# MECHANICAL AND DURABILITY PARAMETERS OF THE CONCRETE BRIDGES UNDER SERVICE IN THE CZECH REPUBLIC

*Petr LEHNER, Marie HORŇÁKOVÁ, Petr KONEČNÝ*

Department of Structural Mechanics, Faculty of Civil Engineering, VSB – Technical University of Ostrava, Ludvíka Podéště 1875/17, 708 00 Ostrava-Poruba, Czech Republic

petr.lehner@vsb.cz, marie.hornakova@vsb.cz, petr.konecny@vsb.cz

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***Abstract.*** *RC bridges are the typical structures exposed to the combined effect of carbonation, chloride ingress, and mechanical load. Due to this, the structures are susceptible to corrosion, which influences the load-carrying capacity and safety. An important part of the preparation for performance-based design is an analysis of the durability of existing structures to improve the reliability of available numerical tools. In this study, the correlations between compressive strength, chloride content, pH, exposure time, and risk factor were analysed. All were evaluated based on the in-situ measurements performed on regular inspections of 14 motorway bridges under service in the Czech Republic.*

## Keywords

***Compressive strength, field inspection, reinforced concrete bridges, chloride, carbonation.***

## 1. Introduction

In recent decades, there has been a significant interest in evaluating the service life of concrete bridges in the Czech Republic and also other countries. Bridges are the typical structures exposed and affected by the combined effects of the environment (especially carbonation and chloride ingress) and mechanical damage. These phenomena pose a significant threat to concrete and reinforcement, which is prone to corrosion. Corrosion of the reinforcement leads to a reduction of load-bearing capacity and durability, and therefore the service life of the structure is usually endangered.

It is therefore desirable to gain knowledge about the potential threats to our infrastructure and to provide and educate engineers on how to deal with such environmental or human activities. Also, it is necessary to focus on the application of the best practices, inspections, and maintenance of infrastructure and to support research in the field of numerical modelling and predictive skills. To mitigate the threats, it is necessary to identify and describe them with sufficient accuracy. Structural properties are related to the type of concrete, with environmental parameters, or with a load-bearing capacity, and all these properties must be taken in to account [1–5].

Chloride ions from the external environment can penetrate through the structure of concrete. After penetrating close enough to the reinforcing steel level, they support the conditions for the initiation of corrosion and the course of corrosion itself. Due to this process, the concrete structures in aggressive chloride environments are sensitive to corrosion, which can negatively influence load-carrying capacity and therefore constructions safety. The current design is executed by the rules prescribed by Eurocode 2 [6] and EN 206 [7].

However, in terms of estimation of service life, current engineering information is not enough to provide the number of years with the expected precision. Currently, European technical committees and fib Commissions discuss the durability calculations. The intention is to replace them in future performance-based design (PBD) approach standards [8–11].

Therefore, it is important to learn from the past. It is essential to apply the best practices, inspections, and maintenance of infrastructure. It is generally assumed that the structural properties are related to the type of concrete [1, 3, 12] and type of reinforcement [4, 5, 13].

An important part of the preparation for PBD is an analysis of the durability of existing structures under service to improve the authenticity of available numerical tools. Some of them are described for instance in [14–21]. Bridge inspections are regularly carried out and data are available. However, highway agencies or industries are not able to process and analyse data and draw some new and important links and conclusions that could help improve the design of structures in terms of durability. The evaluation of the obtained data is necessary since realistic durability estimation helps to optimize maintenance strategy for reinforced concrete infrastructure [22].

One possible way of reliability assessment is the connection of corrosion initiation modelling [21, 23] and internal forces computation for the analysis of minimal required steel reinforcement cross-sectional area via the bending limit equilibrium equation. For this process, it is necessary to know primarily the real values of compressive strength, among other parameters. The subject of analysis is 14 motorway bridges [24, 25]. The results of the field data are based on a regular inspection with correctly selected points. The correlation between compressive strength, chloride content, pH, estimated exposure time and type of bridges were analysed.

## 2. Methodology and results

### 2.1. In-situ measurements

During regular inspections of the bridges in operation, the concrete samples were drilled from structures. Bridges are in the portfolio of Road and Motorway Directorate of the Czech Republic. The basic information about bridges is shown in Table 1, where is described the number, type, the year when it was put into operation, the year when the inspection was carried out and the exposure time.

**Tab. 1:** Summary of the basic information about the bridges.

| No. | Bridge | Over | Place | Build | Inspection | Exposure time [yrs] |
|---|---|---|---|---|---|---|
| 1 | 54-040 | Water | Slavkov | 1937 | 2014 | 77 |
| 2 | 55I-026a | Road | Otrokovice | 1976 | 2014 | 38 |
| 3 | 55I-030 | Water | Otrokovice | 1953 | 2015 | 62 |
| 4 | 55-033 | Water | Napajedla | 1963 | 2016 | 53 |
| 5 | 57-039 | Water | Nový Jičín | 1985 | 2013 | 28 |
| 6 | 351-026 | Road and Raillway | Třebíč | 1995 | 2018 | 23 |
| 7 | 70-007 | Water | Sudoměřice | 1964 | 2014 | 50 |
| 8 | 50-003.1 | Road | Brno | 1980 | 2018 | 38 |
| 9 | 50-003.2 | Road | Brno | 1980 | 2018 | 38 |
| 10 | D1-248 | Road | Motorway D1 (Velatice) | 1983 | 2014 | 31 |
| 11 | D2-054 | Raillway | Motorway D2 (Lanžhot) | 1980 | 2009 | 29 |
| 12 | D2-046 | Road and Raillway | Motorway D2 (Břeclav) | 1980 | 2012 | 32 |
| 13 | D2-002 | Water | Motorway D2 (Svitava) | 1978 | 2015 | 37 |
| 14 | D1-250 | Road | Motorway D1 (Rohlenka) | 1983 | 2015 | 32 |

### 2.2. Mechanical parameters

The sclerometer method was used on the analysed bridges to determine the strength of the basic load-bearing elements using a Schmidt hardness tester type N according to ČSN 73 1373 in combination with a compressive strength test on the core boreholes.

The obtained values were used to classify the strength class of concrete and to determine the value of cubic strength. All cubic strengths were statistically evaluated by calculating the mean values. Figure 1 shows the mean values for individual bridges.

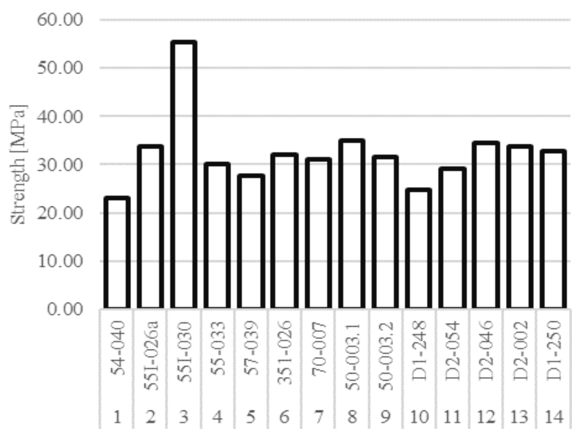


**Fig. 1:** Average values of compressive strength for individual bridges.

### 2.3. Durability parameters

The samples for durability testing were taken in three depths from the concrete surface (0–10, 10–20 and 20–30 mm). Drilled concrete samples were analysed in the laboratory for pH and chloride concentration [26]. An amount of 10 g was mixed with 150 ml of $H_2O$ to obtain an aqueous extract. This fusion was used to further test the pH and water-soluble chlorides. A pH meter with a glass combination electrode was used to measure pH. Figure 2 shows the mean values of pH for individual bridges.

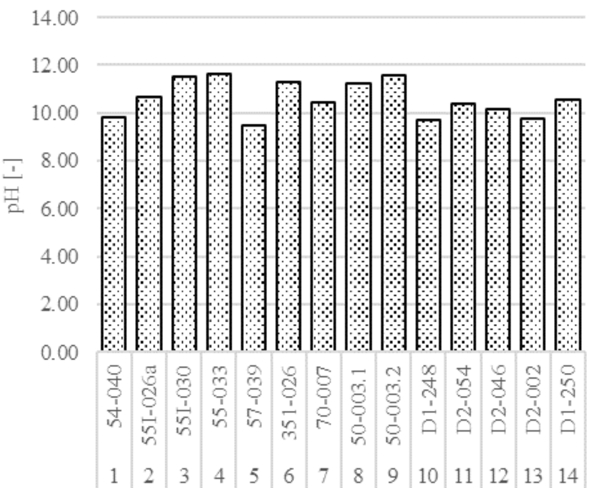


**Fig. 2:** Average values of the potential of hydrogen (pH) for individual bridges.

The amount of water-soluble chlorides was measured by volumetric analysis / titration of a mercuric nitrate solution using a diphenylcarbazone indicator from yellow to purple [26]. Figure 3 shows the mean values of concentrations of Cl– for individual bridges. It was reported in ACI 201.2R-01 that the chloride threshold for the corrosion initiation should be 0.1 – 0.2 [% by mass].

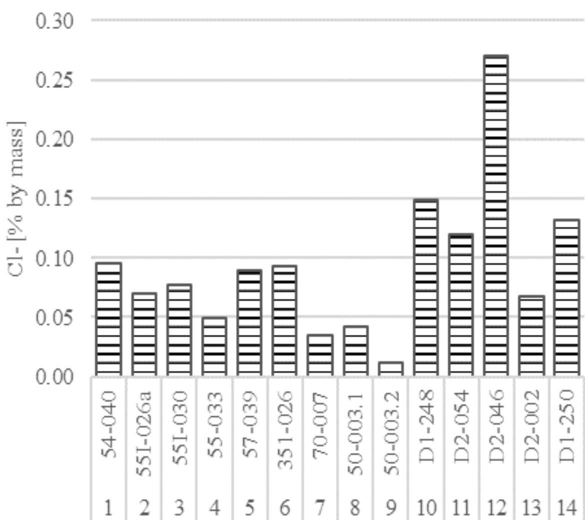


**Fig. 3:** Average values of concentrations of $Cl^-$ for individual bridges.

Based on the measured parameters, the corrosion risk is expressed as the ratio between the concentrations of $Cl^-$ and $OH^-$, which indicates the ability of the concrete to protect the reinforcement. The potential risk of corrosion increases with the ratio of chloride and hydroxide ions; the critical value of $c(Cl^-)/c(OH^-)$ was determined as 0.6 [27]. Figure 4 shows the mean values of potential risk in the log-scale for individual bridges.

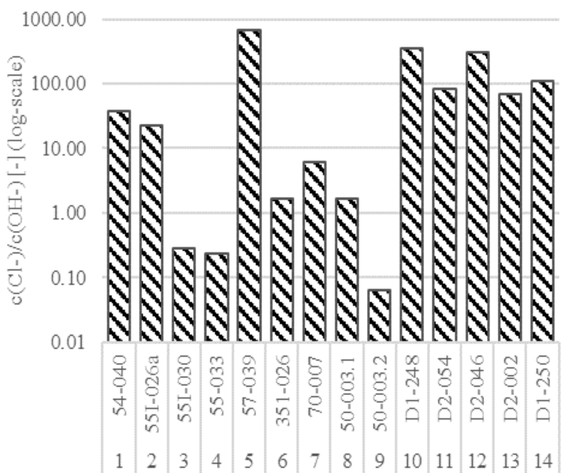


**Fig. 4:** Average values of the ratio of chloride and hydroxide ions $c(Cl^-)/c(OH^-)$ for individual bridges.

## 3. Correlation of results

A simple correlation was made between all the aforementioned parameters. Two groups were created - for correlation with exposure time, and for correlation with compressive strength.

### 3.1. Exposure time

First, Figure 5 shows a correlation between the exposure time and compressive strength. It is interesting that the average compressive strength on the load-bearing parts of bridges is higher in the case of one of the oldest bridges.

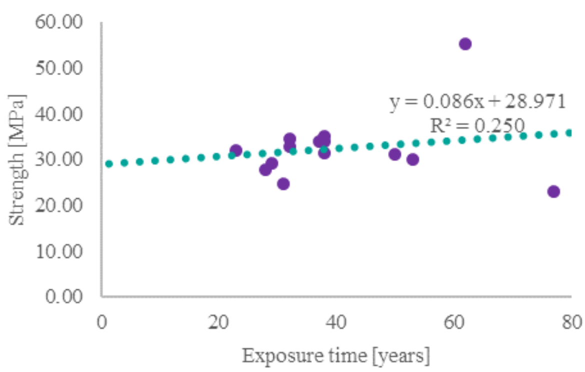


**Fig. 5:** Correlation between exposure time and compressive strength.

The second correlation is between the exposure time and the average potential of hydrogen (pH) and it is shown in Figure 6.

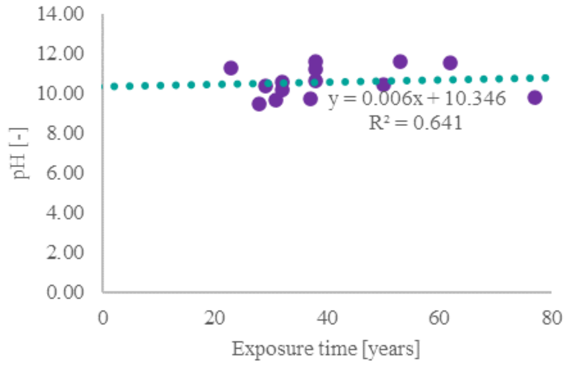


**Fig. 6:** Correlation between exposure time and pH.

The next correlation, see Figure 7, is between the exposure time and the average concentrations of $Cl^-$. Of course, the results must be taken with a perspective because other factors are not considered (e.g., sample location, presence of carbonation). If the chloride value of 0.1 is taken as the limit, it is exceeded in all thirty-year-old bridges.

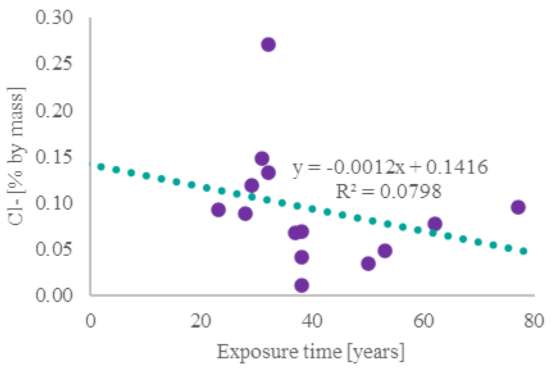


**Fig. 7:** Correlation between exposure time and concentrations of $Cl^-$.

The last correlation in this group is between the exposure time and the ratio value of chloride and hydroxide ions in the log scale (see Figure 8), which expresses corrosion risks when the value is higher than 0.6. This value is not exceeded for only three bridges. No correlation is observed here.

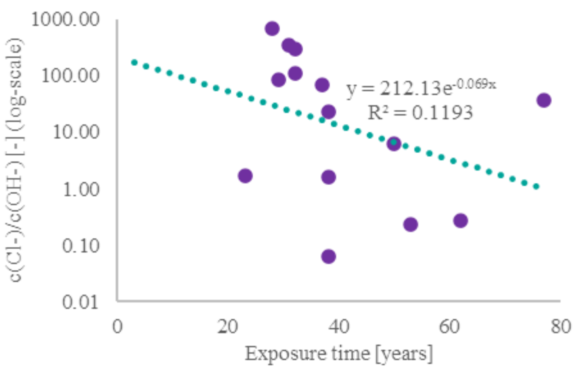


**Fig. 8:** Correlation between exposure time and the ratio of chloride and hydroxide ions $c(Cl^-)/c(OH^-)$.

### 3.2. Compressive strength

The second group is formed by the correlation between compressive strength and other parameters. The first example shows a dependence of pH value on strength, where the correlation curve is less constant than the correlation between exposure time and pH. (see Figure 9).

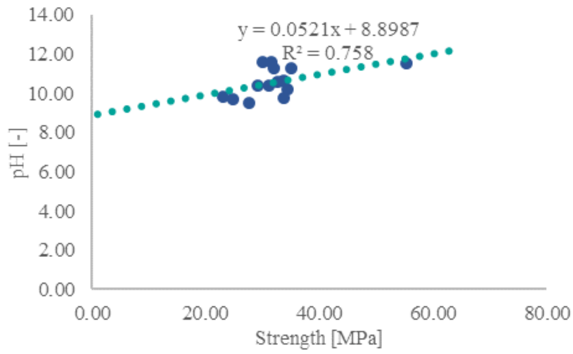


**Fig. 9:** Correlation between compressive strength and pH.

Next, in Figure 10, we can see a correlation with the value of concentrations of $Cl^-$. It could be assumed, that the chloride penetration would be higher in case of lower compressive strength. However, it needs to be noted, that the correlation does not consider the location of the taken sample.

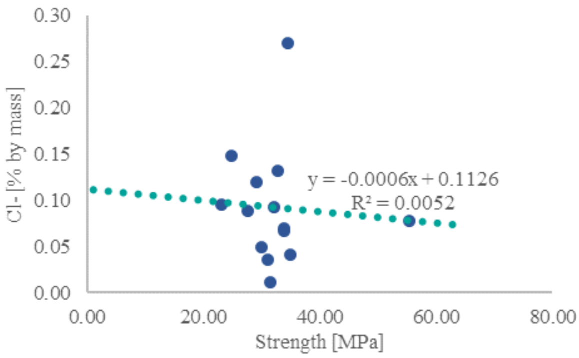


**Fig. 10:** Correlation between compressive strength and concentr. of $Cl^-$.

Finally, Figure 11 correlates with the risk factor, for which we can see that the value of 0.6 was not exceeded in the cases of two bridges with strengths around 30 MPa and one with a strength of 55 MPa.

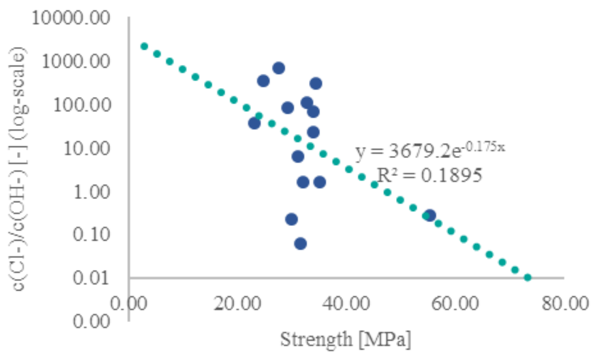


**Fig. 11:** Correlation between compressive strength and the ratio of chloride and hydroxide ions $c(Cl^-)/c(OH^-)$.

## 4. Conclusion

A field data from the 14 bridges under service are analysed in the article. The data taken over from the portfolio of Road and Motorway Directorate of the Czech Republic contains information about compressive strength, chloride content, pH, estimated exposure time, and type of the bridge. Furthermore, the corrosion risk expressed as the ratio between the concentrations of $Cl^-$ and $OH^-$, which indicates the ability of the concrete to protect the reinforcement, was determined.

The process of correlation of measured parameters was divided into two groups; firstly, the correlation was discussed in the case of exposure time, and secondly, the correlation in the case of compressive strength was shown. The surprisingly high risk of corrosion is observed in the case of the youngest bridges built in 1985 and 1983.

Despite the small amount of data, it is possible to point to several interesting trends. For example, at higher exposure times, there is a tendency for lower concentrations of $Cl^-$ and lower ratio of chloride and hydroxide ions $c(Cl^-)/c(OH^-)$. The same trend can be observed with increasing strength, where even in this case the concentration of $Cl^-$ and chloride and hydroxide ratio are lower. In terms of causality, it is possible to observe a certain relationship in exposure time and pH, in the case between strength and pH.

The presented article can therefore be understood as an example of the process of finding possible causality of various parameters, which must be demonstrated on a larger amount of data from the field and also with consideration of the location of the samples. For future inspections, it would be recommended to obtain more data from every location on the bridge for better evaluation in groups based on the part of the construction.

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