

# Half-Cell Potential Mapping Of Reinforced Concrete

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Corrosion evaluation of reinforcement embedded in concrete is often carried out by employing various techniques and tests. Half-cell potential mapping is a well-known technique used mainly to provide information regarding the probability of corrosion in reinforced concrete structures. In combination with other tests such as chloride-content analysis, cover-to-reinforcement measurement, carbonation testing, resistivity testing, etc, this technique can be a helpful tool in corrosion assessment and repair work.

## THEORETICAL BACKGROUND

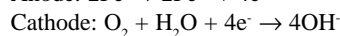
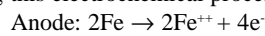
### Corrosion of steel in concrete

Reinforcing steel in concrete is initially protected from corrosion by the passive layer which is formed due to the high alkaline nature of concrete. Corrosion may occur when the passive layer is destroyed or perforated. The layer may be destroyed as a result of carbonation of the concrete or perforated in the presence of chloride ions. As a result of reinforcement corrosion, the rust formed at the anode (Fig. 1) causes the steel reinforcement to expand 4–12 times and places high internal stresses on the concrete, eventually causing spalling and delamination. In addition to concrete deterioration, the nominal cross-section of the steel at the anode reduces, posing a critical concern for the structural integrity of the concrete member.

### Anode and cathode reactions

Corrosion of steel in concrete is an electrochemical process that is associated with a flow of ions and electrons. The electrochemical process is a chemical reaction comprised of two balanced sub-reactions, the anode and cathode reactions. The sub-reactions must occur in a

solution that can conduct ions. This solution is referred to as an electrolyte and, in terms of reinforced concrete construction, is the concrete surrounding the steel. The normal chemical reactions that occur during this electrochemical process are:



The two reactions occur simultaneously, with the electrical charge being moved in the metal as electrons and into the electrolyte as ions.

In a concrete electrolyte that contains chloride ions (such as introduced into concrete structures in a marine environment or present in the concrete mix as a setting accelerator when the structure is cast) the chloride ions cause the passive layer to fail at the location at which they come into contact with the steel. This point then

becomes the anode location with the remaining area being cathodic. The anodic area in relation to the relatively large cathodic area may cause a very rapid pit to be developed. In the case of carbonation, the passivation layer is lost due to reduced concrete alkalinity. In this situation a relatively large area becomes anodic and characteristically surface rust is formed.

### Electrochemical potential and its relationship with half-cell potential mapping

When a corrosion cell is set up as described above, potentials result from the electrochemical reactions. This electrical field is commonly referred to as a potential gradient. Normally a potential gradi-

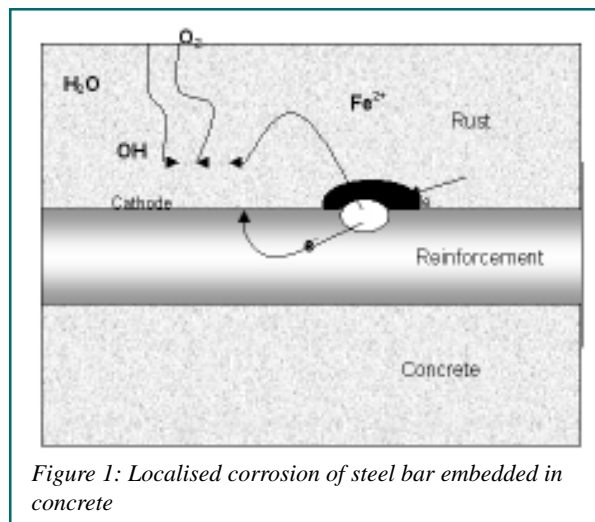


Figure 1: Localised corrosion of steel bar embedded in concrete

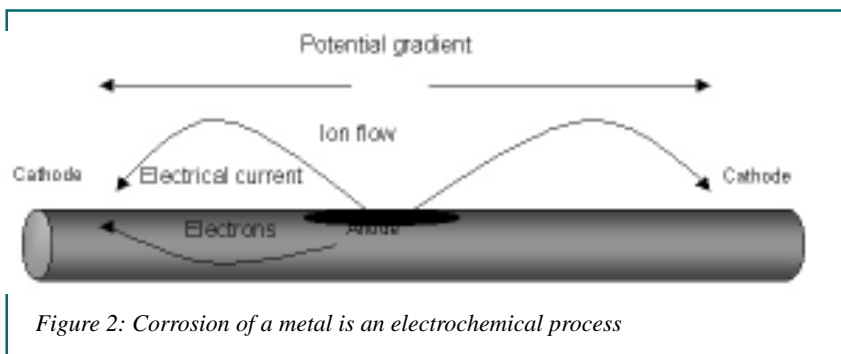


Figure 2: Corrosion of a metal is an electrochemical process

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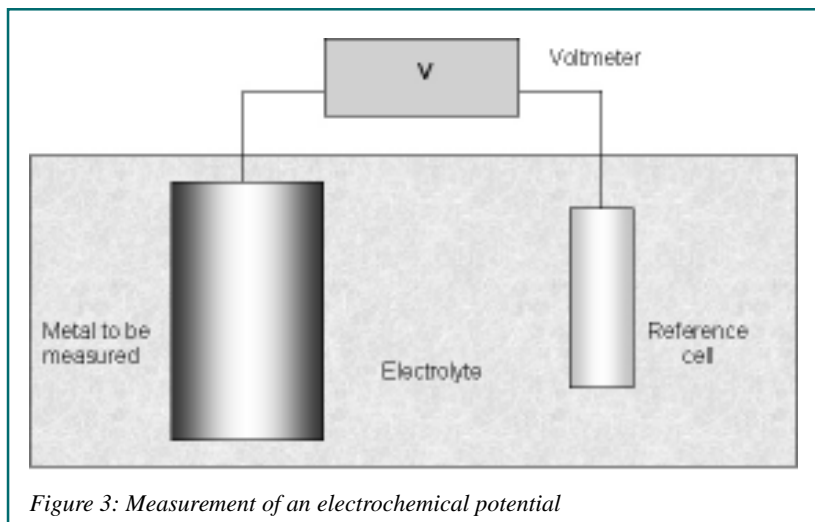


Figure 3: Measurement of an electrochemical potential

ent naturally exists between the anode and cathode as shown schematically in Fig 2, which causes the corrosion to occur. This potential gradient occurs naturally in steel due to the inherent irregularities in its composition and variations in the electrolyte in which the steel is embedded.

The driving force for these reactions is the difference between their electrochemical potentials. This potential difference can be measured between an external 'reference electrode' and the metal at which the reaction takes place. A reference electrode is designed to have as stable an electrical potential as possible. This allows the changes in potential to reflect the actual potential of the anodic or cathodic reaction being measured (see Fig 3).

Traditionally a Copper / Copper sulphate electrode has been used as the reference cell for potential measurements in the field, being both rugged and relatively inexpensive. This electrode is however, not particularly stable as the sulphate slowly reacts with hydroxide in the concrete surface. Furthermore, in chloride-rich environments such as marine concrete surfaces, the chloride ions react with the sulphate, turning it a milky colour that requires changing, sometimes after just one hour of use. It is therefore common practice now to use a more stable electrode such as Silver / Silver chloride as the reference cell and correct the measurements so that the potential is stated with respect to the theoretically true value for Copper / Copper sulphate electrodes (commonly written as 'wrt CSE').

In alkaline concrete (pH range 12–13) without chloride at the steel surface the corrosion products form a thin, tight oxide film referred to as the passive layer. This relatively inert film encases the steel and practically speaking keeps the moisture out and the steel in.

This passive film is not completely insoluble however, and is constantly being damaged and re-formed. For equilibrium to be maintained

there must be a certain concentration of hydroxide at the surface of the steel.

As discussed previously, water in the pores of the concrete paste contains various dissolved ions and serves as the electrolyte. If the passive coating on the steel is destroyed, due to carbonation or the ingress of chloride ions, conditions are favourable for corrosion in the presence of moisture and oxygen.

From the above, it can be concluded that corrosion of embedded steel in concrete requires the following conditions:

1. Loss of passive coating on the steel
2. Presence of moisture, and
3. Presence of oxygen.

If there is an absence of these conditions, no corrosion will occur. If there is a limited amount of water or oxygen, corrosion proceeds at a slow rate. This explains why the corrosion rate of steel in submerged concrete is generally found to be very low. Similarly, dry concrete is particularly resistant to reinforcement corrosion

due to slow ionic movement through the electrolyte (concrete).

Thus, the rate of corrosion depends on the electrical resistance of the concrete surrounding the naturally occurring anodic and cathodic sites on the steel surface, and furthermore, on the availability of oxygen.

## HALF-CELL POTENTIAL MAPPING

### Principle

When there is active corrosion, current flows (ion movement) through the concrete between anodic and cathodic sites and is accompanied by an electric potential field surrounding the corroding bar, see Fig 4.

The equipotential lines intersect the surface of the concrete, and the potential at any point can be measured by using the half-cell potential method. By mapping these potentials on the concrete surface, those portions of the structure where there is a high likelihood of corrosion can be determined by their high negative potentials. Thus, a distinction can be made between corroding and non-corroding locations.

### Execution of half-cell potential mapping

There are two methods available to undertake half-cell potential mapping. Potential measurements can be measured using a voltmeter with a measuring range of at least  $\pm 2$  V and a resolution of 0.1 mV. The second method is the use of automatic equipment.

A pre-requisite of either of these non-destructive investigation techniques is a study of the reinforcement drawings for the structure, if available, plus resistance testing to ensure continuity of the steel over the section being ana-

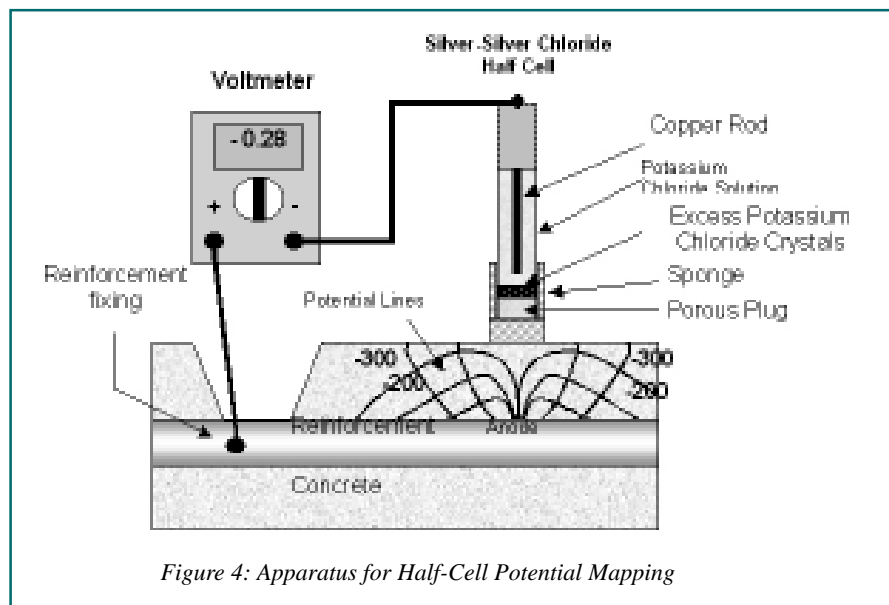


Figure 4: Apparatus for Half-Cell Potential Mapping

lysed. The resistance across the steel extremities should not exceed  $2\Omega$ . This is also important if there is a consideration for use of cathodic protection in the structure.

Secondly, a test area is marked out into a grid system, typically with intervals of 200 x 200mm. However, budget costs and the magnitude of the structure to be examined may govern the test intervals. It may prove more economical to use large intervals initially and where areas of corrosion are noted, a smaller grid system may then be employed.

The Silver / Silver chloride reference cell is then calibrated against a calibration electrode to determine its potential value. The stipulated difference in half-cell readings should be less than 20 mV.

Direct fixing to the exposed steel (rebar) typically makes the reinforcement contact of the half-cell potential mapping system. A suitable rebar is located and all the concrete surrounding it is removed. The rebar is fully exposed over a short distance and filed until white steel is exposed. A clamp (Multi-Grip) with a cable permanently connected, is attached to the steel as shown in Fig 5.

The concrete surface to be examined must have directly below it a good, uniform electrolytic connection between the measuring electrode and the concrete containing the steel reinforcement. There are conditions where this may not be obtainable, as we will discuss later.

A common condition in potential mapping is that the outer concrete layer is so dry that it in fact becomes electrically insulating. To obtain a potential reading it is therefore necessary to pre-water the surface to allow ionic movement, prior to taking measurements.

Measurements are then taken against the concrete surface in the grid formation. When using an automatic system, data referencing defects should be entered during the potential survey procedure. The defect data may be required for later colour calibration denoting active corrosion areas.

**Common problems and errors associated with the technique**

- Humidity and temperature will affect the conductivity of the concrete. The level of humidity and moisture content of the concrete often paints a picture that can sometimes be too optimistic or pessimistic for the actual corrosion of reinforcement.
- External current sources.
- Delaminated concrete cover to reinforcement will not allow potential readings to be detected by the reference cell.
- Electrical continuity throughout the entire steel cage may not occur.
- Poor reinforcement contact.
- The use of non-calibrated reference electrodes.

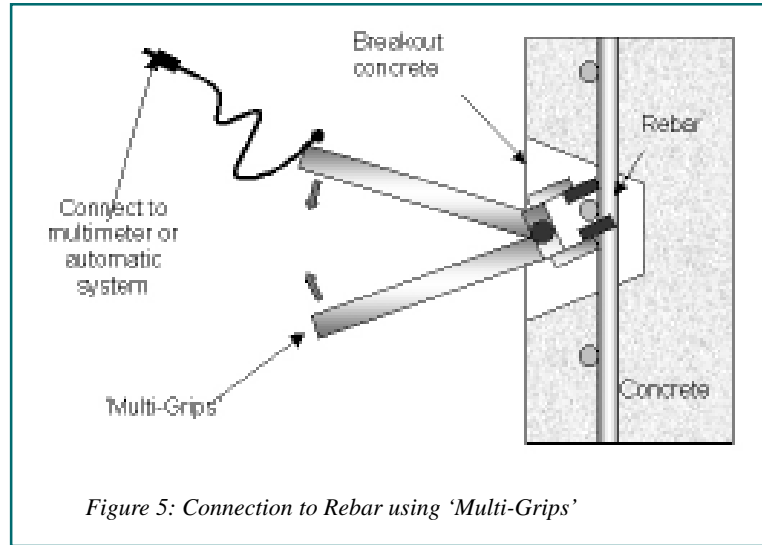


Figure 5: Connection to Rebar using 'Multi-Grips'

**INTERPRETING THE DATA**

The potential gradients indicate the direction of the corrosion currents. The actual corrosion areas are found where the currents leave the rebar and enter the concrete, i.e. where the potentials are most negative.

A precise evaluation of the state of corrosion is not possible. The ASTM-C876-80 Standard provides a general guide for the classification of half-cell potential values based upon probability for corrosion. This guideline is presented in the following table.

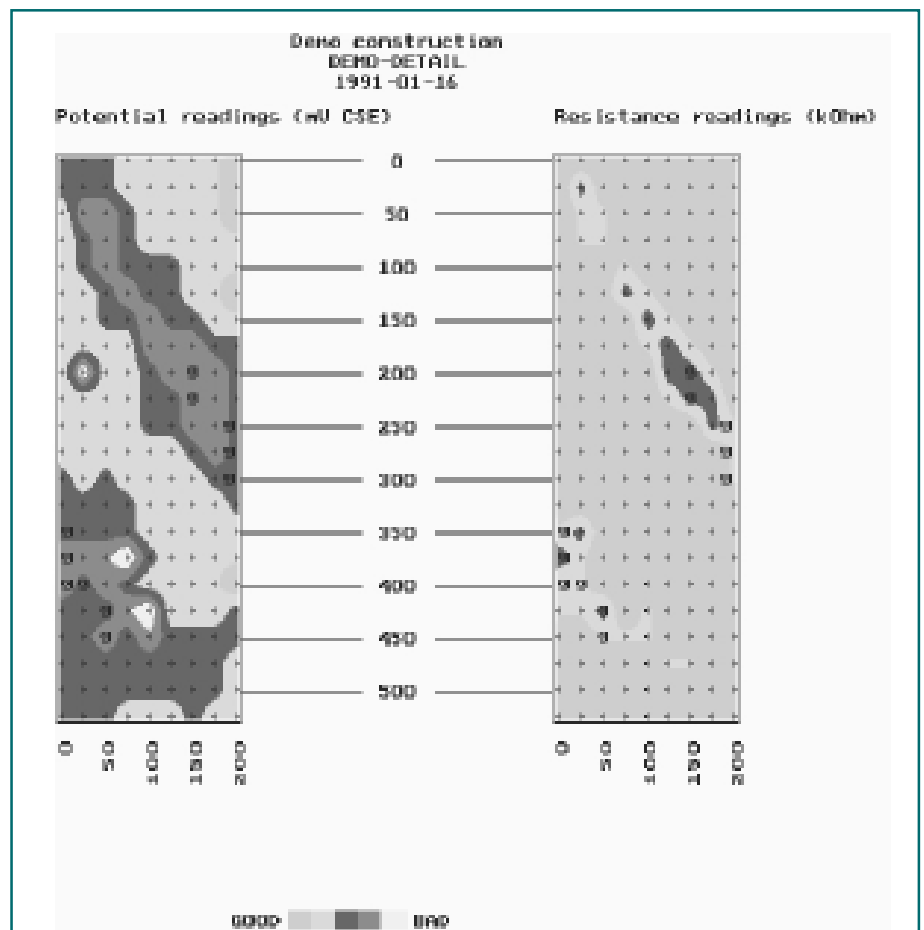


Figure 6: An Example of Potential Mapping, where corrosion activity of reinforcement is represented by different shades

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## Keynote Presentation Abstracts

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POTENTIAL (wrt CSE)	PROBABILITY OF CORROSION
More positive than -200 mV	<5%
-200 to -350 mV	Approx. 50%
More negative than -350 mV	>95%

In addition to the specific reinforcing potential values, the difference in potential greater than 0.100 volts between adjacent grid points usually indicates corrosion activity (ACI Committee 222:1985). Large gradients tend to favour pitting corrosion and higher corrosion rates.

### DATA PRESENTATION

There are several ways to represent the reinforcement potentials. One of the simplest ways is to present the data rather like a weather isobaric chart only with contour lines of equal potential. There is a range of software and potential mapping systems available that provide different formats for presenting the potential mapping data. The graph in Figure 6 shows one example, where corrosion activity of reinforcement is represented by different colours.

### CONCLUSIONS

Half-cell potential mapping is the most widely used non-destructive technique for investigating the corrosion activity of reinforcement in concrete structures. In some cases, a lack of skill and experience of those using this technique has resulted in some apparent failure of the technique to identify corrosion activity of reinforcement for some structures.

### REFERENCES

1. Paul Chess & Fritz Grønvald, "Corrosion investigation - a guide to half cell mapping" pub. Thomas Telford Service Ltd, (UK) 1996
2. Nicholas J. Carino, 'Nondestructive Techniques to Investigate Corrosion Status in Concrete Structures', Journal of Performance of Constructed Facilities / August 1999, pp96-106.

### WATER IS TRUE GRIT

**Lydia Frenzel,  
Advisory Council, USA**

"Water is True Grit," describes L Frenzel's journey from traditional abrasive blasting to waterjetting. "Water is True Grit" describes the importance of consensus and introduces the three components of surface preparation in terms of the three viewpoints that must come together to make a project successful. Above all, to be successful, we must "Take Time to Change with Change".

### PIPELINE COATINGS – THE GOOD THE BAD AND THE UGLY

**David Norman, David Norman  
Corrosion Control, Cornwall, UK**

In order to achieve corrosion protection for the design life of a pipeline the corrosion protection system – the combination of coatings and cathodic protection – has to be designed, specified, applied, constructed, maintained and managed correctly. Case studies of pipeline coating failures, from South America, North Africa, India, and the UK are presented. The key elements in making sure that a pipeline coating is fit for purpose are discussed.

### CATHODIC PROTECTION – COATING INTERACTIONS ON HIGH PRESSURE BURIED STEEL PIPELINES

**CJ Argent, MACAW Engineering  
Limited**

Summary: External corrosion on buried steel pipelines can be controlled by a combination of an insulating coating and cathodic protection (CP). Corrosion at simple coating defects, where the pipe steel is directly exposed to the soil, will be controlled by CP provided the CP monitoring is both accurate and comprehensive. This requires the measurement of accurate pipe to soil potentials and periodic close interval potential surveys. When a coating fails, or deteriorates in

service, to allow water to penetrate beneath the coating the nature of the corrosion risk changes. The risk depends on the extent to which the failed coating shields the pipe surface from the applied CP current. Partial shielding may result in the creation of conditions in which high pH stress corrosion cracking (SCC) can occur. Crack detection pigs can be used to detect and diagnose this problem and some measure of risk management can be achieved by control of the pipeline operating conditions. Complete shielding of the pipe surface from the applied CP current creates the risk of bacterial corrosion, near neutral pH SCC and narrow axial corrosion. An intelligent pig inspection is the only reliable method for detecting these problems and effective control can only be achieved by excavation, and re-coating, of the affected areas of the pipeline.

### STAINLESS STEELS-A REVIEW OF IMPORTANT CONSIDERATIONS FOR EFFECTIVE APPLICATION IN WATERS

**C Powell, Consultant to the  
Nickel Development Institute UK**

Globally, there has been increased growth in the use of stainless steels in water treatment, wastewater treatment and plumbing. Stainless steels have the qualities of being able to handle a wide range of waters and effluent streams experienced by treatment plants in various locations as well as the treated waters and sludges within each plant as they progress through the treatment processes and distribution networks. Extremely low corrosion rates, even at high turbulence, combined with good fabricability allows comparatively lightweight systems and fabrications to be used. Type 304L and 316L grades of stainless steel are the standard materials of construction, with duplex and super austenitic alloys considered for more demanding service. Although very long lives are achievable from these alloys, they are not immune from corrosion under certain situations and it is to

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