CAIT-UTC-NC38

Evaluating corrosivity of geomaterials in MSE walls: determination of resistivity from pore water chemistry

FINAL REPORT
July 2019

Submitted by:

W. Shane Walker, Ph.D., P.E.
Associate Professor

Shahrouz J. Ghadimi
Ph.D. Student

Soheil Nazarian, Ph.D., P.E.
Professor

Jose Luis Arciniega Aguilar
M.S. Student

Affiliation of Authors
Civil Engineering Department, The University of Texas at El Paso, TX, USA

External Project Manager
Ken Fishman, Ph.D., P.E.
McMahon & Mann Consulting Engineers, P.C.

In cooperation with

Rutgers, The State University of New Jersey
And
U.S. Department of Transportation
Federal Highway Administration

Disclaimer Statement

The Center for Advanced Infrastructure and Transportation (CAIT) is a National UTC Consortium led by Rutgers, The State University. Members of the consortium are the University of Delaware, Utah State University, Columbia University, New Jersey Institute of Technology, Princeton University, University of Texas at El Paso, Virginia Polytechnic Institute, and University of South Florida. The Center is funded by the U.S. Department of Transportation.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. CAIT-UTC-NC38	2.Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluating corrosivity of geomaterials in MSE walls: determination of resistivity from pore water chemistry		5. Report Date July 2019 6. Performing Organization Code CAIT/University of Texas at El Paso
7. Author(s) W. Shane Walker, Shahrouz J. Ghadimi, Jose Luis Arciniega Aguilar, Soheil Nazarian		8. Performing Organization Report No. CAIT-UTC-NC38
9. Performing Organization Name and Address University of Texas at El Paso Department of Civil Engineering 500 W. University Ave. El Paso, TX 79968		10. Work Unit No. 11. Contract or Grant No. DTRT13-G-UTC28
12. Sponsoring Agency Name and Address Center for Advanced Infrastructure and Transportation Rutgers, The State University of New Jersey 100 Brett Road Piscataway, NJ 08854		13. Type of Report and Period Covered Final Report June 1, 2016 – January 15, 2019 14. Sponsoring Agency Code
15. Supplementary Notes U.S. Department of Transportation/OST-R 1200 New Jersey Avenue, SE Washington, DC 20590-0001		

16. Abstract

It is critically important to predict the corrosivity of fill materials in mechanically-stabilized earth (MSE) walls which can cause corrosion of steel reinforcement and lead to structural failure. A common way of assessing the corrosivity of fill materials is to analyze readily soluble constituents such as chloride and sulfate. In this study, fill materials with a wide range of geological type and gradation were collected throughout the US and Canada and analyzed with several methods to extract soil leachate. An empirical model was developed to estimate the resistivity of soil leachates as a function of chloride, sulfate, and alkalinity concentrations, and this calculation can be used to corroborate laboratory testing results.

17. Key Words Resistivity, Leach test, Ionic composition, Pore water		18. Distribution Statement	
19. Security Classif (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages 14	22. Price

Form DOT F 1700.7 (8-69)

Acknowledgments
The authors gratefully acknowledge the strong and essential support of the UTEP Center for Transportation Infrastructure Systems (CTIS), especially Imad Abdallah and Jose Garibay, as well as the many research students who work collaboratively for the benefit of all.

Table of Contents

List of Figures

List of Tables

Evaluating corrosivity of geomaterials in MSE walls: determination of resistivity from pore water chemistry

DESCRIPTION OF THE PROBLEM

Mechanically stabilized earth (MSE) walls are one of the most cost-effective soil retaining structures and became popular in the U.S.A. for transportation applications and soil stabilization in the 1980s (Elias, Fishman, Christopher, & Berg, 2009; Snapp, Tucker-Kulesza, & Koehn, 2017; Thornley, Siddharthan, Luke, & Salazar, 2010). Fill materials in MSE walls are often reinforced with metallic strips or wire mesh to improve strength, but corrosion of metallic reinforcement decreases the strength of a MSE wall and may result in failure (Armour & Bickford, 2004). Measuring corrosivity of a fill material is dependent on various electrochemical factors such as pH, resistivity, and salt content (Elias et al., 2009).

The electrical resistivity (Ω·cm) of a solution is the reciprocal of its electrical conductivity (S/cm) and shows how much a material prevents the passage of electrical current. The electrical resistivity of a soil-water mixture is inversely proportional to the concentration of soluble ions such as sodium and chloride (Charola, Pühringer, & Steiger, 2007; Thapalia, Borrok, Nazarian, & Garibay, 2011). Several correlations have been proposed (Figure 1) between the electrical resistivity of a solution and its concentration of sulfate or chloride (Rehm, 1980; Richard, 1954). Unfortunately, these correlations of solution resistivity were developed based on the concentration of only a single ion, and there is significant variability of salt constituency across geologic types, so these correlations are not necessarily generalizable to all geomaterials used in MSE walls.

However, to our knowledge, the effects of a multi-component mixture of ions in soil leachates have not been reported, and a more thorough understanding of the relationship between resistivity and ionic content could provide a basis for more confident selection of materials for use in MSE walls. In addition, this understanding can be used as a tool for quality control of measured on-site data of concentration and resistivity.

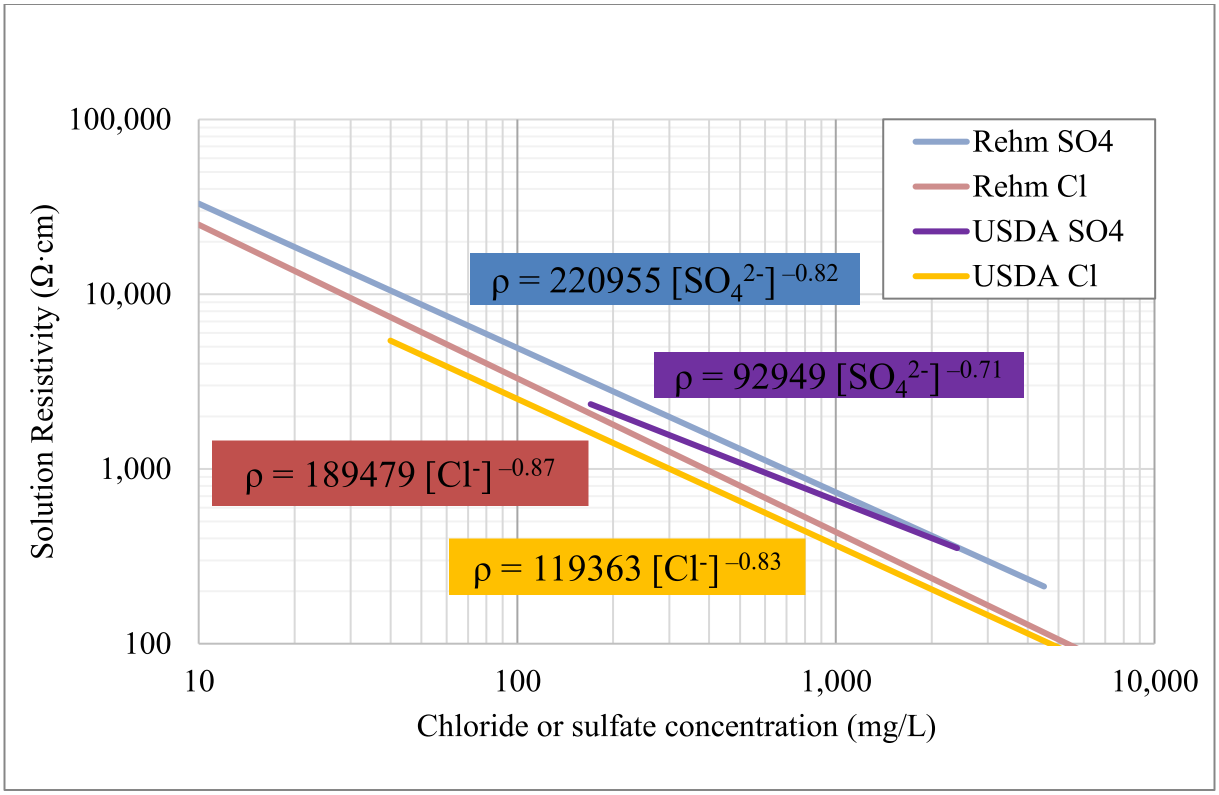

Figure 1. Interpolated empirical correlations of solution resistivity (reciprocal of conductivity) to either chloride or sulfate concentration (Rehm, 1980; Richard, 1954)

APPROACH

To predict the resistivity of soil leachate samples based on multicomponent ionic content, several fill materials from the U.S.A. and Canada were analyzed with several leaching methods. The conductivity of extracted soil leachates was measured, and the concentrations of chloride and sulfate were measured by ion chromatography. Also, alkalinity of the leachates was measured with an automated acid titration. Measurements of resistivity on compacted soil specimens in a box were performed as described by TEX-129-M (UTEP method). Utilizing obtained data, a semi-empirical model was developed to predict resistivity (*i.e.*, the reciprocal of the measured conductivity) of the samples.

METHODOLOGY

Soil Samples

Thirty-two soil materials from the U.S.A. and Canada were analyzed in this study (collected from Texas, Oklahoma, Arkansas, Florida, South Carolina, North Carolina, New York, British Columbia, Alberta, and Nova Scotia). The material samples included geologic types of limestone, sandstone, quartz, and shale, and the gradation of the materials is shown in Figure 2.

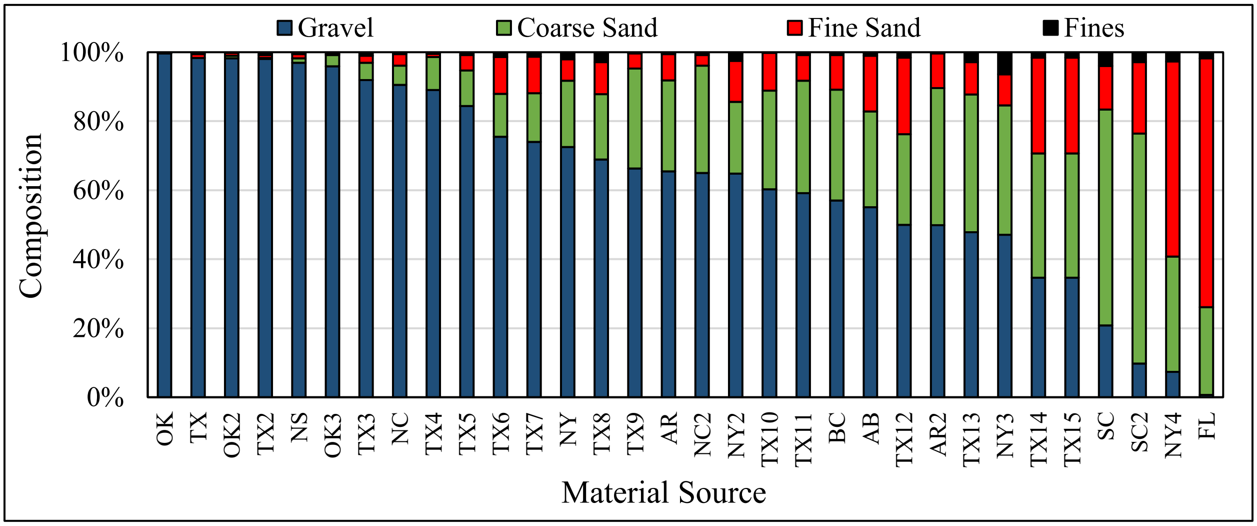

Figure 2. Gradation of collected soil materials

The objective of this study was to develop a mathematical relationship between the conductivity of a leachate sample and its concentrations of sulfate, chloride, and alkalinity. To determine the amount of salt content existing in the collected samples, several leaching methods were used and are summarized in Table 1.

Table 1. Soil leaching test methods for ionic content and conductivity

Test Method	Analyte	Gradation	Temp	Water/Soil (mL/g)	Mixing Method	Duration
AASHTO T-289	pH	Passing #10	Amb.	1	Shake by hand	1 hr
AASHTO T-290	Sulfate	Passing #10	Amb.	3	Shake by hand	5 min
AASHTO T-291	Chloride	Passing #10	Amb.	3	Shake by hand	1 hr
Tex-128-E	pH	Passing #4	50±5 °C	5	Stirring Plate	1 hr
Tex-145-E	Sulfate	Passing #40	Amb.	20	Shake by hand	12 hr
Tex-146-E	Conductivity	Passing #40	Amb.	20	Shake by hand	12 hr
Tex-620-J	Chloride, Sulfate	Passing #40	66±11 °C	10	Stirring plate	12 hr
Tex-620-M2	pH, Chloride, Sulfate, Conductivity, Alkalinity	Passing 1 ¾”	Amb.	10	Roller	1 hr

Conductivity and pH were measured with a calibrated meter and probe, and alkalinity was measured with an automated acid titration. The leachate was filtered through a 0.45-μm membrane, and chloride and sulfate concentrations were measured by ion chromatography with a DIONEX ICS-2100 instrument. The total number of combinations of (a) fill material, (b) material gradation, and (c) soil leaching test method (Table 1), with (d) leachate water quality analyses including conductivity, chloride, sulfate, and alkalinity and (e) corresponding box resistivity measurement was 160. (That is, water quality test results were only included if all four parameters were measured for the same fill material, gradation, and leach method.) Thirty-two of these samples had an electrical resistivity less than 10,000 Ω-cm (*i.e.*, electrical conductivity greater than 100 μS/cm) which were used for model development.

Model Development

Generally, a natural aqueous solution is electrically neutral, which means that the equivalent concentration of anions and cations are equal. Hence, any charge imbalance can be attributed to unanalyzed constituents or incorrect measurements. In most natural waters with $4 < pH < 10$, almost all of the anionic content is due to chloride, sulfate, and alkalinity. Within a neutral pH range, alkalinity is typically constituted predominantly by bicarbonate, HCO_3^{2-}, with a small contribution from carbonate, CO_3^-. The distribution of anionic (meq/L) content of all the leachate samples is shown in Figure 3. The anionic content of most of the leachate samples was predominantly alkalinity or sulfate, but there were a few chloride-dominated samples.

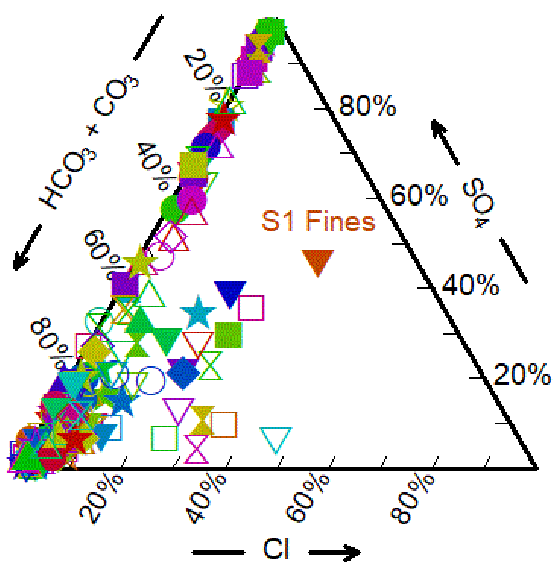

Figure 3. Distribution of sulfate, chloride, and alkalinity among 160 leachate samples

The normality of a leachate sample, N (meq/L), is the total anionic concentration (or total cation concentration) leached, which is calculated by summing chloride, sulfate, and alkalinity concentrations (meq/L), as shown in Equation 2, where the brackets indicate concentration in meq/L:

Equation 1 $$N = \sum anions = [Cl^-] + [SO_4^{2-}] + [ALK]$$

The specific normality, N_s (meq/kg), is the total anionic concentration (or "normality") leached per unit mass of soil material, which is calculated by dividing the leachate normality by the soil-to-water dilution factor (kg/L). The effects of the main cationic constituents, sodium and calcium, on electrical resistivity are relatively similar (Zimmerman & Kaleita, 2017), so the conductivity of the solution is assumed to be more sensitive to the anionic constituency.

Unfortunately, as shown Figure 4, the specific normality is not well correlated with box resistivity (R^2 of 0.48), and especially for box resistivity less than 10,000 Ω·cm (R^2 of 0.36), so further model development focused on regression of the leachate resistivity (*i.e.*, reciprocal of electrical conductivity) with anionic content.

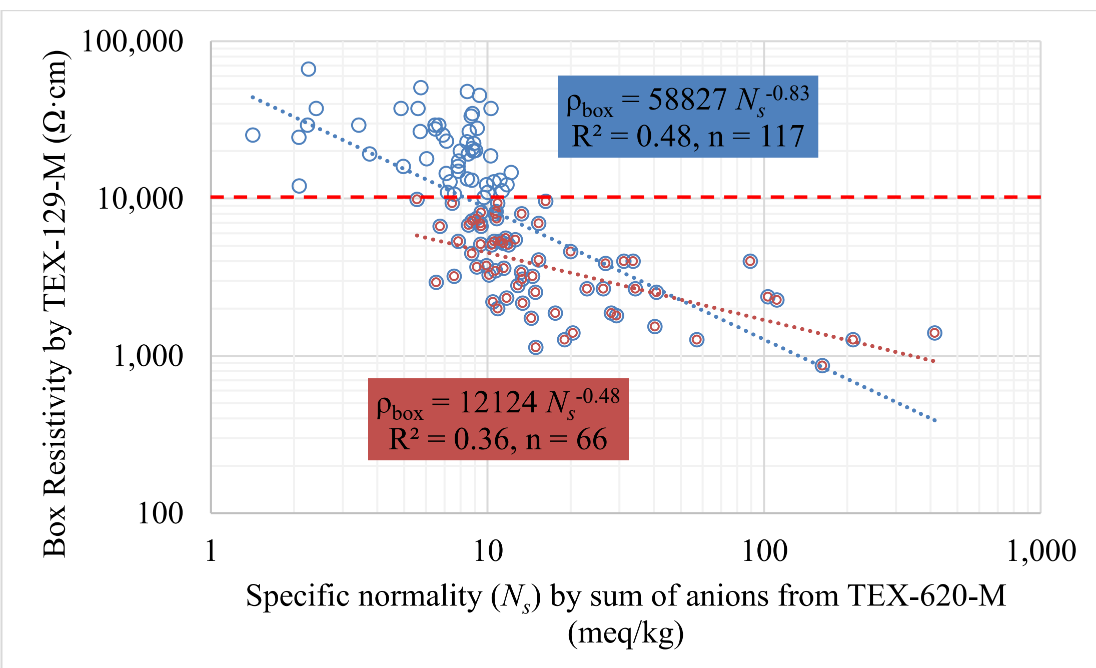

Figure 4. Regression of electrical box resistivity versus specific normality

FINDINGS

The models for leachate resistivity, ρ_l, (Ω·cm) developed in this research (Equation 2 and Equation 3) are mathematically similar to the single ion models shown in Figure 1 but are based on multiple constituents (Equation 1). The regression of 160 leachate analyses (Figure 5) resulted in Equation 2 with an R^2 value of 0.72:

Equation 2 $$\rho_l = 16674\ N^{-0.909} \text{ (for all 160 leachate samples)}$$

Since soils with box resistivity greater than 10,000 Ω·cm are not considered corrosive (Elias et al., 2009), a second regression was performed for the 46 leachate samples with leachate resistivity less than 10,000 Ω·cm (*i.e.*, leachate conductivity greater than 100 µS/cm), which resulted in Equation 3 with an R^2 value of 0.84:

Equation 3 $$\rho_l = 8767\ N^{-0.659} \text{ (for } \rho_l < 10{,}000\ \Omega\cdot\text{cm)}$$

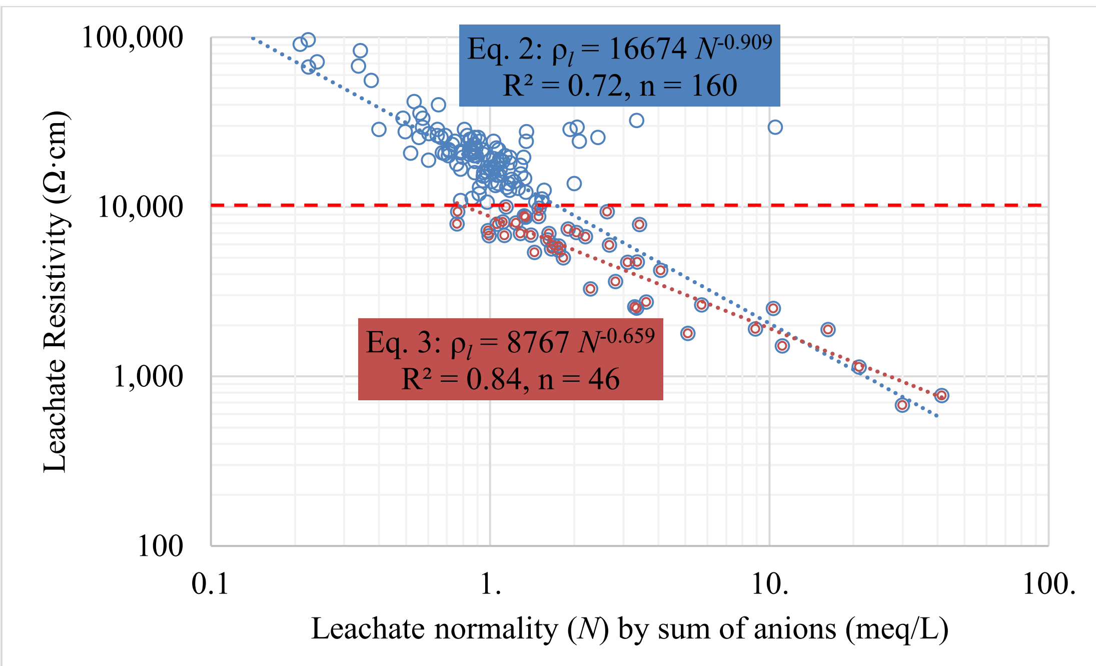

Figure 5. Regression of electrical resistivity of leachate versus leachate normality

The leachate resistivity values predicted by Equation 2 and Equation 3 are compared to measured values in Figure 6. Most of the samples are within 50% difference.

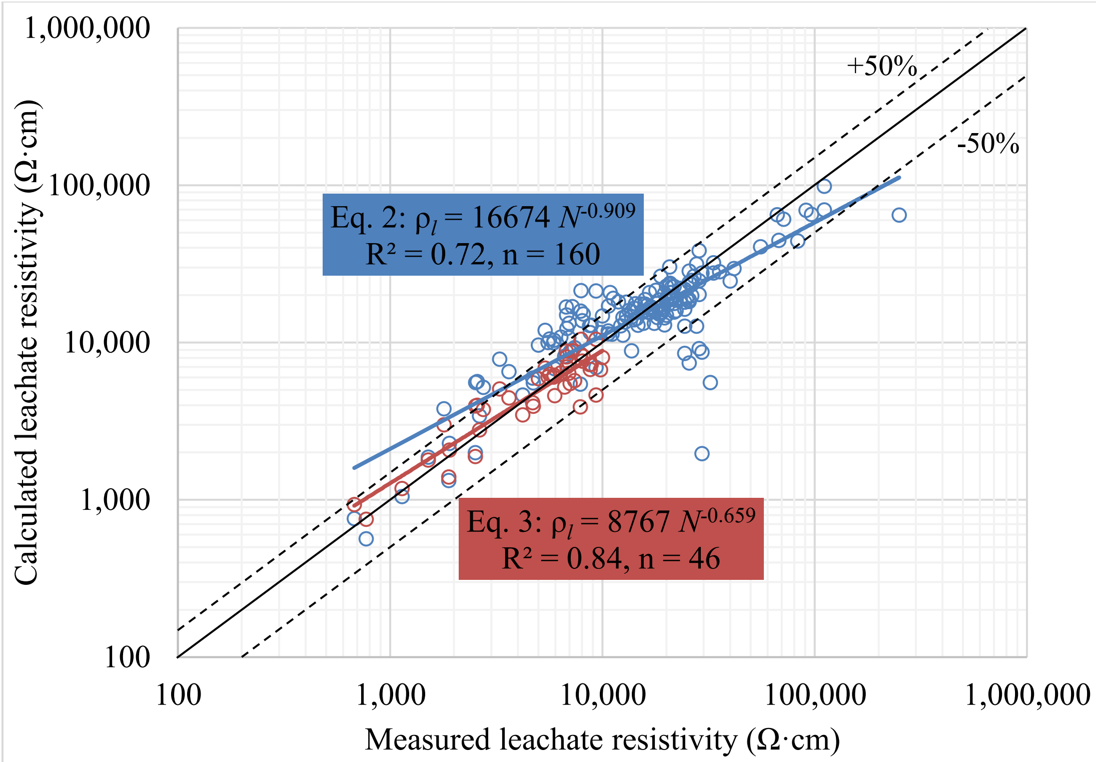

Figure 6. Comparison of calculated and measured resistivity

CONCLUSIONS

A mathematical correlation was developed to predict the electrical resistivity (*i.e.*, reciprocal of electrical conductivity) of a soil leachate based on the leachate normality, which can be approximated from concentrations of sulfate, chloride, and alkalinity. The developed model is accounting for combinations of ionic constituents in leachate, compared to other models which were correlated with only sulfate or chloride. Using the model is beneficial for quality control of on-site and laboratory analyses of soil leachate.

RECOMMENDATIONS

Based on the results of this study, the following recommendations are made:

- Ion chromatography can be used for analysis of chloride and sulfate in soil leachate. Ion chromatography provides accurate, fast, relatively inexpensive, and reproduceable results of concentrations of chloride and sulfate for soil leachate.
- Alkalinity should also be measured in soil leachate, along with chloride and sulfate. Alkalinity (mostly in the form of bicarbonate in soil leachate) is an important contributing factor of electrical conductivity of the leachate (especially for limestone materials). Testing alkalinity with automatic titration is relatively simple, fast, and increases the accuracy of the leachate resistivity prediction.
- The models developed in this research can be used for quality control or corroboration of reported data from a field or laboratory analyses of resistivity or conductivity.

REFERENCES

Armour, T. A., & Bickford, J. (2004). Repair of failing MSE railroad bridge abutment. *Geotechnical Special Publications 136*, 1–15.

Charola, A. E., Pühringer, J., & Steiger, M. (2007). Gypsum: a review of its role in the deterioration of building materials. *Environmental Geology*, *52*(2), 339–352.

Elias, V., Fishman, K., Christopher, B., & Berg, R. (2009). Corrosion/degradation of soil reinforcements for mechanically stabilized earth walls and reinforced soil slopes. *U.S Department of Transportation Federal Highway Administration*, (132042).

Rehm, G. (1980). The Service Life of Reinforced Earth Structures from a Corrosion Technology Standpoint. *Expert Report (Vienna, VA: The Reinforced Earth Company, 1980)*.

Richard, L. A. (1954). Diagnosis and improvement of saline and alkali soils. USDA Hand Book. No. 60. *US Govt. Press, Washington, DC*, 160.

Snapp, M., Tucker-Kulesza, S., & Koehn, W. (2017). Electrical resisitivity of mechancially stablized earth wall backfill. *Journal of Applied Geophysics*, *141*, 98–106. https://doi.org/10.1016/j.jappgeo.2017.04.011

Thapalia, A., Borrok, D., Nazarian, S., & Garibay, J. (2011). Assessment of corrosion potential of coarse backfill aggregates for mechanically stabilized earth walls. *Transportation Research Record: Journal of the Transportation Research Board*, (2253), 63–72.

Thornley, J. D., Siddharthan, R. V, Luke, B., & Salazar, J. M. (2010). Investigation and implications of mechanically stabilized earth wall corrosion in Nevada. *Transportation Research Record*, (2186), 154–160. https://doi.org/10.3141/2186-17

Zimmerman, B. A., & Kaleita, A. L. (2017). Electrical Conductivity of Agricultural Drainage Water in Iowa. *Applied Engineering in Agriculture*, *33*(3), 369–378. https://doi.org/10.13031/aea.12040