Testing Substation Yardstone-Lessons Learned

FIVE YEARS OF NATIONWIDE TESTING SUMMARIZED
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IEEE Standard 80–2000, Section 12.5 suggests that the resistivity of the surface materials used in grounding systems should be tested.

IEEE 80-2000, Section 17.3 includes a sample calculation using a value of 3,000 Ωm for the resistivity of surfacing material. Mistakenly, this value is often utilized as a typical value for surfacing material when values are unknown.

3,000 Ωm is often cited in specifications as a minimum resistivity for surfacing material.

Table D.1 presents a range of resistivity for a variety of surfacing materials. The information lacks standard terminology for describing the materials and too general to assign values.
<table>
<thead>
<tr>
<th>2012 to 2013</th>
<th>2014</th>
<th>2015 to Present</th>
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<tbody>
<tr>
<td>ATC inquired about possibility of testing yardstone surfacing.</td>
<td>Started testing surfacing material at substations throughout the ATC footprint.</td>
<td>PES IEEE Working Group G6 Task Force 1 formed to address standardized testing and prepare technical report.</td>
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<td>“Napkin” sketches of test apparatus and “garage” bench scale tests.</td>
<td>Presented the proposed test procedure and data at professional conferences.</td>
<td>Trafficability over surfacing material prompts a look at composite surfacing sections.</td>
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<td>Coleman retained to develop standard apparatus and test procedure.</td>
<td>Acquired significant data on various surfacing materials.</td>
<td>Continued testing is being completed to gather more information about surfacing materials.</td>
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<td>Published findings in IEEE Transactions October 2013.</td>
<td>Started noticing that 3,000 Ω·m was elusive and not easily achieved.</td>
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Existing Recognized Standard Resistivity Test Procedures

- **ASTM G57** – Discusses the 4 pin Wenner array for field determination of soil resistivity. The procedure extends to laboratory testing using a small test box with 4 pin measurement.

- **ASTM G187** – Discusses a 2 pin method in a small test box. Generally utilized to evaluate soils for corrosion potential for embedded steel construction components (culverts, guy anchors, steel pile, etc.).

- **AASHTO T288** – Presents 2 pin and 4 pin methods referring to ASTM methods.

- Other standard test methods, developed by various electrical utilities, are not universally recognized. Some of these methods were discussed in an informational report published in IEEE 80-2012.
G57 and T288 provide a reasonable approach to measuring electrical resistivity in soils. The approach does not consider coarse materials such as yardstone surfacing materials.

The standards do not address variables that affect resistivity other than indicating the minimum resistivity is considered when sample is saturated.

Conventional test apparatus does not accommodate coarse size particles generally included in surfacing material.

Test procedure does not include discussion on variables that will affect resistivity such as particle geology, grading, compactness and moisture.

The test could easily be modified to include documentation and control of variables as well as accommodate larger particles.

Agencies are reluctant to change test procedures.
Examples of ASTM/AASHTO Test Boxes
What’s Wrong with this Picture?

- Rather than modify the test box, laboratories have modified the samples or used existing equipment.
- Top example shows removing or crushing larger particles to prepare a sample that can accommodate the test box.
- Bottom example tries to utilize a test box that is much too small to accommodate the maximum particle size.
Make the Box Fit the Material

- Larger dimensions allow representing coarse particles in the test procedure.
- Non conductive materials.
- Rigid construction to allow rough service.
- Easily modified to incorporate 2 pin and 4 pin test methods.
- Meets the intent of ASTM and AASHTO.
Gradation alone is not enough

- ASTM Size 57 (Granitic Particles)
  - Resistivity – 2,000 to 3,500 Ω·m
  - Saturated Moisture - 0.5 to 1.5%

- ASTM Size 57 (Limestone/Dolomite Particles)
  - Resistivity 1,000 to 2,000 Ω·m
  - Saturated Moisture 2.0 to 3.5 %
Geology plays an important role

- The geologic origin of surfacing materials contribute to the resistive properties of the particles in surfacing materials.
- Granites, basalts and other metavolcanic rock are dense and less likely to absorb water contributing to high resistivity.
- Limestone, dolomite, shale, sandstone, and other sedimentary or meta-sedimentary rock generally absorb more water contributing to low resistivity.
- Have also tested caliche, coral and coconut straw.
Geographic Limitations

**Bedrock Geology of North America**

- Red oldest; yellow youngest.
- Reds generally very dense volcanic and meta volcanic granite and basalt, very dense (Canadian Shield).
- Blues and purples are moderately dense and consist of meta volcanics and metamorphic rock created from sediments (shales, dolomites, slates).
- Yellows are sedimentary rock very soft and absorptive (limestone, sandstone).

Map courtesy of Kate E. Barton, David G. Howell, José F. Vigil on behalf of the U.S. Geological Survey in collaboration with the Geological Survey of Canada and the Mexican Consejo Recursos de Minerales.
### What Does 3,000 \( \Omega \cdot m \) Material Look Like?

<table>
<thead>
<tr>
<th>Moisture Condition</th>
<th>1/3 Saturated</th>
<th>2/3 Saturated</th>
<th>Saturated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td>13.84</td>
<td>15.44</td>
<td>14.90</td>
</tr>
<tr>
<td>Current (A)</td>
<td>0.000148</td>
<td>0.00026</td>
<td>0.00048</td>
</tr>
<tr>
<td>Resistance (( \Omega ))</td>
<td>93,514</td>
<td>59,385</td>
<td>31,042</td>
</tr>
<tr>
<td>Box Factor</td>
<td>0.131</td>
<td>0.131</td>
<td>0.131</td>
</tr>
<tr>
<td>Resistivity (( \Omega \cdot m ))</td>
<td>12,250</td>
<td>7,779</td>
<td>3,104</td>
</tr>
</tbody>
</table>

- **Maximum Density:** 101.6 pcf
- **Saturated Moisture:** 1.1%
- **Test Compaction:** 100%
- **Test Method:** Wenner 4 Pin and Modified Test Box
Particle shape and range of sizes affect the support of traffic. Rounded particles all of uniform shape and size reduce trafficability. Angular particles with range of sizes improve trafficability. Some designers are considering composite layers to maintain resistivity and improve trafficability.
What we are seeing to improve trafficability

- Dense graded aggregate placed to enhance traffic support.
- Saturated resistivity 150 to 300 $\Omega \cdot m$
IEEE Working Group G6 Task Force 1 is currently preparing a technical report to discuss electrical resistivity of surfacing material and considers standardized test methods currently being developed.

ASTM Standard Guide being considered which will provide guidance to designer and testing agencies to consider variables when measuring the resistive properties of soil and construction materials.

Vertical oriented test to allow composite layers of surfacing material being considered to evaluate resistivity.
Design and Construction

- Consider a resistivity value that is achievable given local constraints of materials available.
- Consider regional limitations of available surface materials.
- Establish submittal process to test surfacing materials to confirm that minimum resistivity criteria is met or achievable.
- Do not rely on gradation alone. Gradation is only one variable. Consider geologic composition and shape of particles and absorption characteristics.
- Consider trafficability of surfacing material. Include a minimum crushed particle content.
- Consider constructing traffic lanes which can accommodate lower resistivity materials which will support traffic.
Questions?

THANK YOU