MONITORING OF REINFORCEMENT CORROSION IN MARINE CONCRETE STRUCTURES BY THE GALVANOSTATIC PULSE METHOD

H. E. Sørensen* and T. Frølund

FORCE Technology, Park Allé 345, DK-2605 Brøndby

** E-mail: hes@force.dk , Phone: +45 43267000, Fax: +45 43267011,*

ABSTRACT

Half-cell potential measurements (HCP) have been used for many years to evaluate the corrosion activity of the steel reinforcement in concrete structures. However, this technique has some limitations: It is not possible to estimate the corrosion rate - only a corrosion risk, and, the HCP measurements are difficult to interpret in wet conditions. Therefore, much effort has been done to develop new electrochemical techniques, which can give more detailed information of the corrosion activity in reinforced concrete structures. This paper presents one of these techniques - the galvnostatic pulse technique. This technique can provide fast and reliable measurements of the corrosion activity and also give an estimate of the corrosion rate in concrete structures.

1. INTRODUCTION

One of the main causes for durability problems in marine concrete structures is chloride induced reinforcement corrosion. After an initiation period depending mainly on the concrete quality and cover depth the ingress of chlorides from the seawater will inevitably reach the reinforcement, break down the passive layer and start corrosion in the splash zone and later on even in the atmospheric zone.

Knowledge of the mechanisms governing chloride penetration into concrete is very important for service life predictions of these structures. This topic has been studied very thoroughly in the Scandinavian countries within the last 10 years. A comprehensive State-of-the-Art report has been published in the Danish HETEK programme [1].

One conclusion of the HETEK programme was that more knowledge on mechanisms governing reinforcement corrosion was needed. Chloride threshold values and the effect of environmental conditions on electrochemical potentials were topics, which needed more attention.

Today, several options are available if you want to collect information on the actual state of reinforcement corrosion in a concrete structure. You can 1) measure the corrosion activity directly on the reinforcement by the use of non-destructive equipment based on electrochemical methods, 2) monitor the corrosion activity on the reinforcement by the use of cast-in reference electrodes, or 3) predict a future corrosion initiation on the reinforcement by the use of specially applied corrosion probes. These techniques are constantly being developed to more sophisticated levels. FORCE Technology is deeply involved in this work, and this paper presents the current state of corrosion activity measurements by the use of the galvanostatic pulse method.

2. THE GALVANOSTATIC PULSE METHOD

The galvanostatic pulse method has been introduced for field application in 1988 [2] to overcome problems with interpretation of corrosion risk of reinforcement occurring when half cell potential readings are applied in wet, dense or polymer-modified concrete, where access of oxygen is limited. Since the introduction of this technique further development has been conducted in order to allow quantitative evaluation of the ongoing reinforcement corrosion and also to increase the capacity by reducing the measurement time down to 5-10 sec [3], where other electrochemical methods typical take several minutes.

2.1 Principle

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.

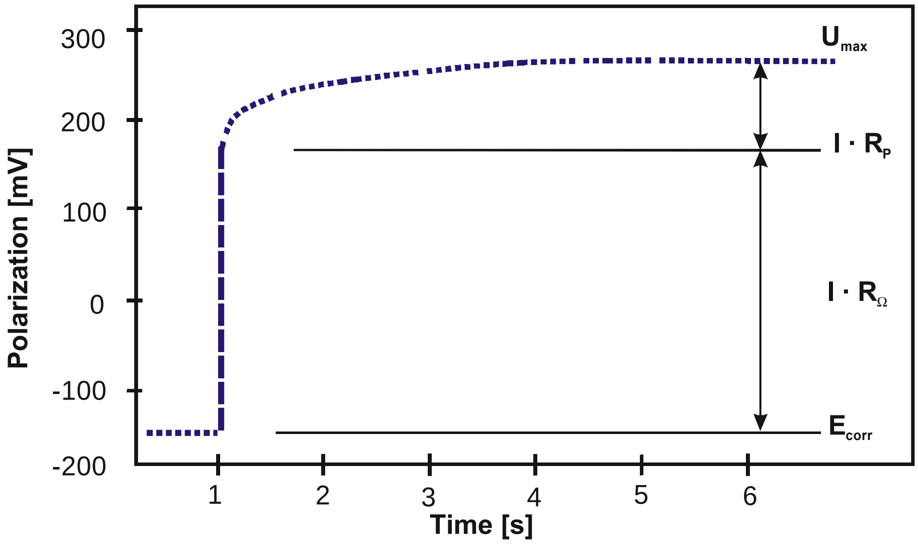

Fig. 1. Typical polarisation pattern

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 :

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

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 [2]:

$$I_{corr} = B/R_p \qquad (2)$$

where B is an empirical constant usually taken as 26 mV for actively corroding steel.

The DC polarisation resistance technique with calculation of the instantaneous corrosion current (I_{corr}) from the 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, (guard ring) has been used to confine the current to the area of the central counter electrode, Fig. 2.

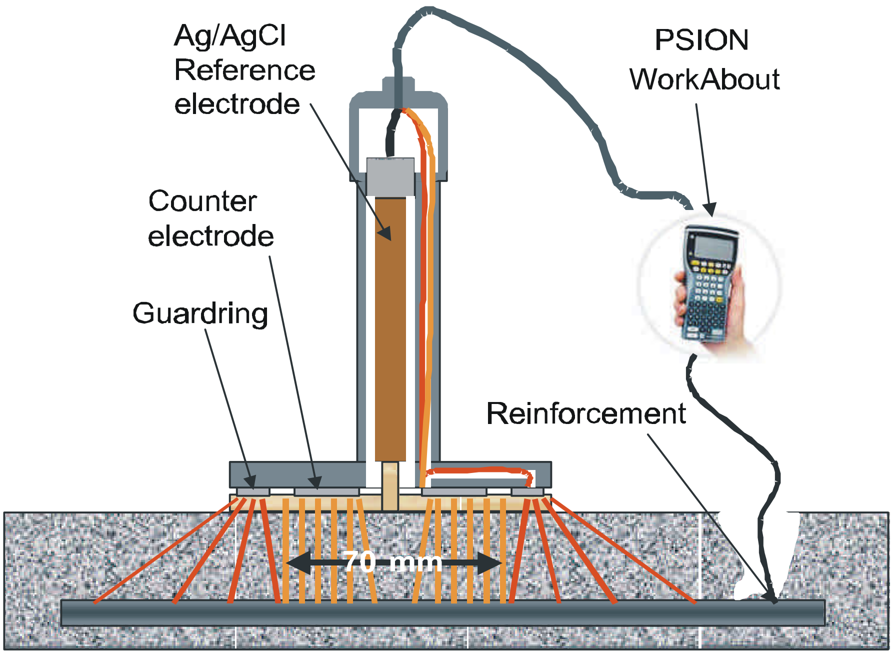

Fig. 2. Schematic setup showing the confined area.

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.

2.2 Verification in the laboratory

The measurements of corrosion rate by the galvanostatic pulse technique were recently tested in the BRITE/EURAM funded programme Smart Structures [4], where measurements performed with a galvanostatic pulse equipment were compared to determinations of weight loss of the corroded bars. Details on this survey are given in [5].

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 the galvanostatic pulse method. At the end of the exposure time, all the blocks were crushed and the reinforcement was cleaned for corrosion products. The weight loss of every reinforcement bar was determined and translated to $\mu A/cm^2$ by means of Faraday's law. As the weight loss corresponds to the average corrosion rate during the exposure period it has been necessary calculate this value by integration of the corrosion measured by the galvanostatic pulse method over time in order to compare the results.

	weight loss whole bar	**current density from weight loss**	**mean current density calculated from GPM over 4 months**
Description	Δm [g]	i_{corr} [$\mu A/cm^2$]	i_m [$\mu A/cm^2$]
bar A (2 cm depth)	1,30	4,8	3,6
bar B (3 cm depth)	1,36	5,0	1,5
bar A + B (center)	2,66	4,9	5,0
exposed / polarized surface		95cm²	31cm²

Table 1. Comparison between weight loss measurements and galvanostatic pulse measurements. From [5].

There is a very good correlation between the corrosion rates determined by galvanostatic pulse measurements and by weight loss measurements. In a standard laboratory corrosion test [6] on steel bars in a liquid medium the corrosion rate can not be expected to be determined better than by a factor of 2. For steel reinforcement in concrete structures this factor may very well be considerably higher due to less controlled parameters and difficulties in predicting the active corroding area.

The general underestimation of the corrosion rate by the galvanostatic pulse method for the unconnected bars in this laboratory test is probably due to the length of the bars. When the bars are not connected the spread of the guard ring current is limited and will influence the confined area.

2.3 Measurements on a bridge column

The galvanostatic pulse method (GPM) has been used since 1994 for corrosion measurements on a de-iced highway bridge built in the Copenhagen area in the late 1960'ies. The lower part of a column has been monitored by GPM measurements in a 50×25cm grid. The GPM results for the height 75cm above ground level are shown in Fig. 3. It emerges clearly from the figure that the corrosion rate is low for the first 4 years, but has been increasing since 1998 in all 7 positions. This shows that the passive layer on the reinforcement has been broken down and active corrosion is starting. The corrosion rate is highest in the position 0,5m. The measured value of almost 6 ìA/cm^2 in this position corresponds to a cross sectional reduction of approx. 60 ìm/year.

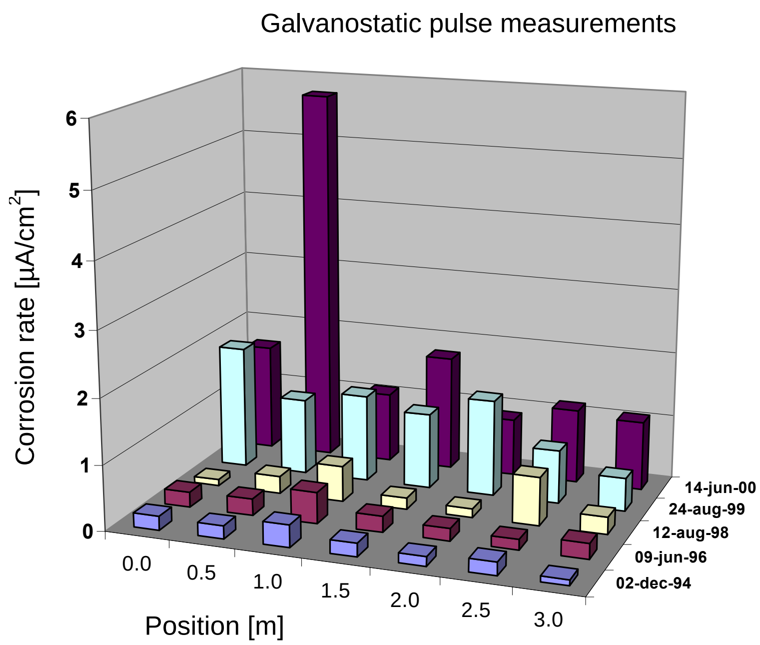

Fig. 3. Corrosion rates for reinforcement in bridge column at the height of 75 cm above ground. The measurements are done by GPM in the period 1994 - 2000.

When using GPM at investigations it is important to remember that the GPM measurement only gives an instant picture of the condition of the reinforcement. In concrete structures the corrosion activity of the reinforcement is influenced by a number of different parameters, e.g. moisture, temperature and oxygen concentration. Typically, considerable variation will be found in measured corrosion rates, depending on season and weather at the time of the investigation. It is important to take these conditions into account when evaluating a GPM survey.

The actual corrosion rate, which will constitute a risk for the durability of the concrete structure is also depending on the environmental action, which cause the reinforcement corrosion. The corrosion rate will normally be slow in carbonated con-
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ues are often 5-10 times higher in chloride-contaminated concrete. However, it is a well-known fact that delamination of concrete cover often takes place at much less cross sectional reduction in carbonated concrete than in chloride-contaminated concrete. Therefore, when doing GPM measurements it is important to add supplementary investigations to identify the cause for corrosion.

A GPM survey makes it easy to point out corroding areas on the structure, see next page regarding the use of 2D surface plot. Unfortunately, it is not possible to determine the cross sectional reduction from a GPM measurement. To get this information, it is necessary to make small reinforcement exposures in the main corroding areas, which easily can be identified by the use of 2D surface plot.

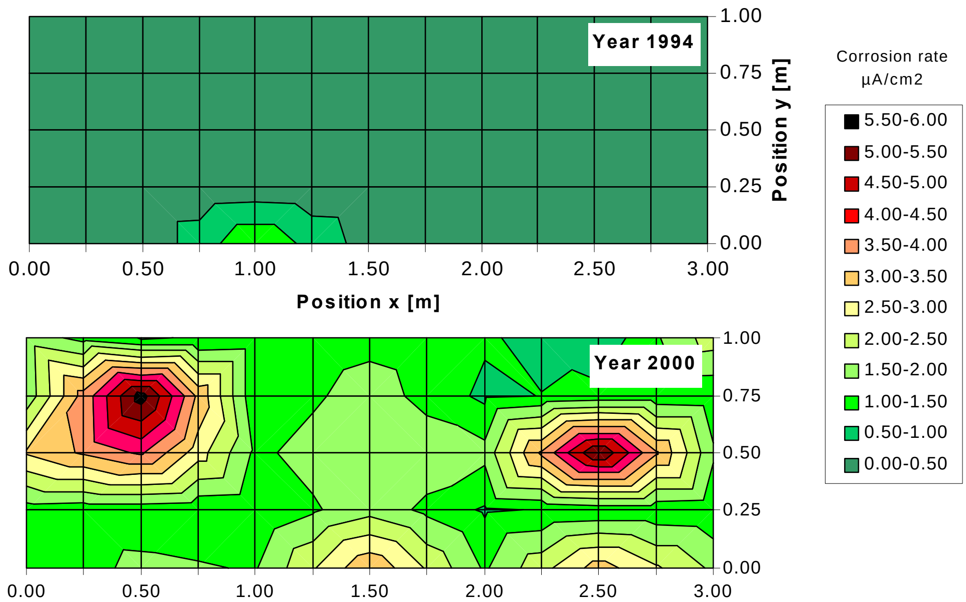

Fig. 4. 2D surface plot of corrosion rates measured by the galvanostatic pulse method in 1994 and 2000, respectively.

Fig. 4 shows a 2D surface plot for the monitored part of the bridge column including all GPM measurements in 1994 and 2000. The trend towards increasing corrosion rates from 1994 to 2000 is clear. The cause for monitoring this particular bridge column for many years is, that experience from similar bridges told, that the reinforcement probably would start to corrode within reasonably few years from 1994. Repeated measurements showed that this was true. Corrosion started gradually in 1999 - see Fig. 3.

3. CONCLUSION

The galvanostatic pulse technique has been tested in the laboratory, where corrosion measurements with this method were compared to weight loss measurements on corroded steel bars. A very good correlation was found from measurements over a period of 4 month. When measuring with guard ring on single bars the galvanostatic pulse measurements had a tendency to underestimate the weight loss.

It is important to remember that corrosion measurements only give an instant picture of the condition of the reinforcement. Typically, considerable variation will be found in measured corrosion rates, depending on season and weather at the time of the investigation. It is important to take these conditions into account when evaluating a GPM survey.

The cross sectional reduction can not be estimated from a single corrosion measurement. An average value might be estimated over a period where multiple corrosion measurements have been undertaken, but the uncertainty of this value will be large, because the active corroding area on the reinforcement is unknown.

4. REFERENCES

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