

# PRO'S AND CON'S OF HALF-CELL POTENTIALS AND CORROSION RATE MEASUREMENTS

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Structural Faults + Repairs, International Conference, London, U.K., July 1st-July 3rd, 2003

KEYWORDS: Half cell potential (HCP), Corrosion rate ( $I_{\text{corr}}$ ), Galvanostatic Pulse Measurements (GPM), concrete structures

## ABSTRACT

Half-cell potentials and corrosion rate measurements are compared and evaluated.

The paper presents four different on-site cases. The first example is from a bridge pillar exposed to de-icing salts. This example shows a good correlation between corrosion rate and half-cell potential mapping. The second is a dry structure where high half-cell potentials were measured and shown to be directly misleading, while the corrosion rate provided the reliable results.

In the third testing case very low half-cell potentials were measured in a wet structure, and shown not to be a reliable indicator of the corrosion activity, again indicated accurately by the determination of corrosion rate.

The last example is an underground parking with leaking water/ de-icing salts from the above street. In this case the half-cell potentials indicated high corrosion risk while the corrosion rate is rather low. In all cases the actual corrosion was documented by exposing the reinforcement during visual inspection.

## BACKGROUND

Since 1978 Half Cell Potential (HCP) mapping [1] has been used for detecting corroding areas on concrete structures in Denmark. In the beginning (after balcony gangway has totally collapsed) this method was mainly used on carbonated structures and balconies exposed to de-icing salts. Later the method was used for all kind of structures and the experiences were discussed in Newsletters published by the Danish Corrosion Centre [2]. It was early recognised that the interpretation of the HCP results were difficult or misleading in wet and semi-wet structures where lack of oxygen as well as corrosion would lead to potential gradients. A typical potential map of a highway bridge pillar is shown in fig.1. The pillar is exposed to de-icing salts splashed from the passing cars up to a level of 2 meters, but also has a high humidity at the ground level caused by capillary suction. The water filled pore system in the concrete makes the potential drop because the oxygen necessary to maintain the passive film will not be able to diffuse into the concrete fast enough.

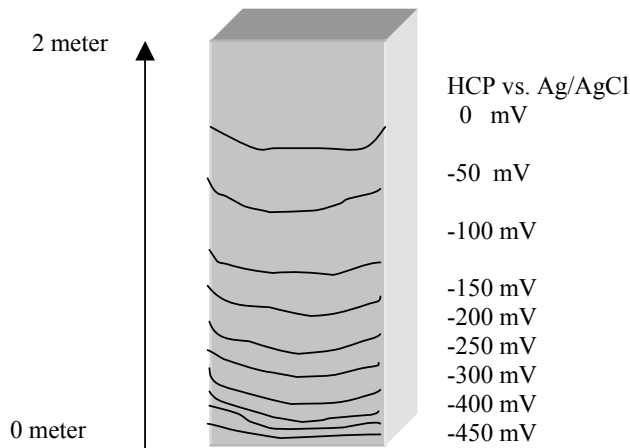
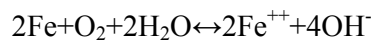


Fig.1. Typical potential map of a high way concrete pillar exposed to de-icing salts

The ongoing corrosion process is described by the chemical reaction:



The  $\text{Fe}^{++}$  forms at the high pH in concrete a complex protective film with oxygen. This film can be broken down by the chloride ions from de-icing salts or by neutralising of the high pH eg. by carbonation. The interpretation problem is that the potential will drop either because the loss of passive film due to lack of oxygen (the corrosion process will not be able to proceed without oxygen) or because chlorides breaks down the passive film and start corrosion.

In 1994 it was decided to develop an equipment for concrete structures based on well know techniques for determination of corrosion rates to be able to distinguish between active corrosion and the lack of oxygen situation.

The results presented in this paper are all based on Galvanostatic Pulse Measurements (GPM). This polarisation technique makes it possible within a short time (typically 10 seconds) to calculate the corrosion rate [3,4]. The equipment gives both the corrosion rate and the half-cell potential as well as the resistance between the hand-held electrode placed on the examined concrete surface and the reinforcement.

Four different examples from on-site investigations are described below, one where there is a good correlation between the HCP method and the GPM method and 3 where the HCP measurements are misleading.

## EXAMPLES OF ON-SITE INVESTIGATIONS

### Example nr.1

Two parallel bridges were built in 1965-67 in the Copenhagen area, where the highway crosses over a railway line, a parking lot and two minor roads. The eastern bridge was rehabilitated extensively at a very high price in 1978, after which the western bridge have only received much less rehabilitation, but substantial inspection, test- loadings, probabilistic assessment etc., which essentially have kept the bridge in function at a much less cost that the eastern part.

Initial inspections, core investigations and chloride profiling in 1999 (fig. 2) pointed out column No.S303 to be suitable for corrosion rate measurements. Electrical continuity in the reinforcement was checked and a permanent connection was welded to the reinforcement.

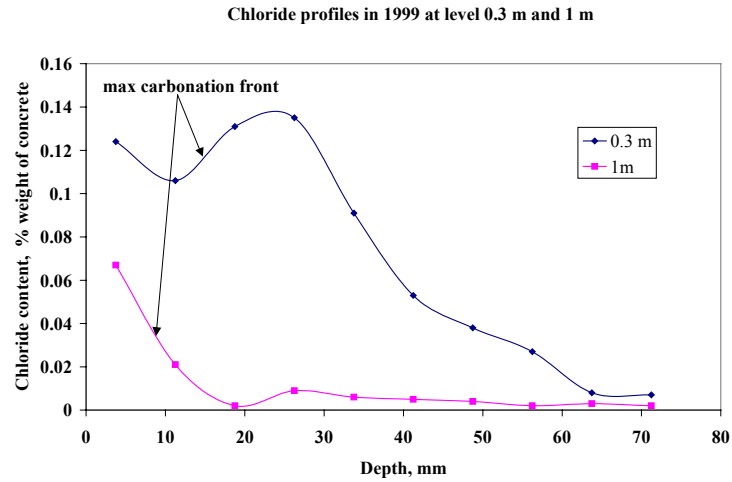


Fig 2. Chloride profiles at level 0.3m and level 1 m

The vertical reinforcement ( $\varnothing 35$  mm) is typically in 60 mm depth and the horizontal ( $\varnothing 14$  mm) in 40 mm depth. Already in 1999 the chloride content in level 0.3 m is so high that active corrosion can be expected. In September 2000 and in April 2001 corrosion rates were determined together with the half-cell potentials and resistance measurements [5] (fig 3).

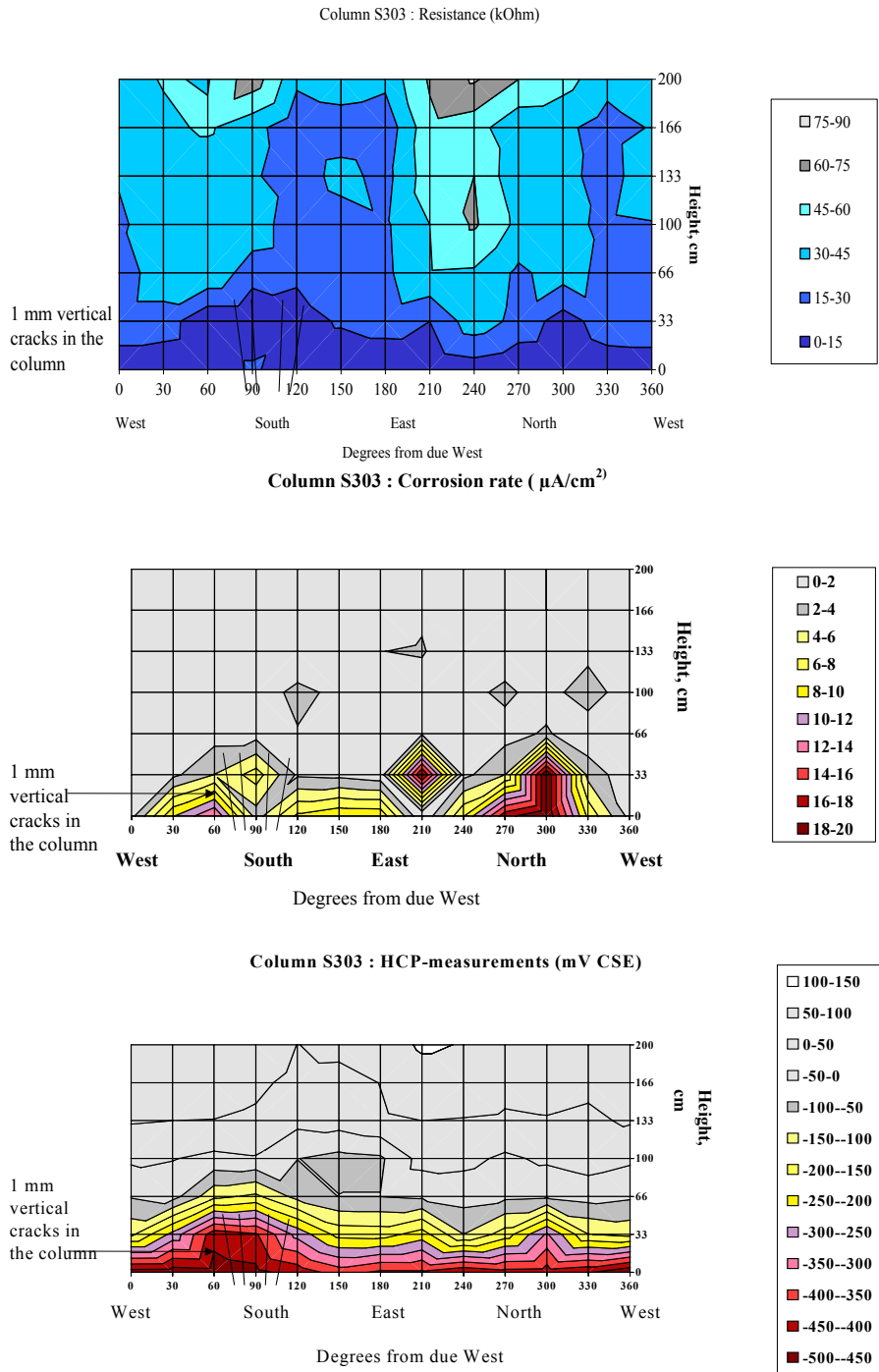


Fig. 3 Resistance, half-cell potentials and corrosion rates in September 2000

In this case there is a rather good correlation between resistance, half-cell potential and corrosion rate mapping. To verify the corrosion state a break-up was made at the position 90 degrees south near ground level, see fig. 4.



Fig. 4 Corroding reinforcement. Cross section loss : 1-2 mm

As the constructions have been examined close during the last 20 years it is possible to make a good estimate of the initiation of corrosion. Calculation of the average corrosion rate from the cross section loss of app. 2 mm and assuming the corrosion was initiated after app. 10 years gives an average corrosion rate of  $9\mu\text{A}/\text{cm}^2$ , which is with in the range of corrosion rates determined at this position by the GPM. The very low half-cell potentials agree with the high corrosion activity.

Example 2.

The next two examples are from a bridge foundation and a bridge deck in Greenland. The foundation was investigated in the tidal zone as shown in fig. 5 [6].

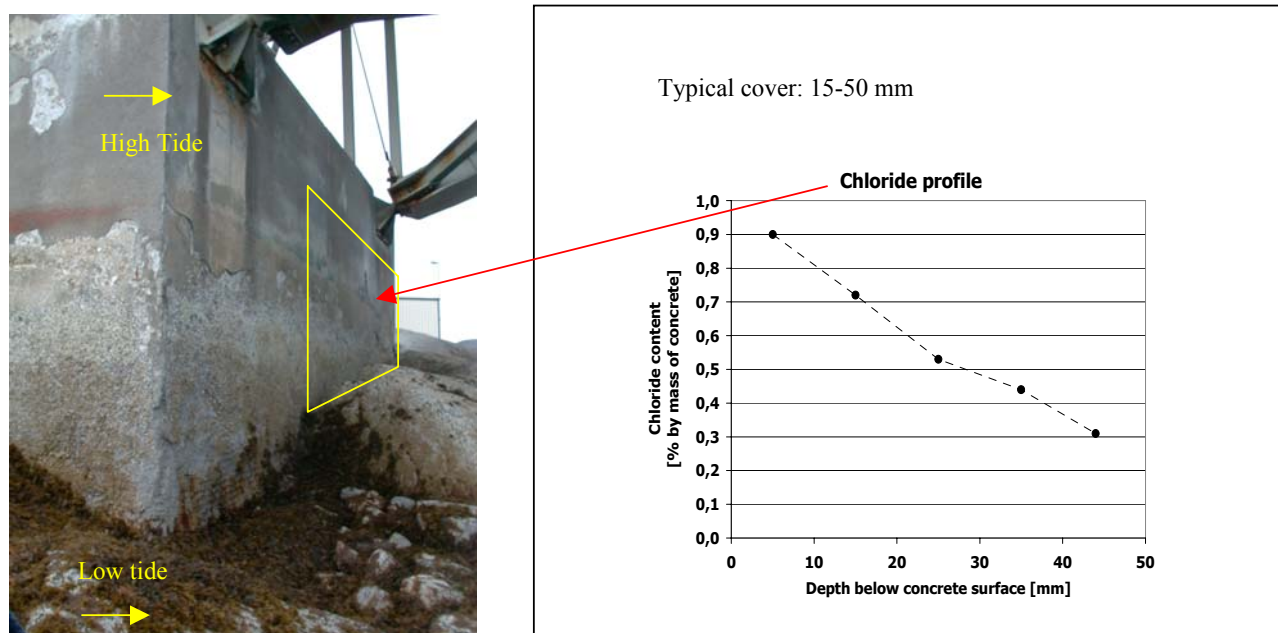
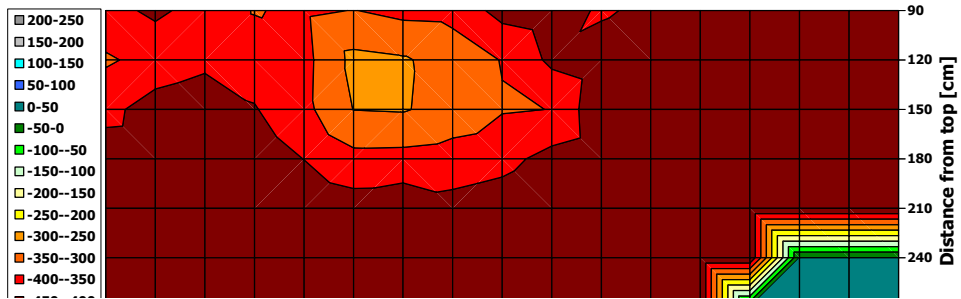


Fig. 5. The investigated area and the location of the chloride profile.

The chloride concentration in the depth of the reinforcement is in the range between 0,3% and 0,7% of the concrete weight. As indicated by the half-cell potential measurements corrosion should therefore be expected. However the measured corrosion rates are low and the verification by visual inspection (fig. 7) shows no damage to the reinforcement.

Half cell potential map of bridge foundation. Potential in mV vs. Ag/AgCl



Corrosion rate map. Corrosion rates in  $\mu\text{A}/\text{cm}^2$

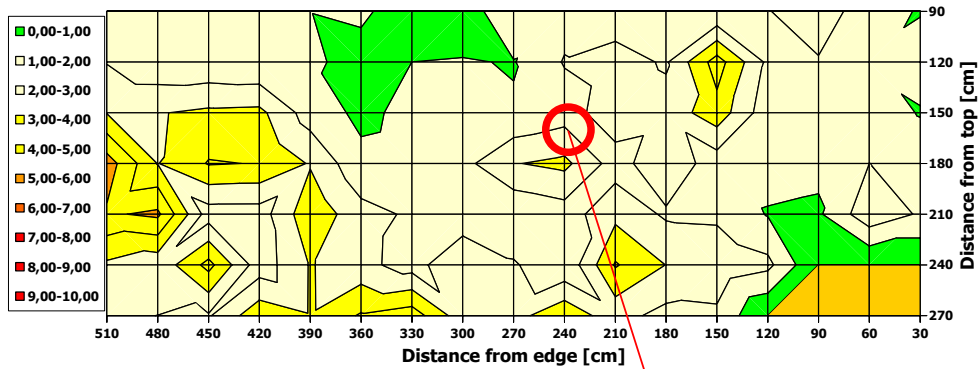


Fig. 6 HCP and  $I_{\text{corr}}$  of bridge foundation



Fig. 7 Foto of break-up

Example 3.

The bridge deck from the same bridge in Greenland showed very different results as shown on fig. 8 and fig. 9.

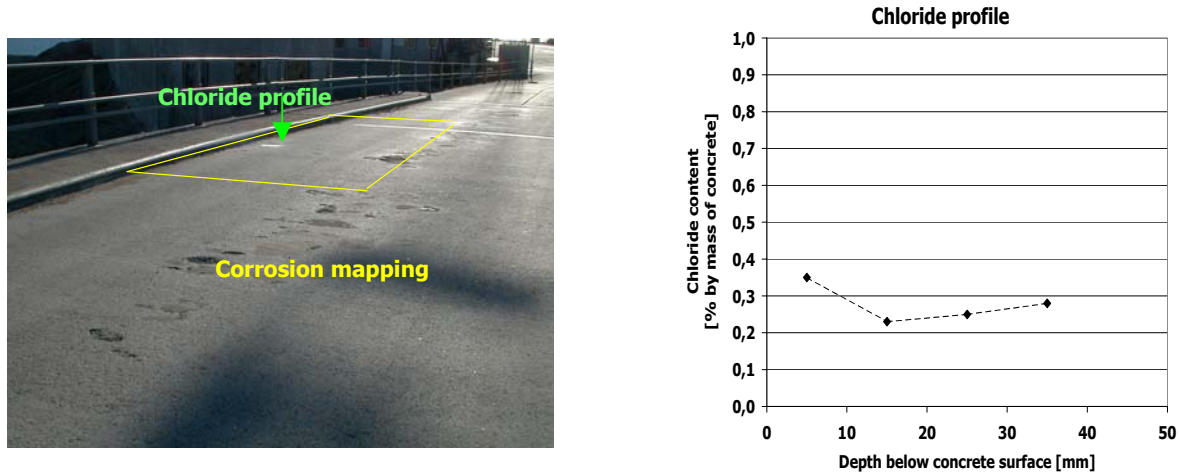


Fig.8 The investigated area and the location of the chloride profile.

The typical dept of the reinforcement is here minimum 40-50 mm and the chloride concentration in this depth is near 0, 3% of the concrete weight. At this high chloride concentrations the half-cell potentials are expected to be low but the most negative values measured are all above -100 mV vs. Ag/AgCl (fig. 9).

Half cell potentials in mV vs. Ag/AgCl reference electrode

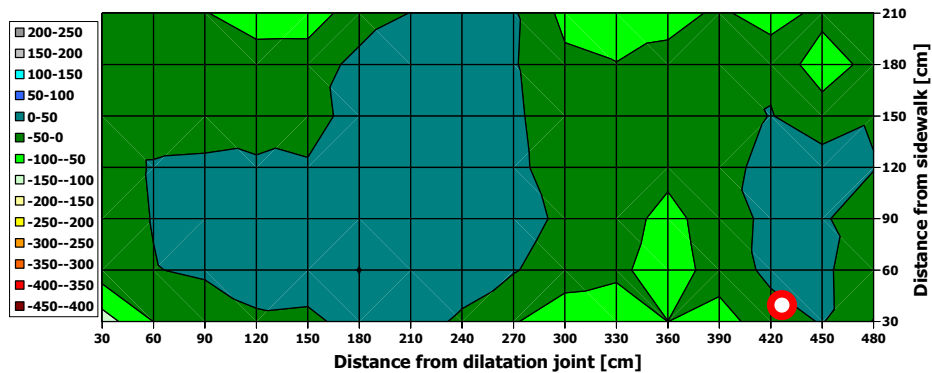


Fig.9. The read circle indicates the location of the chloride profile and the break-up shown at fig. 11.

The corrosion rate map fig.10 shows a completely different picture and indicates active corrosion at several locations.

Corrosion rates in  $\mu\text{A}/\text{cm}^2$

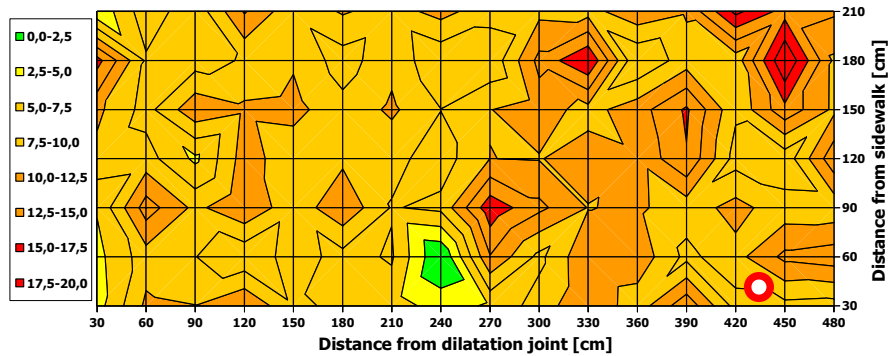


Fig.10. Corrosion rate of the bridge deck. The read circle indicates the location of the chloride profile and the break-up shown at fig. 11. The photo in fig 11 shows the reinforcement covered with a thin layer of corrosion products. The ribs at the reinforcement are still intact but corroded.



Fig.11. The first picture shows the corroded reinforcement and some water from cooling the diamond cutting blade. The second picture shows the damage and the mortar repairs.

General comments to examples 2 and 3.

This bridge is located in a very cold environment. During the measurements described above the temperature was  $15\text{ }^{\circ}\text{C}$  at midday and this explains the rather high corrosion rates at the bridge deck. Further there were some damages to the concrete surface due to the traffic directly on the concrete surface and a lot of mortar repairs.

#### Example 4.

The last example is an underground car park in the Copenhagen area. The rather constant temperature is around 15 °C during the whole year. Most of the observed damages are due to the leakage of water/de-icing salts from the street above. Also de-icing salt from the parked cars in the winter causes damage to the walls near the floor. The concrete was very dry during the investigation. The walls were surface treated with the protective coating. At the locations where water was leaking into the construction the coating was scaling (fig. 12.)



Fig. 12. Leaking of water and de-icing salts cause scaling of coating.

Due to high resistance caused by the coating it was difficult to measure the corrosion rate in the coated areas. Furthermore the half-cell potential measurements are unreliable at the locations with high resistance. In the scaled areas measurements were performed with both HCP and GPM techniques .

The HCP measurements from a typical area of the wall are presented in fig. 13.

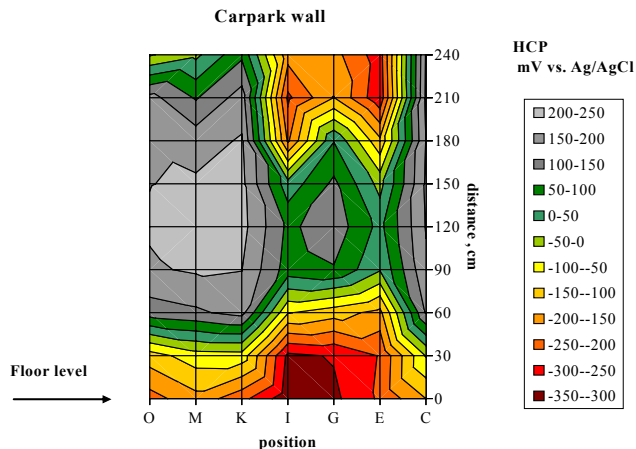


Fig. 13. Potential map of typical area with leakage of water from the street above and capillary suction of water from the car park floor.

By galvanostatic pulse measurements the actual corrosion rate in the position between I and G at floor level was estimated to be 0,9  $\mu\text{A}/\text{cm}^2$ . The picture (fig. 14) shows some corroded area but no cross section loss and the tie wire is intact. In this example both HCP and GPM measurements point out places

with active corrosion. The rather low corrosion rate is in good correlation with the cross section loss observed while the low half cell potentials indicates a high risk of high corrosion activity.



Fig.14. Exposed reinforcement at floor level in car park wall where HCP show very low values.

#### CONCLUSIONS:

1. Two techniques for evaluation of reinforcement corrosion, half-cell potential (HCP) and galvanostatic pulse measurements (GPM) are presented and discussed.
2. The evaluation of corrosion by means of the traditional half-cell potential technique using the existing standards may lead to mistakes in cases where the concrete is water saturated, carbonated and also exposed to the very low temperature.
3. Complimentary measurements by means of galvanostatic pulse technique determining the corrosion rate contribute to the unambiguous evaluation of reinforcement corrosion also under conditions where the results obtained by the HCP technique could be misleading.
4. Four examples from on-site measurements are presented. Three of them show the need of using corrosion rate measurements together with half-cell potential for reliable evaluation of the actual corrosion state.
5. It is not possible to estimate the actual loss of cross sectional area of the reinforcement from a single GPM measurement. If multiple GPM measurements are taken over a period of time, an average value can be estimated. Alternatively the reinforcement must be exposed in the most corrosion active areas as done in these 4 examples.

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