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Influence of the environment aggressiveness on durability of girders made of S355 steel in Poland

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Abstract
The following article discusses the problem of durability of girders made of structural steel S355 affected by corrosion. It presents the Polish procedure for calculating the time between failures of steel elements of bridge and durability factors necessary to estimate the impact of corrosion on the durability of steel road bridges. According to the presented procedure, two real bridges of steel structure were analysed. The bridges selected for analysis are located in extremely different corrosive environments in Poland. This bridges were built in different areas of the country which are characterized by different (mountain, urban) aggressiveness of the environment. The objects of the analysis differ in terms of corrosion type occurring on the bearing system. Their age is also different which has a significant impact on their safety.The results obtained allowed to determine the time when, with the existing corrosion damage, failures may occur.

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1. Introduction

Girders are load-bearing structural elements of steel or composite bridges. They are usually made of S355 structural steel (PN-EN 100202003, PN-EN 1993). Atmospheric corrosion is a destructive phenomenon, which negatively impacts the strength and durability of the steel I-beam or truss girders. Corrosive environment and the age of a bridge have the greatest impact on the rate of corrosion. It is caused above allby chloride ions from salt used for winter road maintenance. A winter road maintenance process depends on a road class. Results of scientific research show that the rate of corrosion is greatly affected by the environment category where a bridge is located. The environment aggressiveness classes are described in the standard of PN-EN ISO 12944-2:2001 Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 3: Classification of environments (PN-EN ISO 12944-2:2001). Inadequate maintenance of construction, aggressive environment and improper service of construction result in a quicker corrosion damage, which shortens the time between failures of steel bridges. The anti-corrosion protection is important and allows areduction in material and energy consumption and pollutant emissions.

2. Polish procedure for determining the durability and time between failures of the bridge - characteristic parameters and reduction factors

Estimation of the corrosion impact on the durability of bridge structures is a complex procedure. This procedure requires, above all, the analysis of the object and determining the type and size of corrosion construction. It is also important to determine the location of corrosion on the surface of the load-bearing steel elements because irregular distribution of corrosion products, and the mass losses of the material in cross-sections of the bearing elements causes stress concentration. The effect of corrosion, together with periodical stress changes, causes a greater decrease of the construction bearing capacity than each of these factors individually. Variable tensions intensify the corrosion process, which accelerates the fatigue of structural material. The Polish estimation method of corrosion impact on the durability of steel bridges, developed by the Research Institute of Roads and Bridges (CZEREPAK A., CZUDEK H., PRYGA A., WYSOKOWSKI A. 2003) is based on the analysis of the integrated system of the material and the environment, where the material must have a high resistance and durability, whereas the environment is a destructive and aggressive factor and negatively affects the material. In this procedure, the reduction coefficients of durability (Tables 1) and mathematical formulas are used, which enables the lifetime of corroded bridge to be determined (PN-EN 1993-2:2010).

Table 2. Reduction coefficient of durability

Coefficient associated with level of aggressiveness of the environment - S_A		
Corrosivity category	Type of aggressiveness of the environment	Value
Cl Very low atmospheric	Atmospheres with very low level of pollution. Mostly rural areas.	0.99
C2 Low atmospheric	Urban and industrial atmospheres with low level of pollution. Coastal areas with low salinity.	0.98
C3 Medium atmospheric	Urban and industrial atmospheres, moderate sulphur dioxide pollution. Coastal areas with medium salinity.	0.97
C4 High atmospheric	Industrial areas and coastal areas with moderate salinity.	0.96
C5-I Very high (industrial) atmospheric	Industrial areas with high humidity and aggressive atmosphere.	0.95
C5-M Very high (marine) atmospheric	Coastal and offshore areas with high salinity.	
Coefficient associated with type of corrosion - K_R		
Type of corrosion		Value
uneven corrosion, pitting corrosion		value should be calculated (CZEREPAK A., CZUDEK H., PRYGA A., WYSOKOWSKI A. 2003)
homogenous corrosion		0.97
creep corrosion, crevice corrosion, weld corrosion,galvanic corrosion		0.99
Coefficient associated with technical condition of the bridge - T_W,T_D, T_i,		
Evaluation of technical condition of the bridge		Value
0		0.90
1		0.94
2		0.96
3		0.98
4		0.99
5		1.00
T_W - coefficient depending on the technical conditions of bridge drainage system, T_D - coefficient depending on the technical conditions of bridge dilatations, *Ti* - coefficient depending on the technical conditions of bridge insulation.		
Coefficient associated withthe road class- β		
The road class		Value
Class road A		0.90
Class road S		0.93
Class road GP		0.95
Class road G		0.96
Class road Z, L, D		0.99

Source: study based on CZEREPAK A., CZUDEK H., PRYGA A., WYSOKOWSKI A. 2003

At the beginning, it is obligatory to analyze the fundamental data from the last technical inspection of thebridge and the parameters related to its location. This information allows several reduction coefficients associated with (S_A) – the level of aggressiveness of the environment to be determined where a given bridge is located, (K_R) – the type of corrosion existing in its load-bearing structure and the technical conditions of: (T_W) – the drainage system of the bridge, (T_D) – dilatations and (T_i) – insulation. Those factors allow the calculation of (S_T) the level of shortening of the construction life span. The next step is to determine the βcoefficient related to the road class, which is determined based on the type of traffic. It is also obligatory to define (W) – the age of the analyzed bridge and (T_m)– the projected life span of the bridge. Those parameters (S_T, β, W and T_m) are used to determine (T_e)– the time between failures of structure due to corrosion, where the corrosion is progressing with a high probability (about 90%) (SVOBODOVA J. 2013, ULEWICZ R., MAZUR M. 2015, WYSOKOWSKI A. 2001).

3. Analysis of the durability of the real structure depending on the location and the corrosive environment

For the analysis a bridge in Wisla (Fig. 1), which is part of the inter-regional road 942, and the bridge, which is part of the inter-district road 1661D in Wroclaw (Fig. 2), were chosen. The analysis was carried out based on the data from the inspection reports for selected bridges (ZARZĄD DRÓGI KOMUNIKACJI WE WROCŁAWIU. 2016, ZARZĄD DRÓG WOJEWÓDZKICH W KATOWICACH. 2016).

Fig 2. The analyzed bridges -stream Malinka in Wisla

Source: own study

Fig 2. The analyzed bridges -lock in the city in Wroclaw

Source: own study

Based on this data, values of the durability reduction coefficients were selected. Subsequently, using the procedure described in (PN-EN 1993), the measure of shortening the time between failures of objects and the total time between failures of structure due to corrosion were calculated. The results are presented in Tables 2 and 3.

Table 2. Data for the analyzed bridge in Wisla

BRIDGE IN WISLA – Silesian province			
Type of barrier		stream Malinka	
Road number	942	Placement	km 36+566
Durability reduction coefficient			
S_A	K_R	β	W
0.98	0.923	0.96	54
T_W	T_i	T_D	
0.98	0.90	-	
Level of shortening the time between failures of structures		S_T	0.850
Time between failures of structure due to corrosion		T_e	27

Source: own study

Table 3. Data for the analyzed bridge in Wroclaw

BRIDGE IN WROCŁAW – Lower Silesian province			
Type of barrier		lock in the city	
Road number	1661D	Placement	Sienkiewicza Street
Durability reduction coefficient			
S_A	K_R	β	W
0.98	0.891	0.99	81
T_W	T_i	T_D	
0.99	0.96	0.96	
Level of shortening the time between failures of structures		S_T	0.847
Time between failures of structure due to corrosion		T_e	3

Source: own study

The analysis showed that the reduction coefficients depending on the type of corrosion has the greatest impact on the level of shortening the time between failures of bridges. The class of aggressiveness of the environment is also important, because air pollution and salt, accelerates the rate of corrosion, as seen in the case of the bridge in Wroclaw. Additionally, the amount and concentration of salt, which prevents from forming of ice, black ice and the remains of a fresh snow in the winter periods, which also contribute to corrosion girders, is associated with the class of the road winter maintenance (BIEŃKA J., DZIENIS T., GODLEWSKI T., KAMELA R., RADOMSKA E. 2006). It should be noted that the bridge in Wroclaw is a bridge in the city center. The second bridge in the Wisla city is located in the mountain resort in Silesia province. Therefore, winter maintenance of roads on these bridges is crucial for urban infrastructure. In winter, these bridges must be very frequently sprinkled with salt.

The bridge in Wisla is part of the road from Wisla to Szczyrk through the mountain pass, Samopolska, characterized by a large slope and a dozen sharp curves. In winter, for safety reasons, this road must be perfectly maintained. The technical conditions of the elements of the analyzed bridges are alarming or insufficient, in most cases, the evaluation of the technical conditions of all objects is 2-3. The scale of assessment of the technical condition of individual elements of the bridges has 6 states, where 0 is the state of emergency, 1 is the state before emergency, 2 is the state of in sufficiency, 3 is the state of alert, 4 is the state of sufficiency, 5 is the state of appropriateness. Very often, after screening, it is concluded that the existing damage can pose a threat to public safety or may limit the utility of the bridge structure. Therefore, the maintenance and renovation of objects and their corrosion protection are very important, as they allow an extension of a period of time between their failures.

4. Conclusions

Presented method allows a quick estimation of time between failures of structure due to corrosion. The results of the analysis have given important information about steel bridges. The information is useful for preparing reports from periodic inspections of the technical condition of bridges and viaducts. The analysis shows that the greatest impact on the time between failures of bridge is imposed by the type of corrosion existing on the structural elements, class of corrosiveness and location of the object. Although, the analyzed roads are only of the G and L classes (with the low value of the reduction factor β), frequent and intense salt spreading is required to prevent the formation of ice and snow cover in winter, due to their importance for the local infrastructure. Estimating the rate of corrosion of steel bridges through a preliminary analysis of durability of construction, which takes into account the environmental conditions and the exploitation, is very important for the planned modernization works and renovations.

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波蘭環境侵蝕對S355鋼大樑耐久性的影響

關鍵詞
鋼橋
大樑的耐久性
結構鋼S355
腐蝕鋼

摘要

在這篇文章中討論了由結構鋼S355製成的梁由於腐蝕的耐久性問題。文章介紹了計算橋樑鋼構件失效之間的時間和估計腐蝕對鋼橋橋樑耐久性的影響所需的耐久因素的抛光程序。根據提出的程序，分析了兩個真實的鋼結構橋樑。選擇用於分析橋樑位於極端不同的腐蝕環境在波蘭。這個橋樑建在國家的不同地區，特點是環境的不同（山，城市）侵略性對像不同在軸承系統發生的腐蝕的類型。橋樑在物體的年齡方面也不同，這對其安全性具有顯著影響。所獲得的結果允許確定具有現有腐蝕損傷的施工的失效之間的時間。