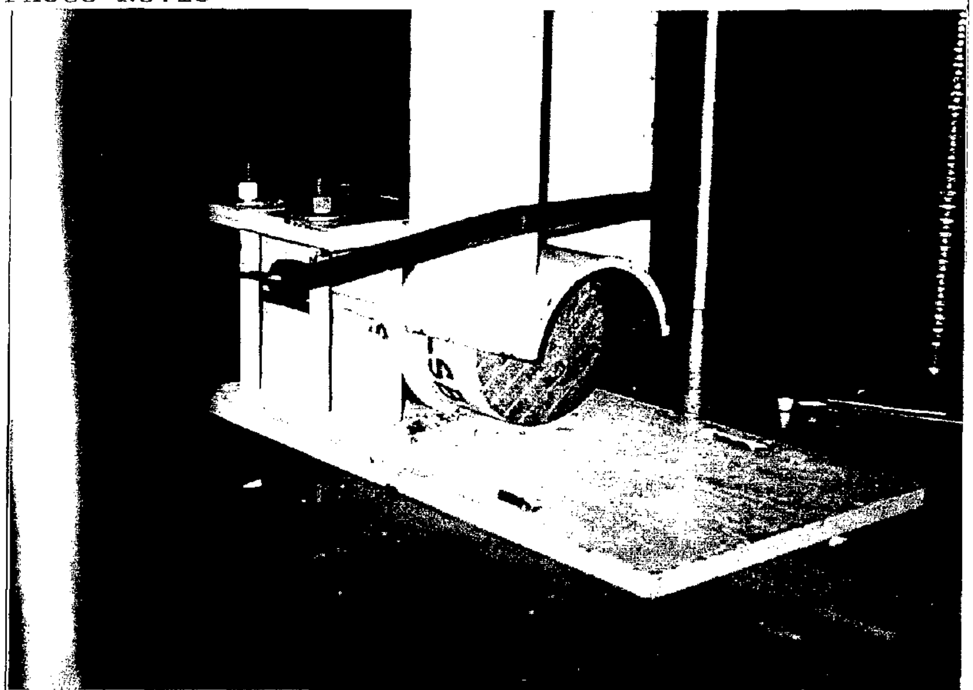


Drilling full depth cores from panels

Photo No. 12

Removal of core from concrete panel

Photo No.13

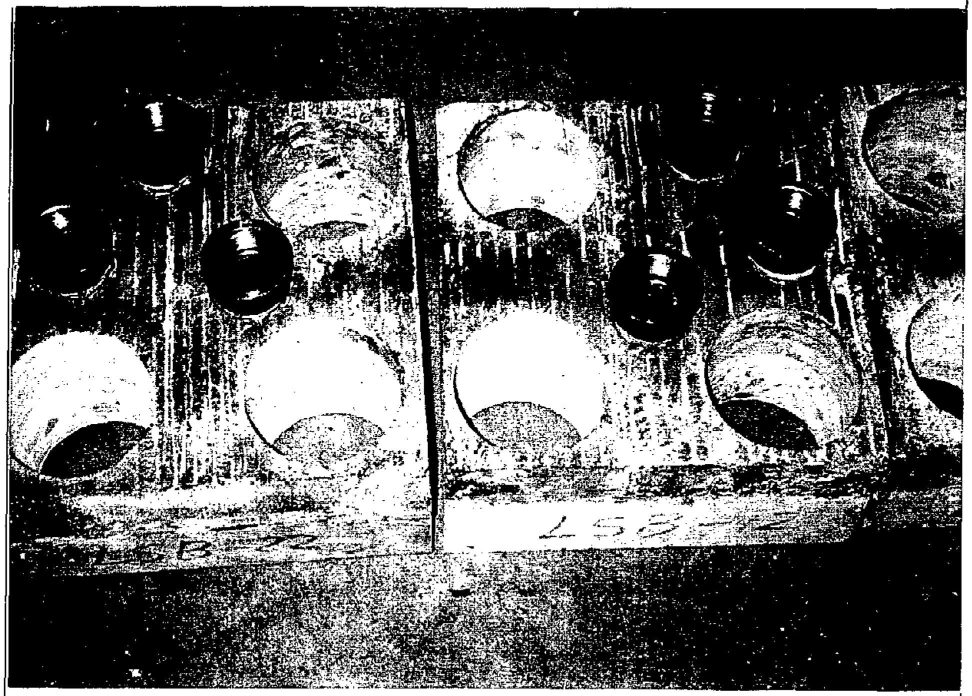


View of core in testing jig ready for breaking

Photo No. 14

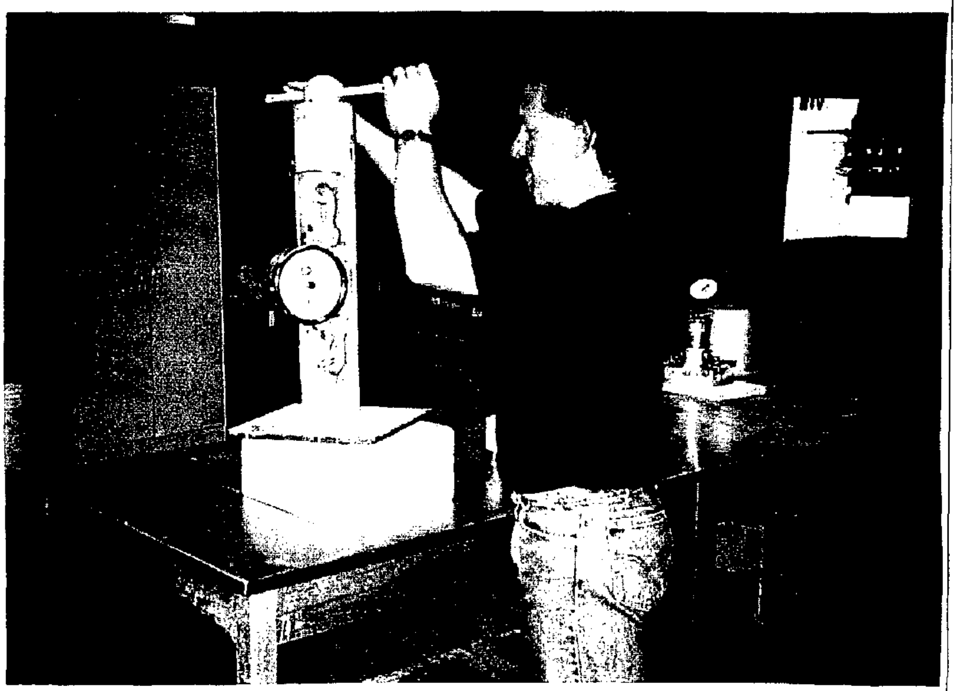
View of core after shearing off overlay

Photo No.15



View of pipe caps epoxyed to top of drilled cores

Photo No. 16



Pulling caps (tensile bond test in progress)

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