

BETOSCAN – An Instrumented Mobile Robot System for the Diagnosis of Reinforced Concrete Floors

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Abstract

A huge number of reinforced concrete floors, e.g. of parking garages or bridge decks are exposed to de-icing salts and thereby a high risk of chloride induced reinforcement corrosion exists. To be able to properly maintain such concrete floors the whole concrete surface needs to be assessed regarding the following key parameters: concrete cover, carbonation depth, chloride profile, cracks, spallings, hollow areas, condition of the reinforcement, etc..

As optimal basis for such an assessment several measurements have to be carried out over the whole concrete surface including mapping of electrochemical potentials and the parameters as mentioned above. For large structures with areas of often some thousand m² the costs for a full evaluation are usually not accepted by the clients resulting in reduced diagnosis works and design decisions for protection and repair measurements far on the safe side due to the limited data.

To overcome this problem a research and development project has been initiated with several partners from research and industry to develop a robotic system which is able to drive over large concrete surfaces and to take all relevant data automatically in one step. Furthermore the data collected from the measuring systems can be evaluated together resulting in different synergetic effects: Evaluations on the optimal repair method can be carried out for single points and certain areas enabling the engineers to divide the whole concrete surface into areas with different damage zones. These damage zones can be related to repair zones from doing nothing over e.g. applying protective coatings up to traditional repair by removing the concrete cover. Furthermore detailed maps are available for design and execution of repair works including cracks and locally damaged concrete.

Currently a prototype of the system is under development. This paper focuses on the possible fields of applications for the BETOSCAN system.

Keywords: Corrosion, diagnosis, steel, concrete, reinforcement

BETOSCAN – Ein mobiles Roboter Messsystem für die Diagnose von bewehrten Betonböden

Zusammenfassung

Eine Vielzahl flächiger Stahlbetonbauteile, wie etwa in Parkhäusern oder Brücken werden im Winter Tausalzen ausgesetzt. Dadurch entsteht ein hohes Risiko für chloridinduzierte Korrosion der Stahlbewehrung. Um diese Bauteile korrekt unterhalten zu können, ist es notwendig, die gesamte Oberfläche hinsichtlich folgender Parameter zu untersuchen: Betonüberdeckung, Karbonatisierungstiefe, Chloridprofil, Risse, Abplatzungen, Hohlstellen, Zustand der Bewehrung usw.

Zur Erhöhung der Aussagewahrscheinlichkeit sollten die Messungen über die gesamte Oberfläche ausgeführt werden. Dazu zählen die Aufnahme der örtlichen Verteilung des elektrochemischen Potentials sowie die oben genannten Parameter. Bei großen Gebäuden mit Flächen von mehreren tausend m² sind die Besitzer oft nicht bereit, die hohen Kosten für eine flächendeckende Zustandserfassung zu übernehmen. Dies führt notwendigerweise zu einer eingeschränkten Analyse. Wegen der begrenzt zur Verfügung stehenden Daten liegen dann die Entscheidungen für den Schutz und die Instandsetzung weit auf der sicheren Seite, was üblicherweise zu unwirtschaftlicheren Instandsetzungslösungen führt.

Um dieser Situation entgegenzuwirken, wurde ein Forschungs- und Entwicklungsprojekt mit mehreren Partnern aus den Bereichen Forschung und Industrie gestartet, um ein Robotersystem zu entwickeln, das in der Lage ist, auf der Betonoberfläche zu fahren und alle notwendigen Daten automatisch und gleichzeitig aufzunehmen. Außerdem können die vom Messsystem aufgenommenen Daten gesamtheitlich ausgewertet werden. Dies führt zu den folgenden synergetischen Effekten: die optimale Methode zur Instandsetzung kann für bestimmte Bereiche bestimmt werden. Dadurch wird der Ingenieur in die Lage versetzt, die gesamte Oberfläche in Zonen mit unterschiedlicher Schädigung einzuteilen. Die unterschiedlichen Schadenszonen können in Instandsetzungszonen übersetzt werden, wie beispielsweise (a) nichts tun, (b) Aufbringen einer Schutzschicht und (c) übliches Instandsetzen durch Entfernen der Betonüberdeckung. Hierdurch können vom sachkundigen Planer Detailpläne für die Planung und Ausführung der Instandsetzung erstellt werden.

Zurzeit ist ein Prototyp dieses Systems in der Entwicklung. In diesem Beitrag konzentrieren wir uns auf mögliche Anwendungen des BETOSCAN Systems.

Stichwörter: Korrosion, Diagnose, Stahl, Beton, Bewehrung

1 Introduction

A large number of floors from parking structures or bridges are suffering from severe corrosion problems world-wide. Mainly due to the ingress of de-icing salts or insufficient concrete quality of elder structures the steel reinforcement starts to corrode causing cracking, spalling and losses in cross section leading finally to structural problems of the whole structure. To evaluate the condition of such structures adequately usually extensive investigations are necessary. However, to save the costs for the required works often only simple investigation programs are carried out, which are not suitable as a basis for an adequate design of measures for maintenance, repair and protection of the structures. Subsequently often improper measures are carried out leading finally to higher total costs than the complete investigations based on a reliable database of the structure. This situation has been the basis for a research and development project to develop a robotic system which is able to drive over large floors and measure the relevant parameters of the concrete surface simultaneously. The collected data is stored for each investigated point of the structure allowing complex evaluations of the data regarding the assessment of the condition,

prognosis of the future state, design of measures for protection and repair as well as quality control.

The BETOSCAN-system shall meet the following requirements:

- Speed to measure some thousand m² of floors per day
- Simultaneous measurement of all key parameters
- Different fields of application for at least two tasks: Diagnosis before repair and quality control after repair
- Modular set-up to upgrade the system with further sensors
- Storage of all measured data in a defined format based on a defined coordinate system of the positions
- Evaluation of the data by single and combined plots of the data

A prototype of the BETOSCAN-system is currently under development. For this purpose three research establishments syndicated with seven small- and medium-sized enterprises (SME) and one industry partner (see Table 1).

Table 1: Institutions involved in the BETOSCAN project

Category	Institution	
1	2	
research establishments	ibac	Institute of Building Materials Research of Aachen University
	BAM	Federal Institute for Materials Research and Testing, Berlin
	IZfP	Fraunhofer Institute for Non-Destructive Testing, Saarbrücken
SME	GPS	GPS GmbH, Department Robotics, Neobotix, Stuttgart
	IGF	Engineering company for repair of buildings, Gieler-Breßmer & Fahrenkamp GmbH, Süßen
	SKP	Specht, Kalleja + Partner GmbH, engineering company, Berlin
	CITeC	Concrete Improvement Technologies GmbH, Dresden
	Ger mann Instruments	In-Situ Test Systems for Concrete and Reinforced Concrete Structures, Copenhagen (DK)
	ACSys	Acoustic Control Systems, Ltd, Moscow (RU)
	Arxes	Information Design Berlin GmbH
industry partner	Sika	Supplier of specialty chemicals, AG, Stuttgart



Figure 1: Potential Mapping using an handheld instrument point by point and a rolling wheel system

2 Condition Surveys of Floors: Actual State

Especially for concrete structures exposed to de-icing salts the first step of a condition survey should be a potential mapping of the whole concrete surface. Since recent years instruments to measure, store and plot economically the electrochemical potentials of the reinforcement at the concrete surface are commercially available. As

electrodes single reference cells, multiple arrays, wheels or sets of wheels are used (see Fig. 1).

Figures 2 and 3 show potential maps of different decks within a parking structure. They have been measured using a wheel electrode with a scanning distance of 50 cm. Critical areas with a high probability of corrosion can be identified by locally low potentials and steep gradients towards the corroding spots.

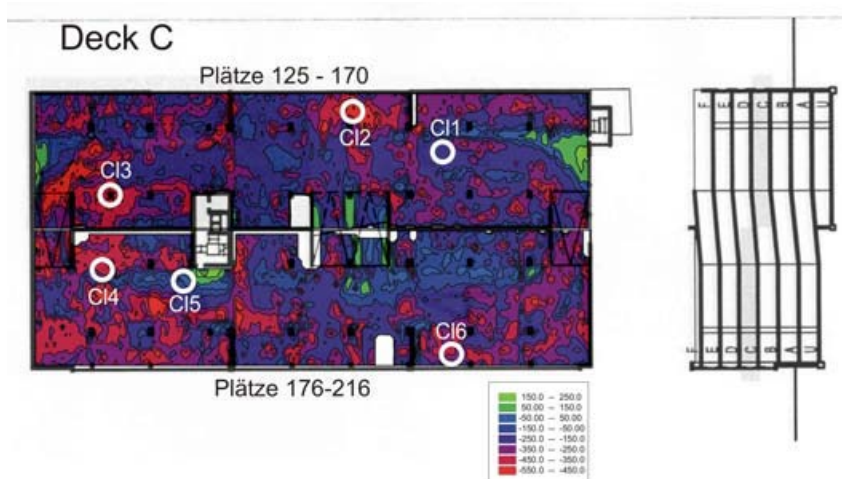


Figure 2: Potential map of a parking deck with a high amount of corroding areas (values in mV_{CSE})

However, the potential maps show only critical areas, but do not allow to decide upon if and which measures are required. For this purpose further parameters like the distribution of the concrete

cover, cracks, hollow areas etc. need to be determined. The idea of the BETOSCAN-system (see Fig. 4) is to measure as much additional relevant data as possible in parallel.

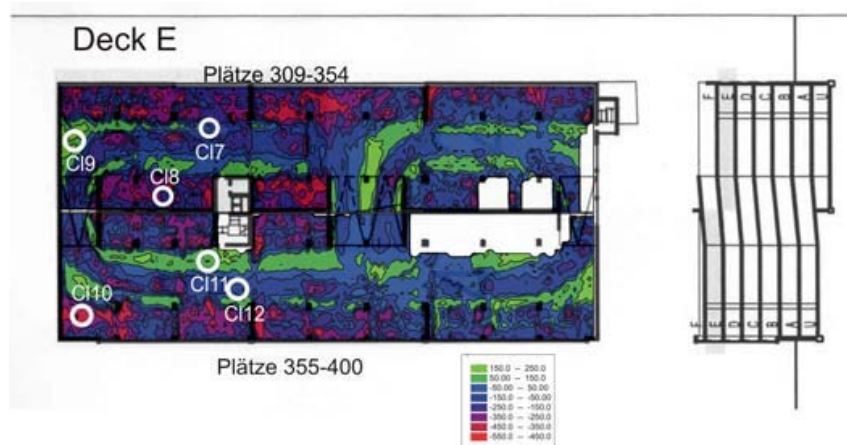


Figure 3: Potential map of a parking deck with locally limited corroding areas (values in mV_{CSE})



Figure 4: The BETOSCAN robotic system

3 Features of the BETOSCAN-System

To investigate the above-named parameters of a reinforced concrete structure, different commercially available sensors have been chosen to be integrated in the robotic system. Each parameter can be investigated with a corresponding sensor before it is saved with the appropriate coordinates in a database where all relevant information are collected. The operator can track the gained data at the same time via WLAN and can generate first maps on site. With this information further investigations can be planned, prepared and performed without time delay (Stoppel, 2008). The different measuring methods, the corresponding parameters and the

further processing of the data are shown in the schematic diagrams in Fig. 5 and 6.

Most of the integrated sensors have proven their reliability over many years and are commercially available as investigation instruments. To integrate the sensors in the robotic system the automation of the measuring method and opened interfaces in the handhelds have to be assured.

4 Capabilities of Using the BETOSCAN - System

The BETOSCAN-system opens several new possibilities for the management of concrete structures:

- Diagnosis: Complete assessment of the condition of a structure
- Prognosis: Basis for a detailed evaluation of the future state of the structure
- Service life management: Possibility of repeated or cyclic diagnosis to update and sharpen prognoses
- Planning of measures: Selection of suitable measures for protection and repair
- Quality control: Determination of key parameters of protection and repair measures after application

These points are discussed in the following sections more in detail.

5 Diagnoses

The diagnoses of reinforced concrete structures by means of the BETOSCAN-system can be divided into 4 steps which are shown in Fig. 7.

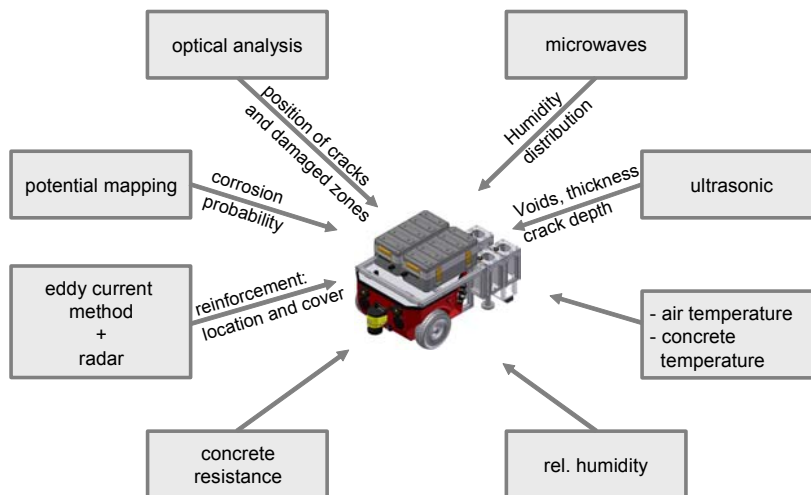


Figure 5: Investigation methods of the BETOSCAN-system

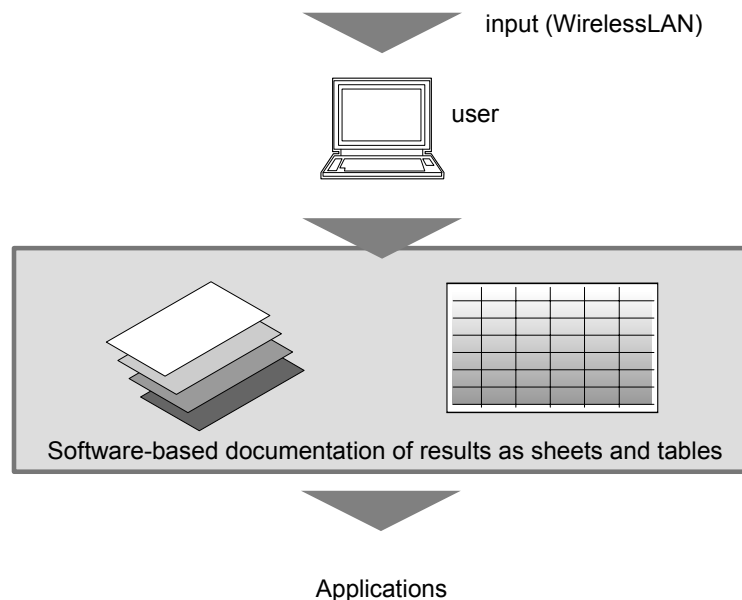


Figure 6: Further processing of the diagnostic data

One major advantage of the BETOSCAN-system is the possibility to divide the whole surface into zones with defined damage classes. Such damage classes could be:

- No damage due to high concrete cover and good concrete quality
- Corrosion of the reinforcement due to carbonation
- Chloride induced corrosion of the reinforcement
- Cracking due to corrosion
- Spalling due to corrosion
- Concrete damages due to frost, etc.

6 Prognosis of Service Life

The data from diagnosis can be used to calculate:

- Time to corrosion induced by chloride ingress, carbonation, etc.
- Time to reach a critical limit state induced by reinforcement corrosion or
- Optimal time to initiate protection or repair measures.

Suitable models on corrosion initiation (chloride ingress and carbonation of the concrete) are available and models for the propagation phase (corrosion of the reinforcement) are actually investigated in an extensive research project /www.dfg-for537.de.vu/.

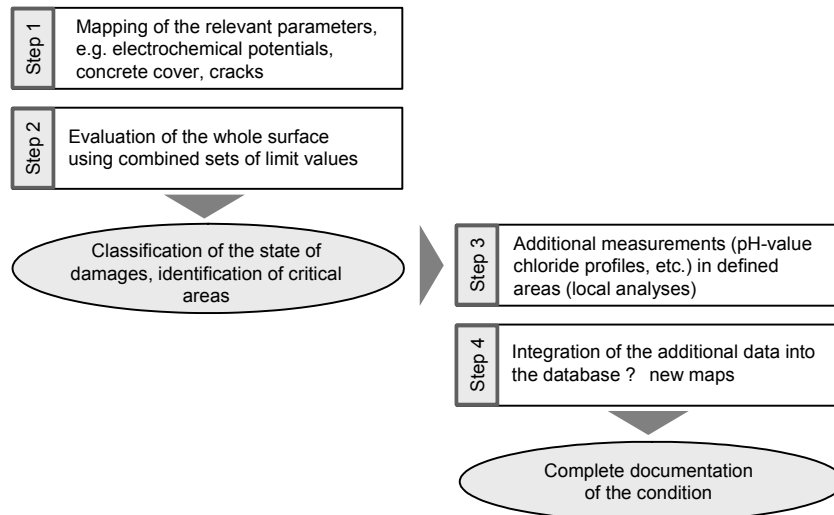


Figure 7: Schematic description of the analysis procedure

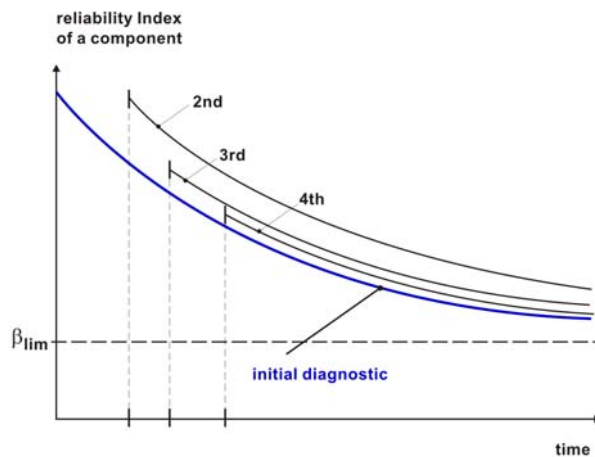


Figure 8: Possible development of the reliability index of a structure

When the concrete cover is known for the whole surface and reliable estimations for the speed of carbonation or the ingress of chlorides is worked out based on the data from the diagnosis, the time to corrosion or the time to reach a critical limit value can be calculated for each position of the surface. This allows again to divide the surface into zones with defined classes regarding the prognosis. A classification of the zones could be done as follows:

- No actions required for the next 20 years
- No actions required for the next 10 years
- No actions required for the next 5 years
- Immediate actions required, etc.

These maps could be a useful basis for the service life management of reinforced concrete structures.

7 Service Life Management

A reliable prognosis of the condition and behaviour of a structure is an important basis for an effective service life management. After finishing the building process an initial diagnosis could be carried out to document the initial state of the structure as basis for a first prognosis (birth certificate). From time to time additional diagnoses allow an update of the prognosis leading to an increased reliability of the prognosis with time.

By means of the BETOSCAN-system the costs for a complete survey can be reduced and the data base for a service life management can be improved economically.

8 Planning of Repair and Protection Measures

If repair or protection measures are required, the data from diagnosis are a valuable basis for the selection of

- suitable principles and methods of protection and repair and
- zones, where the same methods could be applied.

As result detailed maps for the design of measures for protection and repair will be available.

When suitable data for the costs for the measures are available the cost effectiveness could be integrated into the evaluation models.

9 Quality Control

During and after the application of protection and repair measures different key parameters can be determined for quality control purposes using the BETOSCAN-system like

- thickness of coatings
- concrete cover depths after the replacement of the concrete by a repair mortar

Scanning the whole surface area allows a reliable statistical evaluation of the data and a detailed localisation of critical zones.

10 Summary and Outlook

The investigations of large reinforced concrete floors, e.g. of parking garages or bridge decks, are time-consuming and expensive works. Various non-destructive testing instruments are available in

which every single investigation result forms a jigsaw piece of the actual state. By combining the different methods in one procedure the analysis will be accomplished faster and more accurate as up to the present. The introduced system can be applied in addition to the analysis to work out various damage zones which can be differentially repaired. In order to manage the service life of a component or to control the quality of a repair achievement, the operator can gain accordant data in an economic manner.

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