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DETERMINATION OF REINFORCEMENT CORROSION RATE BY MEANS OF THE GALVANOSTATIC PULSE TECHNIQUE

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Key words: Corrosion rate, reinforcement, weight loss, service life predictions.

Abstract *In the BRITE/EuRaM project, " Smart Structures ", an integrated monitoring system was developed by eight European partners. The aim of this project was reduction of inspection and maintenance costs as well as traffic delay and regulation costs.*

One part of this project was concerned with evaluation of portable techniques for quantifying reinforcement corrosion. During this work software for equipment based on the galvanostatic pulse method (GPM) was developed.

The GPM is a fast polarisation technique independent of the concrete resistance. It makes it possible within 5-10 seconds to determine the half-cell potential, the corrosion rate and the resistance between the reinforcement and a hand held electrode system at the concrete surface.
The software was designed to be the user interface between a galvanostatic pulse generator, a transient response analyser and a handheld PSION WorkAbout .
This paper presents the results and analysis of the GPM measurements performed on a highway-bridge exposed to de-icing salts as well as the results of laboratory tests.
Results of average corrosion rates determined by weight loss and galvanostatic pulse technique are compared. At last the necessary precautions to be taken when the on site data are used for prediction of the remaining service life of structures are discussed.

1. INTRODUCTION

A high number of the European infrastructure has reached an age where the capital costs have decreased, but the inspection and maintenance costs have grown to such extent that they constitute a major part of the current costs of running the infrastructural system [1].
In the BRITE/EuRaM project, " Smart Structures ", an integrated monitoring system was developed by eight European partners. The aim of this project was reduction of inspection and maintenance costs as well as traffic delay and regulation costs.

One part of this project was concerned with evaluation of portable techniques for quantifying reinforcement corrosion. During this work software for equipment based on the galvanostatic pulse method (GPM) was developed. After developing the software, 3 Galvanostatic Pulse equipment's were produced by FORCE Institute, one for laboratory tests and two for on site tests. [2]

2. THE GALVANOSTATIC PULSE METHOD (GPM)

Galvanostatic pulse method is a rapid non-destructive polarisation technique, which has been used for evaluation of reinforcement corrosion both in laboratory and on site.

A short time anodic current pulse is impressed to reinforcement galvanostatically from a counter electrode placed on concrete surface together with a reference electrode. The applied current is normally in the range of 5 to 400 μA and the typical pulse duration is up to 10 seconds. The small anodic current results in change of reinforcement potential, which is recorded as a function of polarisation time. Reinforcement is polarised in anodic direction compared to its free corrosion potential. Typical potential transient response is shown in Fig. 1.

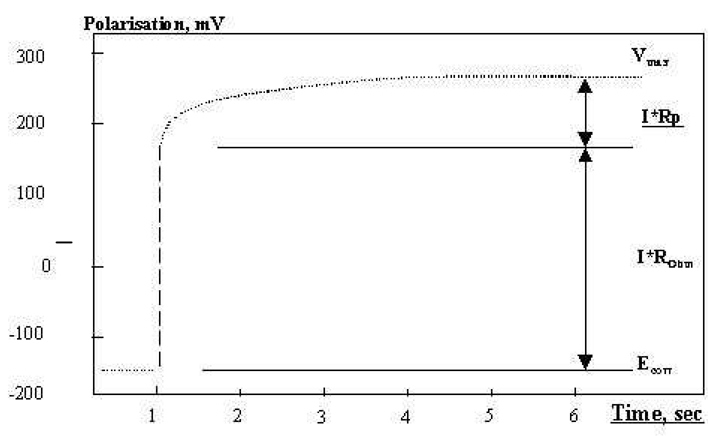


Fig.1 Typical polarisation pattern

When the constant current I_{app} is applied to the system, the polarised potential of reinforcement V_t, at given time t can be expressed as:

$$V_t = I_{app} [R_p [1- \exp(-t / R_p C_{dl}))] + R_\Omega]$$

where:
R_p = polarisation resistance
C_{dl} = double layer capacitance
R_Ω = ohmic resistance

After the polarisation resistance R_p is determined by means of this analysis, the corrosion current I_{corr} can be calculated from Stern Geary equation[5]:

$$I_{corr} = B/R_p$$

where B is an empirical constant determined to be 25 mV for actively corroding steel and 50 mV for passive steel.

The DC polarisation resistance technique with calculation of the instantaneous corrosion current, I_{corr} , from Stern Geary equation, has been applied extensively since 1970.
The problem is that in real structures the area of counter electrode is much smaller than that of the working electrode (reinforcement) and the electrical signal tends to vanish with increasing distance.
As a result, the measured effective polarisation resistance can not be converted to a corrosion rate.

To overcome this problem a second concentric counter electrode, (Guardring) has been used to confine the current to the area of the central CE Fig 3.

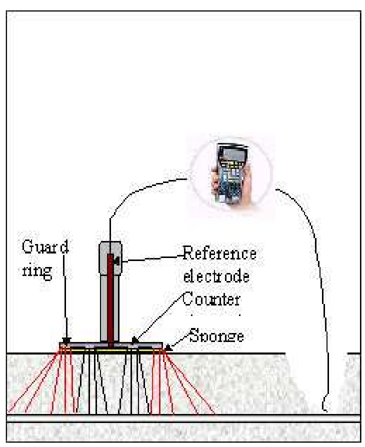


Fig 2. Schematic set-up is showing the confined area.

When the diameter of the reinforcement and the exposed length of the reinforcement (counter electrode diameter) are known the instantaneous corrosion rate can be calculated.

3. ON-SITE INVESTIGATIONS

The project choose to use the Skovdiget bridge north of Copenhagen, Denmark as a test bridge, as the bridge has serious problems with most of the relevant deterioration mechanisms (chloride, carbonation, corrosion, ASR, freeze/thaw). Two parallel bridges were built in 1965-67, 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 4.) pointed out column no. S303 to be attractive to corrosion rate measurements. Electrical continuity in the reinforcement was checked and a permanent connection was welded to the reinforcement.

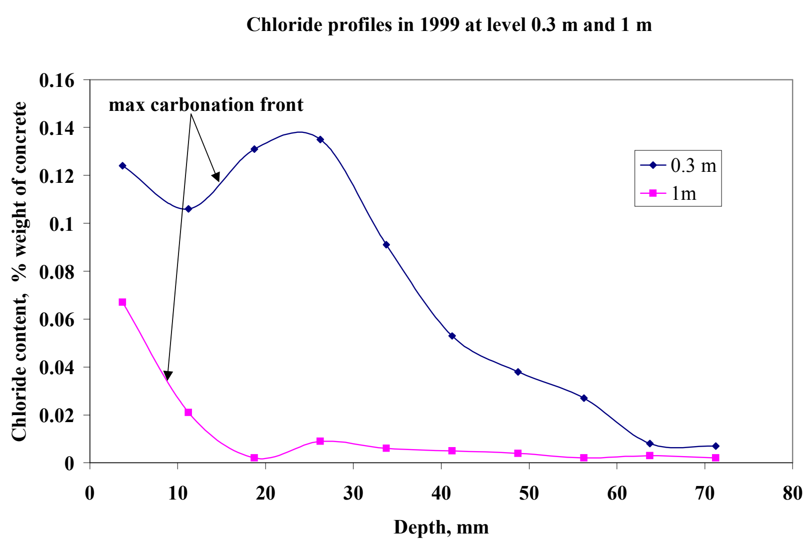
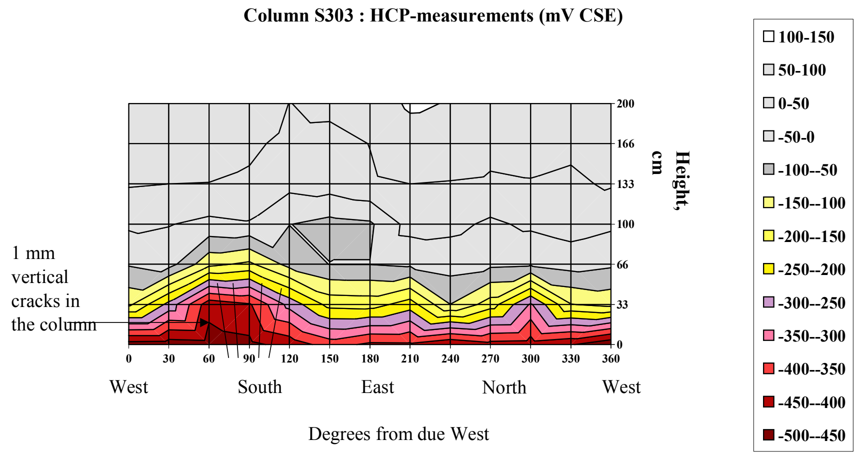


Fig. 3. The vertical reinforcement (Ø35 mm) is typically in 60 mm depth and the horizontal (Ø14 mm) in 40 mm dept. Already in 1999 the chloride content in level 0.3 m is so high that active corrosion can be expected.

In September 2000 and in April 2001 corrosion rates were determined as well as the half-cell potentials (fig 4).



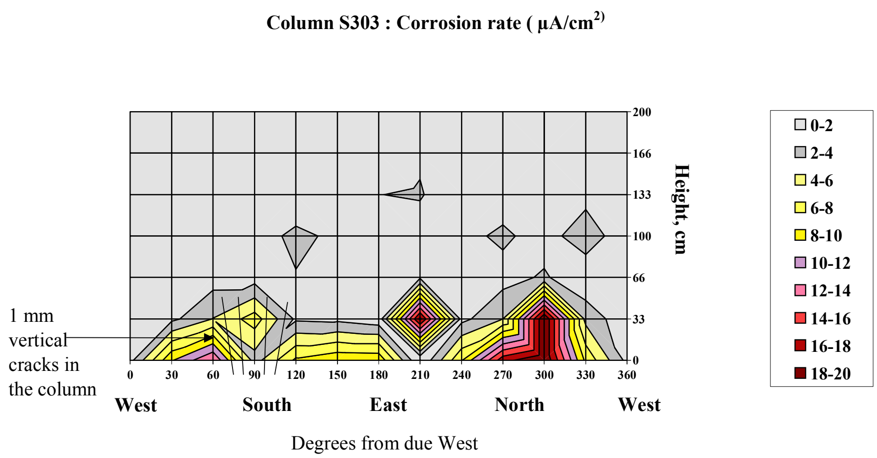


Fig. 4. Half cell potentials and corrosion rates in September 2000

The corrosion rate is up to 32 $\mu A/cm^2$ at 300 degrees as high as level 33 cm at a potential of –300mV vs. CSE. At the same level at 90 degrees the corrosion rate is
7 $\mu A/cm^2$ at a potential lower than –450mV vs. CSE. The potential level here indicates lack of oxygen in agreement with the somewhat lower corrosion rate.
The differences of corrosion rates in September 2000 and April 2001 are shown in fig. 5

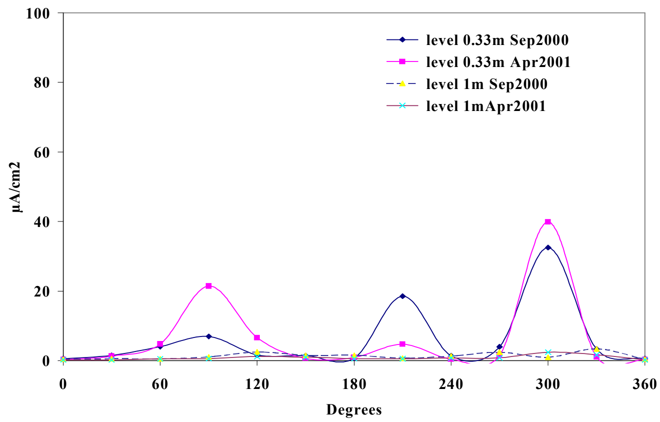


Fig.5 Difference in corrosion rate from September 2000 and April 2001

As reported in former work [7] there is a change in the corrosion rate over the year due to changes in temperature and water content in the pore water system. These data show that the changes at some points can change in either direction with a factor of at least 2.
Exposure of the reinforcement in 1999 at 90 degrees and at level 0.1m showed reinforcement cross section reduction in the range of 1-2 mm). A cross section reduction of 2 mm over 33 years corresponds to an average corrosion rate of approx.
5 μA/ cm^2. Assuming that the corrosion did not initiate before 10 years, increases the average corrosion rate to 9μA/cm^2, which is with in the range of corrosion rates determined at this position by the GPM.

4. LABORATORY TESTS

Parallel to the on-site investigations a number of laboratory tests were made.
7 concrete test blocks were made with 2 reinforcement bars. These blocks were exposed to chlorides for 40 days and the corrosion rate was measured regularly by GPM to determine the variation of the corrosion rate over time (fig 6).

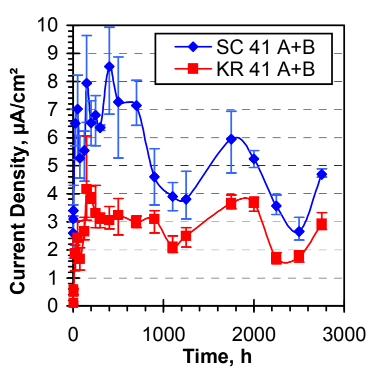


Fig.6. Variation of corrosion rates determined by GPM

At the end of the exposure time, the blocks were crushed and the reinforcement was cleaned for corrosion products. The weight loss of every reinforcement bar was determined and by means of Faradays law translated to $\mu A/cm^2$. As the weight loss corresponds to the average corrosion rate it has been necessary to integrate the corrosion rates as determined by GPM over time in order to compare the results.

	Weight loss	GPM	
Description	Avg. Corr.rate µA/cm²	mV vs. Ag/AgCl	Avg. Corr.rate µA/cm²
bar A	4.6	-345	3,11
bar B	4,8	-334	2,47
bar A and B connected	4,7	-345	5,24

There is a good correlation between the corrosion rates determined by GPM and the rates determined by weight loss. The under estimation of the rate at the bars not connected is probably due to the length of the bars. When the bars are not connected the spread out of the Guard ring current is limited and will influence the confined area.

5. CONCLUSIONS

It is important to emphasise that the obtained corrosion rate is an instantaneous average rate for the confined area that strictly apply to the measuring conditions.
To overcome this problem it was necessary to integrate the frequent corrosion rate measurements over time in the laboratory for comparison of the corrosion rate determined by weight loss measurements. The results from the laboratory show very good correlation between corrosion rates determined by weight loss and corrosion rates determined by GPM.
Corrosion rates obtained on-site by the galvanostatic pulse method (GPM) are comparable to average corrosion rates calculated from actual cross section loss at places where the actual corroding area is the same as the confined area.
It is obvious that wrong estimation of the amount of reinforcement fx.3 bars parallel or crossing make the average corrosion rate to high but also cracks and delamination are often the reason for wrong corrosion rate estimates.
For lifetime predictions a more detailed knowledge of the daily and seasonal changes of corrosion rate is required in order to obtain meaningful values. It is essential to combine the corrosion rate measurements on-site with fx. post mounted corrosion and chloride sensors or a number of other NDE methods to determine the concrete integrity and penetration rates.

6. ACKNOWLEDGEMENT

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