Reinforced Concrete Corrosion Wireless Monitoring System

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ABSTRACT: Corrosion of reinforcement steel is on of the main durability issues for concrete structures, especially in costal areas and in countries where de-icing salt is regularly used. The SensCore system, dedicated to the monitoring of corrosion in reinforced concrete structures, is a wireless sensor network, designed to detect and predict the onset of steel corrosion in concrete. The system consists of sensors, dataloggers and a measurement hub that concentrates the data from several dataloggers and transmits it to a central database, where it can be accessed by the authorized users. The sensors are able to measure several parameters, which are critical to evaluate the present and future risk of rebar corrosion in concrete. In particular the corrosion current and the concrete humidity are measured at several depths between the concrete surface and the rebar depth, to analyze the progression of the corrosion front as well as evaluate the performance of hydrophobic coatings or waterproof membranes.

The sensors are extremely simple to deploy and can transmit their data wirelessly to the measurement hub, thus eliminating the need to install any wiring in the structure to be monitored. Because of its modular design, this system is adapted to structures of all sizes, from a small overpass to a long tunnel and can be installed in both new and existing structures. The SensCore system integrates seamlessly with other sensing technologies, based on electrical, vibrating wire or fiber optics. It is therefore possible to combine several technologies in order to implement an optimal monitoring network for a specific structure. The SensCore system has been deployed on tens of structures, including the I35 St. Antony Falls Bridge in Minneapolis, USA, the Gotthard street tunnel in Switzerland and the Colle Isarco Bridge in Italy. This paper presents the system architecture and several application examples.

1 SENSCORE SYSTEM OVERVIEW

The system is composed of four main elements:

- The sensors, measuring corrosion current, resistivity and temperature
- Dataloggers to record the date and transmit it wirelessly
- Central Unit, receiving and concentrating the data from the dataloggers and transmitting or storing it for further analysis.
- Software for data management and publishing, including web interface

The overall system is presented schematically in Figure 1.

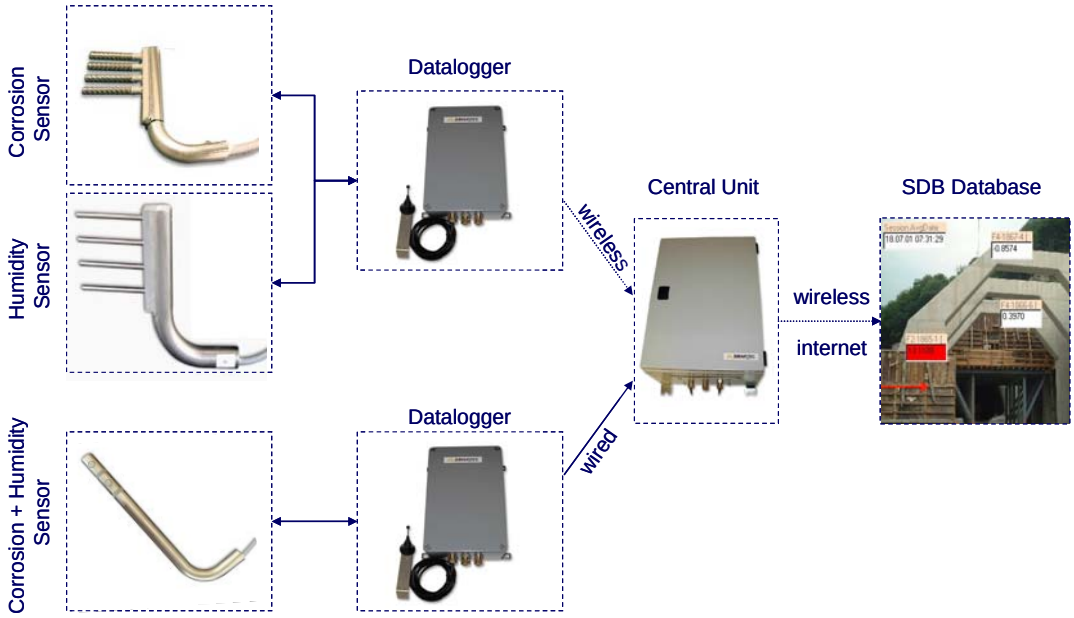

Figure 1: SensCore system overview

We will now present each component in more detail.

1.1 Corrosion Current Sensor

The SensCore Corrosion Sensor measures two critical parameters for the evaluation of the corrosion condition of a reinforced concrete structure: corrosion initiation and corrosion rate. Those two measurements are performed at 4 different depths, between the concrete surface and the reinforcement bars depth. This allows the evaluation of the corrosion front progression. The owner can therefore determine how quickly the corrosion front is approaching the rebars and plan appropriate interventions accordingly. These sensors are also useful in for epoxy coated rebars, because they indicate the possibility of corrosion in case of epoxy damage. Used in conjunction with the SensCore Humidity Sensor, it provides a complete picture of the corrosion initiation and progression in a reinforced concrete structure.

The Corrosion sensor is composed by 4 mild steel rebars that are anchored to a stainless steel support. The 4 dummy rebars are placed in the concrete at 4 different depths as shown in Figure 2. The SensCore datalogger measures the corrosion current for each rebar separately.

A zero current indicates that the corrosion is inhibited at that depth. A non-zero current indicates that the conditions for rebar corrosion are present at that depth, while the corrosion current gives an indication of the corrosion rate.

This sensor is designed for installation in new structures or for repair work, when the concrete cover is replaced as shown in Figure 3.

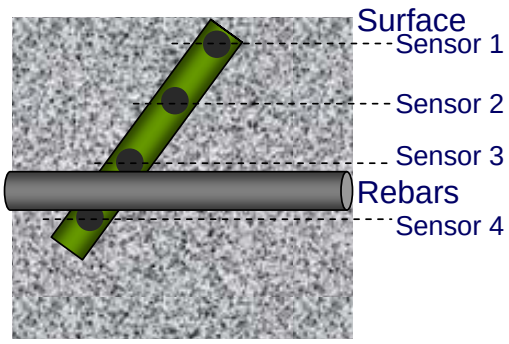

Figure 2: Layout of the corrosion sensor

Figure 3: Installation of the corrosion sensor in the case of a repair intervention

1.2 Concrete Humidity Sensor

The SensCore Humidity Sensor measures two parameters for the evaluation of the humidity content of concrete: electrical resistance and temperature. Those two measurements are performed at different depths, typically placed between the concrete surface and the reinforcement bars depth. This allows the evaluation of water content and transport phenomena across the concrete depth.

The owner can therefore determine how water is entering, respectively exiting the structure. This is particularly useful to evaluate the effectiveness and degradation of sealing membranes or hydrophobic treatments of concrete.

Used in conjunction with the Corrosion Sensor, it provides a complete picture of the corrosion initiation and progression in a reinforced concrete structure.

The humidity sensor is composed by 4 stainless steel bars that are anchored to a stainless steel support. The 4 bars are placed in the concrete at 4 different depths as shown in Figure 4. The SensCore datalogger measures the resistivity between pairs of bars to determine the concrete resistivity across the depth. A low resistivity indicates higher humidity and vice versa. The concrete temperature also influences the resistivity and is therefore measured at two depths.

This sensor is also designed for installation in new structures or for repair work, when the concrete cover is replaced (see Figure 5).

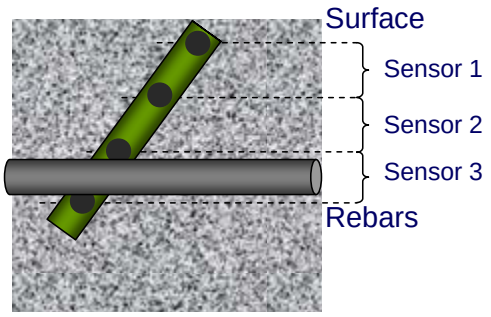

Figure 4: Layout of the humidity sensor

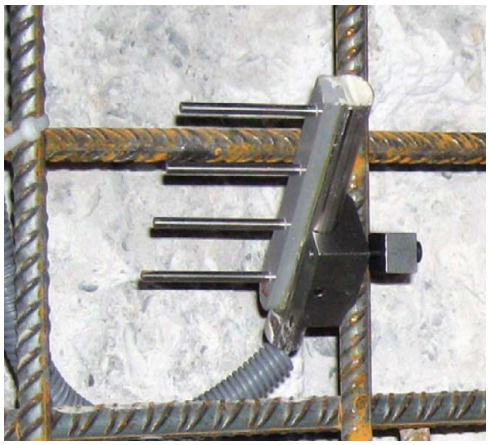

Figure 5: Installation of the humidity sensor in the case of a repair intervention

1.3 Combined Humidity and Corrosion Sensor for existing structures

The SensCore Humidity Sensor measures all critical parameters for the evaluation of the corrosion state of an existing reinforced concrete structure: corrosion initiation and rate, humidity content and temperature. Those measurements are performed at different depths, typically placed between the concrete surface and the reinforcement bars depth. This allows the evaluation of water content and transport phenomena across the concrete depth as well as the progression of the corrosion front towards the rebars. The owner can therefore determine how water is entering, respectively exiting the structure and how close to the rebars the corrosion in no longer inhibited. This is particularly useful to evaluate existing structures before and after a repair or maintenance intervention, such as painting, hydrophobic treatment, application of a sealing membrane and others.

The Combined sensor is composed by a cylindrical element containing mild steel elements and stainless steel elements (see Figure 6). The stainless steel rings are used to measure the concrete resistivity, which is inversely linked to the moisture content of concrete. The mild steel elements measure the corrosion current at different depths. Two temperature sensors complement this information.

This sensor is designed for installation in existing structures. It is installed in a 20 mm hole drilled into the concrete and sealed in place with a special mortar as shown in Figure 7. After a stabilization period, the sensor and mortar assume the same humidity and pore-water chemical content of the surrounding concrete and reliable measurements can start.

Figure 6: Layout of the combined sensor

Figure 7: Installation of the humidity sensor in the case of an existing structure

1.4 Wireless Datalogger

The SensCore datalogger is compatible with all SensCore sensors: corrosion sensor, humidity sensor and combined sensor. It measures the electrical parameters from the sensors with high precision and stability and forwards them to the SensCore Central Unit. The connection to the Central Unit can be wireless or wired. The Datalogger can be configured to read other electrical sensors.

The SensCore Datalogger is contained in a rugged enclosure that can be permanently installed outdoors (Figure 8). It is able to measure the following combination of sensors:

• 2 Corrosion Sensors + 2 Humidity Sensors

• 4 Corrosion Sensors

• 2 Combined Sensors

• 1 Corrosion Sensor + 1 Humidity Sensor + 1 Combined Sensor

The wireless antenna is connected with a cable to allow an optimal positioning of extended communication rage.

Figure 8: Wireless Datalogger

Figure 9: Central unit

1.5 Wireless Central Unit

The SensCore Central unit is compatible with the dataloggers and aggregates the data from all dataloggers installed in a structure. The data can be saved in its internal memory for manual retrieval, sent to a remote SDB database by GPRS wireless cell phone connection or transmitted by an Ethernet connection to a local PC.

The connection to the Dataloggers can be wireless or wired. In the case of wired connection, the Central Unit also provides power to the dataloggers.

The SensCore Datalogger is contained in a rugged enclosure that can be permanently installed outdoors (see Figure 9). The unit can be powered by DC or AC and is compatible with solar panels. The wireless antenna is connected with a cable to allow an optimal positioning of extended communication rage.

1.6 Data Management and publishing software

The SOFO SDB software is an integral part of the SensCore monitoring system. It is fully compatible with all SMARTEC monitoring systems in particular is also designed for the data acquisition, data representation and for the control of SOFO reading unit, MuST, SOFO Dynamic, SOFO optical switches, and other data acquisition devices. SOFO SDB is also used to store and manage data in database form. The main functions of this software are aimed to measure sensors either interactively with the user or automatically according to a predefined schedule. The operator can view on-site the sensor's measurement history in graphical and tabular form. The program stores all information related to a given project in a single database structure. All data can be easily exported to SDB advanced analysis packages and third-party software. Multiple users can access the same SDB file simultaneously from different PC (locally or remotely over a modem or LAN).

The SDB View package enables a more advanced navigation within a measurement database. It provides a simultaneous display, within the same window, of several different views on sensors chosen from the database over a defined monitoring period. The display can be of a tabular or a graph plot with associated options such as thresholds plot, colors and sounds on alert, software actions on alert (e-mail, phone calls) as shown in Figure 10. The data output can either be generated as a screen display or saved in a file, with the option of manual or automatic display, hence allowing the generation of automatic reports that exploit the update of links. Tables, graphs and maps can be easily published on a web-site for immediate access by authorized users. SDB View allows not only the management of warning states in the form of pre-warning and warning thresholds but also, triggers a corresponding and user-defined action like displaying a message sound on alert, generate a phone call or send e-mail.

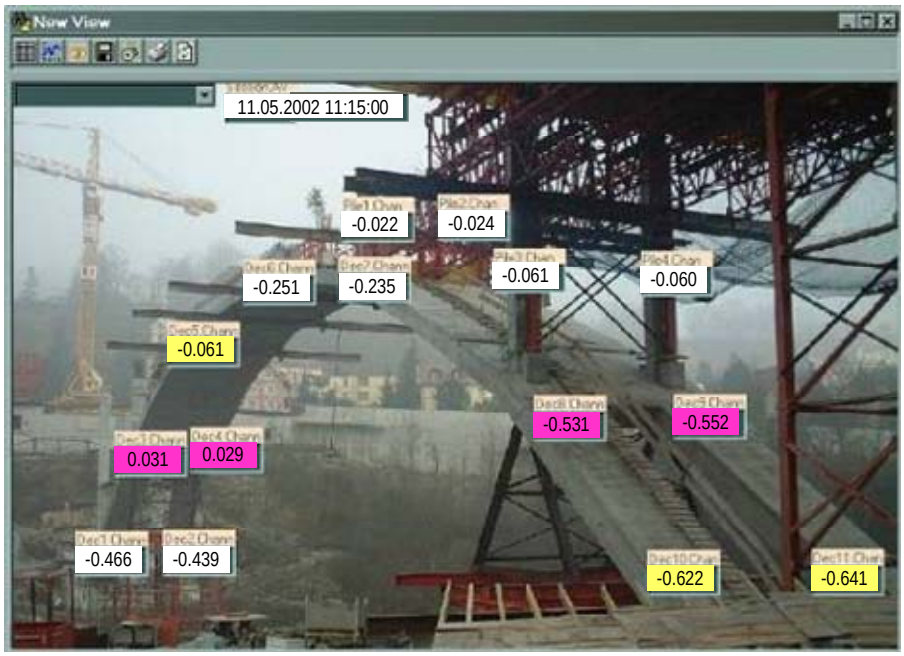

Figure 10: Example of data representation using SDB view.

2 APPLICATION EXAMPLES

The presented system has been applied to several structures worldwide, in particular Bridges and Tunnels, including the following:

- New I35W Bridge, Minneapolis, USA
- Fredrik's Bridge, Helsinki, Finland
- Gotthard Tunnel, A2 highway, Switzerland
- Gallery Presella A13 highway, Switzerland
- Ponte Cebbia II, highway A13, Switzerland
- Colle Isarco bridge, Brennero highway, Italy
- Tunnel Franzenfeste, Brennero highway, Italy
- San Bernardino tunnel, A13 highway, Switzerland

We will now present examples in more detail.

2.1 Concrete Tunnel repair

In this tunnel application, the concrete lining was replaced because of ageing damage. During the repo rifling of the inner layer of concrete, corrosion sensors were installed to compare the performance of different types of concrete. Figure 11 shows the sensor installation in the tunnel.

In Figure 12 it is possible to observe when the corrosion is activated at different depth. In this example the concrete under test performed very poorly, allowing corrosion to progress in the structure at a high rate.

Figure 11: Installation in Tunnel

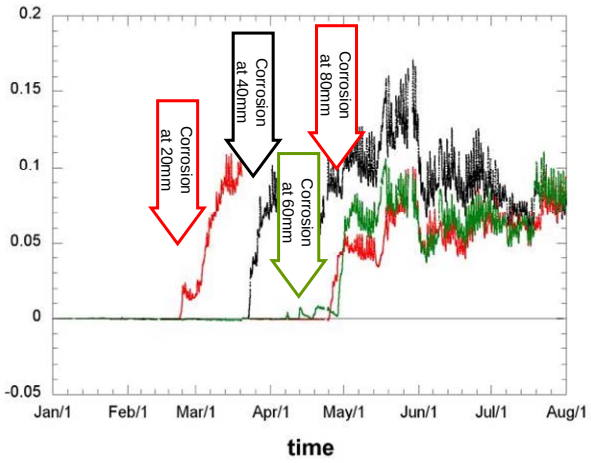

Figure 12: Activation of corrosion at different depths.

2.2 *Testing of hydrophobic treatment*

In this example, the humidity sensors were used to assess the effectiveness of a hydrophobic treatment applied on a concrete bridge.

Figure 13 shows the resistivity recorded at 4 depths as a function of time, while the vertical bars indicate the amount of rainfall recorded each day.

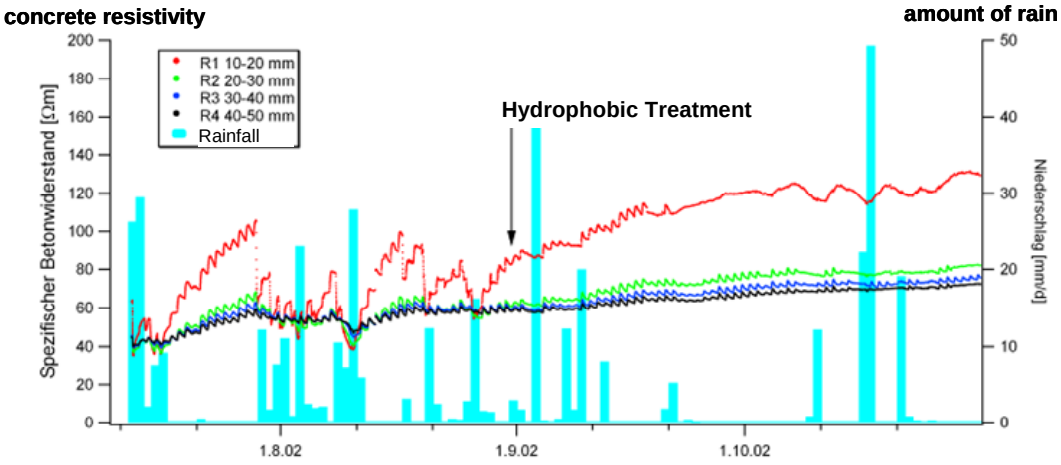

Figure 13: Resistivity as a function of depth and precipitation, before and after hydrophobic treatment.

The following information can be gathered form the measurements:

Before the treatment, the resistivity drops when rainfall starts, indicating a humidity increase in concrete. After a few dry days the resistivity increases again, indicating concrete drying. This occurs faster for the layer of concrete closer to the surface.

After the hydrophobic treatment the humidity no longer increases after rainfall, indicating that the treatment is effective and stops humidity from entering in the structure.

In the weeks after the treatment, the concrete resistivity increases at all depths, indicating a general drying of the concrete.

The system can be used to determine when the next treatment is required, by observing when the correlation between rainfall and humidity becomes observable again.

3 CONCLUSIONS

The presented system was developed to allow a simple but permanent evaluation of the corrosion potential in reinforced concrete structures. Combining measurements of corrosion currents on dummy rebars, resistivity measurements and temperature measurements, it becomes possible to follow the propagation of the conditions that allow initiation of corrosion, form the surface to the depth where the real rebars are installed.

The SensCore system has been deployed on tens of structures, including the I35 St. Antony Falls Bridge in Minneapolis and the Gotthard Tunnel.

Corrosion is one of the leading concerns in reinforced concrete structures and often limits their durability. It is therefore advantageous to complement the current monitoring strategies with a direct measurement of the corrosion progression.

4 ACKNOWLEDGEMENTS

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