PRELIMINARY ANALYSIS OF DURABILITY RELATED FIELD INSPECTION OF HIGHWAY BRIDGE NO. 57-039

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Abstract - The aim of this work is to summarize and analyze the data from in-situ measurements performed on reinforced concrete bridge No. 57-039 built in 1985 that is a part of the road network in the Czech Republic. The explorations were performed in order to evaluate the ability of the concrete to protect steel reinforcement from corrosion. To quantify this, the pH and the amount of water-soluble chlorides were evaluated on concrete samples drilled from the bridge at the age of 28 years. Based on these parameters, the ratio between the concentrations of Cl^- and OH^- that indicates the ability of concrete to protect reinforcement was calculated. Consecutively, all the data were statistically summarized and the correlations among them were found. This study also aims to pick up experiences for the new experimental measurements planned on the actual reinforced concrete bridges in our country.The analysis of the data from bridges under service is intended to help in the development and enhancement of the methodology for the assessment of durability of reinforced concrete structures.

Index Terms - Corrosion, Chloride Concentration, pH, Reinforced Concrete Bridge

I. INTRODUCTION

Steel embedded in a reinforced concrete structural member exposed to the combined effect of carbonation, chlorides ingress and mechanical load is prone to corrosion that threatens its durability and reduces the service life and bearing capacity. Typical constructions are the bridges in the Central European region where the aggressive substance comes from winter deicing. The current design of typical structural elements with respect to exposure conditions is executed by the deemed-to-satisfy rules utilizing EN 1992-1 and EN 206. This approach is limited mainly to concrete cover and water/cement ratio with vague assumption of an indicative lifespan; so without a possibility to control the relevant reliability level and structure design for a specified/required service life. Currently, the discussion and benchmarking on durability calculations based on these deemed-to-satisfy rules have been undertaken by the European technical committees and fib Commissions. It is intended to replace them with a performance-based design approach (PBD) in future standards [1]–[3].

An important part of preparation for PBD is analysis of the durability of existing structures under service in order to improve the authenticity of available numerical tools. Some of them are described e.g. in [4]–[11]. This paper is a part of research aiming on the improvement of the design and prediction methodology for the service life of reinforced concrete structures exposed to de-icing agents in the Central Europe. The data from regular inspections of highway bridges in the Czech Republic are analyzed herein with respect to the durability aspects and modelling. The chloride concentration profile and pH in various depths of concrete cover are of special interest here. These parameters are important for numerical modelling of corrosion initiation time. However, the relationship among chlorides concentration, pH and time to corrosion initiation is usually neglected even though it has a significant effect [10]. Thus, it is important to evaluate if available data allows for the enhancement of available models with e.g. surface chloride concentration and/or typical diffusion coefficient. The analysis of the bridge No. 57-039 [12] is primarily discussed below.

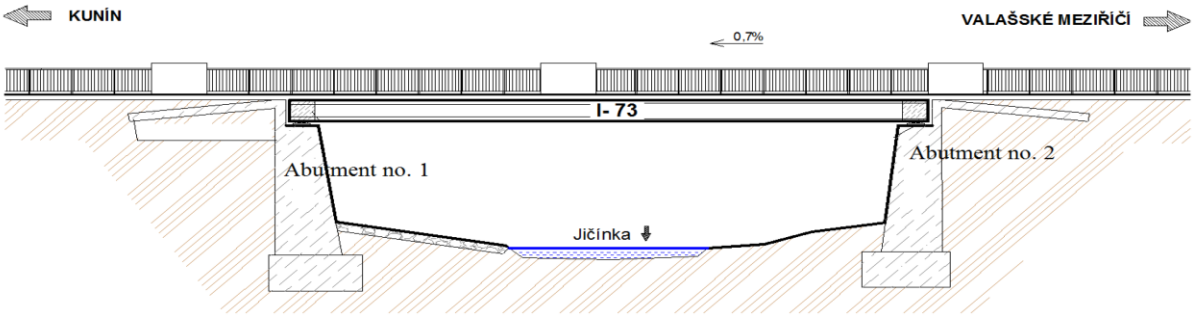


Figure 1: Longitudinal cross-section of the bridge No. 57-039 [12].

II. IN-SITU DATA AND LABORATORY ANALYSIS – BRIEF OVERVIEW

The subject of inspection is the highway bridge No. 57-039. It overpasses the local road No. 57 over the Jičínka river in Šenov town nearby Velký Jičín. The bridge was built in 1985 and the samples were extracted in the form of drilled cores at the age of 28 years. The longitudinal cross-section of the bridge is depicted in Fig. 1.

For chemical analysis of concrete, the different locations on the bridge were chosen. They are numbered from 1 to 13 and their description is in Fig. 2. In each location, the samples were taken from three different depths of 0–10, 10–20 and 20–30 mm from concrete surface. Subsequently, the value of pH and the amount of water-soluble chlorides were measured in water leaches in laboratory [12]. Based on these parameters, the ratio between the concentrations of Cl^- and OH^- that indicates the ability of concrete to protect reinforcement was calculated. Furthermore, the compressive strength of concrete was determined indirectly via Smidth hammer but is not the part of this paper.

III. SUMMARIZATION OF RESULTS

The values of pH and Cl^- and ratios $c(Cl^-)/c(OH^-)$ are graphically depicted in Fig. 2. The water soluble chlorides Cl^- were measured as mass percentage of concrete. Each parameter was assessed at 13 locations on the bridge and three different depths of concrete. Furthermore, the means and standard deviations were calculated. It is visible from the graphs that there is no significant dependence between the observed parameter and the depth of the concrete. Also, there is a relatively large scatter for all the measured parameters which is due to variety of locations.

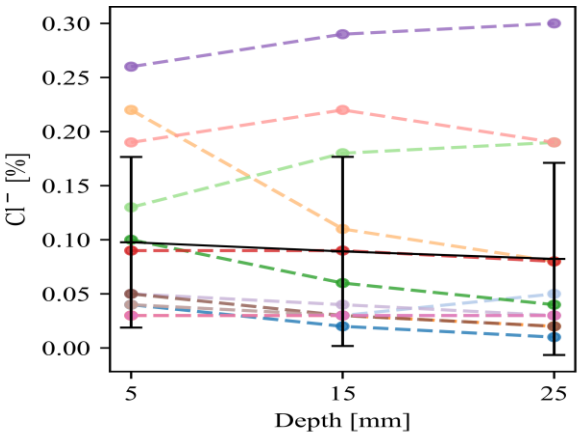
To predict the ability of concrete to protect the reinforcement from corrosion the numerical models are often utilized [4], [7]–[9], [11]. Those estimations are usually based on the calculation of so-called initiation time that is estimated either based on critical degree of carbonation or critical concentration of chlorides around the reinforcement. There are several models assuming both, the effect of carbonation as well as amount of chlorides. Many existing analytical models are implemented in a probabilistic software FReET-D [4]–[5].

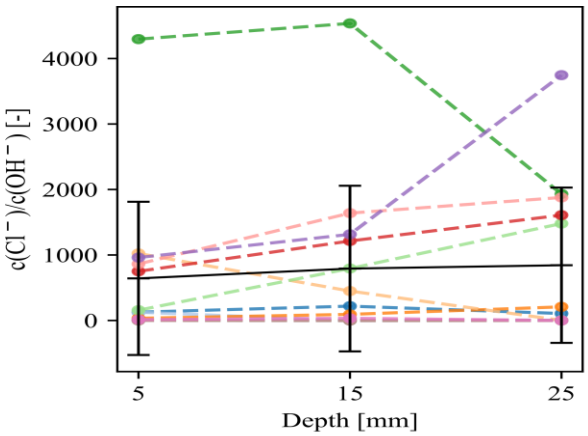
For the real structures, the ability of concrete to protect the reinforcement from corrosion is quantified by pH value that indicates the degree of carbonation and mainly from the ratio $c(Cl^-)/c(OH^-)$ that connects the effect of both, carbonation and chlorides concentration. Note, that the values higher to 0.6 indicates assumption of reinforcement corrosion [13]. To quantify the dependance among the observed parameters, the Spearman correlation was calculated and the results are given in Table I. Very small correlations of –0.377 and 0.476 are between pH and Cl^- and $c(Cl^-)/c(OH^-)$ and Cl^-, respectively. Correlation of –0.625 for pH and $c(Cl^-)/c(OH^-)$ indicates a little bit closer connection between these parameteres. Thus, it follows from the found correlations that the degree of carbonation and chloride concentration in concrete are independent variables and should not be assumed separately in numerical modelling. In the other words the effect of both should be taken into account.

Table I: Spearman correlations.

	pH	$\%Cl^-$	$c(Cl^-)/c(OH^-)$
pH	1	–0.377	–0.625
$\%Cl^-$	–0.377	1	0.476
$c(Cl^-)/c(OH^-)$	–0.625	0.476	1

The data from the other bridges in the Czech Republic are available too. Some of them were also processed by the authors of this paper. In Figs. 3–5 see the comparison for five different reinforced concrete bridges under service. The age on the horizontal axis is the age of the bridge in time of in-situ observations. The above described bridge is also included in these graphs (28 years old one).





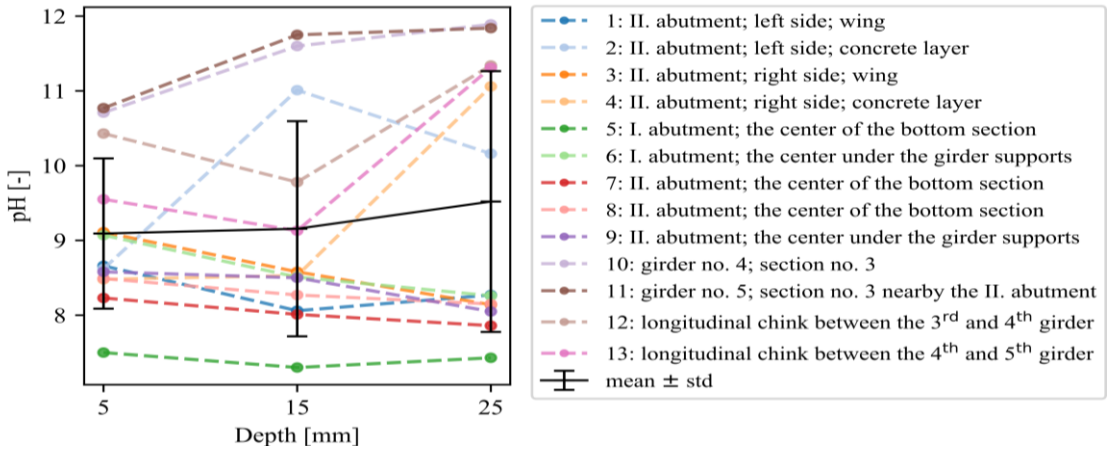


Figure 2: Observed parameters vs. depth of concrete for 13 locations on the bridge.

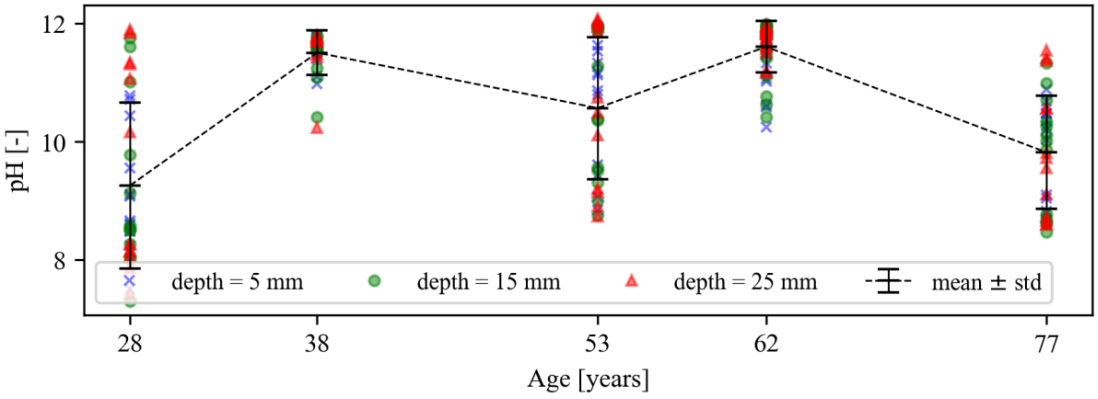


Figure 3: pH vs. age in time of in-situ measurements for five reinforced concrete bridges.

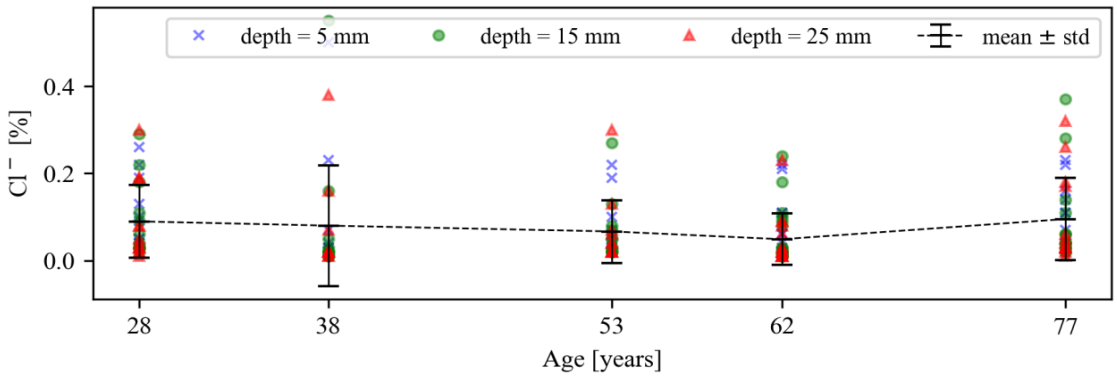


Figure 4: Chloride concentrations vs. age in time of in-situ measurements for five reinforced concrete bridges.

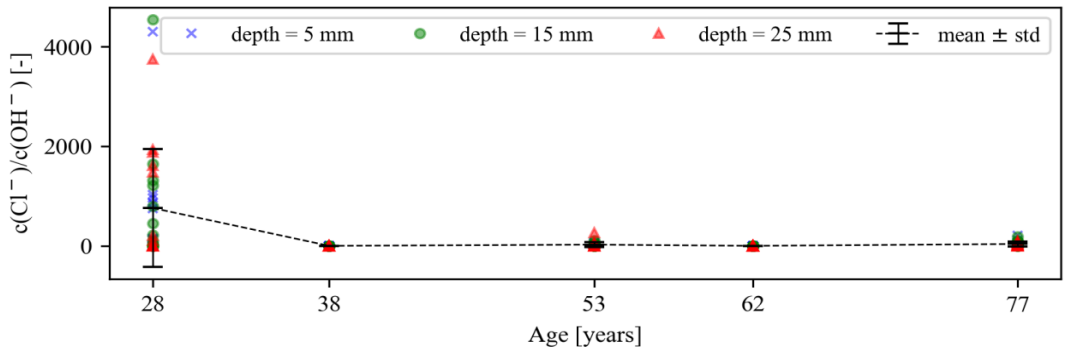


Figure 5: Ratio c(Cl–)/c(OH–) vs. age in time of in-situ measurements for five reinforced concrete bridges.

It can be seen from Figs. 3 and 4 that there is no significant relationship between bridge age and pH and Cl^- ratio, respectively. Regarding the results of the $c(Cl^-)/c(OH^-)$ ratio in Fig. 5, the youngest bridge is the most vulnerable to corrosion. The $c(Cl^-)/c(OH^-)$ ratio is much higher than the limiting value of 0.6. The difference between the result for the respective bridge and the other bridges deserves further attention.

ACKNOWLEDGEMENTS

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CONCLUSIONS

Presented is the analysis of field inspection of reinforced concrete bridge under service. The explorations were performed in order to evaluate the ability of the concrete to protect steel reinforcement from corrosion. For this purpose, the pH and the amount of water-soluble chlorides were measured and the ratio between the concentrations of Cl^- and OH^- was calculated.

The detailed analysis of the available data from bridges under service still continues. However, till now it is apparent that the amount of chlorides evaluated per mass of concrete is not proportional to the risk of corrosion initiation and propagation. Thus, the effect of chloride concentration nearby reinforcement on the initiation time should not be assumed separately and as the only parameter in numerical modelling. In other words, the effect of both, carbonation and chloride ingress should be taken into account.

From the point of view of numerical modelling and predictions of concrete carbonation, chloride ingress and initiation and propagation of corrosion we need more parameters to derive from the measurements on the structure. Such as diffusion coefficient, chloride surface concentration, etc.

As a further step to complement, the available data from bridges under service will be accompanied by the data on concrete samples exposed to the chloride exposure at a real traffic zone. Seasonal variation of chloride loading will be studied via analysis of chloride deposition using analysis of chloride content on deposition plates or analogic device. Also, small concrete cubes are planned to be exposed simultaneously to a similar environment in order to study the correlation between the measured deposition and chloride penetration.

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