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Maintenance of Structures along National Highway N2 in Switzerland

Maintenance des ouvrages d'art de la route nationale N2 en Suisse

Erhaltung der Kunstbauten der Nationalstrasse N2 in der Schweiz

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SUMMARY

This paper describes the concept for the rehabilitation of structures on the Federal Highway N2. This highway, built between 1965 and 1980, is one of the most important road links across the Alps. Survey of conditions, assessment of conditions, forecasting of future behaviour, and corrective measures are discussed. A method of weighted parameters, with which the development of corrosion in reinforcement can be estimated, is described

RÉSUMÉ

L'article décrit le concept pour la remise en état des ouvrages d'art de la route nationale N2 du canton d'Uri, une des plus importantes transversales alpines. Celle-ci a été réalisée par étapes entre 1965 et 1980. Le recensement et l'évaluation de la condition des structures en béton, l'estimation du comportement futur et les mesures effectuées pour la remise en état sont présentés. En particulier une méthode est discutée qui permet une estimation de l'évolution de la corrosion de l'armature.

ZUSAMMENFASSUNG

Beschrieben wird das Instandsetzungskonzept der Kunstbauten der schweizerischen Nationalstrasse N2 im Kanton Uri, eine der wichtigsten alpendurchquerenden Verbindungen Europas, welche in den Jahren 1965 bis 1980 abschnittsweise erbaut wurde. Eingegangen wird auf die Zustandsaufnahmen der Betonstrukturen, die Zustandsbeurteilung, die Prognose über das zukünftige Verhalten und letztendlich auf Massnahmen der Instandsetzung. Insbesondere wird die Methode der Wirksumme beschrieben, welche u.a. erlaubt, den Verlauf der Bewehrungskorrosion abzuschätzen.

1. INTRODUCTION

The four-lane National Highway N2 in the Swiss canton of Uri, one of the most important routes across the Alps, was built and placed into service in several phases beginning in 1965 until its completion in 1980. The N2 is a true mountain freeway, located at elevations ranging from 430 to 1100 meters above sea level. The 70 km long highway includes numerous bridges and tunnels, the most significant of which is the 17 km long Gotthard tunnel at the southern end of the highway. After the Gotthard tunnel was opened in 1981, the N2 was used by 3.1 million vehicles per year. In 1994, this number has grown to 7 million vehicles per year.

Due to steadily increasing traffic and the action of deicing chemicals and airborne pollutants, many of the structures on the N2 are in need of rehabilitation. Much of this work is currently in progress. To minimize costs to the public arising from the closure of bridges and tunnels, rehabilitations must be designed to ensure that, apart from replacement of expendable components such as wearing surfaces and expansion joints, service life can be extended maintenance free for 50 years.

For concrete structures, this implies that structural components currently in rehabilitation must be capable of resisting the actions of chlorides and carbonation without major deterioration for the next 50 years. Effective rehabilitations are designed on the basis of a detailed survey and assessment of conditions, followed by a forecast of the expected behavior of the structure during the remainder of its service life. When shown to be necessary by such an investigation, appropriate corrective measures can then be implemented.

2. SURVEY OF CONDITIONS

Procedures for condition surveys must distinguish between homogeneous regions with no visible defects and regions with inhomogeneities such as cracks and actual visible defects (e.g. gravel pockets, moist areas, and spalls).

Condition surveys were often restricted to an inventory of inhomogeneities. The condition of reinforcing steel in the apparently intact homogeneous regions was not questioned. Nowadays, since service lives after rehabilitations of several decades are required, reliable information on the condition of reinforcing steel in these regions is required as a basis for the design of corrective measures. Loss of passive protection and incipient corrosion can take place even in homogeneous regions.

Surveys of inhomogeneities present no problems, since these normally occur in limited numbers. This is not the case, however, for the extensive homogeneous regions, which cannot normally be examined in their entirety. For example, the recovery of concrete cores should be kept to an absolute minimum. Questions regarding sample size and the significance of individual measurements can be answered on the basis of the principles of statistics. A combination of continuous measurements on a large sampling grid over the entire structure and discrete measurements on a smaller grid for selected concreting steps has proven itself to be effective.

The parameters to be measured should be decided in advance. The definition ot the parameters to be measured follows from the methods given in the following sections for assessment of conditions and forecasting. Non-destructive methods of measurements are preferable.

Due to restricted accessibility, condition surveys often require the use of expensive equipment capable of reaching under structures. Such equipment is often available only for limited periods of time. Traffic restrictions must also be kept to as short a time as possible. Condition surveys must therefore be planned in detail with regard to type, location, and number of parameters to be measured, to ensure that all of the required data can be collected in the available time.

3. ASSESSMENT OF CONDITIONS

The assessment of existing conditions serves as basis for decisions regarding possible immediate corrective measures. These decisions are made to ensure safety and serviceability.

Assessment of conditions is based on the interpretation of measurements made during the survey of conditions and can be carried out according to several different methods. Until now, such methods were limited to identifying areas with depth of carbonation greater than concrete cover or with chloride concentrations greater than 0.4% of cement measured by mass. It is now recognized that neither method allows reliable statements to be made regarding the effective condition of reinforcement.
Results of much greater reliability can be obtained through half-cell measurements and by application of the method of the weighted parameter sum, described in Section 5. Both can be used in homogeneous regions and for the assessment of cracks. They cannot be used, however, for the assessment of defects, especially for regions with large gravel pockets. This is because the method of the weighted parameter sum was developed only for use in homogeneous regions and at cracks. Moreover, the electrolytes required for half-cell measurements is normally lacking in gravel pockets. At the present time, defects such as these can only be assessed by individual exploratory openings.

4. FORECASTING

It is common nowadays to require bridges after rehabilitation to have a mainenance free service life of several decades. To enable decisions to be made regarding which corrective measures, if any, are necessary, a forecast of the future behavior of the structure is required. For structural components that are still intact, the loss of passive protection of reinforcement must be prevented. Concrete protection is an issue of considerable importance in this regard. For reinforcement already undergoing active corrosion, the further development of corrosion is of interest, particularly its speed and the associated loss of cross-section of steel. Only when these issues have been adequately addressed should appropriate corrective measures be implemented based on criteria of safety and serviceability.
Methods of forecasting include the $\sqrt{t}$ method, in which the increase of depth of carbonation is assumed to vary with the square root of time, and the previously mentioned method of weighted parameters. The former method predicts the time to loss of passive protection; the latter method predicts the time to actual onset of corrosion. These two events are not necessary simultaneous. For this reason, as shown in Section 5.2, only the method of weighted parameters gives reliable results. Neither method, however, allows any statement to be made regarding speed of corrosion or loss of cross-section. Relaible methods for predicting these phenomena do not yet exist.

5. METHOD OF WEIGHTED PARAMETERS

5.1 Description

The method of the sum of weighted parameters was developed within the framework of a research project carried out in 1990 and 1991 at the Federal Institute of Technology in Zurich under the direction of Professor Christian Menn [1,2]. Its primary objective was to develop a method for assessing the effect of cracking on corrosion of reinforcement in reinforced concrete and prestressed concrete structures. Since homogeneous regions needed also to be considered in order to determine whether or not a given crack could lead to corrosion, the range of application of the method could be readily expanded to homogeneous regions.
The method of weighted parameters is an empirical method based on measurements made on full-scale structures in service. Similar methods have often been used in other fields, for example to assess the risk of corrosion of stainless and other corrosion resistant steels based on weighted proportions of the elements in a given alloy.
Data used to develop the method were obtained from 39 structures aging from 15 to 90 years. The following quantities were measured at precisely defined locations: intensity of corrosion (depth of pitting), concrete cover, absorption of water in the covering layer in a 3 hour period, and chloride content at the level of reinforcement. In addition, the following quantities were measured

at cracks: width of crack, type of crack (normal crack or crack with penetration of water), and orientation of crack (transverse or parallel to reinforcement). Each of these parameters has a direct effect on corrosion. Over 6'600 measurements were made. Except for absorption of water and chloride content, each of the quantities could be measured using non-destructive methods.
Each parameter is weighted in accordance with Figure 1. The sum of the weights G_i is denoted S. In homogeneous regions, S is made up of the first four parameters. At cracks, all seven parameters are considered. The weighting functions were defined to optimize the correlation between the computed sum of weighted parameters and the measured intensity of corrosion (depth of pitting).

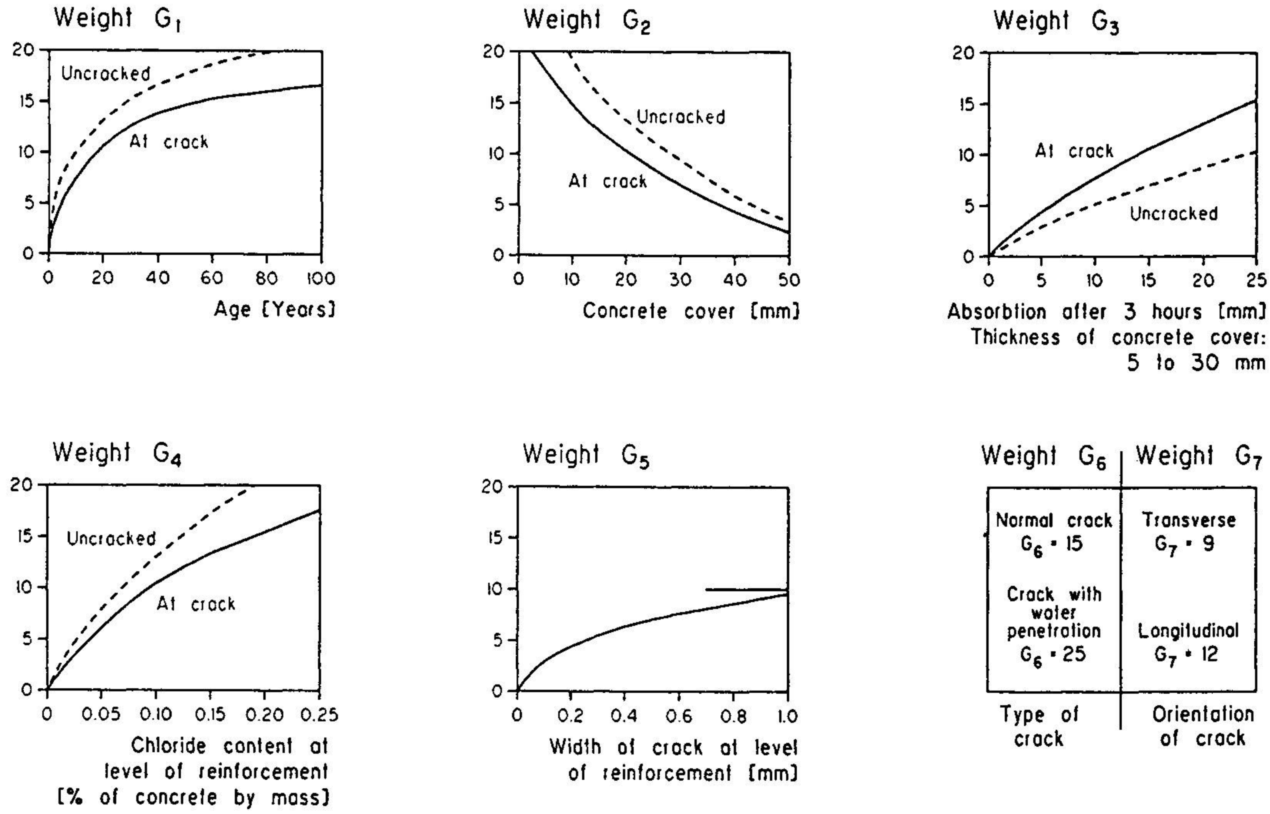

Fig. 1 Weighting functions

Based on these results, threshold values were defined for S in homogeneous regions and at cracks, beyond which corrosion of reinforcement could be deemed to begin. These threshold values are S=40 for uncracked homogeneous regions and S_R=65 at cracks.
It was observed that the effect of crack width on corrosion is minor. Of far greater importance is wether or not water can penetrate through cracks. Such cracks, which are recognizable by deposits on the surface of the concrete, are always associated with corrosion.
The method is simple to use and can be implemented deterministically or probabilistically. In the latter application, all parameters are expressed in terms of normally distributed random variables with average μ_i and standard deviation σ_i. The corresponding sums $S(\mu_S,\sigma_S)$ are also normally distributed. This probabilistic formulation makes possible global conclusions based on individual measurements.

Deterministic consideration of homogeneous regions

$$S = \sum_{i=1}^{4} G_i \geq 40$$

Probabilistic consideration of homogeneous regions

G_i (μ_i, σ_i) normally distributed random variables

$$\mathbf{S\ (\mu_S, \sigma_S) \geq 40}$$

$$\text{where } \mu_S = \sum_{i=1}^{4} \mu_i \quad \text{and} \quad \sigma_S = \left(\sum_{i=1}^{4} \sigma_i^2 \right)^{0.5}$$

$$\text{and} \quad G_1 = G_{age} \quad \text{with} \quad \mu_1 = G_1 \text{ and } \sigma_1 = 0$$

An important parameter affecting corrosion, which could only be indirectly dealt with in the previously mentioned research project, is microclimate. Application of the method of weighted parameters is therefore limited to structures exposed to normal atmospheric conditions. It is not valid for special ventilation conditions (e.g. in tunnels) or for extreme conditions (e.g. in storage facilities for salt). In special cases, however, microclimate can be dealt with by calibration of threshold values to results of half-cell measurements or by confirming threshold values in general based on half-cell measurements.

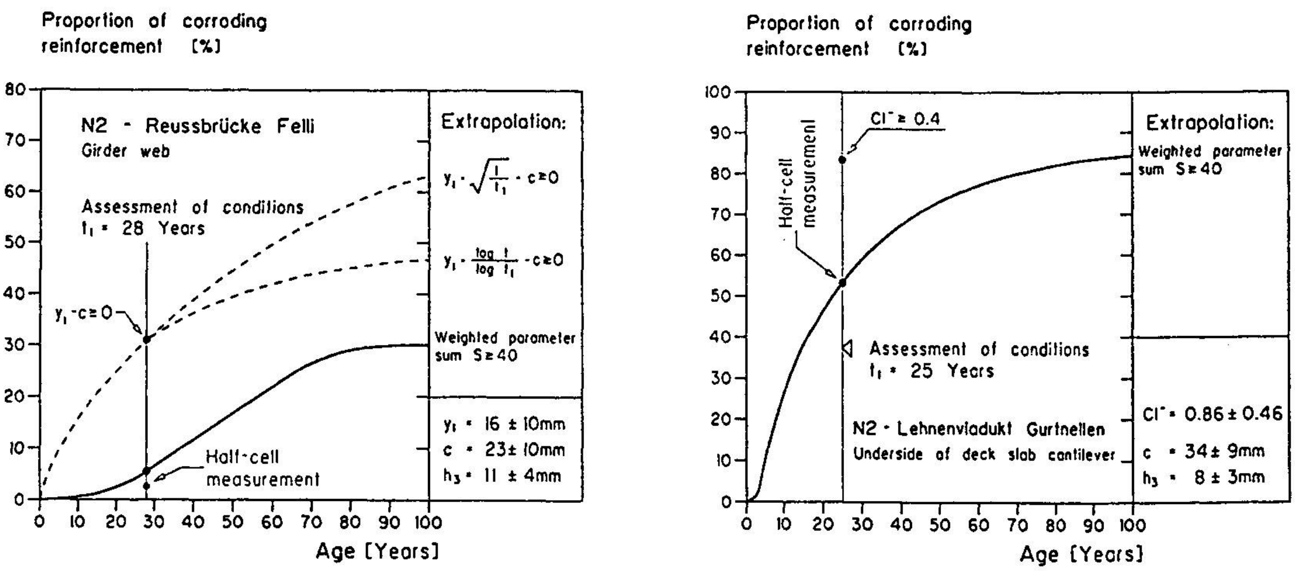

Fig. 2 Forecast of the development of corrosion of reinforcement: (a) Reussbrücke Felli, girder web; (b) Lehnenviadukt Gurtnellen, deck slab cantilever (y_1 = depth of carbonation, c = concrete cover, h_3 = water absorption, Cl^- = chloride content at the level of reinforcement (% of cement by mass). All parameters are normally distributed.)

5.2 Previous applications

The method of weighted parameters was applied for the first time to the assessment of conditions and forecast for the rehabilitation of two bridges on Highway N2 in the Swiss canton of Uri, Reussbrücke Felli and Lehnenviadukt Gurtnellen.
Figure 2a shows selected results for the left girder web of the southbound structure of Reussbrücke Felli, a T-girder bridge, which is exposed to carbonation. Also shown are predictions of carbonation computed by the $\sqrt{t}$ method and by the method of weighted parameters. At age 28 years, there is a good agreement between half-cell measurements and the method of weighted parameters in the estimate of the proportion of reinforcement experiencing corrosion. This proportion is roughly 4%, even though 30% of the reinforcement is located in carbonated regions. Extrapolation with the sum of weighted parameters yields a plausible prediction as opposed to the $\sqrt{t}$ method. Until the carbonation front has reached the steel with the thinnest covering layer, no corrosion is apparent. After roughly 80 years the proportion of corroding reinforcement reaches a limiting value. The proportion of corroding steel is grossly overestimated by the $\sqrt{t}$ method. Probabilistic use of the method of the sum of weights yields results that are valid for the entire surface of the web.
Figure 2b shows an interpretation of results for the underside of the right deck slab cantilever of the northbound structure of Lehnenviadukt Gurtnellen. Due to leaks in the longitudinal joint between the northbound and southbound structures, this region is severely attacked by chlorides. Assessment of conditions was carried at age 25 years. There is good agreement in the proportion of corroding reinforcement (roughly 55%) as predicted by the sum of weighted parameters and as observed through half-cell measurements. The limiting value of 0.4% of cement content by mass, however, gives an overly high value of 84%.
Based on forecasts made using the sum of weighted parameters, decisions regarding areas requiring rehabilitation and areas requiring only protection of the concrete could be made for both bridges, to ensure a maintenance free additional service life of 50 years. As result of positive experiences gained on these two bridges, the method of weighted parameters is likely to be used on other stages of rehabilitation of Highway N2.

6. CORRECTIVE MEASURES

Apart from immediate measures resulting from the assessment of conditions, specific corrective measures can be designed on the basis of the forecast. Corrective measures range from protection of the concrete itself (various coatings or cladding with ceramic components), actual rehabilitation measures (removal and replacement of concrete, or cathodic protection), or even replacement of the structure. Unfortunately, electrochemical rehabilitation procedures (chloride removal or restoration of alkalinity) and use of inhibitors are not yet ready for field applications. The great advantage of such applications relative to currently used removal and replacement of the covering layer of concrete is that the original structure is not altered. Replacement of large areas of concrete using shotcrete generally results in a weakening of the structure, in spite of the considerable progress that has been made in shotcreting technology. Intensive research in the area of corrosion inhibitors is currently underway in Switzerland.

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