

Evaluation of Test Methods for Characterizing Steel Corrosion Potential in MSE Wall Fill

Kenneth L. Fishman and Hamidreza Fakhri
McMahon & Mann Consulting Engineering and Geology, P.C.
Buffalo
New York, 14214
USA

Soheil Nazarian, W. Shane Walker, and Arturo Bronson
The University of Texas at El Paso
El Paso
Texas, 79968
USA

ABSTRACT

Mechanically stabilized earth (MSE) walls include galvanized steel reinforcements embedded within granular fills to add tensile strength and internal stability to the reinforced soil mass. The potential for corrosion of the steel reinforcements is managed by selecting fills to be non-corrosive, and this requires the implementation of proper techniques for sampling, measurement of electrochemical properties, and characterization of the corrosion potential. This study summarizes the most important findings from NCHRP Project 21-11, "Improved Test Methods and Practices for Characterizing Steel Corrosion Potential of Earthen Materials.", which aims to assess and improve the current methods for characterizing the steel corrosion potential for MSE wall fills. Although most transportation agencies currently specify AASHTO Standards, including T-288 (resistivity), T-289 (pH), T-290 (sulfate content), and T-291 (chloride content), for evaluating the corrosivity of earthen materials, these standards are limited to materials having a significant component passing a No.10 sieve (*e.g.*, sand and fines), which do not represent typical sizes of MSE wall fills (*e.g.*, coarse gravel or larger). In this study, the veracity of results obtained from these standards is evaluated and compared to data from alternative test methods that accommodate sample domains with a broader range of grain sizes. The test data are evaluated in terms of precision, bias, and how well they correspond to observations of corrosion rates and performance from steel reinforcements that have been embedded in the same fills that were included in the laboratory test program. Based on these comparisons, we recommend protocols for selecting the appropriate program of sampling, testing, and characterizing corrosion potential depending upon the physical characteristics of the materials.

Keywords: corrosion, soil corrosion, MSE wall, galvanized steel, sulphate, chloride, resistivity, pH

INTRODUCTION

Numerous factors influence the corrosion of buried steel, including temperature, acids, alkalis, soil particle distribution, porosity, microbial activity, electrical resistivity, degree of saturation, pH, dissolved salts (ions), and oxygen concentration^{1, 2}. Most salts are active participants in the corrosion reaction with the exception of carbonate, which forms an adherent protective scale on the surface of most metals and inhibits corrosion rate. According to the literature, chloride, sulfate, and sulfide are the major components promoting corrosion in steel reinforcements embedded in earthen materials/concretes³⁻⁵. Given its relationship to salt content (e.g., mass fraction), Romanoff⁴ and King⁶ established resistivity as the most significant indicator of corrosion potential in earthen materials.

Most transportation agencies evaluate electrochemical properties of earthen materials using current AASHTO laboratory test standards, which were adopted in the early 1990s. Specified test methods to measure the electrochemical properties of geomaterials are AASHTO T 288⁷ (resistivity measurement), AASHTO T 289⁸ (pH measurement), AASHTO T 290⁹ (soluble sulfate content measurement), and AASHTO T 291¹⁰ (soluble chloride content measurement). AASHTO describes the electrochemical requirements for fill material to be suitable for MSE wall construction as shown in Table 1.

Table 1
AASHTO requirements for the fill materials in MSE walls

Parameter	Acceptable range	AASHTO standard
Minimum resistivity	> 3000 Ω -cm	T-288
pH	5 – 10	T-289
Sulfate content	< 200 ppm*	T-290
Chloride content	< 100 ppm*	T-291

* mass-fraction in parts per million (ppm) = mg of ion per kg of test material

The AASHTO test methods do not apply to all earthen materials that encompass a broad range of physical and electrochemical characteristics, nor do they distinguish issues inherent to particular types of infrastructure construction. For example, AASHTO T 288⁷ is used to determine the minimum resistivity ($\rho_{\min}$) of earthen materials at a saturated or slurry state. However, a slurry state does not represent a condition that occurs during the effective service lives of earth retaining structures. Hence, the minimum resistivity obtained from such a test is not representative of the resistivity of earthen materials experienced at any time during the service lives of metal elements placed within them. Also, AASHTO T 288⁷ specifies how test specimens are prepared by separating the sample into factions that only incorporate particles finer than the No. 10 sieve. Resistivity measurements for earthen materials are affected by soil texture, thus including only the finer portion of the sample within the test specimen renders resistivity measurements that are different from what would be measured if all of the particle sizes inherent to the sample were included. The AASHTO tests may not be appropriate for determining the corrosivity of coarser types of earthen materials and do not consider practical limits on moisture contents that may be experienced in the field. In this case, an alternative test method should be considered.

Alternatives to AASHTO tests to measure soil resistivity include ASTM G187¹¹, Tex-129-E¹², Tex-129-M¹³, and ASTM WK24261. This paper summarizes the most important findings from NCHRP Project 21-11¹⁴, which evaluated the veracity of results obtained from the above-mentioned standards and compared them to the data from alternative test methods that

accommodate sample domains with a broader range of grain sizes. NCHRP Project 21-11¹⁴ evaluated these test data in terms of precision, bias, and how well they correspond to observations of corrosion rates and performance from steel reinforcements⁽¹⁾ that have been embedded in the same fills that were included in the laboratory test program. Based on these comparisons, protocols for selecting the appropriate program of sampling, testing, and characterizing corrosion potential are recommended depending upon the physical characteristics of the materials. In this paper, we present the resistivity test results from the laboratory measurements and compare them considering different soil samples.

LABORATORY MEASUREMENTS

The objectives of laboratory measurements in this study were to determine when test results from the current AASHTO test procedures (Table 1) are most applicable to characterize the steel corrosion potential of earthen materials and when alternative test methods for measurements of geochemical and electrochemical properties should be applied. We studied alternative laboratory test procedures for measuring the resistivity and salt content of soils applied to a sampling domain incorporating a broad range of materials (mostly those commonly used in MSE wall constructions). The data include the measurements of geochemical and electrochemical properties of the samples including electrical resistivity (which is inversely proportional to the total salt content) and chloride and sulfate contents. Herein, the key results obtained from different test methods in the form of resistivity/conductivity are presented. In addition, trends observed within the data sets are discussed and comparisons are made between the results from the alternatives with the results from AASHTO test methods.

Results obtained from different test procedures are compared in terms of (a) precision/repeatability of the results, (b) bias of the results compared to those obtained from the current AASHTO tests, and (c) trends we identified from the data.

Resistivity and Salt Content Test Results and Discussions

Resistivity test methods are of two general types that include (1) measurements of voltage drop in response to an applied current passing through specimens that are compacted in a *soil box* (galvanostatic test), or (2) conductivity measurements on aqueous solutions extracted from solid samples (*leachates*). Typically, the process for observing the resistivity from soil box tests include (a) drying, separating, and adding moisture to the specimen (b) compacting the material into the box, (c) connecting the soil resistance meter to the two- electrode resistivity box, and (d) obtaining a measurement of resistance, which is then converted to resistivity via a geometric “box factor.”

Generally, leaching tests for measurement of resistivity include (a) preparing measured amounts of material for testing, which are then (b) added to a measured volume of distilled or deionized water, and (c) measurements of conductivity are carried out on the extracts. Differences include dilution ratios (*i.e.*, mass of water per mass of soil), methods of mixing, and how long the mixture stands before making measurements ¹⁴.

In this study, test methods performed on specimens compacted in a soil box included Tex-129-E ¹², AASHTO T 288 ⁷, Tex-129-M ¹³, ASTM G187 ¹¹, and ASTM WK24261. These test procedures

⁽¹⁾ We documented performance data (*i.e.*, corrosion rates) of plain and galvanized steel specimens, embedded in 20 different sources. While electrochemical test results were used to characterize the corrosion potential of each source, the performance data were used to correlate these characterizations to the corrosion rates. Details of performance data can be found in the report for NCHRP Project 21-11 ¹⁴.

vary in terms of the particle sizes included in the test specimen, the specimen preparations prior to testing, the size of the test box (depends on the maximum particle size), and the moisture content at which the minimum resistivity is reported. Brief descriptions of the test procedures used in this study are presented in Table 2. Table 2 also presents the statistics describing the precision observed from testing replicates and the bias of each test procedure with respect to AASHTO T 288 ⁷.

Table 2
Summary of resistivity tests, precision, and bias

Test	Salient details	Precision		Bias w.r.t. AASHTO T-288	
		$\mu^{1\text{cov}^3}$	σ^2_{cov}	μ	σ
Soil box tests	Measure resistivity (ρ) of compacted specimens				
AASHTO T-288	Sample passing No. 10 sieve, incremental addition of water (10% by weight), curing for 12 hours, compacting the specimen into the soil box, and measuring the resistance. Keep adding water until reaching ρ_{min} or ρ_{sat}	4.6	4.5	-	-
ASTM G-187	Scalp material greater than ¼ inch , saturating the specimen while compacting in a soil box and measuring resistivity at saturation, ρ_{sat} . Saturation is determined visually	5.3	4.5	1.4	0.4
ASTM WK24261	Include particle sizes up to 1 ¾ inches , curing for 24 hours, compacted specimen into the soil box. The specimen is allowed to drain before making the resistance readings	7.4	5.8	3.8	5.1
Tex-129-E	Similar to AASHTO T-288 except the material is separated on a No. 8 sieve before testing	3.2	4.3	1.1	0.2
Tex-129-M	Include particle sizes up to 1 ¾ inches , the sample is removed from the box after each measurement and re-mixed with additional water, the test continues until the additional moisture cannot be absorbed and the specimen has reached either ρ_{min} or ρ_{sat}	4.8	2.8	2.3	1.9
Leaching tests	Measure conductance (κ) of aqueous solution	μ_{cov}	σ_{cov}	μ	σ
SCT 143 ¹⁵	Include particle sizes up to 1 ¾ inches , diluting the sample at a 1:1 ratio, agitating for 3-minutes at the 30-minute, 2-hour, and 4-hour intervals, standing for 20 hours, and filtering the sample before conductivity measurements	4.9	4.5	1.9	1.7
Tex-620-J	Sample passing No. 40 sieve, diluting the sample at a 10:1 ratio, heating to 140°F while stirring every hour for 12 hours, measuring the conductivity of the mixture	4.9	1.9	1.6	0.9
Tex-620-M	Include particle sizes up to 1 ¾ inches , diluting the sample at a 10 L:1 kg ratio, mixed continuously for 60 minutes, not allowed to stand before the conductivity measurements	4.5	3.1	5.2	3.4

¹ μ = Mean

² σ = standard deviation

³COV = coefficient of variation ($\frac{\sigma}{\mu}$)

The first five test procedures presented in Table 2 directly measure the resistivity of a compacted soil specimen in a soil box. The remaining three test procedures measure the conductivity of a leachate extracted from a soil/water solution (the resistivity of this solution is the inverse of conductivity). Results from leaching tests cannot be directly correlated to those obtained from compacted specimens. This is because other factors including tortuosity of the electrical current path through an actual compacted specimen significantly affect the resistivity measurements. Other differences between the tests are in terms of sample treatments that may include sieving, air drying, heating, methods of mixing, time of settling/curing, and filtering. Soil box tests allow for the effects on resistivity from the level of compaction, moisture content, and texture of the soil to be investigated.

Results from the alternative test methods are normalized with respect to those obtained from the same samples tested via AASHTO T 288 ⁷. Here the ratio between results from an alternative test method to that from AASHTO T 288 ⁷ is defined as the bias for the alternative test method.

Comparison of the resistivity test results from Tex-129-E ¹², ASTM G187 ¹¹, Tex-129-M ¹³, and ASTM WK24261 against the resistivities obtained from the AASHTO T 288 ⁷ are shown in Figure 1. In general, the data appear to be positively correlated; meaning materials with relatively higher resistivity values via AASHTO T 288 ⁷ also showed high resistivity values via the alternative test procedures. An important observation is that the resistivities from Tex-129-E ¹² and ASTM G187 ¹¹ are more strongly correlated to those obtained from AASHTO T 288 ⁷ (Figure 1 (a) and Figure 1 (b)) compared to the resistivities from Tex-129-M ¹³ and ASTM WK24261 (Figure 1 (c) and Figure 1 (d)).

According to Table 2, the mean bias is approximately one for Tex-129-E ¹² with a COV of 22%. These statistics are manifested in the relatively narrow band and proximity to the line of equal values depicted in Figure 1 (a). The results from Tex-129-E ¹² and AASHTO T 288 ⁷ are expected to be close because of the similarities between these test methods. The two tests differ in terms of the sieve size used to separate the specimen from the sample (No. 8 vs. No. 10) and the 12-hour curing period prescribed by AASHTO T 288 ⁷ for the first moisture increment. For the materials tested in this study, these differences did not have a significant impact on the results. Other test procedures show mean bias values that are noticeably higher than 1.00 (as high as 5.22 in Tex-620-M) with COVs generally higher than 50%. The mean bias is greater for test procedures that involve coarser gradations (i.e., ASTM G187 ¹¹, Tex-129-M ¹³, and ASTM WK24261). ASTM G187 ¹¹ includes particle sizes up to 1/4", but Tex-129-M ¹³ and ASTM WK24261 both include particle sizes up to 1 3/4". This is reflected in the mean bias values, which are higher for results obtained from ASTM WK24261 and Tex-129-M ¹³ compared to those from ASTM G187 ¹¹. The bias from ASTM WK24261 is higher than that from Tex-129-M ¹³ due to the manner in which measurements are taken after the sample is drained for ASTM WK24261.

The mean bias for the tests on compacted soil specimens and tests performed with leachates are 2.13 and 2.95, respectively. The observed differences between results were expected because the effects of tortuosity are not included with conductivity measurements from leachates. In addition, biases from tests on leachate are all greater than one, even for samples that are separated into finer components (e.g., for Tex-620-J ¹⁶ the sample is separated on a No. 40 sieve). This is due to the different dilution ratios, and methods of mixing and extracting leachates used in different leaching tests compared to soil box tests.