Corrosion rates determined by the GalvaPulse

C.G.Petersen
Germann Instruments A/S
Emdrupvej 102
DK-2400 Copenhagen
Denmark
E-mail: Germann@post6.tele.dk

December 1st, 2003

1. Introduction

The GalvaPulse equipment offers a fast estimation of the corrosion rate of reinforcement in concrete structures by means of the galvanostatic pulse method.

The time required for each measurement is 5-10 seconds. This special feature of the GalvaPulse should be seen in contrast to the linear polarization technique requiring 4-10 minutes for each measurement.

Doubt has recently been cast about the reliability of the GalvaPulse; ref. 6.1, claiming the GalvaPulse is overestimating the corrosion rate, in general.

The purpose of this paper is to explain why the GalvaPulse in passive areas of the reinforcement in fact is overestimating the corrosion rate, while the GalvaPulse in active corroding areas is estimating the corrosion rate accurately.

Passive areas is defined as areas where the potential curve has not reached a steady-state potential within the time pulsed over, 5-10 seconds, while active corroding areas are exhibiting such a steady-state potential.

With the GalvaPulse the following corrosion rates are typical in passive and active corroding areas:

- Passive areas: < ~ 5 µm/year (< ~ 0.5 µA/cm²)
- Areas with low corrosion activity: ~ 5 to 50 µm/year (~ 0.5 to 5 µA/cm²)
- Areas with moderate corrosion activity: ~ 50 to 150 µm/year (~ 5 to 15 µA/cm²)
- Areas with high corrosion activity: > ~ 150 µm/year (> ~ 15 µA/cm²)

The explanation is substantiated by examples from testing cases where the GalvaPulse measurements – and prediction of the loss of cross-section of the reinforcement – are compared to the actual loss of reinforcement established after exposure of the reinforcement.

In addition, an example is given where the GalvaPulse was applied for estimating the time of initiation of corrosion.

2. The GalvaPulse

The galvanostatic pulse technique is described in detail in ref. 2, 3, 4 and 5.
A transient current pulse is impressed into the reinforcement from an electrode placed on the surface. The electrode contains a reference electrode, a counter electrode and a guard ring, fig. 1.

Prior to pulsing, the reference electrode picks up the free potential. The counter electrode impress the transient current pulse delineated by the guard ring, and the reference electrode picks up the resultant potential in the time domain.

![Fig. 1. The GalvaPulse shown schematically. The electrode contains a reference electrode placed centrally, a counter electrode and a guard ring.](image)

The applied current is normally 50 µA and the time polarized over 5 seconds. Should the polarization pattern recorded not be regular as illustrated in fig. 2, the settings are altered to higher values until a regular polarization pattern is achieved. This is typical required in areas with high corrosion rates. In passive areas the potential of the reinforcement is easy to change, while it is more difficult in active corroding areas since the level of corrosion current is high prior to the pulsing.

![Fig. 2. Typical polarization patterns for active corrosion (left figure) and passive corrosion (right figure)](image)
3. Explanation for overestimation of the corrosion rate with the GalvaPulse in passive areas

The corrosion current is calculated from the transient polarization curve in fig. 2 after a linear transformation of the curve has been applied. This calculation is outlined in ref. 3 in detail.

The corrosion rate calculation requires the steady-state maximum of the polarization curve, the $V_{\text{max}}$, to be established. In the GalvaPulse calculations the potential measured after the selected 5 – 10 seconds of pulsing is always used.

Within the short time pulsed over with the GalvaPulse, the $V_{\text{max}}$ will be reached in active corroding areas, while it will not be reached in passive areas. A steady-state potential in passive areas will require several minutes of pulsing.

By using the non-steady voltage after 5-10 seconds in passive areas in the calculations, the corrosion current is overestimated 3-4 times. The designers of the GalvaPulse considered this as a minor problem, taking into consideration the consequence of the alternative – that each measurement will take a long time – in combination with the minor practical importance of estimating correct corrosion rates in passive areas.

4. On-site testing cases comparing the GalvaPulse corrosion rates to actual measured loss of cross-section

4.1 Bridge columns for corrosion rate (Ref. 6.4)

A circular bridge pillar supporting a motorway in the Copenhagen area was investigated. The pillar is exposed to deicing salts up to a level of 2m. In 1999 chloride profiles were made by the RCT-method and the results are shown in fig 3.

![Chloride profiles in 1999 at level 0.3 m and 1 m](image)

Fig. 3. Typical chloride profiles in level 0.3 m and level 1 m in 1999
The concrete cover on this pillar varies from 2.5 cm to 5 cm and the reinforcement is therefore in some places surrounded by a high content of chlorides.

In year 2000 GalvaPulse were performed (fig. 4 and a break up in the corroding area was made for visual inspection (fig. 5).

At a level of 33 cm at 300 degrees corrosion rates up to 32 $\mu$A/cm$^2$ were determined. The potential here was -300 mV vs. CSE. At the same level at 90 degrees the corrosion rate was 7 $\mu$A/cm$^2$ at a potential lower than −450 mV vs. CSE. The potential level here indicates lack of oxygen in agreement with the somewhat lower corrosion rate.

Exposure of the reinforcement in 2000 at 90 degrees and at level 0.15 m 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 $\mu$A/ cm$^2$. Regular visual inspections make it reasonable to assume that the corrosion did not initiate before 10 years of service life. Using this assumption increases the average corrosion rate to 9$\mu$A/cm$^2$, which is within the range of corrosion rates determined at this position by the GalvaPulse.

Fig. 4 GalvaPulse results from year 2000 on a circular bridge pillar

Exposure of the reinforcement in 2000 at 90 degrees and at level 0.15 m 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 $\mu$A/ cm$^2$. Regular visual inspections make it reasonable to assume that the corrosion did not initiate before 10 years of service life. Using this assumption increases the average corrosion rate to 9$\mu$A/cm$^2$, which is within the range of corrosion rates determined at this position by the GalvaPulse.
4.2 Bridge abutment for half-cell potentials and corrosion rate (Ref. 6.3)

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. 6.

Fig. 6. 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.

Fig 7. Half cell potential map of bridge foundation. Potential in mV vs. Ag/AgCl
4.3 Bridge deck for half-cell potentials and corrosion rate (Ref. 6.3)

The bridge deck from the same bridge in Greenland showed very different results as shown on fig. 10 and fig. 11.

Fig. 10. 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. 11).
Fig. 11. The read circle indicates the location of the chloride profile and the break-up shown at fig. 13

The corrosion rate map fig. 12 shows a completely different picture and indicates active corrosion at several locations.

**Corrosion rates in μA/cm²**

Fig. 12. Corrosion rate of the bridge deck. The read circle indicates the location of the chloride profile and the break-up shown at fig. 13. 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
4. 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 °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.

4.4 Swimming pool for corrosion rate

In this example the conditions for performing corrosion rate measurements were not ideal. The inside of the swimming pool was covered by tiles but preliminary GalvaPulse measurements showed that the joint filler was porous and performing corrosion rate measurements were possible. The outside reinforcement was corroding at the casting joint between the pool floor and the pool walls and it was found necessary to investigate the inside reinforcement although no rust stains were visible.

Fig. 13. 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

Fig. 14. Swimming pool wall and bottom with tiles
The results were projected to a plane plot where the cast joint is in the center of the plot fig. 16.

Even at these un-ideal measuring conditions the GalvaPulse pointed out the reinforcement corrosion points which was confirmed by visual inspections in breakups fig. 17.
4.5 Bridge columns, corrosion rates for initialization of corrosion

The final example is demonstrating how yearly corrosion rate measurements can determine the time for the reinforcement corrosion to initiate. The GalvaPulse measurements have been supplied with macro cell measurements. Connecting a corrosion sensor to the reinforcement will form a macro cell when the sensor starts to corrode. Measuring the macro cell current quantifies the corrosion activity, but does not determine the real corrosion rate.

A motorway bridge pillar exposed to de-icing salt was examined from 1994 to 2000 by GalvaPulse equipment. Experiences from similar bridge pillars supported by chloride profiles showed that active corrosion would start within the next 4-8 years.

Corrosion rate mapping of the bridge pillar in 1998 up to a level of 1 meter showed that corrosion rate in level 0.75 m were increasing. It was decided to support the GalvaPulse measurements with corrosion sensors in this level (Fig. 2).
The sensors 1, 2, 3, 4, 5, 6, 7 and 8 are placed in the same depth as the reinforcement, around sensor 3 and sensor 5 two extra sensors were placed, one deeper than the reinforcement and one close to the concrete surface. Note that the sensor 5 is placed near the orange area where corrosion appears in 1999 as shown in fig. 21 and fig. 22.

The sensor in 55 mm depth show no macro cell current (passive), but the sensors in the same depth as the reinforcement (37 mm) show some corrosion activity in agreement with the GalvaPulse measurements of the near by reinforcement (fig. 22). The sensors near the surface show high corrosion activity in agreement with the higher concentration of de-icing salts.
5. Conclusions

5.1 With the GalvaPulse a fast estimation of the corrosion rate is performed within 5-10 seconds. The trade-off is a corrosion rate estimated in passive areas 3-4 times higher than the actual one.

5.2 Passive areas are defined as areas where the potential curve on the instruments computer screen has not reached a steady-state after pulsing over 5-10 seconds.

5.3 In areas with active corrosion, areas where the potential curve exhibit a steady-state potential after 5-10 seconds, the corrosion current is measured as accurate as it can be expected from an on-site measurement taking into account the variation of the area of the reinforcement polarized over, the actual corroding area of the reinforcement and the inherent variations in moisture condition of the concrete and the temperature.

5.4 Despite the overestimation of the corrosion current in passive areas, the estimation of the time of corrosion initialization can be determined precisely. Following such an initialization, the GalvaPulse corrosion rate in combination with established chloride and carbonation profiles will provide valuable information for service life calculations.
6. References


