



Implementation of New Specification Requirements for Coarse Backfill Materials for Mechanically Stabilized Earth (MSE) Walls

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**Center for Transportation Infrastructure Systems
The University of Texas at El Paso
El Paso, TX 79968
(915) 747-6925**

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Jose Luis Arciniega, MSCE
Diana Cabrer, MSCE
Troy Svede, MSEN
Sergio Rocha, BSEE
Jose Garibay, MSCE

Arturo Bronson, PhD
W. Shane Walker, PhD, PE (113368)
Soheil Nazarian, PhD, PE (66495)

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By

**Jose Luis Arciniega, MSCE
Diana Cabrera, MSCE
Troy Svede, MSEnE
Sergio Rocha, MSEE
Jose Garibay, MSCE
Arturo Bronson, PhD
W. Shane Walker, PhD, PE
and
Soheil Nazarian, PhD, PE**

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El Paso, TX 79968-0516**

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Abstract

The service life of mechanically stabilized earth (MSE) walls depends on the rate of corrosion of the metallic reinforcements used in their construction. Assessment of corrosion potential requires the accurate evaluation of pH, resistivity, and ionic (e.g., sulfate and chloride) concentrations of aqueous solutions in contact with the surrounding aggregate. There is a tendency to utilize larger-size aggregates that contain only a small amount of fine material (passing No. 40 sieve) in the backfill. Evaluation of the electrochemical parameters of coarse aggregates is challenging because traditional methods utilize only fine-grained material.

Under Project 0-6359 entitled “Characterization of Backfill Materials for Prevention of Corrosion of MSE Metallic Wall Reinforcement,” more representative geochemical testing protocols were recommended for the consideration by TxDOT. Based on the promising results from that study, this follow on study was carried out to standardize the test protocols and provide specifications that TxDOT personnel can readily use the proposed methods. The outcome of this study is two standards that can potentially supplant the test procedures for resistivity (Tex-129-E); pH (Tex-128-E), Chloride and Sulfate (Tex-620-J) of the backfill materials.

Based on testing more than two dozen backfill materials collected from throughout Texas, these methods seem to be more representative and more practical than the current tests especially for the coarser backfills.

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Chapter 1 - Introduction

The service lives of mechanically stabilized earth (MSE) walls depend on the rate of corrosion of the metallic reinforcement used in their construction. The proper assessment of the corrosion potential requires the accurate evaluation of the pH, resistivity, and ionic (e.g., sulfate and chloride) concentrations of the aqueous solutions in contact with the surrounding aggregates. There is a tendency to utilize larger size aggregates that contain only a small amount of fine material (passing No. 10 sieve) in the backfill. The evaluation of the electrochemical parameters of coarse aggregates is challenging because traditional methods utilize only fine-grained materials. Previous studies have demonstrated that the fines collected from the field can be enriched with chemicals that when exposed to water decrease pH and resistivity, as well as increase the chloride or sulfate concentrations relative to the bulk rock. This phenomenon may bias the traditional soil testing results and therefore the assessment of the corrosion potential.

The goal of this project is to establish material specifications for coarse aggregates (Item 423: Retaining Walls, Type AS and DS) used to construct MSE walls in Texas. Under Project 0-6359 entitled “Characterization of Backfill Materials for Prevention of Corrosion of MSE Metallic Wall Reinforcement,” more representative geochemical testing protocols were recommended for the consideration by TxDOT. This study was carried out to standardize the test protocols and provide specifications that TxDOT personnel can readily use. The outcome of this study is two test procedures that can potentially supplant the test procedures for resistivity (Tex-129-E); pH (Tex-128-E), Chloride and Sulfate (Tex-620-J) of the backfill materials.

To achieve this goal of this project, the following milestones were achieved:

- 1) Produce material property data using the field leach test procedures (referred to as Tex-620-M) developed in Project 0-6359 and compare with the data from traditional TxDOT methods including Resistivity (Tex-129-E), pH (Tex-128-E), and Chloride and Sulfate Contents (Tex-620-J).
- 2) Collect field performance data to establish limits of acceptable material properties using electrochemical methods.
- 3) Develop guidance documents for proper selection and inspection of coarse aggregates used in constructing MSE walls.
- 4) Provide support and training to TxDOT personnel for the proper use of coarse aggregates in MSE backfill.

Organization of Report

The report consists of five chapters. Chapter 2 describes the laboratory test setup, specimen preparation, equipment and protocol used for monitoring the specimens with a summary of typical results acquired. Chapter 3 summarizes and interprets the geotechnical and corrosion results obtained. Chapter 4 covers the field-testing done for this project; including the site selection, description of the sensors used and the layout of those sensors at each site. Chapter 5 contains practical recommendations and summary and conclusions derived from the project.

Chapter 2 – Methodology

Figure 2.1 shows the process of the characterization of the soils from the start to finish. The first step was to retrieve the materials from either the construction site or the quarry. Once a material arrived at UTEP laboratory, it was first processed and characterized as per Tex-104-E (liquid limit), Tex-105-E (plastic limit), Tex-106-E (plasticity index), Tex-107-E (linear shrinkage), and Tex-110-E (grain size distribution). The materials were then sorted in order to carry out the electrochemical tests and geochemical tests.

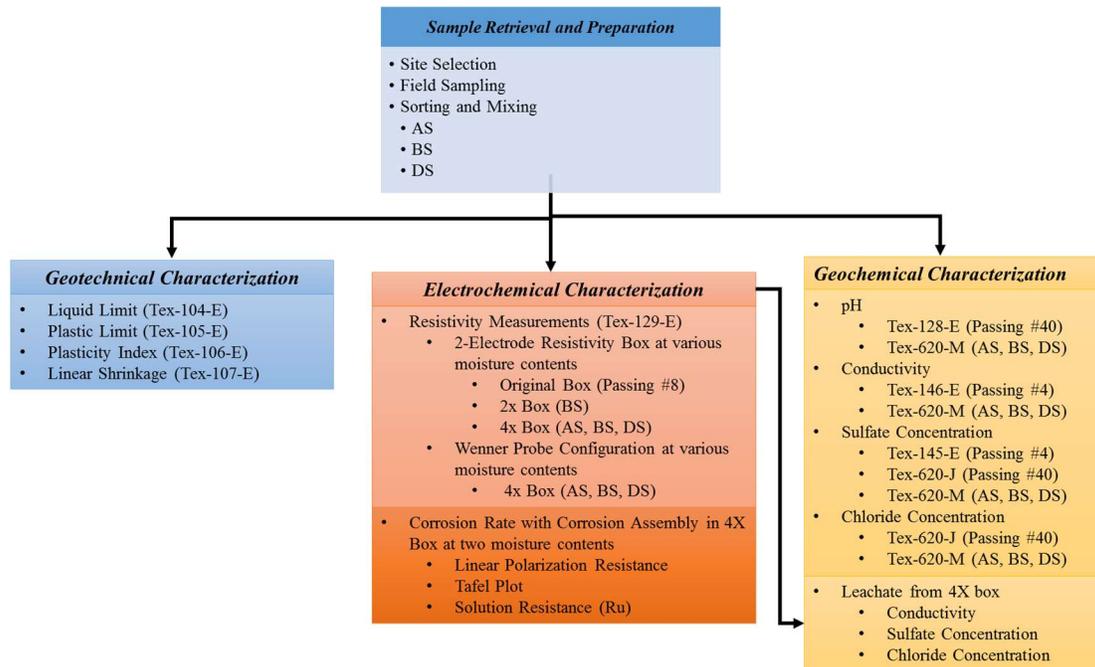


Figure 2.1-Flow Chart of Procedures for Testing

The electrochemical tests included resistivity testing and corrosion testing. The resistivity of the material was measured with a two-electrode resistivity box as per Tex-129-M as provided in Appendix A, in addition to Tex-129-E. A methodology for estimating the corrosion rate of metallic members embedded in the soil boxes was devised and implemented as discussed later.

The geochemical tests included five different tests to measure different chemical constituents of the soil. The pH of the soil was measured as per Tex-128-E. The conductivity (proportional to the reciprocal of resistivity) was measured with Tex-146-E. Test procedure Tex-620-J was used to measure the chloride and sulfate concentrations. As shown in Figure 2.2, the proposed test procedure Tex-620-M (see Appendix B) was also used to measure the same geochemical properties for comparison purposes. The leachate in the resistivity box generated during the electrochemical testing was also sampled and characterized for conductivity, chloride concentration and sulfate concentration during the geochemical tests. Each group of tests are described below in more detail.

Geotechnical Characterization

This study focused on Types AS, BS, and DS gradations as specified in Item 423. Figure 2.2 shows the representative particle size distributions for the three backfill gradations. Type AS backfill

contains a higher proportion of intermediate particles and a very small fines content (1.5%), while Type DS has a more gap-graded distribution with very high amount of gravel and low amount of sand and fines with the fines content also being very low (2.5%). Type BS is a well-graded material with a high fines content (7.5%).

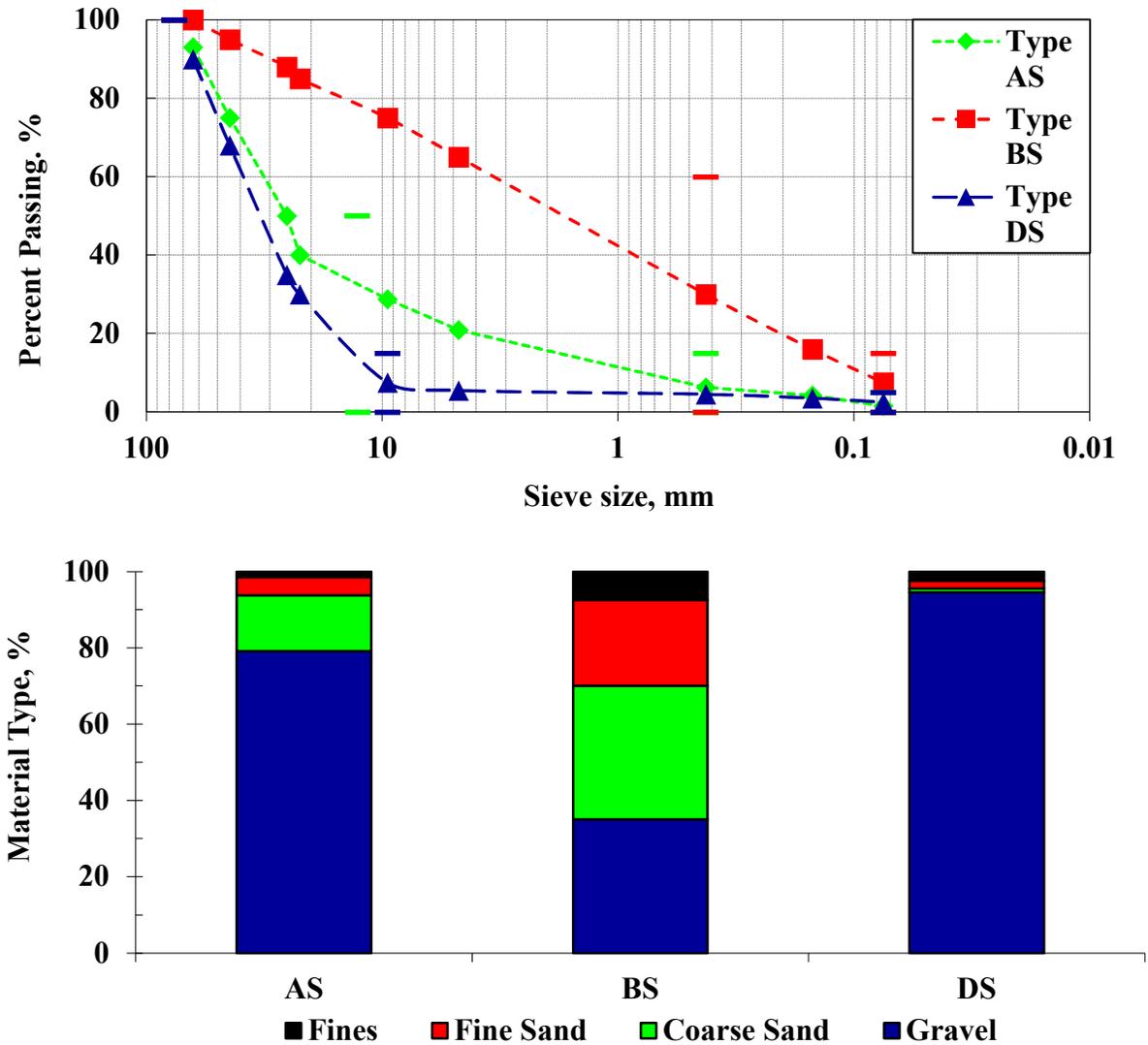


Figure 2.2-Typical Grain Size Distributions of TxDOT Type AS, BS, and DS Backfills

Each material was subjected to sieve analysis as per Tex-110-E to separate them into a number of bins including 1½ in., 1 in., 7/8 in., 3/8 in., #4, #40, #100, and #200 sieves. Materials from different bins were remixed to achieve the appropriate grain size distributions shown in Figure 2.2. In addition to these three gradations, each backfill material was also separated to gravel (particles between 3 in. and No. 4 sieve), coarse sand (between No. 4 and No. 40 sieves), fine sand (between No. 40 and No. 200 sieves) and fines (passing No. 200 sieve). The materials passing the No. 8 sieve as required by Tex-129-E were also prepared as per these gradations.

For completeness, the liquid limit (Tex-104-E), plastic limit (Tex-105-E), plasticity index (Tex-106-E), and linear shrinkage (Tex-107-E) were also determined.

Electrochemical Characterization

All two-probe resistivity tests were based on test procedure Tex-129-E. Two additional boxes with the dimensions that were double and quadruple of the original resistivity box were built to accommodate testing of coarse aggregates as per Tex-129-M (see Figure 2.3). The distributions of tests across the box sizes is illustrated Table 2.1.



Figure 2.3-Original, Doubled Dimension and Quadrupled Dimension Two-Electrode Resistivity boxes

Table 2.1-Tests carried out per Tex-129-E and Tex-129-M

Size	Gradation			Constituent				Tex-129-E
	Type AS	Type BS	Type DS	Gravel	Coarse Sand	Fine Sand	Fines	
Original		✓			✓	✓	✓	✓
2X		✓			✓			
4X	✓	✓	✓	✓				

To address the concern that the change in the box dimensions could be a source of variability, a series of experiments was performed on the boxes which followed the same procedure as Tex-129-E, using material passing the No. 8 sieve. The amount of material used and deionized (DI) water added were proportioned in order to give the same relation by volume as in the original size test procedure. Thus, the 2.9 lb (1300 g) of material were multiplied by 64 for the largest box volume conversion and became 183 lb (83 kg). Similarly, the 0.1 lb (50 mL) of water added became 7 lb (3.2 kg) of water per cycle (assuming density of DI water is 1 g/mL). The tests were prepared by mixing 183 lb (83 kg) of material with 7 lb (3.2 kg) of DI water in a concrete mixer and using that material for all three soil boxes. The samples for all three boxes were compacted to the same dry density to minimize the impact of that parameter on the resistivity. Figure 3.4 compares the resistivity of a limestone backfill using the materials passing the No. 8 (Tex-129-E procedure) sieve in all the three box sizes against the degree of saturation. The results are generally consistent, as judged by the low coefficient of variation (COV) and high coefficient of determination (R^2).

The resistivity decreases with the increase in moisture content. Performing this test confirmed that it was possible to obtain consistent results across the three box sizes and that the tests were repeatable.

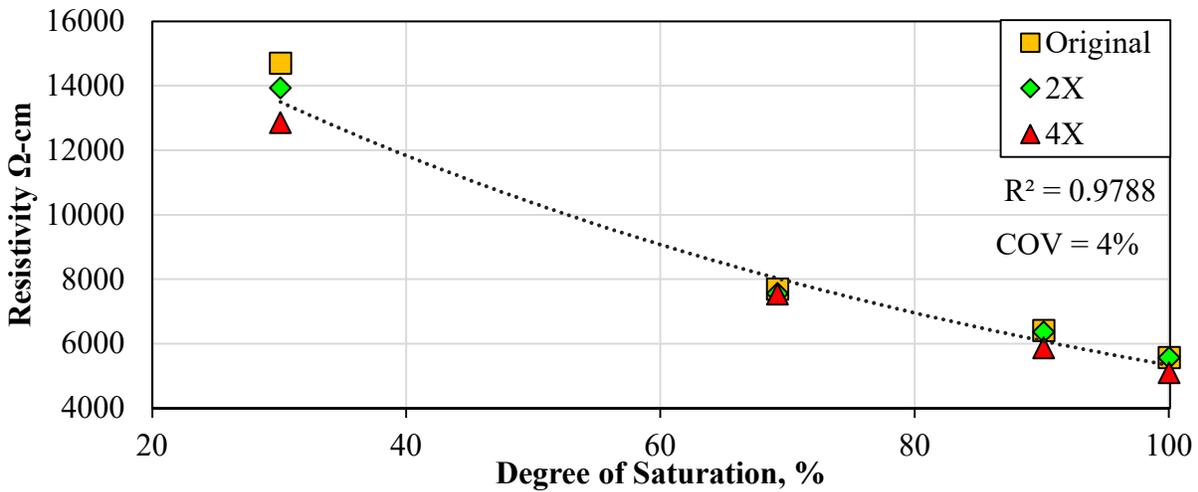


Figure 2.4-Resistivity vs. Degree of Saturation across three box sizes

During the resistivity testing, a corrosion assembly with three working electrodes (see Figure 2.5) was embedded into the 4X resistivity box. The three working electrodes included a corroded steel bar, a non-corroded steel bar, and a protected steel bar covered with a paint coating to minimize corrosion. All bars were 3 in. (75 mm) long and 0.5 in. (12 mm) in diameter. The four bars were connected with two PVC plates.

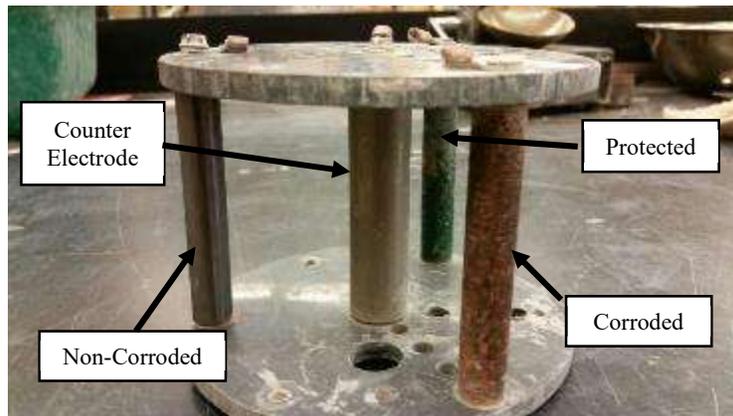


Figure 2.1-Corrosion Testing Device

Figure 2.6 shows the set up for corrosion testing of these coupons. The counter electrode was a stainless-steel bar that has a diameter of 0.75 in. (19 mm). The three working electrodes were placed 2 in. (50 mm) from the center on which the counter electrode was positioned. Figure 2.7 displays a close up of the electrode connections. All potentials were measured with respect to a half-cell potential of 0.318 V generated from a copper-copper (II) sulfate reference electrode. A Gamry Reference 600 potentiostat was used to regulate the potential between the working electrode and the reference electrode inside the electrolyte. In this case, the soil moisture acts as the electrolyte.

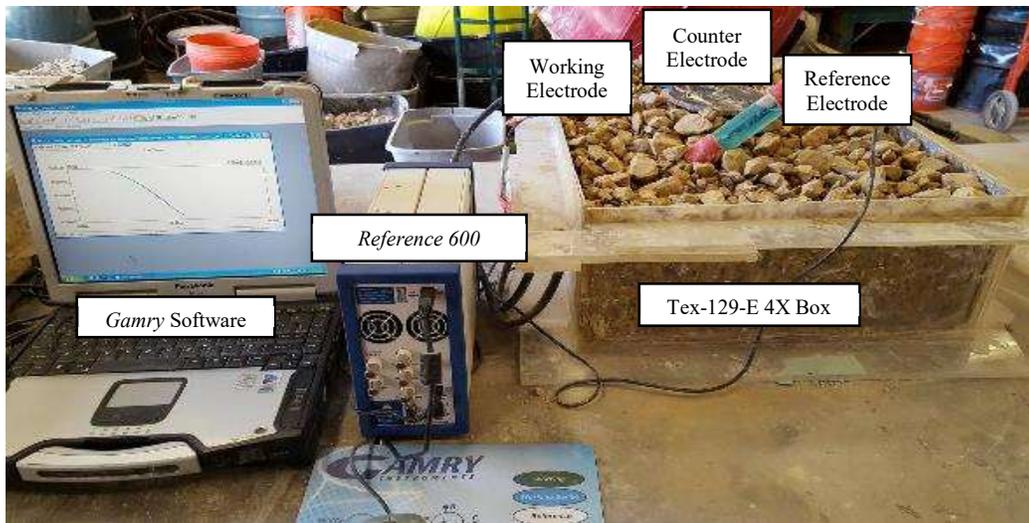


Figure 2.2-Corrosion Testing Setup

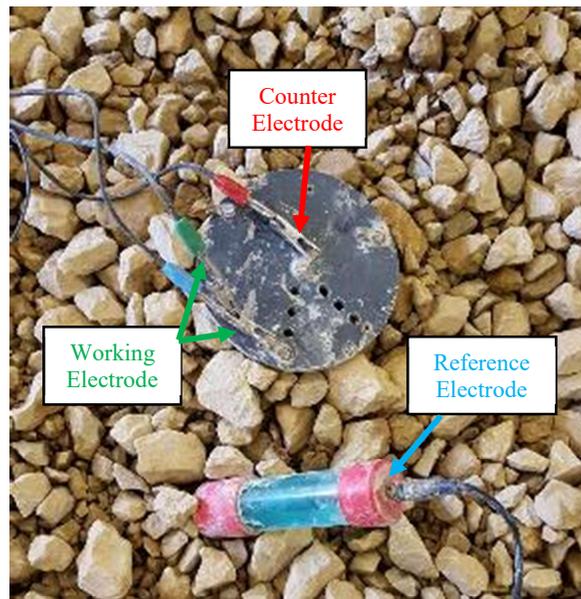


Figure 2.3-Device Close-up

To estimate the corrosion rate, an electrochemical corrosion test cell must be created. A test cell consists of three electrodes submerged into an electrolyte as shown schematically in Figure 2.8. The three electrodes consists of a counter electrode, a test or working electrode, and a reference electrode. A potentiostat is used to regulate the potential of the working electrode inside the electrolyte. The electric current coming from a potentiostat changes the working electrode potential from open circuit potential into a potential value that is determined from the magnitude of the potentiostat current. The process of changing an electrode potential from its open circuit potential is called polarization. Polarization is measured as a potential difference between a working electrode and a reference electrode. Since no current flows between the potentiostat and the reference electrode, the reference electrode maintains an open circuit potential that acts as a reference point for corrosion measurements. Ultimately, the relationship between the electrode

potentials and the corresponding currents, or voltage frequencies and corresponding impedance values, are used to determine the corrosion rates.

The Tafel plot and linear polarization resistance (LPR) techniques were sequentially performed at two different moisture conditions to measure the corrosion rate of the three components of the corrosion assembly. Only the specimens prepared with the gradations of AS, BS and DS in the 4X resistivity box were tested. The first moisture condition was the first wetting cycle, while the second moisture condition corresponded to the saturation condition. In the Tafel technique, the corrosion current (I_{corr}) was measured to estimate the corrosion rate (CR). With the LPR technique, I_{corr} was also estimated and verified to obtain the corrosion rate. The Tafel and LPR techniques were performed using the *Gamry Framework* software by scanning (or perturbing) the DC voltage between the working and reference electrodes as the current response was simultaneously measured between the working and counter electrodes.

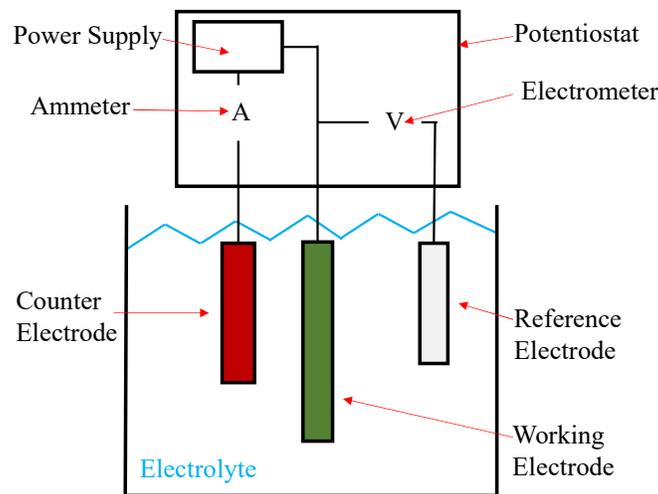


Figure 2.8 -Three Electrode Test Cell

Geochemical Characterization

To obtain a direct point of comparison with the electrochemical tests, leachate was extracted from the saturated specimens prepared with the AS and DS gradations in the 4X resistivity box through a valve installed in that box, as visible in Figure 2.3. The extraction of a workable amount of leachate from the saturated BS gradation took over twelve hours and thus was deemed impractical and abandoned. The leachate was sampled twice (immediately after the completion of the electrochemical testing of the box, and at least 12 hours after the preparation of the specimen). These leachates were tested for conductivity, chloride concentration, and sulfate concentration.

In addition, test procedures Tex-128-E, Tex-129-E, Tex-145-E, Tex-146-E, and Tex-620-J were used to geochemically characterize the soils in pH, conductivity, chloride content, and sulfate content as baseline measurements. These were then compared with the results obtained from the modified procedure Tex-620-M. As opposed to Tex-620-J, Tex-620-M permits the use of large particles and not just the portion passing the #40 sieve. Also, Tex-620-M standardizes the mixing method.

Chapter 3- Laboratory Results and Analysis

Twenty materials were sampled from the sources shown in Figure 3.1. The sources were selected in a way to include diversified sources in the study. The results from tests are presented here.

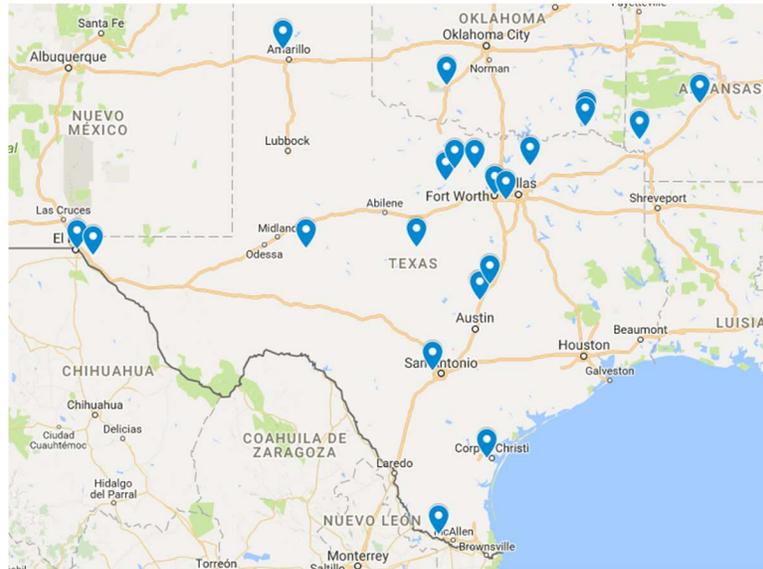


Figure 3.1-Location Map for Aggregate Sources

Table 3.1 shows the index values obtained for the 20 materials. Most materials were non-plastic. Figure 3.2 shows the minimum resistivity values measured with the two-electrode resistivity boxes. The acceptance limit is. Most materials irrespective of gradations pass this required minimum resistivity value of 3000 ohms-cm.

Figures 3.3 summarize the corrosion rate at saturation for the steel bar. At least quantitatively the rate of corrosion is the reciprocal of the minimum resistivity values shown in Figure 3.2.

Figure 3.4 shows the measured pH with test method Tex-620-M for each material. Most materials exhibit pH values that are within the acceptable limits of 5.5 to 10. The concentrations of the sulfate and chloride ions for each gradation of the twenty materials are shown in Figures 3.5 and 3.6, respectively. The sulfate concentrations of most materials are within the acceptance limit of 200 mg/L. The concentrations of the chloride ions are way below the limit 100 mg/L. Figure 3.7 shows the conductivity of the specimens measured with test procedure Tex-620-M as a surrogate for the box resistivity. Conductivity is the reciprocal of resistivity.

Figure 3.8 shows the average ratios of the measurements obtained for each gradation to the existing procedures for the two-electrode resistivity, conductivity, chloride content, sulfate content, and pH. The resistivity measurements obtained from the materials with the coarse (AS and DS) gradations are three to four times greater than the measurements obtained under current procedures. For these coarse gradations, the conductivity values, and the sulfate and chloride concentrations are less than the corresponding values obtained using the current specifications. The conductivity values from Tex-620-M are about 50% less from the modified procedures. Chloride and sulfate concentration measurements more or less show similar behaviors to the conductivity, which could indicate a direct correlation among these parameters.

Table 3.1-Index Test Results

Site	Tex-104-E (Liquid Limit)	Tex-105-E (Plastic Limit)	Tex-106-E (Plasticity Index)	Tex-107-E (Linear Shrinkage)
A	23	13	10	11
B	21	11	10	10
C	Non-plastic			
D	Non-plastic			
E	Non-plastic			
F	18	10	8	8
G	12	5	7	7
H	Non-plastic			
I	18	10	8	8
J	19	6	13	13
K	15	9	6	7
L	20	12	8	9
M	Non-plastic			
N	Non-plastic			
O	Non-plastic			
P	Non-plastic			
Q	In Progress			
R	In Progress			
U	Non-plastic			
V	Non-plastic			

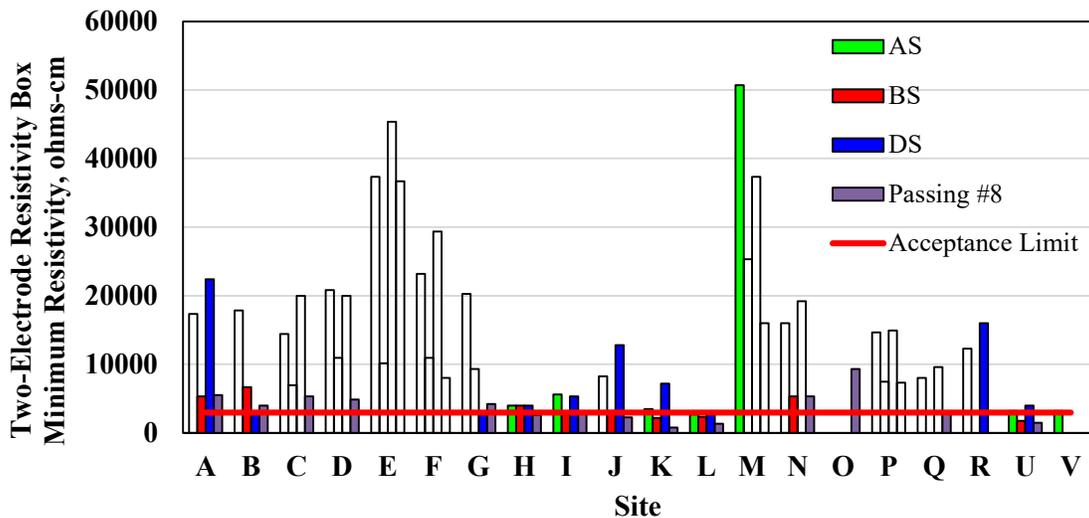


Figure 3.2-Minimum Resistivity Values from Two-Electrode Resistivity Box

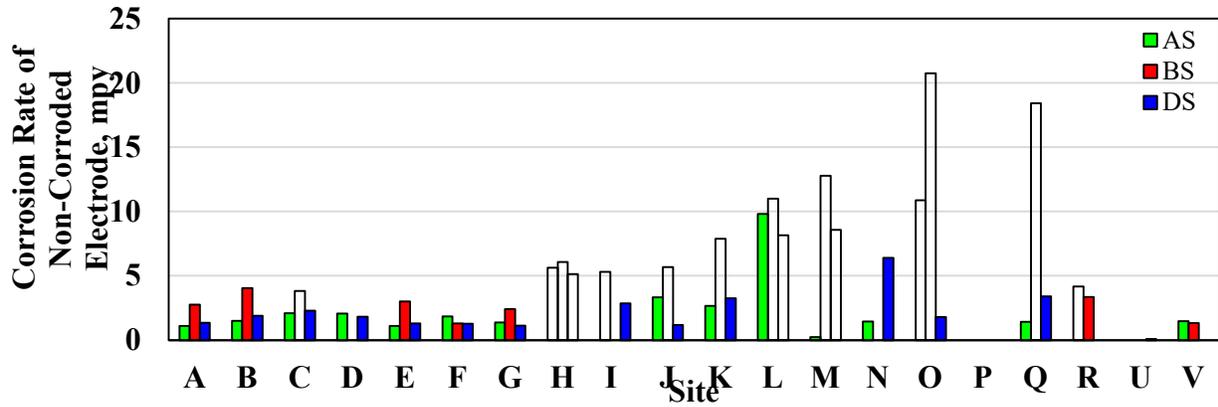


Figure 3.3- Steel Element Corrosion Rates

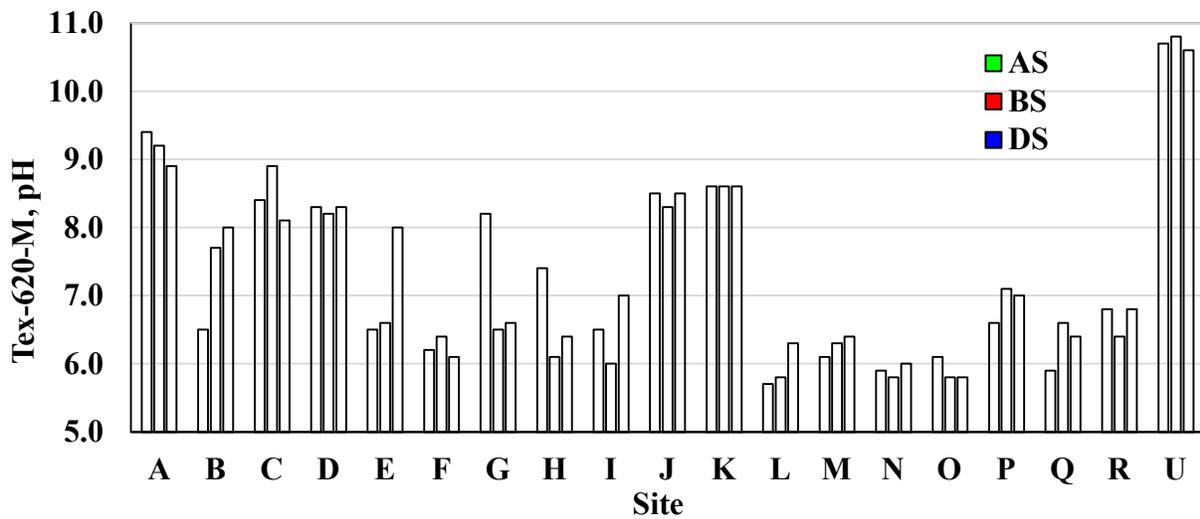


Figure 3.4-pH for Tex-620-M

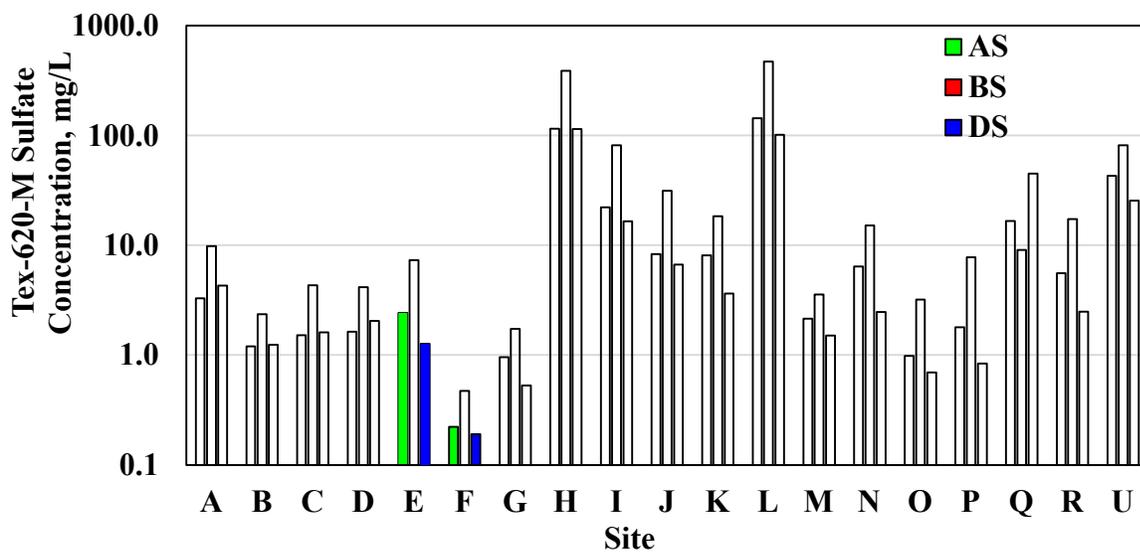


Figure 3.5-Concentration of sulfates for Tex-620-M

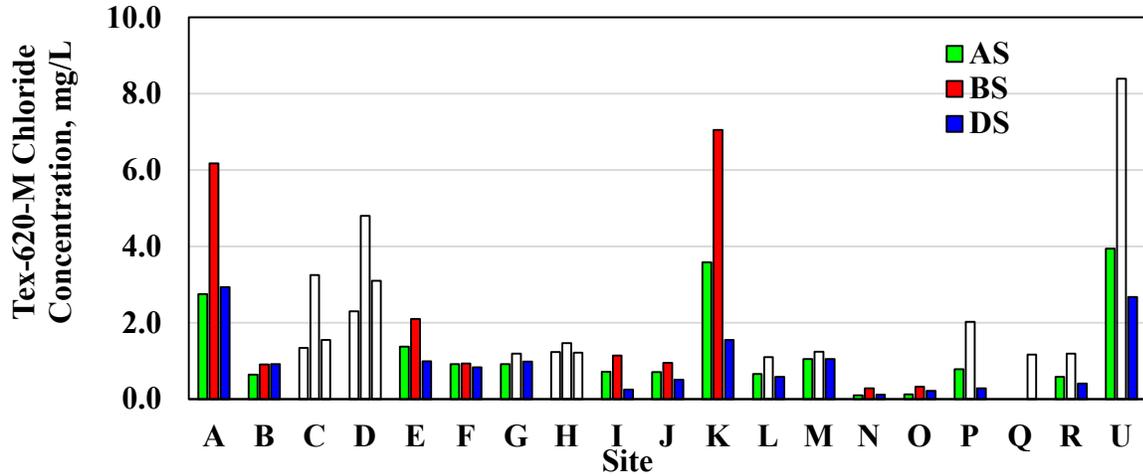


Figure 3.6-Concentration of chlorides for Tex-620-M

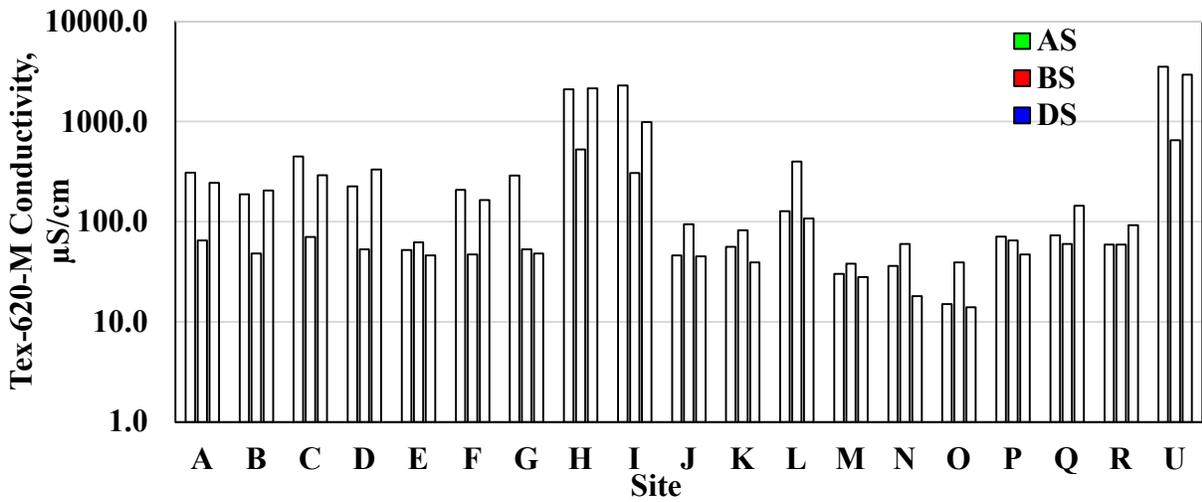


Figure 3.7 -Conductivity for Tex-620-M

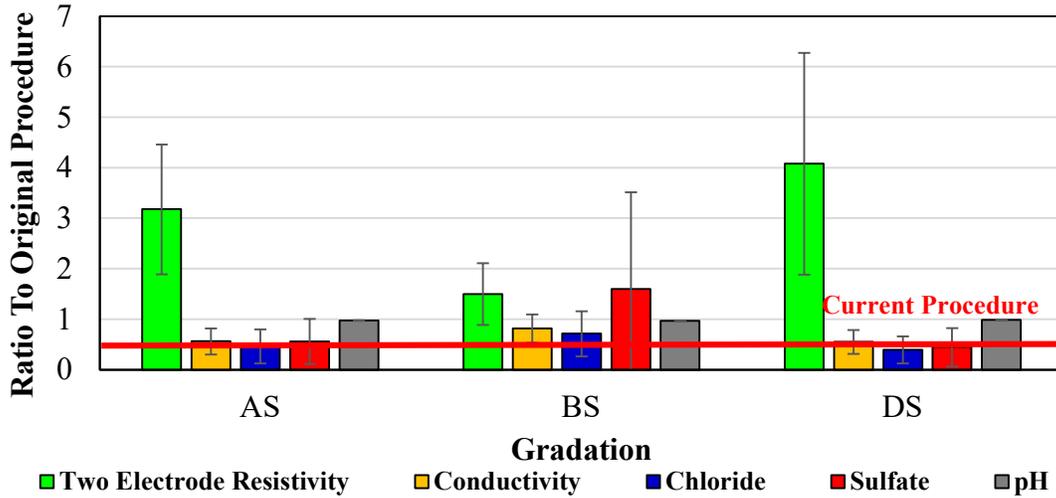


Figure 3.8- Summary of Ratios of Modified Procedure to Current Procedure

For the materials with the BS gradations, which correspond to well-graded backfill materials, the measured values are closer to those obtained from the current procedures. The resistivity values and sulfate contents are about 50% greater, while the conductivity values and chloride contents are about 25% less than the corresponding values measured with current TxDOT test procedures. The pH values from the proposed and the existing methods are similar.

The results indicate that the current test procedures are not representative of the actual values for the materials with the AS and DS gradations. Test procedure Tex-129-M is recommended for the measurement of the resistivity in coarse-grained backfills. Test procedure Tex-620-M is recommended for the measurement of the conductivity, pH, chloride and sulfate concentrations.

Corrosion Rate Results

Figure 3.9 show the box plots and cumulative distributions of the corrosion rates measured through the methods outlined above for the non-corroded steel elements. The corrosion rates are higher for the BS gradations, than in the AS and DS gradations. The similarity between the corrosion rates of the AS and DS gradations is evidenced by the overlap between the cumulative distribution graphs.

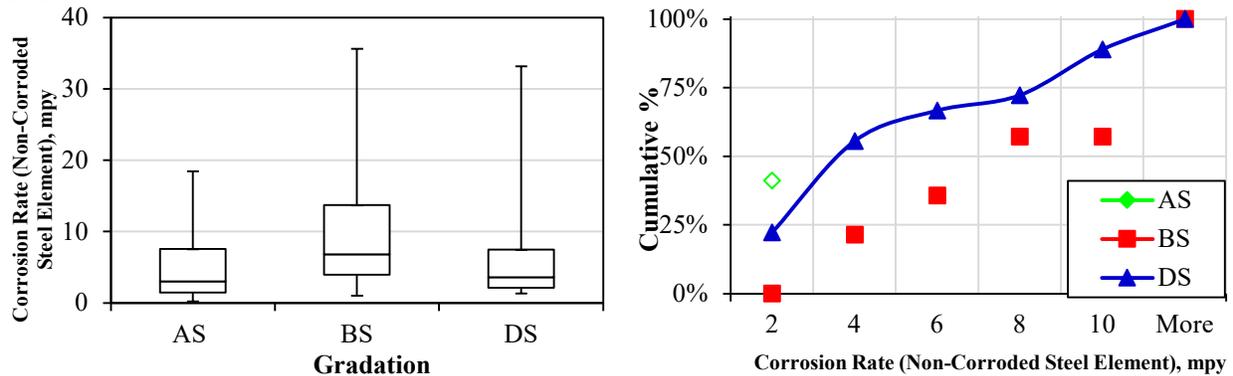


Figure 3.9- Box Plots and Cumulative Distribution of the Corrosion Rates for Non-corroded Specimen

The variations in the corrosion rate as a function of the reciprocal of resistivity (named pseudo-Conductivity) are shown in Figure 3.10. The two parameters are well correlated, indicating the reasonableness of measuring resistivity/conductivity as a surrogate for the corrosion rate.

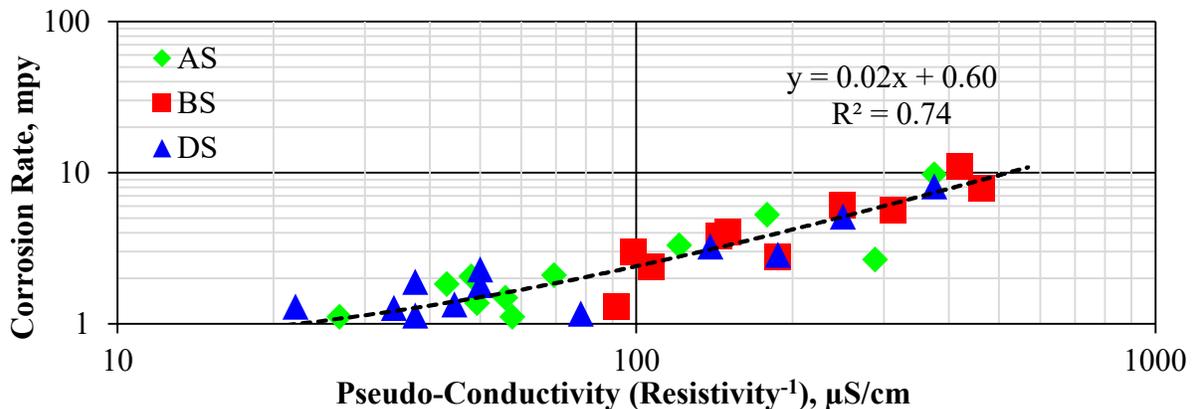


Figure 3.10 – Variations in the Rate of Corrosion with Box Resistivity

Chapter 4- Field Testing

Identification and quantification of field performance

To connect more accurately the laboratory test results with on-site corrosion behavior, five MSE walls under construction were instrumented during the course of this project so that the changes in the geochemistry, field resistivity and the rate of corrosion and moisture content could be monitored and compared with the laboratory processes.

Figure 4.1 shows the location of the five MSE walls instrumented for this study. Wall A is an MSE wall for an overpass on US 71 located in Bastrop. Wall B is for an entrance ramp to US 151 in San Antonio. Wall C is for a bridge in North Carolina Dr. in El Paso. Wall D is for an exit ramp on IH35 to MLK Jr. Blvd. in Waco. Wall E is part of Border Highway extension in El Paso.



Figure 4.1- Instrumented MSE Wall Locations

Figure 4.2 shows a close-up of the backfill materials used on the corresponding walls. All walls used coarse backfill except for Wall C. Two types of samples were taken from the sites where coarse aggregate were used: one before compaction and one after compaction. Materials A and B, D and E are coarse aggregates, while Material C is a sand. The compacted samples are substantially to marginally finer than the aggregates before being compacted. Specifically, Material A exhibits a greater amount of crushing due to compaction, as the compacted sample was overall finer than the sample before being compacted. Material C is missing a compacted sieve analysis since no compacted samples were collected at these site, as there was no expectation for the crushing of aggregate given the size of the particles. While material E is a coarse aggregate, no compacted sample is available.

Figure 4.3 illustrates the placement of the instrumentation in each of the MSE walls. To account for possible changes in moisture along the height of the wall, each wall was instrumented at two locations: one at a one-third height of the wall and another at a two-thirds height from the wall. Each of these stations contained the following items:

- a resistivity probe to measure the backfill resistivity,
- a Stevens Hydra-Probe II Moisture Probe to measure the moisture content, conductivity, temperature and dielectric constants of the backfill simultaneously,
- a lysimeter to sample the water penetrating the backfill, and
- a reference electrode.

Measurements were taken from an instrumentation box installed in the outside of the wall.

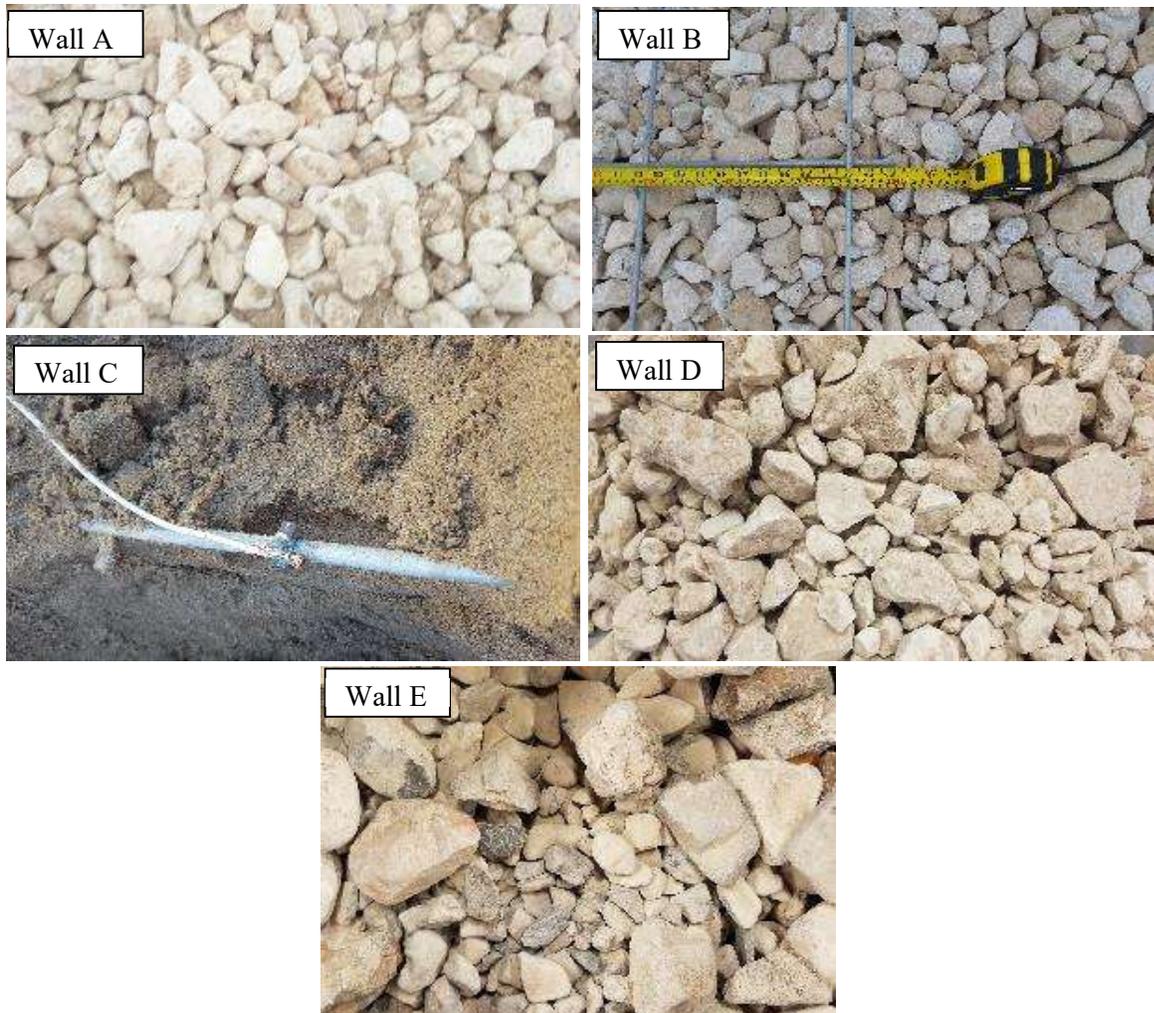


Figure 4.2 - Backfill Material of Instrumented MSE Walls

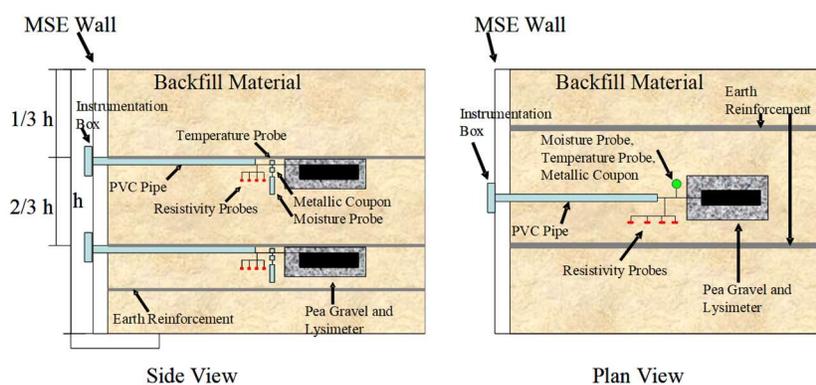


Figure 4.3- Side and Top View of Instrumentation Placement

Figure 4.4 illustrates the instrumentation placed at each of the sites and the wiring of the steel elements. Two electrically isolated metallic reinforcements were located once the target MSE wall height was reached.

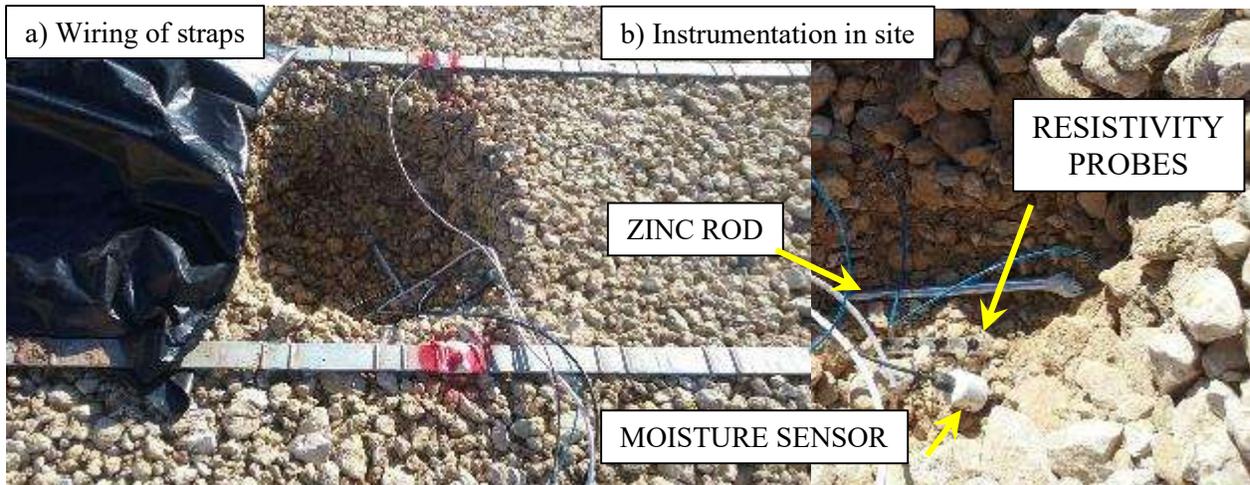


Figure 4.4 - Installation of Sensors in MSE Walls

Laboratory Tests on samples collected

To be able to correlate the results obtained from the field instrumentation, samples obtained directly from the field were tested and characterized following the procedures discussed before. These include the gradation and electrochemical tests (resistivity, conductivity, chloride, and sulfate). Samples were taken from these walls before compaction as well as after compaction whenever possible.

The procedure detailed in Chapter 2 was used to measure the resistivity of the field samples. Figure 4.6 shows the minimum resistivity of all samples. The minimum resistivity for the compacted sample of Material A is significantly lower than the one before compaction. The compacted sample for Material B exhibited slightly higher resistivity than the one before compaction. All materials except Material C had a resistivity well above the acceptance limit. Material C had an average resistivity of 3017 ohms-cm, which is barely above the 3000 ohms-cm acceptance limit. The coarse materials had a much higher resistivity than the fine material. When comparing the resistivity of the compacted samples to the resistivity of the samples before compaction, it appears that only Material A exhibited a substantial difference. In Materials A and D, the compacted samples had a marginally higher minimum resistivity than the corresponding samples one before compaction.

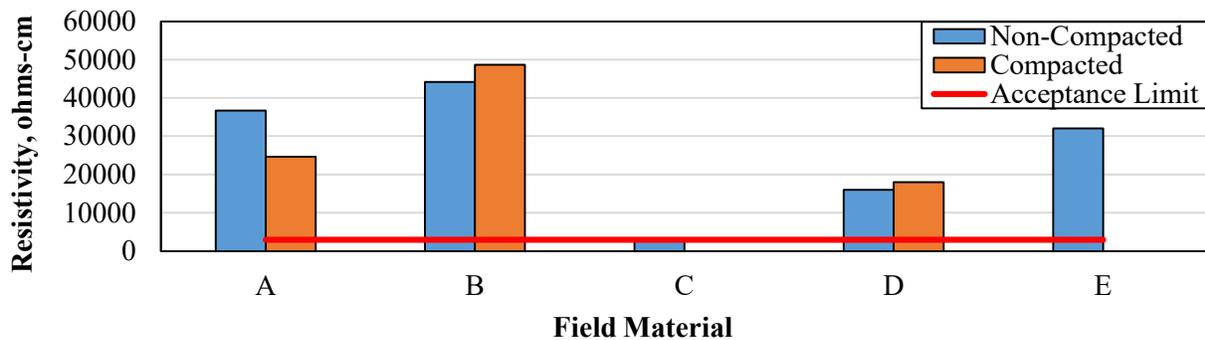


Figure 4.4- Minimum Resistivity of MSE Wall Backfill Material

Leachate was extracted as previously discussed from the resistivity tests of each coarse aggregate. These leachates were tested for conductivity, chloride content, and sulfate content on all materials but Material C. Because of the particle size distributions of Material C, it was not possible to extract fluid from the resistivity tests. Figure 4.7 shows the conductivity, chloride content, and sulfate content measurements. The conductivity values of compacted samples were higher than the samples before compaction for the three materials where such samples were collected. A similar pattern can be observed in the sulfate and chloride concentrations. None of the materials are close to the acceptance limits for chloride and sulfate, which are 100 and 200 mg/L, respectively. This is in line with the resistivity measurements, which indicate that the materials are far from failing the tests.

Summary of Results from Post-Construction Monitoring

Data Logger

The moisture probe recorded readings of moisture content, temperature, dielectric constant, and conductivity every four hours throughout the duration of the monitoring. Figure 4.8 shows the moisture content measured over time for Site A. For this wall, the upper level remained at a higher level of moisture than the lower level. The temperature, conductivity, and dielectric reading for Site A, as well as the readings for all the other walls can be found in Appendix C.

Corrosion Rate

Figure 4.9 shows the corrosion rate measurements taken at each of the site visits. The corrosion rates appear to have remained constant throughout the monitoring period. In Walls A, C, and D the corrosion rates were higher in the upper level than in the lower level. The corrosion rates are relatively low, rarely exceeding 1 micron per year. The corrosion rate in the upper level of wall A is exceedingly high. This could be due to an error in the installation of the instrumentation or a bad contact in the connections, so the results from this section of the wall are not comparable with the rest.

Resistivity

Figure 4.10 shows resistivity measurements taken at each of the sites. The resistivity of the lower level of the wall was higher than on the upper level. Walls A, D, and E exhibited very low resistivity in the upper level, with some measurements being lower than the 3000 ohm-cm limit. This correspond with the corrosion rate, since in these walls the corrosion rate was higher in the upper level than in the lower level.

Lysimeter

Throughout the monitoring of the five walls, the team was only able to extract leachate from Wall D on two occasions: in February 2018 and April 2018. The pH, conductivity, chloride concentration, and sulfate concentration, as well as the resistivity and corrosion rates measured on the fluid extracted at those dates are listed in Table 4.1. The chloride and sulfate concentrations, as well as the pH increased slightly while the conductivity decreased slightly. It appears that the increase in the chloride and sulfate concentrations could relate to the increase in the corrosion rate.

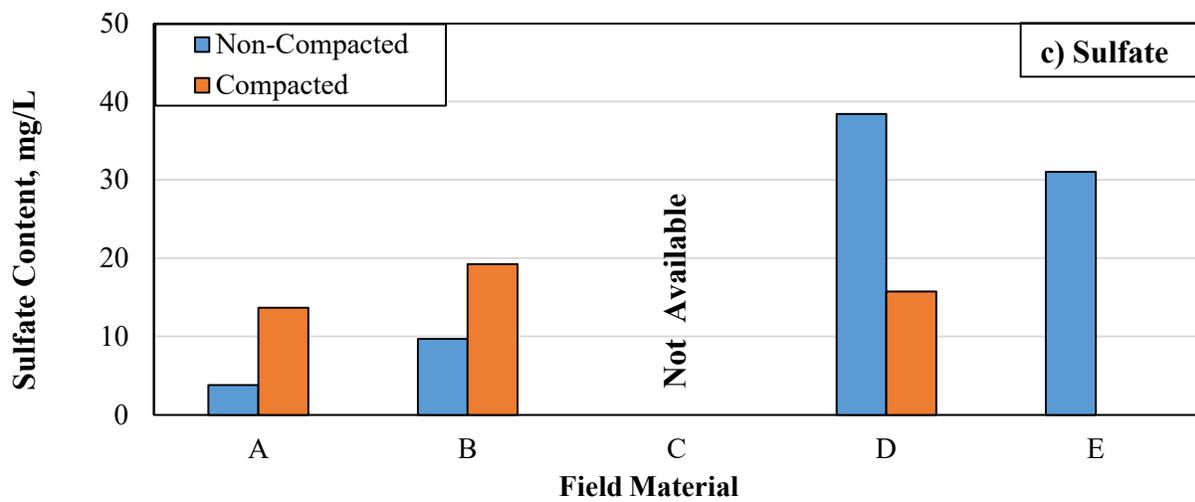
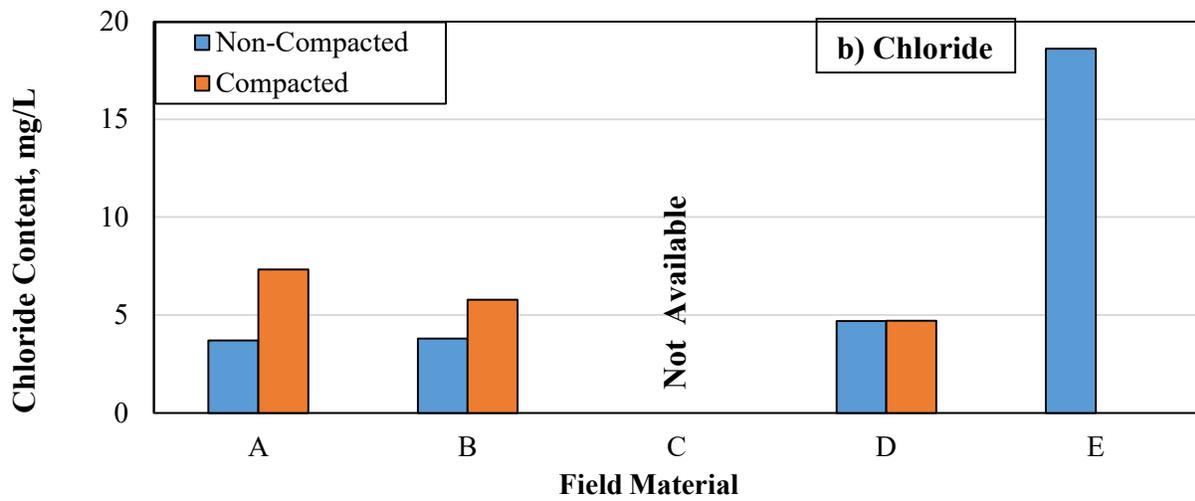
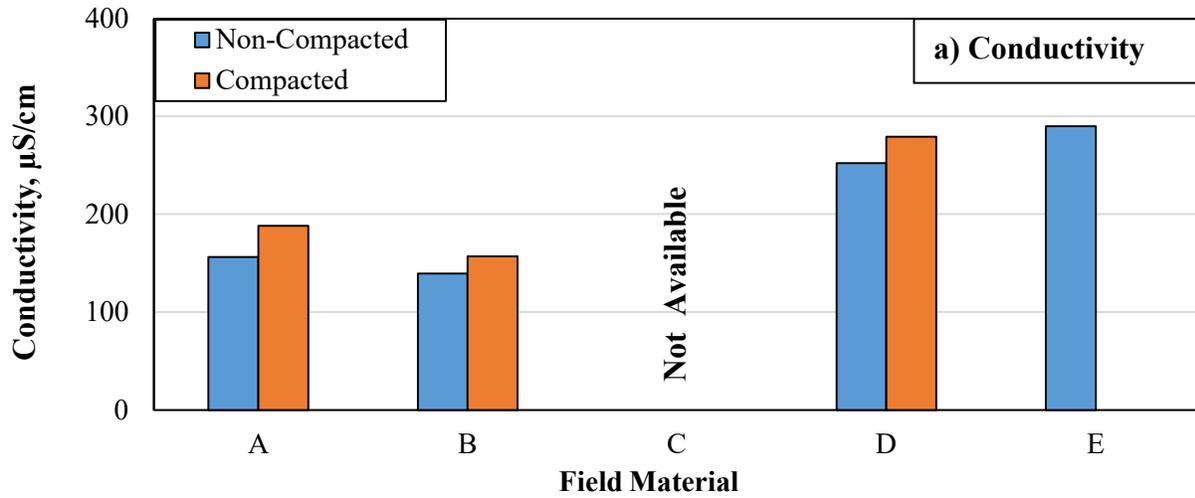


Figure 4.5- Leachate Test Results

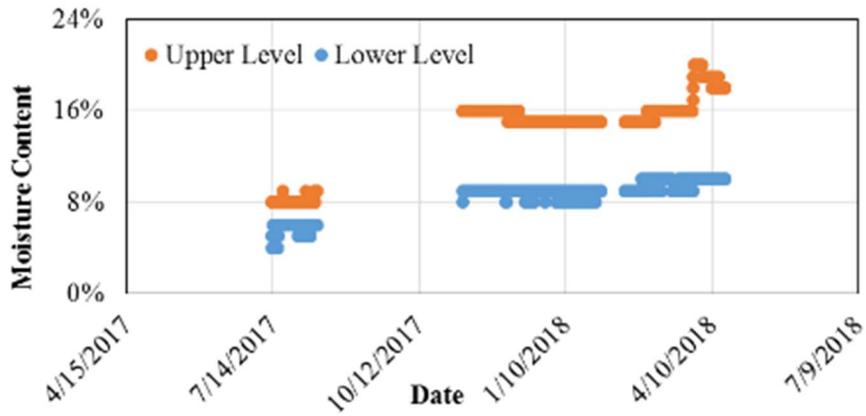


Figure 4.6 - Moisture Readings from Wall A

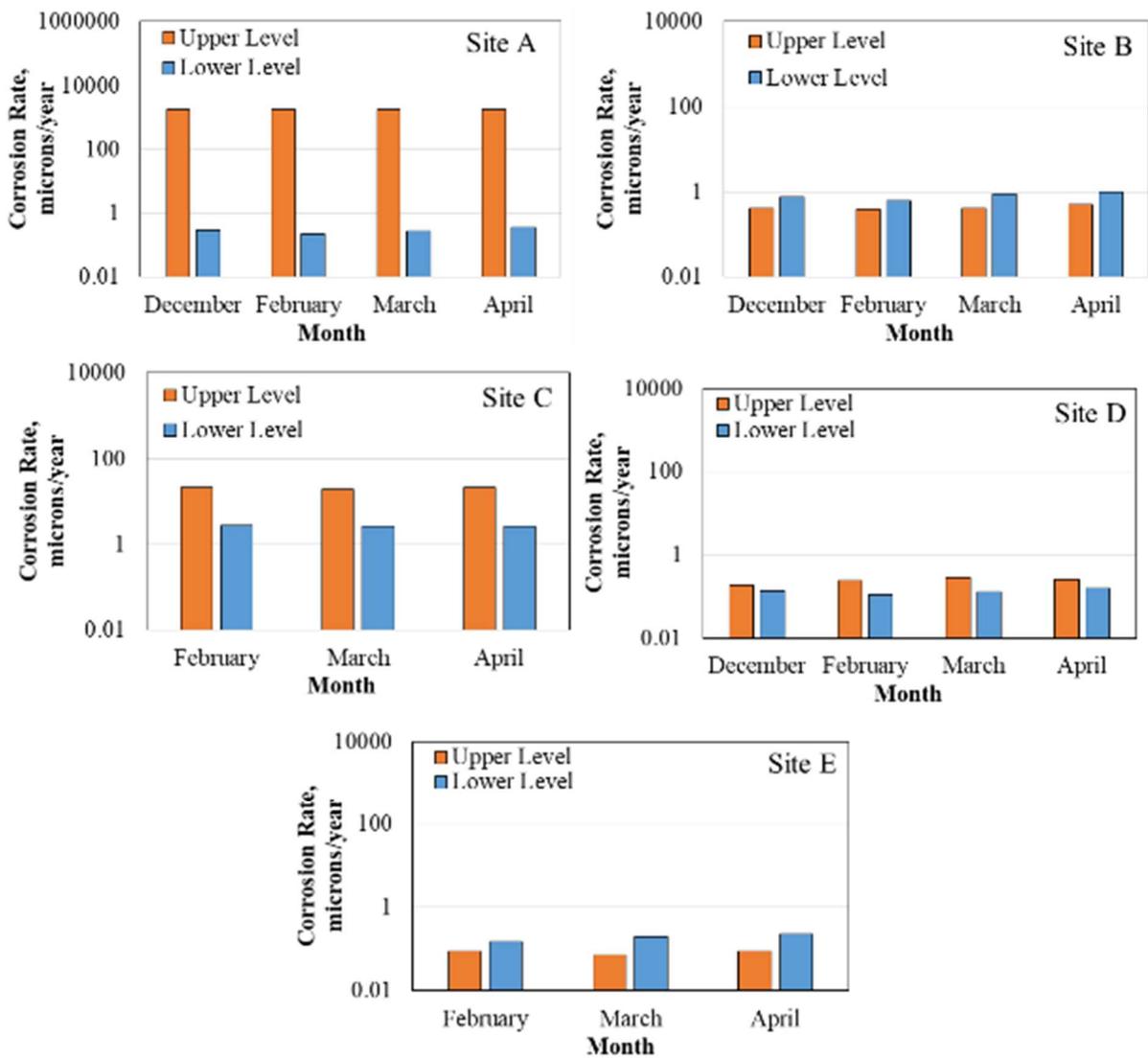


Figure 4.7- Corrosion Rate Measurements from Instrumented Sites

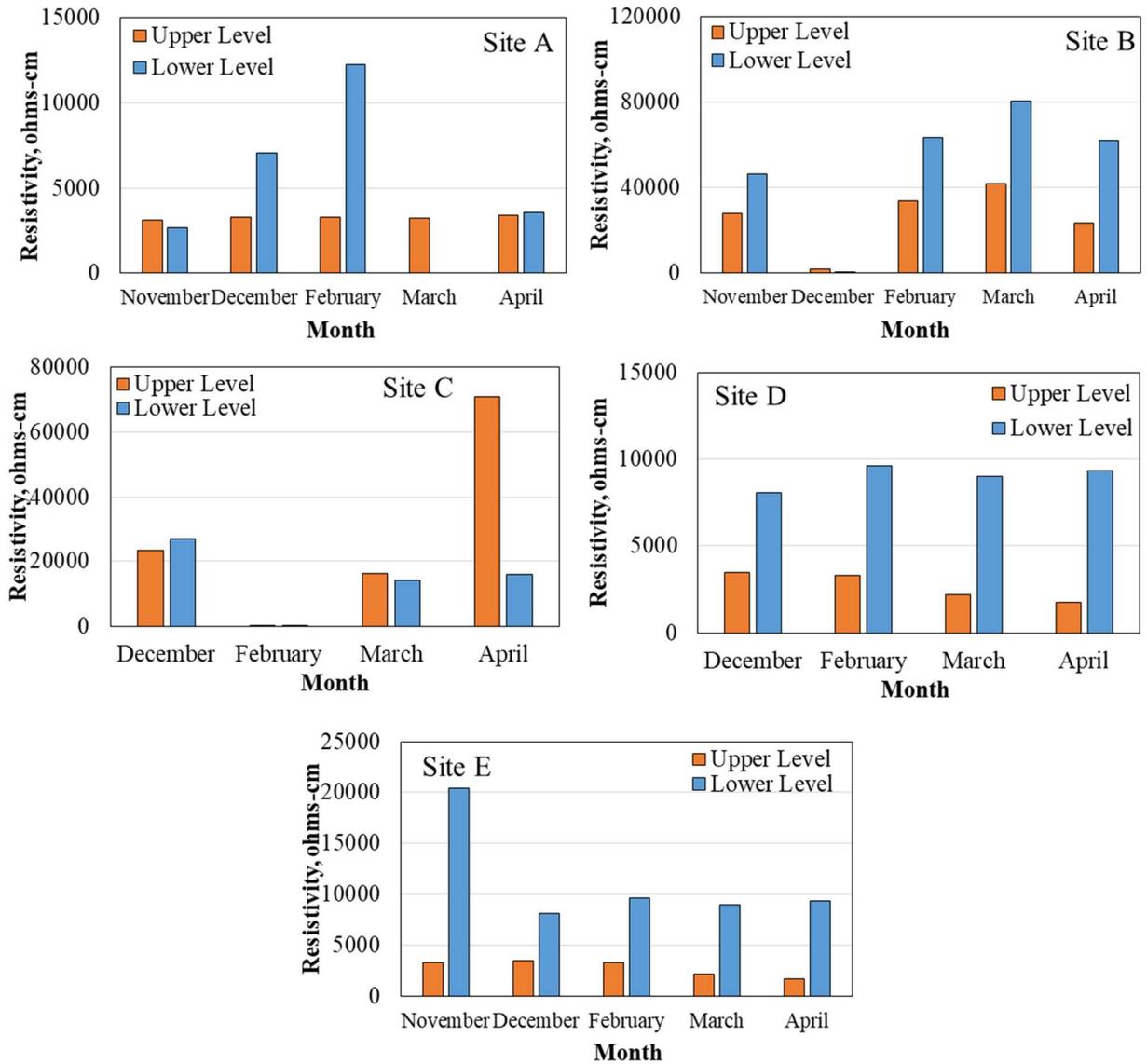


Figure 4.8- Resistivity Measurements from Instrumented Sites

Table 4.1- Leachate Samples from Lower Level of Wall D

Date of Sampling	2-15-2018	4-18-2018
pH	7.2	7.4
Conductivity (µs/cm)	371	358
Chloride (mg/L)	7.0	11.2
Sulfate (mg/L)	17	21
Resistivity (ohms-cm)	9654	9358
Corrosion Rate (microns/yr)	0.11	0.16

Chapter 5- Conclusion

This report contains results for each of the study objectives listed in the introduction. The main goals of this project were:

- Producing data using proposed specifications for the measurement of Resistivity and geochemical parameters in MSE Wall materials (Tex-129-M and Tex-620-M) and compare them to data from traditional TxDOT methods for Resistivity (Tex-129-E), pH (Tex-128-E), and Chloride and Sulfate Contents (Tex-620-J).
- Conducting field tests to establish limits of acceptable material properties for the proposed specifications

The conclusions and recommendations obtained from the above actions items are summarized below.

Resistivity Testing

A new test procedure for measuring the resistivity of MSE Wall backfill materials was developed. This procedure improves on the existing Tex-129-E by allowing the use of particles that are retained above a #8 sieve. This procedure is referred to as Tex-129-M in the report. Testing was performed on the standard TxDOT gradations AS, BS, and DS using both the new procedure and Tex-129-E. It was found that for AS and DS, which are coarser gradations, resistivity measured using Tex-129-M was about three to four times higher than if it was measured with Tex-129-E. For BS, the resistivity measured between the two was much more similar. This seemed to indicate that measurements using Tex-129- E are not very representative of the actual values for coarse materials.

Geochemical Testing

Similar to the resistivity testing, test procedures Tex-128-E, Tex-129-E, Tex-145-E, Tex-146-E, and Tex-620-J were used measure the soils' pH, conductivity, chloride content, and sulfate content as baseline measurements. These were then compared with the results obtained from the new procedure Tex-620-M. As opposed to Tex-620-J, Tex-620-M permits the use of large particles and not just the portion passing the #40 sieve. Also, Tex-620-M standardizes the mixing method and reduces the mixing time to 30 minutes. Results also indicated that the existing methodologies were not representative in coarse gradations, with Tex-620-M yielding conductivity, sulfate content and chloride content values that are about 50% lower than those tested using the existing specifications.

Field Testing

Measurements of corrosion rate, moisture content, and resistivity were obtained from monitoring the instrumented walls throughout the duration of the project. In addition, samples of backfill were taken to the laboratory in order to test the resistivity and the geochemical parameters using the methodology mentioned previously. It was found that lab measurements of resistivity and geochemical parameters can correlate to behavior in the field. Lab testing also helps corroborate the fact that current specifications are not representative since it was found that measured corrosion rate values are also dependent on the gradation of the backfill.

Lessons Learned

The results from project Project 0-6359 entitled “Characterization of Backfill Materials for Prevention of Corrosion of MSE Metallic Wall Reinforcement,” showed that the current geochemical testing protocols were not representative of the material used as backfill in MSE walls. Thus, the development of new procedures was recommended for the consideration of TxDOT. Based on the promising results from that study, this follow on study was carried out to standardize the test protocols and provide specifications that TxDOT personnel can readily use the proposed methods. In resistivity testing, the new procedure (Tex-129-M) yielded much higher resistivity values when compared to Tex-129-E. Similarly, the new procedure for leach testing (Tex-620-M) yielded lower values of conductivity and salt content when compared to Tex-128-E, Tex-129-E, Tex-145-E, Tex-146-E, and Tex-620-J. In summary, the new procedures proved to be more representative of observed field measurements in the testing of coarse aggregate commonly used as backfill in MSE walls.

Final Recommendations

It is recommended that the specifications developed through this project are implemented for the measurement of electrochemical and geochemical parameters of coarse backfill materials as follows:

- Test procedure Tex-129-M to be used for the measurement of the resistivity in coarse-grained backfills. (Appendix A)
- Test procedure Tex-620-M for the measurement of the conductivity, pH, chloride concentration and sulfate concentration. (Appendix B)

Appendix A

Test Procedure for

MEASURING THE RESISTIVITY OF SOILS AND AGGREGATES



TxDOT Designation: Tex-129-M

1. SCOPE

- 1.1 This method determines the resistivity of soils and aggregates.
 - 1.2 Resistivity is an important factor in considering the corrosion potential of soils and aggregates to metal pipe, earth-reinforcing strips, and other metal items in earthwork.
 - 1.3 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.
-

2. DEFINITIONS

- 2.1 Resistivity—Resistivity decreases with an increase in moisture content of the material until reaching the minimum resistivity. This minimum resistivity value is the resistivity of the material.
-

3. APPARATUS

- 3.1 *Portable resistivity meter*, Nilsson Model 400 or equal.
 - 3.2 Three plastic/acrylic/Plexiglas boxes with inside dimensions A x B x C as reflected in Table 1.
 - 3.2.1 Two 20 Gauge Stainless Steel Plates to act as electrodes per box, with dimensions A x B, attached to the boxes in accordance to detail drawing in Figure 1.
 - 3.3 Straightedge.
 - 3.4 Drying pans, mixing pans, trowel, and small scoop.
 - 3.5 Concrete Mixer
 - 3.6 *Set of Standard U.S. Sieves*, meeting the requirements of Tex-907-K.
 - 3.7 *Graduated beaker*, 7 fl. oz. (200 ml.)
-

- 3.8 Water jug or similar container, at least 1 gal.(4 L)
- 3.9 *Balance*, minimum capacity of 55 lb. (25 kg), accurate and readable to 0.1% of the test load.
- 3.10 *Hand Tamper*, 8 in. by 8 in. (200 mm x 200 mm)
- 3.11 *Weight*, 100 g

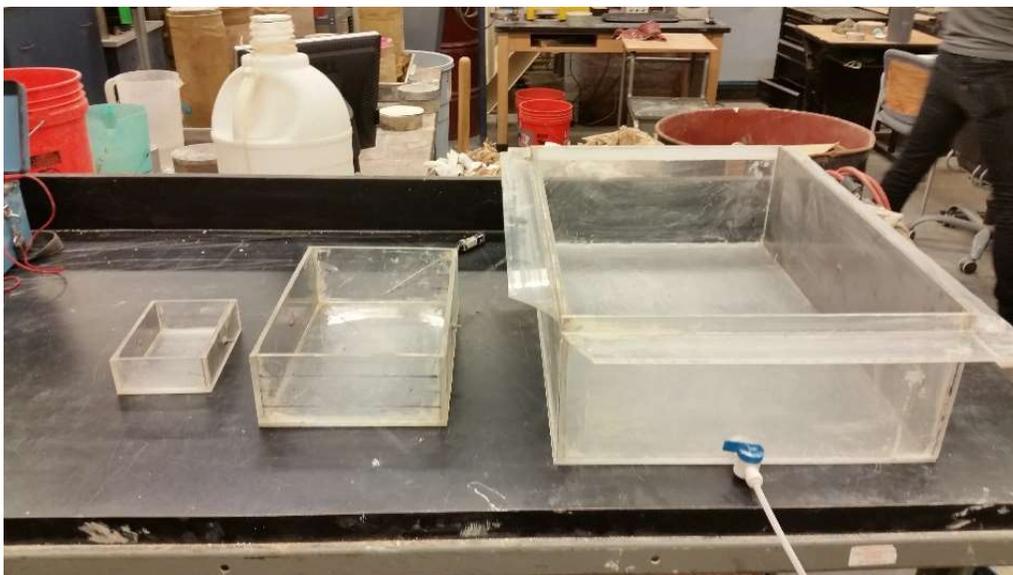
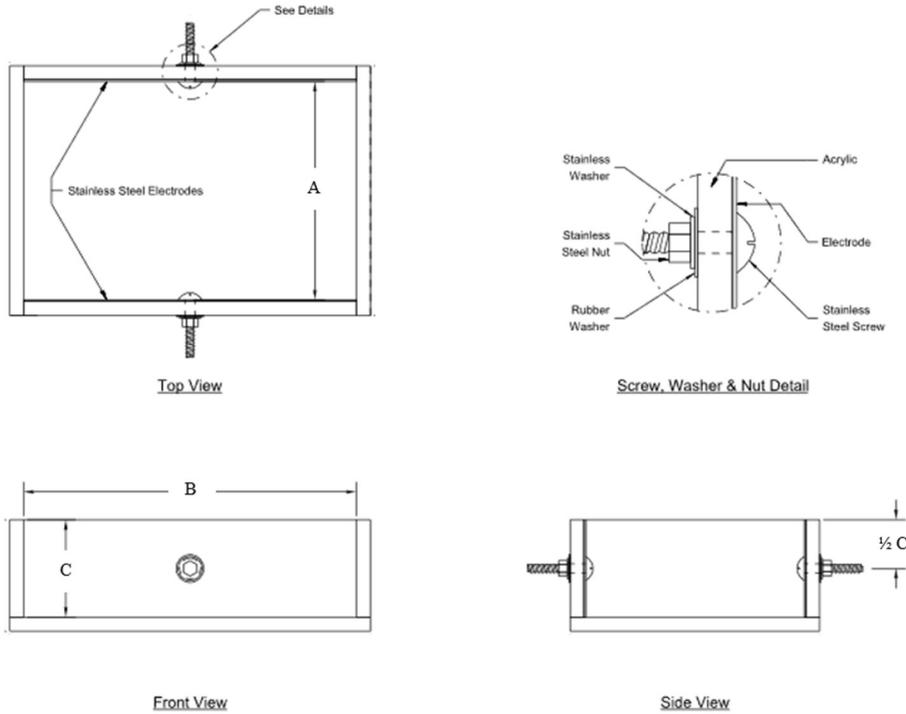


Figure A.1—Laboratory Boxes for Resistivity Determination

Table A.1— Box Dimensions

Box Size	Dimensions		
	A, in. (mm)	B, in. (mm)	C, in. (mm)
Small	4 (100)	6 (150)	1-3/4 (45)
Medium	8 (205)	12 (305)	3-1/2 (90)
Large	16 (410)	24 (610)	7 (180)

4. MATERIAL

4.1 Distilled or deionized water.

5. PROCEDURE

5.1 Follow Tex-100-E to secure a representative sample of material passing the 3” (76.2 mm) sieve to yield enough material to run the test in accordance to Table 2.

5.2 Dry the sample to constant mass in an oven at a temperature of $60 \pm 5^{\circ}\text{C}$ ($140 \pm 9^{\circ}\text{F}$) and allow it to cool at room temperature.

5.3 Conduct a sieve analysis with sieve sizes listed in Table 2.

5.4 Determine nominal maximum aggregate size and use Table 2 to determine which box size to use in testing.

5.5 Add distilled or deionized water to dry sample at room temperature in accordance to Table 2.

Note 1—Any material with a Nominal maximum aggregate size of 7/8” (22.2 mm) or greater will be considered a coarse aggregate.

Table A.2 — Box Size and Material Determinations

Nominal Maximum Aggregate size		Box Size	Sample Weight, lb. (kg)	DI Water per Increment, mL
Sieve Size	in. (mm)			
3"	3 (76.2)	Large	190 (85)	3200
1 3/4"	2.5 (63.5)			
1"	1 (25.4)	Medium	22 (10)	400
7/8"	0.875 (22.2)			
3/8"	0.375 (9.5)	Small	3 (1.3)	50
#4	0.187 (4.7)			
#40	0.017 (0.42)			
#100	0.006 (0.15)			
#200	0.003 (0.07)			

- 5.6 Mix until water is dispersed uniformly throughout sample.
- 5.6.1 Observe if there is unmixed water. If there is, the sample has reached maximum absorption. (This effect is usually observed in samples with low fines contents).
- 5.7 Fill the appropriate soil box by compacting wet sample, making sure the sample completely fills the box.
- 5.7.1 Compact sample by hand or using a small weight if using the small box.
- 5.7.2 Compact wetted sample into the box with hand tamper if using medium or large box.
- 5.8 Level top with a straightedge.
- 5.9 Weigh sample in box and use this weight to control density in subsequent measurements.
- Note 2**—When testing in the large box, weigh the material leftover from the box.
- 5.10 Clip one set of wires on the left side of the box and plug into the left of the meter dial. Clip the other set of wires on the right side of the box and plug into the right side of the meter dial.
- Note 3**—The dial reads resistance in ohms, measured between electrodes.
- 5.11 Move power switch to the adjust position to make a preliminary adjustment.
- Note 4**—If dial is below 0.1 after adjustment, switch the multiplier to the next power down. If dial is above 0.9 after adjustment, switch the multiplier to the next power up.
- 5.12 Place power switch in a read position, read and record the resistance, in ohms, on the data sheet. Resistivity varies with temperature; therefore, it is important that the sample and added moisture be at uniform room temperature when mixed and tested. For coarse aggregates, proceed to Section 5.13. For anything else, go to Section 5.15.
- 5.13 Remove sample from box, and repeat procedure until reaching maximum absorption (5.5.1).
- 5.14 Add DI water into the compacted sample inside the box, taking a resistivity measurement after each increment. Insure that each added increment of water is dispersed evenly throughout the sample before taking a resistivity reading.
- 5.15 Repeat above procedure until reaching the minimum resistivity. Report the resistivity in ohms-cm.

Note 5—For coarse aggregates, the minimum resistivity will be at the point at which the water level reaches the top of the box following Section 5.14.

Note 6—For sandy soils, minimum resistivity will be the point at which total saturation occurs. This happens when water is observed rising to the surface during compaction of the sample. Repeat from Section 5.5.

Note 7—The resistivity for sandy soils is generally higher than for clay soils. The sandy soils may contain higher levels of soluble salts and not always increase after decreasing readings.

6. CALCULATIONS

6.1 Calculate the Soil Box Factor (SBF):

$$SBF = A / D$$

Where:

A = Area of one electrode, cm²

D = Distance between electrodes, cm.

6.2 Calculate the Resistivity, in ohm-cm = SBF x Resistance using resistivity meter:

$$R = SBF(R_{OHM})$$

Appendix B

Test Procedure for

DETERMINING THE CONDUCTIVITY, PH, SULFATE CONTENT, AND CHLORIDE CONTENT OF SOIL AND COARSE AGGREGATE



TxDOT Designation: Tex-620-M-1

1. SCOPE

- 1.1 This method describes how to determine the pH, conductivity and chloride and sulfate content in soil and coarse aggregate using a rice shaker test machine.
-

2. APPARATUS

- 2.1 oven, capable of maintaining a temperature of $60 \pm 5^\circ\text{C}$
- 2.2 balance, calibrated to weigh to nearest 0.1 g
- 2.3 vacuum filter holder and flask – 250 mL
- 2.4 conductivity meter with probe, conductivity range 1 to 10000 $\mu\text{S}/\text{cm}$
- 2.5 pH meter, with glass electrode, pH range 0 to 14 ± 0.1 .
- 2.6 pipette(s) and volumetric flask(s) for preparing standard dilutions
- 2.7 volumetric flask – 1 L
- 2.8 volumetric flask – 2000 mL
- 2.9 bottle roller machine (e.g., Thermo model 88881003 or similar)
- 2.10 Gilson Rice Shaker Test Machine or similar agitating apparatus
- 2.11 wide-mouth plastic bottle (e.g., Nalgene) – 2 L
- 2.12 125 mL plastic sample storage bottles (or similar)
-

3. MATERIALS

- 3.1 distilled or de-ionized water (conductivity less than 1 $\mu\text{S}/\text{cm}$ or resistivity greater than 1 $\text{M}\Omega\cdot\text{cm}$)
-

- 3.2 47 mm diameter, 0.45 μm nylon membrane filter
 - 3.3 pH buffer solutions of pH 4.0, 7.0, and 10.0
 - 3.4 certified anion reference solution, containing 1000 mg/L (1000 $\mu\text{g/mL}$) chloride
 - 3.5 certified anion reference solution, containing 1000 mg/L (1000 $\mu\text{g/mL}$) sulfate
-

4. SAMPLE PREPARATION

- 4.1 Collect a representative grab sample of the material from the field.
 - 4.2 Dry the sample in a 60 ± 5 °C (140 ± 9 °F) oven and cool to 25 ± 3 °C (77 ± 5 °F) in a desiccator to constant weight.
 - 4.3 Weigh out $0.1 \text{ kg} \pm 0.0001 \text{ kg}$ ($100 \text{ g} \pm 0.1 \text{ g}$) of the dried sample.
-

5. PROCEDURE

- 5.1 Before using, thoroughly clean the rice shaker, the vacuum filter holder, and the vacuum flask with distilled or de-ionized water, and air dry. Water must be passed through the filter holder during the cleaning step.
- 5.2 Add soil and deionized water to the bottle to achieve a soil-mass to water-volume ratio of 0.1 kg/L (e.g., $0.100 \text{ kg} \pm 0.0001 \text{ kg}$ of soil with $1.000 \text{ L} \pm 0.001 \text{ L}$ of DI).
- 5.3 Activate the agitating apparatus and allow to agitate on the “high” setting for 30 minutes.
- 5.4 At the end of the 30 minute period pour the sample from the agitating apparatus into the wide-mouth bottle, and let stand for 20 minutes.
- 5.5 While the sample is standing, calibrate the pH meter (buffer solution of pH 4.0, 7.0, and 10.0) and the conductivity meter according to the manufacturer's recommendations.
- 5.6 Clean pH electrode with water.
- 5.7 After standing time, measure pH using the calibrated meter. Place the tip of the electrode approximately 2 in. (50 mm) into the mixture. Allow reading to stabilize
- 5.8 Read and record the pH value to the nearest tenth of a whole number.
- 5.9 Remove and clean the pH electrode with water.
- 5.10 Clean conductivity probe with de-ionized water.

- 5.11 Place the tip of the conductivity probe approximately 2 in. (50 mm) into the mixture in the bottle. Allow reading to stabilize.
 - 5.12 Read and record the conductivity to the nearest micro-Siemen per centimeter ($\mu\text{S}/\text{cm}$). Report this as the sample conductivity in $\mu\text{S}/\text{cm}$.
 - 5.13 Remove and clean the conductivity probe with water.
 - 5.14 Filter 100 mL of the sample using the vacuum filter flask with a new 0.45 μm filter membrane.
 - 5.15 Pour the filtered liquid into the 125 mL sample storage bottle, and secure the cap/lid.
 - 5.16 Store the leachate sample in a refrigerator prior to analysis by ion chromatography.
-

6. ANALYSES OF CHLORIDE AND SULFATE CONTENT USING ION CHROMATOGRAPHY

- 6.1 Prepare 6 standards using the anion standard solution that cover the concentration range from 0.1 to 100 mg/L (e.g., 0.1, 2.0, 10, 50, 100, and 200 mg/L). The same distilled or de-ionized water used in the experiments should be used for preparing the standards.
- 6.2 If high concentrations (>100 mg/L) are suspected, dilute the sample by a factor of 10 using standard procedures prior to analysis. Note that dilutions can be made in separate pre-washed bottles or test tubes. Dilutions should use the same distilled or de-ionized water used in the experiments.
- 6.3 Follow the manufacturer's instructions to start the ion chromatograph's pump and electronic systems. Pump effluent through the column and detector until the ion chromatograph obtains a stable baseline.
- 6.4 Pour leachate samples into properly labeled sample vials. Allow the samples to adjust to room temperature before performing the ion chromatography analysis.
- 6.5 Add one prepared check-standard (e.g., 50 mg/L) and one deionized water blank after every four to five samples to check the accuracy of the chromatograph.
- 6.6 Perform the ion chromatography analysis of the samples to determine the concentration of the chloride and sulfate ions.
- 6.7 Obtain chloride and sulfate concentrations in mg/L as determined by the ion chromatography system. If sample dilutions were made, multiply this concentration by the dilution factor.

- 6.8 Calculate the mass fraction (in mg/kg) of chloride and sulfate by dividing the leachate sample concentration in mg/L by the soil-mass to water-volume ratio in kg/L (i.e., 0.1 kg/L, Step 5.2). For example, if the leachate chloride concentration was 15 mg/L, then the chloride mass fraction would be 150 mg/kg.
- 6.9 Report the chloride and sulfate mass fraction of the soil in units of mg/kg.

Appendix C

Data Logger Information

Shown below are the continuous readings from the data logger at each of the walls. The data logger recorded moisture content, temperature, dielectric constant, and conductivity at four hour intervals throughout the duration of the monitoring.

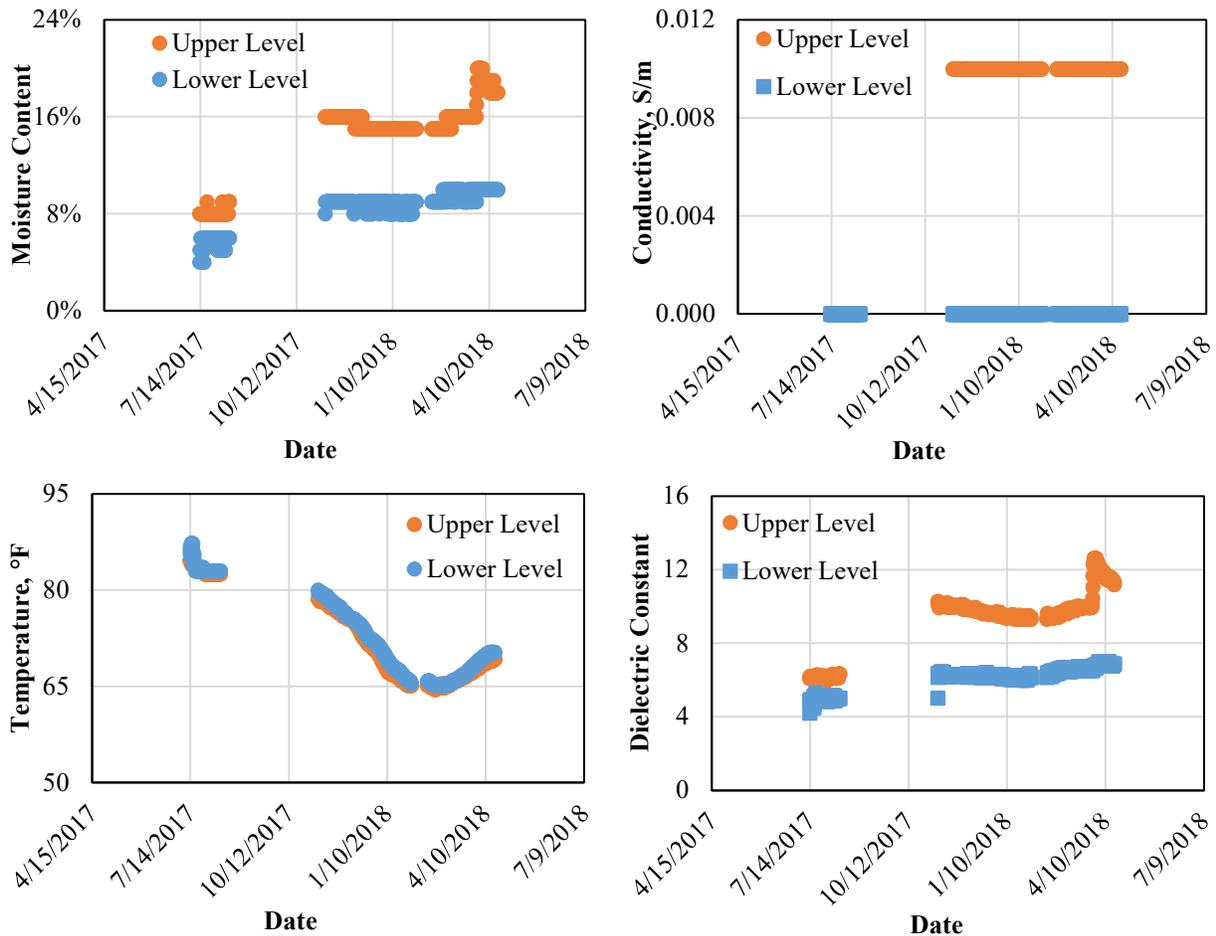


Figure C.1- Data logger Readings at Site A

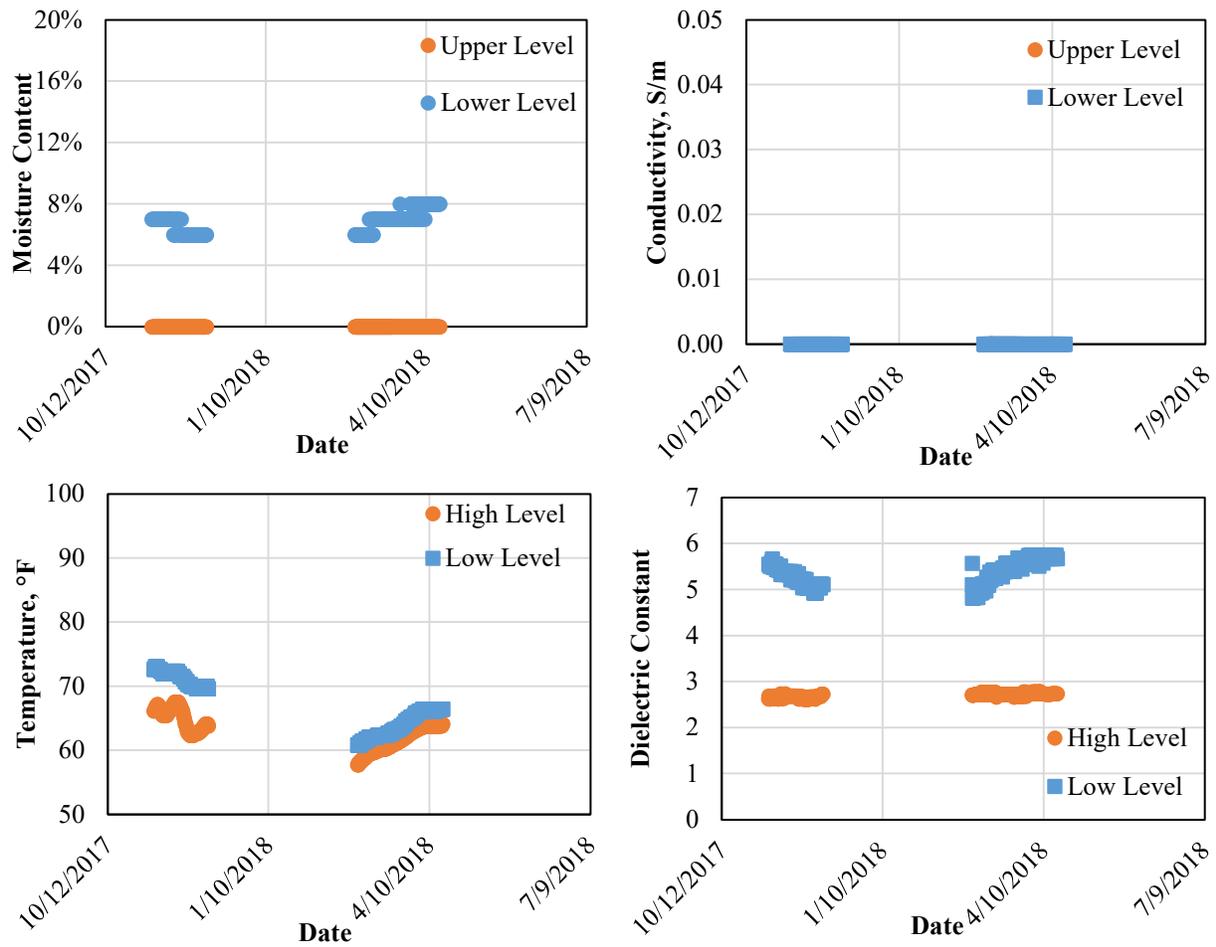


Figure C.2- Data logger Readings at Site B

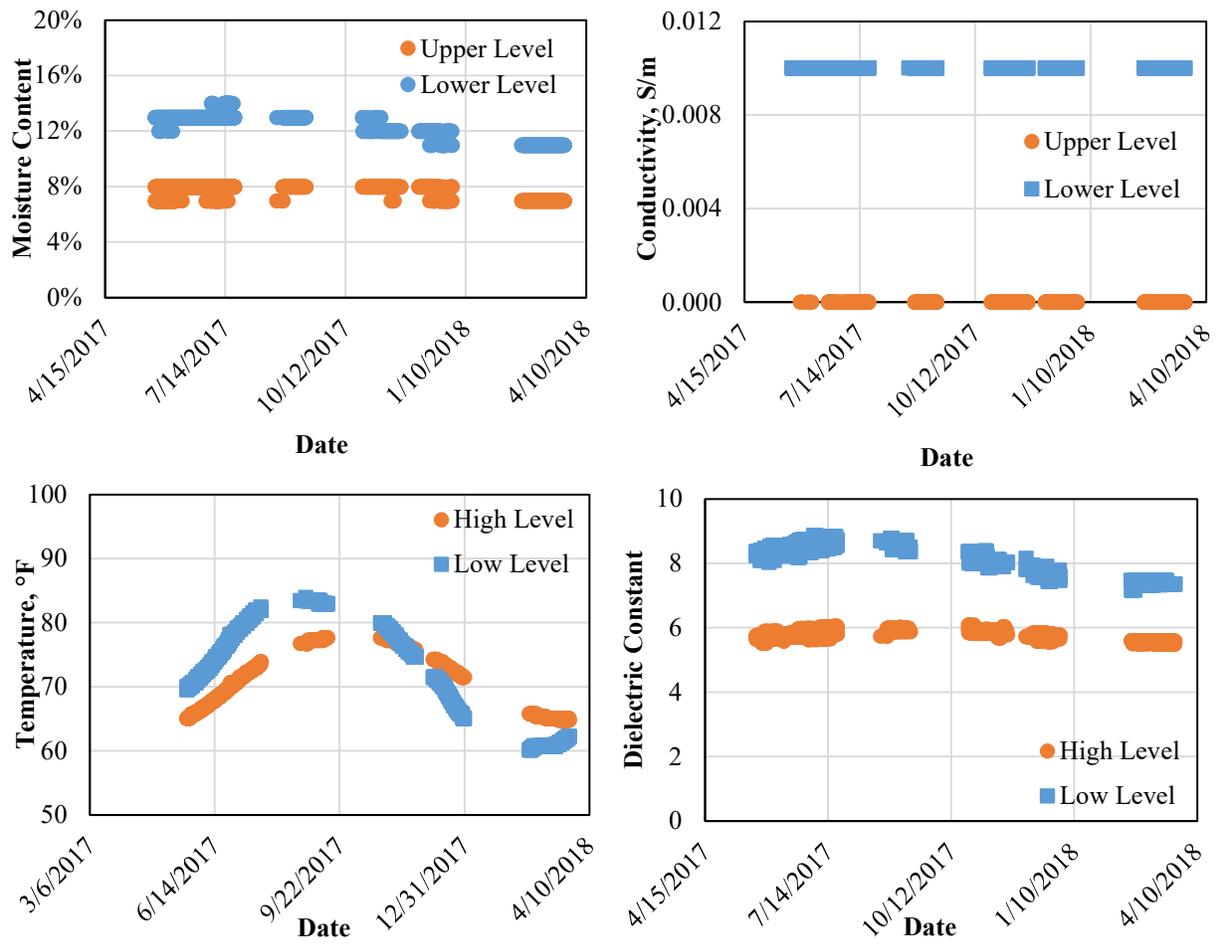


Figure C.3- Data logger Readings at Site C

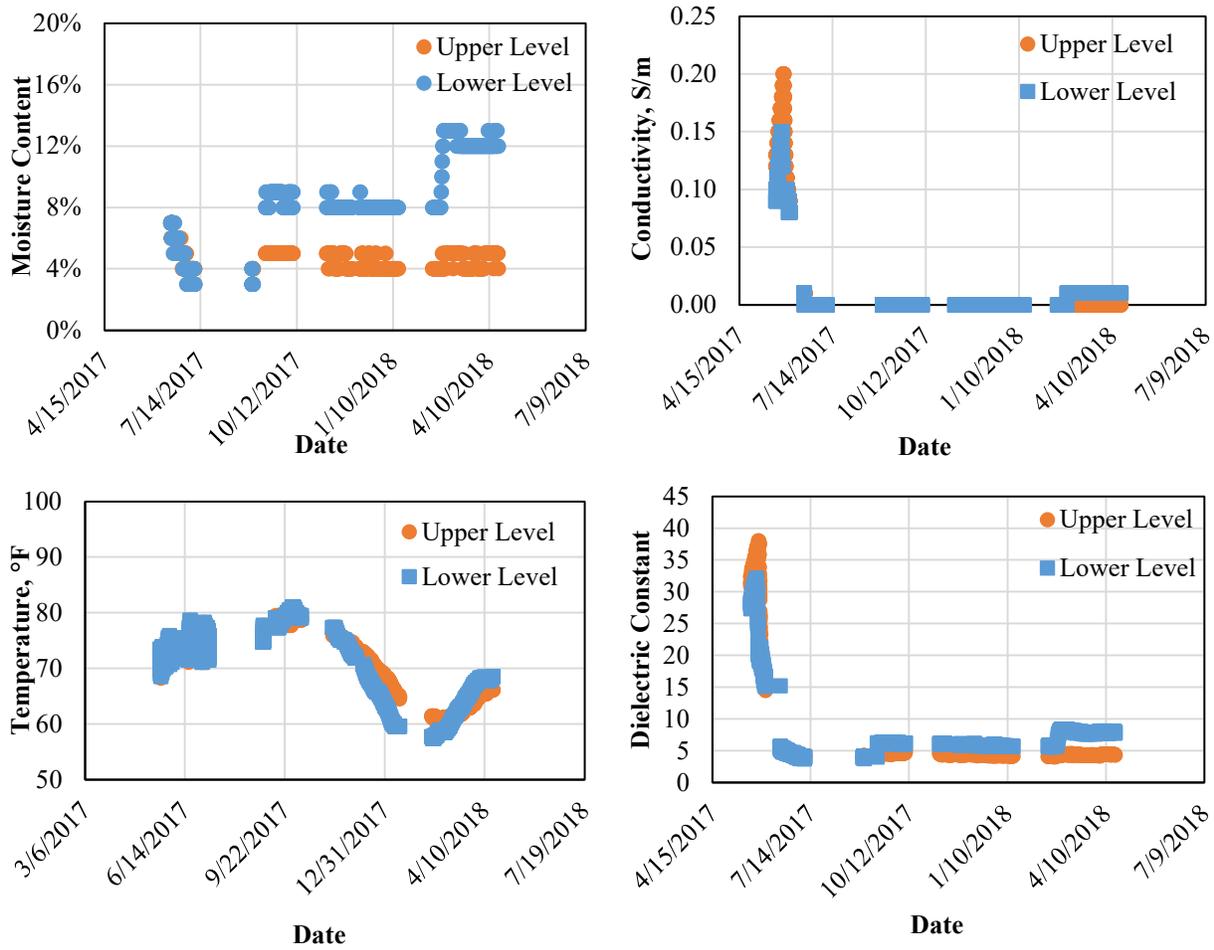


Figure C.4- Data logger Readings at Site D

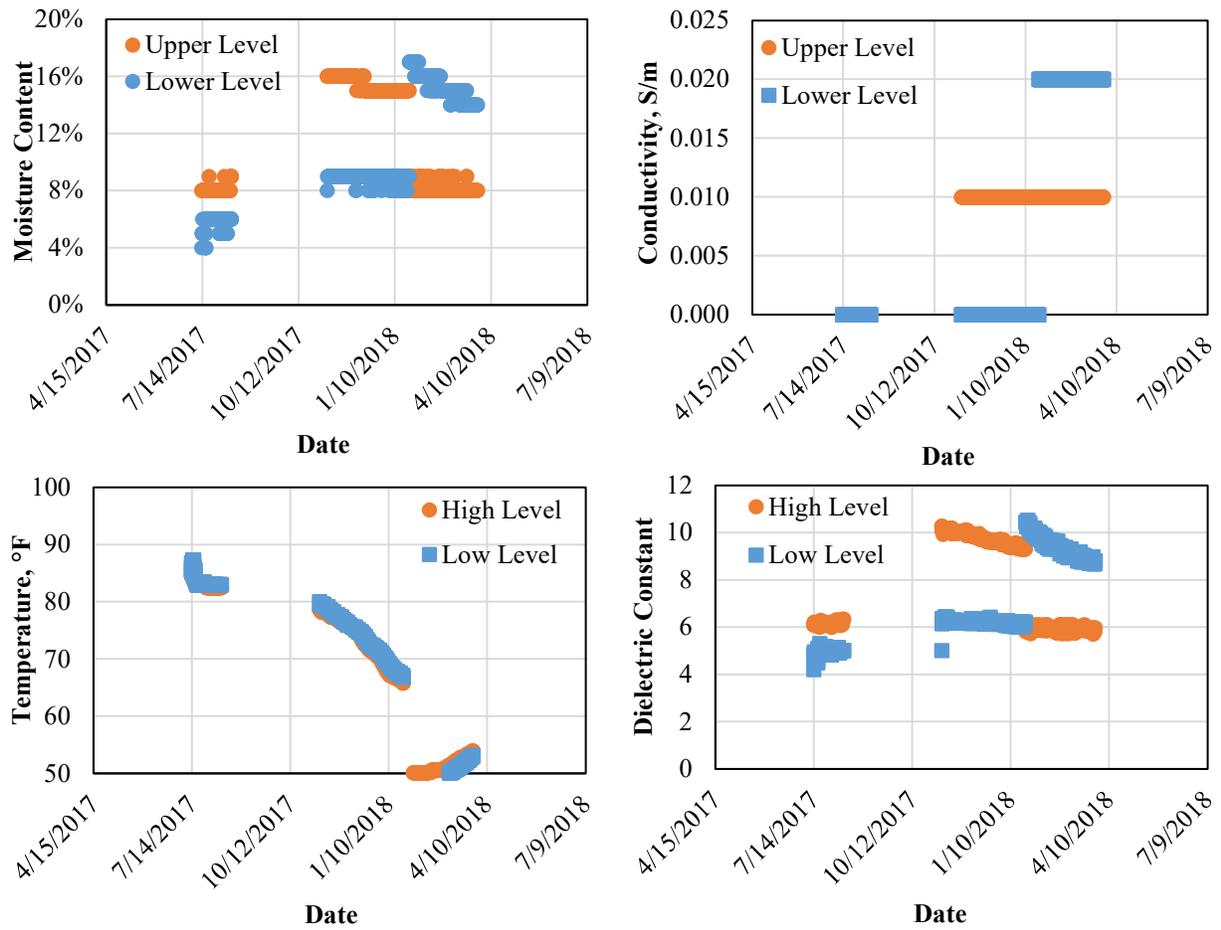


Figure C.5- Data logger Readings at Site E