

CORROSION TESTING

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WHAT IS CORROSION ...

AND WHY IS CORROSION TESTING FOR SOILS IMPORTANT?

Metallic elements such as iron, copper, zinc and nickel occur naturally in the form of 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 and under the right conditions it will attempt to return 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. The Federal Highway Administration has estimated that the total direct cost of corrosion in the United States was determined to be \$279 billion per year, which is 3.2 percent of the U.S. gross domestic product (GDP). This study indicated that major contributions to this value are from corrosion occurring on or in the ground. These include drinking water and sewer systems, highway bridges, and gas and liquid transmission pipelines. 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.



Damage caused by the release of pressurized water, from a corroded water main. Note the fire truck that came to the rescue.

SO WHAT ARE THESE TESTS ANYWAY AND WHY ARE THEY SIGNIFICANT?

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

Resistivity has historically been used as a broad indicator of soil corrosivity. Soil 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 easily when the resistance to electron flow is lower and proceeds more slowly in soils with a high 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

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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 (or 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 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 5-8. 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 protective properties 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 California, 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 gener-



A closer look after fire truck was removed.

ally 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. On the other hand, 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 have probably 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.

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 also tends to decrease the soil resistivity. Chloride may be found naturally in soils derived from marine deposits and contact with brackish groundwater or from external sources such as de-icing salts applied to roadways.

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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.

REDOX POTENTIAL

The redox potential (or Oxidation-Reduction Potential) essentially is 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 significant because it, in part, determines the 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 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. The in-situ redox potential of a soil is subject to change due to sampling. Ideally, redox samples should be collected in such a way as to minimize contact between the



A close up of the smoking gun.

soil and the air. For example, collect a full brass liner of soil then quickly seal it with caps and tape. Because the redox potential can be affected by microbial activity it is best to keep the sample in a cooler with ice until it is delivered to our lab. Even if samples are exposed to the air, we have devised a test method that allows the sample to approximate the in-situ redox potential.

Sulfide

The presence of sulfide indicates reducing conditions in the soil. Sulfides are a reduced form of sulfur and can be created by sulfur reducing bacteria under anaerobic conditions. 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 pres-

ence of oxygen. Because of this, it is best to follow that sample handling procedures mentioned for redox potential. Definitely avoid storing sulfide samples loose in plastic bags and get them to us as soon as you can. This article was written by Peter Jacke. Peter Jacke is the corrosion lab manager and principal at Cooper Testing Labs. You can contact Peter via email at peter@coopertestinglabs.com. Mike Davis is the geotechnical lab manager and principal. Contact Mike at mike@coopertestinglabs.com. David Cooper is now a bum that doesn't do much anymore. david@coopertestinglabs.com



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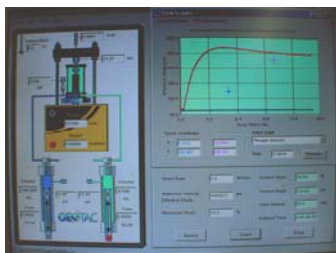
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Large Test System



Computer Screen Shot



Small Test System

NEW CAPABILITIES AT THE LAB

We recently were hired by Geological Associates from Los Angeles to run some large scale drained triaxial compression tests at pressures exceeding 150 psi.

We knew that we had the equipment to do the job but it was aging and would not have the flexibility to do the job in the most accurate way. Most labs measure the volume change by taking burette readings throughout the shearing phase. The pore-water or cell fluid burettes are measured but it is a fairly crude method.

Accuracy was critical to our client so we bought a \$32k computer controlled triaxial system just for this job. We have had the same system in a smaller scale for a few years and love its capabilities. We went to the same manufacturer this time. They put together a one-of-a-kind system for us that provides the capability to test 6" diameter samples under very high confining pressures (up to 500 psi). The system uses

motor actuated hydraulic pumps that control the back and cell pressures. These pumps are very accurate and can measure volume changes to hundredths of a cubic centimeter. Both the pumps and load-frame are computer controlled. We can control and monitor just about any parameter you can think of. These include the strain rate, loading rate, volume change, and the stress ratio. The load-frame can stop at any point to maintain a load indefinitely, which means that it has the capability to consolidate a sample both isotropically or anisotropically. This system enables the user to do more advanced geotechnical testing such as stress-path, K_0 consolidation, constant rate of strain consolidation as well as all the usual drained and undrained triaxial compression tests. Now we have the capability to perform advanced geotechnical testing and high pressure testing on samples with diameters of 2", 2.5", 3", 4", and 6".

With this new equipment we can perform advanced geotechnical testing on samples that contain up to 1" gravel. This type of system is typically used by universities and researchers not commercial labs.

Computer controlled high pressure testing can be very exciting at times. Just drop the confining pressure to zero while the pore-pressure is at 400 psi and watch what happens to a remolded 340 cubic inch sample! Just don't do it here! Just Kidding.

