

History of EFC-WP 11 “Corrosion in Concrete“

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Introduction

In the 1960s first major damages on concrete buildings induced by reinforcement corrosion have been documented. Since about 1975 the amount of damages is increasing considerably resulting in the fact, that in the meantime reinforcement corrosion has become one of the major problems of maintaining the infrastructure. Most critical are structures exposed to chloride environment like offshore of coastal structures exposed to seawater (see e.g. Figure 1) or bridges or parking garages exposed to de-icing salts (see e.g. Figure 2).



Figure 1. Example for chloride induced reinforcement corrosion in concrete exposed to seawater



Figure 2. Example for chloride induced corrosion of the reinforcement exposed to deicing salts within a leaking joint of a parking garage

However, also carbonation of the concrete can lead to depassivation of the steel and subsequent corrosion of the reinforcement, especially when the concrete cover is too low (see e.g. Figure 3) or in cases of insufficient compaction of the concrete (see e.g. Figure 4).



Figure 3. Corrosion of the reinforcement of an old concrete structure caused by insufficient concrete cover



Figure 4. Corrosion of the reinforcement caused by local bad compaction of the concrete



Figure 5. Corroded rebar from a 4 years old building in hot and salty environment

Under aggressive environments the corrosion rates can exceed 1 mm/a or more. Figure 5 shows a rebar which is partially corroded away in the area of a crack in hot and salty environment within 4 years. However, in more moderate climates the corrosion rates are usually lower, but they are still critical: Figure 6 shows a rebar from a parking garage in Germany which has been removed from the area of a wide crack, where de-icing salts had passed through for about 10 years. The loss of cross section has proceeded so far that the remaining load bearing capacity of the steel is negligible.

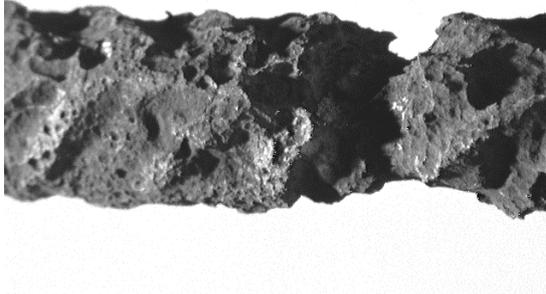


Figure 6. Corroded rebar from cracked concrete of a parking structure exposed to deicing salts

When corrosion of the reinforcement in concrete structures had been realised to be a serious problem world-wide in the 60th and 70th and the amount of damages still increased considerably in the 80th, extensive research programs had been initiated to understand the mechanisms of reinforcement corrosion and to become able to assess, repair and maintain those structures appropriately. Reinforced concrete probes with cable connections to each rebar have been produced extensively to study the potentials, polarisation behaviour, macrocell effects and the influences of the concrete mix as well as the environmental conditions like temperature, humidity, chloride content, etc (see e.g. Figure 7).



Figure 7. Example of electrochemical testing of rebar corrosion in concrete specimen

EFC-Working Party WP 11 founded in 1987

As such research has been carried out in different countries, it was evident to exchange the increasing knowledge in this field. Consequently a new EFC Working Party WP 11 has been formed in **1987 on Corrosion in Concrete**.

In 1987 Dr. Bernd Isecke, Germany, has been its first chairman. Initial topics at that time were the preparation of reports on reference cells for the use in concrete structures and on electrochemical rehabilitation techniques. These activities resulted later in the publication of **EFC-book 24**.

In 1992 Professor Chris C. Page, UK, took over as chairman of WP 11 and new sub-groups were formed to study coated and corrosion-resistant rebars as well as design for durability of reinforced concrete structures.

In 1996 Dr. Juergen Mietz, Germany, became new chairman of WP 11. In the same year WP 11 became involved in COST 521, a collaborative European programme on corrosion of steel in reinforced concrete structures. Furthermore WP 11 became involved in RILEM TC 154 working on methods for the measurement of corrosion in concrete.

In 2005 Professor Michael Raupach, Germany, took over as Chairman of WP 11. He organised the session on “Corrosion in Concrete” of the EUROCORR conferences. The annual meetings of WP 11 are as a tradition held with normally about 20 participants during these EUROCORR conferences.

Electrochemical Protection Methods

One main topic of WP 11 during that time were the electrochemical rehabilitation methods like

- Cathodic protection
- Electrochemical chloride extraction (desalination) and
- Electrochemical realcalisation of the concrete.

Especially for cathodic protection several different anodes systems have been developed, which were discussed in detail in WP 11. As examples Figure 8 shows the thermal spraying of a zinc layer to the concrete surface acting as sacrificial anode and Figure 9 the installation of a carbon mesh into a special connecting mortar as impressed current CP-system.



Figure 8. Sacrificial cathodic protection of steel in concrete by thermal zinc spraying



Figure 9. Cathodic protection by an impressed current using a carbon mesh anode in a special mortar

A successful application of these methods requires special knowledge from civil engineering as well as from corrosion engineering. Within WP 11 experts from both fields worked together to discuss the possibilities and limits of these methods and details how to improve their effectiveness. The results of this successful work has been published as **EFC-book 24** on “Electrochemical Rehabilitation Methods for Reinforcement Concrete Structures – A State of the art Report” in 1998.

In the same year several excellent presentations have been given at the EUROCORR 1997 within the session of WP 11. Selected papers from this session were published also in 1998 as **EFC-book 25** of the EFC series edited by J. Mietz, B. Elsener and R. Polder called “Corrosion of Reinforcement in Concrete: Monitoring, Prevention and Rehabilitation”.

Corrosion Mechanisms

Within the following years major topics of WP 11 were still general corrosion mechanisms and possibilities for corrosion protection. In 2000 **EFC-book 31** has been published on

“Corrosion Mechanisms and Corrosion Protection” edited by J. Mietz, R. Polder and B. Elsener.

Non-Destructive Testing Methods

To detect the probability for corrosion of the reinforcement on site, non destructive methods like potential mapping, linear polarisation resistance devices, anodic pulse devices and special instruments using electrochemical impedance or electrochemical noise techniques have been developed.

Figures 10 and 11 show results from potential mappings of different decks from a parking garage.

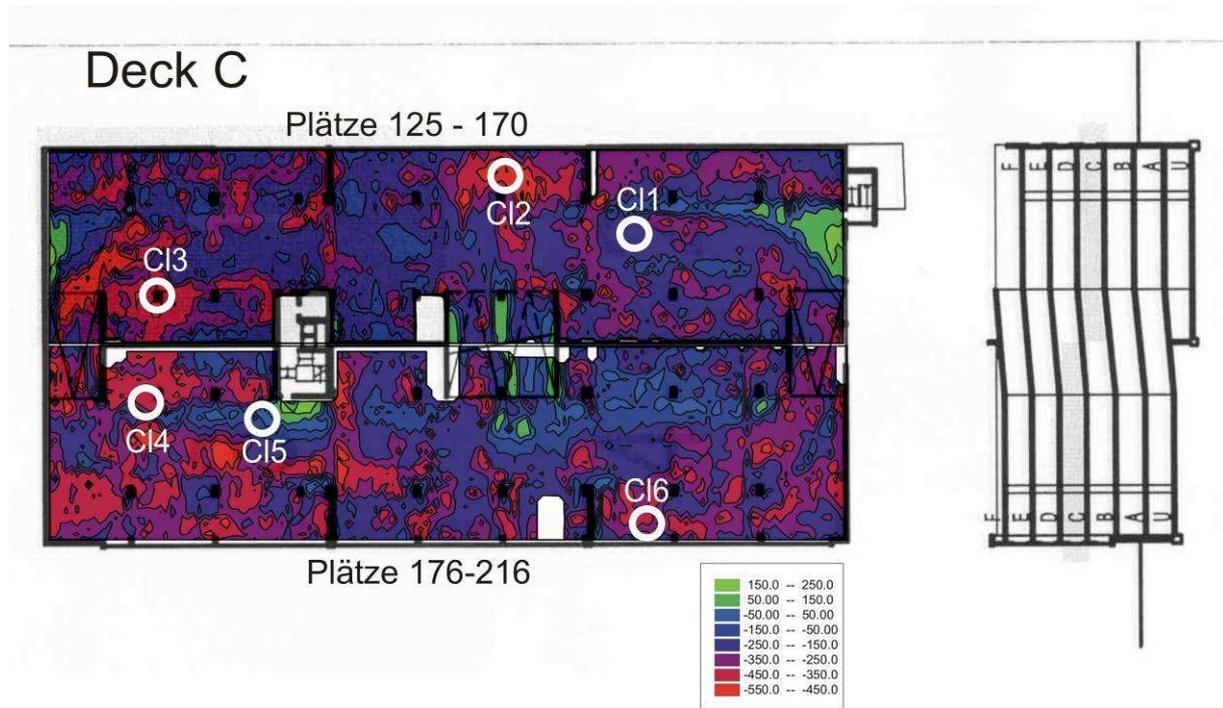


Figure 10: Potential map of a parking deck quite near to the entrance

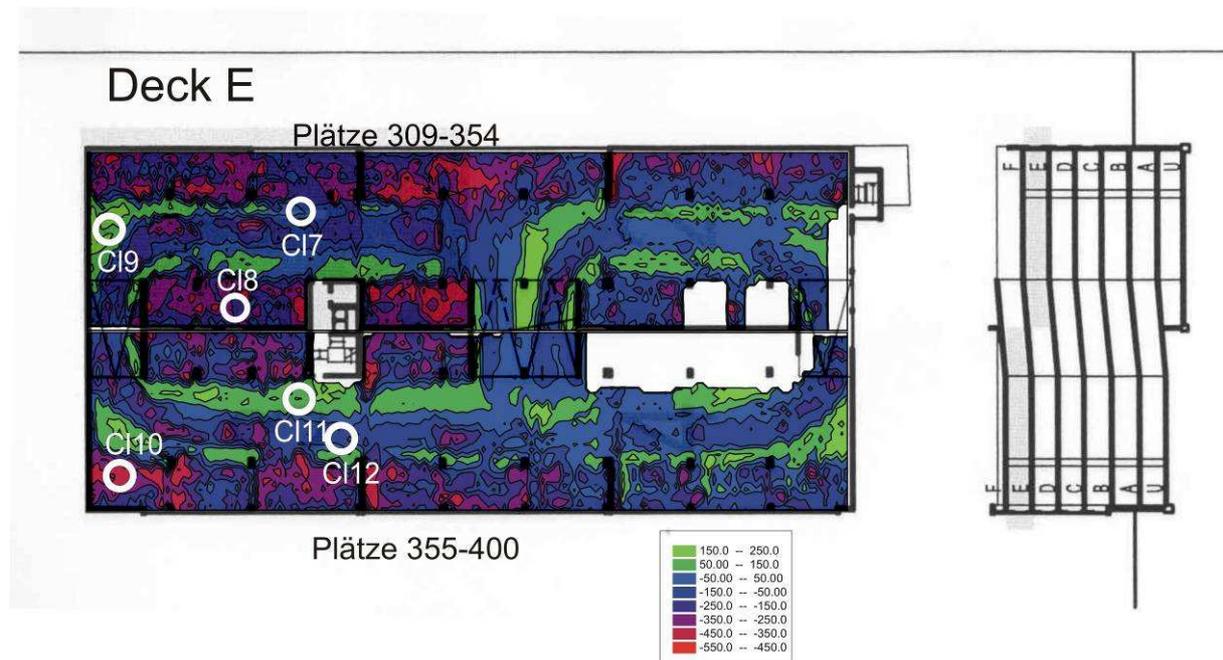


Figure 11: Potential map of a parking deck quite far to the entrance

Within WP 11 the pros and cons of such measurements and especially the methods of evaluation of the data from site have been discussed. This is still an actual topic.

Corrosion Inhibitors

Another major topic were corrosion inhibitors for reinforced concrete. Different types of products have been developed during that time as so called mixed-in or surface-applied inhibitors. Tests showed, that the corrosion rate could be reduced significantly under certain conditions. Extensive discussions have been carried out in WP 11 on the effectiveness, the protection mechanism (pore blocking, passivating, chloride binding, etc.) fields of application (leaching out effects, cracks, etc.) and durability of the different types of inhibitors. As result of these discussions in 2001 the **EFC-book 35** has been published by task group 2 (see table 1).

Stress Corrosion Cracking of Prestressing Steels

A special problem for reinforced concrete structures is the possibility of hydrogen induced stress corrosion cracking of certain types of prestressing steels. This is an extraordinarily dangerous type of corrosion, because it can lead to a sudden failure of prestressed concrete beams or slabs without any early warning by signs of corrosion or deflections or deformations of the structural element. Single collapses of prestressed concrete structures have clearly been identified as such hydrogen induced corrosion mechanism. In 2003 the **EFC book-37** has been published on “Test Methods for Assessing the Susceptibility of Prestressing Steels to Hydrogen Induced Stress Corrosion Cracking” by task group 4.

Besides the risk of hydrogen induced embrittlement also pitting corrosion of prestressing steels has been discussed (see Fig. 12).



Figure 12: Corroding prestressing steels after opening of the duct

Two other EFC books have been prepared under Chairman Dr. Juergen Mietz: “Corrosion of Reinforcement in Concrete: Mechanisms, Monitoring, Inhibitors and Rehabilitation Techniques” (**EFC-book 38**) edited by Michael Raupach, Bernd Elsener, Rob Polder and Juergen Mietz. and “The Electrochemistry and Characteristics of Embeddable Reference

Electrodes for Concrete” (**EFC-book 43**) edited by Roar Myrdal. This book describes the result of task group 5 working on Reference Electrodes in Concrete (see table 1).

Numerical Modelling

Prof. Michael Raupach is continuing his work as chairman of task group 6 on Corrosion Models, where numerical models for the propagation stage of reinforcement corrosion are discussed. Several researchers from six countries contributed to this work, where numerical simulations of special case studies have been carried out and are discussed as basis for a future service life design model.

On-Site Testing

Interesting input data for modelling are available from corrosion monitoring systems in actual structures (see e.g. Figure 13) or exposure tests.



Figure 13. Sensors installed in a concrete structure to monitor the corrosion risk for the reinforcement

As examples Figure 14 shows the measuring unit for exposure tests in the splash water zone of a highway in Germany and Figure 15 the exposure of concrete specimens in seawater environment on the island Helgoland. An extensive German research project on Corrosion Models for the Propagation Phase of Reinforcement Corrosion will continue this work (www.bam.de/dfg537.htm)



Figure 14. Measuring unit of exposure tests at a highway in Germany within the splashwater zone



Figure 15. Exposure tests in seawater of the island Helgoland within a research project supervised by the University of Stuttgart

Task Groups and Publications

Table 1. Task groups of EFC working party 11

Task Group	Title	Chair	EFC-book
TG 1	Electrochemical Rehabilitation Methods for Reinforced Concrete Structures	Mietz	EFC 24
---	Corrosion of Reinforcement in Concrete: Monitoring, Prevention and Rehabilitation	Mietz, Elsener, Polder	EFC 25
---	Corrosion Mechanisms and Corrosion Protection	Mietz, Polder, Elsener	EFC 31
TG 2	Corrosion Inhibitors for Steel in Concrete	Elsener	EFC 35
TG 3	Requirements of Concrete Cover Depth in Environmental Conditions	Gjorv	-
TG 4	Test Methods for a Assessing the Susceptibility of Prestressing Steels to Hydrogen Induced Stressed Corrosion Cracking	Isecke	EFC 37
---	Corrosion of Reinforcement in Concrete: Mechanisms, Monitoring, Inhibitors and Rehabilitation Techniques	Raupach, Elsener, Polder, Mietz,	EFC 38
TG 5	The Electrochemistry and Characteristics of Embeddable Reference Electrodes for Concrete	Myrdal	EFC 43
TG 6	Models for the Corrosion of Steel in Concrete	Raupach Gulikers	Materials and Corrosion Issue 8/2006
TG 7	Corrosion Surveys	Schneck, Raupach	Materials and Corrosion Issue 2/2013

Other Activities

As a joint event together with WP 4 on nuclear corrosion WP 11 participated in the international conference **NUCPERF 2006** in Cadarache. During this conference especially the long-term durability of reinforced concrete structures with service lives of much more than 50 years as usually used for buildings has been discussed. WP 11 has participated in the **COST 534** project on the Protection of Pre-Stressed Concrete and intending to participate in a new **RILEM TC** on modelling of reinforcement corrosion.

Finally it should be noted as considerable success of WP 11 that during the last years at every **EUROCORR Conference sessions** over two full days have been held with presentations in the field of corrosion of steel in concrete showing the continuing interest in the work of WP 11.