The Effectiveness of Corrosion Inhibitors – a Field Study

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Summary

The application of corrosion inhibitors is expected to be a cost-efficient repair method. Unfortunately there are not many results of well monitored long term field studies. The aim of this investigation was to determine and to compare the effectiveness of two inhibitors, sodium monofluorphosphate (MFP) and FerroGard-903, in the case of chloride induced rebar corrosion of elements of the side walls of a road tunnel and to evaluate an appropriate monitoring system for such a repair technique. Results from the condition survey before the application of the inhibitors as well as from potential mapping, corrosion current and concrete resistance measurements after the treatments are presented in this paper.

Keywords: rebar corrosion; rehabilitation; repair; corrosion inhibitors; MFP; FerroGard-903; chloride; monitoring; field study

1. Introduction

The number of reinforced concrete structures showing signs of deterioration or damages due to corrosion of rebars increased dramatically within the last two decades. There is, therefore, an obvious and urgent need of the owners of reinforced concrete structures for simple, quick, durable and cost-efficient repair techniques. The application of corrosion inhibitors might be such a rehabilitation method since the chloride contaminated or carbonated concrete has not necessarily to be removed. Thus, this repair method seems to be very promising. Although inhibitors are used in the practice [1-2] and some field trials are on the way [3-4] there is still a lack of results of well monitored long term field studies as well as established practical experiences.

2. Field Study in the Naxbergtunnel

2.1 Goals of the study

The goal of this 3 year field study is to determine and to compare the effectiveness of two inhibitors, sodium monofluorophosphate (MFP) and FerroGard-903 (FG), in the case of chloride induced rebar corrosion and to verify the results of laboratory experiments [5-6] as well as to evaluate an appropriate monitoring system for such a repair technique. The study was started in 1997 with the condition survey.

2.2 Description of the Naxbergtunnel

The 550 m long Naxbergtunnel, built 1972-79, is a part of the highway A2 from Lucerne, trough the Gotthardtunnel to Italy. It has two normal lines and one emergency line and is located about 1000 m above sea level, thus, in an area where much deicing salt is used during the winter season. The lower part of the side walls of the tunnel is covered with prefabricated, 2.10 m wide elements (panels) with a thickness of only appr. 40 to 50 mm. The reinforcement of the elements consists of one mat of rebars (∅ 4 mm) in the centre.

2.3 Condition survey

Based on results of the preceding condition survey (potential and chloride measurements) of the whole tunnel 16 elements, situated app. in the middle part of the tunnel, have been chosen for this investigations. A more detailed condition survey of these 16 elements was carried out in 1997. The following steps were carried out:

a) Potential mapping (grid of the measurements: 0.15 x 0.15 m)
b) Chloride analysis
c) Removal of the concrete in small areas (openings) and visual inspection of the corrosion state of the rebars.

Fig.1 shows the chloride profiles in different heights above ground (0.45 - 3.0 m) and the relation between the chloride content and the corrosion potential. At the lower part of the elements (< 2.0 m) the chloride content is very high. At the height of about 2.0 to 3.0 m the chloride content near the rebars (cover of the rebars app. 10 - 25 mm) is lower than 0.5 M.% in respect to the mass of cement. Obviously, the corrosion potentials decrease and the intensity of the corrosion process increases with increasing chloride contents.

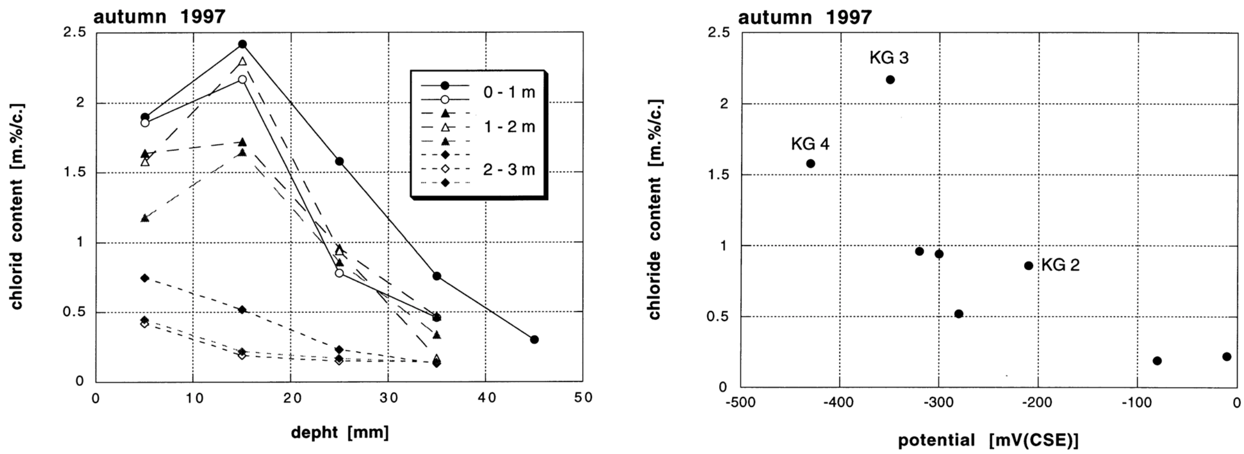

Fig. 1 Chloride profiles in different heights above ground and relation between chloride content and potential and corrosion state of the rebar in openings (KG: grade of corrosion) KG 0: blank, no corrosion / KG 1: slight signs of corrosion / KG 2: small areas with corrosion KG 3: corrosion on the whole surface / KG 4: pitting corrosion

3. Investigation

3.1 Test fields and instrumentation

The 16 elements were used as test fields as follows:
- 4 elements as reference / 4 elements treated with MFP / 4 elements treated with FerroGard-903
- 2 elements treated with FerroGard-903 and Sikagard-701 W (hydrophobic impregnation)
- 2 elements treated with Sikagard-701 W

In the autumn of 1997 these test fields were instrumented with the following monitoring components:
- Electrically isolated rebars
- Instrumented cores for resistivity measurements
- Sensors for humidity and temperature of the air and concrete
- Installation of the data loggers, cabling

Details of these monitoring components as well as additional and general information on the monitoring of concrete structures after a repair are given elsewhere [7-8].

At the same time cores were taken out of the elements to determine the ohmic resistivity of the concrete as a function of the relative humidity under controlled laboratory atmospheres.

3.2 Application of the inhibitors

The application of the inhibitors was carried in June 1998, about eight months after the instrumentation of the test fields. This procedure should allow that the concrete and the new mortar could reach again the equilibrium moisture content.

Before the application of the inhibitors the surface of test fields was washed and cleaned with water. The inhibitors were then applied in several steps. This work was carried out by the providers of the inhibitors under the supervision of the project leader.

The amount of FerroGard-903 applied during the treatment was more than 500 g per m^2 of concrete surface and thus far higher than the target value of 300 g/m2. The concentration of the inhibitors were analysed on concrete cores. The first analysis were made directly after the application and the second will has been made in the autumn 1999. The results of both analysis (4 to 5 cores) gave inhibitor concentrations near the rebars which are higher than the target values (MFP: 0.05 M.% in respect to the mass of concrete, FG: app. 13 ppm).

3.3 Measurements

A full set of measurements was executed about 3 months after the instrumentation of the test fields, then just before and after the application of the inhibitors (June 1998) and thereafter app. every 6 months. It included the following measurements:

- Potential mapping of all elements
- Potential as a function of depth of concrete (potential profiles)
- Corrosion current, Potential difference, polarisation and ohmic resistance of the isolated rebars
- Corrosion current, Potential difference and ohmic resistance of the embedded stainless steel bars
- Ohmic resistance of the instrumented cores (embedded wires)
- Temperature and relative humidity

Some of the above mentioned parameters were continuously registered by data loggers.

4. Preliminary results

4.1 Potential mapping

In Fig. 2 the results of the statistical analysis of the corrosion potentials measured in the different test fields are shown. The following conclusions can be drawn:

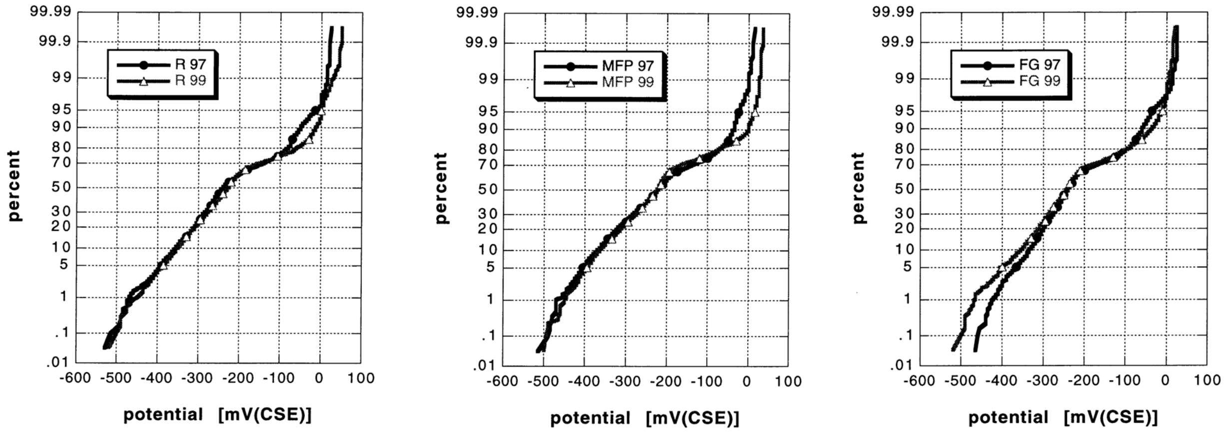

Fig. 2 Statistical analysis of the corrosion potentials measured 1997 and 1999 in the reference fields (R), the fields treated with MFP (MFP) and with FerroGard-903 (FG). 1997: Measurements before the application of the inhibitors 1999: app. 1.5 year after the application of the inhibitors

- There are only minor changes of the corrosion potentials of the test fields between 1997 and 99
- In the reference- and MFP-fields a slightly positive shift can be recognised in the potential range above -50 mV_{CSE}. This might be due to a slightly reduced moisture content of the concrete
- The fields with FerroGard-903 show a slight increase of the potentials in the upper part and slight decrease in the lower part of the curve. This might be caused by the increase of the concrete conductivity of the concrete cover due to the application of the inhibitor (alkaline solutions with salts)
- The potential mapping provides well reproducible results

4.2 Corrosion currents

The course of the corrosion currents over time of some electrically isolated rebars are given in the Fig. 3–4. The cleaning of the surface and the application of the inhibitors led to a sharp increase of the currents by a factor of 1.5 to 3 (increased conductivity of the concrete). This effect is more pronounced in the lower part of the elements where higher corrosion currents were measured and probably a larger amount of water reached the surface during the cleaning. The short term transients (peaks) are caused by some single steps of the whole process (cleaning, pre-wetting, application).

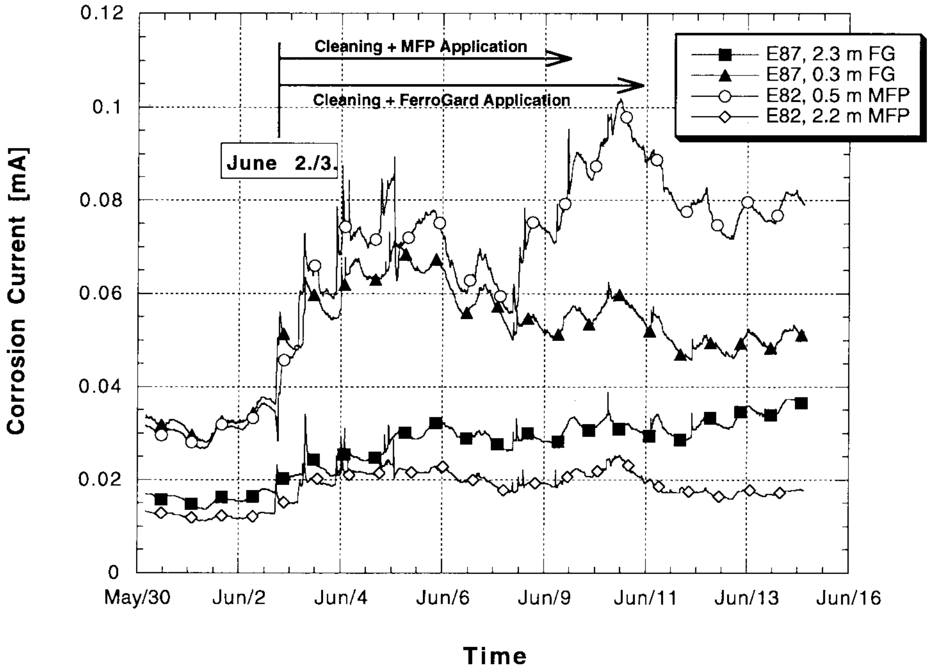

Fig. 3 Corrosion current of some electrically isolated rebars during the time of the cleaning process of the surface and the application of the inhibitors.

The more or less regular variations of the currents within hours or days corresponds to temperature changes. This is more pronounced at higher currents. The highest currents are measured during the summer season. The corrosion process does not stop at temperature below 0 °C.

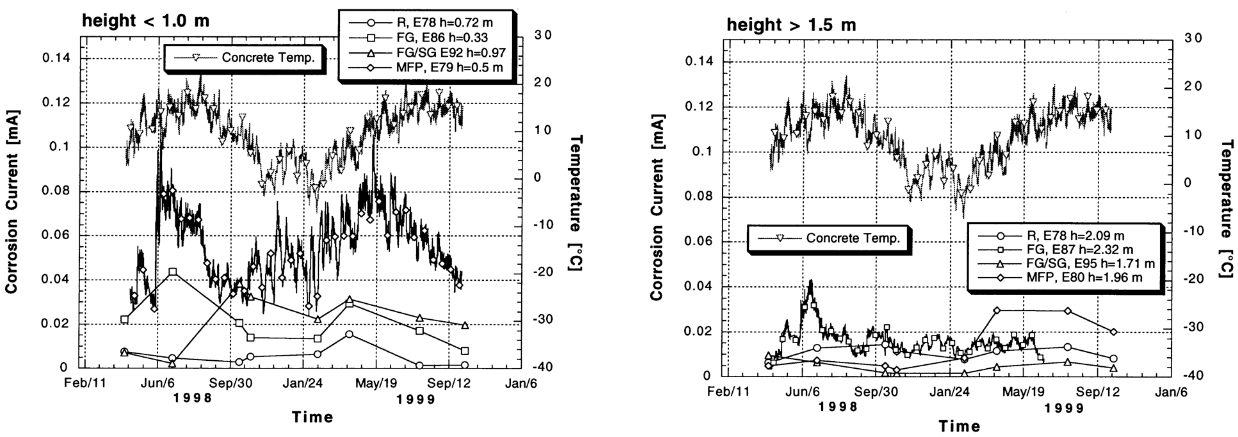

Fig. 4 Concrete temperature and corrosion current of some electrically isolated rebars of the differently treated test fields located at heights of <1.00 m and >1.50 m above ground, respectively

The corrosion currents of the isolated rebars in the lower part of the elements are generally higher than those in the upper part due to the higher chloride content and thus more active anodic areas. A clear decrease of the currents after the application of the inhibitor could not be detected yet.

4.3 Concrete resistances

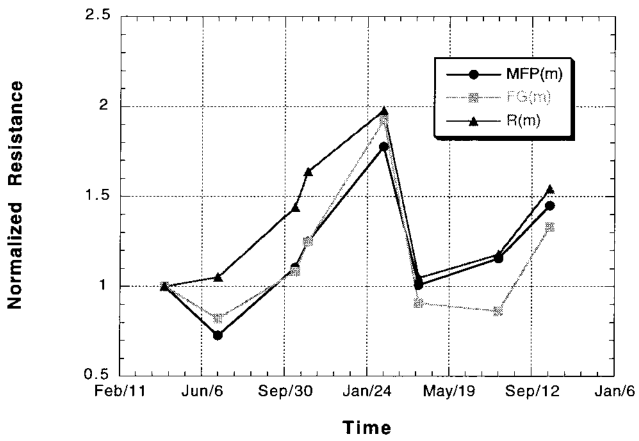

Fig. 5 Normalized concrete resistances (averages) over time measured with the electrically isolated rebars

Cleaning of the concrete surface with water and the application of the inhibitors (June 1998) led to a decrease of the ohmic resistances (Fig. 5-6) which is more pronounced in the concrete cover than in the middle of the elements (Fig. 6). Significant differences between the test fields can not be seen. The highest resistances are measured in the field with the hydrophobic impregnation which probably reduced the moisture content of the concrete. The variation over time corresponds to the seasonal changes of the temperature (winter/summer).

The concrete resistances over the depth (resistance profile) measured with the instrumented concrete cores are shown in Fig. 7 for the lower and upper parts of the elements. The measurements were taken in summer 1998 (after the treatment) and in summer 1999 at similar air temperatures.

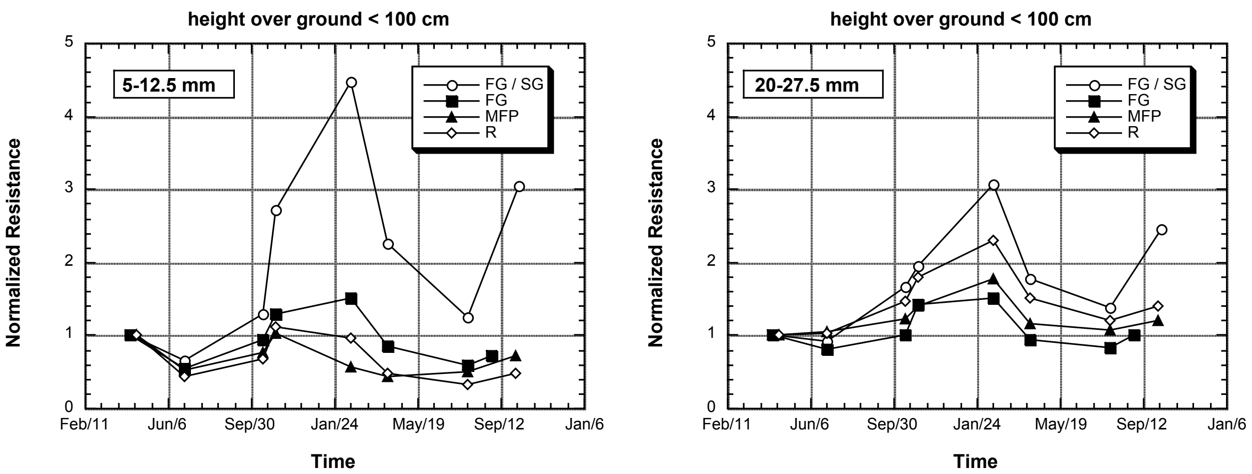

Fig. 6 Normalized concrete resistances over time measured with the instrumented cores at different depths

In most cases the resistances are higher at the exposed side than in the middle or backside of the elements because of the carbonation of the concrete (increases the resistances). Compared to other structures the profiles are rather flat. Apart from the field with the hydrophobic treatment the test fields do not show significant changes of the concrete resistances. The values are similar in the lower and upper parts of the elements.

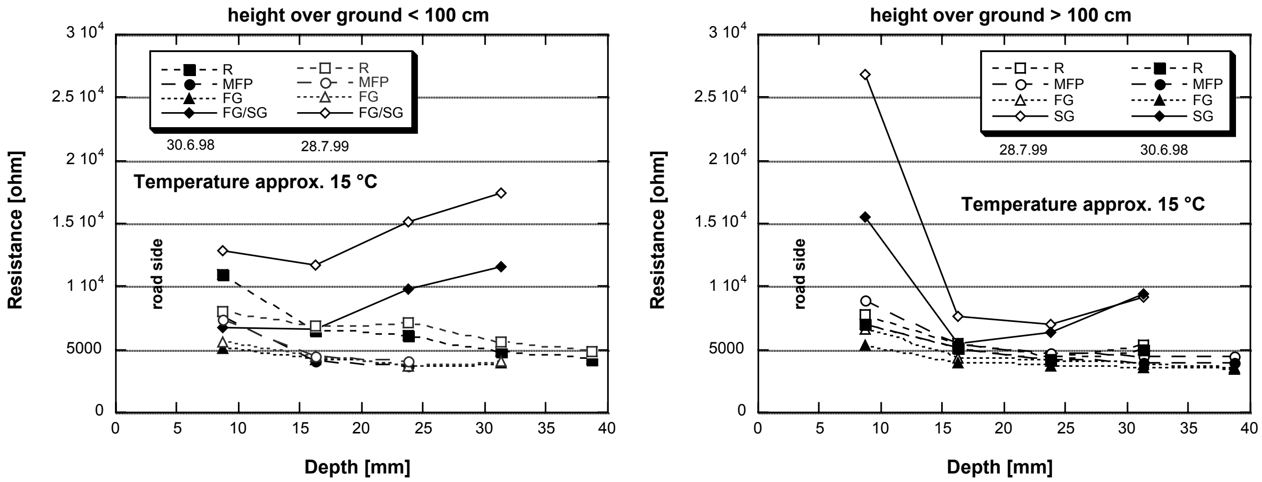

Fig. 7 Concrete resistances over the depht measured with the instrumented cores

5. Conclusions

An extensively instrumented and monitored field study on the effectiveness of corrosion inhibitors was started in 1997 and will last about 3 years. The side elements (panels) of the walls of the Naxbergtunnel were chosen as test fields. 1.5 years after the application of the inhibitors (June 1998) the following preliminary conclusions might be drawn:

- No significant effects of the inhibitors MFP and FerroGard-903 on the corrosion of the rebars could be detected up to now neither with potential mapping nor with the measurements on the electrically isolated rebars nor with the instrumented concrete cores.
- The instrumentation as well as the monitoring (combination of manual measurements with data logging) has proven to be appropriate.
- The hydrophobic impregnation led to increase of concrete resistance due to the reduced moisture content of the concrete.
- The thin, only 50 mm thick elements made the embedding of the monitoring components more difficult.

The project is continuing and the final report will be finished until 2001.

Acknowledgement

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