Experimental Research of Corrosion Effects on Steel Bridges

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Abstract. Bridges are significant elements of the transport infrastructure, so they should be in operation throughout the whole design life. Therefore, it is necessary to know the main causes of damages and failures of the bridges. The corrosion of structural steel caused by atmospheric influences as well as the bridge exploitation cause a cross-sectional reduction of structural elements and, consequently, a decrease of the resistance of steel bridge members. The article deals with corrosion and its impact on steel bridge elements in order to use this data for developing actual corrosion model appropriate for design of structures on durability.

1. Introduction

Durability is important parameter for the design of the engineering constructions, so it is necessary to consider degradation processes during their lifetime. Environment, where structures is placed, is one of the most common reasons of failures and damages. Impact of aggressive atmosphere like corrosion causes huge investment to repairs or reconstructions [1], therefore it is important to properly classify it. Corrosion losses have influence on the load-carrying capacity of structural elements and consequently on overall reliability of structure.

The category of corrosion aggressiveness determined using corrosion losses is specified in the standard STN EN ISO 9223 [2]. Measurements of the corrosion rate using standard test samples is one of two standard approaches and reflects the specific environmental situation of year of exposition. On the other hand, data of pollution like Cl\(^{-}\), SO\(_2\), O\(_3\), PM10, pH, average temperature, rainfall, relative humidity obtained from Slovak Hydrometeorological Institute can be used to determine corrosion rate by dose-response function [3,4] and to create corrosion map for the carbon steel.

2. Measurement in Žilina region

The bridge structures are affected by environmental conditions in which they are located. The environmental loads cause the degradation of structural steel and cross-sectional reduction. Bridges as a part of transportation infrastructure have to deal with corrosion impact caused by aggressive atmosphere, but also with effects of traffic and maintenance of the roads during winter. Results of this two mentioned impacts on steel bridges [5,6] in Žilina region are shown in Figure 1, where standard samples from structural steel were used for measurement of corrosion aggressiveness of environment.
However, those data are complex and don’t show which individual factor have the greater impact on structural members. Reference stations shown in Figure 2 were used to separate effects of winter maintenance, where samples made of structural steel during one-year exposure were dealing only with corrosion aggressiveness of atmosphere. Stations were placed all around Žilina region in six towns, where bridges were also monitored for easier comparison. Structural steel samples with dimensions of 150x100x3 mm were placed on them at the position of the angle of 45°.

After the first year of exposure, the samples were cleaned and weighed and difference compared to the original samples represented a weight loss which was converted into corrosion rate $r_{corr}$ expressed in microns per year. Statistically evaluated data from all station are presented in Table 1, where $m$ represents the mean value and $s$ is the standard deviation.
Table 1. Results after the first year of exposition at reference stations

| Location          | Weight difference [g] | Weight loss [g/m²/year] |
|-------------------|------------------------|-------------------------|
| Dolný Kubín (DK)  | 1.053                  | 32.591                  |
| Liptovský Mikuláš (LM) | 0.470                | 14.581                  |
| Martin (MT)       | 0.960                  | 30.718                  |
| Byča (BY)         | 0.987                  | 31.492                  |
| Žilina (ZA)       | 1.950                  | 57.755                  |
| Čadca (CA)        | 1.545                  | 50.881                  |

Results of weight losses of samples from the reference stations show a very small standard deviation. Comparison after the first year of exposure to the weight losses of samples placed on bridges presented in Figure 3 display many different outcomes. In some towns, the weight losses were bigger as on the bridges, but in some towns it is opposite. Reason of this uncertainties is location of samples on the bridges (outside or inside of girders), while all samples at reference stations were exposed to aggressive environment without any protection.

![Figure 3. Comparison of results of the samples weight losses from bridges and from reference stations](image)

The impact of the repeated cleaning of test samples to the corrosion velocity was other part of the research. Corrosion as an electrochemical or chemical process creates during the initial phase the layer of rust on the surface of steel member, which slowdown the thickness losses $r_{corr}$. Comparison after two years of the exposure is shown in Figure 4, where the first set of samples was cleaned twice (after the first and the second year) and the second set was cleaned only once after two years. Diagram displays obtained results that the repeated cleaning of steel structural members has negative impact on weight losses, or in the other words on the cross-sectional reduction.
3. Measurement in Silesian region

This region was selected because of the concentration of air pollutants like $\text{SO}_2$, $\text{NO}$, $\text{Cl}^-$, PM10 is the highest in comparison to other Polish regions due to high rate of the urbanization. Research at Poland has some differences compared to Slovakia one. In the Silesian region, the structural steel test samples with dimensions of $150 \times 100 \times 2$ mm were placed in two ways, at the bottom flanges and at the webs of the main girders starting the data collection one year before Žilina.

The samples from 11 bridges over different obstacles in three types of winter road maintenance WRM I – WRM III were weighed and cleaned from corrosion products and secondly weighed. Using this approach, the weight of the corrosion product and the overall mass loss of test samples due the corrosion after the second year of exposure was obtained as it is shown in Table 2.

![Image](image_url)

**Figure 4.** Impact of repeated cleaning of samples during two years

| Type of WRM | Place of installation          | Weight loss [g/m²/year] |
|-------------|--------------------------------|-------------------------|
| WRM I       | web of I-beam                  | 100.194                 |
|             | bottom flange of I-beam        | 132.167                 |
| WRM II      | web of I-beam                  | 72.963                  |
|             | bottom flange of I-beam        | 104.889                 |
| WRM III     | web of I-beam                  | 85.704                  |
|             | bottom flange of I-beam        | 150.593                 |

From the results and the enormous standard deviation is especially evident that even the bridges that are in the same type of WRM have different weight losses after exposure in aggressive environment. Structural design of the bridge and type of overcoming obstacle has the greater impact on the corrosion of steel samples than type of the winter road maintenance in which the bridge is located. Comparison of results presented in Figure 5 from the second year of exposure to outcomes from the first year [7] show the increasing of weight losses during time of exposition.
Continuously with the research of the impact of chloride ions due to salt sprays used during winter, the influence of atmospheric aggressiveness was also examined. Poraj, Katowice and Ustroń are three selected districts in the Silesian region, where the reference stations were placed. Similarly, to the bridges structural steel samples, they have the horizontal and the vertical location. After the second year, the samples were cleaned and weighted and the data was statistically processed in Table 3.

**Table 3.** Results after the second year of exposition at reference stations

| Location   | Weight loss [g/m²/year] |
|------------|-------------------------|
|            | m     | s      |
| Poraj      | 162.944 | 3.807  |
| Katowice   | 92.389  | 16.740 |
| Ustroń     | 104.00  | 32.238 |

Among results of each districts are huge differences after the second year. Poraj has the biggest degradations and similar results for horizontal and vertical location. Katowice surprisingly shows the greater values at vertical location, only Ustroń reports expected results showing the bigger weight losses at the bottom flanges. Results from all three districts were compared to results from the first year (see Figure 6) and they displayed the increased values of corrosion aggressiveness at reference stations.

**Figure 6.** Comparison of results from the reference stations after the first and the second year
4. Conclusions
The contribution represents partial output of the research of corrosion impact to structural steel members due to aggressive atmosphere and the winter road maintenance. Corrosion has a stochastic character, which was confirmed by the results. Values from the reference stations in Žilina region were very similar with only little differences between towns. It was caused by the atmospheric condition (average temperature, relative humidity, rainfall). Higher corrosion aggressiveness on the bridges was caused by CL− used during winter road maintenance, although some samples were protected against environment by location on the inside of a bridge structure. Continuity of research in Poland during the second year brought the increased values of weight losses on bridges, while the significant differences of results among horizontal and vertical location of samples were recognised. Reference stations in the Silesian region also showed greater losses of structural steel after the second year, but as it was expected, the losses were less than the ones on the bridges. Research of aggressive effects of environment on steel bridges is about to continue in next years. All this collected data will be used to develop the appropriate corrosion model for the carbon steel.

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