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Original Research Article

THE COST ANALYSIS OF CORROSION PROTECTION SOLUTIONS FOR STEEL COMPONENTS IN TERMS OF THE OBJECT LIFE CYCLE COST

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A b s t r a c t

Steel materials, due to their numerous advantages - high availability, easiness of processing and possibility of almost any shaping are commonly applied in construction for carrying out basic carrier systems and auxiliary structures. However, the major disadvantage of this material is its high corrosion susceptibility, which depends strictly on the local conditions of the facility and the applied type of corrosion protection system. The paper presents an analysis of life cycle costs of structures installed on bridges used in the road lane conditions. Three anti-corrosion protection systems were considered, analyzing their essential cost components. The possibility of reducing significantly the costs associated with anti-corrosion protection at the stage of steel barriers maintenance over a period of 30 years has been indicated. The possibility of using a new approach based on the life cycle cost estimation in the anti-corrosion protection of steel elements is presented. The relationship between the method of steel barrier protection, the scope of repair, renewal work and costs is shown. The article proposes an optimal solution which, while reducing the cost of maintenance of road infrastructure components in the area of corrosion protection, allows to maintain certain safety standards for steel barriers that are installed on the bridge.

Keywords: anti-corrosion protection, Life Cycle Cost, steel materials, LCC analysis methods, total costs, steel barriers

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1. INTRODUCTION

Steel materials and articles made of them are widely available and easy to process, and in addition, almost any shaping is possible, which makes them useful in the execution of basic and auxiliary construction structures. Because of the high strength parameters, steel components are widely applied in infrastructure projects - on roads and bridges, as well as in the construction of various coating systems and road safety components.

Ready-made steel components are characterized by relatively low cost of production in industrial conditions and low costs during processing. The main disadvantage of these materials, however, is its high corrosion susceptibility in atmospheric conditions - in contact with oxygen, water and environmental pollutants [11]. This phenomenon already exists at the manufacturing stage. Degradation of steel material due to corrosive processes is different, depending on the location of the component and the presence of corrosive environment at the site [2]. The steel infrastructure facilities and auxiliary components are exposed to particularly intense environmental impact, due to the operating conditions at the roadway. Environmental and operational hazards vary depending on the road category and its location. The applied paint and metallurgical protection during their operation also undergoes the processes of destruction, which necessitates the periodical renewal to ensure proper protection of the supporting steel elements [1, 5, 6, 10]. In addition, in some areas, the aspect of winter maintenance of roads and roadworks should be taken into account, which is a significant, periodically occurring destructive factor for steel and protective coatings. In winter, it is often necessary to clear up and use anti slippery remedies, which in turn increases the aggressiveness of the corrosive environment in the road area and thus reduces the durability of the corrosion protection of steel structures.

Bearing in mind the above, it is important to note that depending on the type of applied corrosion protection, the initial and operational investment expenditures related to the use of steel elements change. The problem of corrosion protection of steel elements should already be taken into account at the stage of planning and design of the investment [13, 15] as it has a significant impact on the cost of maintenance of the facility during its operation.

Mistakes in the design process can in practice be costly to the user during operation [8,9] both due to the conditions of the corrosion protection and incorrect construction assumptions.

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2. CONDITIONS FOR THE STABILITY OF ANTI-CORROSION PROTECTION SYSTEMS

Each type of anti-corrosive protection of the steel structure has specific destructive nature over time. Therefore, the protection of the basic carrier system is subject to change over time. In the case of metallized zinc coatings, similarly to the protected steel material, this is a natural corrosion process, but in this case it is significantly slower than in the case of protected material (Table 1).

Table 1. The comparison of corrosion losses of metallic materials according to PN-EN ISO 12499

Corrosivity class of the environment	The average yearly corrosion loss of material [µm/year]	
	carbon steel	zinc
C3	25-50	0.7-2,\.1
C4	50-80	2.1-4.2
C5	80-200	4.2-8.4

The paint coating material is also the subject to destructive processes, resulting in changes such as aging of the coating, loss of elasticity and tightness. This causes the environmental corrosive factors to reach metal parts. Mechanical damage also contribute to the loss of protection properties of paint coatings. As a result of the above processes and damage, the corrosion process of the protected steel element is initiated, resulting in the accelerated by destruction of the protective corrosion coatings.

3. CONDITIONS FOR THE SAFETY OF PROTECTION SYSTEMS

The cost of maintaining the steel components at bridge sites is a major part of annual expenses for road infrastructure companies. Frequency and scope of maintenance and repair works depends on the vitality of the steel elements affected by the adopted design standards, the quality of the construction, the established quality of maintenance, also are associated with corrosion protection and aesthetic appearance. In practice, methods and solutions are being sought to increase the efficiency of incurred expenditures and reduce the costs of maintenance of steel structures [3, 7, 12].

In many EU documents promoting sustainable development under the Europe 2020 strategy, LCC (Life Cycle Cost) is the basis for decision making. It involves calculating the total cost of the product, an object, a service generated from the acquisition of raw materials to the waste disposal, taking into account the phase of design, installation, operation, maintenance, recycling or disposal.

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There are two main groups of LCC analysis methods [4, 14]:
1) a simple, easy-to-use comparison that allows to choose the optimal variant without discounting,
2) a complex, including the analysis of discounted cash flows from assembly to decommissioning, integrating various life cycle costs (maintenance, repairs, inspections, dismantling).
3) The choice of the appropriate LCC calculation method depends on the nature, scope and complexity of the project.

The main factors to be taken into account when determining the cost of maintaining steel barriers are [4]: the applied corrosion protection system, winter, summer period, road conditions - the traffic category (road type, average daily vehicle traffic, permissible speed), barrier distance from lane edge, number of lanes, local macro and micro environment and location of the element. Traffic intensity increases the number of errors committed by drivers, and as a result falls out of the lane and collides with the barrier. The importance of the road in the transport system increases the standard of maintenance in winter. In the winter time, it is necessary to frequent snow removal and use of means to eliminate slipperiness. This contributes to the increase of corrosion factors in the vicinity of the road and reduces the durability of the corrosion protection of steel structures. The cost of life cycle barriers is also affected by the number of repairs carried out. The risk of impact of vehicles on the barrier (frequency and range) depends, among others. from: degree of traffic on the road (eg barrier distance from the roadway), road condition (eg wet, slippery road surface). The LCC analysis assumes average operating conditions of barriers and average costs.

The total costs incurred in the lifecycle of a steel structure include: costs of acquisition and ownership. Purchase costs are mainly investment costs - purchase (i.e. the design and manufacture) and assembly. Costs of ownership include maintenance, overhaul, disaster recovery, but also the cost of decommissioning. In practice, in many cases, the cost of ownership exceeds acquisition costs.

4. THE SUBJECT OF ANALYSIS

The steel barrier structure installed on the bridge object and on the driveways was analyzed (Fig. 1).

Three anti-corrosion protection coating systems were considered:
1) a metallic coating of approximately 85 μm made by the hot dip galvanizing immersion process (marked as I);

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2) the three-layer paint coating made on the basis of liquid paints with total thickness adjusted to the corrosive conditions of the operating environment (marked as II),
3) double protection consisting of a zinc coating of approximately 85 μm and double layer coating of approximately 150 μm, which serves as an additional corrosion protection (for zinc coating) but also provides the appropriate color qualities of the object (marked as III).

Each of the mentioned coatings should meet the safety requirements for a period of fifteen years, which is required by the contracting authority in the technical specification of the construction work contract.

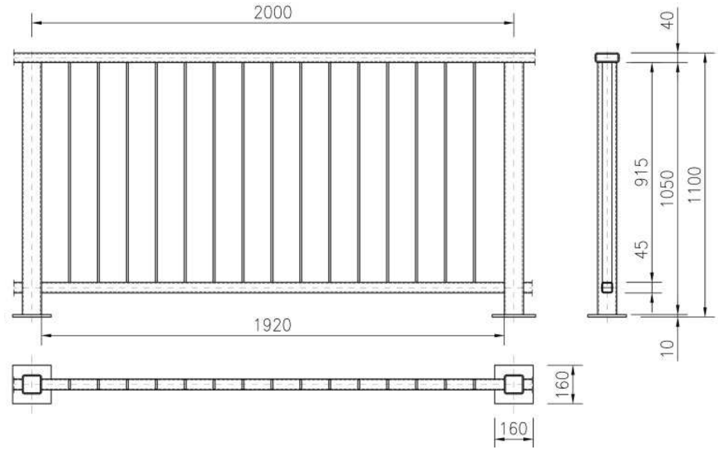

Fig. 1. The analyzed steel element

On the other hand, the steel element should provide safe operating conditions at least for the lifetime of the object, i.e. 100 years.

5. ESSENTIAL REQUIREMENTS FOR PROTECTION

When analyzing the advantages and disadvantages of anti-corrosion coatings protecting steel components of engineering structures, should take into account the period of their durability, which provide full protection, but also the economic aspect. It is important to compare the costs incurred during the element assembly and the protective coating with the costs generated during operation. The life cycle cost of a steel element, including the type of corrosion protection, includes the cost of its performance and the costs of renewal, repair, (within the specified range) or rework (to the full extent).

When analyzing the total cost of life of a particular type of corrosion protection generated in the long run (e.g. 30 years), it should also be considered in terms of durability.

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6. THE ANALYSIS OF OPERATION COST OF ANTI-CORROSION PROTECTION SYSTEMS

The authors have analyzed the use of the three anti-corrosion protection systems described in Chapter 2. The following assumptions were made:

- lifetime: 30 years;
- discount rate: 1.75%;
- for systems II and III every 5 years the work is carried out on cleaning, repair and restoration of anti-corrosion coatings (jet cleaning, washing, degreasing, painting) on 5% of the structure surfac;
- every 15 years work is done on blasting, cleaning, degreasing and painting on 20% of the barrier surface and painting the top coating on 100% of the barrier surface.

The analysis, for each of the three protection systems, also includes the annual discounted cost of washing.

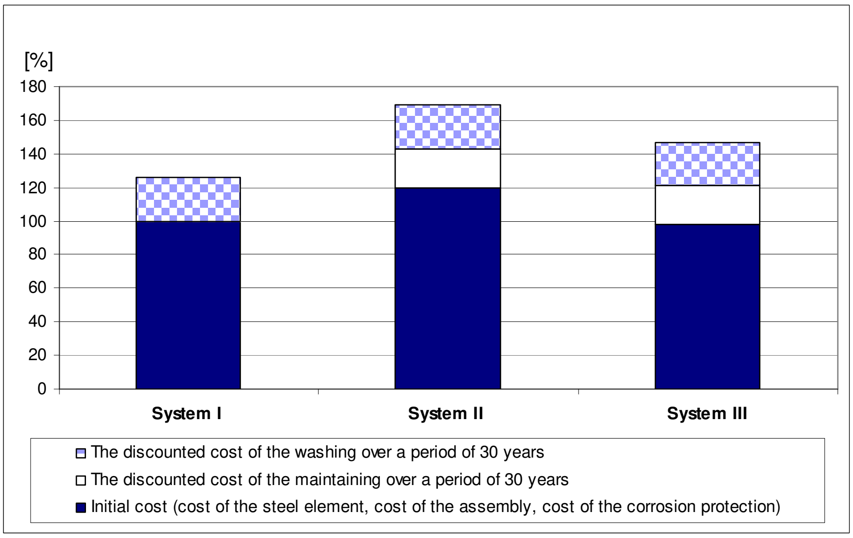

Fig. 2. The discounted cost of manufacturing and maintaining steel components protected by three different technologies

The results of the analyzes (Fig. 2) indicate that only initial investment with the most expensive anti-corrosion protection is included in system II, subsequently I and III. Taking into account the costs associated with maintaining steel barriers over a period of 30 years - the most expensive solution is system II, then III and I. In the longer term, anti-corrosion protection in the form of paint coatings (systems II and III) are more expensive solutions. It determines the fast aging of the protective coatings - which lose their elasticity, scratch out, crack and peel,

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resulting in significant reduction in their durability. In practice it means that every 4-7 years laborious maintenance and repairs in the form of applying new coatings must be repeated. For this reason the costs of painting to grow over time. The cost of protection of a steel structure in the form of a galvanized coating remains unchanged for a longer period of time (only beginning costs, without costly maintenance). Taking into account the total cost, i.e. the initial cost and the 30-year maintenance period of the steel barriers protected in the three systems, the cheapest solution is system I - the galvanized but not painted barriers.

7. CONCLUSIONS

The analysis of the subject literature, the author's own experiences and the LCC analysis justify the formulation of the following conclusions, statements and recommendations.

1) The corrosion protection in the form of anti-corrosion paint coatings made on non-galvanized and galvanized steel elements are more expensive solutions compared to the use of protection only in the galvanizing form.
2) The fast aging of the paint coating significantly reduces its durability during the operation time, due to the need for expensive and frequent maintenance and repairs in the form of new repair coatings.
3) The LCC analysis has confirmed the long-term financial benefits to the user due to the use of corrosion protection only in the form of a zinc coating made by the hot dip galvanizing technology.
4) Maintaining steel elements protected by anticorrosion coatings, in the long run, generates much higher expenses incurred by the property manager and owner.
5) Choosing the right solution, from the ones considered in the article, in practice will increase the efficiency of expenses incurred during maintenance of steel elements and prolong their service life.
6) The authors hereby point to the need to use the LCC analysis in the investment planning process.
7) The application allows to make the optimum choice in terms of the total cost of a given solution, taking into account both the investment costs and the costs of operation.
8) An important element of the approach presented in the article is to familiarize both designers and decision makers with the planned investments, with the conditions of maintenance work for steel components and associated costs.
9) This also includes knowledge of the life-cycle costing method, which is a tool for supporting investment decisions, indicating the optimal solution at the design stage.

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ANALIZA KOSZTÓW ROZWIĄZAŃ ZABEZPIECZENIA ANTYKOROZYJNEGO NA STALOWYCH ELEMENTACH BARIER MOSTOWYCH W KONTEKŚCIE ŻYCIA OBIEKTU

Streszczenie

Materiał stalowy cechuje się łatwością obróbki i niskim kosztem wytworzenia. Zasadniczą jego wadą jest jednak duża podatność na korozję, która jest szczególnie intensyfikowana przez warunki eksploatacji w obszarze pasa drogowego. W zależności od kategorii drogi oraz jej lokalnego położenia, środowiskowe i eksploatacyjne czynniki destrukcyjne mają różne nasilenie. W związku z powyższym wzrastają początkowe I eksploatacyjne koszty zastosowania tego materiału, związane z koniecznością wykonywania odpowiedniego zabezpieczenia antykorozyjnego. Powłokowe i metalizacyjne zabezpieczenia antykorozyjne także podlegają procesom destrukcji w czasie, co powoduje konieczność okresowego ich odnawiania, w celu zapewnienia właściwej ochrony nośnym elementom stalowym. W artykule prezentuje się analizy rachunku kosztu cyklu życia elementów bezpieczeństwa stosowanych na obiektach mostowych przy zastosowaniu różnych wariantów zabezpieczenia antykorozyjnego, narażeń korozyjnych i ich wpływu na koszty użytkowania i utrzymania elementów stalowych barier drogowych. Na przykładzie problemów związanych z użytkowaniem barier oraz generowanych dla każdego rozwiązania kosztów, rozważa się możliwość zastosowania zabezpieczenia jednowarstwowego barier stalowych ocynkowanych zanurzeniowo i zabezpieczenia dwuwarstwowego złożonego z warstwy cynkowej oraz malarskiej powłoki lakierniczej. Ocena dokonywana jest zgodnie z algorytmem szacowania kosztu cyklu życia obiektu (LCC - Life Cycle Cost). Informacje wejściowe prezentowane w artykule zostały pozyskane od firm wykonawczych i zajmujących się utrzymaniem urządzeń bezpieczeństwa ruchu drogowego.

Słowa kluczowe: zabezpieczenie antykorozyjne, koszt cyklu życia, elementy stalowe, metody analizy LCC, koszty całkowite, bariery stalowe

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