WHAT IS CORROSION ... AND WHY IS CORROSION TESTING FOR SOILS IMPORTANT?

BENCHMARK GEOTECHNICAL LABS

February 2018

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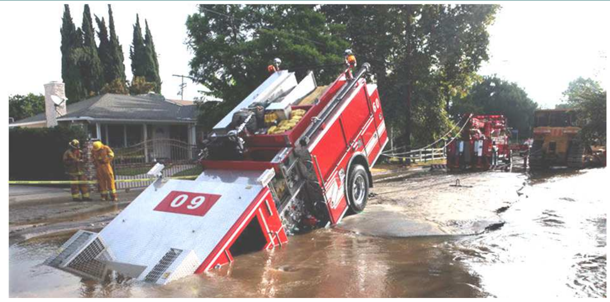
Metallic elements such as iron, copper, zinc and nickel occur naturally as ore in the form of metal oxides, sulfides and carbonates. The conversion from ore to metal separates the metallic element from the oxides, etc. which requires the input of large amounts of energy. The resulting metal or alloy is in a high-energy state when compared to the original ore. Given the opportunity, it will revert back to its more natural lower-energy state by combining with oxides, sulfides, and carbonates. This process is called corrosion.

High liability and costs can arise due to the corrosive actions of soil. In 2002, the Federal Highway Administration and NACE International estimated that the total direct cost of corrosion in the United States was about 3.1 percent of the U.S. gross domestic product (GDP) (Publication No. FHWA-RD-01-156). It also estimated that the indirect costs of corrosion may equal or exceed the direct costs. Given that the 2016 US GDP was $18.75 trillion, we can estimate that corrosion cost the US economy in 2016 was more than $1.1 trillion. This study also indicated that major contributions to this value are from corrosion occurring on or in the ground. This includes drinking water and sewer systems, highway bridges, gas and liquid transmission pipelines, and electrical utilities. Corrosion can be a problem for both metallic and concrete structures in contact with the ground. If corrosion is not considered, the service life of the project may be severely overestimated and public safety may be at risk.

It is becoming more common that corrosion testing is included as a standard part of geotechnical investigations, often for the future use of a corrosion engineer. If your project will include components such as foundations, pipelines, MSE structures, soil or rock anchor systems or culverts, at some point, someone will be interested in the corrosive potential of the soil on the site. They will typically look to the geotechnical engineer for this information.



A $500,000 fire truck damaged in a sinkhole created by a corroded water main.

SO WHAT ARE CORROSION TESTS AND WHY ARE THEY IMPORTANT?

There are six primary parameters to evaluate the corrosion potential of a soil. These are resistivity, pH, sulfate, chloride, redox potential, and sulfide. The following is a quick overview of what these parameters are and why they are important when evaluating the corrosion potential of soils.

RESISTIVITY

Electrical resistivity has historically been used as a broad indicator of soil corrosivity. Soil electrical resistivity is a measure of how easy it is for electrons to flow in the soil. The flow of electrons is essential in most types of corrosion reactions. Other factors being equal, corrosion reactions will proceed more quickly when the resistance to electron flow is lower and proceed more slowly in soils with a higher resistivity. Soil resistivity is affected by both the amount of dissolved solids (salts) in the soil, as well as the moisture content of the soil. The more dissolved solids present in the soil, the lower the resistivity will tend to be. The resistivity of a dry soil will tend to be very high. As the moisture content increases, the resistivity will drop. As the soil approaches saturation the resistivity will reach a minimum (this the worst-case condition). Further increases in moisture content will result in an increase in resistivity as the dissolved solids begin to be diluted by the water. The most conservative measure of resistivity is the 100% saturated resistivity (aka minimum resistivity). Soil resistivity is by no means the only parameter affecting the risk of corrosion damage. A high soil resistivity alone will not guarantee the absence of serious corrosion.

pH

pH is a measure of how acidic (pH < 7) or alkaline (pH > 7) the soil environment is. Soils usually have a pH range of 5 to 8. In this range, pH is generally not considered to be the dominant variable affecting corrosion rates. More acidic soils obviously represent a serious corrosion risk to common construction materials such as steel, cast iron and zinc coatings. Alkaline soils tend to have high sodium, potassium, magnesium and calcium contents. The latter two elements tend to form calcareous deposits on surfaces providing some protection against corrosion. pH, coupled with the oxidation conditions in the soil environment, can dramatically affect the nature of microbiological activity that can have a large impact on corrosion rates.

SULFATE

Sulfate (SO_4^{2-}) is a naturally occurring form of sulfur. In drier parts of the country, soils can be high in sulfate and can be laced with gypsum (Calcium Sulfate) veins. If you see a white powdery substance in the soil that does not react with hydrochloric acid, chances are it is gypsum or another form of a sulfate salt. Compared to the corrosive effect of chloride ions, sulfates are generally considered to be more benign in their corrosive action towards metallic materials. However, the presence of sulfates can pose a major risk for metallic materials because the sulfates can readily be converted to highly corrosive sulfides by anaerobic sulfate reducing bacteria. In addition, sulfates can attack concrete and chemically change the binding compounds causing expansion, cracking, and loss of strength. If you have ever seen a white powdery substance on a concrete surface you may have seen evidence of sulfate attack. In reinforced concrete structures, sulfate attack may expose the rebar to corrosion by other compounds such as chloride or sulfide. Concrete weakened by sulfate attack will begin to irreversibly lose its strength and may be at greater risk of failure from seismic or other loading. In severe conditions, sulfate attack can decrease concrete's lifespan from 150 years to 15 years or less. Knowing the sulfate levels in the soil is an important variable when deciding what type of cement to use for a project and how it should be mixed.

The white powder may be visual evidence of sulfate attack of concrete.

CHLORIDE

Chloride ions are generally harmful as they participate directly in the electrochemical reactions that take place during the corrosion process. Chloride can also destroy the stable layers of protection that can naturally form on the surfaces of some metals, exposing the unprotected metal to further corrosion. In reinforced concrete structures, chloride can migrate through the concrete causing the rebar to begin corroding and swelling, subsequently causing the surrounding concrete to crack and break apart. The presence of chloride in soil also tends to decrease the electrical resistivity. Chloride may be found in soils derived from marine deposits or those in contact with brackish groundwater or those exposed to external sources of chloride such as de-icing salts applied to roadways. Knowing the levels of chloride will help with the proper design of the concrete mix and in determining the amount of concrete cover over rebar and other steel reinforcement.

Corrosion of the rebar in this beam has dramatically shortened its life.

REDOX POTENTIAL/ORP

The redox potential (or Oxidation-Reduction Potential) is essentially a measure of how reduced or oxidized the soil environment is. Reduced conditions (low redox potential, less than about 100 mv) indicate that there is little or no free oxygen available. Oxidized conditions (high redox potential, greater than about 100 mv) indicate that there is free oxygen available. Typically the oxygen concentration decreases with increasing depth of soil and with increasing moisture content. The redox potential is simportant because it, in part, determines the chemical stability of metallic structures in the soil. For example, iron pipe buried in an anaerobic soil (low redox potential) will tend to not rust because the soil will not contain any free oxygen, which is needed

A close-up of an underground storage tank. Corrosion has compromised its integrity. How much are the associated cleanup costs??

for the iron to rust. On the other hand, the combination of anaerobic conditions and sulfur in the form of sulfate or sulfide can lead to corrosion. Soil microbes can convert the sulfides into sulfuric acid if conditions become more oxidized. The redox potential will also greatly affect the types of microbes that predominate in the soil, and thus, the types of microbial induced corrosion that occurs. Ideally, the redox potential would be measured in the field because this value can be affected by sampling and exposure to the air. Fortunately, we use a test method that allows the sample to approximate the in-situ redox conditions.

SULFIDE

Sulfides are a reduced form of sulfur and can be created by sulfur reducing bacteria under anaerobic conditions. The presence of sulfide indicates reducing conditions in the soil. Sulfides can chemically react with metals and degrade their strength. They can also be involved in the generation of sulfuric acid that will attack both metal and concrete. Hydrogen sulfide is one form of sulfide that can be present in soil. If the soil smells like rotten eggs you know that hydrogen sulfide is present. Sulfides are readily oxidized to sulfate by microbes in the presence of oxygen. For the sulfide test, we prepare the sample the same way as the redox potential test to approximate the in-situ redox conditions.

SAMPLING

The reasoning behind a sampling plan for corrosion purposes is not very different than one for geotechnical purposes. However, where a geotechnical program is focused on the physical properties of the soil, the corrosion program is interested in the chemical properties. Therefore, anything that might change the salinity, pH, Redox potential, etc. of the soil is of interest. Examples include saline groundwater in coastal areas, agricultural runoff, grain size, (e.g. clay tends to be more corrosive than sand) and runoff from roads that are deiced in the winter. Proposed imported soils should be tested before they are brought onto the site. Disturbed soils tend to be more corrosive than non-disturbed soils. Samples should be taken for each significant change in material and should be representative, both vertically and horizontally, of the area of study. Compositing samples should be avoided. The best guidance that we have found for the corrosion aspect of site investigations is from the Caltrans Corrosion Guidelines Version 2.1 January 2015. You can easily find this document with a quick Google search.

Samples for corrosivity testing can be either disturbed or undisturbed. As with geotechnical samples, they should be sealed to prevent moisture loss and kept cool. Avoid letting them get hot in the sun. They can be sent to the lab in a variety of containers

A water main failure in southern California.

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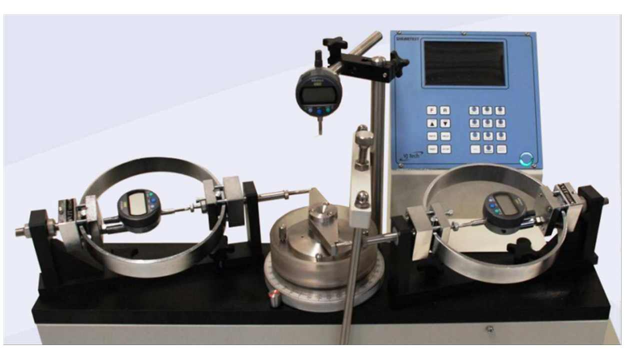
such as tubes, bags or jars. At a minimum we would like to receive about 500g of material (more if the material is gravelly). The equivalent of half full quart -size bag should be enough. We might be able to get by with less material and are happy to try. Additional costs may apply for us to deal with very small samples as this complicates our testing program.

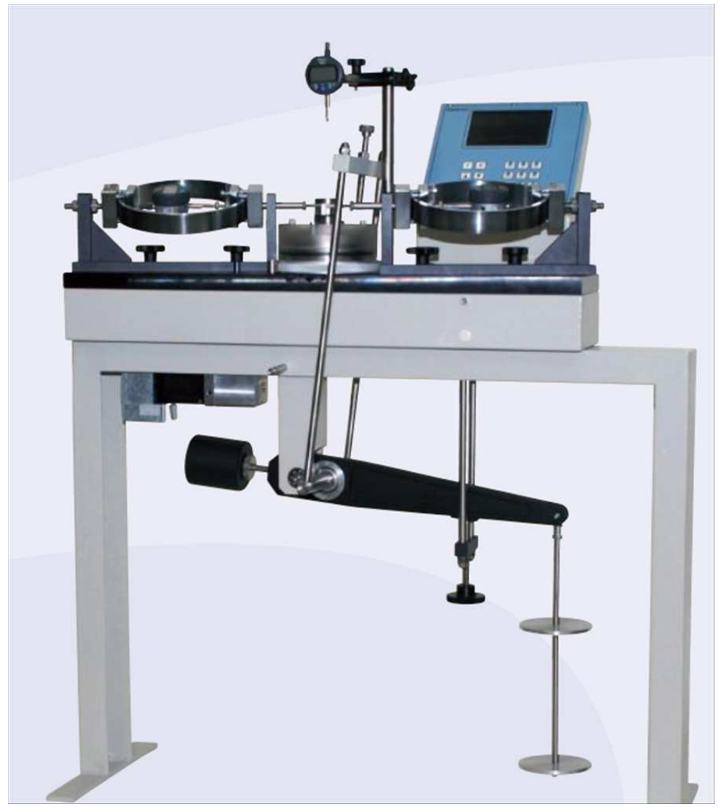
COMBINED GEOTECHNICAL AND CORROSION TESTING

Because it is now so common that samples collected during geotechnical investigations are also needed for corrosion testing, competing uses for individual samples are inevitable. Luckily, in most cases it is possible to run both geotechnical and corrosion tests on the same sample. If you would like to use the same sample for both geotechnical and corrosion testing just contact us to discuss the possibilities. We will do the best we can to get you all of the data you need.

EXPANDED TESTING CAPABILITIES

We are excited to announce that we now have the capability to run both residual and fully softened torsional ring shear tests (ASTM D6467 and D7608 respectively). Residual torsional ring shear testing is far superior to residual direct shear. It lacks the inherent problems of residual direct shear and better duplicates the shearing action of a landslide. It is becoming the standard of care for the determination of residual strength.





ABOUT US

Benchmark Geolabs is an independent full service geotechnical testing laboratory. We serve the geotechnical engineering, environmental engineering and construction industries in the Pacific Northwest and beyond. Our lab in McMinnville, Oregon was originally opened in 2015 by Peter Jacke under the name of Cooper Testing Labs. In 2017, we purchased the lab equipment from CTL and opened Benchmark Geolabs. In 2021, we moved to Massachusetts and opened Benchmark Geotechnical Labs. Peter has decades of experience in Geotechnical and Environmental Engineering, both in the lab and the field.

We take pride in our work, providing accuracy and quality in all our testing services. We run all of the common and many advanced geotechnical tests. See our website for more information:
www.benchmarkgeolabs.com

Questions or Comments

If you have and questions or comments about this newsletter or any testing needs, please feel free to contact Peter Jacke.

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