Concrete *News*

Inspection and examination of concrete • No. 11 • April 2011

This issue

Editorial

Dear Reader,

This time we write about corrosion monitoring prior to corrosion being initiated and monitoring in the propagation phase. Corrosion monitoring is an acknowledged approach, which is most often applied in new structures exposed to extreme environmental conditions, e.g. structures in sea water like the Great Belt and Oresund Links, whereas monitoring of the propagation phase is not very widespread.

We conducted monitoring of the propagation phase of the Skovdiget Bridge near Copenhagen and it showed that the structure's service life could be prolonged significantly with consequent financial and social advantages.

We introduce two new types of measuring equipment, of which the one measures low corrosion currents based on a ***z****ero-****o****hm* ***a****mperemeter principle, hence the name CorroZoa. The other type, the CorroMap, has been developed for Half Cell Potential (HCP) measurements.*

Enjoy your reading.

Oskar Klinghoffer
Editor

New devices for measuring reinforcement corrosion

FORCE Technology has developed two new devices for measuring reinforcement corrosion.

CorroZoa

The first of these devices is a battery-powered and easily operated instrument for measuring of low corrosion current based on a so called **z**ero-**o**hm **a**mperemeter principle; hence the name CorroZoa. The device is specially designed to measure corrosion current from monitoring probes like CorroWatch or the like. These probes are embedded in the concrete cover to register the time until corrosion initiation at different levels below the concrete surface, and thus calculate approximately when corrosion initiation is expected to reach the reinforcement. It is possible to log on to 6 channels with direct choice of time intervals. In addition to corrosion current, the instrument also records connected values of potential and temperature. Measurements can be transferred to portable PC via USB interface.

CorroZoa device

CorroMap

The second device is developed for Half Cell Potential (HCP) measurements, which are applied on-site to quickly assess the corrosion state of the embedded reinforcement. The device is based on Psion Work About PC with Windows CE 5.0 equipped with colour "touch screen", which provides unique possibilities of a quick overview and immediate treatment of data on-site. The new device records connected values of electrochemical potentials and electric resistance in a preset measuring range. It can be chosen whether measuring shall be performed manually or by use of built-in functions for "automatic acceptance". Up to 1024 measurements can be stored, and all measurements can be instantly displayed in colour. Each colour represents a measuring span for potential and resistance. In addition, this device has a zoom function of detail areas reading each measured value. Measuring results are easily transferred to PC for further processing and presentation.

CorroMap device

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Use of monitoring in the initiation phase

FORCE Technology has developed and sells probes and measuring equipment for monitoring of incipient corrosion.

Principle of monitoring in the initiation phase of the corrosion process
The development of corrosion in concrete over time is generally seen as a multistage process as shown in Figure 1. In the first phase, aggressive substances such as chloride ions or carbon dioxide penetrate the cover and ultimately reach the steel, which causes the onset of corrosion (mark 1), called depassivation or corrosion initiation.

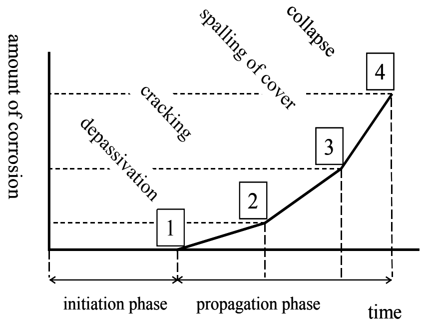

Figure 1: Various stages in the development of reinforcement corrosion in concrete.

The period until mark 1 is called the initiation phase. The period from mark 1 until mark 4 is generally called the propagation phase. Corrosion monitoring makes it possible to verify the penetration by chlorides at an early stage allowing estimation of the phase until mark 1 .

Sensors for monitoring corrosion initiation
Sensors for monitoring corrosion initiation are often based on the so-called "macrocell" principle.

Typically, such sensors consist of a number of carbon steel members also called anodes (typically four or six) located in the concrete cover at varying depths. Additionally, another metal with higher corrosion resistance in concrete than carbon steel, typically titanium or stainless steel, also called cathodes, are located close to carbon steel anodes. The electric current is measured between each individual anode and cathode. At the beginning, when both anode and cathode are not yet corroding, this current is negligible low. After some time, the electric current exceeds the trigger value at the outermost anode when the critical level of aggressive substances, primarily chlorides, has reached this anode. At this time, corrosion is initiated. When the electric current of the next outermost anode exceeds the trigger value, a critical level of aggressive substances has reached this anode, and corrosion has initiated in the depth corresponding to the cover, etc. In this manner, the ingress of the "corrosion front" into the concrete cover can be followed.

An example of such a product, used in the initiation phase, is the CorroWatch sensor developed by FORCE Technology. Further information about the CorroWatch sensor and its capabilities can be seen on our homepage.

CorroWatch is only useful in new concrete structures because its installation is only possible before the concrete is cast. When monitoring of time-to-corrosion initiation is required in the existing structures, a sensor (based on a similar "macrocell" principle as CorroWatch, called CorroRisk) can be used for this purpose. Further information about the CorroRisk sensor can be seen on our homepage.

The readings obtained by CorroWatch and/or CorroRisk sensors can either be registered by means of measurements with a handheld instrument or collected automatically by use of a data logger. An example of a handheld instrument useful for this purpose is the newly developed Zero Ohm Amperemeter with the commercial name "CorroZoa". Further information is available on page 1 and on our homepage.

The data logger system recommended by FORCE Technology for use with CorroWatch and CorroRisk sensors is developed by the Norwegian company Protector and has the commercial name; "CAMUR II".

Field case with application of CorroWatch sensors
A major field case using CorroWatch sensors is the Oresund Tunnel connecting Denmark and Sweden, where 189 sensors were installed in 1998 for the purpose of monitoring corrosion initiation. Twelve years after the installation, all sensors are still functioning very well, which is proved by annual measurements performed in the tunnel.

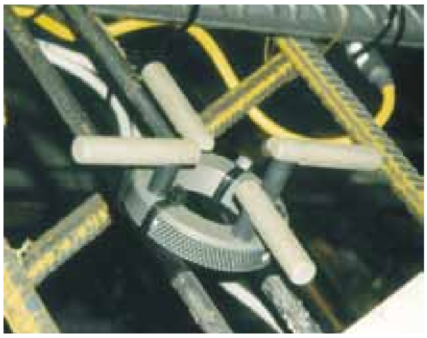

Figure 2: Photo of a CorroWatch sensor.

Figure 3: Typical installation of a CorroWatch sensor and an ERE 20 reference electrode.

Later, the CorroWatch sensors were installed for the same purpose in different other structures. One of the latest applications was in the Xiangan Tunnel in China described already in an earlier edition of "Concrete News"; number 9 from April 2009. Figure 3 shows a CorroWatch sensor mounted in the reinforcement in the Xiangan Tunnel.

The example in figure 4 below shows typical results of measurements performed by means of CorroWatch sensors. These measurements are performed on laboratory samples exposed to corrosive environment and are part of a PhD study carried out at the Technical University of Denmark.

In this example, it is very clear when the measured current changed rapidly indicating the time of corrosion initiation.

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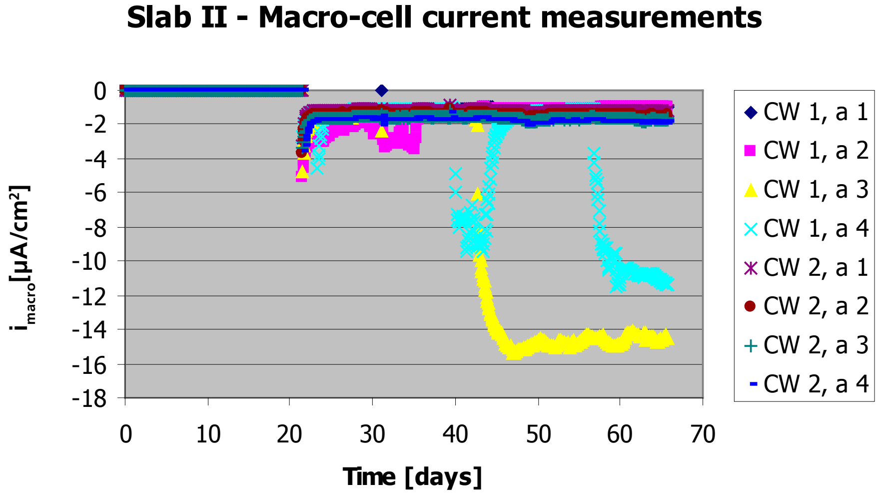

Figure4: Macro-cell current densities, i_{macro} measured with the CorroWatch sensors (CW1 and CW2) on a laboratory sample. The anodes of CW1 and CW2 are located in the cover depths: 18 mm from the concrete surface for anodes 1 and 2, and 14 mm for anodes 3 and 4.

During measurements in the field, it is not always that easy to see such a clear tendency, and therefore the readings of corrosion current are supplemented by measurements of corrosion potential and concrete resistance. By combining and analysing this information, it is possible to define time to corrosion initiation with pretty great accuracy.

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Monitoring of corrosion in the propagation phase

How can corrosion monitoring be used to extend service life of concrete structures?

Normally, concrete structures are renovated or replaced before the deterioration process has gone very far. However, in order to extend the lifetime, it will usually be necessary to wait until the later stage of the deterioration process called the propagation phase. During this phase, the condition of the structure may change very fast, and therefore these conditions must be monitored in detail. Monitoring of the important corrosion propagation phase may often profitably be done by corrosion sensors.

The first application of specially designed corrosion sensors is described through field experience from a highway concrete bridge near Copenhagen bound for demolishing. The Skovdiget Bridge is 220 metres long and owned by the Danish Road Directorate. The bridge carries the busy, 65,000-cars-a-day, 4-lane motorway north of Copenhagen in Denmark. The bridge consists of 2 parallel prestressed concrete bridges, and was constructed in 1968. Due to poor durability design and poor workmanship, the eastern bridge was already renovated in 1978-84, but the renovation was so costly (more than 1/3 of the initial cost), that it was decided not to renovate the west bridge; instead, a detailed surveillance of the west bridge was established. A decision was taken that the bridge should be replaced when the load carrying capacity was reduced to an unacceptable level and could not be renovated.

From detailed determination of the construction strength followed by extensive condition monitoring, demolition of the bridge was postponed for 12 years. This postponement resulted in cost savings of approximately 15 million EUR. During demolition of the bridge in 2010, the real condition of the structure was verified and further evaluated by results from the sensors.

Monitoring of CorroEye (CE) sensor
Unlike standard sensors registering time to corrosion initiation, the new sensors

Figure 1: The Skovdiget Bridge

should focus on the measurements in the propagation phase in order to follow the development of corrosion damage. For this purpose, the "CorroEye" sensor was developed.

The CorroEye sensors are based on measuring corrosion rate and are essentially designed as a cross section of the sensor head of the GalvaPulse equipment. The measuring method is based on an adapted polarisation resistance measurement. Assuming an evenly distributed corrosion, the measured corrosion current can be converted to the rate of diameter loss of the reinforcement. Corrosion rates and concrete resistance are registered by using the GalvaPulse equipment at the ends of the cables, which runs from the sensor and down to a monitoring box placed in an easily accessible location.

Results from measurements by means of CorroEye sensors
During 2 years, the corrosion rate, temperature and electrical resistance of the concrete were measured inside the box girders.

As expected, the results show that corrosion rate is very much dependent on temperature and humidity and varies

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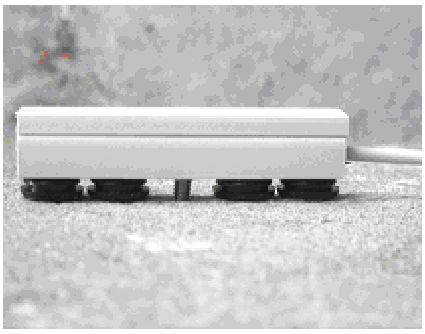

Figure 2: CorroEye-sensor

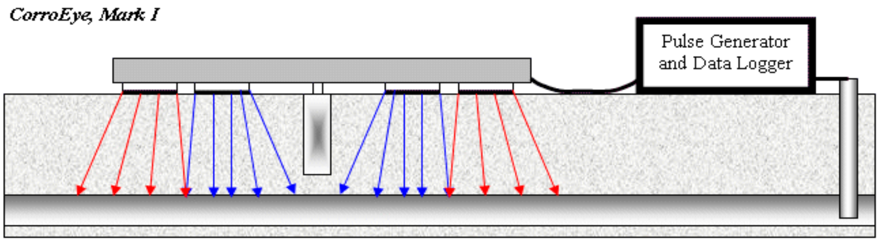

Figure 3: Principle of measurement

over the year. Due to this fact, corrosion rate can only be predicted with some uncertainty. However, the obtained results show very clear advantages by using permanently mounted sensors in corrosion monitoring systems and therefore corrosion monitoring should be maintained during the whole period of lifetime extension.

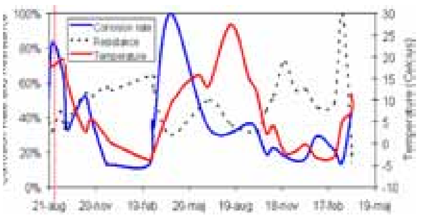

Figure 4: Results obtained by means of measurements with CorroEye sensors in box girder.

The Skovdiget project has shown that significant extension of the normal lifetime is possible thereby giving large financial, functional and environmental benefits. In 2010, the old bridge was demolished and replaced by a new steel bridge assembled of prefabricated elements. All demolition and replacement work was conducted in 8 weeks during the summer when the traffic was not so heavy thus causing less problems for the users.

Monitering of Kalvebod Bridge

The pillars of the Kalvebod Bridge are exposed to seawater with moderate chloride content.

The bridge is constructed in 1987. During the last 5 years, the bridge is investigated by means of GalvaPulse equipment suitable for performance of corrosion rate measurements of reinforcement in concrete. Further information about this equipment is available on our homepage.

Especially the lower parts of the pillars were investigated because most corrosion problems were expected from there. As a result of this investigation, some corrosion attacks were detected in small areas; especially where the reinforcement had been covered.

This area was located only 0.2-0.5 metre from normal seawater level and was accessible only from the raft. Therefore, due to the risk of misinterpretation of the results obtained by means of GalvaPulse, it was decided to install CorroRisk sensors .

The CorroRisk sensors are installed in different but well-known depths in the cover and with various distances to the sea level.
The results after 5 years' measurements show that almost all sensors are working very well. The corrosion has started on about one third of the CorroRisk sensors. From 2011, the measurements will be collected in closer intervals than previously in order to obtain more detailed information about the progress of corrosion initiation on the already corroded sensors, and also to detect when corrosion will occur on the sensors which were still passive when checked in 2010.

Summary

Choice of the correct sensor depends on the type of structure (new or existing) and also on the aim of monitoring (before and after initiation of corrosion). The table below gives a short guidance to the choice of the most suitable sensor depending on the above-mentioned condition.

Initation Phase

New structures	Existing structures
CorroWatch	CorroRisk

Propagation Phase

Existing structures	Major repairs
CorroRisk	CorroWatch
CorroEye	CorroEye
Cut Rebar	Cut Rebar

Figure 5: Close-up of the installation of CorroRisk sensors.

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