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# COMPARATIVE ANALYSIS OF COSTS FOR THE CORROSION PROTECTION OVER THE WHOLE SERVICE LIFE OF STEEL STRUCTURES

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***Abstract:*** *This study is an analysis using "whole-life cost" method of cost implementation and maintenance of corrosion protection of steel structures hall floor type, made by various methods of painting, hot dip galvanizing or duplex combined method for a term life of 100 years, in cases of C3 location in an industrial environment or in a marine environment C5-M. It was highlighted the possibility of reducing costs by 80% and prolonging service life of the steel structure between maintenance interventions if corrosion protection is achieved by galvanizing. Duplex method is more expensive, but can be for aesthetic reasons, especially by providing corrosion protection and sustainable.*

***Key words:*** *whole-life costs, corrosion protection, steel structure, cost reduction.*

## 1. Introduction

Corrosion of steel is a current issue because of its implications on the strength, durability and safety of structures and not only.

They induce costs, raw materials and energy consumption and environmental pollution cannot be overlooked. It is now increasingly clear that to achieve long-term economic development, one solution is to reduce maintenance costs and repairs. For steel structures, this means the application of corrosion protection systems with high durability.

Currently, one of the best technologies that respond to the concept of so-called BAT (Best Available Technology) is hot dip galvanizing.

The advantages of thermal hot-dipping method as corrosion protection of steel and iron products are the following:

- zinc layer is not flammable [3], [4], [17];
- minor degradation (hitting or scratching) does not determine the loss of protection and does not require the recovery of the coating, due to the sacrificial anode of zinc to iron [4], [14], [15];
- by galvanizing between coating and substrate is achieved particularly strong link called intermetallic contact, resulting in an extremely high adhesion [10], [14], [15];
- it is an environmentally friendly technology: meets the requirements of

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environmental protection, is not using solvents, zinc and hot-dip galvanized steel can be recycled and reused and resulting by-products from thermal hot-dipping and/or recycling of zinc are materials that can be used as such a raw material in other industries [2-6];

- waste and emissions from thermal hot-dipping can be easily neutralized and returned in natural cycles (wastewater) or recovered and returned in technological process (gaseous emissions are returned in the technological flow, recovering the heat) [1], [2], [6], [7], [8];
- anticorrosive protection by galvanizing occurs through two mechanisms: by pellicular protection, alike paint films, which creates a barrier between corrosive agents and the steel substrate and cathodic protection, because of the role of sacrificial anode of zinc to iron [4], [10], [13], [17];
- hot dip galvanizing protects steel structures for several decades, thus reducing maintenance costs [1], [2], [16];
- literature indicates a period of about 70 years in which steel elements protected by galvanizing does not require maintenance costs and repair of corrosion protection [7], [9], [10], [11], [13], [15].

The purpose and objective of this paper is to identify and demonstrate the benefits in terms of reducing costs throughout the lifetime, when using corrosion protection by galvanizing of steel structures compared to other methods, namely painting with various products.

In the literature there are studies on the costs of different technologies for corrosion protection of steel structures, but, until now, was not carried out such a comparative analysis.

## 2. Methodology

The international literature indicates several ways of estimating the costs (definitive, parametric or by analogy) [12] respect to realization and maintenance of structures of any type, by default of steel structures.

The method for estimating whole-life cost is defined as the sum of the costs of a structure, including: design, construction, service, maintenance, repairs and post-use (decommissioning, recycling) at end of their service.

Estimated costs of a steel structures, its lifetime includes design costs, manufacturing costs of the structure to achieve corrosion protection costs, costs of maintenance and repair of the structure, respectively the costs of corrosion protection and post-use (Figure 1).

For a certain steel structure design and execution costs are constant and execution of corrosion protection costs, costs of inspection, maintenance and repair varies depending on the chosen method of corrosion protection and its effectiveness.

This study examined the cost of production, maintenance and repair of corrosion protection for steel structure,

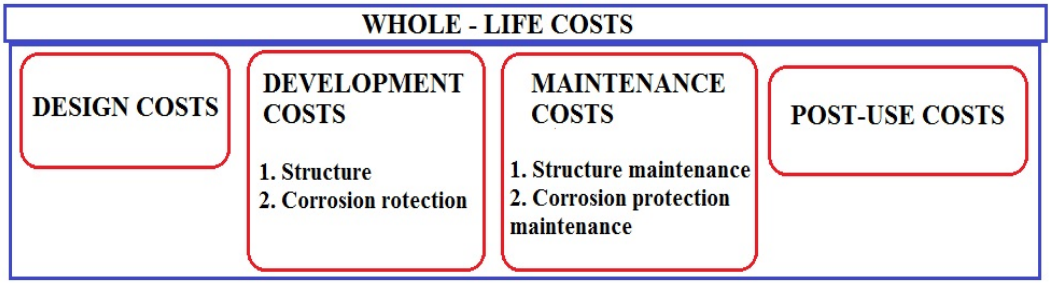


Fig. 1. *Whole-life costs - principle*

through a parametric estimation based on data from the literature, based on previous experiences, and based on information provided by EGGA (European General Galvanizers Association), AGA (American Galvanizers Association) and ANAZ (National Association of Zincatorilor of Romania), compared to the US average prices recorded in 2012-2014 [18], [19], [20].

## 3. Results and Discussion

The aim of this paper is to highlight the economic benefits, respectively reducing costs, if hot-dip galvanizing protection is used for a steel structure, compared to different methods of painting. For this purpose was considered the particular case of a steel structure, floor type, below 15 m in height, with total area of 1000 m², designed for a lifetime of 100 years, located either in industrial environment with high environmental corrosivity, corrosivity class C3 or in a marine environment, with increased degree of corrosion class C5-M. Considering the constant cost data from the design and manufacture of steel buildings with ground location, with manpower, was appreciated that the corrosion protection method and its maintenance will bring *variable costs*.

More parameters were estimated in terms of costs, the time between intervention and their number depending on the type of corrosion protection and environmental corrosivity. The rate of inflation was considered constant throughout the life of the project, respectively 1% / year. Costs were expressed in EURO/m².

Corrosion protection possibilities considered for this study are presented in Table 1.

*Types and component corrosion protection systems* Table 1

| Corrosive environment | Type of corrosion protection |
|---|---|
| Industrial, environment C3 | Hot-dip galvanizing with 100 µm minimum DFT |
| | 3-Coat system comprised of Alkyd/Alkyd/Alkyd with 150 µm minimum DFT |
| | 3-Coat system comprised of Epoxy/Epoxy/Epoxy with 250 µm minimum DFT |
| | Duplex system comprised of Hot-dip galvanizing with 100 µm minimum DFT and Alkyd/Alkyd/Alkyd with 150 µm minimum DFT |
| | Duplex system comprised of Hot-dip galvanizing with 100 µm minimum DFT and Epoxy/Epoxy/Epoxy with 250 µm minimum DFT |
| Marine, aggressive, C5-M | Hot-dip galvanizing with 100 µm minimum DFT |
| | 3-Coat system comprised of Alkyd/Alkyd/Alkyd with 150 µm minimum DFT |
| | 3-Coat system comprised of Epoxy/Epoxy/Epoxy with 250 µm minimum DFT |
| | Duplex system comprised of Hot-dip galvanizing with 100 µm minimum DFT and Alkyd/Alkyd/Alkyd with 150 µm minimum DFT |
| | Duplex system comprised of Hot-dip galvanizing with 100 µm minimum DFT and Epoxy/Epoxy/Epoxy with 250 µm minimum DFT |

*DFT - Dry Film Thickness

The results concerning estimations of production and maintenance cost, of corrosion protection types analysed and, depending on the corrosiveness of the environment, are presented in Figures 2-7.

In Figure 2 are graphically represented production costs for all the analysed corrosion protection systems. It is noticed

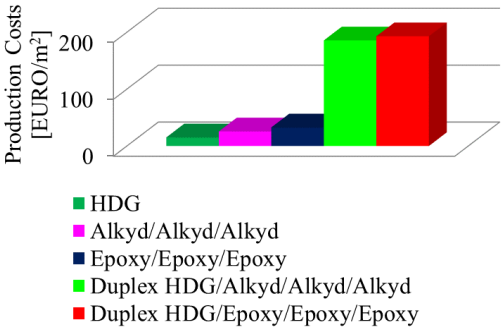


Fig. 2. *Production costs of corrosion protection*

that hot dip galvanizing induce lower costs but comparable to those of an 3 layers alkyd paint and approximately half than in the case of 3 layers an epoxy painting. Obviously, the cost of achieving duplex systems is greater because cumulated costs for hot-dip galvanizing with costs of subsequent surface treatment and painting. However, there are many cases when, for aesthetic reasons, but not only, duplex protection system is preferred, although it is more expensive.

At present, the high cost is due to the alignment of classical painting method to the European environmental directives, which require additional environmental protection measures and, thus additional costs, if these materials are produced and used [8].

In Figure 3, predicted maintenance costs of corrosion protection, during the designed lifetime (100 years), are presented. They take into account an annual inflation rate of 1%. Initially, the cost curves start at approximately equal values, with the exception of those characteristic to duplex systems, fact that is due to their high cost of production. Evolution in time, however, is heavily influenced by two parameters: the type of coating and environmental corrosivity.

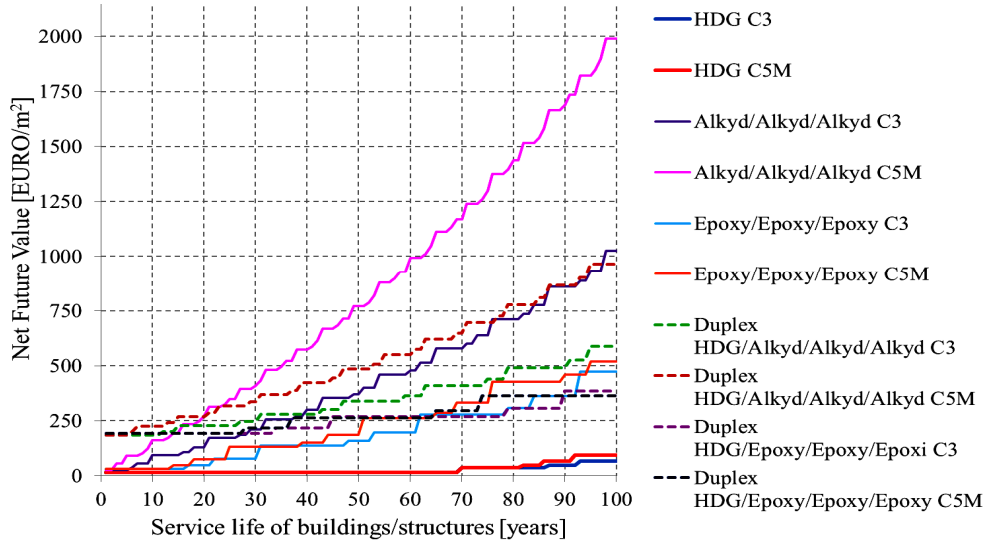


Fig. 3. *Evolution of corrosion protection costs over the entire lifetime*

Looking at this diagram with the graph shown in Figure 4, each behaviour can be explained for each type of corrosion protection system.

Estimative cost curves developed by alkyd paint system, both C3 aggressive environment and in aggressive environment C5-M have many pick-sites, at short intervals and have a strong upward trend.

This is due to the low strength of the coating and the numerous interventions inspection, maintenance and repair that

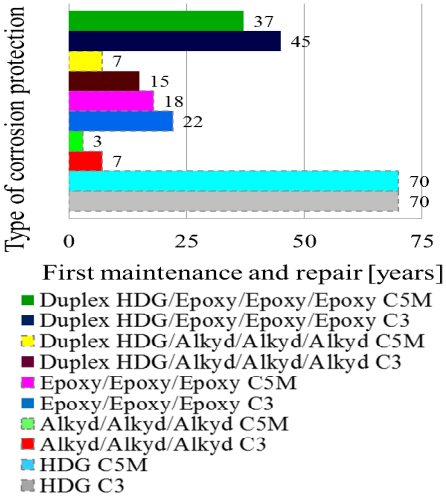


Fig. 4. *Period that occurs after the first intervention of maintenance and repair*

are necessary: In corrosive environment C3 first intervention is required after 6-7 years, and in corrosive environment C5-M, after 3 years and a major repair after only 5 years from the original painting.

Representative curves made by epoxy paint system, in the two considered corrosive environments (C3 and C5-M) shows an upward trend lower over time, but also exhibit high levels of cost with few levels of constant. However, in case of corrosive environment C3, first inspection intervention and minor repair is required after 17 years, and only after 22 years from the application system major repairs are required. In case of corrosive environment C5-M these interventions should be carried out in a shorter period, respectively after 14 years and 18 years of painting epoxy. Compared with alkyd protection system one can observe a real improvement, reducing costs throughout the lifetime and increasing the length of time between interventions, thus prolonging the effective use of the structure.

In case of duplex protection system by hot dip galvanizing - alkyd coating, due to the low strength of alkyd film, is observed that the diagram of costs estimation is similar to that achieved by alkyd paint system. It should be emphasized that, in time, occurs only the damaging of the top layer, respectively alkyd paint film, while the lower layer, covered by galvanizing, is able to perform the necessary corrosion protection. Maintenance costs for this type of protection are significantly lower, peaks on the diagram appear more for aesthetic reasons.

Charts for estimation costs of hot dip galvanizing duplex system - epoxy coating system keeps the types of characteristic diagrams of the corrosion protection system by epoxy, but being positioned at lower cost values. It is remarkable the extension in time of the constant increments costs, indicating an extension of the duration between interventions, interventions that could be yet necessary, again, especially for aesthetic reasons.

Anticorrosive protection by galvanizing shows estimated development cost curves at the lowest values. Firstly this is because production costs less and, secondarily, but very important, due to the fact that for 70 years from the achieved coating, it does not require maintenance costs, as indicated by the literature.

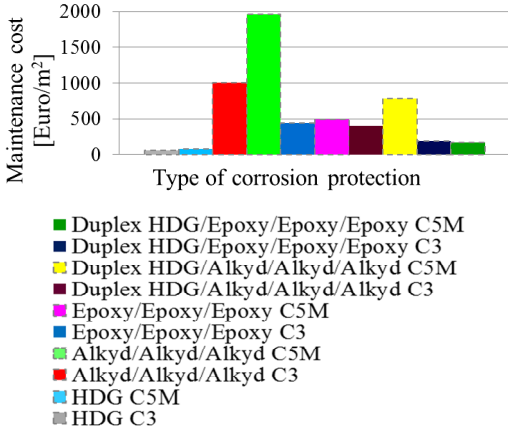


Fig. 5. *Costs of maintenance and repair of corrosion protection, depending on the corrosiveness of the environment, on the designed lifetime*

Based on the above discussion, in Figure 5 are graphically represented the estimated costs for the maintenance, without taking into account the cost of production for discussed corrosion protection systems, in aggressive environmental conditions C3 respectively C5-M. It is noticed that a higher environmental corrosivity induce additional costs, regardless of the type of coating.

On the other hand, considering the number of maintenance interventions required (Figure 6) costs are strongly influenced, increasing with the number of maintenances.

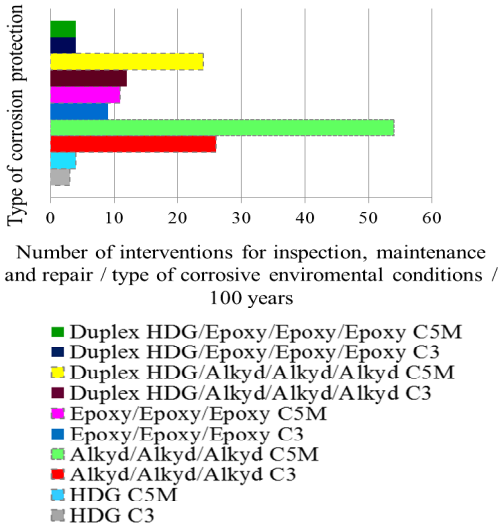


Fig. 6. *Number of maintenance interventions required, depending on the corrosiveness of the environment, on the designed lifetime (100 years)*

Thus, from Figures 5 and 6 it can be said that the poor quality and expensive anticorrosive protection is the protection with classic alkyd painting. These, though are apparently cheap, do not have the necessary capacity to ensure sustainability of the anticorrosion protection in time and involves high costs for materials, labour and stop of structure exploitation for frequent repairs. Even in the case of choosing the duplex system is not preferred that the zinc layer is coated with alkyd products.

Even if corrosion protection is maintained due to thermal hot-dipping, costs imposed by aesthetic criteria are greater.

A more convenient variant in classical painting systems, respectively duplex systems is the use of epoxy.

In calculating the profitability of a corrosion protection system is preferable as little maintenance and a longer period between these, favouring a longer period of use of the steel structure, increasing the possibility of making profit. These criteria are best met by galvanizing.

Reporting the whole-life costs of corrosion protection obtained by painting techniques or duplex at the similar costs induced by hot dip galvanizing it can be observed that for a life expectancy of 100 years of a steel structures and depending on the aggressiveness of the environment, these costs can be reduced by up to 75-80% of their value (Figure 7) by galvanizing.

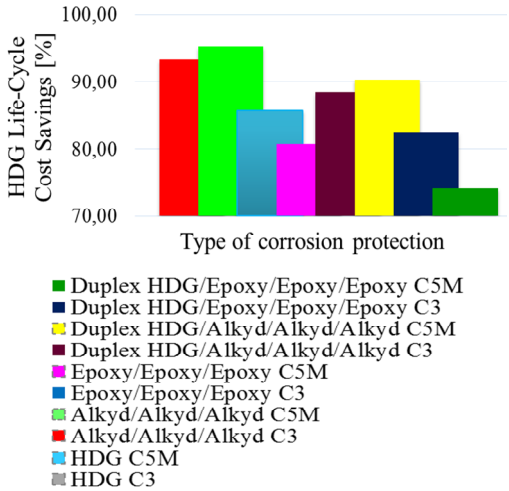


Fig. 7. *Reducing costs during the lifetime of the considered systems when using corrosion protection by galvanizing HDG*

## 4. Conclusions

This study was conducted to compare costs that involve various methods of corrosion protection of a steel ground floor hall type structure, considering its location in the industrial environment C3, respectively marine environment C5M. Based on the literature were highlighted the advantages of thermal hot-dipping which contributes essentially to the reduction of the number of interventions required for maintenance and repair and, implicit to the *whole-life costs*. On this basis we can say that:

- costs of realization of corrosion protection by galvanizing are slightly lower than those of the alkyd paint protection and half the costs of painting epoxy;
- throughout the lifetime of the steel structure, because in the first 70 years hot dip galvanizing coating (HDG coating) does not require interventions, costs are low compared to the other methods analysed either require interventions cheaper but more often, either require more rarely interventions, but more expensive;
- alkyd coating system of corrosion protection proved to be the most expensive, although apparently initially was considered a cheaper method. Even in the case duplex system including alkyd coating, maintenance costs are greater due to aesthetic implications;
- epoxy coating is a compromise solution, having a better behaviour than alkyd coating. Epoxies are relatively expensive, but reduce costs mainly by lower frequency of maintenance interventions and repair of corrosion protection;
- duplex method has a high production cost but offers various aesthetic possibilities and good corrosion protection due to substrate layer deposited by galvanizing. Though, Due to the need for regular maintenance of the outer layer (alkyd or epoxy), costs throughout the lifetime of the anticorrosive protection is higher than in hot dip galvanizing method.

Using *whole-life costs* has revealed that hot dip galvanizing is the most cost effective method of anticorrosive protection being possible to reduce costs by 75-90% comparing to the other analysed methods, but offers limited aesthetic options.

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