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Permanent Corrosion Monitoring for Reinforced and Prestressed Concrete

Contrôle permanent de la corrosion sur les constructions en béton structural

Kontinuierliche Korrosionskontrolle bei Stahl- und Spannbetonkonstruktionen

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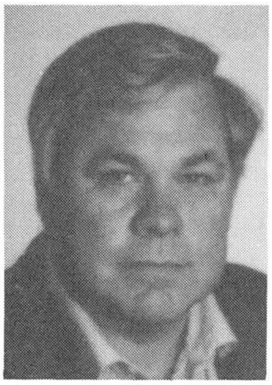

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SUMMARY

In the field of reinforced concrete structures with high chemical pollution, there is a need of quality control of the structures. This is especially true for prestressed steel structures, which are used most by bridges. In addition to the known half-cell monitoring systems which work only on the surface, there is a new monitoring system with an electrode available which is installed in the structure either when first built or when repaired. The new monitoring system, called corrosion monitoring system, is described in this paper.

RÉSUMÉ

Dans le domaine des constructions en béton structural, qui sont exposés à une grande pollution chimique, il est nécessaire d'avoir un très bon contrôle permanent, spécialement pour les ponts en béton précontraint. En plus des systèmes de mesure connus, travaillant seulement en surface, il y a maintenant une possibilité nouvelle de mesurer la corrosion avec une électrode, installée soit pendant la construction, soit ultérieurement au cours de la maintenance. Ce nouveau système de mesure est décrit dans cet article.

ZUSAMMENFASSUNG

Bei Stahlbeton- und Spannbetonkonstruktionen sowie bei Dauerankern, die einem unentwegten chemischen Angriff unterliegen, muss eine dauerhafte Kontrolle des Stahles gefordert werden. Besonders bei vorgespannten Stahlkonstruktionen, wie sie im Brücken-bau verwendet werden, ist eine solche Kontrolle unbedingt erforderlich. Zusätzlich zu den bereits bekannten Messverfahren, die die Oberfläche der Baukonstruktion mit Halbzellen abtasten, gibt es nun eine neue Möglichkeit, mittels einer eingebauten Elektrode, die ent-weder beim Neubau mitinstalliert oder nachträglich bei Erhaltungsmassnahmen ein-gebaut wird. Dieses neue Messsystem, genannt CMS (Corrosions-Mess-System) wird in diesem Artikel beschrieben.

1. FUNDAMENTALS

All over the world bridges and other comparable structures face great problems because large quantities of salt are applied for removing ice and snow on roadways in winter. This salt damages the steel parts of the various constructions and causes them to corrode. In several countries, such as Germany, the USA, Great Britain, Switzerland, Austria, Japan, and many others, requirements for concrete used in construction were toughened (low W/Z factor, definite content of air pores, etc.) in order to avoid this electro- chemical corrosion process. Moreover, the covering of steel parts with various materials was defined more precisely. It has to be pointed out, however, that all these monitoring have not yet lead to a satisfactory situation. Still corrosion of steel can not be absolutely prevented. For this reason a monitoring system is being searched for all over the world which definitively describes the condition of steel with regard to possible corrosion. Since such a system had not been found and thus a great gap between quality guarantees and results for prestressed bridges still existed, the Department of Transport of the United Kingdom decided to no longer permit any prestressed bridge to be built after September 25th, 1992. This was a blow for the entire prestressed concrete industry.

2. ACTUAL MONITORING SYSTEMS

Looking at the current literature on corrosion and corrosion monitorings in reinforced concrete structures you'll find, besides the traditional optical methods, only one system which can measure the electro-chemical process of corrosion in reinforced concrete without damage. The monitoring system is based on the fact, that when corrosion occurs an electro-chemical process takes place which can be directly monitored with an electrode and typical electical monitoring devices. Several systems are offered:

- a permanently installed monitoring electrode in all types of structures or
- a system for surface sounding.

The latter one has the advantage that all accessible steel parts near the surface can be checked fairly quickly and reliably.
In this case the surface of the concrete is surveyed by means of a half-cell and thus the electric potential between the half-cell and the reinforcement steel is monitored.

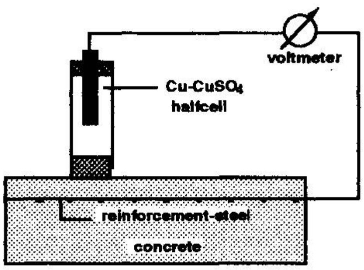

Fig.1 Potential monitoring by means of Cu - $CuSO_4$ half-cell.

Since it is difficult or impossible to investigate the entire area of a structure with only one monitoring cell, monitorings can also be carried out with a series of eight monitoring cells in one operation.

This is shown in the following picture:

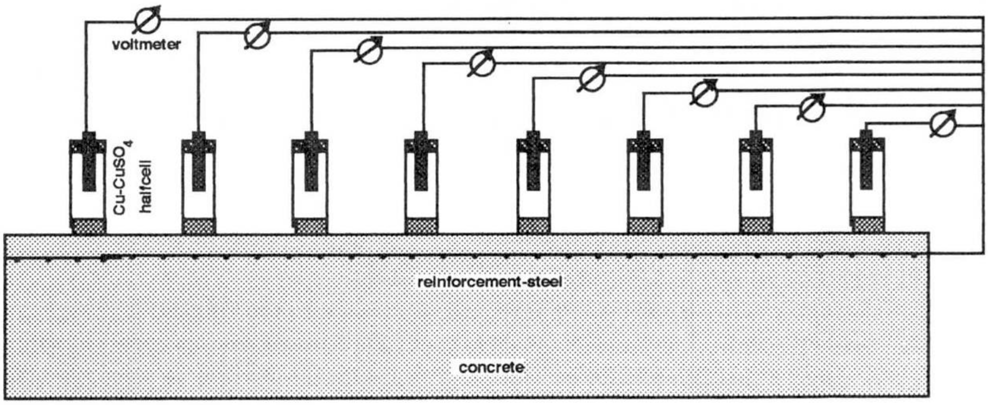

Fig.2 Monitoring system with 8 monitoring cells applied with a bridge construction

For the first time one can obtain a reasonably complete picture of the condition of surface reinforcement on a large area of reinforced concrete structures. The data can now also be evaluated graphically in a way that reveals the respective condition at all surface locations at once. In the following figure you can see an investigation made on the bottom side of a bridge where considerable corrosion areas were found on the projecting sides (overhang).

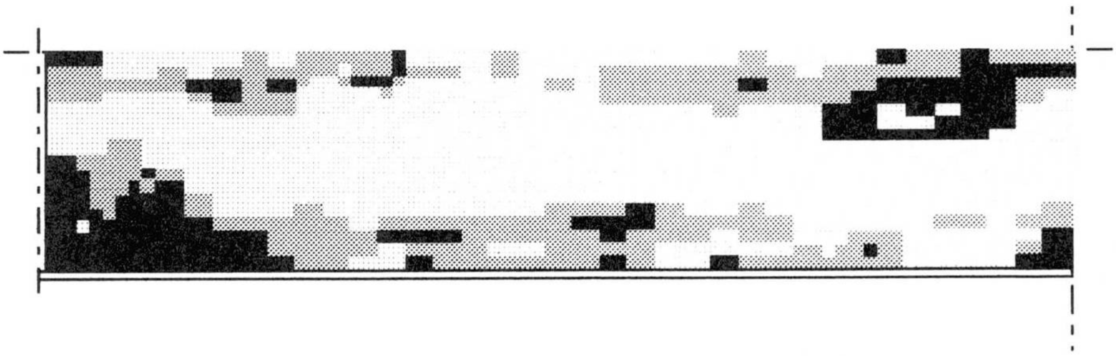

Fig.3 Evaluation of the potential monitoring method applied on the bottom side of a bridge.

Not only with bridges, which are exposed to chloride due to winter service, it is advisable to monitor the entire area of the reinforced concrete structure as well as other structures such as: buildings, water purification plants, sewage treatment plants, dams, etc.

For example, shown are the monitoring results of a sewage treatment plant with a reinforced concrete basin .

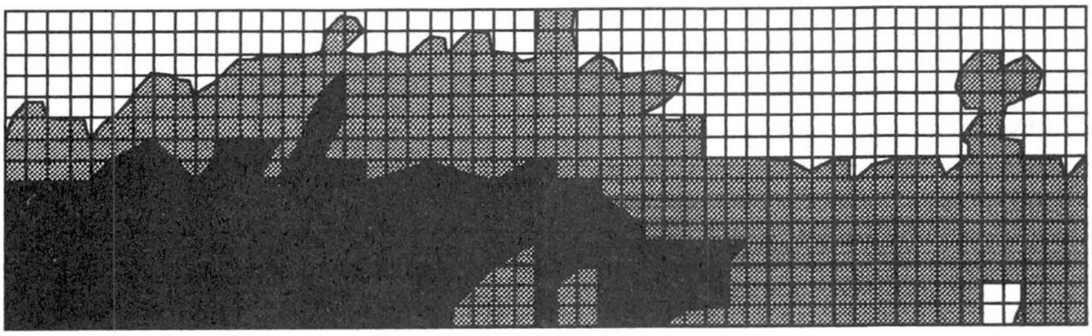

Fig.4 Evaluation of potential monitoring in the basin of a sewage treatment plant.

On first view it is amazing that in case of a basin of reinforced concrete such large corrosion areas occur where the quality of the concrete as well as the sheathing of the reinforcement steel corresponded to the normal standards and practices. Thus one would not expect corrosion to occure moreover, no especially agressive fluids are held in the basin. The pH-value is continously controlled and monitoring 7 which is within the neutral range. The only difference to normal water is that here an extremely high amount of organic parts exists and that these parts contain oxygen and thus activate the necessary biological processes in the basin. This biologically active fluid penetrates the concrete and in the process replaces the usual pore-water. Thus, the pH-value of the concrete can be reduced from its normal value of 13 all the way to 7 in extreme cases.

Under these conditions all the criteria for corrosion in reinforced concrete structures, such a

a) the pH-value goes down to less than 9
b) there is oxygen
c) there is water

exist. This means that the usual concrete covering alone does not guarantee a sufficient protection against corrosion of the reinforcement steel. This necessary protection can only be achieved by additional monitoring which permanently prevent one of the three prerequisites for corrosion. These monitoring are not the subject of this report, they will be described in detail in other papers.

On the whole the surfaces where potential monitoring was carried out show larger areas of corrosion than can be recognized by visual means alone. This makes sense if one remembers that the corrosion products, $Fe_2 O_3$ or Fe (OH) or other iron compounds, have to penetrate the entire layer of sheathing to the surface before they can be optically observed. Moreover, a certain degree of disintegration of the steel is necessary before the corrosion products reach the concrete surface. As a consequence, with the optically recognizable corrosion areas, a diminution of the cross-section of the reinforcement part has already taken place and it is certainly time for reconstruction, at which time a passive monitoring system for the reinforcement steel should be installed.

The greatest disadvantage of potential monitoring by means of these half-cells is that you must have direct access to the place of monitoring when applying this method. Steel parts which cannot be reached by the half-cell cannot be monitored. Therefore, most of the prestressed parts used in prestressed concrete structures cannot be monitored, because, in most cases they are not situated directly on the surface of the concrete but between other normal reinforcement steel elements.

Moreover, most of the prestressed reinforcements are shielded by what is called a protective tube or sheath of metal or plastic so that monitoring in the way described above is impossible. Again and again it can be observed that prestressed links corrode even though they were checked on installation and that subsequent cracking stress corrosion can occur. Since, at present, these sheathed prestressed links can not be monitored after installation and so their future remains a matter of unknown confidence, the United Kingdom made a rigid decision by prohibiting the further use of prestressed links for bridge construction. Experts in this field were thus challenged to find a monitoring method for monitoring single prestressed links for their state of corrosion. When such a system exists, the return to using prestressed concrete constructions in bridge structures in the United Kingdom can be expected.

3. NEW MONITORING SYSTEMS

Two systems for monitoring the usefulness of prestressed links have come on the market, both of them resulting from anchor construction. There too, there always has been an uncertainly about the corrosion of the steel prestressed parts. Therefore, the standards of all countries require a double corrosion protection which offers a certain security as far as corrosion is concerned; monitoring, however, is still not possible. In the following, the two monitoring systems are presented and evaluated according to their usefulness for the owner of the structure.

3.1. Electrical isolation encasement of the prestressed link (Swiss Method)

This method, at present, applied only with anchors in ground and rock, aims at encapsolating the entire steel stress link together with corrosion protecting anchor grout, in an electrically insulating capsle made of plastic and ceramics and at monitoring only the insulating property of the encasement. The measurement on the encasement is made by electrical resistance monitorings which are made during the installation for control purposes as well as after the stressing in order to check the installed anchor. This means that only the electric insolation of the anchor itself is being controlled. For the necessary resistance measurement, relatively high currents (500 volt) are used the impacts of which on the complete system are unknown and potentially damaging if everything is not perfect.

If the resistance monitorings reveal a hole in the encasement this is to be considered a negative result; it still remains uncertain, however, whether the stress link in the encasement will corrode or not. None of the three critical elements necessary for corrosion to occur are checked by this measurement. On the other hand, the prestressed steel can corrode with an intact encasement if the grout within the encasement was not compressed properly as bad experience has shown in many cases with bridge stress links.

Electric encasement serves as a monitoring method for the validity of the encasement. It is a necessary answer for the owner of the building, however, it is missing a key element and therefore it is almost useless. You can't guess from the package whether or not the milk is sour - you have to examine the milk itself!

3.2. Direct corrosion monitoring with installed electrode (CMS)

A special electrode in the shape of a wire is put around the stress link which shall be examined and the potential between the electrode and the stress link is monitored as is done with the potential monitoring method by means of a half-cell. Similarly, as with the potential monitoring method with the half-cell, corrosion can be recognized by the potentials monitored. The electrode is a silver - silver chloride electrode as is used in electro - chemistry as a reference electrode. This kind of electrode has also proved successful for medical purposes, i.e. for millions of electro-cardiograms.

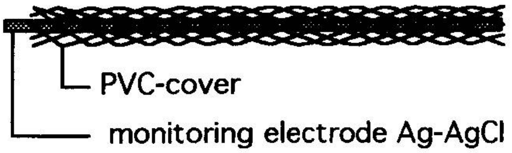

Fig.5 monitoring electrode with PVC-cover as protection against contact

The sensitivity of this system is so high that even with a length of 20 m, a corrosion area of 1 mm can still be recognized. Thus, depending on the arrangement of the monitoring electrodes an exactly defined part of the steel or of the prestressed part can be monitored.
You cannot, however, recognize in which part of the electrode, the corrosion occurs. Also, its extension and intensity cannot yet be defined. It is, however, irrelevant were corrosion occurs on a prestressed part only that it is occuring. When corrosion has been recognized on a prestressed part this part has to be relieved and a respective replacement has to be made. The necessary monitorings can be made either singularly with a normal voltmeter or, in case of larger buildings, by a computer with a fully automatically monitoring device at the site.
In case of a corrosion area, alarm is given automatically and the technical staff can make the necessary decisions for further surveilance. The individual data are, of course, always recorded and stored so that any change of potentials can be recognized subsequently.
With this monitoring method, which is also based on the fundamental principles of electrochemistry, any occuring corrosion can be monitored and the owner of the structure receives the exact information on the quality of the monitored reinforcements and which individual stress steel is involved.

4. CONCLUSIONS

In the field of reinforced concrete structures with high chemical pollution, there is a need of quality control of the structures. This is especially true for prestressed steel structures, which are used most by bridges.
In addition to the known half-cell monitoring systems which work only on the surface, there is a new monitoring system with an electrode available which is installed in the structure either when first built or when repaired. The new monitoring system, called CMS (corroision monitoring system), works in the following applications:

a) Sheated stressed steel members like anchors can now be continuosly monitored for the onset of corrosion.
b) All areas/regions of prestressed steel and reinforced concrete structures can now be monitored for the onset of corrosion, not just surface elements.
c) Thus, through the use of this system, the UK regulations monitoring on prestressed concrete structures can be lifted!

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