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An Approach for Monitoring Impregnated Reinforced Concrete Structures Subject to Severe Chloride Exposure

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Abstract

A water repellent treatment can be used as chloride barrier for the protection of reinforced concrete structures. However the effectiveness of the treatment has to meet very high demands. The inner surface of tunnels is exposed to chloride containing salt water in winter time. Therefore these structures have to be protected. One possibility is to apply a water repellent agent in order to establish a chloride barrier. In order to compare their effectiveness different surface protecting systems were examined in a model tunnel under severe chloride exposure. By means of a monitoring system failure of the protective function can be timely determined.

Keywords: water repellent treatment, chloride barrier, durability, tunnel, monitoring system

1 Introduction

The application of a water repellent treatment to reinforced concrete surfaces often pursues strongly differing goals. A frequent goal is the reduction of the water uptake in order to improve the resistance against frost and freeze-thaw damage [1]. Another goal, which is being increasingly considered, is the protection of reinforcement against chloride induced corrosion. There are only few investigations on long-term stability of a water repellent treatment [2]. Nevertheless the demands on this type of protective measure are often very high and hence, a conceptual approach is required.

The example of a recently constructed open-cast tunnel on the Swiss network of national roads is used to describe a concept aiming at checking the durability of impregnated reinforced concrete structures. Next to the tunnel, a model tunnel of the same concrete quality was constructed, where preliminary tests were meant to take place. The institute was offered the opportunity to carry out chloride exposure tests in this model tunnel. These tests include the comparison of different systems for surface protection. By means of an automated sprinkling installation these protective systems are exposed to wet and dry cycles, the wet cycle based on contact with a chloride solution. One of these sample surfaces—treated in-depth with a water repellent—corresponds to the actual treatment applied to the real tunnel. From the experiences in the model tunnel a possible deterioration of the protective performance of the water repellent treatment in the tunnel can be foreseen in time and therefore appropriate measures, e.g. a retreatment with the water repellent or a coating can be planned in advance. This paper mainly describes the methodology used while detailed results will be published in the near future [3] and presented in part during the conference.

2 Selection of a suitable protective measure

Due to use of deicing salts for road maintenace in winter many traffic related structures are directly exposed to solved chlorides. Chlorides get onto the concrete surface through splash-water [4]. If these surfaces are not exposed to further weathering, the pores are relatively dry. Thus the chloride solution is rapidly sucked in through the capillary system, penetrating very deeply. Even structures with relatively high quality concrete may already show the first signs of corrosion damage after merely a few winter seasons, thereafter requireing costly repairs.

Next to console headings of bridges and supporting columns of galleries the entries of tunnels are mainly exposed. Because of the air circulation that traffic generates, the superficial zone of the concrete tunnel wall rapidly dries out.

For a newly build tunnel on a highway the usage requirements stipulate a repair-free service life of 100 years [5]. Further specifications require that the life cycle costs have to kept as low as possible. In order to achieve these stringent objectives, intensive investigations were carried out before selecting a suitable concept of protection. Among others the following measures were examined:

- High quality covercrete.
- Thin or thick coating of the concrete surface [6, 7].
- Installation of tiles.
- Application of cathodic corrosion protection [8].
- Water repellent treatment.

Since cracks with a 0.3-mm opening or larger could be expected, a thin coating was excluded. So was a thick coating, since in case of an accident crashing vehicles could damage it. Moreover, the relatively rough cleaning techniques which are quite usual in tunnels would additionally damage any coating.

Tiles are extraordinarily resistant to water and chloride penetration and have a high life expectancy. However the mortar joints between the tiles deteriorate over time. Chloride ions can penetrate trough the mortar joint. In addition experiences in other tunnels showed that chloride solution from the lower border rises behind the tiles. Since the concrete behind the tiles is very dry, the chlorides can penetrate very deeply within a short time. Hence tiles were also excluded from this study.

Among the measures mentioned above cathodic corrosion protection is possibly the most effective. However, since a continuous current had to be provided requiring an intensive monitoring, this option was also rejected

As badly executed water repellent treatments had often failed in the past, its application was considered with a lot of scepticism. Moreover no reliable procedures for planning, executing and controlling the quality of the application are available.

An intensive preliminary investigation [9] with laboratory and field surveys was carried out to show whether the application of a water repellent treatment on a compact concrete surface could possibly meet the necessary requirements. A positive result of these investigations was the prerequisite for the decision to make use of a water repellent treatment.

3 Procedure for the examination of the effectiveness of a water repellent treatment as chloride barrier

The first investigations were to evaluate the required penetration depth of the water repellent treatment. Specimens of the same concrete mixture as used in the tunnel were treated with a water repellent [3]. After 28 and 120 days of continuous exposition to a three percent NaCl solution the chloride profiles in these specimens were determined. It could be shown that the in-depth water repellent treatment resulted in penetration depths of 5-mm or more, while a conventional water repel-

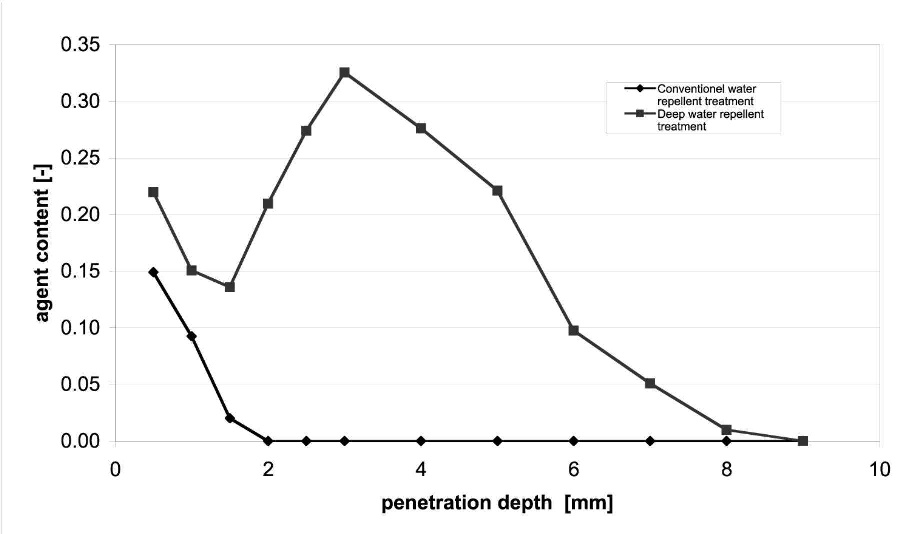

Figure 1: Profiles of an in-depth water repellent treatment and a conventional water repellent treatment

lent treatment with low penetration depth (0.5 - 1 mm) failed after a given time. Figure 1 shows the profiles of an in-depth water repellent treatment and a conventional water repellent treatment as determined by FTIR spectroscopy [10]

It was suggested that an in-depth water repellent treatment, with a minimum effective penetration depth of 5 to 7 mm, be specified, since this penetration depth also allows to overcome any expected cracks problem [11]. Although the specification seems very high it is justified for the severe exposure conditions the treatment has to resist.

The following step were site tests in the tunnel to show whether the required penetration depth could be achieved with the given in situ conditions (humidity, porosity, concrete quality, surface finish, etc.) [9, 12]. For the determination of the water repellent up-take double-chamber cells were used (figure 2). The mode of operation of these measurement cells is described elsewhere [13].

On the basis of the positive results obtained the application of a water repellent treatment was chosen as the protective measure for the tunnel.

Bidding companies were asked to demonstrate the ability of their selected product to fulfill all requests. Only successful companies were invited to submit an offer. Figure 3 shows the significant differences in penetration depth and agent distribution obtained in the preliminary tests of the participating companies.

Figure 2: Preliminary investigation: Double-chamber cells for the measurement of the uptake efficiency of the water repellent by the concrete surface in the tunnel

The in-depth water repellent treatment of the tunnel walls was recently carried out and showed that treatment depths of 5-mm and more can be obtained on high quality concrete under actual conditions at reasonable expense. However the choice of the product and the application technique has to be based on preliminary testing. This procedure could also be used for smaller projects.

4 Description of the measurement system in the model tunnel

A model tunnel, about 5-m long and 4-m in section at ground level, but with the same height, wall thickness and concrete quality, was built right next to the real tunnel. In the model tunnel different sensors were installed [14] that allowed to follow the hydration process, moisture and chloride penetration as a function of

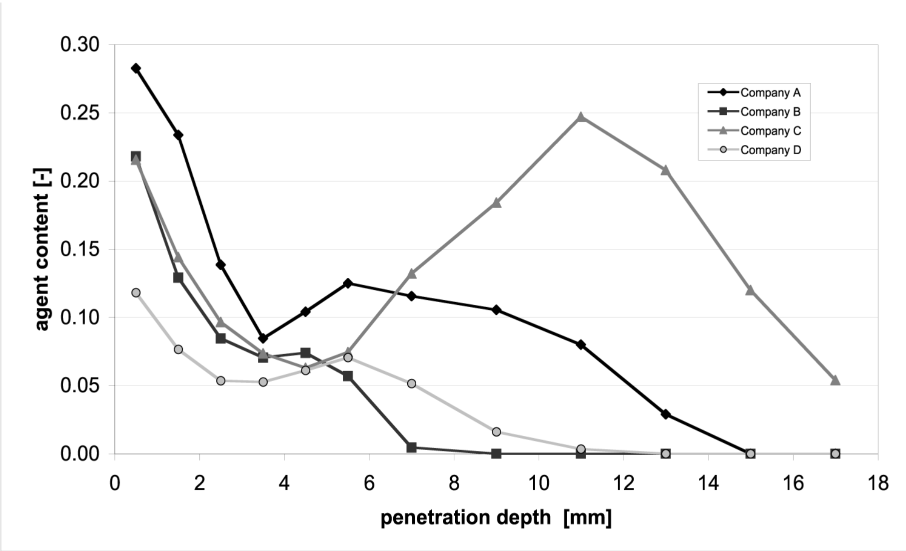

Figure 3: Prequalification: Profiles of the water repellent treatments applied by the participating companies

time. In additon, sensors and data-logging systems were installed to record shrinking deformation, temperature behavior, joint groutings, etc. On a wall area of the model tunnel the same water repellent treatment was applied as on the tunnel walls. Other protective systems were applied for comparison purposes. A sprinkling installation was installed to regularly expose these surfaces to cyclic contact with a three percent NaCl solution. The sprinkling installation is shown in (figure 4).

The following protective systems were installed (figure 5):

- In-depth water repellent treatment as used in the tunnel (area 6a and 6b)
- Conventional water repellent treatment with a penetration depth of 1 to 2 mm (area 4)
- Bitumen coating as used for the sealing of the carriage way (area 5)
- Protective rendering (area 1)
- Cement-bound coating (area 2)
- Cement-bound coating formulated with a water repellent (area 3)

The coating systems were equipped with simple corrosion sensors (so-called anode conductors) [10], in order to measure any chloride penetration. As such corrosion sensors can no longer be installed once the concrete is set, three concrete disks

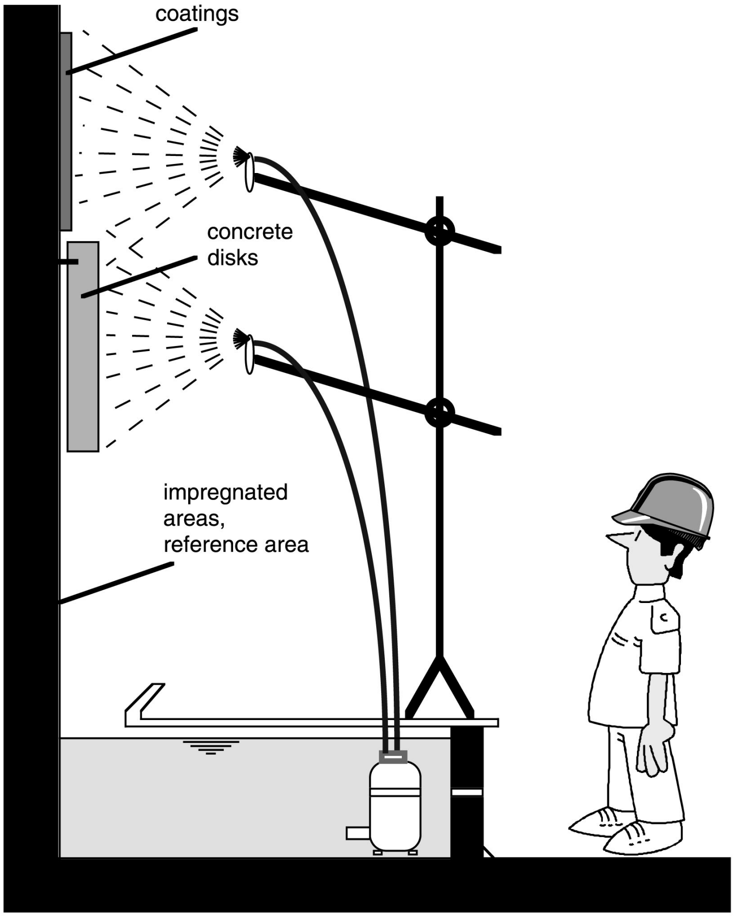

Figure 4: Sprinkling installation in the model tunnel

equipped with sensors were manufactured additionally. They were impregnated and included in sprinkling cycles. The results are constantly recorded with data-loggers.

Drill-cores from the disks and from the different test surfaces are regularly extracted to determine the chloride profiles. Based on these results critical values can be defined to timely foresee a failure of the respective protective measure.

5 Monitoring system in the tunnel

A similar early warning system was also installed in the real tunnel. Several sensors were installed at regular intervals from the tunnel portal (figure 6). These sen-

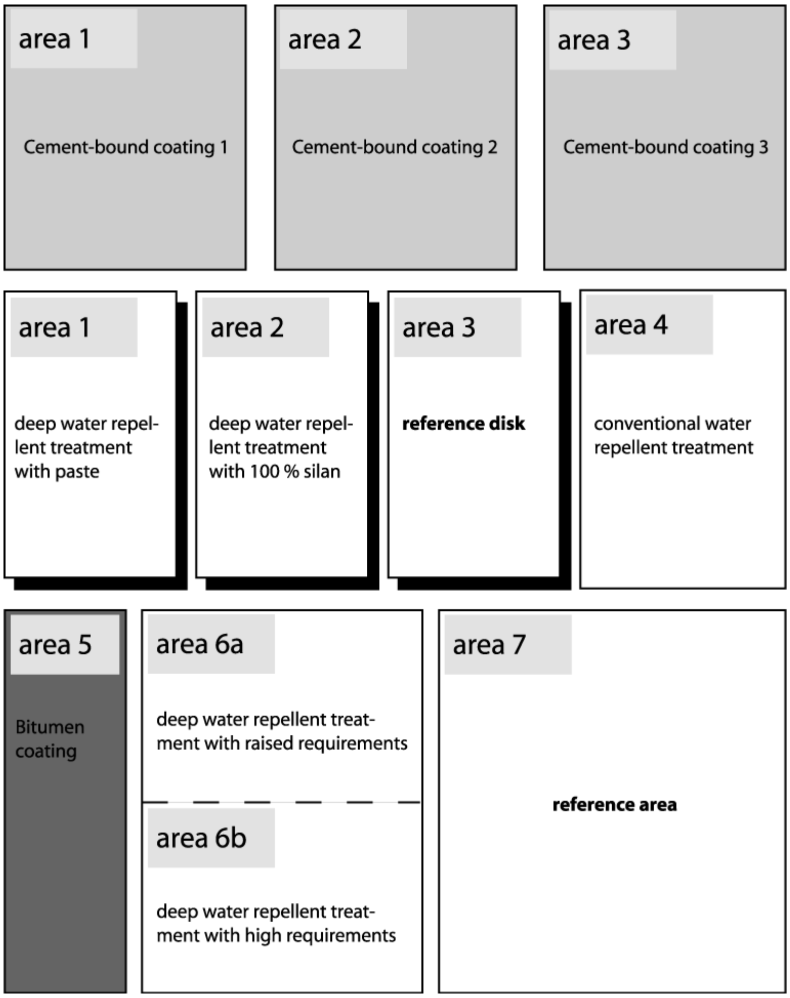

Figure 5: Protecting systems applied in the model tunnel

sors measure the penetration of chloride, the moisture distribution and the temperature development in the tunnel.

Since then, an all-inclusive monitoring system functions inside this tunnel. A huge amount of information of scientific interest is expected to be generated regarding the long-term development of humidity and temperature. However, the main task of the corrosion sensors consists in the timely detection of the decrease in the

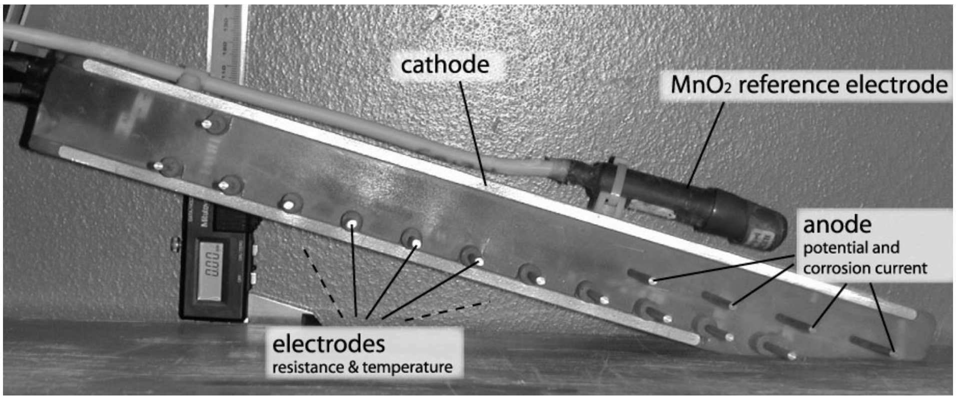

Figure 6: Sensor, as installed in the tunnel and in the model tunnel

water repellent treatment performance. In this case appropriate measures can be initiated before repair becomes actually necessary. The corrosion sensors in the model tunnel serve to estimate the chloride content in the actual tunnel walls at a given time thus avoiding the closing of the tunnel for drill-core sampling.

The monitoring systems installed, the model tunnel and the in-depth water repellent treatment of the tunnel provide a complete and modern approach to durability evaluation (figure 7). Thus it is likely that the required repair-free service life of the tunnel will be achieved in spite of the high stipulations.

6 Outlook

This summer measurements started in the model tunnel. So far no conclusions can be drawn regarding the effectiveness of the individual protective systems. It is expected that the first results will be available and published towards the end of the year [3].

From the data obtained a numerical model will be developed that simulates the effectiveness of an in-depth water repellent treatment. This model will allow to reliably predict the long-term behaviour of water repellent treatments under strong chloride exposure. It will also become clear which protective measure leads to the lowest life-cycle costs.

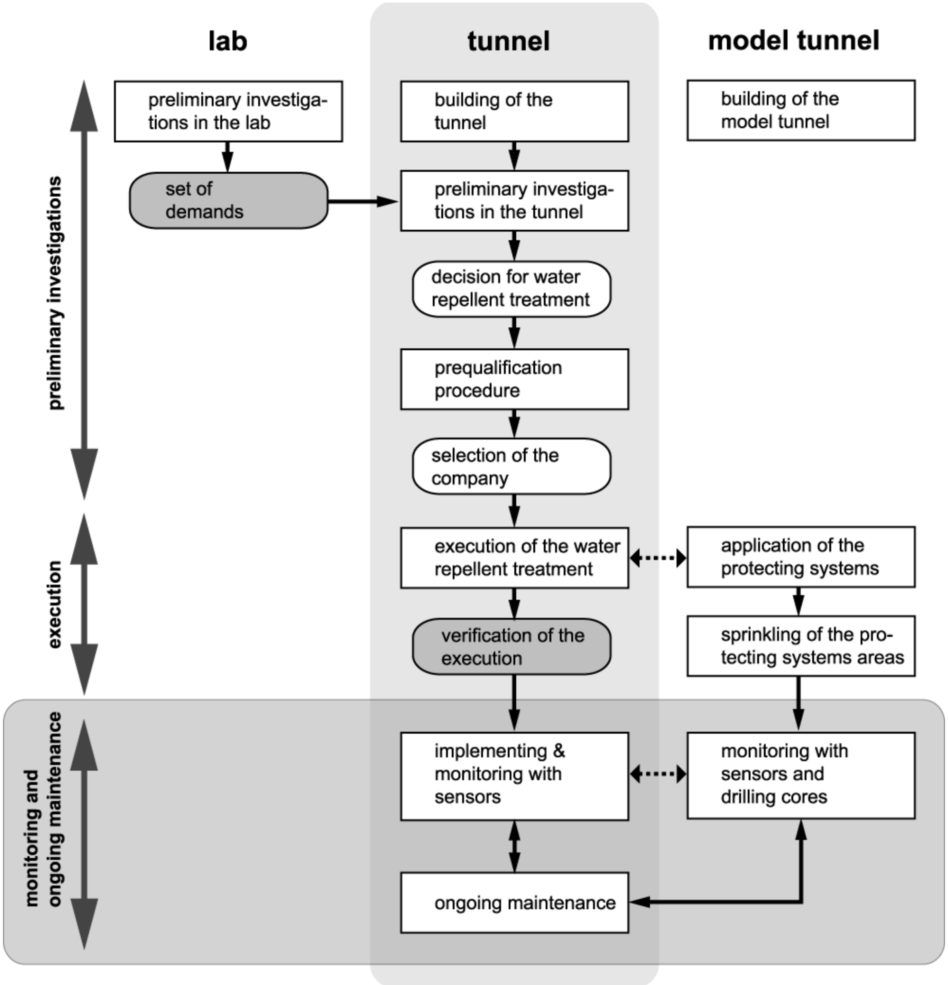

Figure 7: Flow-chart of the approach used to monitor the durability of impregnated reinforced concrete structures

7 Literature

1. WITTMANN, F.H., Hydrophobieren, Trocknen und Frostbeständigkeit des Betons, in WTA-Schriftenreihe ,Heft 10, Aedificatio Publishers, D-79104 Freiburg, 41-57 (1996)
2. SCHUEREMANS, L. UND VAN GEMERT, D., Effectiveness of hydrophobic treatment as chloride Penetration barrier - on site investigations and service life prediction model, Werkstoffwissenschaften und Bauinstandsetzen, Aedificatio Publishers, D-79104 Freiburg, 731-740 (1999)

3. MEIER, S.J., WITTMANN, F.H., Anforderungsprofil und gezielte Anwendung einer hydrophobierenden Massnahme, Forschungsauftrag 83/98, Schweizerisches Bundesamt für Strassenbau, (in press)
4. SCHWARZ, W., Herausgeber, Ursachen der Korrosion von Stahl in Beton, in WTA-Schriftreihe, Aedificatio Publishers, D-79104 Freiburg, Heft 19, 3-16 (1999)
5. UHERKOVICH, I., Hydrophobieren aus der Sicht des Bauherrn, in WTA-Conference Notes, Heft 3, Aedificatio Publishers, D-79104 Freiburg, 49-56 (2001)
6. GERDES, A., Protective Coatings of Concrete Structures for High Durabiliy, in WTA-Schriftenreihe , Aedificatio Publishers, D-79104 Freiburg - Frauenhofer IRB Verlag, Heft 15, 157-169 (1997)
7. FLÜCKIGER, D., ELSENER, B., STUDER, W. UND BÖHNI, H., Schutz von Beton durch Beschichtungen, Heft 22, Schweizerischer Ingenieur- und Architekten Verein, 375-382 (1993)
8. HUNKELER, F., Untersuchungen zum kathodischen Korrosionsschutz von Stahlbeton im Tunnel San Bernardino, Forschungsauftrag 84/93, Schweizerisches Bundesamt für Strassenbau (1992)
9. MOETSCH, H.A., MEIER, S.J., GERDES, A., WITTMANN, F.H., Eindringtiefe eines Hydrophobierungsmittels als Funktion der Qualität, des Feuchtigkeitsgehaltes und des Alters des Betons, Int. Journal for Restoration of Buildings and Monuments, 5 (Heft 3), 289-306, (1999)
10. GERDES, A., WITTMANN, F.H., Charakterisierung einer hydrophobierenden Massnahme durch Anwendung der FT-IR-Spektroskopie, Int. Journal for Restoration of Buildings and Monuments1 (Heft 2), 135-152, (1995)
11. LUNK, P., MÜLLER, T., und WITTMANN, F.H., Feuchtigkeits- und Ionentransport in gerissenen Stahlbetonbauteilen, Forschungsauftrag 85/90, Schweizerisches Bundesamt für Strassenbau (1998)
12. MEIER, S.J., WITTMANN, F.H., Notwendige Kriterien für eine Tiefenhydrophobierung, Werkstoffwissenschaften und Bauinstandsetzen, 5. Int. Kolloquium , Aedificatio Publishers, D-79104 Freiburg, 751-762 (1999)
13. MEIER, S.J.., WITTMANN, F.H., Entwicklung einer Zweikammer-Messzelle zur Bestimmung der kapillaren Flüssigkeitsaufnahme, Int. Journal for Restoration of Buildings and Monuments, 5 (Heft 3), 177-186 (1999)
14. MARTINOLA, G., Ein Messsystem zur kontinuierlichen Überwachung von Stahlbetonbauwerken, Int. Journal for Restoration of Buildings and Monuments, 7 (Heft 3/4), 381-394, (2001)