IMPLEMENTATION OF CORROSION INTELLIGENT MONITORING AND DURABILITY EARLY WARNING EXPERT SYSTEM FOR THE LARGE MARINE CONCRETE STRUCTURES

Guihong Dong (1), Shengnian Wang (1), Quanke Su (2), Yue Chen (2)

(1) Engineering Technology Research Co., Ltd. of CCCC Fourth Harbor Engineering Co., Ltd., China
(2) Hong Kong-Zhuhai-Macao Bridge Authority, China

Abstract

To ensure 120 years design life of the large marine concrete structures in South China, and assess the status of the development of durability of concrete structure in real time, a research has been performed on embedded-non-destructive corrosion monitoring sensor systems, data acquisition and software integration, combined exposure test of concrete under environment in South China more than 30 years and laboratory test. It is a new type of technology for corrosion monitoring, assessment and early warning, which based on electrochemical principle, network transmission, expert software system, integrated the durability of the project full set of intelligent real-time monitoring and early warning expert systems.

1. SUMMARY

The Hong Kong - Zhuhai - Macao Bridge across the Pearl River waters which the designed service life is 120 years. It is connected to Hong Kong, Zhuhai and Macao large sea - channel construction, and is part of the national expressway net planning in the Pearl River Delta region link key projects. The bridge is cross - harbour traffic cluster project which is made up of tunnel, island, bridge. It is the most complex, environmental protection and construction requirements which require the highest standards. It is also one of the highest projects in Chinese history of traffic construction technology. Survey shows that the durability issue of the marine concrete structure such as bridge, harbour works is very serious. These engineering often widespread reinforcement corrosion, concrete cracks and need major repairs, and some serious structure had to make demolition and reconstruction in 8-12 years
after the completion. The environment shows there may be with the following corrosion factors: (1) Chloride ion corrosion in seawater environment; (2) In depth under the pressure of more than 40 meters, submerged tube tunnels concrete structures had resistance permeability, chloride and other chemical erosion; (3) Under the water and mud it had erosion of potential sulphate, magnesium salt, chemical and salt crystallization; (4) Concrete structure existed carbonation from the environmental and traffic caused by vehicle exhaust.

The corrosion factors can affect the durability of concrete structure, so it is particularly important that the integration and implementation of non-destructive monitoring for such large systems ocean structures. The embedded non-destructive monitoring system in different countries, such as the researchers in the civil engineering from Aachen University Germany have invented the non-destructive durability testing system which was the ladder anodes embedded in concrete structure and After-Loading-Annular-Anode monitoring system. Nagel-System of Danish FORCE Company is for the electrochemical performance of reinforcement corrosion monitoring, but they are unable to monitor chloride concentration in the concrete [6-8]. USA ECI-1 non-destructive examination device is submerged in the concrete to monitor the corrosion. It could monitor some important parameters which include resistivity, chloride ion concentration and temperature, and used a specialized software about reinforced concrete corrosion monitoring system to evaluation. But it hadn’t the concrete service life prediction model for data analysis, so this device cannot be effective life prediction and early warning.

The corrosion intelligent monitoring and durability early warning expert system for the large marine concrete structures has a real-time, automated, integrated, wireless transmission, networking and other features. It uses embedded-monitoring sensor of concrete durability with independent intellectual property rights to implement non-destructive monitoring, and concrete durability model about the system that is specifically designed for marine corrosion environment where Hong Kong - Zhuhai - Macau Bridge is located, this model is more than 30 years of research results, and has been achieved computerization and the establishment of expert system that can effectively analysis collected important parameters, to assess and warn durability for the concrete structures. Development and application of this system are not only for the maintenance of the marine concrete structures to play a significant role in scientific policy guidance, but also collect a lot of valuable measuring data. It has important theoretical and engineering application value that this system gathered valuable data and experience for concrete structures’ health and safety monitoring in China complex marine environment.

2. OVERALL TECHNOLOGY IDEAS

Durability falling of concrete structure in marine environment is generally divided into 2 phases (Figure 1): rebar depassivation stages (t_0 → t_1) and steel corrosion stages (t_1 → t_3). Corrosion stages is bounded by cracking point t_2 of concrete cover that can be divided into 2 periods [(t_2 → t_3) and (t_1 → t_2)]. Generally it believed that in t_1 → t_2 phase of design and construction repairs are often costly, The most cost-effective approach is designed durability
measures r before the rebar depassivation. Obviously, the difficulty of achieving the objective is how to improve the accuracy level of monitoring and early warning in the point $t_1$.

![Figure 1: Relationship between structure of steel bar corrosion and service time](image1)

The system includes the following modules: sensor systems, data acquisition, data management systems, expert systems, and monitoring and assessment and early warning system. Each module is independently developed, and using LabVIEW software platform for integrated interface. The overall design of the system is shown in Figure 2.

![Figure 2: Corrosion of intelligent monitoring and early warning expert systems](image2)

Sensor systems consists of ladder anode and multifunctional sensor that was independently developed. The monitoring data includes steel bar corrosion potential, current, reference electrodes and chloride ion concentrations and concrete PH values. Ladder anode has mainly measurement based on the mutation signal of circuit or open circuit electrical parameters.
when the steel bar is off blunt, it monitors the permeation process of chloride ion in concrete cover. And multifunctional sensor is embedded in steel surface of structure that are used to monitor corrosion conditions with a combination of multiple parameters to achieve the precise level of warning. Sensor monitoring principles is shown in Figure 3. Expert system consisting of exposure test and laboratory test results of concrete more than 30 years under environment in South China is established databases, it compares the durability of physical quantities to analyses these signals to come to the durability of the structure parameters. According to the durability parameters monitoring assessment early warning system gives the assessment warning light signals and digital display signal and automatic store durability parameters in the database for the technical personnel application.

![Figure 3: Durability monitor principle](image)

3. SYSTEM HARDWARE CONFIGURATION AND SOFTWARE DEVELOPMENT ENVIRONMENT

3.1 Wireless data acquisition system

The system of data collection instruments uses Wi-Fi DAQ of NI company wireless data acquisition platform, the devices combined IEEE 802.11 wireless or Ethernet communication, direct sensor connectivity, and the flexibility of NI LabVIEW software implements remote monitoring of electrical and physical signals Wi-Fi DAQ makes it easy to achieve a wireless connection, because devices are used to build data acquisition system with a modular form, so it can use different test module according to the different measurement tasks [1, 2].

3.2 Data administration system

Because of the system need continuously monitor for a long time, the acquisition of signals will collect enormous physical datum, so the system needs to have a stable database. Expert system database includes the construction of concrete structure, geometric information, monitoring information, analysis results and all others data, it is the core of structural health
monitoring system, which provide the necessary support for the stability of the system. The system uses a large relational database SQL SERVER 2000 as a central database for structural health monitoring system, integrated in LabVIEW development platform.

The systems using NI database connection kit database connectivity toolkit for database access. Database Connectivity Toolkit is the LabVIEW on SQL SERVER 2000 database access tool, to quickly build and features such as data connections, queries, actions [3].

4. IMPLEMENTATION OF SYSTEM FUNCTION

Hardware and software of corrosion intelligent monitoring and durability early warning expert system for the large marine concrete structures design of modular structure independently, each function module is relatively independent, according to the different structure and progress of the project, it can facilitate improvements to the module or the develop new functional modules to expand the system.

4.1 Ladder electrodes and chloride ion sensors monitoring

This system using ladder electrodes, Ag/AgCl reference electrode and chloride ion sensor embedded in reinforced concrete structures, measured concrete corrosion of electrode potential, current, resistance and chloride ion concentration in different depth. The system identifies penetration depth and situation of chloride ion through ladder electrode signal mutation, using specialized software to continuously monitor and early warning prompts, the ladder electrode sensor system’s function is qualitative measurement about concrete corrosion situation. And chloride ion sensor monitor the chloride ion concentration at different depths, the collected data uses for real-time assessment of the structure' life. Sensor monitoring needs using a variety of data acquisition instrument module includes NI 9205 collects potential acquisition of ladder anode, reference electrode and chloride ion concentration sensors ; NI 9217 is responsible for collecting resistivity signal; NI 9207 collects corrosion current. Data collection interface as shown in Figure 5.
4.2 Multifunctional sensor monitoring

Multifunctional sensor system is directly embedded into the surface of steel bar, it shall include the following core sensor, corrosion potential sensors, corrosion current sensors, chloride ion concentration sensors, reference electrode and concrete PH sensor. These sensors with expert system reach quantitative and qualitative evaluation for the corrosion of concrete structures reinforcement. And chloride ion sensor directly measures chloride ion concentration of reinforced surface, but expert system software calculates chloride ion concentration by comparison with the reference electrode and amended PH value and in contrast that critical chloride ion concentration in database, the system reaches assessment and early warning. The sensor system monitoring is also need to use a variety of data acquisition instrument module includes NI 9205 that collects potential signal of chloride ion sensors, corrosion potential sensors and PH value sensor. NI 9207 collects current signal of corrosion current sensors. All the collected signals is translated into durability parameters by the software calculation in the background. Data acquisition interface and early warning as shown in Figure 5.

4.3 Durability assessment and early - warning expert system

Corrosion intelligent monitoring and durability early warning expert system for the large marine concrete structures implements durability assessment and early warning functions with the structure of expert system which manages data of component type, environmental information, load and use situation, particularly for durability experience numerical parameters can be managed, makes its systematic, complete, and play a greater role.
Durability assessment which required experience values of main parameters such as: chloride ion surface concentrations, chloride ion critical concentration, diffusion coefficient attenuation parameter, the test results come from more than 30 years laboratory and exposure researches in the environment where is the large marine concrete structures in South China. The part of the judgment in the expert system database is followed.

1. When concrete resistivity is less than 150 kΩ•cm wide, the steel starts corrosion that uses probability to show its.

2. The component critical concentration (free chloride ion concentration) range is 0.0276~0.0375 in southern China

3. In southern China, splash zone of surface concentration takes 0.80% (Portland cement concrete), 0.95% (fly ash concrete), 0.7% (slag concrete) and 0.75% (silica fume concrete).

4. A large number of field application shows that adopting a criterion of absolute potential is not accurate, the changes of pH value and concrete resistivity is made steel passivation of potential change, when the partner cell potentials less than -200mV it’s the signs of reinforcement corrosion’s beginning and uses the corroded probability to judge the concrete corrosion.

4.3.1 Durability assessment

The mathematical model of the durability system is based on Fick's second law of diffusion, using data acquisition system to collect the chloride ion sensor signals in different depth, it reaches chloride ion concentration curve in order to forecast the life of the component[4]. What concrete corrosion situation decides by expert system based on environments information, concrete mix information, component information (Using concrete strength, cover thickness reinforced type, size) and other information. Durability assessment interface as shown in Figure 6.

Figure 5: Durability assessment results interface

The article uses the concrete component as durability assessment in South China environment. The region's average annual temperature is 23.1°C; Component exposure range
is splash zone; the minimum layer thickness 65 mm. The concrete mix were: water/cement ratio 0.35 and 30% fly ash. The service life of this mixture was calculated as 62.8 years by the system [6]. The calculation results show that assessment data approached the actual situation.

4.3.2 Early warning

System of early warning function collects the data of chloride ion sensor ladder anode sensor and multifunctional sensor systems which is buried in the component bar by the data acquisition system, it reaches steel reinforced concrete of surface chloride ion concentration, ladder anode current, voltage, resistance, and chloride ion concentration in a certain depth. When the collected chloride ion concentration reaches the critical concentration, system sound an alarm. And what the system needs the parameters decides on which is environments information, concrete mix information, component information (Using concrete strength, cover thickness reinforced type, size) and other information. Early warning monitoring interface is shown in Figure 7.

Figure 6: Marine component assessment and early warning monitoring interface
5. CONCLUSIONS

- This system uses a part of the independent development of concrete durability monitoring sensors, it implements real-time monitoring, durability assessment, early warning function. System implements the following features:
- System adopts international mature on ladder anode sensors, and independent development of multifunctional sensor system and implements integration and package between the different sensors.
- Using LabVIEW software platform we implement software acquisition system successfully with independent intellectual property rights. It integrated sensor system, data acquisition system, expert system, monitoring, assessment and early warning software systems and database management system, its main features is easy to operate and has a user-friendly interface and graphics which show the datum.
- Through combining with the marine environment engineering computer model for service life prediction of concrete structure, the system implements that it determines the structure of health status in real time and predicts concrete component residual service life, which bases on the collected chloride ion concentration of component data, environment information and other major parameters. It improves monitoring level and precision of the removal blunt phase of concrete reinforcement.

REFERENCES


