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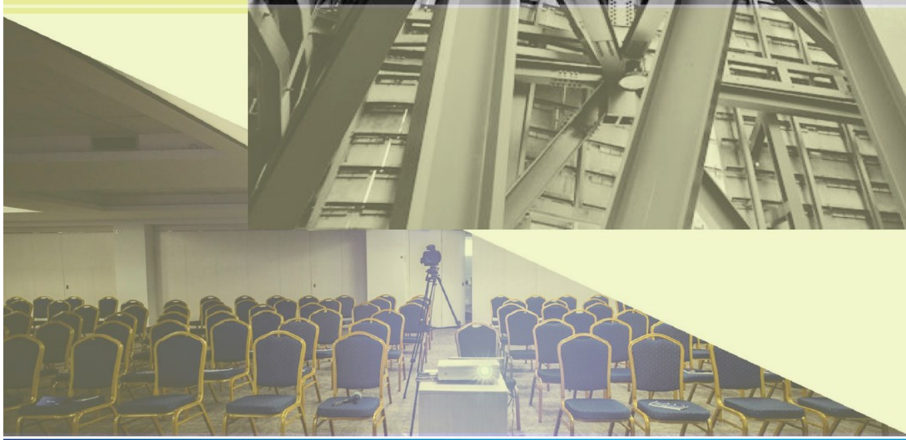
CONDITION ASSESSMENT, MAINTENANCE AND REHABILITATION OF CIVIL ENGINEERING FACILITIES



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Originalni naučni rad

Milan Spremić[1], Isidora Jakovljević[2], Aljoša Filipović[3]

ENVIRONMENTAL EFFECTS ON THE DURABILITY OF STEEL STRUCTURE – A CASE STUDY OF ADVERTISING BILLBOARD POLES

Summary: *The steel structures of canopies, public garage columns, street lighting, power lines and other street furniture are constantly exposed to weather effects in their service life. The steel structure of street furniture is often exposed to the effects of de-icing salts from the roads. The paper analyses the effects of the urban environment on the durability of steel structures. The macroscopic visual inspection included 181 steel billboard poles on the territory of the City of Belgrade. The analysis of the surface treatment, the condition of the structure and its location provided conclusions regarding the durability of steel structures in urban environments. The environmental corrosivity on the territory of the City of Belgrade has been analysed. The analysis included the bearing steel structure of poles and the joint between the steel structure and foundations.*
Keywords: *Surface treatment, urban mobilier, corrosion of steel structure, durability.*

UTICAJ SREDINE NA TRAJNOST ČELIČNE KONSTRUKCIJE – STUDIJA SLUČAJA STUBOVA REKLAMNIH MEDIJA

Rezime: *Čeličnu konstrukciju nadstrešnica, stubova javnih garaža, ulične rasvete, dalekovoda i drugog urbanog mobilijara karakteriše stalna izloženost atmosferskim uticajima tokom životnog veka. Čelična konstrukcija urbanog mobilijara je neretko izložena i uticaju soli za održavanje saobraćajnica. U radu je analiziran uticaj gradske sredine na trajnost čelične konstrukcije. Stručnim vizuelno-makroskopskim pregledom obuhvaćen je 181 stub čelične konstrukcije za nošenje reklamnih medija na teritoriji grada Beograda. Analizirajući vrstu antikorozione zaštite, stanje konstrukcije i lokaciju konstrukcije izvedeni su zaključci o trajnosti čelične konstrukcije u urbanoj sredini. Analiziran je i stepen korozivnosti sredine na teritoriji grada Beograda. Analiza je obuhvatila noseću čeličnu konstrukciju stubova i detalj veze čelične konstrukcije i temelja.*
Ključne reči: *Antikoroziona zaštita, urbani mobilijar, korozija čelične konstrukcije, trajnost.*

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1. INTRODUCTION

Steel corrosion is an electromechanical process that is one of the most important aspects of structural steel durability. Water (H_2O), oxygen (O_2) and steel (F_e) form the hydraulic ferrite oxide (Rust – $2Fe_2O_3H_2O$), meaning that steel corrosion requires the presence of both water and oxygen on the steel surface. The applied surface treatment should protect the steel surface from water. The wetness factor (time of wetness of a steel structure) is a factor which determines the corrosion process. The atmospheric pollution could accelerate the corrosion process, while sulphates and chlorides could cause the pollution of air or water. Areas around large urban communications are zones with high levels of air pollution. In addition, winter de-icing procedures of these communications using salts create water which is, to a certain extent, saturated with salts.

Surface treatment of steel structures is performed using the system of coatings according to the current provisions of SRPS EN ISO 12944 standard [1]. There are several ways to define the corrosion classifications of the environment. The most common corrosion classes vary from C1 (very low) to C5 (very high) and CX (extreme corrosivity) based on the ISO 12944 standard [1]. The level of protection, using the coating systems of the steel structure surfaces is defined by the level of environmental reactivity. Alternatively, the steel structure can be treated using the hot-dip galvanisation procedure. This surface treatment procedure has its advantages and disadvantages. The hot-dip galvanisation procedure, which provides extended durability, imposes certain limitations in terms of the maximum dimensions of prefabricated elements which depend on the hot-dip galvanisation tub. Also, hot-dip galvanised structures cannot be joined by welding. Additional protection of steel surfaces may be accomplished by a duplex system, through painting or powder coating over hot-dip galvanised steel to enhance corrosion protection.

Considering all of the above, the structural designer is supposed to classify the corrosivity of the environment and decide the appropriate methodology for the protection of the steel structure. The aim of this paper is to assess the durability of a steel structure in an urban setting subjected to high air pollution and other environmental effects, as well as to identify the positive and negative practices of surface treatments and structural design.

2. THE CASE STUDY OF ADVERTISING BILLBOARD POLES

The macroscopic visual inspection included 181 steel billboard poles on the territory of the City of Belgrade. The locations of billboards which are analysed are along the main communications in Belgrade:

- Novi Beograd – Bulevar Mihajla Pupina, Bulevar Nikole Tesle, Bulevar Zorana Đinđića and Bulevar Milutina Milankovića
- Kneza Miloša Street from Takovska Street to Mostar Interchange;
- Bulevar Kralja Aleksandra from Ustanička Street to Takovska Street;
- Bulevar Oslobođenja from Slavija Square to Autokomanda Square;
- Bulevar Despota Stefana from Višnjička Street to Republic Square.

All of these routes reflect streets with similarly intense traffic in Belgrade, with high traffic frequency throughout the day. The locations of the inspected billboards are categorised by their position relative to the roadway, which is related to the probability of the pole being exposed to water from the roadway.

The bearing structure of the analysed poles is classified according to the adopted structural design. All of the poles are cantilevers, but the design of cross-sections and chord and bracing elements differs. The variety of structural systems has made it possible to observe the positive and negative aspects of structural design. The following structural systems are evaluated:

- pole made of a massive box cross-section (Figure 1a),
- pole made of a circular hollow section (Figure 1b),
- pole made of two square hollow sections (Figure 1c),
- pole made of two hot rolled I sections and a horizontal strut (Figure 1d),
- pole made of two hot rolled U sections and truss bracing (Figure 1e),
- pole made of two circular hollow sections and a horizontal strut (Figure 1f),
- pole made of two cold-formed sections in the form of a half polygon connected by horizontal struts (Figure 1g).

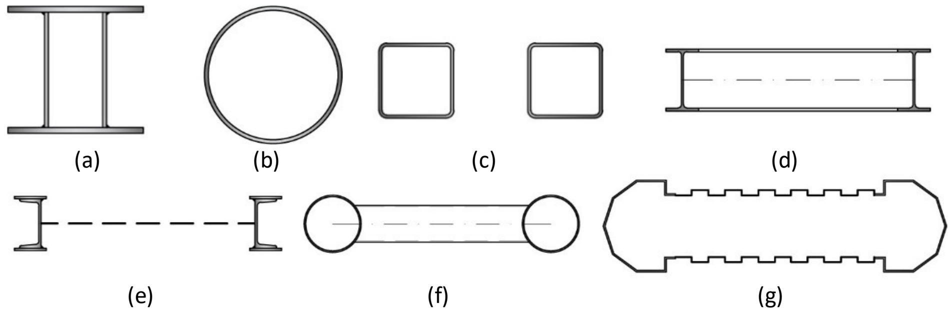

Figure 1. Cross-sections of billboard poles: (a) a massive box cross-section, (b) a circular hollow section, (c) two square hollow sections, (d) two hot rolled I sections with a horizontal strut, (e) two hot rolled U sections with truss bracing, (f) two circular hollow sections and a horizontal strut, (g) two cold-formed sections in the form of a half polygon.

The average age of a billboard pole is 21 years. Poles that have been constructed and assembled recently are excluded from the analysis. The steel structure's condition and level of corrosion are analysed, and the poles are classified based on the urgency of replacement, rehabilitation or reconstruction.

3. DAMAGE LEVEL OF STEEL STRUCTURE

In the course of the visual macroscopic inspection, the poles are classified into several groups according to the corrosion level of the main bearing structure. The corrosion levels are defined based on the visual inspection and the adopted criterion considering the damage level:

- Stage of Corrosion 0: The painted steel surface has shown no sign of cracking or paint bubbles, no pitting. The surface shows no rust stain or trace of rust. Surface coating is not comprised.
- Stage of Corrosion 1: The painted steel surface is bubbly or the paint bubbles have broken. Rusty red or white corrosion deposits on the metal surface are visible. There are no granular deposits on the surface and pitting, if any, is not visible.

- Stage of Corrosion 2: The granular powder deposits on the steel surface. Only steel surfaces could be etched or pitted.
- Stage of Corrosion 3: The same as stage 2, but small holes in the steel could be visible. The corrosion is accompanied by etching and pitting, and extensive steel surface degradation is evident. Loose of granular steel condition.
- Stage of Corrosion 4: The corrosion has advanced to the point where the metal has been penetrated throughout. There are holes in the surface area, and the steel is completely missing along the edges.

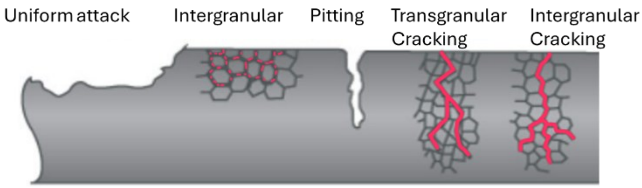

Figure 2. Types of corrosion [3]

In the case of the stages of corrosion 0, 1 and 2, it is possible to rehabilitate the surface treatment and steel structure. Structures with corrosion stage 3 can be rehabilitated and reconstructed in certain cases. Structures with corrosion stage 4 require a detailed reconstruction and complete replacement of steel structure elements.

According to the stages of corrosion, criteria for replacement and rehabilitation of structural poles of billboard are defined in the following way:

- Stage of Corrosion 0 – No rehabilitation needed,
- Stage of Corrosion 1 – Surface treatment rehabilitation is required in the next 4 years.
- Stage of Corrosion 2 – Surface treatment and structure rehabilitation are required in the next 2 years.
- Stage of Corrosion 3 – Urgent rehabilitation of the steel structure is required.
- Stage of Corrosion 4 – Urgent replacement of the steel structure elements (with new elements) is required.

4. RESULTS ON THE BILLBOARD POLE ASSESSMENT

According to the described classification of corrosion stages, the inspected billboard structures may be divided into five groups, corresponding to the estimated damage level. The share of billboard poles corresponding to each stage of corrosion is illustrated in Figure 3. Rehabilitation is not needed for almost a quarter of 181 inspected poles (23%), while 13% of structures require urgent replacement. About one-third of poles have corrosion stage 3 or 4, needing urgent rehabilitation or replacement work.

The correlation between the steel structure's surface treatment and the stage of corrosion is illustrated in Figure 4. To the majority of the inspected billboard structures, the anti-corrosion paint system was applied. Considerably smaller is the number of billboards with zink coating applied through the hot-dip galvanisation. Even smaller is the number of billboards with duplex system for corrosion protection, formed by painting or powder coating over hot-dip galvanised steel. The relation between the steel surface treatment and the structure damage level is evident – rehabilitation work is not needed for any of the poles with the duplex system and almost all poles with zink coating. On the contrary, less than 5% of poles with the applied anti-corrosion paint system do not require rehabilitation work. Almost 40% of billboard structures with anti-corrosion paint system have corrosion stage 3 or 4. Results demonstrate the advantages of zink coating and duplex system as long-lasting corrosion protection, reducing the need for frequent maintenance and rehabilitation work.

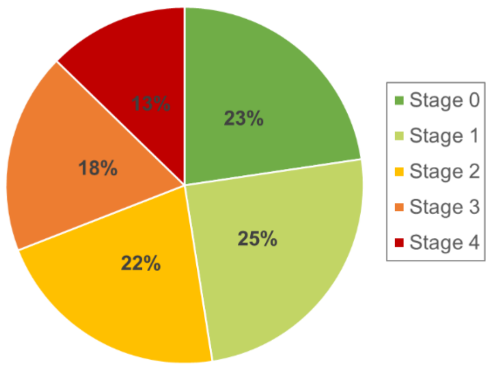

Figure 3. Inspected billboards according to the stage of corrosion

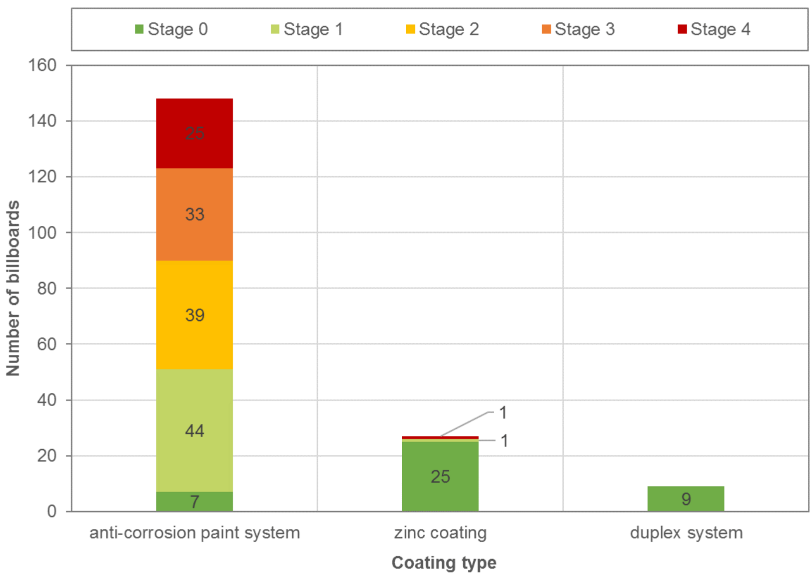

Figure 4. The stage of corrosion: Steel surface treatment

Because of their good condition, billboard poles with duplex systems and zink coating are excluded from the following analysis, which examines the influence of cross-section and distance from the roadway on the damage level. Therefore, the results shown in Figures 5 and 6 are confined to poles coated with anti-corrosion paint.

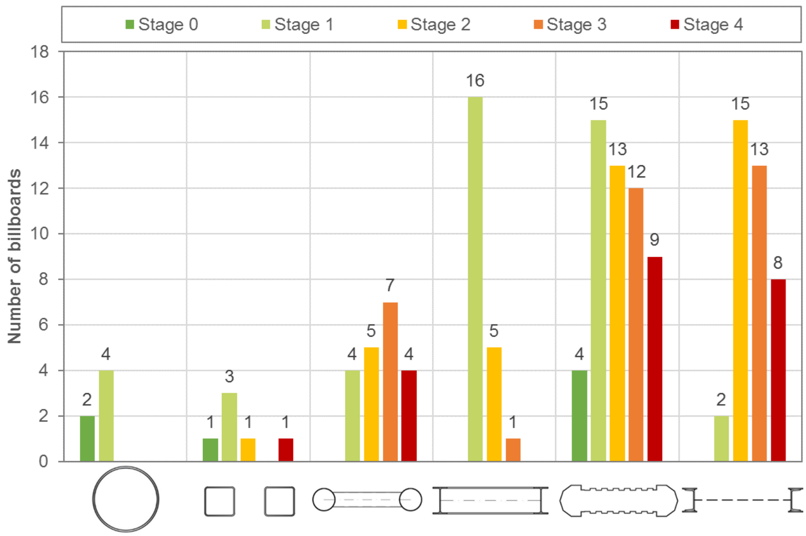

Figure 5. The stage of corrosion of billboards with applied anti-corrosion paint: Different cross-sections

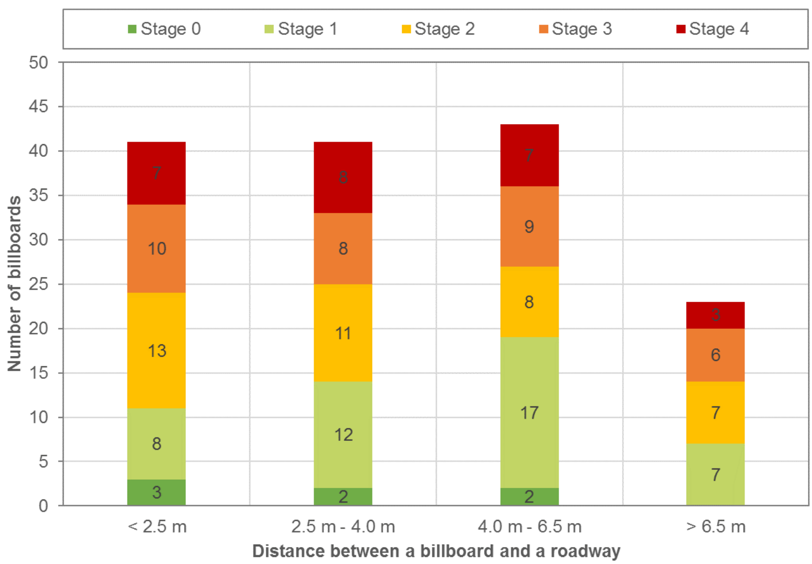

Figure 6. The stage of corrosion of billboards with applied anti-corrosion paint: Distance from the roadway

The effect of applied structural design on the corrosion of billboard pole steel structure is shown in Figure 5. All examined poles of a circular hollow section were assigned a corrosion stage of 0 or 1. On the opposite, almost all billboards with chords made of hot rolled U sections and truss bracing have a corrosion stage of 2, 3, or 4. A high percentage of poles in corrosion stages 2, 3, or 4 is also present on billboards composed of cold-formed sections in the shape of a half polygon. The provided findings show that using massive cross-sections, excluding bracings and avoiding thin-walled sections is favourable in terms of corrosion protection.

The relation between the distance from the billboard pole to the roadway and the damage level due to corrosion is discussed in Figure 6. Inspected billboards are classified into four groups depending on their position relative to the roadway: shorter than 2.5 m, between 2.5 and 4.0 m, between 4.0 and 6.5 m, and longer than 6.5 m. The overall number of billboards in the first three groups is roughly equal. When comparing the first three groups, the number of billboards with corrosion stage 1 increases as the distance between the pole and the roadway increases. There is also a decrease in billboards with corrosion stage 2 as the pole-to-roadway distance gets longer. Although the number of billboards with corrosion stages 0, 3, or 4 remains nearly constant over the first three groups, the overall data demonstrate a higher average level of corrosion for billboards closer to the roadway.

5. ENVIRONMENTAL CORROSIVITY IN BELGRADE

In order to explain the poor condition and high damage levels of a non-negligible number of inspected billboard poles, the environmental corrosivity on the territory of Belgrade is discussed.

The structural designer needs to consider the corrosivity of the atmosphere when defining the level of steel structure surface treatment. While EN ISO 12944 [1] defines the corrosivity of the atmosphere in descriptive terms, the standard ISO 9223 [2] provides the range of key atmospheric parameters which affect steel corrosion. According to EN ISO 12944, urban environments are classified in corrosion class C3. In order to define the corrosivity class according to ISO 9223, average annual values of sulfur dioxide SO_2 and nitrous dioxide NO_2 in the air on the territory of Belgrade in the period between 2010 and 2022 were analysed [4]. The locations of Despota Stefana Street, Mostar Interchange and Novi Beograd were covered by analysis. For these three locations, the average annual concentration of SO_2 exceeds the value of 30 µg/m3, which is the limiting value [2] between urban and industrial environments. With this in mind, the territory of the City of Belgrade should be categorised as an industrial environment with corrosion class C4 according to the corrosivity of the atmosphere. Maximum average annual values of SO_2 in the air reach up to 41 $\mu g/m^3$. The maximum values of nitrous oxides NO_2 in the air resulting from the traffic reach the upper limit defined in the standard [2] of 150 $\mu g/m^3$. However, the average annual values of nitrous oxides are closer to the lower limit for the urban environment of 20 $\mu g/m^3$.

Both standards [1,2] interpret the presence of chlorides in the water as the pollution of the environment. The passage of vehicles through salt water during winter contributes to the increase of corrosion on steel structures with the additional negative effects coming from the mechanical impacts of grit. Structures at a distance less than 15 metres from the roadway must be protected from salt water, according to standards.

The condition of the billboard pole steel structures, as determined by visual macroscopic inspection, reveals that the structure's protection with the paint system for corrosion class C3 is insufficient. The effect of roadway distance and salt water from the roadway on the corrosion of steel structures was confirmed. Salt water from the road additionally endangers the lower part of the steel structural column, resulting in a significantly higher degree of corrosion of the steel structure at the connection with the foundations.

6. CONCLUSIONS

During the design and construction phases, special attention should be paid to the corrosion protection of steel street furniture and other structural elements under the open air on the territory of the City of Belgrade. Based on the data presented in this paper, the following conclusions can be drawn:

- The corrosivity of the atmosphere in Belgrade along the large streets is of a C4 category.
- All steel structures in the Belgrade city core which are constructed without façade cladding should be surface-treated against corrosion using the system of coatings corresponding to at least the C4 corrosion class.
- It was confirmed that massive and robust structural systems are more resistant to corrosion in comparison to truss structures and thin-walled structures.
- Urban street furniture assembled in the traffic road zones at a distance lower than 15 m from the edge of the roadway must be surface treated against corrosion using a system of coatings corresponding to at least the C5 corrosion class or the hot-dip galvanisation.

7. REFERENCES

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