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Obtaining Effective Half-Cell Potential Measurements in Reinforced Concrete Structures

by Ping Gu and J.J. Beaudoin

The half-cell potential measurement is an electrochemical technique commonly used by engineers to assess the severity of corrosion in reinforced concrete structures. This Update explains how various factors can affect the reliability of the data obtained.

Corrosion of steel reinforcement is a major factor in the deterioration of highway and bridge infrastructure. A survey of the condition of a reinforced concrete structure is the first step towards its rehabilitation. A rapid, cost-effective and non-destructive condition survey offers key information on the evaluation of corrosion, and aids in the quality assurance of concrete repair and rehabilitation and in the prediction of remaining service life.

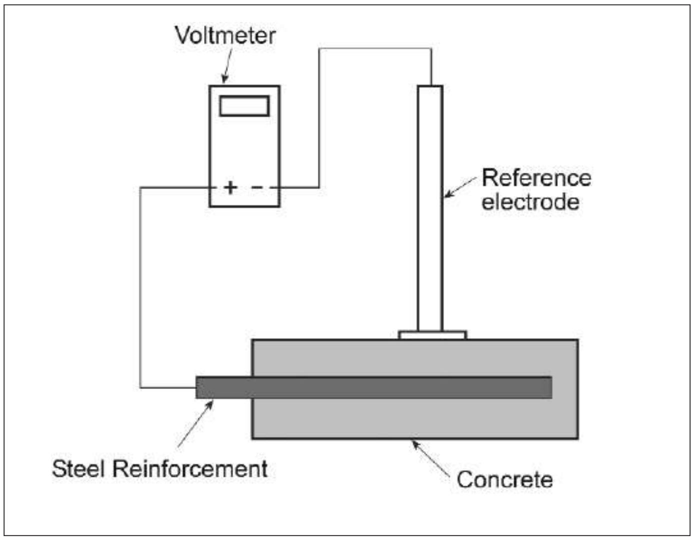

Figure 1. Schematic showing basics of the half-cell potential measurement technique

Half-Cell Potential Measurement

The simplest way to assess the severity of steel corrosion is to measure the corrosion potential, since it is qualitatively associated with the steel corrosion rate. One can measure the potential difference between a standard portable half-cell, normally a copper/copper sulphate ($Cu/CuSO_4$) standard reference electrode placed on the surface of the concrete with the steel reinforcement underneath. Figure 1 illustrates the basics for such a measurement, also called half-cell potential measurement. The reference electrode is connected to the negative end of the voltmeter and the steel reinforcement to the positive.

Confidence in the half-cell potential measurement as an indication of corrosion potential has evolved owing to the success of bridge deck corrosion surveys. An indication of the relative probability of corrosion activity was empirically obtained through measurements during the 1970s.[1-2] This work formed the basis of the ASTM standard C876, which provides general guidelines for evaluating corrosion in concrete structures as outlined in Table 1.

Factors Influencing Half-Cell Potential Readings

When interpreting half-cell potential data, one must consider factors such as oxygen and chloride concentration, and concrete electrical resistance, all of which have a significant influence on the readings. Assessment has also become more complicated owing to

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Table 1. Probability of corrosion according to half-cell readings

Half-cell potential reading, vs. $Cu/CuSO_4$	Corrosion activity
less negative than -0.200 V	90% probability of no corrosion
between -0.200 V and -0.350 V	an increasing probability of corrosion
more negative than -0.350 V	90% probability of corrosion

advances in concrete and repair technologies, such as dense material overlays and concrete sealers, corrosion inhibitors, chemical admixtures, and cathodic protection systems. It is important to understand and consider these complicating factors during the half-cell potential survey and to supplement the assessment with other non-destructive surveys.

A simple comparison of the half-cell potential data with the ASTM guideline on steel reinforcement corrosion probability could prove meaningless. For instance, a more negative reading of potential is generally considered to indicate a higher probability of corrosion. This general "rule" may not always be valid; many factors can shift the half-cell potential readings towards more positive or negative values but these shifts may not necessarily be related to the severity of the steel corrosion.

Oxygen Concentration

Oxygen concentration at the interface of the steel reinforcement and concrete affects the half-cell potential readings significantly. A decrease in oxygen concentration at the surface of the steel reinforcement will result in a more negative corrosion potential reading. This kind of negative potential reading may not necessarily be associated with a high probability of steel corrosion. For example, the steel reinforcement underneath a dense concrete cover with low permeability would have a more negative corrosion potential reading than a porous concrete with a higher permeability. But such a negative reading does not necessarily indicate a high probability of corrosion.

Carbonation

Concrete carbonation (a reaction between the carbon dioxide in the atmosphere and calcium hydroxide in the concrete) reduces the pH value of the steel reinforcement/concrete interface and increases the steel corrosion. In such a case, the half-cell potential reading will shift towards more negative values although the shift may not be very large. However, even a small shift in values can be associated with a large increase in the rate of corrosion.

Chloride Ion Concentration

An increase in chloride ion concentration causes significant steel corrosion. This chloride-induced corrosion is associated with a significant shift of the corrosion potential towards more negative values and an increase in the severity of the steel corrosion. This is a case that the ASTM C876 standard predicts well.

Use of Corrosion Inhibitors

The effects of corrosion inhibitors on the half-cell potential reading are more complicated because these chemicals can modify the corrosion potential of the steel reinforcement. As a result, the shift of the corrosion potential can be either positive or negative, depending on whether an anodic or cathodic inhibitor is applied.

An anodic corrosion inhibitor is a strong oxidizing agent. An example is calcium nitrite (a commonly used commercial product). The use of this chemical shifts the corrosion potential of the steel to a more positive value and significantly reduces the corrosion rate. A half-cell potential reading obtained from a reinforced concrete structure containing calcium nitrite would normally be more positive than one without it.

In contrast to the anodic corrosion inhibitor, a cathodic inhibitor causes the corrosion potential to shift towards a more negative value, with a corresponding reduction in the severity of the steel corrosion. Many commercial corrosion inhibitors fall in this category. Therefore, the effects of the corrosion inhibitor must be taken into account when interpreting the half-cell potential readings if a cathodic inhibitor has been applied to the structure being tested.

There also exists what is called a mixed corrosion inhibitor. Its influence on the steel corrosion potential could be in either direction; i.e., the corrosion potential shift can be in either the negative or positive direction. For tests in such cases, the commercial producer should be asked to clarify how the mixed corrosion inhibitor affects the corrosion potential of the steel.

Epoxy-Coated and Galvanized Rebars

The ASTM C876 standard clearly indicates that the half-cell potential technique is not suitable for measurements involving epoxy-coated and galvanized steel reinforcement. The former does not provide a good enough electrical connection for the measuring circuit. An authentic, stable half-cell reading may not be achievable, though in some cases what appears to be a stable reading may be obtained because of coating defects or damage and unprotected rebar ends.

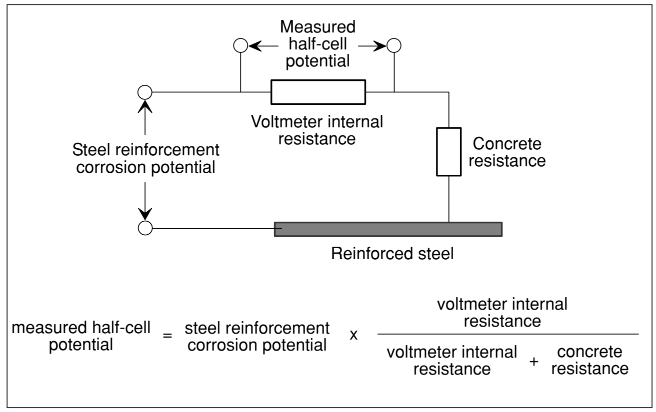

Figure 2. Schematic illustrating the half-cell measurement circuit

For the latter, the galvanic metal (normally zinc) protects the steel reinforcement. The measured half-cell potential reading is no longer the corrosion potential of the steel reinforcement but the mixed potential of steel and zinc. Therefore, a simple comparison of half-cell potential data with the ASTM standard may not be useful. However, long-term monitoring of the change of potentials may be useful provided that a corrosion specialist interprets the data.

Dense Concrete Cover

A dense concrete cover provides a good physical barrier protecting the steel from chloride-induced corrosion. It also limits the oxygen diffusion process. The oxygen concentration in the reinforcing steel/concrete interface could be very low and, as a result, the corrosion potential could shift to a more negative value. It can not be used to indicate a high probability of steel corrosion.

Concrete Resistance

A high concrete resistance can introduce significant errors in the half-cell potential data. Figure 2 is a schematic diagram illustrating the measurement circuit. The measured half-cell potential reading is the potential between the two ends of the voltmeter internal resistor. It is only when this resistance is much larger than the concrete resistance that the measured half-cell potential reading is close to the true corrosion potential of the steel reinforcement. Therefore, there are two ways to increase the accuracy of the measurement. The first is to decrease the concrete resistance, e.g., by wetting the concrete surface. The second is to use a voltmeter with a high internal resistance (larger than 20 MΩ is recommended). Positioning the reference electrode on the concrete surface directly above the steel reinforcement can also decrease the concrete resistance and increase the measurement precision.

Organic Coatings and Sealers

Half-cell potential measurements made on reinforced concrete with organic coatings and sealers may prove to be inaccurate or impossible owing to their high resistance. However, measurements can be made on areas where the coating is removed or damaged. If the coating is oxygen impermeable, the oxygen depletion must be considered in the data interpretation.

Concrete Patch Repair

Concrete patch repair normally creates an environment dissimilar to the existing concrete. This leads to the so-called electrochemical potential imbalance between the steel reinforcement embedded in the existing concrete and the new concrete in the patch. Unusual behaviour of the half-cell potential reading on the patch areas and adjacent areas may occur along with a possible acceleration of the steel corrosion.

Cathodic Protection Systems and Stray Current

An energized cathodic protection system and stray current will make half-cell potential measurements meaningless. A measurement should not be made unless the structure's cathodic protection system is shut down and at least 24 hours of depolarization of the steel reinforcement is completed. If the half-cell potential reading is unstable and undergoing large fluctuations involving both positive and negative values, it could indicate the existence of a stray current.

All Factors Considered

There are still other factors or a combination of them that can alter the precision of half-cell potential readings. An understanding of how various factors influence the measurement is the key to a meaningful interpretation. Table 2 summarizes the discussion of the factors reviewed in this Update.

Precautions for Taking Half-Cell Potential Measurements

A reliable half-cell potential survey of corrosion damage of a reinforced concrete structure requires good planning and preparation, careful measurement and data validation. The ASTM C876 standard provides a satisfactory measurement

Table 2. Effect of the various factors on half-cell potential shift and corrosion probability

Situation	Half-cell potential shift	Corrosion of steel reinforcement	Applicable to ASTM C876
Decrease in oxygen concentration	to negative	may not increase	no
Carbonation/decrease in pH	to negative	increase	yes
Increase in chloride concentration	to negative	increase	yes
Anodic corrosion inhibitor	to positive	decrease	yes
Cathodic corrosion inhibitor	to negative	decrease	no
Mixed corrosion inhibitor	to positive or negative	decrease	no
Epoxy-coated rebar	to positive	not related	no
Galvanized rebar	to negative	not related	no
Dense concrete cover	to negative	not related	no
Concrete resistance	to positive	not related	no
Dry concrete	to positive	not related	no
Reference electrode position	to positive	not related	no
Coatings and sealers	to positive	not related	no
Concrete repair patch	to positive or negative	not related	no
Cathodic protection	to negative	not related	no
Stray current	Fluctuating between positive and negative	not related	no

Table notes: The first column presents the situation and the second column shows how the half-cell potential responds to such a condition. The shift may be towards more positive or more negative directions. The third column shows how such a half-cell potential shift relates to the severity of the steel reinforcement corrosion. For example, the half-cell potential shift may be associated with corrosion activity that is high or low, or a particular situation may not relate to the reinforcement corrosion probability. The fourth column indicates whether the ASTM corrosion probability guideline can be applied directly.

procedure to follow. The following information should be obtained before taking measurements:

- Basic information about the structure such as the reinforcing materials and the steel blueprint, the concrete admixture used, if any, the concrete composition, the quality and amount of cover on the reinforcing steel;
- The previous repair and protection history, including patch repair and protection measures applied;
- The previous condition survey, including previous half-cell potential data, visual examination data and delamination survey results, and chloride content analysis.

The half-cell potential data should always be validated by other measures before an interpretation of corrosion probability is made. Many methods are commonly used, along with the half-cell potential technique, in field assessment of corrosion. These include visual inspection, delamination survey, chloride content measurement, concrete resistance measurement, concrete cover-depth survey, carbonation profile determination, and rate of corrosion measurement at selected locations.[3] The methods selected usually depend on the resources available and the specific conditions of the structure. The first four especially are essential for a meaningful evaluation of the half-cell potential data.

Summary

A more negative reading of potential is generally considered to indicate a higher probability of corrosion. However, this general "rule" may not always apply because of the complexity of today's concrete and repair technologies. Evaluation of rebar corrosion from the "absolute" half-cell potential values may mislead engineers and cause errors in judgment if other factors are not taken into account.

It must be stressed that the half-cell potential measurement only reveals the corrosion probability at a given location and time. Long-term monitoring of the half-cell potential reading is more meaningful.

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