



NRC Publications Archive Archives des publications du CNRC

Assessment of corrosion of reinforcement in concrete

Qian, S. Y.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Canadian Civil Engineer, 18, Spring 2, pp. 20-21, 2001-06-01

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=edb00c97-7959-494a-889e-d00dea4dc206>
<https://publications-cnrc.canada.ca/fra/voir/objet/?id=edb00c97-7959-494a-889e-d00dea4dc206>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.





National Research
Council Canada

Conseil national
de recherches Canada

NRC - CNRC

Assessment of corrosion of reinforcement in concrete

Qian, S.Y.

NRCC-44684

A version of this paper is published in / Une version de ce document se trouve dans :
Canadian Civil Engineer, v. 18, no. 2, Spring 2001, pp. 20-21

www.nrc.ca/irc/ircpubs



Assessment of Corrosion of Reinforcement in Concrete

Shiyuan Qian

Institute for Research in Construction
National Research Council Canada

Durability problems arising from the corrosion of reinforcement in concrete are common, mostly due to attack by chloride ions or carbonation of the concrete by atmospheric carbon dioxide. The first is more serious in North America since the climate demands extensive use of deicing salts on highways and bridges. Chloride ions from deicing salts break down the protective layer on reinforcing steel leading to various forms of corrosion-induced damage such as cracking and spalling. A significant percentage of highway bridges is suffering from serious premature decay. In extreme circumstances, catastrophic collapse of bridges has occurred. A reliable corrosion assessment of concrete bridges is therefore essential. This article briefly describes shortcomings of commonly used assessment methods, discusses the effect of oxygen and introduces an approach to reach a reliable corrosion assessment.

HALF-CELL POTENTIAL METHOD

Since the early 1980's, the use of half-cell potential measurements for the identification of reinforcing steel corrosion in concrete or the assessment of the condition of existing concrete structures has been frequently employed. This method only provides an indication of the relative probability of corrosion activity through measurement of the potential difference between a standard portable half-cell and the reinforcing steel, and is unable to determine corrosion rates or the degree of corrosion that has occurred. Factors such as chloride and oxygen concentrations, temperature and moisture content can affect half-cell potentials over a certain range. The ASTM standard C876 [1] provides interpretative guidelines for the evaluation of corrosion probability for reinforcing steel in concrete. According to this standard there is a 10% probability of reinforcement corrosion if half-cell potentials are more positive than -200 mV; a 90% probability of reinforcement corrosion if half-cell potentials are less than -350 mV with reference to a copper/copper sulphate half-cell (Cu/CuSO₄). In many cases, the predicted corrosion state based on the guidelines are quite different from the actual corrosion conditions. Severe discrepancies between the assessment of the corrosion state using the ASTM guidelines and the actual deterioration that has been observed at the time of repair on many bridges [2]. Studies on European bridge decks [3], where waterproofing membranes are used or where deicing salts are applied less frequently, have resulted in a different set of interpretive guidelines.



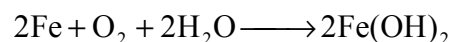
Slab from old Perley Bridge with top reinforcement exposed

LINEAR POLARIZATION METHOD

Practical experience with this technique has shown that in some simple electrolyte solutions relatively good correlation is achieved between the corrosion rate deduced by linear polarization measurements and the rate measured on corroding coupons. The corrosion rate is a time indicator, i.e. the corrosion information obtained is indicative of the conditions at *the time of measurement* and may change in a matter of days or even hours as temperature, oxygen and moisture content change. In chloride contaminated concrete, corrosion often starts as pitting. When this type of corrosion occurs, the corrosion current can at first be very high; however, the current could change with time depending on the activity of the cell, the build up of corrosion products on the steel surface and the availability of oxygen. Hence, prediction of future corrosion activity should include an evaluation of dynamic environmental factors. The most active corrosion may not, in fact, be occurring at the time of measurement. Therefore continuous or intermittent monitoring over a period of time gives a more reliable appraisal of the situation but this may not be realistic in the field.

OXYGEN AFFECT ON THE CORROSION PROCESS

The corrosion of steel reinforcement under conditions of access to air can be written as follows:



The product of reaction, which is ferrous hydroxide, is further converted to Fe₂O₃·nH₂O (rust). The key factors to support this ongoing corrosion reaction are moisture (H₂O) on the surface of the reinforcement and adjacent concrete and the availability of oxygen (O₂).

Corrosion products have a volume several times greater than the volume of steel from which they are derived. The build-up of corrosion products on the surface of the steel creates tensile forces in the concrete. When the embedded steel becomes corroded, the production of a voluminous corrosion product induces internal stresses in the concrete surrounding the reinforcement. If internal tensile stresses exceed the concrete tensile strength, cracking and spalling of the concrete cover will occur.

Half-cell potentials are very sensitive to the ambient environment, especially the oxygen concentration at the interface between the reinforcing steel and the concrete. Usually, a decrease in O_2 can drive the half-cell potential significantly towards more negative values. Completely water-saturated concrete can lead to O_2 starvation, resulting in potential values more negative by up to 200 mV [4]. Tests carried out on carbon steel in laboratory electrochemical cells showed that a significant shift of potential towards more negative values by 350 mV could be observed when O_2 was purged from the electrolyte by bubbling N_2 gas into the cell.

If the concrete cover is saturated by water, O_2 is not freely available at the metal surface because O_2 is not very soluble in aqueous solutions. The rate of reinforcement corrosion is controlled by the rate of arrival of oxygen at the metal surface. Because of the diminution in O_2 concentration the corrosion potential will shift to more negative values. These values can be much more negative than -350 mV vs. Cu/CuSO₄ in many conditions and can lead to an improper prediction of the state of corrosion even though the reinforcement is still in good condition.

For bridge decks that have been repaired several times, the concrete cover may become thick. The humidity at the surface of the concrete can change with the ambient conditions easily but the relative humidity at the now deep level of the reinforcement is very difficult to change and remains at relatively high values. Under these RH conditions, most pores in the concrete are saturated with water and the transfer of O_2 through the concrete pores to the reinforcement takes place almost entirely through liquid-phase diffusion. Therefore the concentration of oxygen is reduced and the corrosion potentials (half-cell potentials) are shifted to more negative values.

The shifting of half-cell potential by O_2 concentration change was confirmed from the measurements conducted on barrier walls of a highway bridge in a recent study. The results show that the potentials were shifted to more negative values than normal when the concrete cover was saturated by rainfall.

COMPARITIVE ASSESSMENT

A research project was conducted at the Institute for Research in Construction, National Research Council of Canada, to study reinforcement corrosion in repaired concrete slabs taken from an old bridge (Perley Bridge) in Hawkesbury, Ontario. Several corrosion measurements

were performed on these slabs including half-cell potential, linear polarization, concrete resistivity and chloride ion concentration profile. The relative humidity and the temperature of the slabs were also monitored. After the completion of the corrosion measurements and core removal, the concrete cover on the top layer of the reinforcement was removed with a jackhammer to expose the reinforcing bars for visual inspection of the corrosion. The visual corrosion results then were compared with the results predicted by the corrosion measurements conducted before the concrete cover removal. It was concluded that a reliable prediction of the corrosion state of reinforcement can be achieved by analyzing the data from both half-cell potential and corrosion rate measurements jointly with consideration of the effect of environmental conditions.

It was found that when the concrete cover is very thick or saturated by water due to rainfall, half-cell potential readings more negative than -350 mV should not be simply interpreted as high probability of corrosion. In such a case, the results of corrosion rate should be considered. If the corrosion rates were low and stable in the area then the probability of reinforcement corrosion was very small. If the half-cell potential readings were generally very negative (say < -450 mV), and corrosion rates were high (> 0.5 $\mu A/cm^2$) and fluctuated from one location to another, then the probability of active corrosion was high. In corrosion-active areas, the section with more negative potentials was found more corroded, as confirmed by visual inspection.

It was concluded that a statistical analysis of a large number of half-cell potential values, the results of corrosion rate and the concrete resistivity together could facilitate the interpretation of the corrosion results and provide a more reliable evaluation of the corrosion state of reinforcement.

ACKNOWLEDGEMENTS

The National Research Council Canada (NRC) wishes to acknowledge the financial support of Public Works and Governmental Services Canada (PWGSC) for the Perley Bridge Project, with special thanks to Dr. M. S. Cheung, Director Technology & Environment at PWGSC for his encouragement and support.

REFERENCES

- 1 ASTM C876-99 (1999): Standard Test Method for Half-cell Potentials of Reinforcement in Concrete, ASTM, Philadelphia.
- 2 Elsener B. and Bohni H., ASTM STP 1065, N. S. Berke et al., ed., ASTM, Philadelphia, 1990, p. 143.
- 3 Raherinaivo A., Contrôle de la corrosion des armatures dans les structures en béton armé. Bulletin De liaison des Laboratoires des Ponts et Chaussées, 158, Nov./Dec. 1988, 29-38.
- 4 Vassie P. R., TRRL Application Guide 9, 1991, pp 30.