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Protection of Existing Highway Bridges by Means of Water Repellent Treatment – A Pilot Project

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Abstract

Bridges all over the world, and that includes bridges on German motorways, are exposed to strong impacts especially regarding the use of de-icing salts that can cause corrosion of the reinforcement. The consequences are important, from the technological, environmental and economic point of view: repairs are expensive and time-consuming. The pillars in the middle of a motorway bridge are especially vulnerable to splash water.
The costs of repairing these pillars amount approximately to the sum of 200,000 €, including cost for traffic management during the work. Taking these facts into account, and in order to avoid these damages, it is essential to improve the resistance against chloride penetration in building materials by surface protection measures.
In order to develop a strategy to extend the service life of new and existing constructions without or with only minor repair works, a research project was begun. The study focused on in-depth impregnation with a water repellent agent as a surface protection measure. In co-operation with those responsible in the Motorway Authority of South- Bavaria, a preventive surface protection was elaborated and tested in the context of a pilot project on 17 bridges. The paper presents and discusses the results of this pilot study.

Keywords: bridges, water repellents, in-depth impregnation,

1 Initial situation

The bridge structures in the German road network are exposed to utilisation-related environmental influences which can lead to damage to the structure. The extent of this damage has now reached a large economic proportion. According to a DEKRA study, 14,000 of the approximately 120,000 bridges are in an extremely poor condition and comprehensive renovations are necessary for a further 20,000 bridges, these figures being provided by the federal ministry of transport. In order to secure competitiveness in the global market, it is therefore of great importance to restore and maintain the functionality of this infrastructure.

What causes this damage?

De-icing salts in winter should be listed as the first cause. These salts are absorbed by the concrete and transported into the construction material. Should they reach the reinforcement, they can trigger corrosion of the steel in certain conditions. The consequence is spalling of the covering concrete, which exposes the reinforcement steel to further corrosion.

Some of the most heavily affected areas are the central supports of bridges built over motorways. These stand unprotected in the splash zone of de-icing salts and are therefore exposed to high chloride burdens during the winter months leading in time to heavy corrosion damage in the concrete. When this occurs, technologically, economically and ecologically costly renovations are necessary. This will be made clear through a practical example.

Figure 1: Bridge over the motorway

- **Technologically**

  For renovation, the defective covercrete must be milled down to the reinforcement. The steel must be cleaned and provided with a corrosion protection coating. The removed covercrete must then be reprofiled. The application of new cement mortar on the original concrete creates a new interface between new and old concrete. If the two materials are not optimally matched, damage may reappear after just a few years, something that is also frequently observed in practice.

- **Economically**

  Investigations have shown that the repair price for this type of bridge pillar is many times higher than its original construction cost. The financial expenditure for the pillar renovation is in the order of some 30,000 € while the costs for traffic diversion range between 100,000 to 120,000 €. The indirect congestion costs. (e.g. additional fuel and time expenditure) are not considered in this calculation.

- **Ecologically**

  Besides a high financial expenditure, renovations are as a rule very demanding construction measures in terms of energy and resources, associated with significant ecological impacts. The environmental costs of a renovation can add up to three times those associated with the initial construction.

This shows that avoiding this damage has a high priority. A technical route for this is a preventive surface protection with in-depth impregnation.

2 Pilot project: In-depth impregnation of existing bridge constructions

In-depth impregnation of new construction is accepted as a preventive protection measure in several countries such as Sweden and Switzerland. For this reason, a pilot project was developed to investigate whether the service life of existing bridge structures could also be significantly extended in this manner. The project was carried out in co-operation with the motorways directorate for South Bavaria, and incorporated collaborations from Wacker AG (Burghausen), Sto AG (Stühlingen), Konstruktionsgruppe Bauen (Kempten) and the company Aquastahl (Kisslegg). Scientific direction was provided by the University of Applied Science, Karlsruhe and the Karlsruhe Research Centre. With the results of this study, an approach was to be developed to provide preventive protection to existing concrete structures of varying age and chloride content.

2.1 Preliminary investigation of the bridges

During the preliminary investigations, carried out by the University of Applied Sciences, Karlsruhe, in co-operation with the Karlsruhe Research Centre [1], the condition of 17 bridges of varying ages in the Bavarian motorway network was recorded. For this, drill cores were obtained for later investigation in the laboratory. The bridge pillars standing in the splash zone were inspected. From each pillar, two sets of cores were drilled for each of the selected heights: approximately 0.30 m (cores 1-1 and 1-2); 1.30 m (cores 2-1 and 2-2); and, 2.30 m (cores 3-1 and 3-2). The diameter of the cores is 70 mm, their length varies between 50 and 70 mm.

Figure 2: Points of drill core sampling

The cores were stored in air-tight plastic bags at a temperature of 20 °C.

The following analysis and tests were carried out on the drill cores:

- Carbonatation depth.
- Water absorption capacity and porosity.
- Chloride content.

From construction records, the age and concrete quality could be obtained. Environmental conditions were also compiled for the areas and periods under study.

The bridges were divided into 4 groups by age to simplify data interpretation:

Group I : > 15 years
Group II : 10 - 15 years
Group III : 5 - 10 years
Group IV : < 5 years

2.2 Results of preliminary investigations

2.2.1 Carbonatation depths of drill cores

The carbonatation depth was determined using the phenolphthaleine test. Figure 3 plots the carbonatation depth for the four groups of concrete bridges.

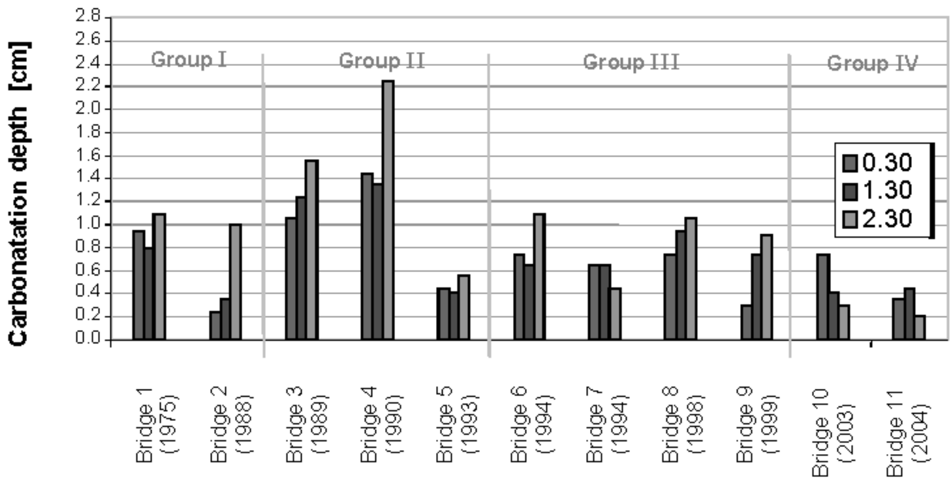

Figure 3: Carbonatation depth at several heights for the four groups of concrete bridges

The bar diagram shows that the maximum carbonatation depth is at 2.4 cm while the reinforcement covering of the bridges is on average 6 cm deep. Therefore, the corrosion risk induced by carbonatation is relatively low for all bridges. Even when considering an increase in the carbonatation rate, the remaining lifespan to be expected for these bridges is about 100 years.

2.2.2 Porosity measurements of drill cores

On one set of drill cores, porosity was determined from water absorption measurements and expressed as % w/w of the dried material. Measurements were carried out both on the entire drill core (results shown in Figure 4) as well as a function of the core depth by sawing it into successive disks (results shown in Figure 5).

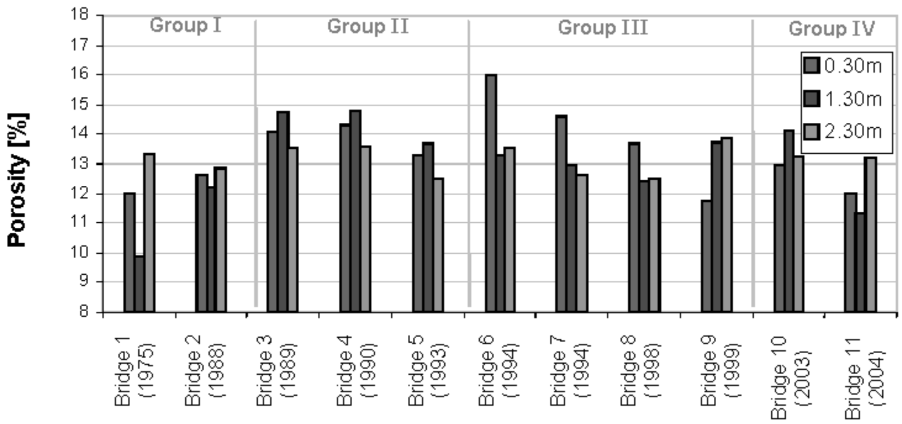

Figure 4: Porosity of drill cores from concrete at different heights for the four groups of bridges

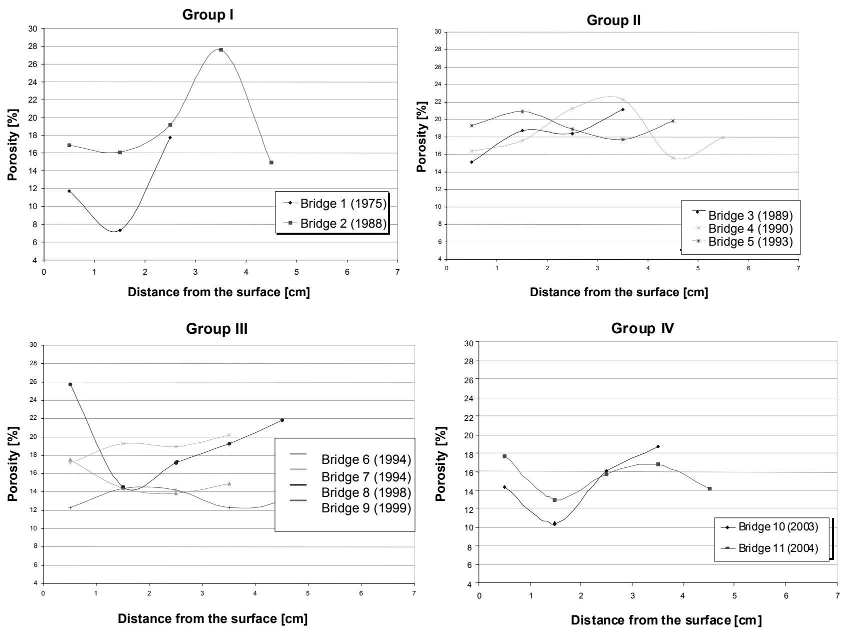

Figure 5: Porosity profiles as a function of core depth for the four groups of bridges.

The average porosity of the cores is approximately 13.1% (Fig. 4). For some bridges the porosity can reach 16 % while the lowest values are in the range of 10%. A direct relationship between porosity and the carbonatation depth could not be obtained. For almost all cores, the porosity increases towards the centre. The lower porosity at the surface could be due to carbonation leading to a densification of the microstructure.

2.2.3 Chloride profiles of the drill cores

On the second set of drill cores the chloride profiles were determined by ion chromatography**.** For that, 1 cm disk specimens were sawn from the core and then powdered using a disk swing mill. The powdered samples were suspended in water, filtered and the chloride concentration in the filtrate determined by ion chromatography (Metrohm, 761).

The chloride profiles are shown in Figures 6 and 7 where the position of the reinforcement is also illustrated. The data presented are the average of two drill cores per height for the indicated bridge.

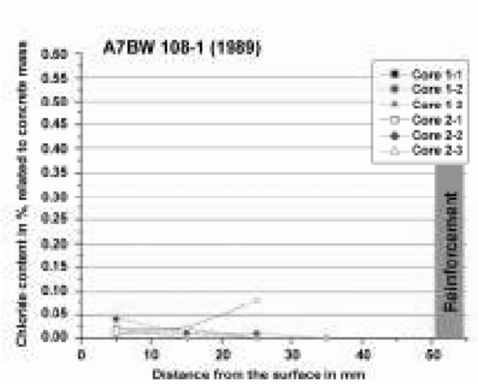

Figure 6: Chloride profile bridge 4 (1989)

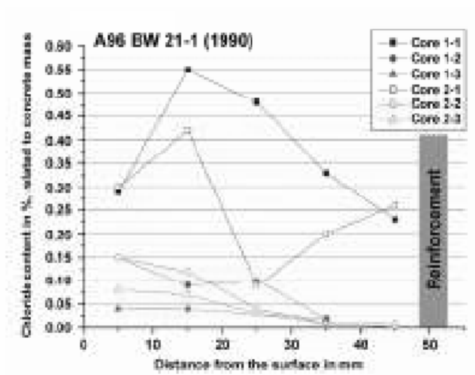

Figure 7: Chloride profile bridge 1 (1990)

As the reinforcement cover for all bridges is relatively thick, approx. 6 cm, the risk of reinforcement corrosion from chlorides can be estimated as relatively low for the majority of structures (bridge 4, Fig. 6). In individual cases, however, the chloride penetration depth already reaches the level of the reinforcement, as for example in bridge 1 for the core drilled at 0.30 m (see Fig.7).

2.2.4 Additional information

In order to carry out an evaluation of the results that would allow the development of a preventive protection approach for these concrete structures, additional information was required, such as the traffic level on the individual motorway sections related to the bridge pillars in question, as well as the average amount of de-icing salt used per winter.

2.3 Evaluation of the results

Due to the rather thick average concrete cover of the reinforcing steel, the condition of most bridge structures can be estimated as good with respect to the carbonatation problem.

On the other hand, the chloride burden on the structures is admittedly relatively high in individual cases (e.g. cores 1-1 and 2-1 from bridge 4 in Fig. 5) and could lead to corrosion of the reinforcement in the near future if no protection measures are taken. Therefore, damage by chloride-induced corrosion is the determining condition in this case.

If the chloride front reaches the reinforcement, classical renovation will prove necessary. If not, in-depth impregnation may be the solution. Thus, the decision for the required type of treatment only be made on the basis of the chloride profiles.

2.4 Execution

2.4.1 Selection of the application parameters

In parallel with the above research program, tests to evaluate the penetration depth of water repellent agents were carried out on the same cores. For this purpose, millimetre thick samples were milled successively from the treated specimens. The resulting powder was analysed with Fourier Transform Infrared spectroscopy (FT-IR) in KBr pellets [2].

On the basis of these results it was concluded that:

- The active agent in the water repellent product used for in-depth impregnation should be an iso-octyltriethoxysilane;
- The water repellent product should be a highly viscous paste;
- The active agent content should be 0.25 % w/w of dry concrete at 6-mm depth.

2.4.2 Execution of the in-depth impregnation with water repellents

In order to fulfil the requirements described above, a water repellent product capable of delivering an active agent amount of approximately 0.6-0.65 kg/m² for the lower parts (below 2 m) and of approx. 0.5 kg/m² for the higher parts (above 2 m) was specified.

For the application, the contractor selected a product that allowed the specified application quantity in a single application using a gel formulation. During the application, it became clear that additional protective measures were required. The high traffic density and the immediate proximity of vehicles to the central pillars originated wind vortices that lead to misting and hence loss of the impregnation product. For this, a special application procedure was developed by the contractor. Firstly, a PE-foil was placed around the column with a distance to the column surface of 2 m. After that, the water repellent product was sprayed on the column. Finally, the foil was removed and disposed. In this way pollution of the road could be avoided.

2.4.3 Quality control of the application

For the quality control of the application, the following steps were specified:

1st step: (contractor)

The deep impregnation was carried out in accordance to the manufacturer's instructions. Deviations from this method should only be carried out with advance agreement from the manufacturer. Relevant data (such as type of product, quantity applied per m² of impregnated area, weather conditions etc.) should be recorded.

2nd step: (customer)

The sampling of the impregnated surfaces required a number of drill cores to be taken. This number should be in relation to the size of treated surface. For central bridge pillars, it is advisable to drill four cores as was done in the preliminary investigations. The location of sample removal should be recorded.

3rd step: (external testing institute)

Evaluation of the active agent penetration depth and profiles in the samples treated with the water repellent product using FT-IR-spectroscopy.

In the context of the project, the Chair for Construction Chemistry at the University of Applied Science, Karlsruhe was contracted to analyse the cores from the impregnated surfaces.

4th step: (results of the procedure)

Quality control of the bridges showed that for 2 bridges the planner's specifications had not been met. These two bridges were re-impregnated. The defined requirements were met for the remaining bridges.

3 Conclusions

Concrete structures, particularly infrastructures such as bridges, often show damage after just a short period of service as a consequence of heavy environmental contamination, i.e., the use of chloride-containing de-icing salts in winter. This damage requires renovation associated with significant economic expenditure.

The results so far indicate that the number of renovations to be expected in future can be significantly reduced by using the strategy developed in the pilot project for preventive surface protection of existing reinforced concrete structures. This will be associated with significant technological, economic and ecological advantages.

The basis for this, however, is a detailed preliminary investigation of the reinforced concrete structural elements, so that preventive protection measures, such as in-depth impregnation with water repellents, can guarantee a durability of the reinforced concrete elements over years to come.

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