Online-monitoring of concrete structures: Cost-effectiveness and application

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ABSTRACT: The functionality and safety of reinforced concrete structures needs to be ensured over their entire service life. Since the reinforcement exhibits a relatively high risk for corrosion, these structures must be inspected regularly and observed damages have to be repaired. The control of reinforced concrete structures is typically performed by visual inspection. As soon as structural problems are observed, a more thorough and expensive analysis is performed. Online-monitoring could represent an alternative with higher accuracy of detection of damages and, thus, lower overall costs.

1 INTRODUCTION

1.1 Motivation
The annual costs for the maintenance of the Swiss national road networks amount to SFr. 560–640 millions (Donzel 2002). Due to the limited means and the large number of engineering structures at the critical age between 30 and 45 years cost-effective solutions for the monitoring and the maintenance of these structures have to be found (Schiegg 2002).

1.2 Contribution
This paper’s contribution is the investigation of the running costs for an engineering structure with/ and without use of an online-monitoring system. Online-monitoring means sensors embedded in concrete in combination with continuous data acquisition.

2 CONNECTION BETWEEN INSPECTION AND REPAIR COSTS

2.1 Theoretical Background
To compare the costs of a sensor-network (online-monitoring system) with classical inspection for a structure over the lifetime the following equation (1) for the total costs was used (Frangopol et al. 1997):

\[ C_{\text{TOTAL}} = C_{\text{CON}} + C_{\text{MAI}} + C_{\text{INS}} + C_{\text{REP}} + C_{\text{F}} \]  (1)

where \( C_{\text{TOTAL}} \) = total costs over lifetime
Since the costs for construction (\( C_{\text{CON}} \)) and maintenance (\( C_{\text{MAI}} \)) remain the same for both cases of monitoring (classical inspection and online-monitoring) it is assumed that the inspection costs (\( C_{\text{INS}} \)), the repair costs (\( C_{\text{REP}} \)) and the costs for a possible collapse (\( C_{\text{F}} \)) are changing depending on the monitoring method.

2.2 Impact of damage detection on costs
The quality in monitoring a structure is a result of the reliability of damage detection for a given general condition of a structure. In the case of an online-monitoring system the accuracy of the damage detection due to the corrosion of the reinforcement depending on the total surface area \( A \), the number of sensors \( S \) and the corroding area \( \eta_{\text{Korr}} \) was identified. For the calculation of the detection probability of the corrosion the following equation was used (Steiner 2007):

\[ d(\eta) = 1 - \left( \frac{(A - S)!}{(A - S - A \cdot \eta_{\text{Korr}})!} \right) \]  (2)

Applying equation (2) for a bridge model (\( l = 117 \, \text{m}, \, w = 25 \, \text{m} \)) with 44 sensors in the cover concrete the accuracy of damage detection was calculated. Figure 1 shows clearly, that in this case a damage rate of 5% can be detected with a probability of 90%.

Compared to an online-monitoring with sensor networks a visual inspection has the same accuracy for damage detection in case of a damage rate of 25% according to equation (3) (Mori/Ellingwood 1994). However an initial investment is required for the online-monitoring system.

\[ C_{\text{INS}} = 0.07 C_{\text{CON}}(1-\eta_{\text{min}})^{20} \]  (3)

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2.3 Theoretical results

In a next step the costs of a repair work of the bridge model was calculated, assuming that a damage has to be repaired after its detection. Using an online-monitoring system cost savings up to 30% result due to an early detection of the damage (Figure 2).

2.4 Repair costs of a large swiss road-tunnel

The benefit of an online-monitoring system for the repair of a damaged structure is shown for a corroding tunnel slab in a large Swiss road-tunnel. After a detailed condition survey the following urgent measures were performed:

- Hydrophobic treatment of the tunnel slab over 250 m (portal zones).
- Installation of an online-monitoring system with macrocell-current and resistivity sensors.

The effectiveness of the urgent measures could be evaluated by using an online-monitoring system. To test the water repellent effect of the hydrophobic treatment on the corrosion propagation the tunnel slab was sprinkled with water during two nights. Figure 3 shows the material loss of the corroding reinforcement steel inside four test fields after half a year of measurements. A clear reduction of the corrosion propagation due to the impregnation can be seen. However the exposure conditions have a decisive influence on the ongoing corrosion process.

The application of a hydrophobic treatment combined with an online-monitoring system could be a time- and cost-saving measure compared to other methods. A gradual increase of water uptake in the concrete would be detected by the online-monitoring system on an early stage.

3 CONCLUSIONS

Using an online-monitoring system can lead to a clear reduction of the running costs over the lifetime of a structure as follows:

- For use in new structures – early warning system and extensive reduction of repair costs.
- After visual detection of damages – cost reduction is a result of a more detailed condition assessment and therefore more adequate repair measures.

REFERENCES