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Final Report

On

Improvements to the External Corrosion Direct Assessment (ECDA) Process (WP # 360)
Potential Measurements on Paved Areas (Project #243)

for

Pipeline and Hazardous Materials Safety Administration (PHMSA)

U.S. Department of Transportation

Contract No. DTPH56-08-T-000012

by

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Acknowledgements

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Executive Summary

On June 28, 2007, PHMSA released a Broad Agency Announcement (BAA), DTPH56-07-BAA-000002, seeking white papers on individual projects and consolidated Research and Development (R&D) programs addressing topics on their pipeline safety program. Although, not specifically suggested by PHMSA, three Direct Assessment projects were proposed by Corrpro based on an in-house gap analysis of the External Corrosion Direct Assessment (ECDA) process. A white paper was submitted for a consolidated Research and Development (R&D) program entitled “Improvements to the External Corrosion Direct Assessment (ECDA) Process”. It was eventually approved for implementation by PHMSA with the following 3 projects:

- Cased pipes
- Severity ranking of ECDA indirect inspection indications
- Potential measurements on paved areas

The ultimate goal of each of the programs was to present the results and recommendations to the applicable Standards Development Organizations (SDOs) to ensure the strengthening of industry consensus standards and the timely implementation of research benefits for improved safety, environmental protection, and operational reliability. It was also to expand DA applicability and increase the knowledge of the DA methodology.

The accomplishments and conclusions of the research on potential measurements on paved areas are summarized as follows:

- Gravel & Asphalt:
  - Simple, straightforward pre-survey surface resistance measurements can be used to determine if on-pavement potential surveys will yield accurate results
  - A surface resistance threshold of ~$2x10^5$ ohm-ft^2 has been determined, i.e. standard potential measuring procedures can be used with reference electrodes on the paving when surface resistances are less than this value
  - A standard 3” diameter reference electrode with wetted towel or sponge is adequate to minimize the effect of contact resistance
- Concrete:
  - No clear, consistent method for making accurate pipe-to-soil potential measurements was determined, other than through the use of drilled holes
  - Future research is in order to evaluate the feasibility of accurate DCVG and or ACVG measurements with reference electrodes placed on the concrete surface

1. Introduction

A Government and Industry Pipeline R&D Forum was held in New Orleans, February 7-8, 2007, by the U.S. Department of Transportation (DOT), Pipeline and Hazardous Materials Safety Administration (PHMSA). The 2-day event included approximately 240 representatives from Federal, State and international government agencies, public representatives, research funding organizations, standards developing organizations, and pipeline operators from the U.S., Canada and Europe. The R&D Forum led to a common understanding of current research efforts, key challenges facing government and industry, and potential research areas where exploration can help meet these challenges, and should therefore be considered in developing new research and development applications. On June 28, 2007, PHMSA released a Broad Agency Announcement (BAA), DTPH56-07-BAA-000002, seeking white papers on individual projects and consolidated Research and Development (R&D) programs addressing topics on pipeline safety program areas identified at the R&D Forum, namely:

1. Excavation Damage Prevention Technologies
2. Direct Assessment Methods for Transmission and or Distribution Pipelines
3. Defect Detection/Characterization
4. Defect Remediation/Repair/Mitigation
5. New Fuels Transportation

Several specific R&D projects were suggested in the BAA. Although, not specifically suggested by PHMSA, three Direct Assessment projects were proposed by Corrpro based on an in-house gap analysis of the External Corrosion Direct Assessment (ECDA) process. Over several years, ECDA has been used to assess the condition of thousands of miles of natural gas and petroleum pipelines. Corrpro's gap analysis identified three key areas of opportunity to enhance application of the technology. A white paper was submitted for a consolidated Research and Development (R&D) program entitled "Improvements to the External Corrosion Direct Assessment (ECDA) Process". It was eventually approved for implementation by PHMSA. One of the three components of the consolidated R&D program is as follows:

Potential measurements on paved areas: Pipe-to-soil potential is the voltage difference of the pipe-to-soil boundary layer, as measured with respect to a stable reference electrode contacting the soil over the pipeline. For the measurement to be accurate, the reference electrode is commonly placed in contact with the soil (same electrolyte as the pipe) directly over the pipeline, and the voltage measurement must be free from IR drop error. In urban areas, including regulated high consequence areas (HCAs), buried pipelines are often inaccessible due to the presence of concrete or asphalt cover such as paved roads, sidewalks and parking lots. Surveys on pipe under pavement have been shown to be unreliable in many instances. In HCAs, any catastrophic pipe failure carries severe consequences to health, safety, the environment and the economy. Accordingly, there is a great need to develop a proven acceptable methodology for pipe-to-soil potential measurements on pipe under pavement.

This report covers research relating to the potential measurements on paved areas. Research results associated with the other two opportunities, cased pipes and severity ranking of ECDA indirect inspection indications, are reported separately.

2. Project Objectives

The objectives of the project on potential measurements on paved areas are to:

- Conduct literature search on potential measurements
- Conduct controlled laboratory tests
- Develop prototype tools to correct for potential measurement error
- Conduct field testing
- Analyze field test results to determine the accuracy of the measurement tool
- Implement the revalidated tool in the field as necessary
- Develop guidelines for potential measurements on paved areas to be provided to standards organizations for development into recommended practices
- Produce a project report
- Provide outreach to industry through a web-based workshop and public presentations

The project is designed such that its outputs primarily parallel PHMSA program elements, namely pipeline assessment, defect characterization, improved design of data collection systems, human factors, and safety.

3. Project Justification

Pipe-to-soil potential is the voltage difference of the pipe-to-soil boundary layer, as measured with respect to a stable reference electrode contacting the soil over the pipeline. For the measurement to be accurate, the reference electrode is commonly placed in contact with the soil (same electrolyte as the pipe) directly over the pipeline, and the voltage measurement must be free from IR drop error. When pipe-to-soil potential measurements are taken at close intervals (approximately 2.5 feet) along the pipeline, a tool referred to as *Close Interval Survey* (CIS), corrosion and cathodic protection levels can be assessed along the entire surveyed section of pipe. This is one of the tools used in performing ECDA.

In urban areas, however, buried pipelines are often inaccessible due to the presence of concrete or asphalt cover (such as paved roads, sidewalks and parking lots). Urban areas typically include regulated high consequence areas (HCAs) where a catastrophic pipe failure carries severe consequences to health, safety, the environment and the economy. Accordingly, there is a great need to develop a proven acceptable methodology for pipe-to-soil potential measurements on pipe under pavement. New tools, technologies, or error correcting algorithms are needed to address and resolve this technical challenge. Laboratory and field verification is vital to build a high degree of confidence in the newly developed tool.

The primary goal of the research is the development of tools that facilitate accurate measurement of potentials on uncased pipe underneath pavement. The new assessment methodologies, based on improved tools, are to achieve an industry-accepted level of reliability and accuracy. It is possible that one tool alone may not lead to the ultimate result, and that a combination of two or more tools may be needed to gain a high degree of confidence in the results. The aim is not only to improve the technology, but also to develop a reliable and repeatable data integration methodology. The key is to be able to answer unresolved questions such as:

- How should potentials be measured on an uncased pipeline under pavement? Within the context of this research, “potentials” references DC pipe-to-soil potentials and DCVG coating indication potentials.
- Is it acceptable to measure the potentials with the reference electrodes placed on the pavement? Within the context of this research, “pavement” references asphalt, concrete, and gravel.
- What impact do concrete thickness, reinforcement and bedding have on the measurement accuracy?
- Similarly, what impact do asphalt thickness, cracking and bedding have on measurement accuracy?
- What happens when the pavement surface is wetted or flooded with water?
- Could accuracy be enhanced by emerging instrumentation?

The work scope includes the following pavement types and measurement procedures:

- Paving Type: asphalt, concrete, and gravel
- Measurement Procedures:
  - CIS – Close interval pipe-to-soil potential survey (DC)
  - DCVG – Direct current voltage gradient measurements to evaluate coating quality

Some of the key issues include the basic characterization of:

- Junction potentials
- Pavement contact/surface resistance
- Pavement bulk resistivity
- Impact of thickness, compaction, compressive strength and porosity
- Impact of pH and steel reinforcing (concrete)
- Impact of surface wetting
- Impact of damage and wear/deterioration, e.g. cracks and delaminations

4. <u>Review of Current Practices</u>

Because of limited published work on the subject matter (see references, Section 11 of this report), various practitioners were polled to determine their procedures for making potential measurements when a pipe passes under paving. The methods determined can generally be grouped as follows:

- Drilling through the pavement every 5 to 10 feet
- Offset measurements in adjacent unpaved areas
- Surface wetting to lower contact resistance

- Skipping the paved section

Of the above techniques, drilling through the pavement is most prevalent. As illustrated in the photograph in Figure 1, this can be a cumbersome task, often requiring costly traffic control and other safety precautions. Skipping the paved section completely could result in missing coating indications or other anomalous conditions that might represent a pipeline integrity threat.

While drilling through the pavement is the most prevalent approach, there were also strong conflicting indications from our initial data gathering that surface wetting provided reportedly accurate potential measurements, particularly for asphalt paving. The surface wetting ranges from a light wetting of the paving in the immediate area of the reference electrode (less than 1 square foot) to "flooding" large areas. In particular, a natural gas local distribution company (LDC) in a major metropolitan area has been collecting pipe-to-soil potential measurements and DCVG measurements for roughly 8 miles of pipe annually under predominantly asphalt paving. Measurements are made at 5-foot intervals with a 3-inch diameter reference electrode after wetting the asphalt only in the immediate area of the reference electrode. This procedure has been in place for several years after initial comparative data to validate the approach. The validity of the data during a typical survey is determined by trending. When suspect measurements are encountered, holes are drilled through the paving and the measurements repeated with the reference electrode in direct contact with the soil. The repeat measurements are in good agreement with the measurements with the reference electrode on the paving upstream and downstream of the suspect area. The need for repeat measurements through drilled holes in the paving is infrequent, accounting for less than 10% of the total annual survey length.

The extensive experience of the above LDC coupled with other data sources was quite contrary to the general trend of drilling holes through the pavement to obtain reliable potential measurements. Given these compelling factors and the experience of the researchers, it was postulated that if basic electrical data such as resistance could characterize a pavement, then decisions and guidelines regarding the validity of making potentials with a reference electrode placed on the paved surface could be made. The concept of straightforward, user-friendly field measurements as a precursor to a potential survey through a paved area would eliminate the need to determine the many variables associated with the paving, e.g. thickness and sub-base material. The goal of the advanced field measurements would be reliable data collection for use in an ECDA evaluation without the need to drill holes except when absolutely necessary. This basic postulation set the foundation for subsequent research activities described in the following sections of this report.

5. Laboratory Tests

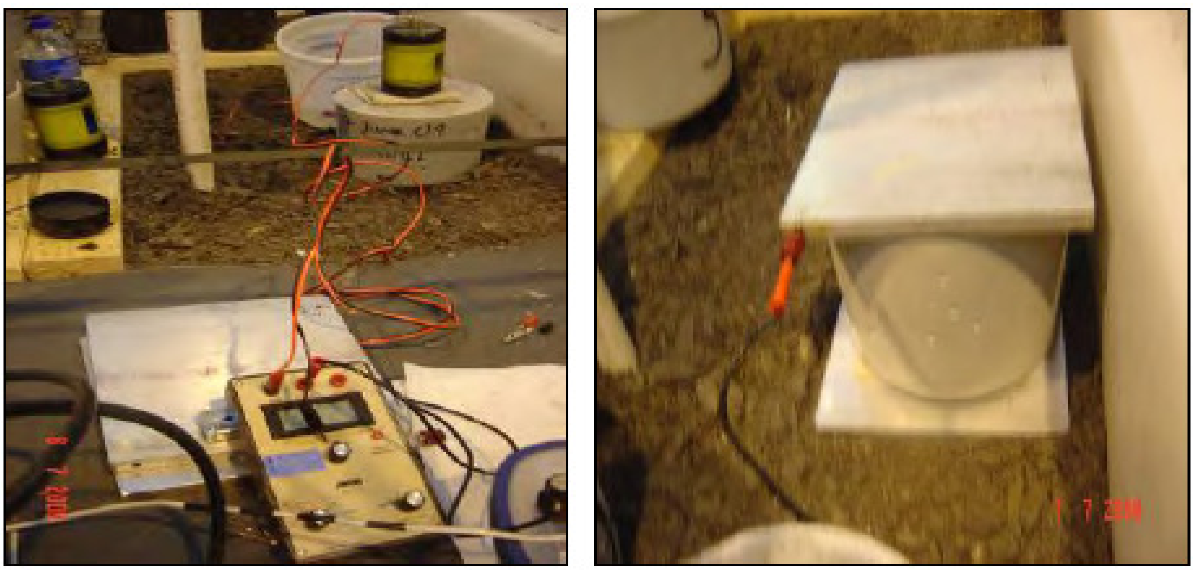
A fiberglass tub was filled with top soil to perform electrical resistance and electrical potential measurements on asphalt and concrete samples. The photographs in Figures 2 and 3 illustrate these laboratory tests. Steel reinforcing bars were placed in the top soil to simulate a buried pipe under the paving. Figures 4 through 6 present data from some of the tests.

Figure 1: Drilling holes in pavement for potential measurements

Figures 4 and 5 show asphalt sample resistivity and normalized resistance (resistance per unit surface area) determined using procedures similar to ASTM D257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials.* These measurements were made using a digital meg-ohmmeter having a maximum 1,000 volt DC source specifically manufactured for high resistance circuits. Most measurements were made with one terminal of the meg-ohmmeter connected to an 8-inch by 8-inch metal plate electrode placed atop the sample and the other terminal connected to one of the steel reinforcing bars in the top soil several inches below the sample. Very little difference in measured value was obtained when the meg-ohmmeter was connected across two metal plates “sandwiching” the asphalt sample.

(a) (b)

Figure 2: Asphalt resistance/resistivity measurements



(a) (b)

Figure 3: Concrete potential and resistivity measurements

Referencing Figure 4, the bulk resistivity of the asphalt samples ranges from $4x10^{10}$ ohm-cm to approximately $3x10^{11}$ ohm-cm. The corresponding normalized resistance, which is not dependent on sample thickness, is shown in Figure 5 and ranges from $8x10^7$ ohm-ft.^{2} to $8x10^8$ ohm-ft.^{2}. The resistance measurements are important relative to the electrical circuit and instrumentation used if one were to attempt to make reliable potential measurements through asphalt paving without drilling holes. For these particular measurements, no wetting of the asphalt sample was made other than via the moisture in a damp towel placed between the metal plate and the sample to minimize contact resistance. The measurements were made approximately 2 minutes after positioning the plate electrode and towel on the asphalt sample. Care was taken so no water from the towel bridged the sides of the sample.

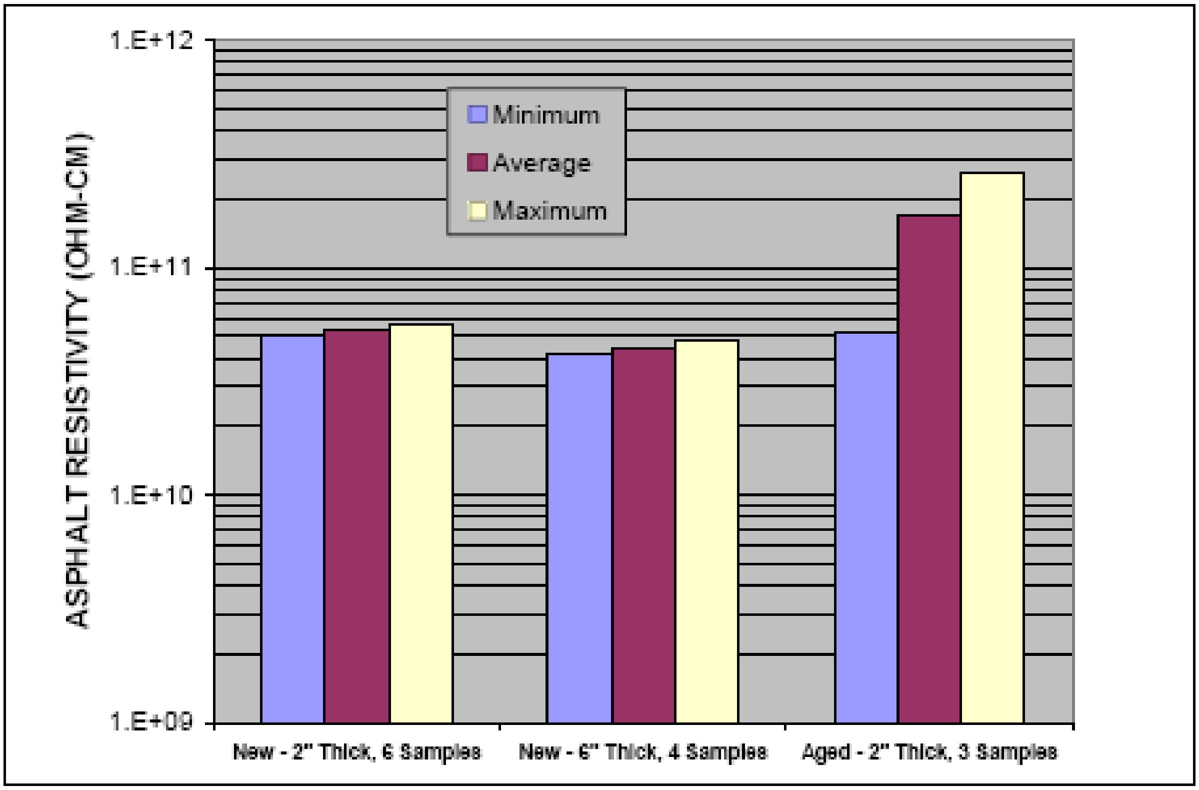


Figure 4: Laboratory tests: Asphalt resistivity

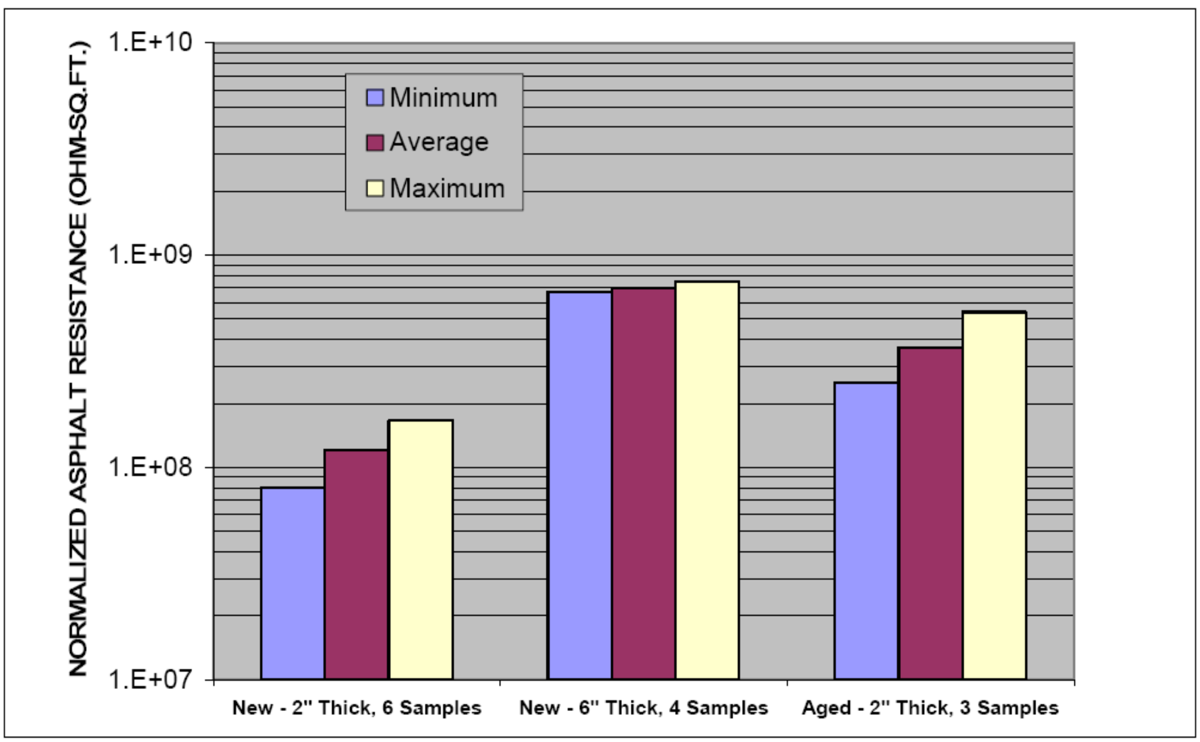


Figure 5: Laboratory tests: Normalized asphalt resistance (same samples as Figure 4)

Figure 6 shows the laboratory potential measurement data for the concrete samples. These data were obtained using a digital voltmeter with a variable internal resistance ranging to 200×10^6 ohms. The data shown are with the voltmeter internal resistance set at 200×10^6 ohms. There was little difference between these data and those with the voltmeter internal resistances set at 50×10^6 and 100×10^6 ohms. Meter circuit loading was evident at voltmeter internal resistances of 10×10^6 and 25×10^6 ohms. The measurements were made using a 3-inch diameter copper/copper-sulfate reference electrode with a damp towel placed between the electrode and the top of the concrete sample. For five of the six samples (all but Sample #4), the instantaneous potential with the reference electrode on the concrete is more negative than the potential with the reference electrode on the top soil, by 0.011 to 0.058 volt. The potential with the reference electrode on the concrete becomes even more negative after waiting three minutes, by an additional 0.003 to 0.045 volt. These data suggest a time dependency when making potential measurements on concrete. While the data set shown in Figure 8 indicates a more negative potential over time, another laboratory data set indicates a less negative potential over time by roughly the same range in magnitude. Samples #3 through #6 were laced with salt to evaluate the impact of chlorides in the concrete, the equivalent of 3 pounds per cubic yard for Samples #3 and #4, and the equivalent of 5 pounds per cubic yard for Samples #5 and #6. The addition of the salt shows no apparent effect.

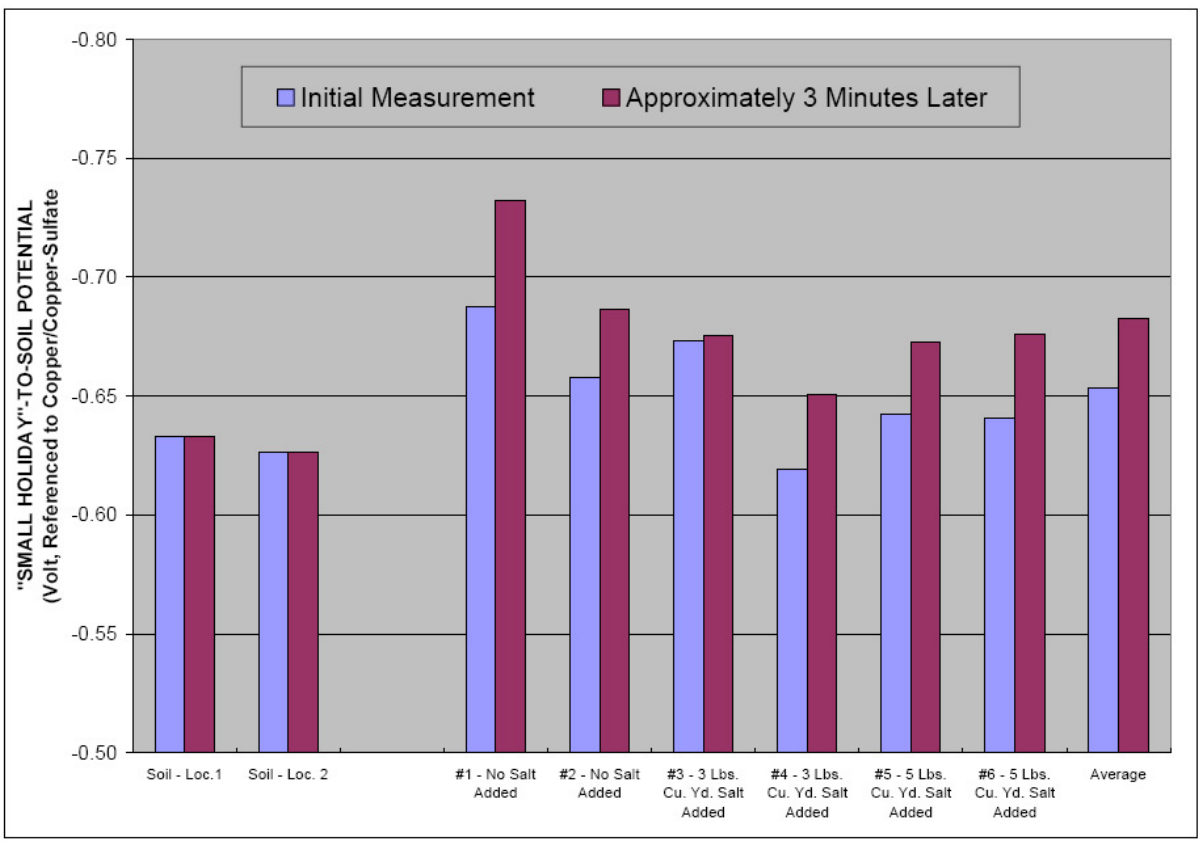


Figure 6: Laboratory tests: Concrete potential measurements

6. Initial Field Tests

Resistance and potential measuring techniques similar to those described above for the laboratory tests were performed in-situ at various locations throughout the Houston area to further electrically characterize different paving types and determine variations. The data from some of these field measurements are presented in Figures 7 through 11.

Figure 7 shows the resistance through asphalt using the metal plate on the paved surface and a nearby electrical ground connection as an earth electrode. Figures 8 through 10 show the differences in potential between a reference electrode on the paving surface (asphalt, concrete, and gravel) versus the potential within a few feet with the reference electrode on soil. Similar to the laboratory tests, no surface wetting was done for these measurements, other than to use a damp towel directly under the metal plate electrode for the resistance measurements and under the reference electrode for the potential measurements. For the potential measurements, when voltmeter loading was prevalent at a meter internal resistance of 200×10^6 ohms, the measurements were made using two or more lower internal resistances and a "true" potential calculated from these data.

Figure 11 shows potential versus time traces for a section of pipe under a reinforced concrete roadway. The pipe-to-soil potential with the reference electrode on the concrete over the pipe increases over time, approaching that using a reference electrode immediately adjacent on the soil over the pipe, only after several minutes.

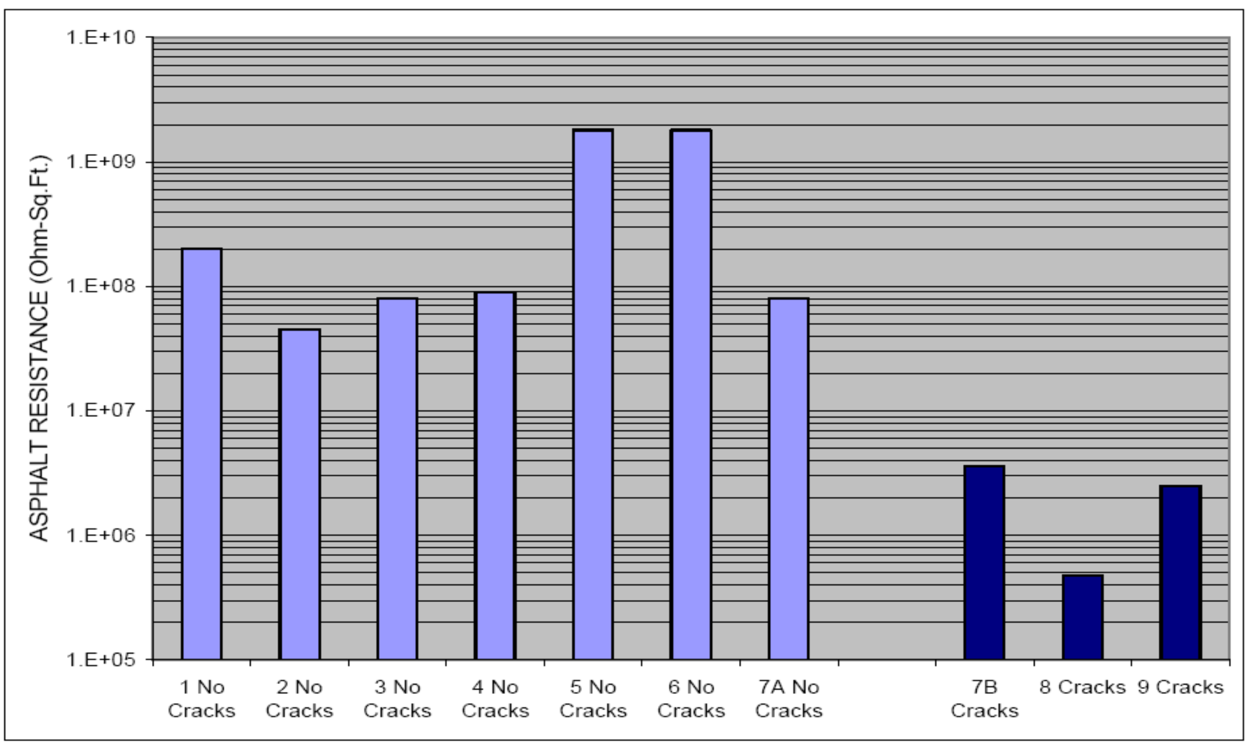


Figure 7: Initial Field Tests: Asphalt Resistance

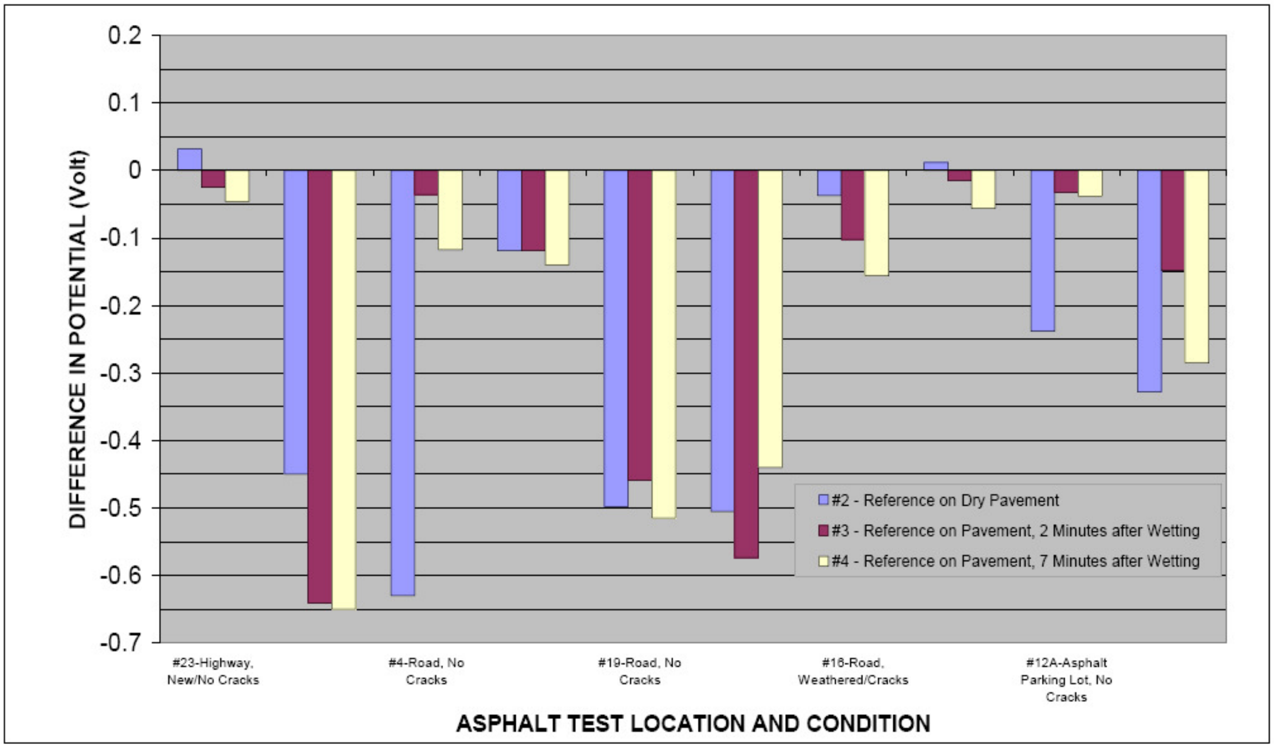


Figure 8: Initial Field Tests: Comparing potentials on asphalt vs. soil

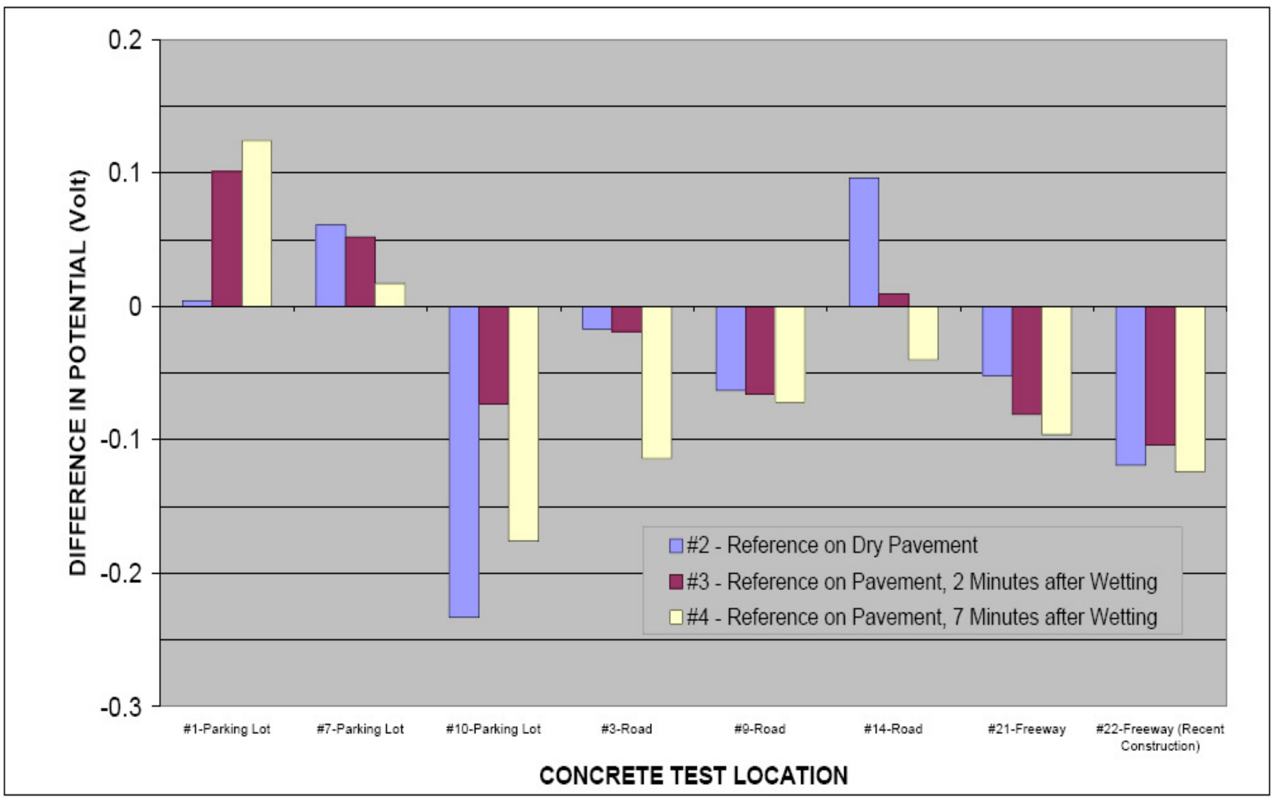


Figure 9 Initial Field Tests: Comparing potentials on concrete vs. soil

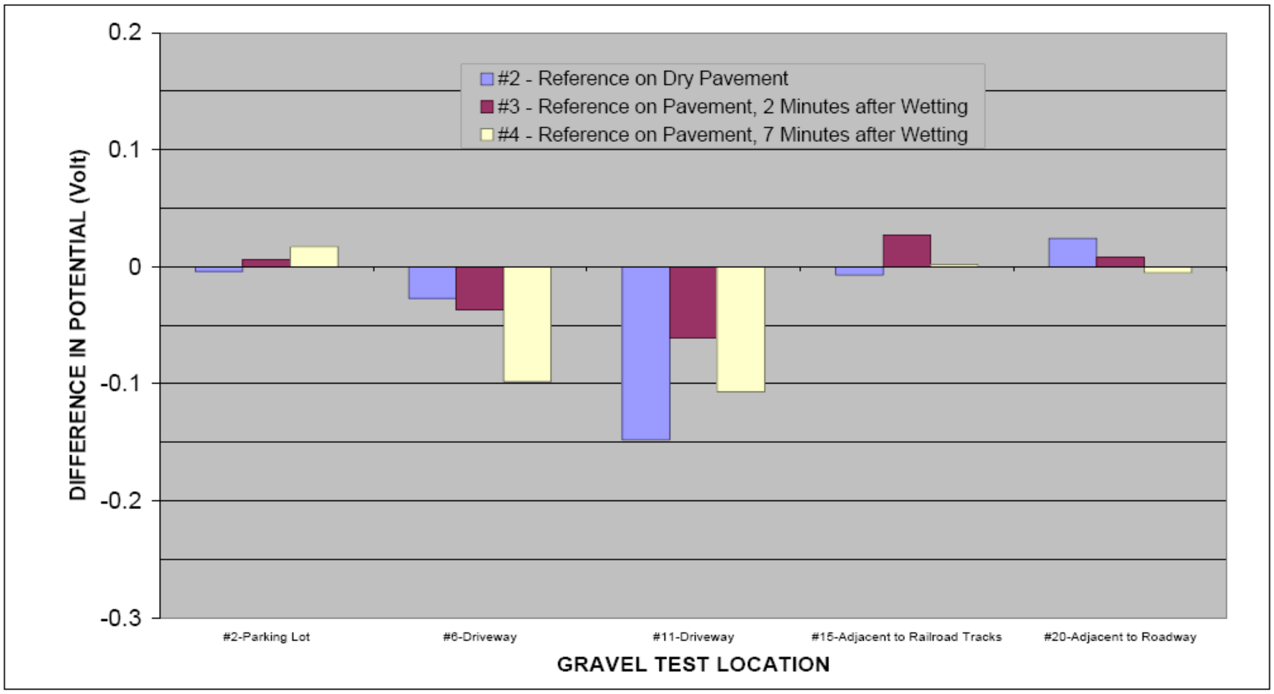


Figure 10: Initial Field Tests: Comparing potentials on gravel vs. soil

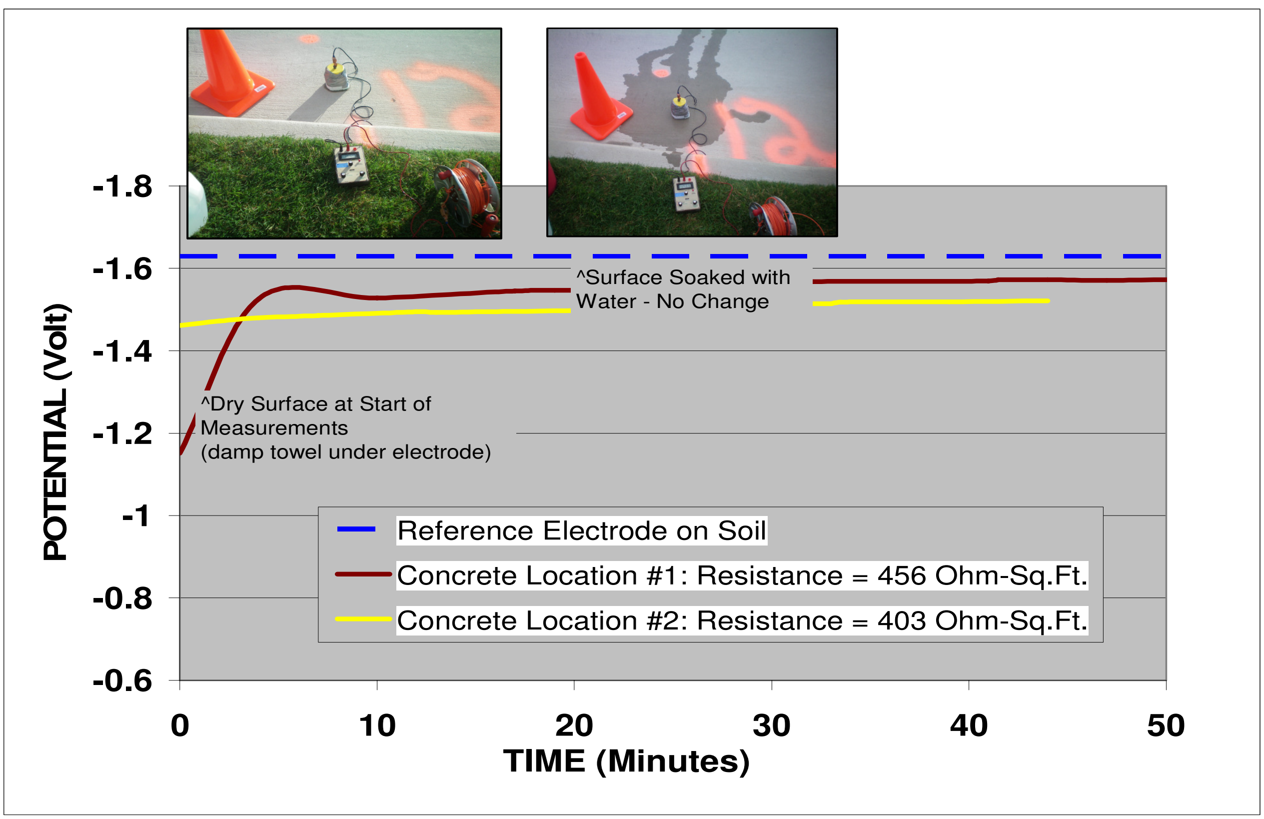


Figure 11: Initial Field Tests: Comparing potentials on concrete vs. soil

Key findings from this aspect of the research are consistent with the laboratory tests and include:

- Knowledge of the paving electrical resistivity/resistance characteristics can likely be used to determine the validity of making potential measurements directly through the paving (particularly asphalt), i.e. without drilling holes or otherwise having direct contact between the reference electrode(s) and soil
- Of all the paving types and conditions evaluated, gravel exhibited the smallest variation in potential when compared to the corresponding potential on soil
- Potentials on concrete paving yielded no consistency and no clear method for correction/adjustment

7. Comparative Pipeline Surveys

As indicated previously, the direction of this research is toward electrically characterizing a given pavement at the onset of a potential survey to determine whether accurate over-the-pipe procedures can be employed with reference electrodes placed atop the paving. Initial research indications suggested this is plausible under many conditions. As such, "real-world" survey efforts were undertaken to determine influencing factors and limitations. These activities establish the basis for procedures developed as part of this research that can be used by industry when performing potential surveys in paved areas. The key to this procedure is accurately identifying and conveying when it is feasible to use reference electrodes on the paving and when it is not.

Following are six example potential surveys performed in paved areas – asphalt, concrete, and gravel. The first four directly compare potential measurements with reference electrodes atop the paving versus measurements through a drilled hole at roughly the same location and interval. The fifth example is for an asphalt parking lot where the measurement interval atop the paving is nominally every 2.5 feet. Measurements over the pipe in soil occur every 50 feet or so in small "block-outs" used to place pipeline markers. The sixth example is for piping passing beneath a reinforced concrete roadway. The example surveys illustrate the impact of different reference electrode configurations and surface wetting. Paving resistance/resistivity measurements were included to evaluate the effect of this parameter on the potential measurements. The photographs embedded in the data figures show the pavement condition.

Pipeline Survey #1 – Recently Constructed Well Compacted Gravel (Figure 12): The "on" and "instant-off" pipe-to-soil potentials using the drilled holes are slightly more negative than those with the reference electrodes on top of the gravel. This condition is likely related mainly to subtle variations in potential that occur over time, i.e. the potentials in the drilled holes were measured five days prior to the other measurements. It is believed there would have been little difference in the potentials had the data been collected on the same day.

DCVG procedures determined no noteworthy coating indications. This was true regardless of whether the reference electrodes were placed atop the gravel or in the drilled holes. The pavement surface contact resistance and bulk resistivity are relatively low, which contributes to the consistency in the potential measurement techniques.

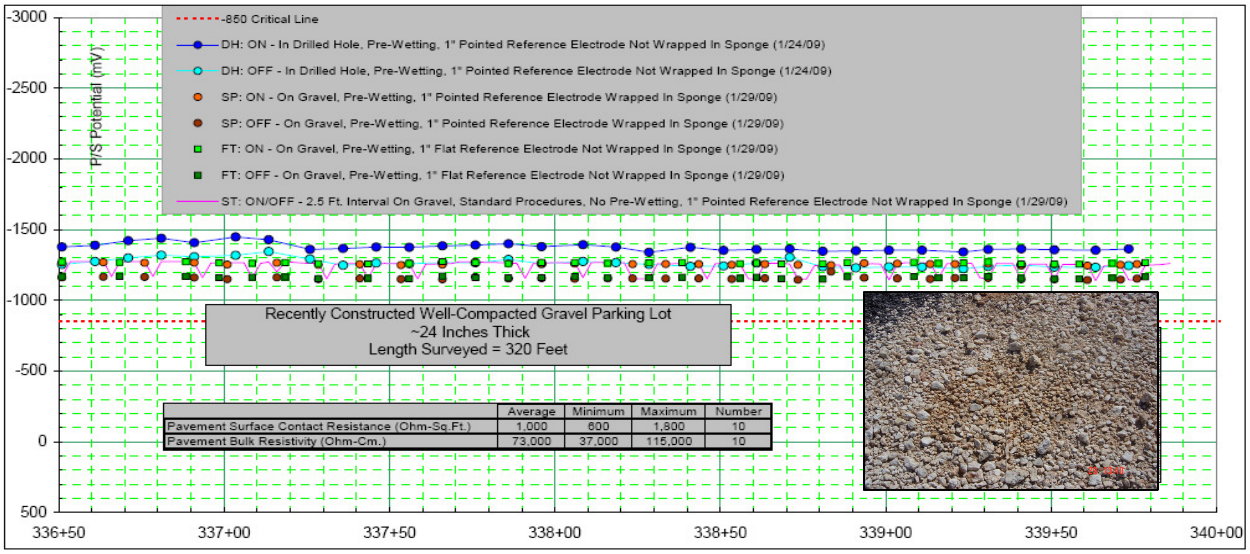


Figure 12: Pipeline survey #1: Well compacted gravel

<u>Pipeline Survey #2 – Weathered Asphalt/Rock (Figure 13):</u> The different measurement techniques (holes vs. no holes) yield very comparable "on" and "instant-off" pipe-to-soil potentials with no discernible difference. Similar to Pipeline Survey #1, the relatively low surface contact resistance and bulk resistivity are major contributing factors. No DCVG coating indications were measured using any of the techniques.

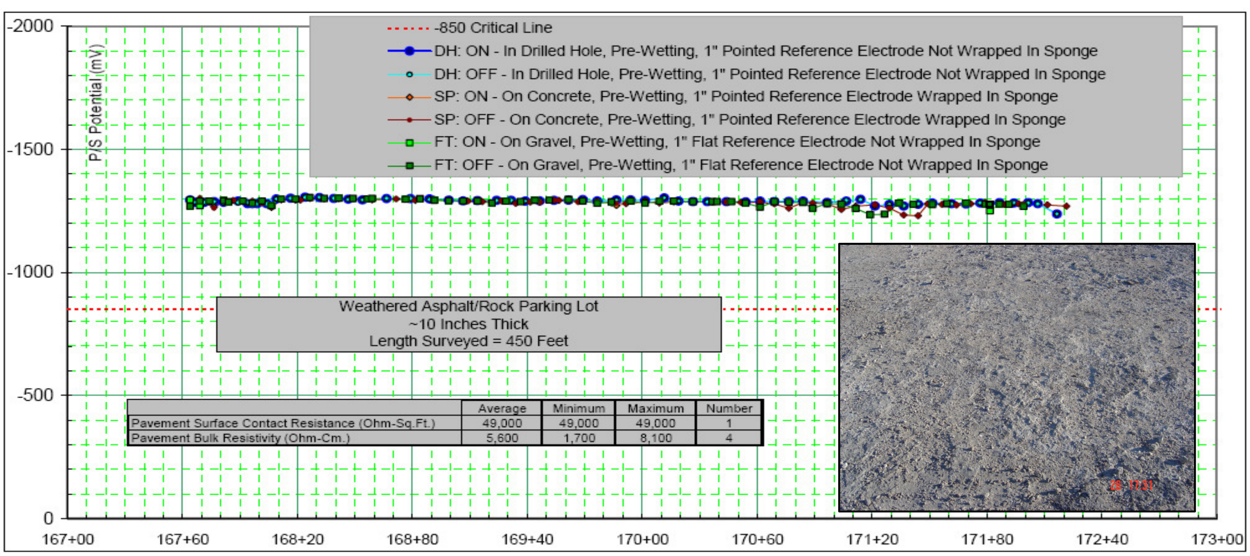


Figure 13: Pipeline survey #2: Weathered asphalt/rock

<u>Pipeline Survey #3 – Weathered Concrete (Figure 14):</u> The potential measurements with the reference electrode on the concrete surface range from 0.15-volt less negative to 0.25-volt more negative than measurements with the reference electrode atop the sand-filled hole; the average difference is approximately 0.10-volt more negative. While most measurements are more negative, the first several feet of the survey exhibited less negative potentials with no apparent visual difference in concrete condition. There is no well defined correlation between the measurement techniques based on this data set.

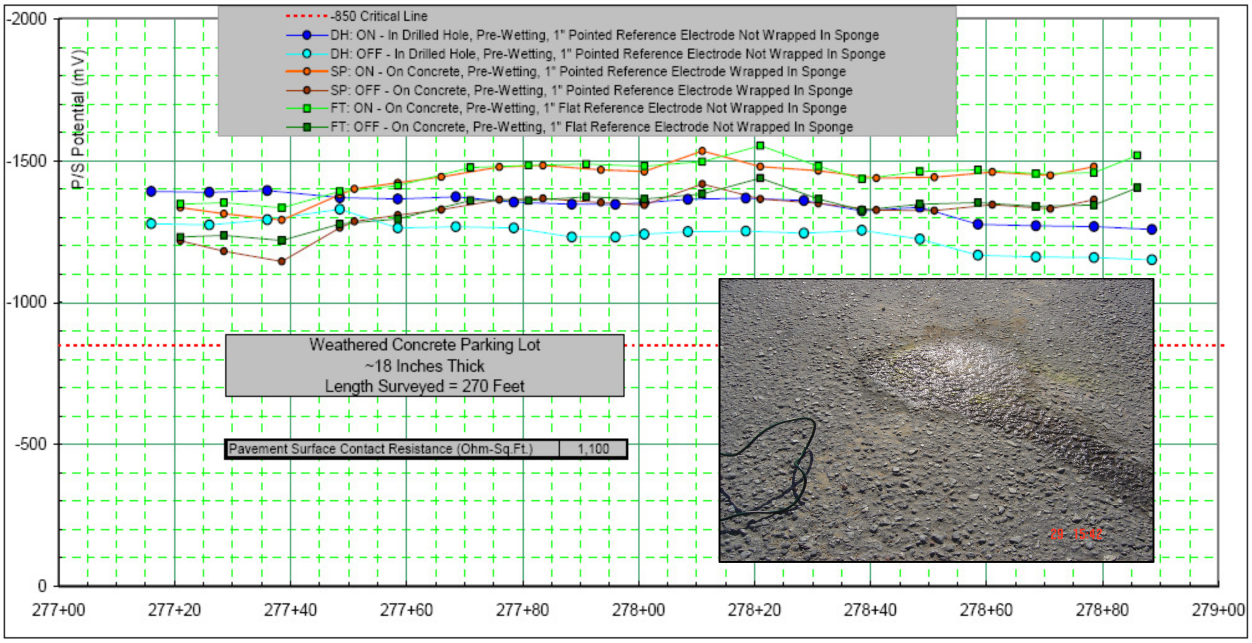


Figure 14: Pipeline survey #2: Weathered concrete

<u>Pipeline Survey #4 – Weathered Asphalt (Figure 15):</u> There are no variations in potential versus distance using the drilled holes through the survey section. However, there are wide, erroneous swings in potential with the reference electrode on the asphalt surface. Pavement resistance is in the 10^6 – 10^7 ohm-ft.^{2} range, much greater than the other sample pipeline surveys. Also, the paving surface had many loose stone chips. The combination of the high resistivity and the poor electrical contact of the reference electrode to the asphalt surface are predominant influencing factors to the erroneous data.

<u>Pipeline Survey #5 – Weathered Asphalt (Figure 16, 17 and 18):</u> This asphalt parking lot was constructed approximately five years ago. The potential measurements without surface wetting were erroneous. After a light surface wetting (using a sprayer, see photographs in Figure 17), most of the potential measurements on the paving were quite comparable to those in the soil “block-outs”. As the asphalt resistance measurements in Figure 18 show, lightly wetting the surface of the asphalt without visual cracks reduces the resistance from in excess of 10^7 ohm-ft.^{2} to approximately 10^4 ohm-ft.^{2}. Some drying seems to be occurring as the resistance increases by up to a factor of ten after ten minutes. Measurement Location #3 is at a crack and exhibits a resistance of less than 10^4 ohm-ft.^{2}. Measurement Location #4 is at a crack that had standing water from nearby lawn sprinklers. The resistance at this location was 10^2 ohm-ft.[2]

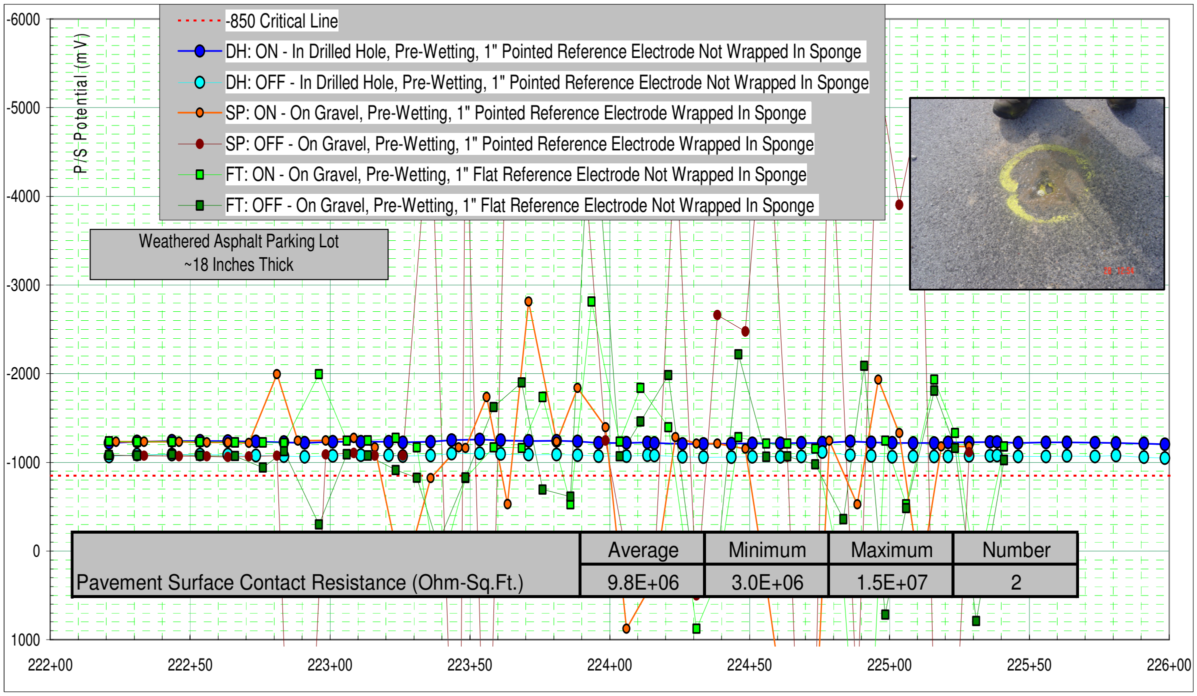


Figure 15: Pipeline survey #4: Weathered asphalt

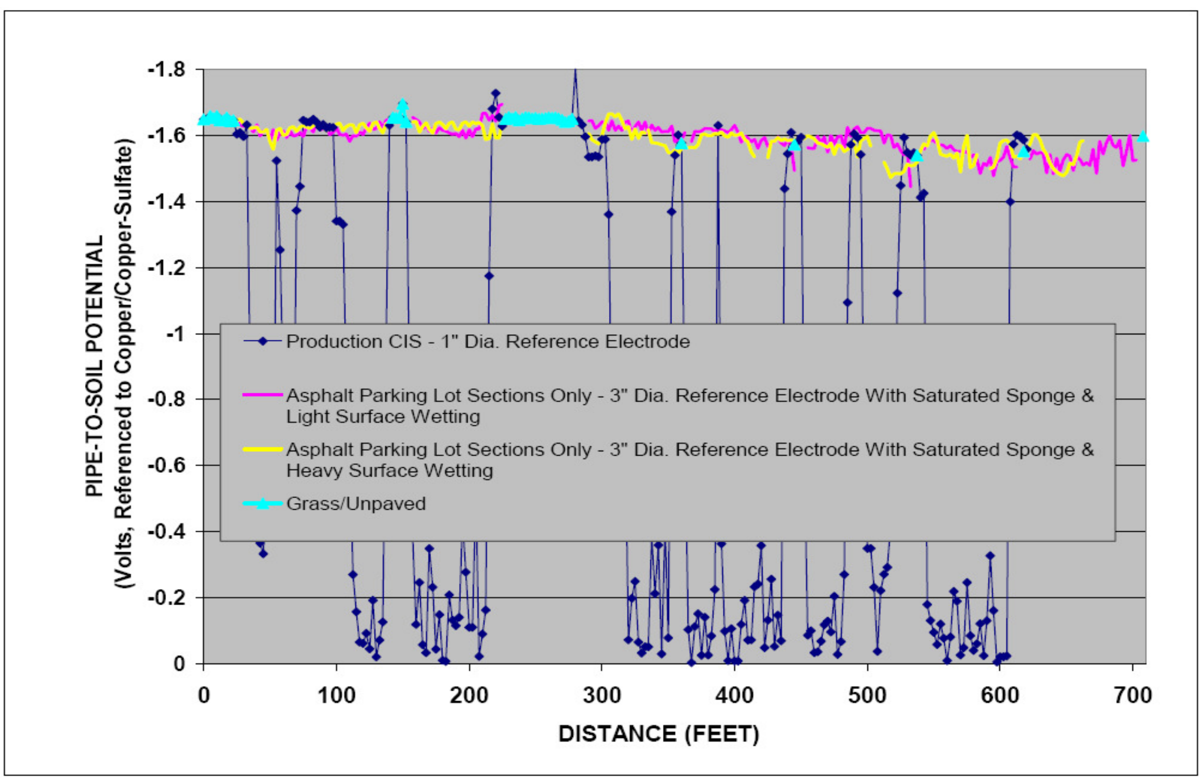


Figure 16: Pipeline survey #5: Weathered asphalt

Figure 17: Pre-wetting for pipeline survey #5: Weathered asphalt

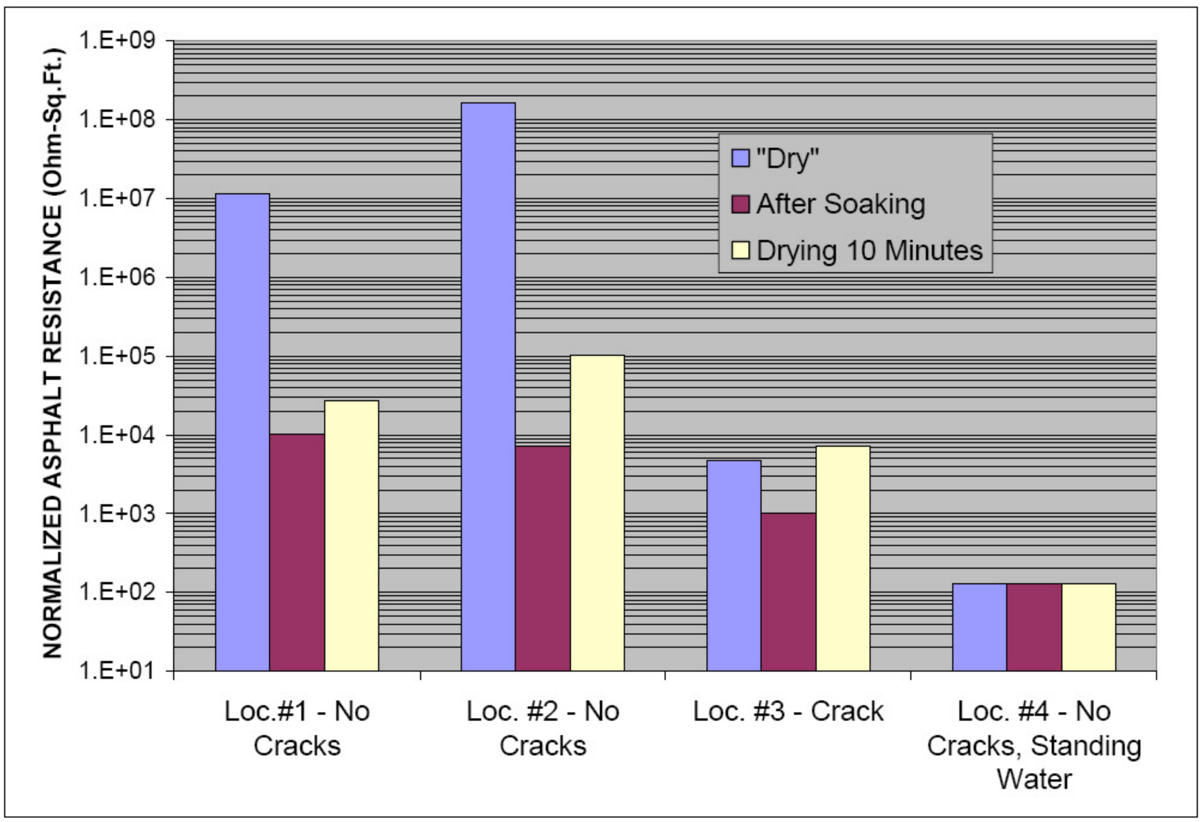


Figure 18: Pipeline survey #5: Asphalt resistance

<u>Pipeline Survey #6 – Reinforced Concrete Roadway (Figure 19)</u>: This 4-lane reinforced concrete secondary roadway is approximately four years old. There is a grass median between the different travel directions. Erroneous potential measurements on the concrete using a standard 1-inch diameter reference electrode are readily apparent. While increasing the reference electrode diameter to 3-inches and wetting the surface seems to provide for more consistent measurements across the paving, the potentials are typically less negative than the potential on soil by approximately 0.2 volt. Similar procedures on other concrete paved areas shows a range in potential from less negative to more negative when compared to data with the reference electrode directly contacting the soil.

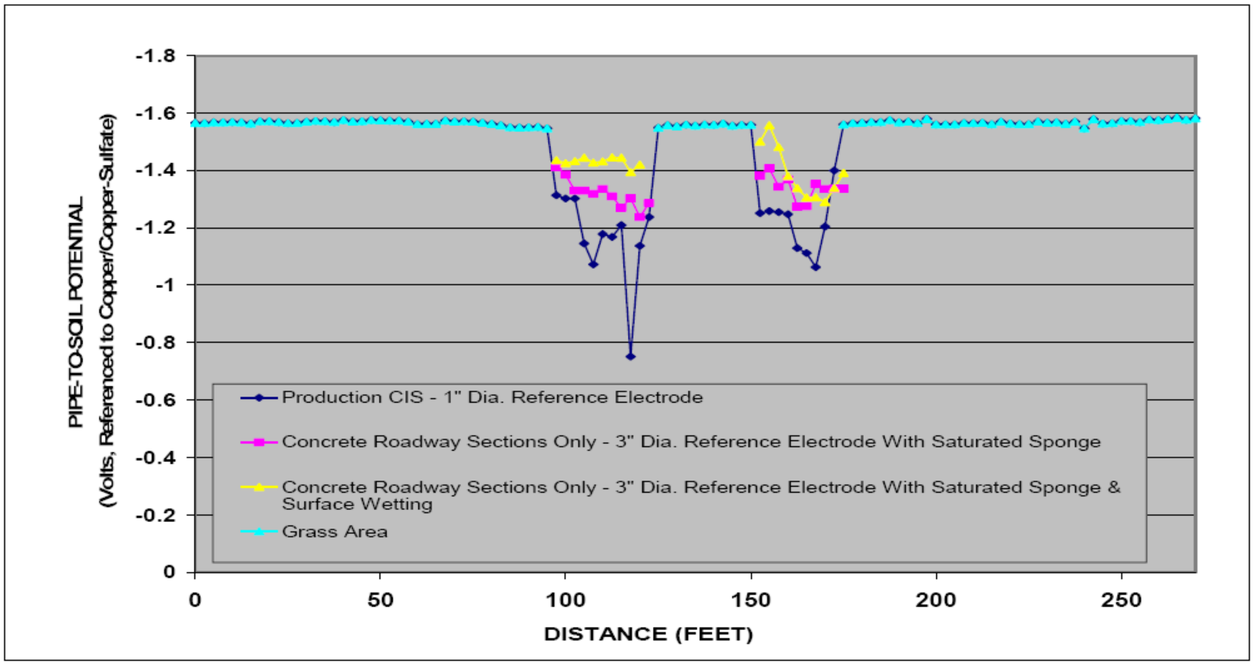


Figure 19: Pipeline survey #6: Reinforced concrete

8. Enhanced ECDA Methodology for Potential Measurements on Paving

The results of this research are:

- Resistance measurements of asphalt and gravel paving can be used to determine the feasibility of making potential measurements with reference electrodes on the paving surface. Based on analysis of the various research data (Figure 20), a resistance threshold of $2x10^5$ ohm-ft^2 has been established. That is, measured paving resistances less than $2x10^5$ ohm-ft^2 will yield potential measurements consistent with those where the measurements were made with reference electrodes on the underlying soil.
- No clear, consistent method or correction factor for potential measurements on concrete paving was determined from this research.

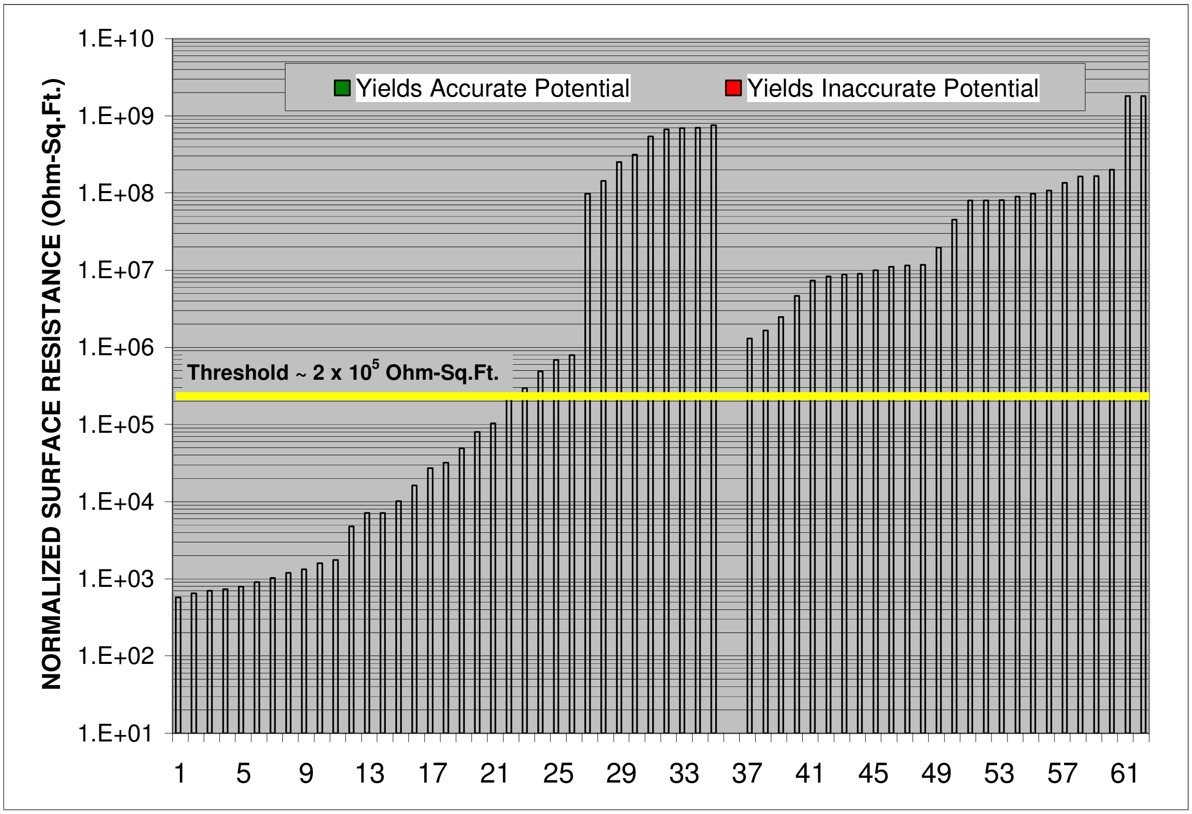


Figure 19: Paving Resistance Data and Threshold

Regarding asphalt and gravel paving, Appendix 1 of this report contains a standard test method that can be used. The table of contents for the test method is listed below for reference.

- General
- Related Standards
- Safety Considerations
- Equipment and Instrumentation
- Paving Resistance Measurement Procedures and Calculations
- Paving Resistance Measurement Guidelines
- Data Analyses
- Visual Guides for Determining Suitability of Potential Measurements with Reference Electrodes on Paving
- Error Sources and Impact on ECDA Analysis

9. Prospective Future Research Project

The results of this research provide industry with guidance on potential measurements in asphalt and gravel paved areas. Additional research in the following area is in order:

- ***Advanced Procedures for Potential Measurements on Concrete Paved Areas***

10. Conclusion

The methodologies developed under this research represent advancement in the conventional methods of measuring potentials on paved areas, principally through the use of drilled holes for placement of reference electrodes on the underlying soil. The research shows that, for asphalt and gravel paving, characterizing the paving through simple electrical resistance measurements will aid in decision making relative to potential measurements used as part of the ECDA indirect inspection process. To this end, a straightforward, user-friendly test method has been developed as a precursor to a potential survey through a paved area. The procedure and analyses do not require knowledge of paving particulars such as thickness and sub-base material.

11. References

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Appendix 1

Standard Test Method:
Paving Electrical Resistance Measurments to Augment Potential Measurements in Paved Areas

Draft Recommended Standard Test Method

for

Potential Measurements on Paved Areas

for

External Corrosion Direct Assessment (ECDA)

to

Pipeline and Hazardous Materials

Safety Administration (PHMSA)

U.S. Department of Transportation

Contract No. DTPH56-08-T-000012

Improvements to the External Corrosion Direct Assessment (ECDA) Process

(WP # 360)

Potential Measurements on Paved Areas

Project #243

by

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Foreword

This recommended Standard Test Method closely follow the format used by NACE International or ASTM. The Standard Test Method is written in this manner because the format is widely recognized, accepted, and used by the pipeline community. Additionally, it is expected that PHMSA will provide these guidelines to NACE and/or ASTM for consideration and perhaps used for further development. If this happens, having the recommended Standard Test Method in a format that follows the NACE and ASTM format should reduce the time and effort required for final development.

Draft Standard Test Method

External Corrosion Direct Assessment

Paving Electrical Resistance Measurements to Augment Potential Measurements in Paved Areas

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1. General

1.1 This standard test method details procedures that can be used in conjunction with aboveground electrical potential survey techniques performed as part of External Corrosion Direct Assessment (ECDA) evaluations where buried pipe is routed beneath paving.

1.2 In conjunction with other procedures and sound engineering judgment, the process described herein provides the means and methods for determining if electrical potential measurements made with reference electrodes on the paving are sufficiently reliable for making ECDA-related engineering decisions that are comparable to measurements with the reference electrodes placed on the soil beneath the paving, e.g. as may be measured by placing the reference electrodes through drilled holes in the paving so they are in direct contact with the underlying soil.

1.3 The process is intended to be used primarily as a precursor to an electrical potential survey through a paved area, to determine if the survey can be accurately performed with the reference electrodes placed on the paving surface.

1.4 This standard test method is applicable to paving that is principally asphalt or gravel. While the procedures can be performed for concrete paving with or without reinforcing, and for asphalt paving with a concrete sub-base, the user is cautioned that measured potentials with reference electrodes directly on concrete paving may not be comparable to measurements with the reference electrodes placed on the soil beneath the paving. Misinterpretation of these data could result in an improper assessment of external corrosion conditions. This is particularly true for measurements where the reference electrode is placed directly atop concrete paving.

1.5 This standard test method has been developed based on research performed under Pipeline and Hazardous Materials Safety Administration (PHMSA) project WP #360, "Improvements to the

External Corrosion Direct Assessment Process". The research and resulting procedures are for DC potential measuring techniques, i.e. DC pipe-to-soil potential measurements and DCVG coating indication procedures. While the research did not specifically address ACVG coating indication procedures, the test method described is likely applicable to ACVG measurements as well.

1.6 The provisions of this test method shall be applied by personnel who have acquired by education and related practical experience the principles of cathodic protection of buried metallic piping systems and the principles of aboveground electrical potential survey techniques and data interpretation performed as part of the ECDA process.

2. Related Standards

2.1 NACE International Standard Practice SP0502, *Pipeline External Corrosion Direct Assessment Methodology.*

2.2 NACE International Standard Test Method TM0109, *Aboveground Survey Techniques for the Evaluation of Underground Pipeline Coating Condition.*

2.3 NACE International Standard Test Method TM0497, *Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems.*

3. Safety Considerations

3.1 Recognizing the safety risks when working in paved areas used for vehicular and other traffic, all personnel and equipment shall be sufficiently visible. Personnel shall wear the appropriately colored reflective vests at all times. Other personal protective equipment shall be employed as well depending on specific conditions and requirements.

3.2 Equipment shall be positioned in such manner that it will not impede traffic and so that it does not present a safety hazard to personnel or passersby.

3.3 Traffic control measures shall be implemented as appropriate to maintain safety in full compliance with all applicable codes, statutes and owner requirements.

3.4 Job safety analyses (JSAs) or similar pre-job safety reviews shall be completed and documented to identify project-specific hazards and to implement the necessary controls.

3.5 All equipment must be in good working condition and all personnel operating the equipment must be familiar with its use and safety precautions. Electrical instrumentation and test wiring shall be appropriately insulated electrically.

3.6 When drilling holes through pavement is or could be part of the work, the appropriate underground utility service alert notifications must be made in advance in accordance with state law and or other jurisdictional requirements. During the course of the work, the holes shall be sufficiently marked and cordoned off so as to not present a tripping hazard. Upon completion of the work, or as it progresses as appropriate, the holes shall be filled flush to grade in a manner acceptable to the agency or owner responsible for the paving. An expansive material compatible with the parent paving is typically used for this purpose.

3.7 A pipeline depth of cover shall be performed prior to the drilling of any holes.

3.8 This test method entails high voltage test equipment for measuring the resistance through the paving. All necessary electrical safety precautions shall be used including full compliance with the manufacturer's written procedures to be provided with the equipment.

4. Equipment and Instrumentation

The following standard, commercially available equipment and instrumentation are required:

4.1 Voltmeter or datalogging system for measuring potentials on and through the paving. The instrumentation shall have an internal impedance of 200 megohms. This would typically be the data measuring system used for electrical survey measurements upstream/downstream of the paved area. Meter internal impedances less than 200 megohms may be used if it can be shown there is no circuit loading and the measurements are comparable to instrumentation having an internal impedance of 200 megohms. Internal impedances greater than 200 megohms are often susceptible to electrical noise and typically are not appropriate for pipe potential measurements.

4.2 Three-inch diameter portable copper-copper sulfate reference electrodes, or similar with the same or greater contact area. A very damp cloth towel, cloth washer's mitt, or similar should be wrapped around the base of the electrode, taking care not to have a moisture bridge between the instrument connection to the electrode and the towel or paving (Figure 1).

4.3 Source of water for light surface wetting of the pavement in the immediate vicinity of the various measurements. A pressurized insecticide sprayer is typically adequate.

4.4 Two-terminal battery powered resistance meter with 1,000-volt source voltage, capable of measuring at least 10^8 ohms, with an accuracy of 10% or better and a resolution of at least 2 significant digits.

4.5 Insulated test wiring with the minimum gauge and insulation suitable for the specific instrumentation and measurement. AWG No. 16 gauge insulated wire is typically adequate for resistance measurements using the above mentioned two-terminal resistance meter.

4.6 8-inch by 8-inch by 0.5-inch thick flat aluminum, steel or other metallic plate of comparable surface area with suitable lugs or other means for making electrical connections. In no case shall the meter surface area be less than 50 square inches.

4.7 Very damp (but not soaking wet) cloth towel, layered paper towels, or similar for placement between the metallic plate and the paving surface, to assure good electrical contact. The thickness of the towel should be nominally ¼-inch and such that it provides an electrical bridge between the entire bottom of the plate and the paving, taken into account any surface variations of the paving.

4.8 Ground rod or similar for use as a counter electrode in the paving resistance measurements.

5. <u>Paving Resistance Measurement Procedure and Calculations</u>

5.1 Instrumentation and equipment setup for paving resistance measurements shall be as shown in Figure 2.

5.2 The very damp (but not soaking wet) cloth towel (or similar) positioned between the metallic plate and the paving shall extend beyond the plate no more than 0.5-inch in all directions. Once positioned, slight pressure should be applied to the top surface of the plate then released.

5.3 The counter electrode for the measurement can be a temporary rod or probe driven into the soil, an existing electric utility ground connection (power neutral), a buried pipe test wire or other suitable nearby structure/equipment. The particular counter electrode used shall have an effective resistance to earth of no more than 25 ohms. The counter electrode shall be a minimum of 30 feet from the metallic plate used for the resistance measurement. The counter electrode shall be chosen such that there will be no electrical hazard or equipment damage resulting from the applied test voltage.

5.4 Operation of the resistance meter shall be in accordance with the manufacturer's written instructions. If the meter has the capability to measure resistances at applied voltages less than 1,000 volts, only the 1,000 volt setting shall be used. For meters that have the capability to measure resistances at applied voltages greater than 1,000 volt, the greater voltages should only be used if an accurate reading cannot be obtained at the 1,000 volt setting.

5.5 Operation of the resistance meter shall be done in such manner to avoid an electrical hazard, taking all necessary precautions.

5.6 The resistance meter reading, associated meter test voltage, metallic plate dimensions, counter electrode used and distance from measurement, measurement location, and simple description of the paving surface type (e.g. asphalt) and appearance (porous, cracked, well sealed, aged, etc.) shall be recorded.

5.7 Once the data are recorded (paragraph 5.6), the test set up shall be dismantled. Prior to touching the metallic plate or counter electrode, the test cable for the plate shall be safely and temporarily connected (shorted) to the test cable for the counter electrode, to safely dissipate any capacitive charge that may have resulted from the applied test voltage.

5.8 The measured resistance shall be normalized and recorded along with the other data (paragraph 5.6) using the following equation:

$$R_{paving}\ (\text{ohm-ft}^2) = R_{measured}\ (\text{ohms})\ \text{X}\ A_{plate}\ (\text{ft}^2)$$

where:

R_{paving} = Normalized resistance

$R_{measured}$ = Measured resistance

A_{plate} = Plate surface area in contact with the paving

5.9 Potential measurements with reference electrodes on asphalt and compacted gravel paving have been shown to be comparable to potential measurements with the electrodes on the underlying soil provided the resistance is less than $2x10^5$ ohm-ft^2 and the voltage measuring instrumentation and electrode configuration comply with the requirements of this test method. Figure 3 shows the research data used to develop this resistance threshold.

6. Paving Resistance Measurement Guidelines

6.1 Paving resistance measurements shall be made over the pipeline at intervals no greater than 500 feet. Resistance measurements can be made laterally from the pipe by up to 10 feet if measurements over the pipe are not practicable, provided there are no visible changes in paving appearance/condition/type.

6.2 A minimum of five evenly spaced measurements shall be made for each paved area if less than 2,000 feet.

6.3 For asphalt paving, the measurement setup should be such that no visible cracks are in the paving under the metallic plate or for at least 1 foot in all directions.

6.4 Measurements made in standing water shall recognize that the resistance obtained as well as any potential measurements may not reflect conditions directly over the pipe as the water may provide an electrical path along the paving away from the pipe.

6.5 Measurements shall be made when there are changes in paving appearance, type, or condition that might materially increase the resistance when compared to paved surfaces upstream/downstream from these areas, e.g. paving in shaded areas or under an overpass/bridge, and repaved areas or paving repairs. When there are visible changes in appearance/type/condition, a minimum of five evenly spaced measurements shall be made within each area, regardless of length.

7. Data Analyses

7.1 The range and magnitude of the measured resistances shall be analyzed relative to the feasibility of making potential measurements with the reference electrodes on the paving. Figure 3 should be referred to as part of the analysis.

7.2 Potential measurements with reference electrodes on paving that exhibits resistances consistently greater than $2x10^5$ ohm-ft^2 should not be made unless additional procedures and analyses beyond those described herein are employed to assure valid data collection and interpretation.

7.3 As the resistance measurements are being made, spot potential measurements with reference electrodes on the paving at or near the resistance measurements will help in the decision making process.

7.4 Decisions to make potential measurements with reference electrodes on the paving that are based on resistance measurements some time before the potential measurements should acknowledge that precipitation, temperature, and other factors can materially impact (change) the resistance through the paving. When this is the case, spot resistance measurements should be made on the day of the survey to determine the impact and whether alternate procedures are in order to make the potential measurements.

7.5 Trending of the potential measurements with reference electrodes on the paving, including comparison with measurements with the electrodes on the soil upstream/downstream of the paved area, is one tool that can be used to determine the validity of the measurements.

7.6 Potential measurements with the reference electrodes through drilled holes in the paving that are also over the pipe are another tool that can be used to determine the validity of potential measurements with the reference electrodes on the paving. The user shall determine the need for and extent of drilling holes based on a thorough analysis of the paving resistance measurements and other factors. Particularly critical assessments and potential surveys over extended lengths of paving should include a sufficient quantity of validation measurements through the drilled holes as a matter of course. When holes are drilled, the thickness of the paving and sub-base materials should be estimated and recorded.

8. Visual Guides for Determining Suitability of Potential Measurements with Reference Electrodes on Paving

8.1 Visual guides to assist in determining the suitability of potential measurements with reference electrodes on paving are contained in Appendix A. The photographs shown illustrate paving conditions found to be suitable and not suitable along with the paving resistance measured as described in this test method.

8.2 The visual guides augment the resistance measurements and other analyses to determine potential measurement suitability. They are not intended for use in lieu of the resistance measurements and related analyses.

9. Error Sources and Impact on ECDA Analyses

9.1 Error sources that can result in erroneous paving resistance measurements or misinterpretation of the resistance data include:

- Resistance meter malfunction
- Resistance meter out of calibration
- High resistance test connections
- Counter electrode resistance to earth is the same general magnitude or greater than the resistance to earth of the metallic plate through the paving
- Electrical bridges caused by surface water and other surface electrical leakage, such that the measured resistance is the parallel combination of that through the paving directly under the metallic plate and other electrical paths to adjacent or underlying soil

9.2 Error sources that can result in erroneous potential measurements with reference electrodes on paving, above and beyond those that might be encountered for measurements with reference electrodes on soil, include:

- Erroneous resistance measurements used as the basis for the measurements
- High contact resistance between reference electrode and paving, e.g. because of debris, stone chips, etc. on the paving surface
- Reference electrodes become contaminated because of oil and other deleterious materials on the paving surface (this should be minimized using an arrangement similar to that shown in Figure 3 for wrapping the base of the electrode)

- Electrical bridges caused by surface water and other surface electrical leakage, such that the measured potential is not indicative of that which would exist if the reference electrode(s) were on the underlying soil at the same location

- Voids in paving sub-base

- Paving resistance has changed (increased) since the resistance measurements were made, to the point where the potential measurements with the reference electrodes on the paving are no longer accurate

- Measurements with reference electrodes on concrete (reinforced and non-reinforced)

- Measurements on multi-layer paving, where the underlying layer(s) are materially different than the surface layer

9.3 Erroneous potential measurements in paved areas can impact an ECDA analysis in the following ways:

- Pipe-to-soil potentials less than actual, and or otherwise inaccurate

- Coating indications not detected

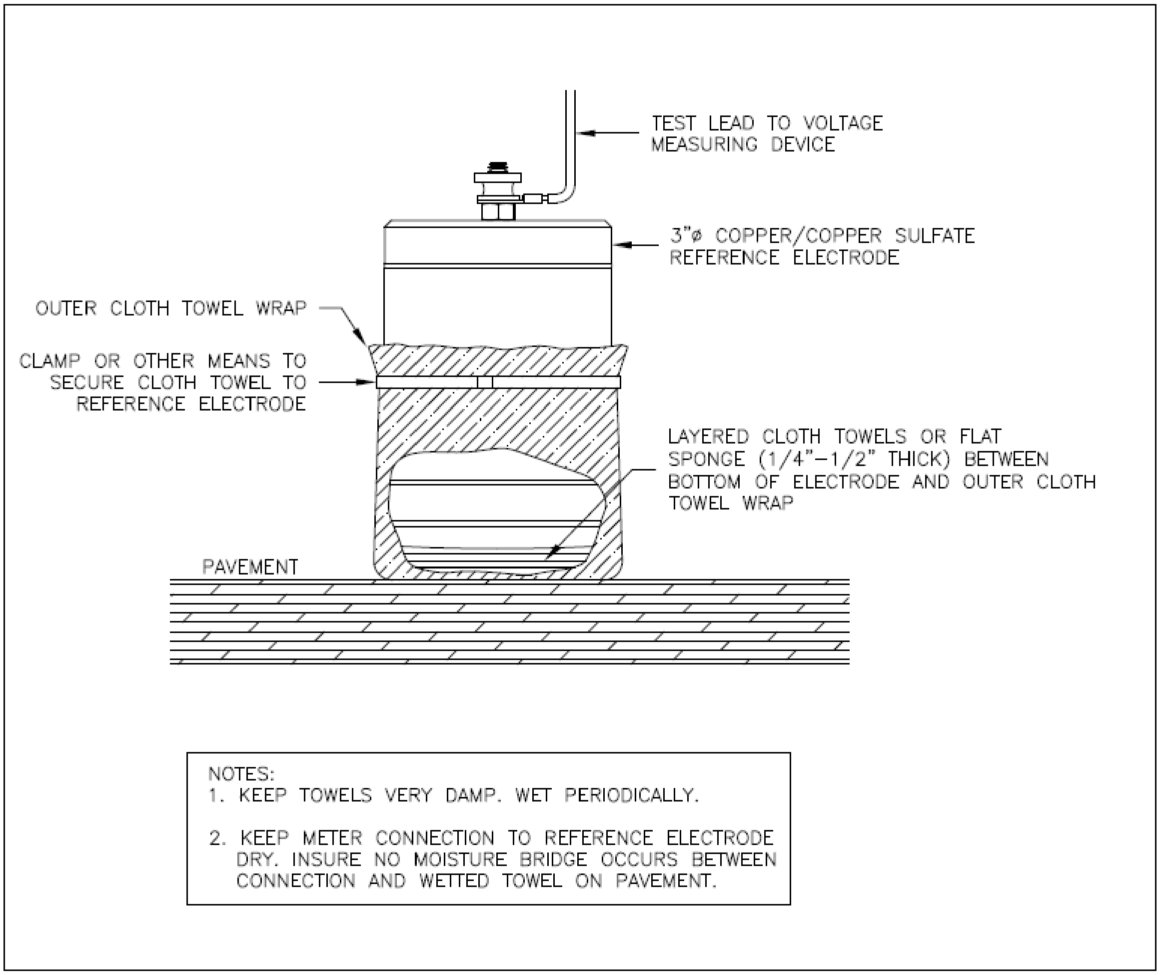


Figure 1: Reference Electrode Preparation and Placement

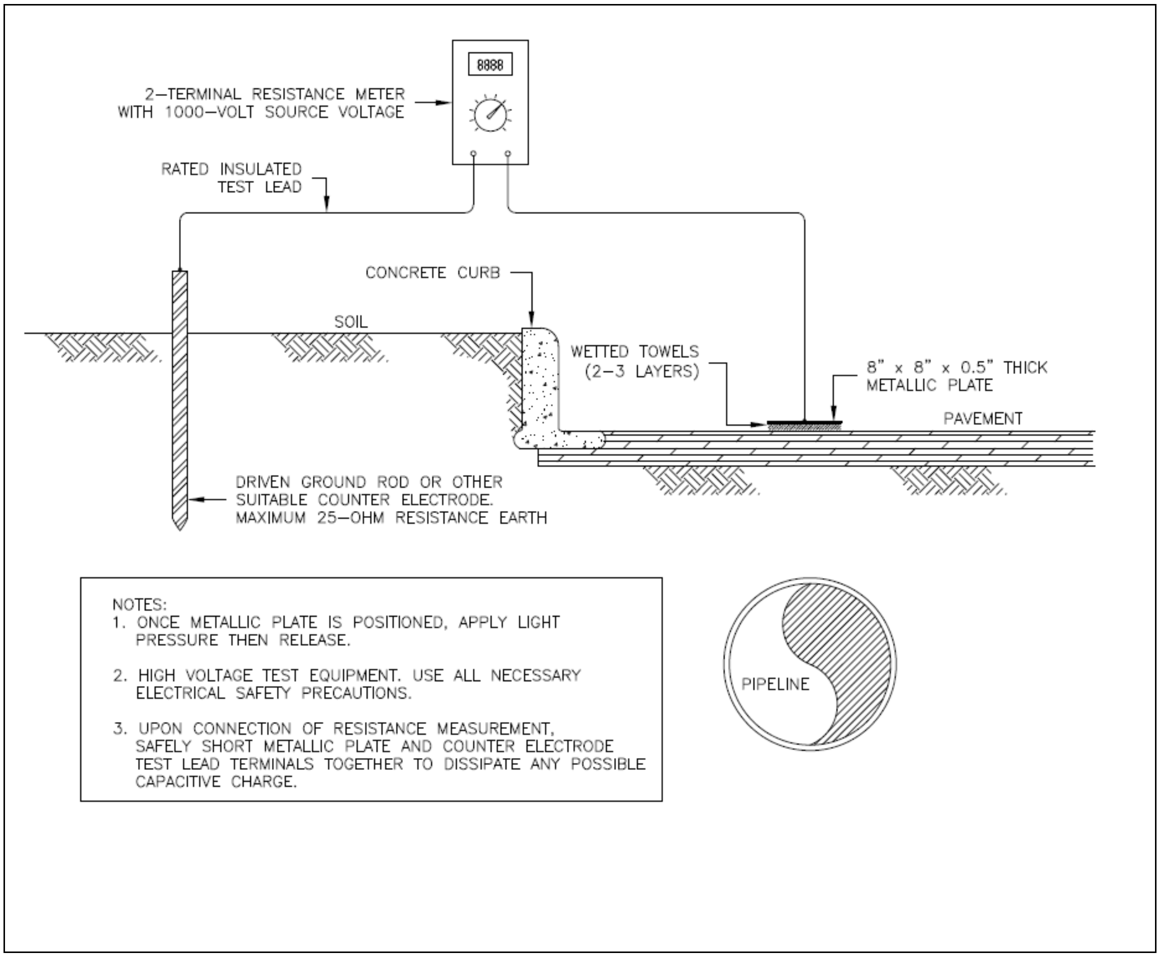


Figure 2: Paving Resistance Measurement Setup

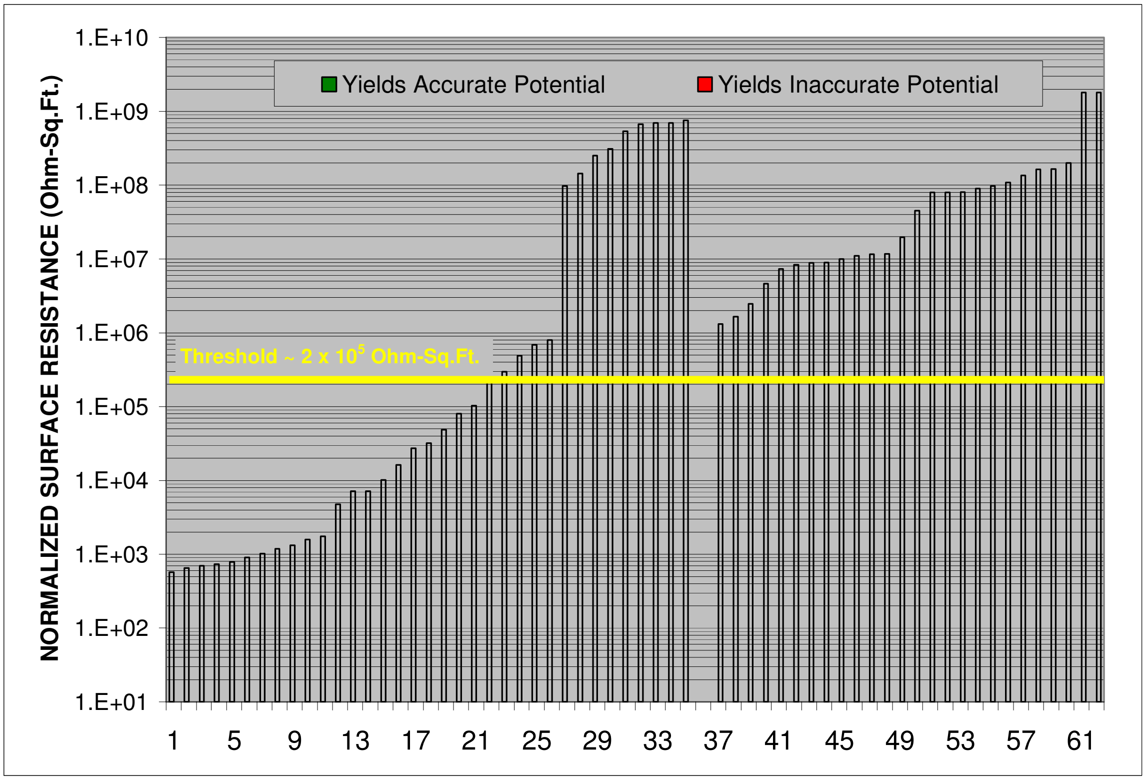


Figure 3: Range of Paving Resistance

APPENDIX A

VISUAL GUIDES

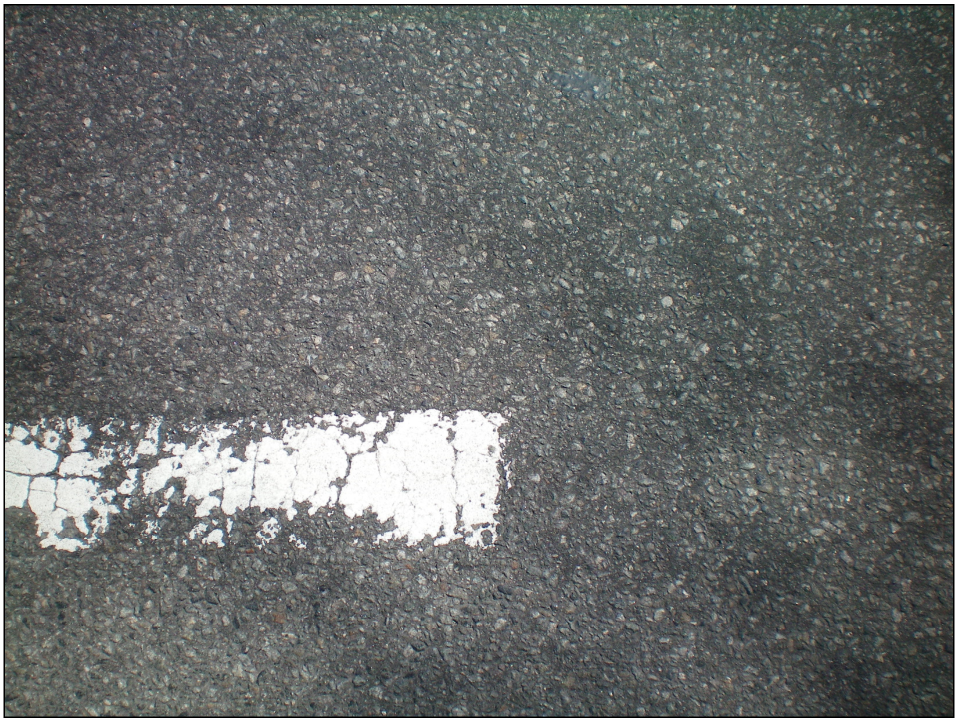
Condition 1: Weathered Asphalt/Rock
Acceptable for Potential Measurements
Resistance = 49,000 Ohm-Ft^2

Condition 2: Asphalt (~4 years old)
Acceptable for Potential Measurements After Light Surface Wetting
Dry Resistance = 10^7 - 10^8 Ohm-Ft^2
Wet Resistance = 10^3 - 10^4 Ohm-Ft^2

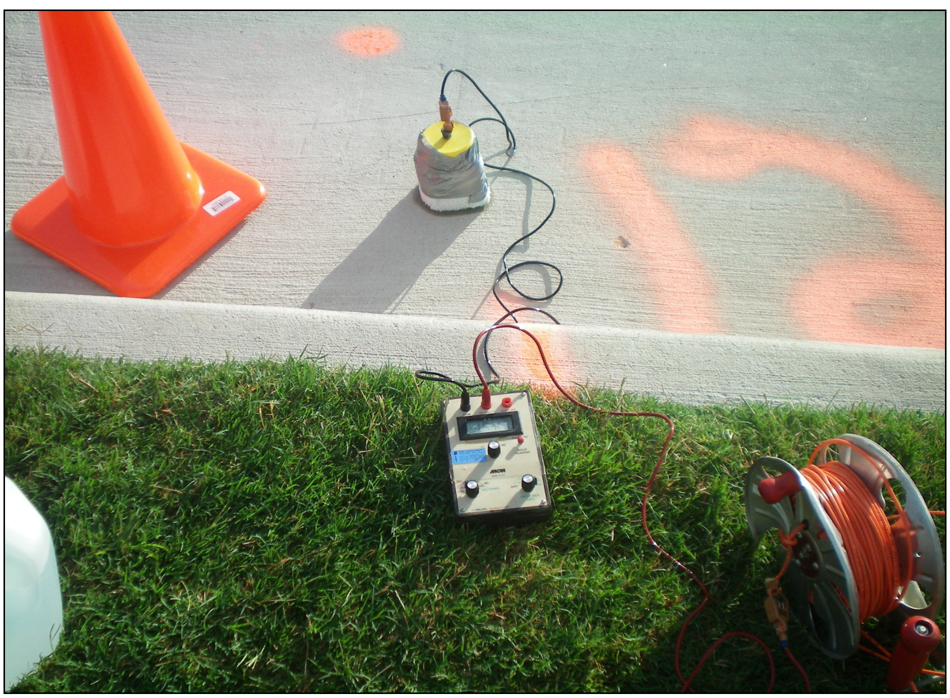
Resistance 10 Minutes after Wetting, i.e. Drying = 10^4 - 10^5 Ohm-Ft^2

Condition 3: Asphalt
Unacceptable for Potential Measurements, Dry or After Light Wetting
Resistance = 10^7 - 10^8 Ohm-Ft^2

Condition 4: Compacted Gravel (~24 inches thick)
Acceptable for Potential Measurements
Dry Resistance = 600 – 1,800 Ohm-Ft^2



Condition 5: Asphalt
Acceptable for Potential Measurements
Resistance After Light Surface Wetting = 10^3 - 10^4 Ohm-Ft^2



Condition 6: Reinforced Concrete
Resistance = 500 Ohm-Ft^2

Potentials generally become more negative over time

Condition 7: Weathered Concrete/Asphalt Mix
Acceptable for Potential Measurements
Resistance = 1,100 Ohm-Ft^2

Condition 8: Asphalt
Unacceptable for Potential Measurements
Drilled Holes Required