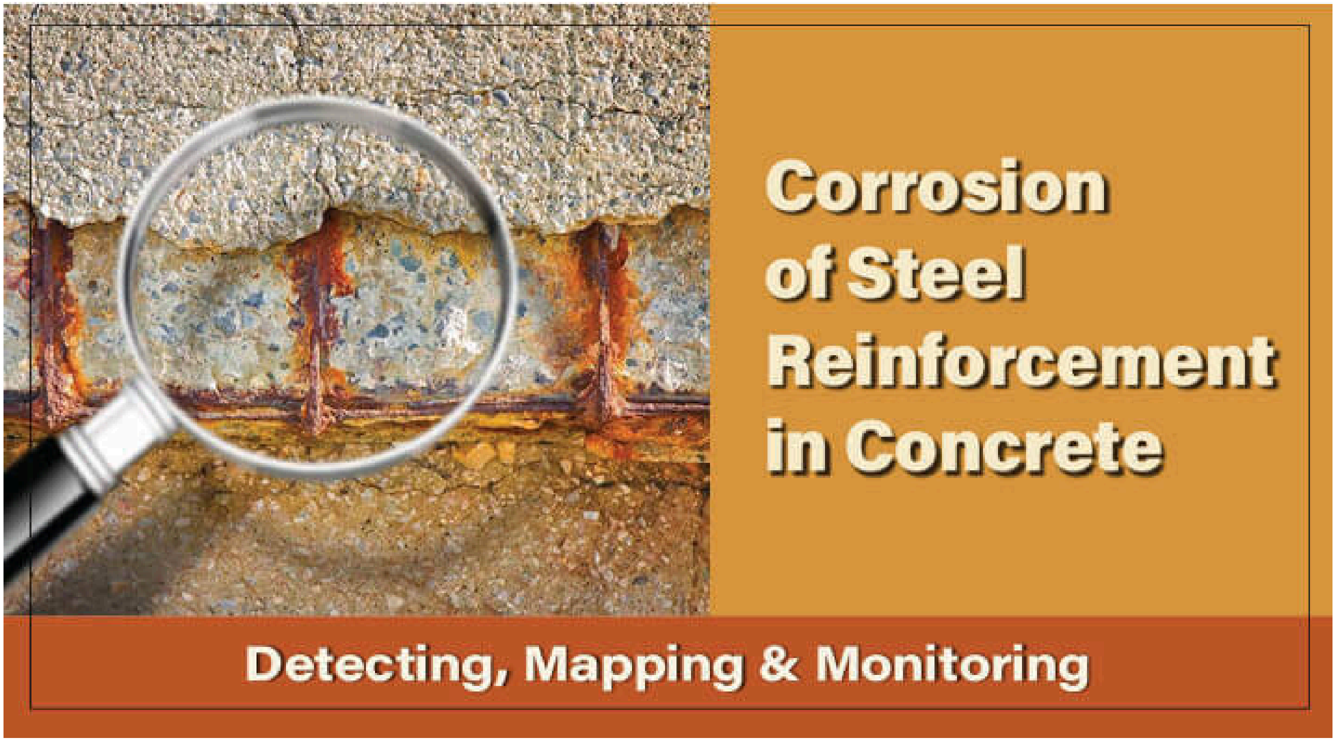
Corrosion of Steel Reinforcement in Concrete: Detecting, Mapping, and Monitoring



Data published by the National Association of Corrosion Engineers (NACE) over twenty years ago notes that the cost of damage caused by reinforcing steel corrosion in concrete highway bridges alone ran into several billion dollars at that time. Indirect losses for shutdowns, service disruptions, etc., dramatically increase the real total. All these expenses from damage to our nation's infrastructure are borne by local, state, and federal agencies, or simply put, by you and me as taxpayers.

History of Corrosion in Concrete

Corrosion of reinforcing steel has been recognized as a serious issue for well over a century. Two different reports in 1911, one regarding a meatpacking plant and another a marine jetty, found that electricity from lighting sources found a path through moist concrete and grounded out to embedded steel, causing rapid and severe damage to the concrete structures. By 1917, an extensive study of marine structures with no nearby electrical sources revealed that the deposition of water-borne chlorides and other salts in the concrete pores accelerated steel deterioration. Electrochemical corrosion mapping, the basis of modern methods described in ASTM C876, was first used in 1957 to study a causeway in California.

A network of bars, wire mesh, and tensioning cables crisscross reinforced concrete structures to increase strength. Embedded plates and anchors secure structural steel and various conduits route plumbing, electrical, and data utilities. Most of these embedded elements contain at least some metals prone to corrosion if not appropriately protected.

Causes of Corrosion in Concrete

We often think of steel-reinforced concrete structures in terms of strength, longevity, and permanence. However, like most metals, steel is an unstable material and begins to slowly return to its natural state of iron oxide, or rust, as soon as it is manufactured.

Just after concrete placement, a layer of passive alkaline material bonds to the surface of the embedded reinforcing steel in concrete, protecting it. Water with a high concentration of chloride ions from deicing salts or seawater forms an ideal electrolyte solution to promote electrochemical reactions. If this water migrates through cracks or the pore structure of the concrete, it will attack the protective layer on the steel.

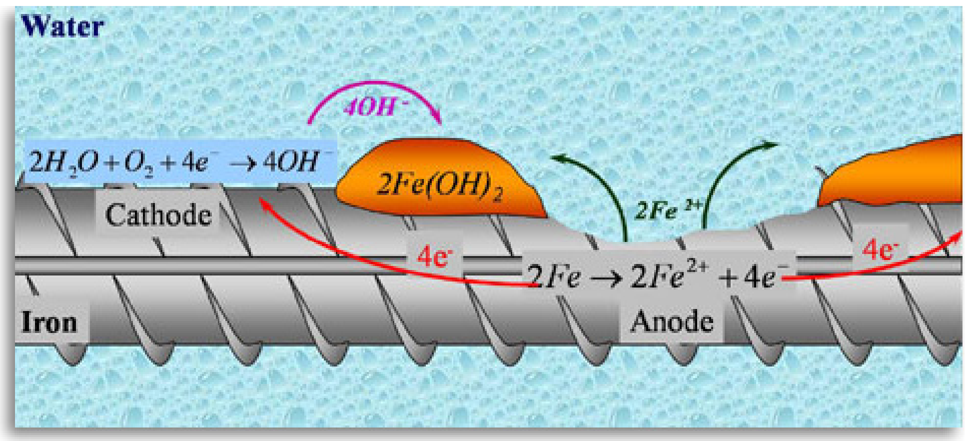
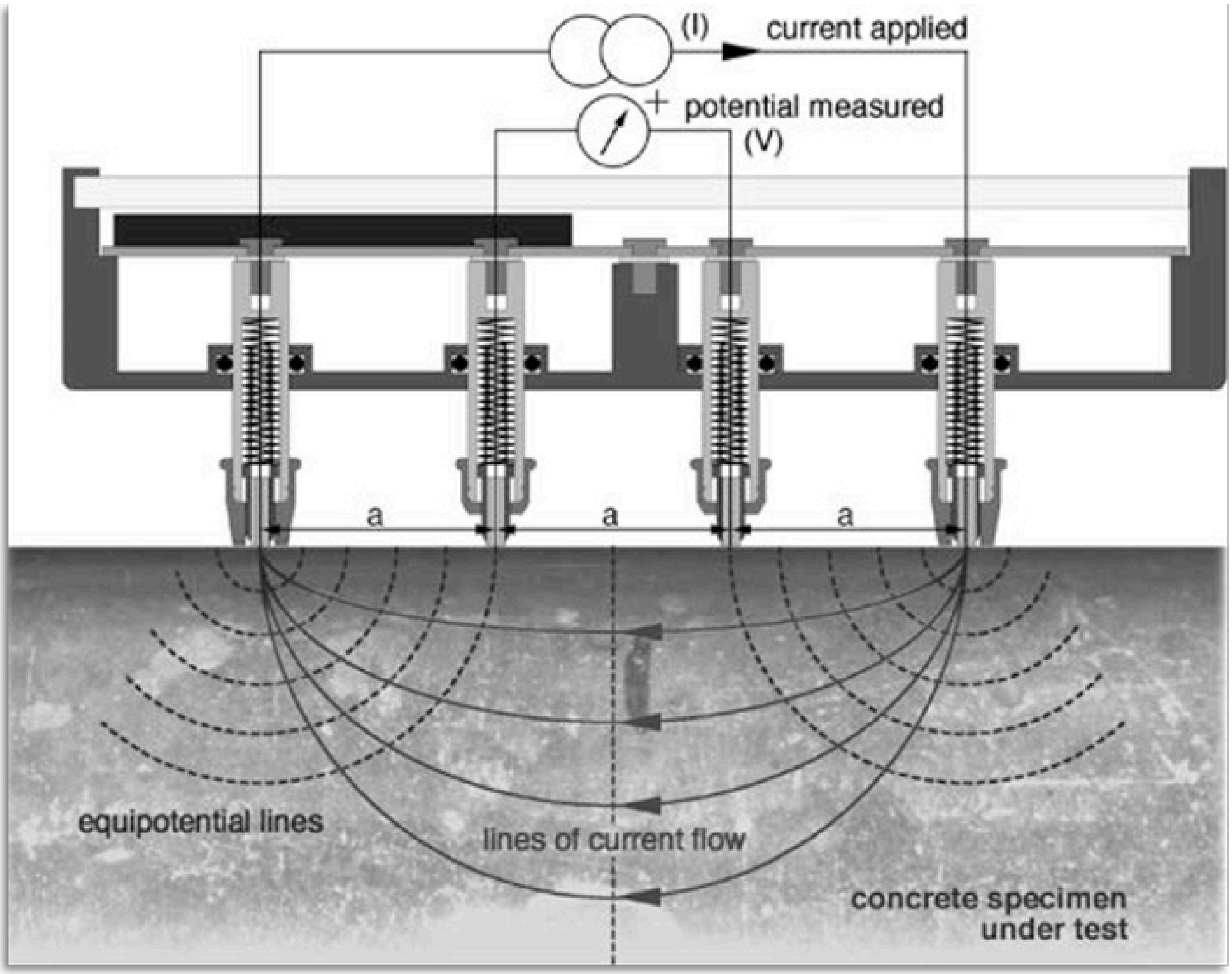


Photo Credit: Cement.org

Corrosion begins when electrons migrate from electrically active points on the steel (anodes) to locations on the bar with the opposite polarity (cathodes). At the same time, ferrous ions lost from the steel diffuse into the surrounding concrete. When the electrolyte solution contacts an active area, iron hydroxide (rust) begins to form.

If the corrosion becomes established and is allowed to progress, it creates some big problems. Rust reduces the load-bearing capacity of the steel, lowering its effectiveness at carrying structural loads in tandem with the concrete. More concerning is that as the steel reverts to iron oxide, its volume increases two or three times, placing enormous internal forces against the surrounding concrete. The concrete loses its bond to the reinforcing steel, further reducing load capacity. Cracks form, allowing increased amounts of water, chlorides, and oxygen, accelerating the deterioration cycle.

The various strategies for delaying the onset and severity of corrosion focus on keeping the water/chloride mixture away from the reinforcing steel. Producing concrete mixtures that feature low permeability and reduced tendency for cracking and providing adequate cover depth during placement are effective measures. Using corrosion-inhibiting admixtures, coating rebars, cathodic protection systems, and surface sealants are effective secondary measures.



Corrosion Prevention

The best way to control concrete reinforcing steel corrosion is to make sure it never starts. Careful design and production of mixes that minimize cracking and limit concrete permeability effectively restrict the ingress of water and chloride solutions. Two testing instruments measure hardened concrete permeability and predict the likelihood of chloride ion penetration before it begins.

- Resipod Concrete Resistivity Meter is a versatile handheld device that measures the surface electrical resistivity of concrete strength test cylinders, other specimens in the lab, or concrete structures in the field. The device uses four electrodes fixed in a Wenner array to detect resistivity and conforms to AASHTO T 358 requirements. This previous blog discusses the Resipod meter in detail.
- Rapid Chloride Permeability Tester performs bulk resistivity tests on concrete cores or prepared specimens. Current is measured between two ends of the specimen immersed in different solutions. The ASTM C1202 AASHTO T 277 test method is limited to laboratory use and requires extensive sample preparation and testing time.

Corrosion Prevention

Early detection of corrosion allows cost-effective strategies for mitigation. When damage is detected early and monitored, less expensive repair methods can be more effective. The most common procedures involve removing damaged materials in limited areas and replacement after cleaning and application of coatings for bonding and corrosion protection.

Manual Sounding of Concrete

Photo Credit: Rutgers University

Sounding concrete surfaces is a low-tech way to assess and monitor general concrete quality and may detect the early stages of corrosion, subsidence of bases under slabs-on-grade, and large voids. The method is simple, tapping with a hammer or dragging a heavy chain across an area and listening for “dead” zones. Such areas should be marked for further examination with advanced nondestructive (NDT) test instruments.

Once a corrosion issue becomes severe, the problem becomes easier to spot visually. Obvious signs include rust stains on the surface, cracking, spalling, delamination over reinforcement, and exposed rebars. If the deterioration has reached this stage, options are sometimes limited to complete demolition and replacement.

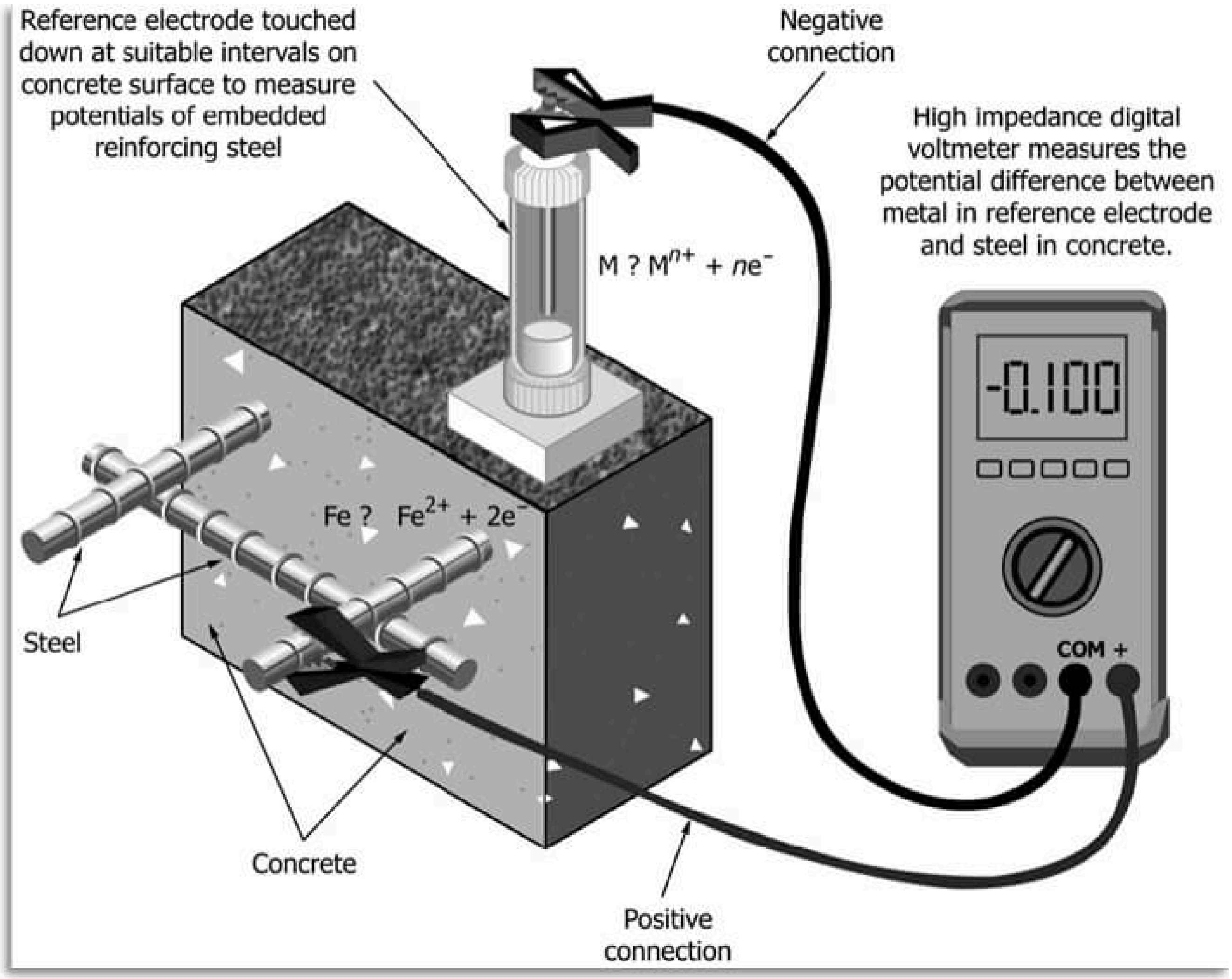
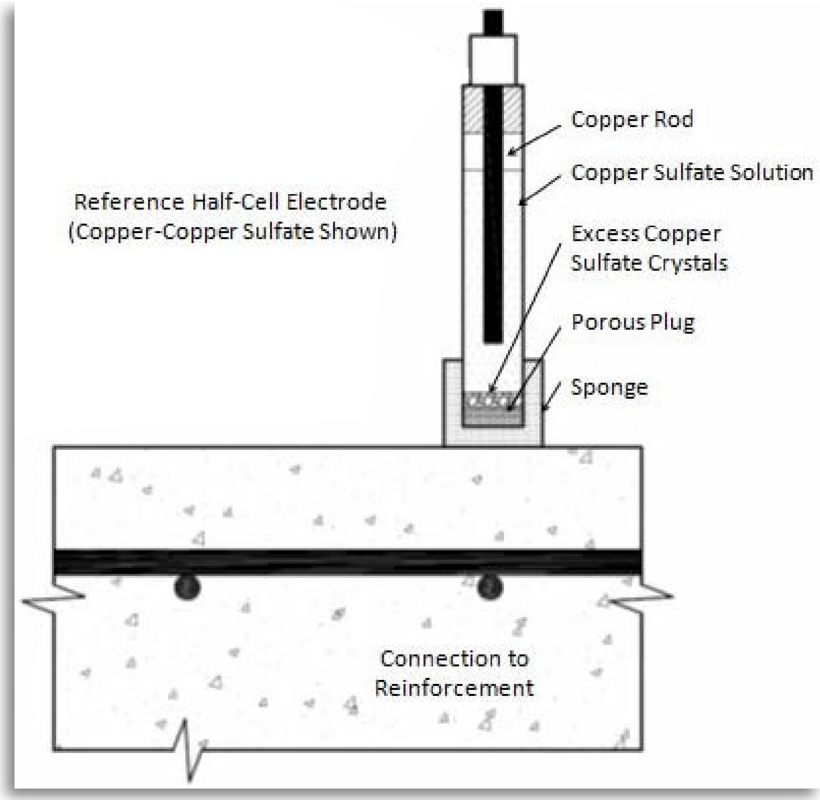


Photo Credit: CONSEN Inc.

Mapping and Monitoring

Mapping and continued monitoring of known areas of corrosion is the best way to manage the condition and limit the damage. The half-cell measurement method described in ASTM C876 is an accepted procedure to detect, quantify, and document the location and condition of corroded reinforcing bars in the concrete by measuring the electrical potential of the steel reinforcing.

The system determines the current flow between a reference electrode and a connection made to the reinforcing grid. Connecting to the rebar requires locating a rebar and exposing a small section by chipping through the concrete. The entire rebar grid may not be electrically interconnected and could require testing for continuity.



The reference electrode consists of a copper tube immersed in a copper sulfate solution. The surface electrical connection to the concrete is made through a solution-saturated sponge at the end of the probe. After the grounding connection to the rebar grid is made, the operator simply pushes the saturated sponge against the concrete to acquire a reading.

Gilson offers two options for half-cell measurement and mapping:

- Profometer® Corrosion Meter is equipped to test to ASTM 876 requirements with a copper-copper sulfate electrode and will accept silver-silver chloride probes from other manufacturers. The meter features a color touchscreen display and 8Gb of memory for processing and storage of test information for upload to a PC. Graphic display of data on-screen allows easy visual discovery of problem areas. Testing efficiency in large areas is maximized with optional single-wheel or four-wheel rolling electrodes., An available kit quickly converts the Corrosion Meter to a Profometer® 600 Covermeter for rebar location.
- Concrete Corrosion Mapping System is an all-inclusive kit in a rugged transport case, ready to perform basic corrosion analysis using the copper-copper sulfate half-cell method on bridge decks, slabs, pavements, and reinforced concrete structures. The system conforms to ASTM C876. Readings are manually recorded on paper or marked with chalk on the concrete to document corrosion activity. A Rebar Locator is suggested for the accurate location of reinforcing bars.

We hope this blog post has helped you understand the corrosion of reinforcing steel in concrete and how to detect, assess, and manage it. For more information, visit our corrosion measurement equipment page, or please contact our testing experts for questions or help with your application.

Meet the Author

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Content Contributor and (retired) Vice President of Technical Operations for Gilson Company, Inc.

Ben is a member of the American Concrete Institute and active on a number of ASTM C09 and ASTM D18 subcommittees. He has over 40 years of experience in the construction materials testing industry and is a NICET senior engineering technician.