Effect of Environmental Actions on Engineering Constructions

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Abstract. Durability is a very important parameter for design of the engineering constructions because of influence due to degradation processes in the form of structural steel and reinforcement corrosion caused by the environmental actions within structure lifetime. Those degradation processes are affecting the cross-sectional and structural member resistance and deformation parameters of structure. The paper is focused on the study of the corrosion characteristics of the steel bearing structures of engineering constructions to know corrosion effects on the structural steel and to develop the methodology of design for durability.

1 Introduction

Increased activities of the environmental actions become the worldwide problem significantly influencing serviceability of the engineering constructions whose maintenance and repairs or reconstructions require large funds [1, 2]. Whereas the environmental actions cause the massive degradation of engineering constructions, it is needed to predict in advance their influence on reliability and mainly durability of structures. Standard [3] specifies two approaches to classification of the corrosion aggressiveness of the atmospheric environment. The first one is based on the measurements of the corrosion velocity using standard test samples. The second approach processes information related to the environment obtained from measurements of air pollution. Both methods have some uncertainty and limitations. The degree of corrosion aggressiveness determined using corrosion losses measured within one year reflects the specific environmental situation of this year of exposition. On the other hand, determination of degree of corrosion aggressiveness by means of dose-response function reflects statistical uncertainty of the given function. But the determination based on informative approach using comparison of local conditions describing typical atmospheric environment could give incorrect interpretation.

Measurements of environment aggressiveness run already a long-time in the World and also in Slovakia. The information obtained is processed into so-called corrosion maps that indicate environmental actions on building objects in terms of increase of corrosion losses. Similarly, in Slovakia, the map was gradually developed in frame of projects of the

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Research Centre UNIZA [4]. Now the research activities continue in the frame of SK-PL project [5] in cooperation with the Polish partner - University of Czestochowa, Faculty of Civil Engineering. The main goal of the project is to obtain information related to performing environmental actions in the term of corrosion effects on bridge structural members using in-situ measurements and also those performed in laboratory conditions. Based on the obtained information, the time-dependent corrosion models for structural steel could be developed to define cross-sectional and member time-dependent resistance. The obtained information should be implemented in the concept of the bridge members design for durability respecting the limit state principles using form of partial safety factor method.

2 Experimental research in Poland

Firstly, the analysis of the impact of selected factors (SO₂, NO_{xx}, atmospheric particulate matter PM10 and relative humidity) affecting the rate of corrosion process of steel bridge structural members was investigated. The concentration of air pollutants in Silesia region was evaluated as the highest in comparison to other polish counties due to high rate of urbanization. Therefore the Silesia region was selected for the observation of the corrosion effects on structural steel caused by the air pollution. As the reference samples, 36 test samples in vertical and horizontal position were placed in three independent measurement stations constructed to directly investigate the effect of air pollution on the degradation of structural steel due to corrosion.

Fig. 1. Location of observed bridges in the Silesian province.

The obtained information related to the corrosion losses should be used to accurate the formulas for dose-response function [6] determined by means of air pollution data from IMWM - Institute of Meteorology and Water Management.

Secondly, the influence of chloride ions, which are a product of the Winter Road Maintenance (WRM), on the corrosion process was analyzed. In Poland, depending on traffic, all roads are classified into one of the five standards of the WRM designated by means of the Roman numerals from I to V. Based on the analyzed factors of air pollution and type of WRM standards, the Silesia region was divided into three zones in accordance with the Road Administrative divisions and type of WRM. In total, 11 steel bridge structures were selected for placing the measurement samples (see Fig. 1).

Test samples were installed in November 2015 at all sites. For each bridge object, 12 samples on the surface of the vertical web and horizontal lower flange of the main girder were discretely glued (see Fig. 2) to simulate the effect of web and flange corrosion.

Fig. 2. Test samples laid out on the steel girder bridge in Marcinków.

The test samples were made of structural steel S355J2+N having nominal geometrical parameters of 100x150x2 mm. Before the installation, each sample was weighed with accuracy of 0.01 g and the dimensions of length, width and thickness were measured. The chemical composition of test samples was determined too. In July 2016 after one year of exposition to aggressive environment due to WRM, six samples were taken off (three samples placed on lower flange and three ones placed on the web) from each of the 11 bridge structures. The samples were then weighed and mechanically cleaned from corrosion products and secondly weighed. Triple weighing allowed ascertaining the weight of the corrosion product and the overall mass loss of test samples due the corrosion after the first observation period. Concurrently, six reference test samples were taken off (three samples located in horizontal positions and three ones from vertical positions) from each of the 3 measurement stations.

Table 1. Results of statistical evaluation of corrosion weight losses.

Type of WRM	I (g/m ²)	II (g/m ²)	III (g/m ²)	All types of WRM (g/m ²)
Horizontally located samples	m = 97.06 s = 18.86	m = 187.50 s = 192.82	m = 114.59 s = 48.03	m = 67.38 s = 29.76
Vertically located samples	m = 63.50 s = 9.72	m = 67.17 s = 31.59	m = 72.85 s = 41.73	m = 134.73 s = 126.16
Both locations	m = 80.28 s = 22.51	m = 127.33 s = 150.69	m = 93.72 s = 49.60	m = 101.06 s = 97.65

The same process of investigation of corrosion losses was realized with the reference test samples as in the case of bridge samples to compare obtained results and to determine effect of WRM. The chemical composition of all investigated samples was also determined after exposition. The obtained results of corrosion weight losses (ML_{steel}) were statistically evaluated with characteristics (m - mean value, s - standard deviation) showed in Table 1. Reference test samples corroding in normal atmospheric environment showed the following statistical characteristics of corrosion weight losses after one year of exposition: $m = 80.81 \text{ g/m}^2$, $s = 36.41 \text{ g/m}^2$ for horizontally located samples and $m = 87.44 \text{ g/m}^2$, $s = 20.87 \text{ g/m}^2$ in the case of vertically located samples.

The corrosion losses of samples thicknesses ($\mu\text{m/year}$) were statistically evaluated too. Results of evaluation are presented in Table 2.

Table 2. Results of statistical evaluation of corrosion losses of thickness.

Type of WRM	I $\mu\text{m/year}$	II $(\mu\text{m/year})$	III $(\mu\text{m/year})$	All types of WRM
Horizontally located samples	$m = 12.27$ $s = 2.37$	$m = 23.61$ $s = 24.00$	$m = 14.43$ $s = 6.05$	$m = 16.98$ $s = 15.88$
Vertically located samples	$m = 8.05$ $s = 1.24$	$m = 8.48$ $s = 3.98$	$m = 9.19$ $s = 5.26$	$m = 8.51$ $s = 3.75$
Both locations	$m = 10.16$ $s = 2.83$	$m = 16.04$ $s = 18.97$	$m = 11.81$ $s = 6.25$	$m = 12.75$ $s = 12.29$

Reference samples corroding in normal atmospheric environment showed the following statistical characteristics of thickness losses after one year of exposition: $m = 9.24 \mu\text{m/year}$, $s = 3.58 \mu\text{m/year}$ for horizontally located samples, while $m = 11.44 \mu\text{m/year}$, $s = 2.58 \mu\text{m/year}$ in the case of vertically located samples. Result comparison indicates the higher corrosion thickness losses of samples placed on the bridges. Also the standard deviations are higher in the case of bridge samples as reference ones. The significant differences of standard deviations of the observed values means considerable dispersion of corrosion weight losses measured on bridges. Both type of tested samples proved the more significant corrosion effect of samples located on bridge in horizontal position.

3 Experimental research in Slovakia

The results of measurements of concentrations of air pollution carried out by the Slovak Hydro meteorological Institution (SHMI) from 1971 are the basic background for evaluation of the air quality in Slovakia. Using this information, the dose-response functions were presented for structural steel [7] and for zinc [8]. The in-situ measurements were carried out using standard test samples having nominal dimensions 150x100 mm in accordance with [9]. The thicknesses of samples were specified of 3 mm with respect of long-term measurements. In total, 360 test samples were made of steel S355J2. Each of them was designated, weighed and the real sample dimensions were measured. The location of test samples was oriented on the Žilina self-governing region (Fig.3). The 24 sets of 15 test samples were placed on the following locations:

- 1 set was placed in own corrosion station in the area of University of Žilina (UNIZA) in cooperation with the Research Centre of UNIZA (Fig. 4 -left);
- 11 sets were placed (Fig. 4-rigth) on chosen bridges in frame of Žilina self-governing region;
- 8 sets were placed on roofs of buildings in the cities of Žilina self-governing region;
- 4 sets of samples will be used for corrosion chamber measurements.

Fig. 3. Location of observed bridges and building roofs in the Žilina self-governing region.

Fig. 4. Location of test sample in the area of UNIZA (left) and on the chosen bridge (right)

Covering heterogenous environment of the Žilina self-governing region was the basic criterion for sample location on bridges. Test samples were installed in modified plastic holders in slope of 45° (see Fig. 4 - right). The measurements of the corrosion losses will be realized in June 2017. The obtained results in-situ measurements will be completed by rapid testing in corrosion chamber. The pilot analyses were carried out to define amount of NaCl causing the same effects as the results recorded by in-situ measurements. The course of dependence of NaCl on the value of corrosion loss obtained within one year of sample exposition on bridge was derived. The calibration should also continue after two years of sample exposition on bridges.

4 Conclusions

The contribution described the preparation and particular results of the research related to the investigation of air pollution and its effect on degradation of structural steel due to corrosion. The outputs of measurements of corrosion losses of test samples located on bridges in Silesian region after one year of exposition were presented. Future research activities in this field of study were also introduced. Based on the obtained information, the time-dependent corrosion models for structural steel should be developed [10] to define cross-sectional and member time-dependent resistance. The results obtained in frame of long-term observations should be implemented in the concept of the bridge members design for durability [11] respecting the limit state principles using form of partial safety factor method.

The paper presents results of the research project SK-PL-2015-0004 and the research project APVV-14-0772 supported by the Slovak Research and Development Agency and the project 012ŽU-4/2016 supported by the Cultural and Education Agency of Slovak Republic.

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