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A COMMENTARY ON THE IMPLEMENTATION OF VIRGINIA TEST METHOD NUMBER 39, "ELECTRICAL RESISTIVITY TESTING OF WATERPROOF MEMBRANES"

by

W. T. McKeel, Jr.
Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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INTRODUCTION

Waterproof membranes provide one of the several methods available for protecting bridge deck reinforcing steel from corrosion. While other protective systems are preferable for use at the time of construction, the membrane has its place in the protection of existing decks which are not highly contaminated by deicing salts or those which must be brought to grade through the application of an asphaltic concrete wearing course.

As used on bridge decks, membrane systems commonly consist of a waterproof layer, applied either as a liquid or in sheet form, a protective layer of roofing sheet or a sand asphalt mixture, and an asphaltic concrete wearing course at least $1\frac{1}{2}$ in. in thickness.[(1)] Field evaluations have been made of several such systems to determine their effectiveness and to gain an awareness of any problems that might be encountered in the operational use of the products.[(2)] Those products found acceptable based on the field evaluations and information from other agencies have been incorporated into a special provision of the Virginia Department of Highways and Transportation's specifications.[(3)] The use of three preformed sheet membranes, each of which must be covered by a layer of 65 lb. grade asphalt roofing sheet, is currently allowed.

The experimental evaluations have shown that those membrane systems covered in the Virginia specification can be installed effectively, but considerable care is required, particularly during the paving operations in which the asphaltic concrete wearing course is applied over the membrane. The most rugged of the available systems can be punctured or torn by the heavy paving equipment, and the resulting damage and any subsequent distress of the underlying concrete is often concealed by the wearing course. Because of the possibility of hidden damage should sufficient care not be exercised, it was decided to include the electrical resistivity test described later in this report as an inspection requirement in the specification. The technique for conducting the electrical resistivity test, the only way now available to confirm the integrity of a membrane covered by a wearing course, is prescribed by the recently developed Virginia Test Method (VTM) Number 39, given in Appendix A of this report.

The first use of the new test method was in conjunction with the special provisions for waterproofing several bridge decks on Route 495 which has been widened.[(4)] Since uses of the electrical resistivity test prior to that time had been in conjunction with research operations, personnel of the Research Council were asked to assist the Culpeper Construction District personnel in implementing the test method. The purpose of this report is to provide information on the experience gained in using VTM 39 on the Route 495 bridges and to serve as a commentary to aid in the further implementation of the test method. As will be discussed further in the next section of this report the electrical resistivity test has weaknesses that render it difficult to use as an inspection tool, and proper performance of the procedure is critical. It was found, however, that the availability of the test was useful in encouraging proper care during the application operations.

THE ELECTRICAL RESISTIVITY TEST

The electrical resistivity test, developed by Spellman and Stratfull of the California Department of Transportation, (5) has been discussed in an earlier Council report, (3) but, for convenience, some of that material is repeated here.

The resistance is measured through the circuit shown in Figure 1, in which an ohmmeter is connected to the deck reinforcement and to a copper plate and sponge on the wetted deck surface. The equipment requirements are fully described in the appended copy of VTM 39, as is the basic testing procedure.

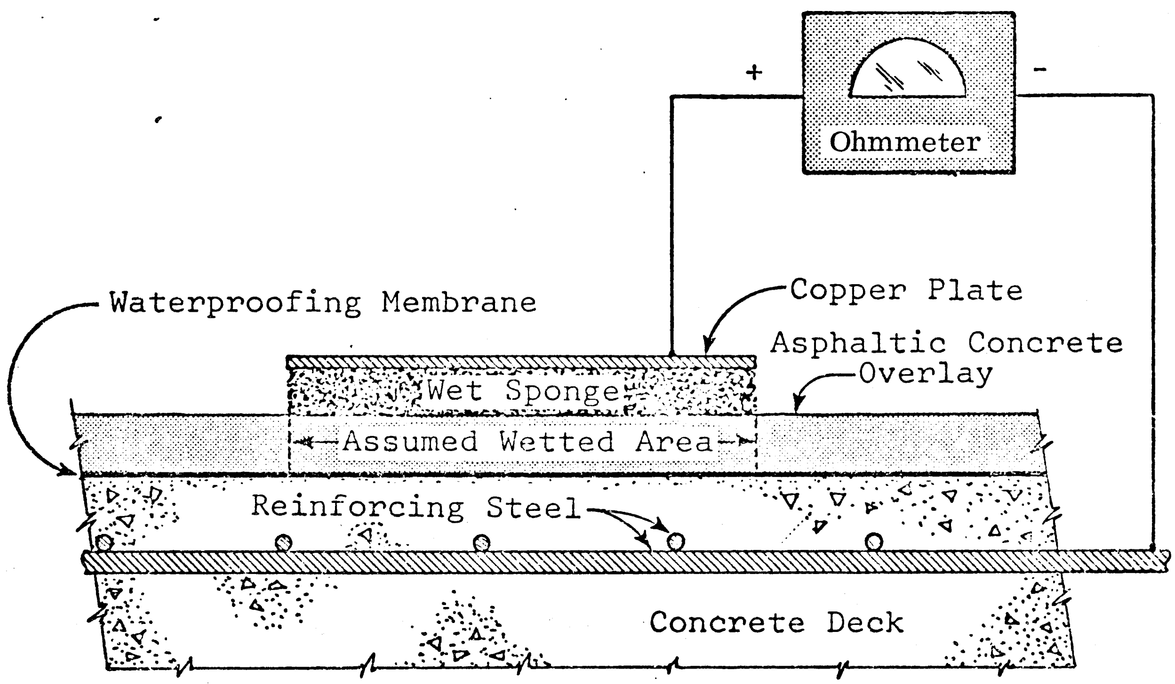

Figure 1. Assumed circuit for the electrical resistivity test.

Before the copper plate is placed on the deck, a mixture of water and a wetting agent is applied to the surface of the overlay and given time to permeate the asphaltic concrete. If the membrane, which must be nonconductive, is completely waterproof, the ohmmeter will indicate an infinite resistance when the copper plate is in position. Holes in the membrane which allow the passage of water reduce the resistance. On the basis of labratory tests, Spellman and Stratfull initially established a value of 500,000 ohms per square foot as being indicative of an effective membrane, and this value has been adopted in the Virginia specification.(3) Since the size of the copper plate is specified as 12 in. by 12 in., the ohmmeter reading will be in ohms per square foot. Research experience has indicated that the extrapolation of values obtained through the use of smaller sized plates does not provide equivalent results.

The Virginia specification and VTM 39 are closely patterned after similar documents developed by the Colorado Department of Highways, which also uses the resistivity test as an inspection tool.(6,7) All are based on Spellman and Stratfull's original procedure. There are, however, difficulties involved in the use of the electrical resistivity test as an inspection tool. For example, a recent report on FHWA NEEP No. 12 contains the following assessment of the procedure.(8)

> The only nondestructive field test for membranes is the electrical resistivity test. It was developed by California and is discussed in, "An Electrical Method for Evaluating Bridge Deck Coatings," by Spellman and Stratfull (See HRB Record #357, 1971). This method is a good research tool, but has not proven consistent for specification use or progress evaluations on specific bridge membranes in the field. Although its field application is very subjective, it can establish performance trends if progressive test series show logical results.

The inconsistencies in the test and the reservations about its use in making progressive measurements are due primarily to the difficulty in determing or controlling the amount of water in the asphaltic concrete overlay. As shown in Figure 1, the wetted area in the overlay is assumed to coincide with the area of the copper plate, but many factors, including the amount of water applied to the overlay during testing or by preceding rainstorms, can invalidate this assumption.

It is obvious that to be of value the electrical resistivity test must be performed with care, and the following sections of this report relate the testing techniques developed in the previously mentioned research work and the evaluations of the Route 495 bridges.

TECHNICAL CONSIDERATIONS IN THE ELECTRICAL RESISTIVITY TEST

Connection to the Reinforcing Steel

The connection to the reinforcing steel, shown schematically in Figure 1, is made by attaching an alligator clamp to a piece of exposed reinforcing bar or to a fixture on the bridge that is connected to the steel. Since the curb and parapet reinforcement is connected to the deck reinforcement, the railing bolts or date plates can usually be used if no steel is exposed. Other metal fixtures can provide acceptable connections, but the circuit should always be checked in accordance with sections 4.2.1 and 4.3.2 of VTM 39.

The ground connection for resistivity testing is not as critical as it is in the case of the somewhat similar corrosion potential measurements, because different electrical properties are being measured. In evaluating a deck for active corrosion of the reinforcement (potential measurements) a direct connection to the steel is almost mandatory, or false readings will be obtained. While the location of the ground connection affects the resistivity reading, the effect is slight in comparison to the high resistivity obtained through a satisfactory membrane. In fact, a connection in one span can often be used to obtain resistivity readings on adjacent spans if more suitable ground connections are not available, because of electrical continuity through the substructure elements. The ground is attached to the negative (-) pole of the ohmmeter.

The Ohmmeter

The ohmmeter specified in VTM 39 is the least expensive instrument suitable for the type readings required. It is used with the dial set on Rx10K ohms, at which point it will indicate its maximum reading of 20,000,000 ohms with a very slight deflection of the needle and the 500,000 ohms reading with the needle near midscale. If available, a more sophisticate meter that has a maximum reading higher than 20,000,000 will better define the stabilization of the values as water is applied to the deck as described in Section 4.3.4 of VTM 39.

The Sponges

Polyurethane sponges are specified in VTM 39 because they have interconnected voids which allow the passage of water. Natural sponges or those of other materials having similar void structures will work as well, but those with sealed passages will not. The sponges normally used to line concrete cylinder containers were used during the Route 495 evaluations with apparently satisfactory results.

Sponges are used for the connection between the copper plate and the deck, and they are also helpful in controlling the wetting of the overlay. In the latter application sponges of the size of the copper plate are placed at the grid points and kept moist. This procedure avoids spreading of the water between grid points and drying of the surface on hot or breezy days, but a large number of sponges are required. It was found during the Route 495 evaluations that as many as 200 sponges could be used by a two-man crew.

Wetting the Deck

Wetting the deck is the most critical phase of resistivity testing because, as mentioned previously, the acceptance criterion of 500,000 ohms per square foot is based on the assumption that the wetted area through the depth of the overlay is the size of the copper plate. The resistance readings will decrease as the wetted area becomes larger. It is most important that the water not be allowed to reach bare concrete at the curb or in an adjacent lane, as this will yield a very low resistance. Failure to control the wetting of the deck can result in an indication of a membrane failure where none exists.

Control of the wetted area is best gained by using sponges to hold water on the surface of the overlay. As indicated by VTM 39, Section 4.3.4, measurements are repeated at intervals until the resistance stabilizes at its lowest point, which is recorded as the final reading. During the Route 495 evaluations the sponges were sometimes kept wet for periods as long as 3 to 4 hours to determine the ultimate variations in the resistance readings. Although no failures were recorded, such a wetting period may be too long for a reliable reading based on a square foot of area, as the water can begin to spread within the overlay. Thus the apparent continuing drop in the ohmmeter reading could be due to the spreading of the wetted area rather than the complete moistening of the overlay. California, according to unpublished notes*, uses a longer wetting period and measures the decreasing resistance on an ohmmeter that has a maximum reading of 200,000,000 ohms. The final reading is reported simply as ohms at the location, rather than ohms per square foot; however, no minimum acceptance value has been determined. For Virginia's purposes the use of the ohms per square foot criterion should be acceptable, but the time of wetting should be shortened from the 3 to 4 hours used in the Route 495 evaluations.

The Colorado procedure,[(7)] on which VTM 39 is based, indicates that the wetting process should not require more than 15 to 20 minutes. This time period would vary with the cooling time of the mix and the composition and density of the overlay, but Virginia's research experience indicates that the stablization of readings usually occurs within 90 minutes. California's experience is that the 1 hour reading provides, in most cases, an indication of whether or not the final reading will be high. It is suggested, therefore, that a wetting period of 1 hour to $1\frac{1}{2}$ hours maximum be used in Virginia. Unfortunately, as is generally the case in resistance testing, the need for judgement on the part of the operator cannot be eliminated by a hard and fast rule as to wetting time.

Performing the Test

The resistivity testing of a membrane system should begin as soon as the temperature of the asphaltic concrete overlay permits. This time will vary with the ambient temperature, but, as a guide, it was often $1\frac{1}{2}$ to 2 hours after the completion of paving on the Route 495 bridges during the fall of the year. Prompt testing is important because rain can invalidate the testing operation. Once an overlay has

* An unpublished document, "Field Trip to Colorado to Check Superseal 4000 Deck Membrance Systems and to Observe Colorado's Method of Taking Electrical Resistance Measurements", November 7, 1974, by M. W. Horn, was very helpful in defining California's testing procedure.

been saturated, it is impossible to tell when it is sufficiently dry. A film of water can remain at the top of the membrane for several days. In this case, a completely waterproof membrane may continue to show high resistances, but low readings may be due to the large wetting area rather than a true failure of the system. In the Culpeper District every effort is made to complete the testing within 4 to 6 hours after the rolling of the overlay is completed.

Since more than one reading of the resistivity at each grid point is required to determine when the readings have stabilized, it is usually convenient to tabulate the readings rather than enter them on a grid diagram. Appendix B shows the form developed for this purpose during the Route 495 evaluations. It is important that the location of the grid points be shown on the diagram at the top of the first page so that the data can be transferred to a grid diagram and problem areas can be located on the deck for later correction.

Because the readings are made at points on the grid, damage in other areas would not be disclosed. In addition to the established grip points, any areas suspected to have been damaged during earlier operations should be located and tested.

Interpretation of the Readings

One advantage of the resistivity test is that the readings obtained on an intact membrane are very much higher than those taken on a bare concrete deck. Generally, the resistance readings taken on the Route 495 bridges were high unless the damage to the membrane had been severe enough to be noticed during the paving operation or rain had fallen on the overlaid deck before testing. In other words, low readings will not generally be obtained on a dry overlay unless damage exists.

The specifications are quite explicit regarding the action to be taken if a membrane fails the resistance test. If more than 30 percent of the covered deck area proves defective, the Department may require that the entire membrane be removed and replaced. If less than 30 percent of the deck fails, those areas showing readings of less than 500,000 ohms per square foot must be repaired by removing the asphaltic concrete and repairing or replacing the damaged membrane. Replacement of the membrane is expensive and partial repair is a most difficult operation in most cases. It is, therefore, in the best interest of all parties that the inspector be sure that the low readings are not caused by water held in the asphaltic concrete overlay. In borderline cases it may be possible to carefully remove the overlay in a small area and check the bare membrane. Removal of a portion of the overlay will usually disclose the presence of water if it is a problem.

Personnel

Because of the great deal of judgment that necessarily enters into the performance of the electrical resistivity test, it is advisable to use the same operators as much as possible. It was originally planned to equip three crews in the Culpeper District to evaluate the large number of bridges on Route 495, but it proved more effective to use a single crew from the District Materials Office. Some materials savings will also be effected if a single crew is used.

SUMMARY

The electrical resistivity test is not ideally suitable as an inspection tool, but it is the only currently available nondestructive test for determing the effectiveness of a waterproof membrane system. Considerable judgment and care are needed to properly conduct the test and interpret its results, but experience on Route 495 has shown the procedure to be workable and of help in controlling the installation operations.

Several important points discussed in the text are reiterated below.

1. Considerable care must be exercised throughout the installation of a membrane system in order to avoid damage. A high level of conscientious inspection is required, particularly during paving operations, to modify any damaging factors and locate potentially troublesome areas for checking during later resistivity testing.

2. It is seldom necessary to uncover the deck reinforcement to obtain a suitable ground connection for resistivity testing. A metal fixture that is connected to any reinforcing steel will usually suffice, but the circuit should be checked by taking readings on bare concrete areas in accordance with VTM 39.

3. The ohmmeter specified in VTM 39 is normally set on the R x 10K scale, and the ground is connected to the negative (-) pole, the plate to the positive (+) pole.

4. The sponges used must have interconnected voids that allow the passage of water. Other sponges will not work. The size of the sponges is given in VTM 39.

5. Wetting the deck is the most critical phase of resistivity testing. The water should not be allowed to flow between grid points or to reach a bare concrete surface. Control of the wetted areas is best gained by placing sponges at the grid points. The sponges should be kept wet and successive readings taken until the magnitudes of the readings stabilize. It is suggested that the maximum wetting period not exceed $1\frac{1}{2}$ hours.

6. Resistivity testing should begin as soon as the temperature of the asphaltic concrete overlay permits. It is difficult to obtain valid results after rain has fallen on the deck.

7. Resistivity readings should be taken at the grid points and at any points where possible damage was noted during the installation operations.

8. If low readings are obtained, it should be ascertained that moisture in the overlay is not the cause. Otherwise, it can be assumed that damage of the membrane exists.

9. It seems generally advisable to use a single crew to perform the resistivity testing within a district, as experienced personnel are required.

ACKNOWLEDGEMENTS

Much of the field work on which this report was based was performed by J. W. French of the Virginia Highway and Transportation Research Council. His advice on field testing, and that of J. E. Galloway, Jr. of the Materials Division, were most helpful. The excellent cooperation and interest of personnel of the Culpeper Construction District, particularly F. L. Prewoznik, C. H. Robson, Jr., and V. C. Brooking, and of the inspection personnel of the Fairfax Residency are deeply appreciated.

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APPENDIX A

VIRGINIA TEST METHOD

FOR

MEASURING WATERPROOFING EFFECTIVENESS OF MEMBRANE-PAVEMENT SYSTEMS

DESIGNATION: VTM-39

SCOPE

1.1 This method describes the procedure for determining the waterproofing effectiveness of membrane-pavement systems as applied to bridge decks. The tests are to be performed on the asphalt pavement overlay surface covering the waterproofing membrane.

APPARATUS

2.1 Ohmmeter, 20,000 ohms per volt rating.

2.2 No. 18 insulted wire, Belden test probe wire or equivalent, two spools, 125 ft. each, with connectors.

2.3 Copper plate, 12 in. x 12 in. x 1/8 in., with clips for connecting the ohmmeter and means to connect a 36 in. wooden handle.

2.4 Polyurethane sponge, 12 in. x 1/2 in. to be attached to the copper plate by rubber bands.

2.5 Pressure spray can, 3 gallon capacity.

2.6 Stone cutters chisel, 3/4 in. face.

2.7 Hammer.

REAGENT

3.1 Wetting agent, Aerosol OT manufactured by the American Cyanamid Company.

PROCEDURE

4.1 Prepare surface to be tested by removing all foreign material by sweeping and/or scraping. Do not use water to clean. Surface must be dry and clean before testing.

4.2 Divide bridge deck into workable subareas similar to that illustrated in Figure 1. If the bridge is to be kept open to traffic, it is advisable to mark and test one lane at a time. Locate a reinforcing bar or other connection to the reinforcing steel in the bridge deck. A positive connection to the top mat of the reinforcing steel is desirable; however, if this is not feasible, the bridge railing, expansion joints, light standards, drainage scuppers, or other exposed steel may provide a positive connection to the reinforcing steel.

4.2.1 A check of the resistance level at various distances along an exposed portion of the concrete must show a constant resistance level, thus indicating a positive connection to the reinforcing steel.

4.3 Uncoil a length of wire ample to reach all areas to be tested, attach the minus (-) jack of the ohmmeter to the reinforcing steel and the plus (+) jack to the 12 in. x 12 in. x 1/8 in. copper plate. Then wet the sponge.

4.3.1 Check ohmmeter battery for satisfactory charge then zero ohmmeter dial indicator.

4.3.2 In order to check for proper overall equipment operation, place copper plate on exposed concrete deck curbing and observe resistance readings on the ohmmeter. These readings will normally vary from 1000 to 3000 ohms per sq. ft.

4.3.3 Using water containing 1 oz. per gallon of wetting agent, wet a spot thoroughly and repeatedly at each grid intersection large enough to accommodate the 1 ft. sq. test plate; taking care that free surface moisture areas (puddles) do not connect with each other.

4.3.4 In order to assure proper moisture penetration through the asphalt pavement to the membrane, select one grid intersection for a check point that is dense-graded and well compacted. Apply water to this point and all other test points on the grid pattern. Allow several minutes for moisture penetration. Then take a resistance reading with the ohmmeter at the check point. Repeat the procedure until it is determined that the resistance has stabilized at its lowest point. The wetting process should not require more than 15 to 20 minutes to complete.

4.5 Proceed to test and record resistance values at each grid intersection. (See Figure 2)

4.6 If it is desired to further define areas for which the electrical resistance is lower than that required by the specifications, a grid pattern to cover grid intersections not previously examined may be made and tested. Before this is done, sufficient time must be allowed for the moisture from the previous testing to dissipate. This length of time will depend on the density and thickness of the pavement as well as the ambient and pavement temperatures.

REPORTING

5.1 Report the resistance values on a grid sheet similar to that shown on Figure 2. Outline on this grid sheet any defective areas that fail to meet the minimum requirements of the specifications. Calculate and report the percentage of deck area that fails to meet specification requirements. Outline these same areas on the bridge deck. Make notations on the grid sheet for repairs or corrections to be made.

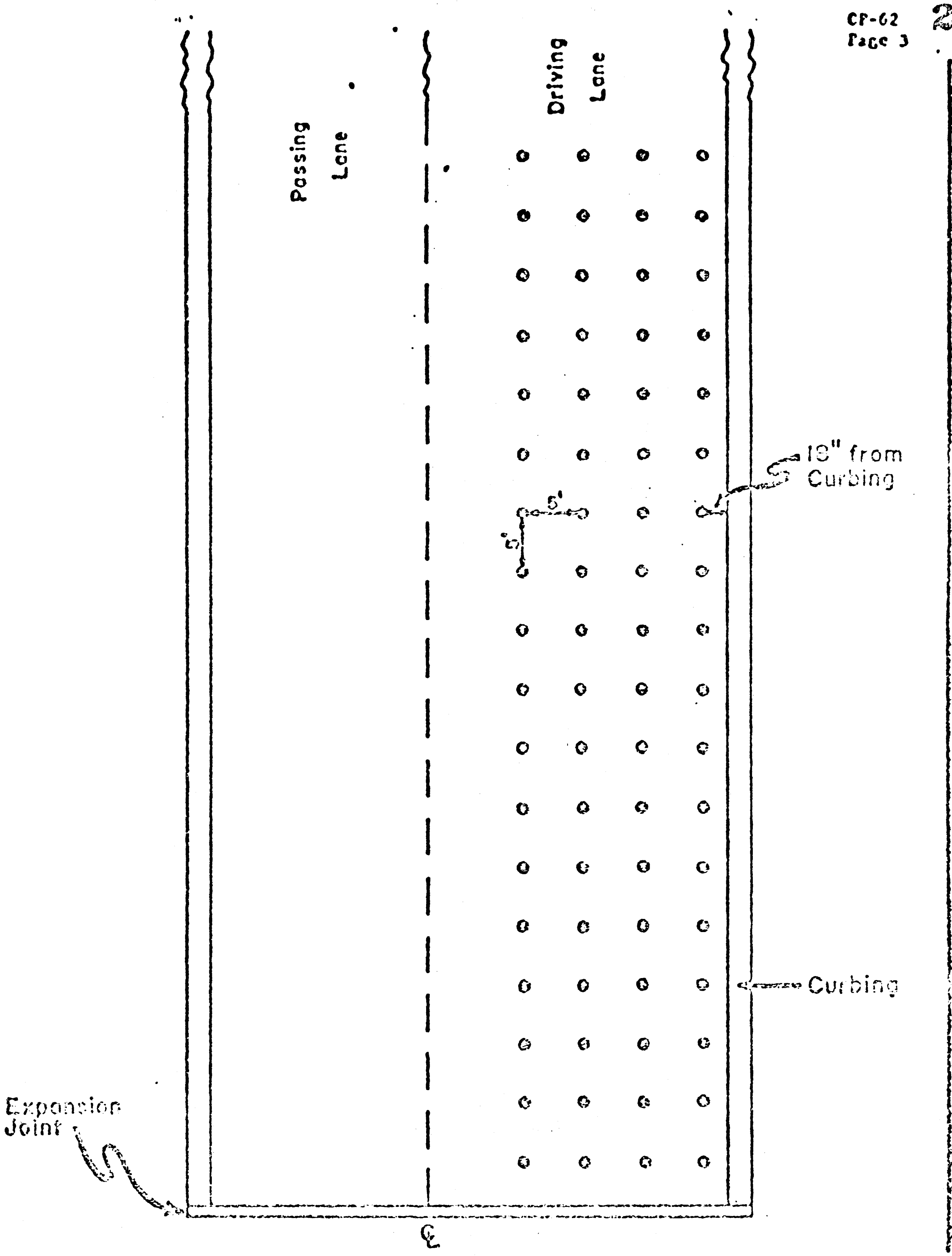


Figure 1. VTM 39.

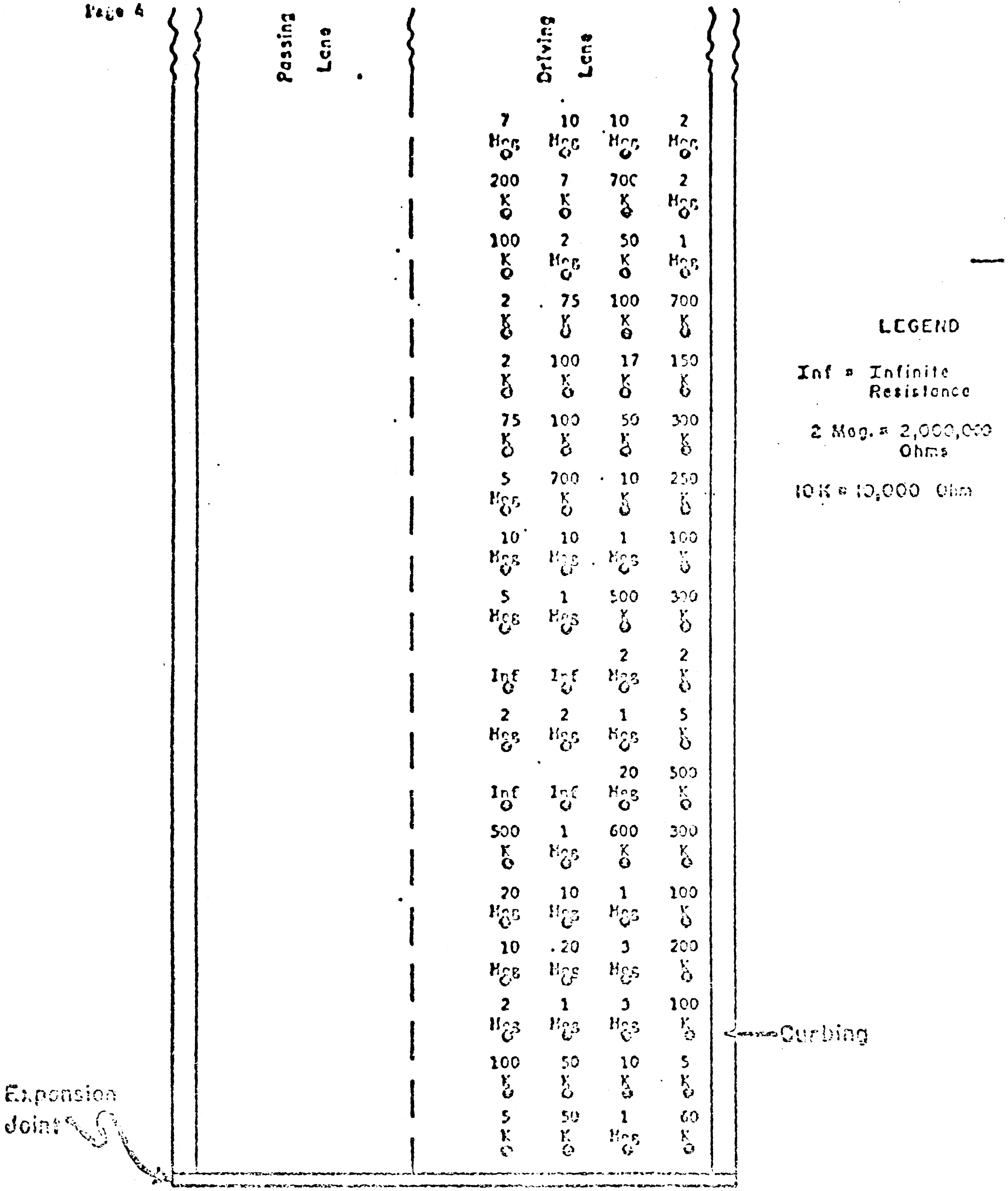


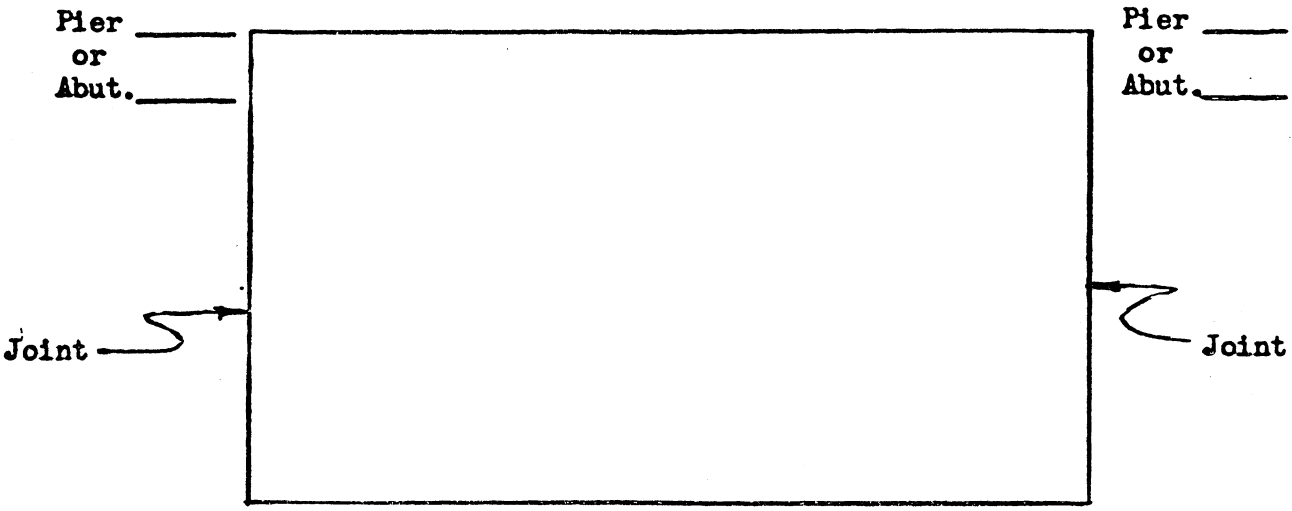
Figure 2. VTM 39.

APPENDIX B

MEASURE OF WATERPROOFING EFFECTIVENESS

DATE ______________________ PROJECT ____________________________________

LOCATION ____



POINT	READING RESISTANCE (ohms)				POINT	READING RESISTANCE (ohms)			
	15 Min.	30 Min.	45 Min.			15 Min.	30 Min.	45 Min.	

1. Points for reading located 18" off of curbing, a minimum 18" off of joint, and on a maximum grid of 5 feet over the remainder of the span.

2. MINIMUM REQUIREMENT 500,000 ohms (Reading of 50 with middle knob set at R x 10,000)

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MEASURE OF WATERPROOFING EFFECTIVENESS (cont'd)

DATE________________ PROJECT________________________________

LOCATION____

POINT	READING RESISTANCE (ohms)				POINT	READING RESISTANCE (ohms)			
	15 Min.	30 Min.	45 Min.			15 Min.	30 Min.	45 Min.	