CASE STUDY – CORROSION MONITORING IN MARINE ENVIROMENT IN CROATIA

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Abstract:

In the last decades it has become well known that the corrosion of reinforcement is the most harmful damage that occures in reinforced concrete structures. The "great" example of such case happened in the Yacht Marine Split, Croatia, where the reinforced concrete structure was exposed to very aggresive marine enviroment. The old reinforced concrete construction elements had been tested in November 2001 (visual inspection, half-cell potential mapping, mechanical and chemical testing) and as a result of those testings, the experts had concluded that the serviceability and load bearing capacity of the main structure elements are critically damaged. All those testings have showed that the reinforced concrete structure was not properly designed and during building proccess not properly constructed. It has been decided to change main span structure elements, which were permanently in tidel zone and partially to use old columns, which were under water and in a good state.
In the spring 2002 a new marine has been built, with prefabricated prestressed reinforced concrete elements. On one of the concrete element corrosion protection with migrating corrosion inhibitor has been applied, because of the tiny cracks, that have occured during production. Since the new elements were placed in the position according the project, the monitoring of the concrete elements with the galvanostatic pulse technique started. The galvanostatic pulse technique is a non-destructive method, suitable for on-site measuring, which is determining the free corosion potential, corrosion current and concrete resistance.The results of these measurements are presented in the paper.

Keywords: case study, concrete, corrosion of reinforcement, deterioration, marine enviroment, monitoring, site measurements.

1. Introduction

In the last decades it has become well known that the corrosion of reinforcement is the most harmful damage that occures in reinforced concrete structures. The case study described in this paper is an example of the reinforced concrete structure exposed to very aggresive marine enviroment for 30 years. The analysis performed during the investigations in November 2001 showed that the structure deterioration degree was in most places at the critical level and the immediate intervention was necessary [1]. In the spring 2002 a new marine has been built, with prefabricated prestressed reinforced concrete elements. Since the new elements were placed in the position according the project, the monitoring of the concrete elements started with the non-destructive galvanostatic pulse technique. This paper is giving the results of the performed tests on the old marine structure and also monitoring results on the new structure.

2. Structure description

2.1. Location

The structure of the marine is located at the Adriatic coast in Dalmatian area, within the city of Split (Fig.1, 2). At this region a typical mediteranean climate is dominating, with very hot summers and mild winters, but during which are blowing strong winds coming either from north (dry and cold), or from south (wet and warm).

Figure 1. Map of Croatia

Figure 2. Yacht marine in Split

2.2. Inspection methodology on the old structure

The old structure was composed of reinforced concrete elements (columns) and prestressed reinforced concrete elements (beams and T-girders), and it was build in the early seventies. During the year 2001 the investigation of the old structure was performed, which summary is following [1].

2.2.1. Visual structure inspection

On the dock construction elements, which were demounted and pulled out from the sea, primarily a visual inspection was done (Fig.3-6). Based on this visual inspection it was concluded that the main beams of the span structure are in the critical state of damage (Fig.3-4), and no futher testings were needed to prove usability of these elements. The columns of the tested dock were completely covered with the shells (Fig.5-6), and on some places concrete cover was destroyed by the reinforcement corrosion (Fig.6).

Figure 3. Span structure (T-beams)

Figure 4. Cracks on the span beam

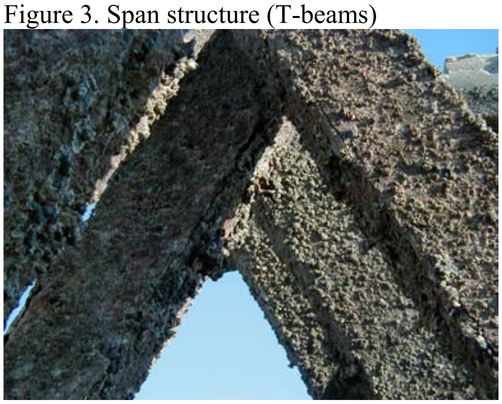


Figure 5. Columns of the tested deck covered with shells

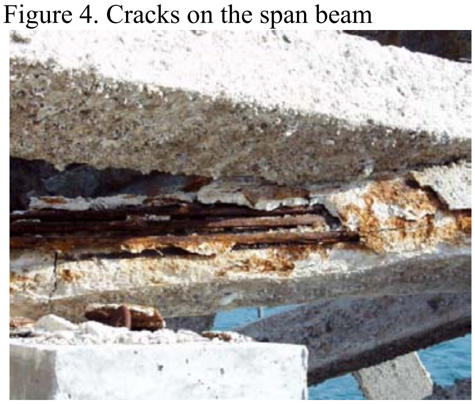


Figure 6. Columns with corrosion damage

2.2.2. Compressive strength core testing

The compressive strength testing was done on six drilled concrete cores from the structure. The results of testing were between 40.1 MPa and 58.1 MPa (recalculated on the characteristic concrete cube strength), which is pointing out that the concrete had higher strength than expected, but this was not enough considering durability criteria.

2.2.3. Concrete chemical analysis

On the drilled specimens from the structure chemical analysis were performed, which included chloride and sulphate content, pH value, carbonation. Test results are shown in next diagrams (Fig.7-8).

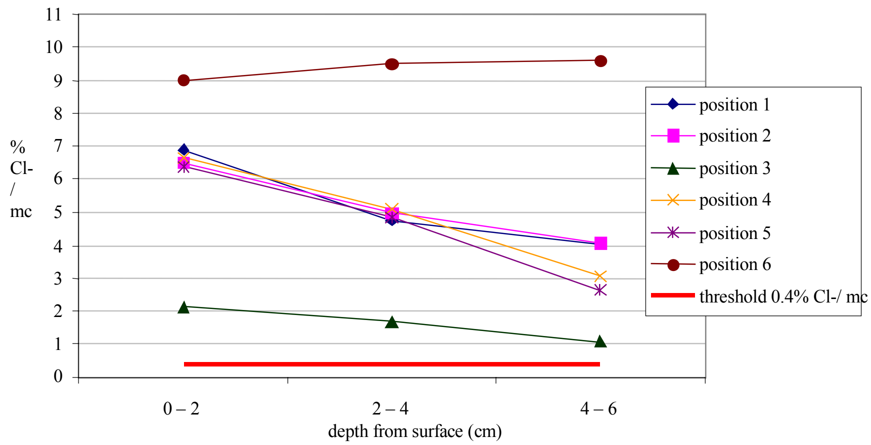


Figure 7. Chloride profile through the depth of the concrete

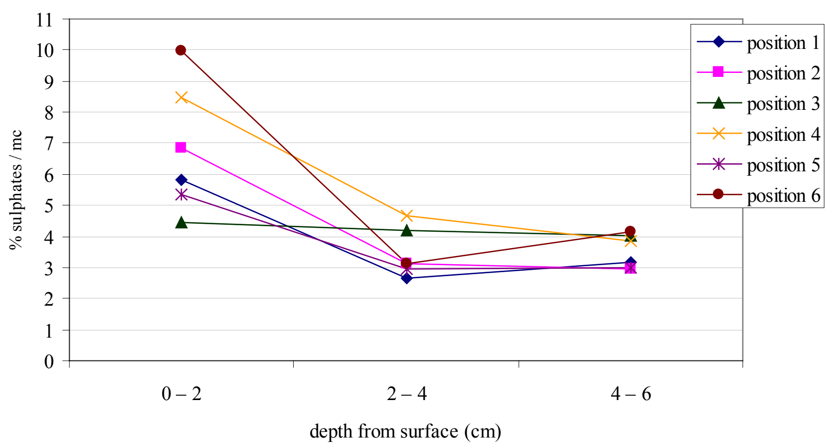


Figure 8. Sulphate profile through the depth of the concrete

The chemical tests on drilled concrete cores showed that the concrete was heavily contamined by chlorides to a depth much deeper than the reinforcement position. The chloride content was multiple greater than the threshold of 0.4% by weight of cement. Values of pH factor were bigger than 12 on all tested specimens.

On the base of visual inspection and laboratory tests the evaluation of the structure degradation level was given. It was obvious that structure was not enough qualitative designed and built, and above that the structure was exposed to the extremely agressive enviroment. Spalling of the concrete cover was visible on many places on the span beams, and also significant corrosion damages of the reinforcement. This damage type belongs to the critical grade and implies a indispensable intervention.

2.3. New marine construction

After the final evaluation of the structure degradation level, the reparation proccess had started. In the spring 2002 a new marine was built, with prefabricated reinforced and prestressed concrete elements. All span structure elements and some columns were changed with new precast elements. The rest of the columns were left in the sea, since they didn't show high degradation level. During production of beam elements for one of the docks (dock F) tiny cracks occured. Considering the agressive enviroment where they would be placed, a corrosion protection with migrating corrosion inhibitor (MCI® 2000) has been applied on the surface. Migrating Corrosion Inhibitors (MCI®) are used for the protection of reinforcing steel in concrete. They can be incorporated as an admixture or topically applied to the concrete surface. Migratory inhibitors are transmitted through concrete to the reinforcing steel by diffusion [2-3].

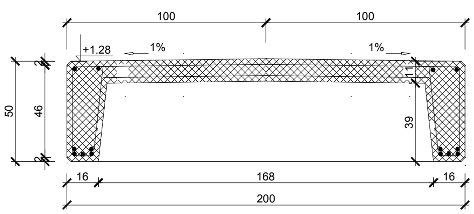


Figure 9. Cross section of the span beam

3. Monitoring

3.1. Monitoring purpose

After a new marine construction was finished, the monitoring of the concrete elements started with the galvanostatic pulse technique. Two docks are monitored, dock B1 which is in the most critical position and unprotected, and dock F, which is protected with MCI® 2000 inhibitor. Dock B1 is at the beginning of the marine (the lowest position above the sea), and beam elements are in a tidel zone. First measuring with galvanostatic pulse technique was performed in June 2002, second in January 2003, and the third one in June 2003. Monitoring with galvanostatic pulse method of this marine construction will be performed continuosly, at least every six months, to get timely data about any change in corrosion current, potential and concrete resistivity. The purpose of the monitoring is to prove the efficiency of the MCI® inhibitor.

3.2. Method description [4 - 6]

Galvanostatic pulse method is a rapid non-destructive polarization technique, which can be used for evaluation of reinforcement corrosion in laboratory and on site. A short time anodic current pulse is applied to reinforcement galvanostatically from a counter electrode placed on the concrete surface together with a reference electrode [Fig.11,12]. 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 polarization time. Typical potential response is schematically shown in Fig. 10.

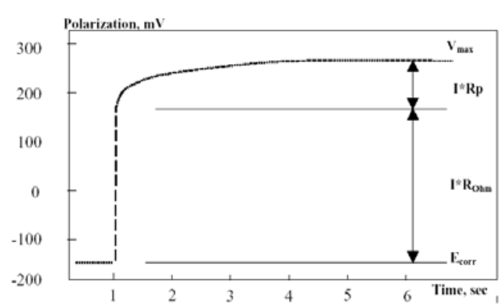


Figure 10. Typical polarisation pattern

When the constant current I_{app} is applied to the system, the polarized potential of reinforcement V_t, at given time t can be calculated as a function of polarization resistance (R_p), ohmic resistance (C_{dl}) double layer capacitance (R_Ω). After the polarization resistance R_p is determined by means of this analysis [6], the corrosion current I_{corr} can be calculated from Stern Geary equation:

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

where B is an empirical constant determined to be 25 mV for actively corroding steel and 50 mV for passive steel. To overcome the problem of the working electrode (reinforcement) and the electrical signal, which tends to vanish with increasing distance, a second concentric counter electrode, so called Guardring, has been used to confine the current to the area of the central counter electrode (Fig.11.).

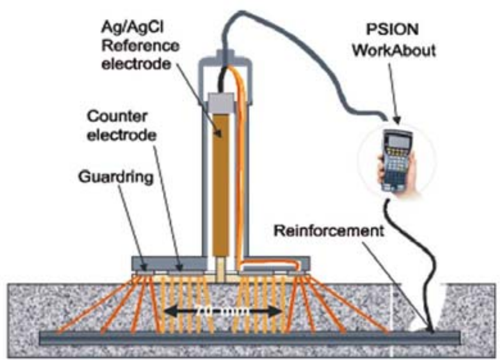


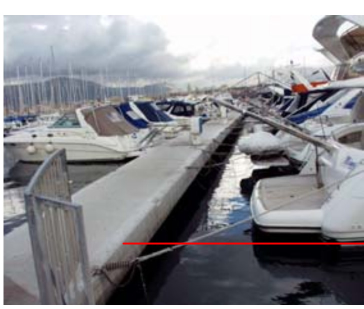
Figure 11. Schematic set-up of the Galva Pulse. Figure 12. Equipment set-up on site.

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 [4-6].

3.3. Monitoring results

3.3.1. Dock B1

Dock B1 was built of the concrete quality C40. Span beams are prestressed prefabricated concrete elements, with U shape in cross section (Fig.9). Concrete surface was done without any protection. On Figure 13 the position of dock B1 is visible and that the first span beam is exposed to sea splashing. Schematic view of test points is are shown on the Fig. 14.



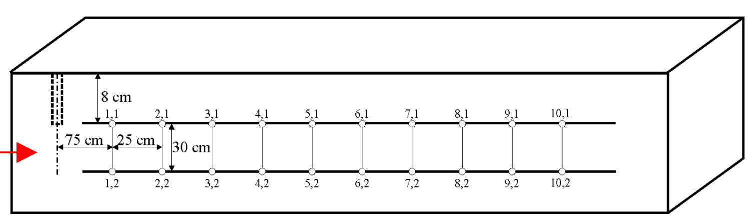


Figure 13. Dock B1. Figure 14. Schematic view of test points.

During the monitoring the corrosion current, corrosion potential and concrete resistivity were measured. On next diagrams the measuring results from dock B1 are shown.

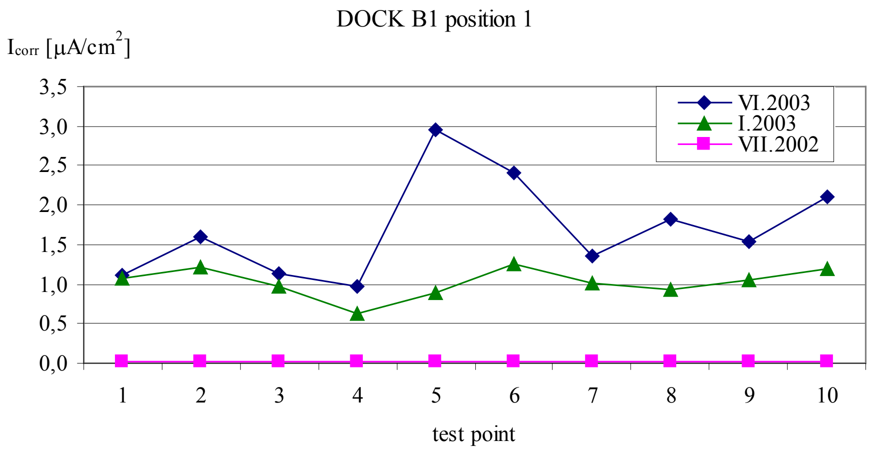


Figure 15. Corrosion current readings on position 1, dock B1

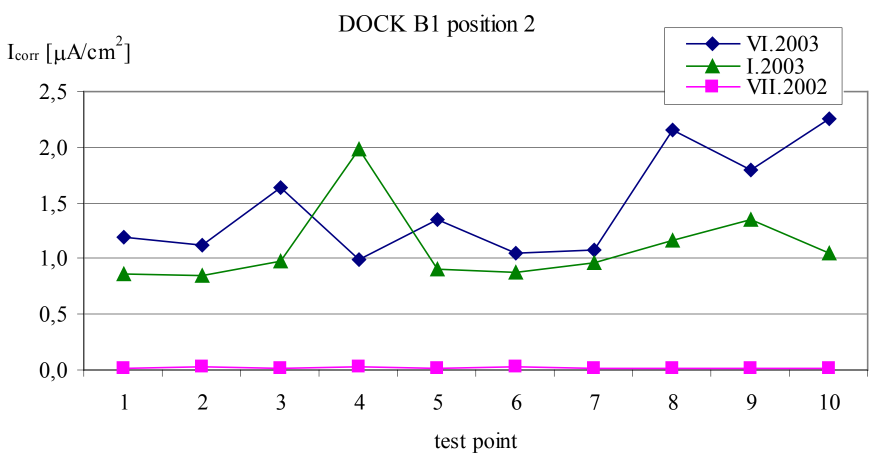


Figure 16. Corrosion current readings on position 2, dock B1

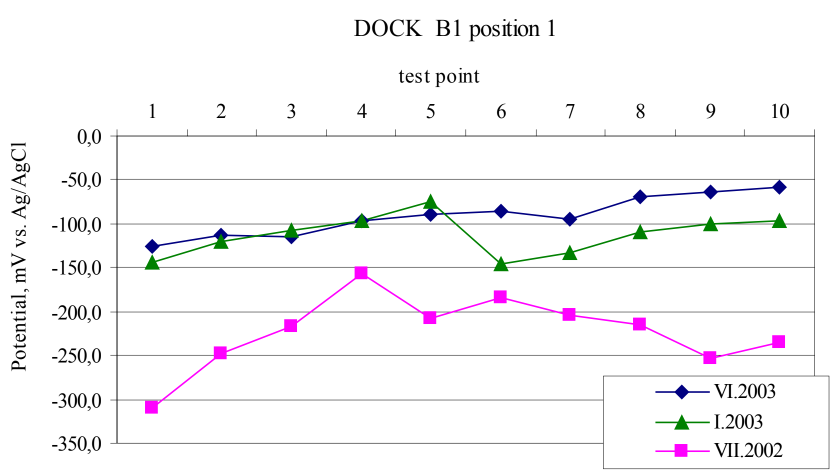


Figure 17. Potential readings on position 1, dock B1

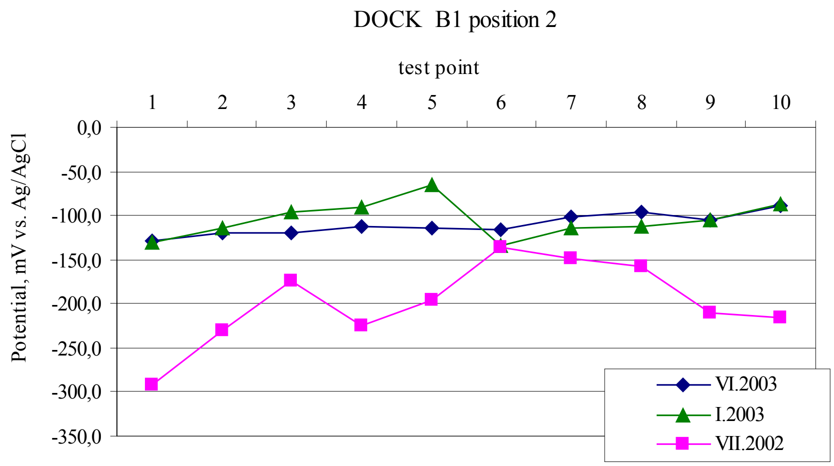


Figure 18. Potential readings on position 2, dock B1

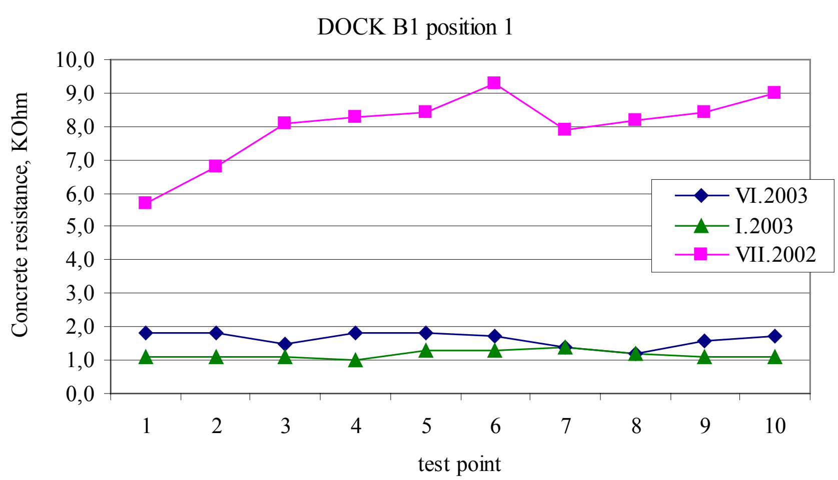


Figure 19. Concrete resistance readings on position 1, dock B1

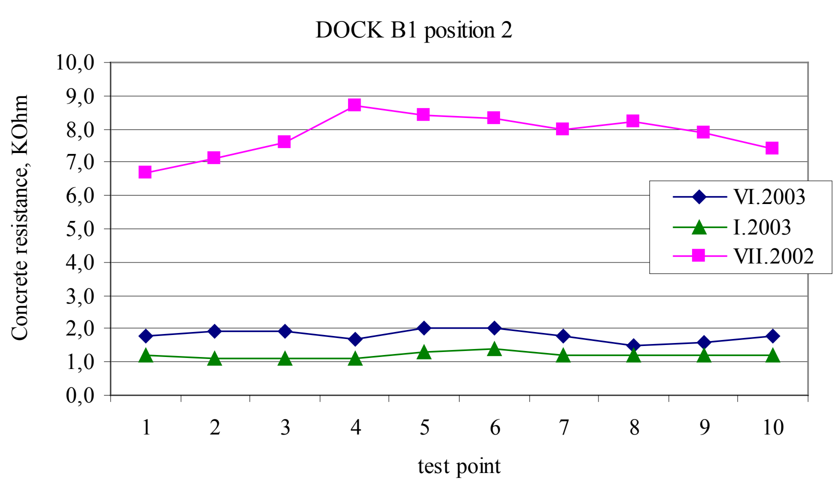


Figure 20. Concrete resistance readings on position 2, dock B1

3.3.2. Dock F

Span structure beams for the dock F (Fig. 21) are built with reinforced prefabricated concrete elements. As already described, these elements are treated with MCI inhibitor, after production. Schematic view of test points is shown on Fig. 22.

Figure 21. Dock F

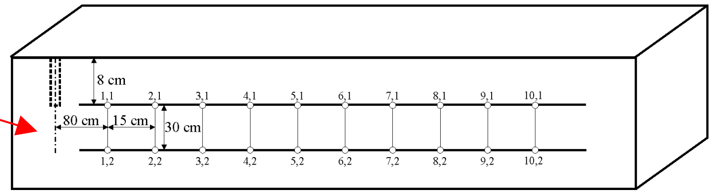


Figure 22. Schematic view of test points

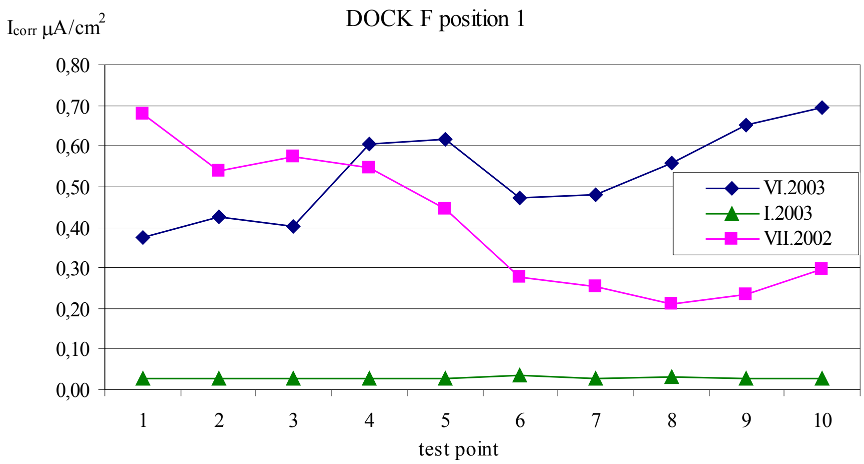


Figure 23. Corrosion current readings on position 1, dock F

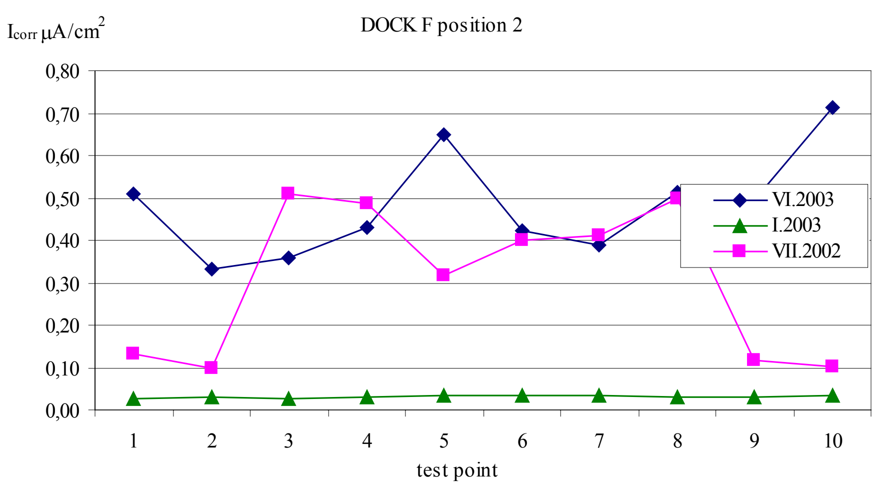


Figure 24. Corrosion current readings on position 2, dock F

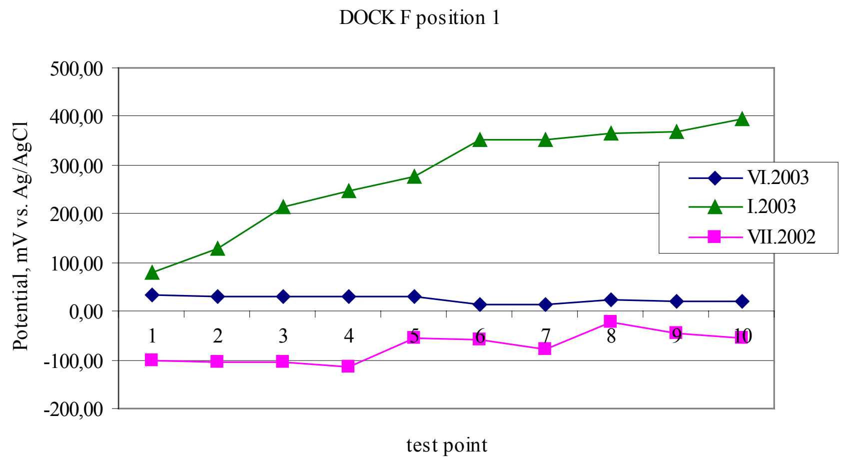


Figure 25. Potential readings on position 1, dock F

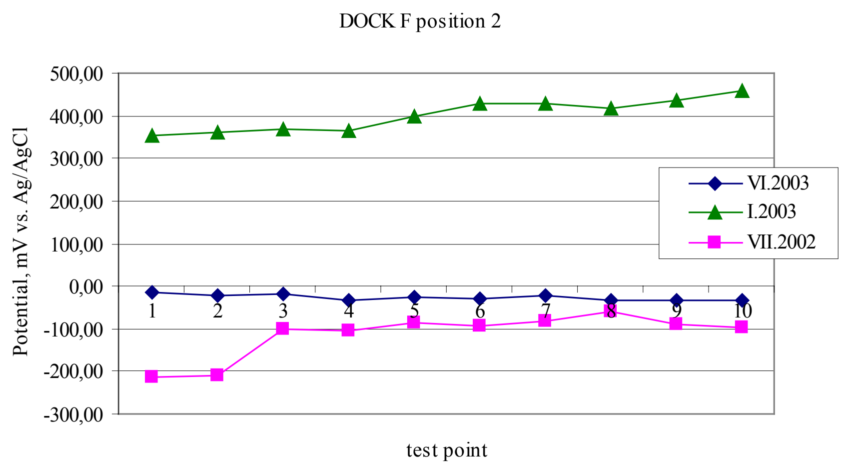


Figure 26. Potential readings on position 2, dock F

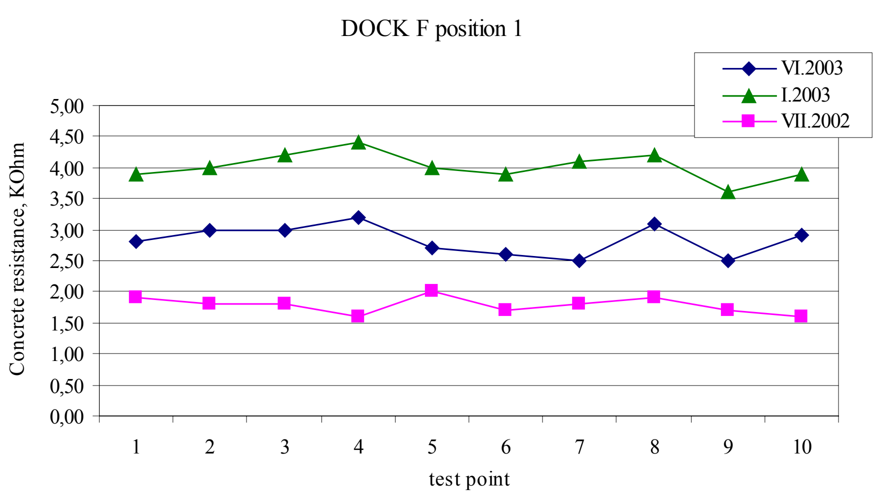


Figure 27. Concrete resistiance readings on position 1, dock F

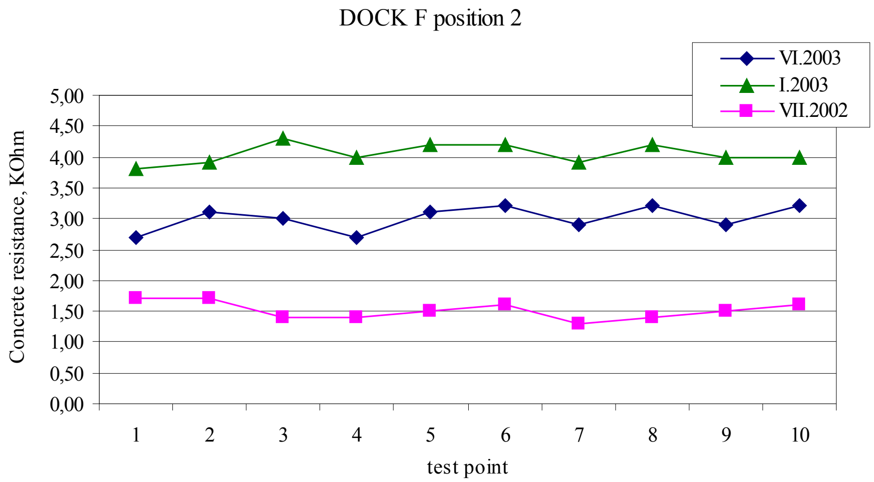


Figure 28. Concrete resistance readings on position 2, dock F

The estimation of the remaining service life based on the measured values of corrosion current can be done according Clear [7], as shown in Table 1.

Table 1.

Corrosion current I_{corr} [μA/cm²]	**Corrosion damage**
< 0.5 μA/cm²	no corrosion damage expected
$0.5 < I_{corr} < 2.7$ μA/cm²	corrosion damage possible in 10 to 15 years
$2.7 < I_{corr} < 27$ μA/cm²	corrosion damage expected in 2 to 10 years
$27 < I_{corr}$ μA/cm²	corrosion damage expected in 2 years or less

Comparing the monitoring results on two marine docks, performed within 1 year, following remarks can be withdrawn:

- it is obvious that the MCI ® (dock F) has lowered the corrosion current;
- according Clear estimation: no corrosion damage is expected on dock F and on dock B1 possible corrosion damage in next 10 to 15 years;
- as presumed from previous measurements with galvanostatic pulse method, the potentials are influenced by inhibitor, so further readings are needed to make conclusion about the influence and the efficiency of inhibitor;
- concrete resistance will be used as a control measuring; resistance is influenced by weather conditions, humidity and temperature;
- the galvanostatic pulse measurements are providing a momentary value of actualy corrosion stage, which significantly depend on actual concrete conditions (humidity, temperature, pH-value, chloride content) [6];
- the problem is the real size of reinforcement cross section on which the current is applied, which has to predicted for on site measuring.

4. Conclusions

Concrete strength for reinforced concrete structures exposed to maritime conditions is just supporting factor, but not the decisive parameter for durability of the construction. For these structures durability criteria is of the bigger importance and should be included in structural design. Concrete durability depends on many parameters and beside structural design, the attention should be directed also on the concrete mix design including corrosion protection, technology of the concrete production, building process and good-quality workmanship. All the structures in the maritime conditions should be monitored during their service life, to avoid high repair costs.

Considering the measuring technique it can be noticed that galvanostatic pulse method is a very suitable technique for on site measuring, since it is rapid and simple. But it is important to underline that the corrosion rate values are very dependent on the environmental conditions and the area on which the current is applied. Different temperature and humidity conditions have a great influence on the measured corrosion rate values [5]. It is essential to combine the on-site corrosion rate measurements with other NDT methods to determine the concrete integrity and state of the reinforcement [8].

5. Literature

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