NDTCE'09 Non-Destructive Testing in Civil Engineering
Nantes, France, June 30th – July 3rd, 2009

Novel method for linear polarisation resistance corrosion measurement

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Abstract

Linear Polarisation Resistance (LPR) can provide a direct evaluation of the instantaneous rate of corrosion. However it has the disadvantage of requiring a localised breakout of the concrete cover to provide an electrical connection to the steel reinforcement. This paper describes an adaptation of the LPR method and the four-point Wenner resistivity method to give an evaluation of the rate of steel corrosion without the requirement for a direct electrical connection to the steel reinforcement.

Résumé

La Résistance par Polarisation Linéaire (LPR) peut fournir une évaluation directe du taux instantané de corrosion. Cependant, elle a l'inconvénient de nécessiter une brèche localisée de la couverture du béton pour fournir une connexion électrique au renfort d'acier. Ce papier décrit une adaptation de la méthode LPR et de la méthode de résistivité Wenner à quatre points pour évaluer le taux de corrosion de l'acier sans besoin d'une connexion électrique directe au renfort d'acier.

Keywords

Steel, reinforcement, concrete, Wenner, resistivity

1 Introduction

Corrosion of steel reinforcement can propagate unseen until expansive corrosion products cause cracking or spalling of the concrete cover. Piecemeal repair can allow ongoing corrosion in adjacent regions, which will quickly cause further cracking to appear. Structure owners need a means of assessing corrosion before it has progressed to the point of cracking or spalling. The traditional assessment methods are the half cell potential mapping technique (1) and the concrete resistivity method (2) but they do not give a direct measurement of the ongoing rate of corrosion.

The Linear Polarisation Resistance (LPR) (3, 4, 5) does make a direct assessment of the rate of corrosion, but it requires a direct electrical connection to the steel reinforcement. In addition LPR requires knowledge or an assumption of the area of steel reinforcing bar being perturbed. This paper reports on a novel adaptation of the resistivity and LPR methods to provide an evaluation of the ongoing rate of corrosion without the need to breakout the concrete cover and expose steel reinforcement and without the need to evaluate the area of perturbation.

2 Existing Corrosion Methods

2.1 Half cell potential mapping

A half cell provides a stable reference against which changes in potential on the surface of the steel bars can be measured (Figure 1). Measurements on a regular grid can be used to identify regions where corrosion activity is probable. However the method does not give any information about the rate of corrosion activity.

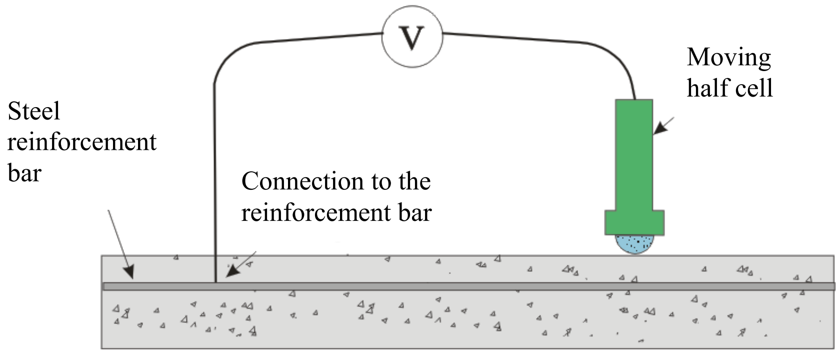


Figure 1. *Half cell potential mapping*

2.2 Resistivity measurement

The concrete Wenner resistivity measurement technique [(6)] was originally developed for geophysical evaluations. A low magnitude AC current, typically 30-60 Hz, is passed between two outer surface electrodes. A measurement of the potential between two inner current electrodes (Figure 2) gives an evaluation of the electrical resistivity of the concrete in the surface region using:

$$\rho = 2\pi a \frac{V}{I} = 2\pi a R \qquad (1)$$

A low resistivity implies that if reinforcement corrosion is occurring then the rate is likely to be relatively high. Thus the use of a resistivity measurement together with potential mapping can give an indication of the location and likely severity of corrosion problems. However these methods do not directly measure the rate of corrosion.

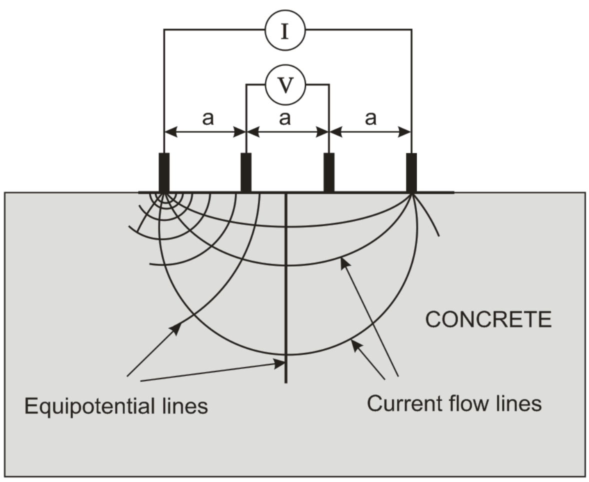


Figure 2. *Resistivity measurement*

One difficulty with the resistivity technique is that a bar in the measurement region can provide a "short-circuit" path, which can cause an erroneous reduction in the measurement. This error is determined by the diameter, cover and orientation of the bar as well as the lateral distance to the measurement location [7]. In conditions where it is not possible to place the surface electrodes remote from any steel bars it is recommended that the electrodes are placed orthogonal and symmetrically over an underlying bar (at position **A**) to minimise the short-circuit influence (Figure 3). A measurement at position **B** or position **C** can result in an apparent resistivity measurement much lower than the actual resistivity of the concrete.

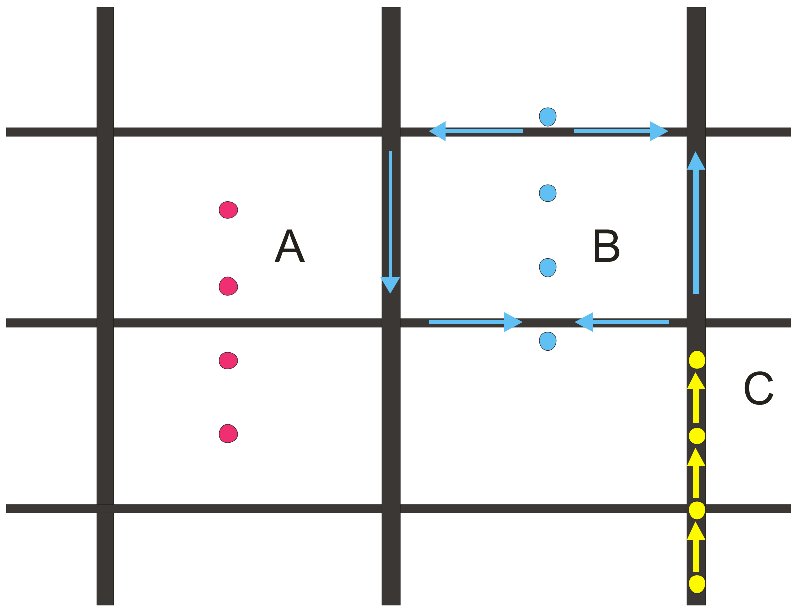


Figure 3. *Resistivity measurements adjacent to steel bars*

2.3 Linear polarisation resistance measurement

The principal of LPR is based upon the introduction of a small perturbative DC electrical signal ΔI, with respect to a reference half cell, to a corroding steel bar using a surface counter electrode (Figure 4). The resulting change in potential, ΔE is measured after a suitable time for equilibrium to be re-established. The polarisation resistance is given by:

$$R_p = \frac{\Delta E}{\Delta I}. \qquad (2)$$

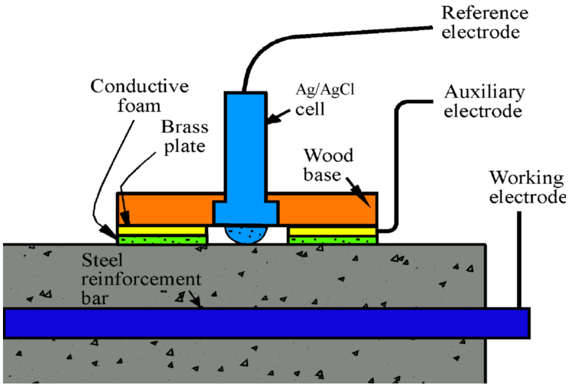


Figure 4. *Linear polarisation resistance measurement*

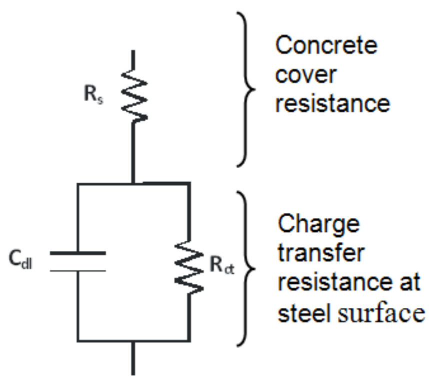


Figure 5. *Randle's equivalent electrical circuit*

The corrosion interface comprises a capacitive ***double layer***, $\boldsymbol{C_{dl}}$ on the surface of the steel bar together with a ***charge transfer*** resistive interface, $\boldsymbol{R_{ct}}$. The rate of corrosion is inversely proportional to $\boldsymbol{R_{ct}}$. Thus a simple electrical circuit known as a Randle's circuit can be used to describe the concrete cover and the corrosion interface (Figure 5). $\boldsymbol{R_{ct}}$ is obtained by subtracting the concrete cover resistance, $\boldsymbol{R_s}$ from the polarisation resistance. $\boldsymbol{R_s}$ is geometrically related to the concrete resistivity by the diameter and cover of the bar and by the area of surface contact. Thus:

$$R_{ct} = R_p - R_s \tag{3}$$

The corrosion current density, i_{corr} requires a knowledge or assumption of the area of steel being perturbed, $\boldsymbol{A}$ and is given by:

$$i_{corr} = \frac{B}{R_{ct}.A} \quad , \tag{4}$$

where B is a constant.

3 New corrosion rate assessment method

The proposed method takes advantage of the short-circuit effect of a steel bar on the resistivity method. If a conventional AC resistivity measurement is taken at position **C** on Figure 3 then the AC signal will pass easily through the capacitance $\boldsymbol{C_{dl}}$, regardless of whether the surface of the bar is corroding rapidly (i.e. $\boldsymbol{R_{ct}}$ is small) or is passive ($\boldsymbol{R_{ct}}$ is large).

If the same four-point resistivity measurement is again taken using a DC current then the effect of steel bar on the apparent resistivity measurement would be expected to be influenced by the rate of corrosion on the bar surface. Using a DC signal the current can no longer pass through the capacitance $\boldsymbol{C_{dl}}$. If $\boldsymbol{R_{ct}}$ is quite small then the apparent resistivity measurement should be close to a similar measurement taken over the bar using an AC signal. However if $\boldsymbol{R_{ct}}$ is large then the apparent resistivity should be close to a measurement taken using an AC signal but when no bar is close.

3.1 Experimental procedure

DC resistivity measurements were taken using a modified electrode array where the two inner standard resistivity probes were replaced with two copper-copper sulphate reference electrodes (Figure 6). These reference electrodes were selected to give a stable surface potential against which to measure changes in potential caused by the outer current probes. For this pilot study three concrete slab specimens were available, each containing a single short 30 mm diameter steel bar, cast with one end protruding from the concrete (Figure 7). The actual rate of corrosion for each specimen was verified by taking a LPR measurement within a short time of the resistivity measurements.

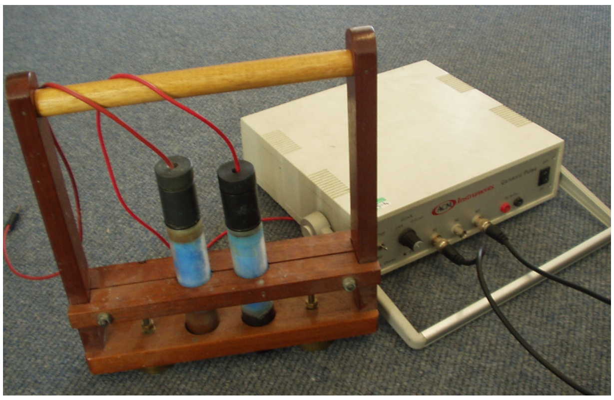


Figure 6. DC resistivity equipment *Figure 7. Reinforced concrete specimen*

Repeated measurements were taken over several days of the AC resistivity both directly over and remote from the steel bar at Position 1 and Position 2, (Figure 8). The DC resistivity measurement was then taken at Position 1.

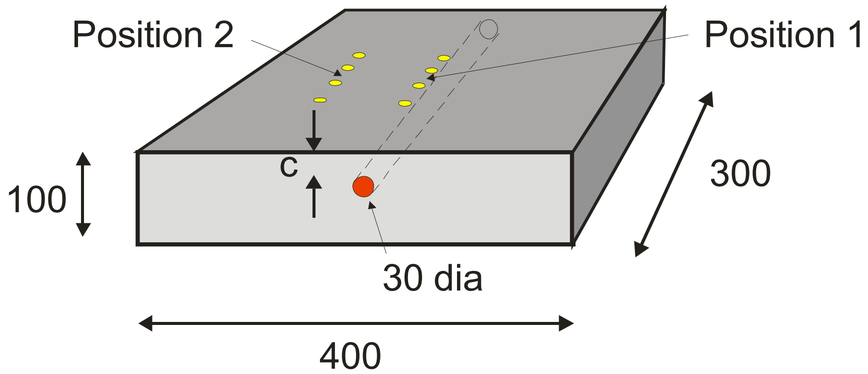
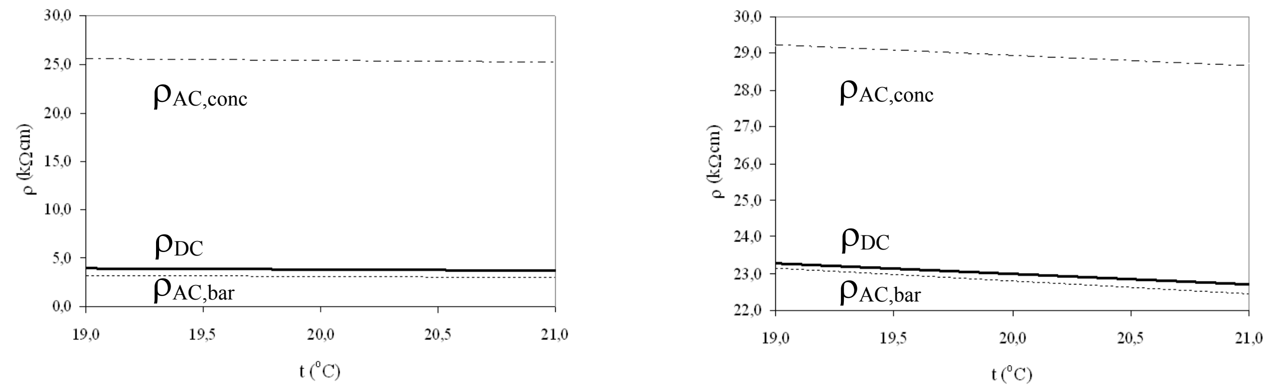


Figure 8. *Resistivity measurement locations on concrete specimen*

3.2 Results

LPR established that two of the bars were corroding quite fast, with corrosion current densities of 8.47μA/cm^2 and 7.28μA/cm^2. From this it was expected that the surface steel bar would have a relatively small charge transfer resistance, R_{ct} and that a DC measurement of resistivity over the bar should give an apparent resistivity much closer to the AC resistivity measurement over the bar than that of the actual concrete resistivity. Figure 9 shows that for both specimens over a small range of ambient temperatures, ρ_{DC} is much closer to $\rho_{AC,bar}$ than to $\rho_{AC,conc}$.



a. 10mm cover, i_{corr} = 8.47μA/cm^2

b. 30mm cover i_{corr} = 7.28μA/cm^2

Figure 9. *Resistivity measurements on specimens with actively corroding bars*

One reinforcing bar had a current density of i_{corr} = 0.46μA/cm^2, close to passivity. In this case a much larger R_{ct} is expected and the presence of the bar should have a relatively small effect on a DC resistivity measurement. From Figure 10 this can be seen to be so. Over the range of ambient temperatures investigated, ρ_{DC} is much closer to $\rho_{AC,conc}$ then to $\rho_{AC,bar}$.

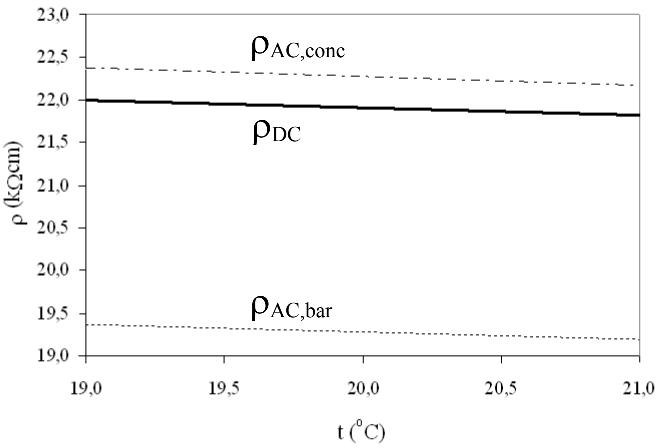


Figure 10. *Resistivity measurements on specimen with passive bar, 20mm cover,* $i_{corr} = 0.46 \mu A/cm^2$

4 Discussion

These pilot study results are quite promising. This new method offers a means of assessing directly the instantaneous rate of corrosion using a procedure which is relatively quick and which does not require breakout of the concrete cover.

5 Conclusions

This study has shown that the short-circuit influence of an embedded steel bar in the vicinity of a concrete resistivity measurement can be used to evaluate the rate of ongoing corrosion on the surface of the bar. From a pilot study of just three specimens a good correlation has been found with conventional LPR measurements. Further study is required to validate this method over a wider range of conditions and configurations.

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