Bridge Deck Moisture Measurement

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16. ABSTRACT

Moisture is a primary contributing factor in the long term durability of bridge decks. Moisture is involved in freeze-thaw problems in portland cement concrete and in corrosion of reinforcing steel. Chloride ions, another factor contributing to corrosion, are normally transported through the concrete bridge deck to the reinforcing steel by moisture.

Moisture measurement techniques were examined and one of the methods, Peltier-type psychrometers, was used to measure bridge deck moisture. Measurements were made at depths of 0.5, 1.5, 3.0 and 4.5 - 5.5 in. Both negative and positive moment regions were instrumented. The degree of saturation at the level of the reinforcing steel was found to be about 90 percent, with little variation over the two month period that measurements were taken. Moisture content fluctuations were greater in the negative moment region than the positive moment region, probably due to a higher degree of tensile cracking in the negative moment region. Moisture fluctuations could lead to increased migration of chloride ions to the reinforcing steel. Measurement of moisture content distributions before and after wetting a bridge deck could be used as an indicator of corrosion protection provided by overlays.

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BRIDGE DECK MOISTURE MEASUREMENT

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DISCLAIMER

Bridge Deck Moisture Measurement

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Abstract

Moisture is a primary contributing factor in the long-term durability of bridge decks. Moisture is involved in freeze-thaw problems in portland cement concrete and in corrosion of reinforcing steel. Chloride ions, another factor contributing to corrosion, are normally transported through the concrete bridge deck to the reinforcing steel by moisture.

Moisture measurement techniques were examined and one of the methods, Peltier-type psychrometers, was used to measure bridge deck moisture. Measurements were made at depths of 0.5, 1.5, 3.0 and 4.5 to 5.5 in. Both negative and positive moment regions were instrumented. The degree of saturation at the level of the reinforcing steel was found to be about 90 percent, with little variation over the 11-month period that measurements were taken. Moisture content fluctuations were greater in the negative moment region than the positive moment region, probably due to a higher degree of tensile cracking in the negative moment region. Moisture fluctuations could lead to increased migration of chloride ions to the reinforcing steel. Measurement of moisture content distributions before and after wetting a bridge deck could be used as an indicator of corrosion protection provided by overlays.

PROJECT OVERVIEW

Purpose

The purpose of this project was to investigate field moisture measurement methods and use one of those methods to better understand bridge deck moisture distributions. Bridge deck moisture distributions can be used to better evaluate the effectiveness of protective overlays and to develop and refine methods of bridge deck protection, thereby improving the long-term performance of bridge decks.

Major Findings

A number of accurate moisture measurement methods exist, both direct and indirect, and there is no best method for every application. The choice of method should depend on the requirements of each application.

The moisture content in a bridge deck receiving regular rainfall can be expected to be quite high. At the level of the reinforcing steel, psychrometers measured saturation levels in the positive moment area of the bridge as high as 88 percent and in the negative moment area of the bridge as high as 92 percent. These moisture contents did not vary much during the period measurements were taken, September 1986 through July 1987. Moisture content fluctuations in the deck above the level of the reinforcing steel and in the low-slump dense concrete overlay were greater in the negative moment area of the bridge.

Recommendations

The field moisture content measurements begun in this study should be continued through autumn 1987 to determine expected seasonal variations in moisture contents. A laboratory study should be conducted to determine the reliability of psychrometers used in the field study, and to verify the field measurements. The combined effects of moisture and chloride content on corrosion rates should also be investigated to determine the threshold levels necessary for corrosion to occur.

In addition to the recommended additional work above, the following implementation is recommended:

1. Consideration should be given to the use of moisture measurement as a method of measuring the expected effectiveness of new overlays in preventing corrosion. Measuring the moisture content in the bridge deck down to the reinforcing steel and then wetting the bridge and remeasuring the moisture could be used to check for porous or cracked sections of overlay. Large changes in moisture content would indicate that the overlay could be relatively ineffective at preventing chloride migration to the reinforcing steel. This evaluation should be performed in summer when the bridge deck is drier, using a non-intrusive, indirect method of moisture measurement such as the FHWA NMR device.

2. The chloride content profiles of bridge decks that have been in service and are scheduled for overlay should be determined. As more is learned about the correlation between corrosion and the chloride-moisture environment, field data, including chloride content at the time of overlaying and the effectiveness of bridge overlays in preventing corrosion, will be useful in refining bridge deck protection strategies.

INTRODUCTION

General

Moisture is a primary factor affecting the durability of bridges and bridge deck overlays. Moisture contributes to damage caused by freezing and freeze-thaw, and it is the primary means by which chlorides migrate to the reinforcing steel. Furthermore, and perhaps most important, moisture combined with chloride ions can corrode reinforcing steel, requiring extensive and expensive rehabilitation.

The relationship between moisture content and chloride ion content and how these affect the rate of corrosion in reinforcing steel is a complex problem and will require considerable research before the corrosion mechanisms and controlling processes are completely understood. However, in order to apply current knowledge of corrosion mechanisms and controlling processes to the prevention of bridge deck corrosion, bridge deck moisture distribution and seasonal fluctuations must be known. As an example, if at a given degree of saturation the minimum chloride content necessary for corrosion is identified, then the required depth of pre-overlay deck removal will be related to chloride content distribution. Because of chloride content distribution, the depth of removal might extend into otherwise sound concrete, and vary for different levels of deck moisture.

PURPOSE

The purpose of this project was to develop the ability to measure bridge deck moisture. Specific objectives were as follows:

1. conduct a literature review of in-situ moisture measurement methods applicable to portland cement concrete and identify the strengths and limitations of each method,

2. install Peltier-type psychrometers in a bridge deck and evaluate their performance,

3. determine a typical in-situ bridge deck moisture content distribution and examine seasonal effects on in-situ moisture, and

4. attempt to evaluate the effect of a bridge deck overlay on moisture content distributions and fluctuations.

BACKGROUND

Direct Moisture Measurement

The field moisture contents of portland cement concrete structures are rarely measured directly because normal sampling procedures influence concrete moisture content. Sawing or coring operations normally require the use of cooling water to prevent damage to and premature wear of the cutting edge. This increases the moisture content. Dry coring produces heat that can evaporate moisture. Sampling by powder techniques, typically drilling, also produces heat that evaporates moisture from the sample. The length of time required to obtain a sample, frequently 10 minutes or longer, also influences evaporation. Furthermore, sample size requirements are a problem. ASTM D 2216 suggests a minimum sample size of 500 g for soils with a maximum particle size of 3/4 in. With the potential for large variation in moisture content between concrete paste and coarse aggregate particles, similar minimum sample size requirements should be observed for concrete. However, a 500 g powder sample is difficult to obtain, while a smaller sample creates uncertainty about whether paste or aggregate is being sampled.

Because of the difficulties involved in direct moisture content measurement, indirect methods must be used to determine moisture contents in bridge decks and overlays. Indirect methods can be either intrusive, requiring the installation of some type of sensor; or non-intrusive, using some type of detector on the surface. Though intrusive methods require traffic control during installation, readings can usually be taken from a somewhat remote location. This is useful when measurements need to be repeated on a regular basis. Non-intrusive methods require traffic control every time readings are taken, but allow measurements to be taken at any location rather than a specific installation. Potential indirect moisture measurement methods are discussed below.

Electrical Resistance

The electrical resistance of many non-conducting porous materials is quite dependent on the degree of saturation of the material because electricity flows through the pore fluid rather than through the solid matrix. This concept can be used for moisture measurement by constructing a sensor of non-conducting material and measuring the electrical resistance of the sensor for a range of degrees of saturation. When the sensor is placed in the material for which moisture is to be measured, it absorbs moisture from the material until an energy equilibrium is reached. The resistance of the sensor can then be measured, and with appropriate laboratory calibrations, the moisture content of the material in question can be determined.

Electrical resistance devices are permanently installed in the material being monitored, with the electrical leads terminating at a convenient distance from the installation. Corrections can be made for unusually long leads, and the data acquisition can be automated.

The response of electrical resistance devices to changes of moisture in the material being measured is as fast as water can flow between the resistance device and the material being measured. The sensitivity of electrical resistance devices is best at low degrees of saturation, where a small increase in pore fluid can give a large decrease in resistance. Electrical resistance devices can be quite sensitive to dissolved salts because the ion concentration of water affects electrical conductivity. Some electrical resistance devices are therefore made from soluble materials such as gypsum. With these, the pore fluid is always a saturated solution and ions in the pore fluid of the material being measured have minimal effect. Of course the soluble electrical resistance devices eventually dissolve and must be replaced (1).

Filter Paper

When filter paper is placed in contact with a partially saturated material, some moisture will flow into the filter paper, until an energy equilibrium is reached between the moisture in the paper and the moisture in the material being measured. If the moisture content of the filter paper is then determined by direct means, the moisture content of the partially saturated material can be determined by appropriate laboratory correlations.

The filter paper does not need to be in physical contact with the material being measured. Water vapor, or relative humidity, is in equilibrium with the moisture content of the partially saturated material (1). Therefore the filter paper establishes an equilibrium between moisture content and relative humidity. This method is more advantageous because the filter paper is not contaminated by dissolved salts in the partially saturated material. Dissolved salts tend to increase moisture content, and can lead to inaccurate readings.

The filter paper method of moisture content determination is inexpensive, accurate over a wide range of moisture contents, and does not require sophisticated equipment; however, there are some problems. The installation must be accessible for the removal and replacement of filter papers. A field installation that is accessible is very difficult to seal to prevent the infiltration of rainfall. Traffic control is necessary for installations in traffic lanes. The amount of time required for the filter paper to reach equilibrium depends on how much water must flow into the filter paper and whether the flow is through intimate contact with the material being measured or by water vapor movement. Equilibrium may be reached in up to one week. Thus the filter paper method may not be appropriate for rapidly changing moisture contents. Once the filter paper is removed from the installation, it must be quickly sealed in a sample container to prevent evaporation. Errors in moisture content can occur due to sample handling time, especially on days when the relative humidity in the air is quite different from the relative humidity in the unsaturated pores of the material (2).

Nuclear Magnetic Resonance

When a partially saturated material is exposed to an appropriate pulsed radio frequency magnetic field, hydrogen nuclei present in the material resonate. The strength of this resonance can be detected and related to the amount of hydrogen nuclei present in the material. Because the principal source of hydrogen is water, the moisture content can be indirectly determined. The depth of penetration of the magnetic field can be controlled by varying the power supplied to the magnetic field generator.

Nuclear magnetic resonance (NMR) is a non-intrusive method of moisture measurement and is quite effective for moisture determination at depths of up to about 3 in. As depth increases, the reliability and precision of the measurement decrease, while power requirements for the magnetic field generator increase rapidly. Though NMR has the advantage of not requiring a permanent field installation, the equipment is heavy and requires traffic to be shut down on the lane of the bridge being measured. The actual volume sampled is rather small, with dimensions of approximately 1/2 in. This means that more frequent measurements must be taken to eliminate errors caused by measuring aggregate rather than paste moisture content. NMR does not work well with aggregates containing iron because of interference with the magnetic field, but the small sample volume means that reinforcing steel can easily be avoided (3).

Psychrometers

Relative humidity is related to the moisture content of a material when equilibrium exists between the rate of evaporation and the rate of moisture condensation. This equilibrium normally exists in the pores of unsaturated materials. Moisture content can be determined by measuring the relative humidity in the pores and converting the measurement to moisture content with appropriate laboratory calibrations.

Peltier-type psychrometers are normally used to determine relative humidity. A Peltier-type psychrometer is a thermocouple inside of a protective housing that permits vapor exchange with the surrounding partially saturated material. To measure the relative humidity, a current is passed through the thermocouple which results in cooling (called the Peltier effect). When the thermocouple cools below the dew point, water vapor condenses on it. After the cooling is stopped, the thermocouple warms back to its initial temperature and the moisture evaporates. During the evaporation, the thermocouple temperature holds at a constant temperature for a few seconds. This is the dew point, and can be converted to relative humidity.

This method of moisture measurement is accurate for a wide range of moisture contents but cannot be used for very dry or very wet materials. Another limitation is that the method is sensitive to temperature changes during the 20- to 60-second period required for a reading. Readings should not be attempted while the material being measured is either warming or cooling. As with all field installations of sensitive electronics, the psychrometers should be duplicated or triplicated to account for sensors damaged during or after installation (4).

Thermal Conductivity

The thermal conductivity of a porous material is directly related to its moisture content. If a small electric heater and a temperature sensor are imbedded in a porous block, the rate of heat dissipation after a known heat input can be used to calculate the moisture content of the block. Laboratory correlations are used to relate sensor moisture content to the moisture content of the material being measured.

This method appears to be especially good at measuring high moisture contents but may not be as precise at measuring lower moisture contents because more of the thermal conductivity occurs through the porous solid than through the partially saturated pores. Extreme care must be exercised during installation to ensure good contact between the sensor and the surrounding material. Varying degrees of contact between the sensor and surrounding material affect the thermal conductivity at the interface. The sophistication of the sensor and electronic measurement equipment can also cause problems. Careful calibration of the sensors and measurement equipment is required, and errors can develop due to extreme field environment conditions. As improvements are made in field instrumentation, the reliability of this method should improve (2).

Ultrasonic Velocity

Ultrasonic pulse velocity in porous materials is also dependent on the moisture content of the material. Sound travels much faster through a water-filled pore than through an empty pore. A sensor could be developed that comprised a pair of ultrasonic transducers separated by a porous ceramic. The pulse velocity through the ceramic could be calibrated in terms of moisture content and laboratory correlations could be used to relate moisture content in the ceramic to moisture content in the material being measured. Though commercial adaptations of this concept have not been developed, this method has potential for moisture determinations in porous materials (5).

Summary

Any time that an indirect measurement method is used, careful calibration is required to convert the actual measurement to the desired information. This is especially true with indirect moisture measurement. Potential for error exists in the original measurement, and additional error is possible in the conversion correlations. Whatever method of indirect measurement is chosen should not only be applicable for the range of moisture contents expected, it should also be sensitive enough that a small change in moisture content results in a large change in the property being measured. Good sensitivity will minimize the impact of measurement errors.

The frequency with which the moisture is measured should also influence the measurement method chosen. If repeated measurements will be taken at the same site, an intrusive method using sensors that can be read without interfering with traffic should be chosen. One-time measurements may not justify the time required to install a permanent sensor, but temporary traffic diversion for non-intrusive measurements could be tolerated. If the sensors will be left in place throughout winter in a freezing climate, porous ceramics in sensors may be destroyed by freeze-thaw if they are at a high degree of saturation. There is no best method of moisture measurement for every application, and the choice of method should be controlled by the requirements of each application.

RESEARCH METHOD

General

Bridge deck moisture contents were determined by installing sensors in a bridge deck and taking readings approximately twice a month. The readings were converted to moisture contents by laboratory correlations. Readings were originally planned for every two weeks from installation in early September 1986 through the end of the project in early spring 1987. The bridge chosen for instrumentation was at Snoqualmie Pass on Interstate 90, and weather conditions at the pass made readings either impossible or unsafe from November 1986 through March 1987. Readings taken during September and October 1986 and May and July 1987 are included in this report.

Sensor Type

The researchers expected to make moisture content determinations every two weeks for the duration of the project, so a moisture measurement method that did not interfere with normal traffic flow was desired. Previous experience (5) with concrete pavements in an area receiving moderate amounts of rainfall indicated that moisture levels are frequently above 80 percent saturation, but evaporation could substantially decrease moisture levels near the surface. Peltier type psychrometers were chosen for this installation because the electronics were reliable, the measurement method was quite sensitive over the expected range of moisture contents, and the sensors did not contain porous materials that could be damaged by freezing conditions.

Figure 1 shows a typical psychrometer. It is approximately 1-1/4 in. long and 1/4 in. in diameter. The rubber boot is flexible and can be folded to reduce the effective length of the psychrometer. This is quite useful because previous work (5) has shown that installing the psychrometer perpendicular to the direction of principal thermal gradient is important in order to reduce the effect of temperature fluctuations on psychrometer response.

Field Installation

The bridge chosen for instrumentation was Gold Creek Bridge on westbound Interstate 90, east of Snoqualmie Pass. This was Washington State Department of Transportation (WSDOT) bridge number 90/106N. The bridge was a three-span, continuous deck, 20 in. thick and 139 ft. long. The deck was protected by a low-slump dense concrete overlay approximately 2 in. thick. The total depth to the reinforcing steel was about 4.5 in. This bridge was chosen for the following reasons.

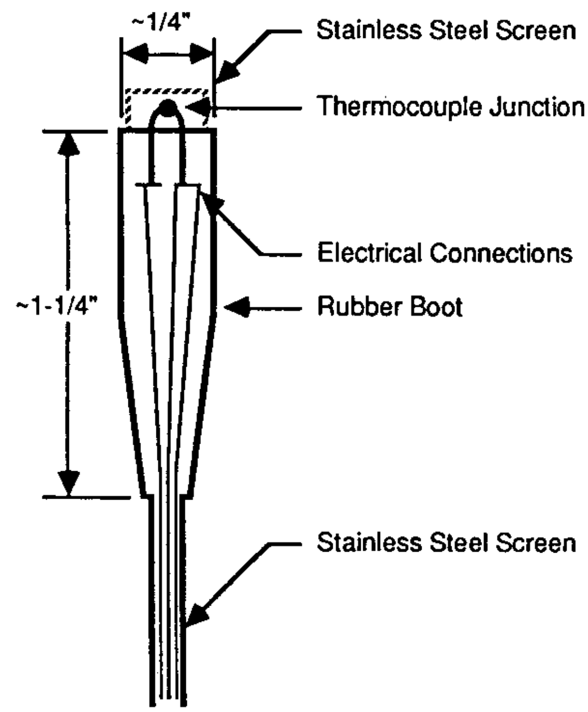

Figure 1. Peltier-Type Psychrometer

1. The bridge was relatively close to the Seattle area and less than a half day would be required to travel to the bridge, take readings, and return to Seattle.

2. The bridge was a part of WSDOT Project Y3399, Task 2, "Concrete Overlays for Bridges." A part of this project was a series of extensive tests of bridge deck condition, including chloride content, half-cell readings, crack surveys and delamination measurements. This information could be useful in relating bridge deck moisture and overlay performance.

3. The approach to the bridge provided good sight distance and the bridge had a wide shoulder with no on or off ramps. This would provide a safe location for bi-weekly readings.

Two locations were instrumented on the bridge: a negative moment area near the east pier, and a positive moment area approximately centered between the two piers (Figure 2). Both locations were in the outside traffic lane, 1 ft. from the lane-shoulder line.

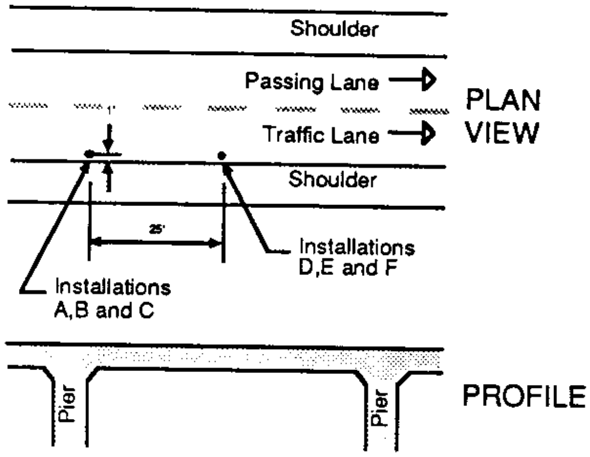

Figure 2. Psychrometer Installation, Gold Creek Bridge

The installation at each location consisted of psychrometers at four depths (Figure 3). Holes 1 in. in diameter were drilled to a depth of between 5 and 6 in. Each psychrometer was placed in a bed of moderately dry sand-cement grout. The grout was rodded in place and a layer of silicone sealer was placed above each psychrometer to prevent the intrusion of rainwater. The installations at each location were triplicated to improve the overall reliability. A summary of the installations including depths and locations is given in Table 1.

The electrical leads were placed in a saw cut and sealed with hot bituminous sealer. A saw cut led from each location to the shoulder of the bridge, where 2-in. core holes provided access to connectors on the electrical leads. The core holes were sealed on the sides and bottom with epoxy and covered on top with plastic plumbing cleanout covers set flush with the bridge deck. The 2-in. cores obtained from the bridge shoulder extended through the dense concrete overlay and approximately 2 in. into the deck concrete. These cores were

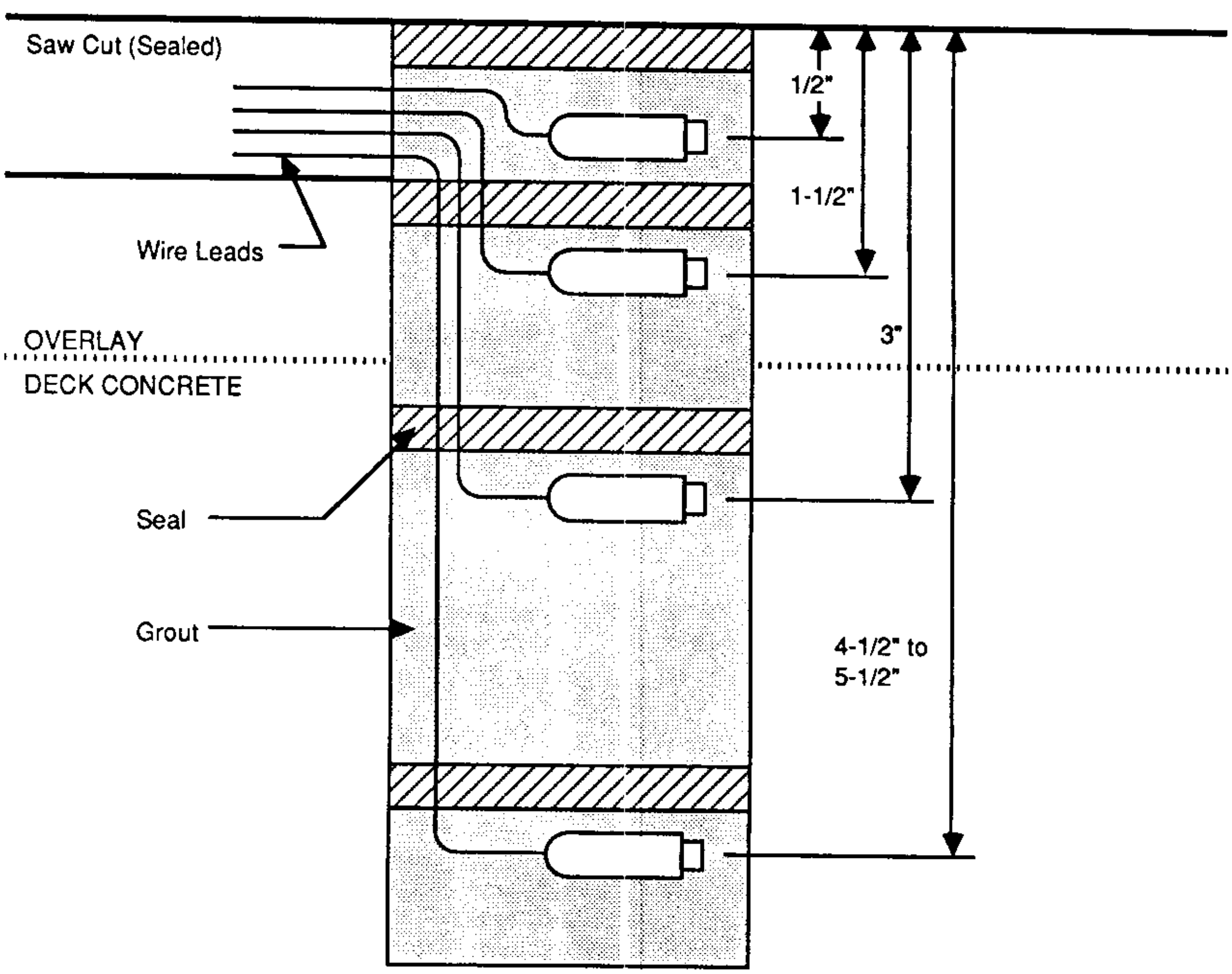

Figure 3. Detail of Psychrometer Installation

brought back to the laboratory for tests that would be used to convert field readings to moisture content.

Laboratory Calibration

Cores obtained during the field instrumentation were cut into 1/4-in. thick horizontal slices. The overlay and base concrete portions were kept separate and each slice was labelled as to which core it had come from. The slices were then vacuum saturated, towel dried to a saturated-surface dry condition, and weighed. The samples were placed in a 100-bar moisture extractor for determination of a moisture characteristics curve. Moisture contents were determined by oven drying the samples at 115C. A description of the laboratory procedure is given by Janssen (5).

A moisture characteristics curve is a relation between the moisture content of a material and the energy required to remove moisture from the material. This is a unique relationship for every material and is dependent upon the pore volume and pore size distribution of the material. The energy required to remove moisture is usually given in terms of

Table 1. Summary of Psychrometer Installations

INSTALLATION NUMBER	DEPTH INCHES
A-1	0.5
A-2	1.5
A-3	3.0
A-4	5.5
B-1	0.5
B-2	1.5
B-3	3.0
B-4	4.5
C-1	0.5
C-2	1.5
C-3	3.0
C-4	5.5
D-1	0.5
D-2	1.5
D-3	3.0
D-4	5.5
E-1	0.5
E-2	1.5
E-3	3.0
E-4	5.0
F-1	0.5
F-2	1.5
F-3	3.0
F-4	5.5

Installations A, B and C are in a negative moment region.

Installations D, E and F are in a positive moment region.

All installations are in the right lane of the bridge, approximately 1 ft. from the lane-shoulder line.

suction, with units of cm. of water. This corresponds to the height of capillary rise in the material. If gravity is the force trying to remove moisture from the material, the moisture characteristics curve shows how much moisture will remain in the material for a given height above the water table.

Gravity is not the only force that can remove moisture from a material. The 100-bar moisture uses positive pressure to force water out of samples. This equipment is capable of pressures of up to 1,450 psi, which simulates a suction of 100,000 cm. of water. Evaporation can also remove moisture. Relative humidity can be related to suction by the equation

$$pF = 6.5 + \log(2 - \log(RH)) \qquad (1)$$

where

pF is the log of the suction in cm. of water,

and

RH is the relative humidity in percent.

Additional information on moisture characteristics has been given by Hillel (1) and Janssen (5).

Table 2. Moisture Characteristics Data

LOW-SLUMP DENSE CONCRETE OVERLAY

PRESSURE PSI		SUCTION CM WATER	MOISTURE CONTENT PERCENT
0	(SSD)	0	8.50
10		703	7.95
150		10,550	7.60
1,450		102,000	7.28

BASE CONCRETE

PRESSURE PSI		SUCTION CM WATER	MOISTURE CONTENT PERCENT
0	(SSD)	0	8.50
10		703	7.95
150		10,550	7.60
1,450		102,000	7.28

DATA ANALYSIS

Moisture Characteristics Curves

Though the individual samples used in the pressure plate were quite small, with oven dry weights of 10 to 20 g., the combined weights from all of the samples were used to calculate moisture contents. This gave a sample size of 426 g. for the concrete overlay and 291 g. for the base concrete. The samples came from six separate cores and were felt to be representative of the overlay and base concretes.

Table 2 shows the saturated-surface dry moisture contents along with the moisture contents at 10, 150, and 1450 psi extraction pressures. Note that even at high extraction pressures the concrete is at a high degree of saturation. This is because the pores in concrete are extremely small and large amounts of energy are required to remove moisture from extremely small pores.

The data from Table 2 is plotted in Figures 4 and 5. The vertical scale on the graphs, suction, is logarithmic to accommodate the large range in suction values. The point plotted at a suction of 1 cm. of water is actually the saturated-surface dry moisture content for each material.

The moisture characteristics curves for the overlay, Figure 4, and base, Figure 5, concretes appear similar due to similar pore size distributions in the paste portions of each concrete. The higher saturated moisture content of the overlay concrete is probably due to the overlay having a smaller maximum aggregate size and a larger percentage of paste. Both materials remain at relatively high moisture contents even up to 100,000 cm. of suction.

Field Measurements

The field measurements were converted to moisture contents using the moisture characteristics curves shown in Figures 4 and 5. These moisture contents are shown in Table 3. The psychrometer at installation A at the 3-in. depth never worked and was probably damaged while it was installed. Psychrometers at installation E at the 1.5- and 3-in. depths worked initially but failed after a few weeks. These may also have been damaged during installation, or perhaps they had loose wires in their connectors. A number of psychrometers gave meaningless readings (suction values less than 0), which could have been caused by temperature gradients in the bridge deck, improper installation of the psychrometer, or moisture condensed on the psychrometer prior to the measurement. The exact causes of the meaningless readings were difficult to determine. Readings were attempted on November 30, 1986, but all of the readings were meaningless. This was probably due to the low temperature of the bridge deck, 4 C, which caused moisture to not only condense on the cooled thermocouples but also to freeze. A procedure has not been developed for interpreting results from frozen psychrometers.

Table 4 shows the average moisture content for each depth and reading date for both the negative and positive moment areas in the bridge. Though some depths and dates are missing values, sufficient information was collected for general trends to be identified.

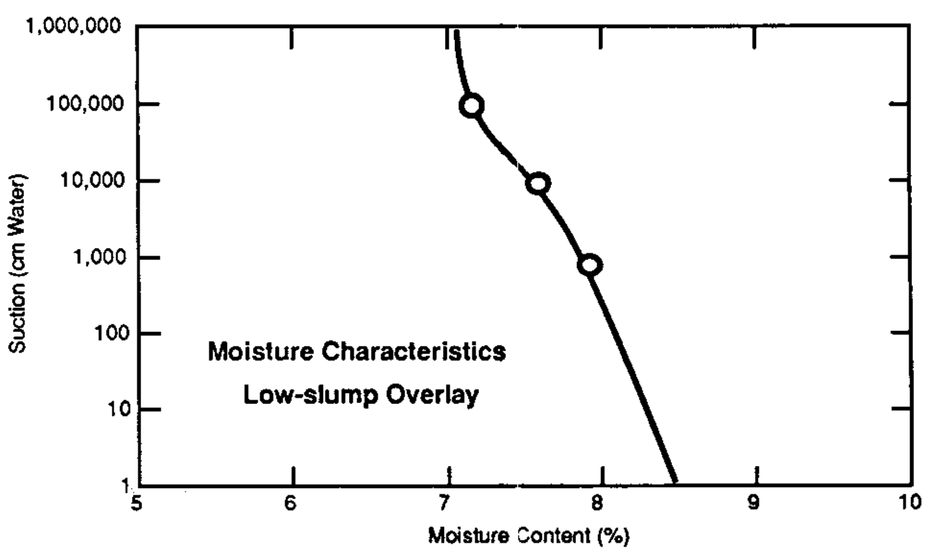

Figure 4. Moisture Characteristic Curve for Overlay Concrete

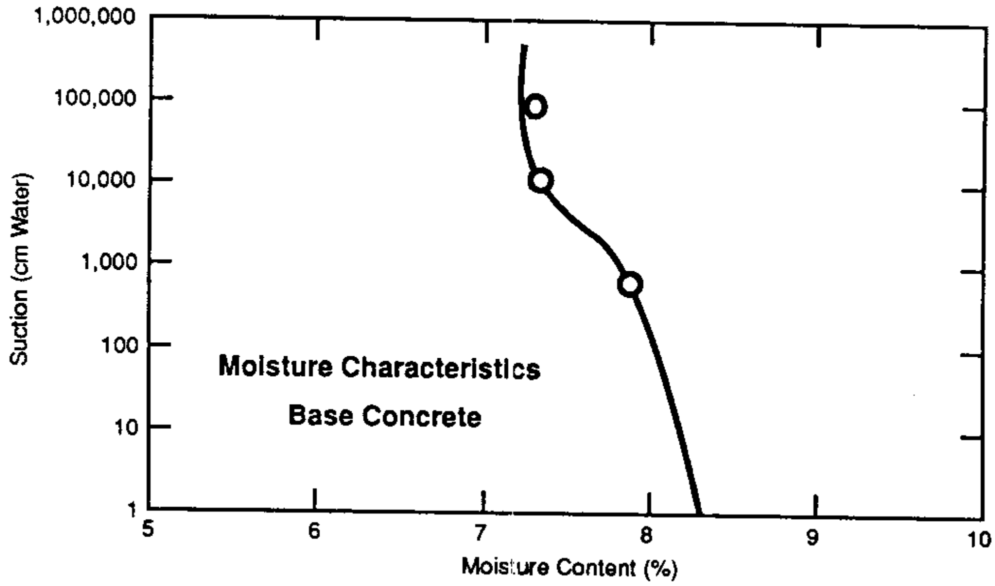

Figure 5. Moisture Characteristic Curve for Base Concrete

RESULTS

Moisture Variation with Location and Depth

Table 4 shows that the negative moment area appeared to have slightly higher moisture contents and more fluctuation of moisture contents than the positive moment area. The top of the bridge deck was in tension in the negative moment area, which could have led to a higher degree of very fine cracks. These cracks would not only have allowed moisture to enter the bridge deck more easily, they would also have improved the removal of moisture by evaporation.

The positive moment area of the bridge showed much less fluctuation in moisture content (Table 4). The permeability of uncracked concrete is normally very low, so significant changes in moisture with depth were not expected.

The moisture content at the level of the reinforcing steel, 4.5 in., varied from 7.4 to 7.7 percent. This was a range of saturation from 88 to 92 percent. The moisture content at the depth of the steel was higher in the negative moment area.

Moisture Variation with Time

The overall variation of moisture content for this bridge deck was minimal for the period during which readings were taken. Moisture would normally be expected to increase during the wetter winter season and decrease during the drier summer. The period of time during which measurements were taken was not long enough to identify any strong trends in moisture variation with time. For the measurement period shown, the largest variation in moisture content was from 7.5 to 8.0 percent for the 0.5-in. depth in the negative moment area.

This study examined a variety of methods for measuring bridge deck moisture and identified strengths and weaknesses of these methods. One of the methods, Peltier-type psychrometers, was used to measure moisture in Gold Creek Bridge at Snoqualmie Pass, WSDOT bridge number 90/106N. The results of these measurements led to the following conclusions:

1. The moisture content at the level of the reinforcing steel was high, with a saturation of about 90 percent.
2. Variation in moisture content with depth was minimal for the time period measured.
3. The variation in moisture content with depth and with time was higher for the negative moment area of the bridge than for the positive moment area.

These conclusions led to the following recommendations:

1. The moisture measurement at this bridge should be continued through autumn 1987 to evaluate seasonal moisture variations.

Table 3. Field Moisture Contents, All Data

DEPTH INCHES	DATE	INSTALLATION A	B	C	D	E	F
	9-11-86	8.1	7.5	7.9	7.4	7.5	7.5
0.5	9-30-86	-	-	-	7.5	-	7.4
	10-16-86	7.5	7.4	7.5	7.7	7.8	7.5
	10-31-86	-	-	-	7.9	-	7.5
	5-5-87	-	-	7.7	7.6	-	7.5
	5-21-87	-	-	7.6	-	-	-
	5-27-87	7.8	-	-	-	-	7.5
	7-1-87	8.0	-	7.9	7.5	-	7.8
	7-23-87	7.9	-	-	7.6	-	-
	9-11-86	7.4	8.0	7.4	7.4	7.7	7.6
1.5	9-30-86	-	-	7.6	7.6	-	7.4
	10-16-86	7.5	-	7.6	7.6	-	7.5
	10-31-86	7.8	8.1	8.1	-	-	7.5
	5-5-87	7.5	-	7.4	-	-	7.5
	5-21-87	7.8	-	7.8	-	-	-
	5-27-87	-	-	7.8	-	-	7.6
	7-1-87	7.5	7.4	-	-	-	-
	7-23-87	7.5	-	7.6	-	-	7.8
	9-11-86	-	-	-	7.4	7.4	-
3.0	9-30-86	-	-	-	7.5	7.4	-
	10-16-86	-	7.4	7.5	7.4	7.4	-
	10-31-86	-	7.5	-	-	-	-
	5-5-87	-	-	7.5	-	-	-
	5-21-87	-	-	7.9	-	-	-
	5-27-87	-	-	-	-	-	-
	7-1-87	-	-	7.5	-	-	-
	7-23-87	-	-	7.5	-	-	-
	9-11-86	7.5	7.5	7.9	7.4	7.4	7.4
4.5-5.5	9-30-86	7.6	7.5	7.8	7.4	7.4	7.4
	10-16-86	7.5	7.4	7.6	7.4	7.4	7.5
	10-31-86	7.6	7.5	-	7.4	7.4	7.9
	5-5-87	-	-	7.4	7.4	7.4	-
	5-21-87	-	-	-	-	-	-
	5-27-87	7.7	7.7	7.6	7.5	7.5	-
	7-1-87	-	-	7.4	7.4	7.4	-
	7-23-87	7.4	-	-	7.4	7.4	-

Table 4. Average Field Moisture Contents

NEGATIVE MOMENT REGION

DEPTH INCHES	DATE OF MOISTURE MEASUREMENT 9-11-86	9-30-86	10-16-86	10-31-86
0.5	7.8	-	7.5	-
1.5	7.6	7.6	7.6	8.0
3.0	-	-	7.5	7.5
4.5-5.5	7.6	7.6	7.5	7.6

POSITIVE MOMENT REGION

DEPTH INCHES	DATE OF MOISTURE MEASUREMENT 9-11-86	9-30-86	10-16-86	10-31-86
0.5	7.5	7.5	7.7	7.7
1.5	7.6	7.5	7.6	7.5
3.0	7.4	7.5	7.4	-
4.5-5.5	7.4	7.4	7.4	7.5

NEGATIVE MOMENT REGION

DEPTH INCHES	DATE OF MOISTURE MEASUREMENT 5-5-87	5-21-87	5-27-87	7-1-87	7-23-87
0.5	7.7	7.6	7.8	8.0	7.9
1.5	7.5	7.8	7.8	7.5	7.6
3.0	7.5	7.9	-	7.5	7.5
4.5-5.5	7.4	-	7.7	7.4	7.4

POSITIVE MOMENT REGION

DEPTH INCHES	DATE OF MOISTURE MEASUREMENT 5-5-87	5-21-87	5-27-87	7-1-87	7-23-87
0.5	7.6	-	7.5	7.7	7.6
1.5	7.5	-	7.6	-	7.8
3.0	-	-	-	-	-
4.5-5.5	7.4	-	7.5	7.4	7.4

2. Attempts should be made to correlate moisture content and chloride content to determine the minimum chloride contents that can cause corrosion in bridge decks near 90 percent saturation.

3. A laboratory study should be conducted to determine the reliability of psychrometers used in the field study, and to verify the field measurements.

APPLICATION AND IMPLEMENTATION

The primary purpose of a bridge deck overlay is to prevent corrosion of the top mat of reinforcing steel. This is accomplished by preventing the accumulation of chloride ions and moisture at the reinforcing steel. Large fluctuations in moisture content indicate that moisture can easily move into and out of the bridge deck, and chloride applied to the deck can easily migrate to the reinforcing steel.

When a bridge deck that has been in service is being overlaid, there is normally some distress in the deck. Standard practice is to remove defective or damaged deck concrete, patch the area, and then overlay the bridge. However, chloride contamination can remain in the undamaged deck concrete. This study has shown that the moisture content in a bridge deck can be expected to be quite high. If there is sufficient chloride contamination in the bridge deck, corrosion may occur even though the overlay prevents further chloride contamination.

The results of this research could be implemented in the following ways.

1. Consideration should be given to the use of moisture measurement as a method of measuring the expected effectiveness of new overlays in preventing corrosion. Measuring the moisture content in the bridge deck down to the reinforcing steel, and then wetting the bridge and remeasuring the moisture could be used to check for porous or cracked sections of overlay. Large changes in moisture content would indicate that the overlay could be relatively ineffective at preventing chloride migration to the reinforcing steel. This evaluation should be performed in summer when the bridge deck is drier, using a non-intrusive, indirect method of moisture measurement such as the FHWA NMR device (3).

2. The chloride content profiles of bridge decks that have been in service and are scheduled for overlay should be determined. As more is learned about the correlation between corrosion and the chloride-moisture environment, field data including chloride content at the time of overlaying and the effectiveness of bridge overlays in preventing corrosion will be useful in refining bridge deck protection strategies.

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