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Life Cycle Costing of Structures Fabricated from Carbon and Stainless Steel

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Abstract- **Historically, the choice of structural materials has been influenced by the expense of the initial construction. Nevertheless, rising pressure on the construction sector to assess projects' long-term financial and environmental impacts is driving a more comprehensive approach. As a result, materials with higher starting costs but lower expenses over the life cycle of a construction project are gaining popularity. In this study, the life cycle costs of structures made of two such metallic materials (steel made of stainless and steel made of carbon) were investigated. Two building applications are studied: a typical administrative structure and a bridge. The initial construction cost per ton ratio (steel made of stainless: steel made of carbon) was calculated to be 4.0:1.0. Going of follow a preparatory structural design to current European design guidelines that took into consideration material densities and structural features (stiffness and strength), it was discovered that steel made of carbon provides the most competitor solution for both the typical administrative structure and the bridge on an initial cost basis. However, when additional life cycle expenses such as maintenance, end-of-life expenses, and the residual value of the structure are taken into account (appropriately deducted to current values), the findings demonstrate that steel made of carbon provides the most competitor life cycle solution for the typical administrative structure but the costliest life cycle solution for the bridge. Generally, steel made of stainless is believed to provide higher competitive solutions than steel made of carbon for bridges and uncovered sections of building structures over their full life cycle.**

Keywords: **Life cycle costing, whole life costing, stainless steel, carbon steel, material properties, and steel structure**

1. INTRODUCTION

When selecting materials, there is an increasing recognition that life cycle (or entire life) expenses, not only initial construction expenses, should be addressed. Even if the initial material prices are higher, experience suggests that adopting a rust-resistant material to minimize future maintenance, outage, and repair is a more expenses choice. Life cycle expenses are considered [1: 4]:

- Initial construction expenses
- Maintenance expenses
- Landfill reduction and recycled material
- Lifespan and environmental impact

According to the category of steel made of stainless, a steel structure made of stainless manufacturer's initial raw construction expenses is much more than that of a comparable steel made of carbon product. Nevertheless, reducing corrosion-resistant coatings may result in early cost reductions. The use of high-strength steel made of stainless can minimize material needs by lowering section size and total construction weight, resulting in lower initial construction expenses. Additionally, by avoiding the requirement for covering maintenance or part removal owing due to rust, considerable long-term maintenance cost reductions can be realized [1].

Stainless steel's strong corrosion resistance allows for decreased inspection frequency and costs, as well as lower maintenance expenses and a longer lifespan.

Steel made of Stainless has a relatively high cash value (the value of a building at the end of its life), however this is usually determining factor for a long-life construction (for instance, over 50 years). Scrap is deposed in the environment and recycled into new steel due to the high remaining scrap value, and end-of-life (EOL) rates are relatively high. Steel made of Stainless companies employ all available scrap, although the material's overall average service life of 20 to 30 years restricts scrap supply. For all category of steel made of stainless, the recycled content is typically at least 60%. Steel made of Stainless is 100% recycled and may be used endlessly to create high-quality steel made of stainless [1].

To bring all expenses to current-day values, life cycle costing employs the conventional accounting theory of discounted cash flow. Prices, bank rates, taxation, and perhaps an attribute component are all factored into the discount rate. This enables a true assessment of the various possibilities as well as the possible long-term benefits of utilizing stainless steel over other material choices.

Life cycle cost (LCC) analyses were undertaken in this study to determine financial fields feasibility of these different metals in construction and as an encouragement to capitalize on the environmental benefits that come with their endurance. The study focuses on the costs directly related to the two structural metallic (stainless steel and carbon steel) materials under consideration. The expenses used in the research were obtained from the latest current available sources, including estimates from manufacturers and values provided in study documents that will be described for each specific building studied. Sensitivity experiments were performed to demonstrate how the findings of the study may alter owing to modifications in the variables used. LCC is used in this study for two different building cases: a typical administrative structure and a bridge. These cases varied in size, average life span, environmental good rust resistance, maintenance needs, expenses of disturbed usage, and funding method [1: 4].

Abbreviations

EOL	End-of-life
LCC	Life cycle costs ($)
IC	Initial construction costs ($)
AC	Additional initial costs ($)
MC	Maintenance and inspection expenses ($)
E	End-of-life expenses ($)
R	Residual value of construction ($)
i	Discount rate (%)
t_i	Time of Intervening (year)
t_K	Total design life (year)
σ_y	Material tensile stress (MPa)
$\sigma_{0.2}$	Material tensile stress at 0.2% (MPa)
E	Young's modulus (MPa)
A_o	Strain (%)
ρ	Density (t/m^3)
α	Thermal expansion 20-100^{O}C ($10^{-6}/^O$C)
k	Thermal conductivity (W/m^{O}C)

2. LIFE CYCLE COSTING (LCC) ANALYSIS METHOD

Eq. (1) summarizes the life cycle cost estimates performed in this study, as well as the specific issues and expenses considered. As demonstrated in Eq. (1), initial construction costs (IC) and additional initial expenses (AC) are considered costs of capital, whereas maintenance and inspection costs (MC), end-of-life expenses (E), and the residual value of construction (R) are eventual expenses that are reduced to current value that use the discount rate (i). Although maintenance and inspection costs are decreased throughout the maintenance year (t_i), end-of-life expenses and the structure's resale value are reduced over the whole design life (t_K) (in year) [2, 5].

$$LCC = IC + AC + \sum_{0}^{t_K}\left(\frac{MC}{(1+i)^{t_i}}\right)+\left(\frac{E}{(1+i)^{t_K}}\right)-\left(\frac{R}{(1+i)^{t_K}}\right) \quad (1)$$

Where:
The initial construction costs (IC), involve:
- Basic ingredients (alloying members)
- Alloy production (alloying members)
- Member fabrication

And the additional initial costs (AC), involve:
- Resistance to corrosion
- Protection against fire

The maintenance and inspection (MC), involve:
- expenses of material for fire and rust resistance fixes
- Structure use has been interrupted

The end-of-life costs (E), involve:
- Destroy/ Disassembly

Finally, the residual value of construction (R) involves recycle

The discount rate for this study was set at 5.0%, as suggested the Book of Green [6]. This data is taken from Annexure 6 of the Book of Green. The government suggested this discount rate to examine expenditures in all government budget efforts, and the department for transport uses it in examining bridges with time spans of thirty years or fewer. For longer time periods, reduced interest rates may be applied (e.g., a 3.5% discount rate is recommended for 31–75 years). For uniformity, the 5.0% discount rate has been used in all of the life cycle analyses given here, and a sensitive analysis performed as part of the research exposes the effect of adopting a various discount rate.

3. MATERIAL PROPERTIES

The life cycle performance of two metals, steel made of stainless, and steel made of carbon, was investigated in two civil applications: a typical administrative structure and a bridge. Each material's usual structural categories have been chosen (see Table 1). The analyses cover a variety of relevant aspects, which are discussed in the following subsections. Table 1 summarizes the major material features of steel made of stainless and steel made of carbon.

4. STRUCTURAL APPLICATIONS OF (LCC) ANALYSIS

The life cycle expenses of two building (a typical administrative structure and a bridge) made of the two chosen civil metal materials are discussed in this section. Four-story, flat-roofed typical office structure. The structure's overall area was 650 m^2 on plan, with an inter story height of 3.0 meters. The main beams had a span of 6.0 meters, the secondary beams had spans of 6.0 meters. The second life cycle costing analysis was based on a standard plate girder highway bridge with a span of 30.0 meters and width of 10.0 meters. Based on current material costs for two structural materials (steel made of stainless and steel made of carbon), the analyses yield an initial material cost per ton ratio of 4.0: 1.0. The first anticipated building material expenses for the structure and bridge were calculated using the expenses of material per ton, densities, and an initial of the principal components of the buildings (in line with current European building design guidelines [7, 8] shown in Table (2)). The following sub-sections provide a brief overview of the structures as well as a discussion of the life cycle costing results.

Table 1. Properties of material steel made of stainless, and steel made of carbon [1, 7 and 8]

	Stainless steel	Carbon steel
Grade	1.4301/1.4307 (304/304L)	S275
Material tensile stress σ_y or $\sigma_{0.2}$ (MPa)	230	275
Modulus of elasticity E (MPa)	200000	210000
Strain A_o (%)	45	24
Density ρ (t/m^3)	7.90	7.85
Thermal expansion 20-100^{O}C α (10^{-6}/m^{O}C)	16×10^{-6}	12×10^{-6}
Thermal conductivity k (W/m^{O}C)	15	53
Total amount of recyclable material (%)	70	60

A. Typical Administrative Structure

The life cycle costing research was based on a conventional, four-story, flat-roofed typical office structure described before. A 50-year design life was supposed to be possible. While it is assumed that shielded interior steelwork will require little maintenance, four scenarios were evaluated (two of which allow for corrosion-resistant inspection and maintenance at ten-year periods, supposing an exterior or uncovered building):

- Maintenance expenditures each 10 years, as well as end-of-life destroy.
- There are no maintenance expenditures, expenses, but had end-of-life destroy.
- Maintenance expenditures each 10 years, as well as end-of-life disassembly.
- There are no maintenance expenditures and had end-of-life disassembly.

Table 3 shows the results of the typical administrative structure LCC made of steel made of stainless and steel made of carbon. The expenses represented as a ratio of the total construction expenses for the steel building made of carbon. The initial construction cost of the typical administrative structure made of stainless steel normalized to that of the steel building made of carbon, was determined to be 4.20:1.00, taking into consideration the construction cost per ton, densities, and building properties. When the additional initial expenses (rust resistance and fire resistance) are included, the initial expenses ratios are 4.34:1.38. These ratios demonstrate that, in terms of initial expenses, steel made of carbon is the most cost-effective choice. When assessing the structure's end-of-life and maintenance expenses, it is possible to see that the durability and residual value of steel made of stainless option expenses savings, but these savings are small when deducted to their present values, and on a life cycle expensing basis, the steel structure made of carbon remains the most economical option for all four cases have been examined. Figure (1a) depicts the collection of normalized life cycle expenses (containing maintenance) over time for the two building materials in the more likely case of structure destroy.

According to the results of the typical administrative structure, the greater initial construction expenses of the steel made of stainless are not compensated by decreased corrosion resistance, maintenance, and decommissioning expenses during the structure's life cycle. This is pretty much true for all low-maintenance solutions. These materials, on the other hand, could be useful in uncovered parts of a building's structure, specifically in hostile environments where maintenance could be greater, and aesthetics may well be enhanced. The exterior bracing system on Helsinki's Sanomatalo structure [5, 9] is a sample of how steel made of stainless has been used in such a situation (Figure (2)).

B. Bridge

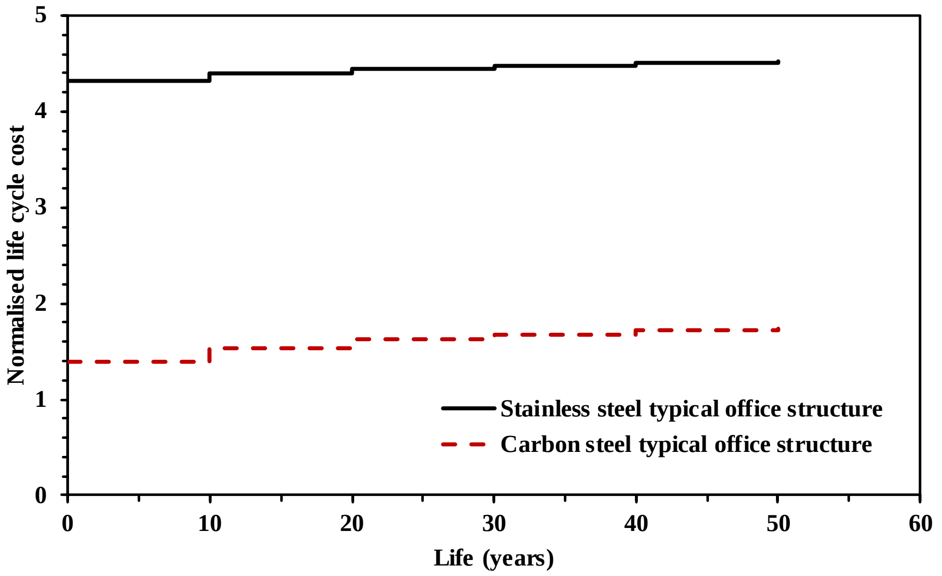
Contemporary bridges are built with a 120-year life span in mind, which, along with the more accessible character of the building components, means that maintenance expenses are frequently a substantially bigger proportion of the entire life cycle expenses than in the case of structures. The total annual expenses of highway overpass repair in the United States (to avoid corrosion), for example, has been estimated to be between 3.67$ billion and 5.79$ billion [10]. According to the same research, the resulting traffic disturbance is estimated to cost 10 times the cost of corrosion prevention in lost productivity. In the second life cycle costing analysis for a standard plate girder highway bridge with a span of 60 meters. The main members were initially sized in accordance with current European design specifications; fatigue due to traffic loads was not taken into account.

Table 2. Data utilized in the LCC analysis for two different types of structures [5]

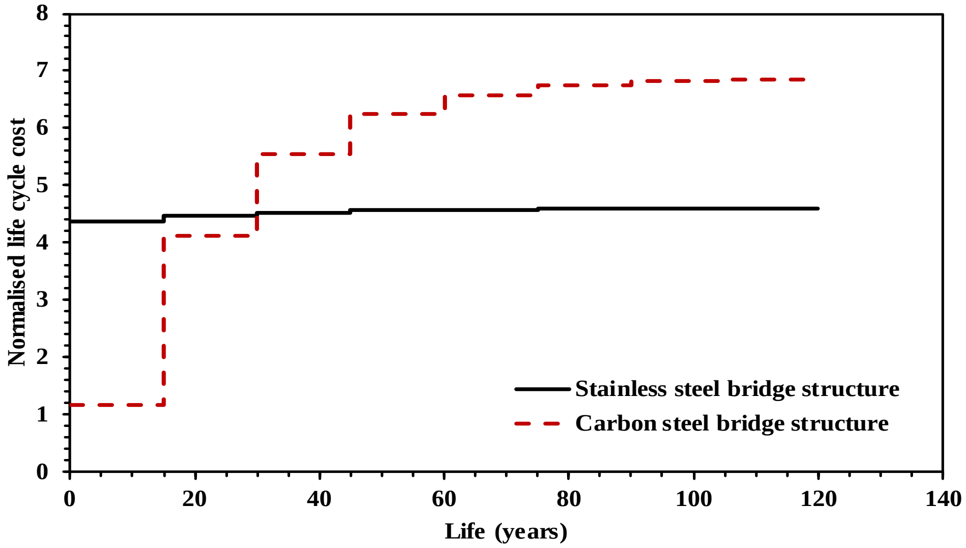
	Stainless steel	Carbon steel
Building code	EN 1993-1-4	EN 1993-1-1
Typical administrative structure		
Total design life (year)	50	50
Initial construction cost ($/ton)	5835	1460
Corrosion resistance ($/m^2)	-	7.20
Time of intervening (year)	10	10
Fire protection ($/m^2)	10.25	20.50
Material recuperation – Destroy (%)	80	80
Cost of Destroy ($/ton)	100	100
Material recuperation – Disassembly (%)	90	90
Cost of Disassembly ($/ton)	200	200
Scrap value refunded ($/ton)	2100	180
Bridge		
Total design life (year)	120	120
Initial construction cost ($/ton)	5835	1460
Corrosion resistance ($/m^2)	-	1250
Time of intervening (year)	15	15
Maintenance intervals (days)	5	10
Traffic control and interruption cost ($/day)	12000	12000
Maintenance cost ($/day)	14000	14000
Decommissioning cost ($/ton)	200	200
Scrap value refunded ($/ton)	2100	180

Table 3. LCC statistics for the typical administrative structure (expenses normalized to initial construction expenses of steel building)

Typical administrative building	Stainless steel	Carbon steel
Normalized weight of building	1.05	1.00
Initial costs		
Construction cost	4.20	1.00
Corrosion resistance cost	-	0.10
Fire resistance cost	0.14	0.28
Total initial costs	4.34	1.38
Maintenance costs (deducted)		
Maintenance	0.13	0.22
Decommissioning costs (deducted)		
Destroy	0.01	0.01
Disassembly	0.03	0.03
Residual value (deducted)		
Value refunded (Destroy)	0.23	0.02
Value refunded (Disassembly)	0.28	0.02
LCC		
Total cost containing maintenance (Destroy)	4.53	1.73
Total cost excluding maintenance (Destroy)	4.51	1.71
Total cost containing maintenance (Disassembly)	4.55	1.74
Total cost excluding maintenance (Disassembly)	4.53	1.72



(a) Typical administrative structure



(b) Bridge structure

Figure 1. Cost accumulation across the life cycle of the buildings

Two scenarios were considered: one that included maintenance and one that did not. Table 4 displays the findings of the life cycle costing research. The initial construction expenses ratio for the bridge was determined to be 4.40:1.00, and the material weight ratio for each structure was determined to be 1.10:1.00. Whereas steel bridges made of stainless were found to be 110% the weight of steel bridges made of carbon. Figure (1b) depicts the accumulation of normalized life cycle expenses (containing maintenance) over time for the two building materials used in bridges.

The life cycle cost ratio for the first scenario (which contained maintenance) was determined to be 4.596:6.88, steel made of stainless is the most economical choice, whereas steel made of carbon is the least expensive. Steel made of stainless has the least expensive maintenance expenses and the greatest residual value, as a result of which economical life cycle option than steel made of carbon, but it has a higher starting cost. When all maintenance expenditures are excluded, the life cycle expenses ratio is 4.39:1.15; however, the carbon steel structure's performance and life expectancy are visibly compromised, and the no maintenance scenario is untenable.

Figure 3 depicts a steel bridge made of stainless in London at St. Saviours Dock as an example of the usage of steel made of stainless in bridges [5, 9].

5. Conclusions

1- Based on the results, steel made of carbon is the most cost-effective life cycle stainless steel option for typical administrative structures.

2- According to the results, carbon steel is a more cost-effective solution than stainless steel throughout the life cycle of bridges.

3- Overall, it was concluded that in the long run, steel made of stainless may be a more cost-effective option than steel made of carbon for bridges and uncovered parts of building structures.

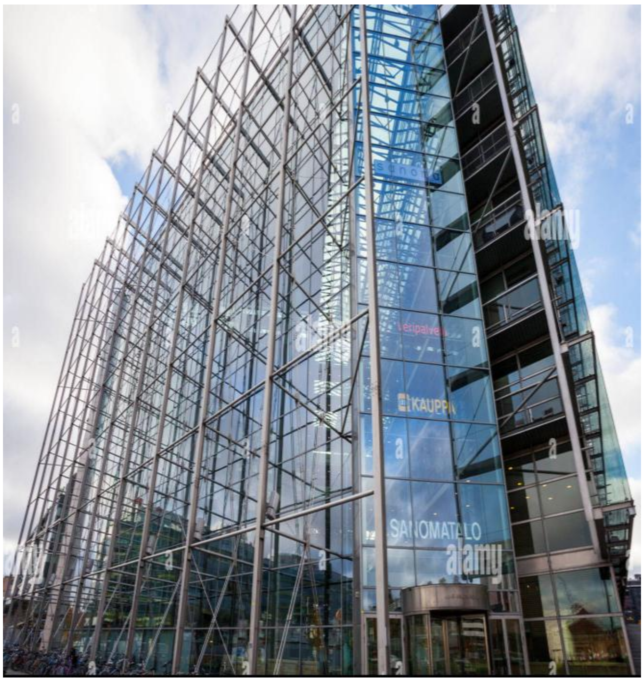


Figure 2. External bracing made of stainless steel, Sanomatalo Structure in Helsinki [5, 9]

Figure 3. Steel bridge made of stainless, St. Saviours Dock, Shad Thames, London [5, 9]

Table 4. LCC statistics for the bridge (expenses normalized to initial construction expenses of metal building)

Bridge	Stainless steel	Carbon steel
Normalized weight of building	1.10	1.00
Initial costs		
Material cost	4.40	1.00
Corrosion protection cost	0.00	0.15
Total initial costs	4.40	1.15
Maintenance costs (deducted)		
Corrosion resistance	0.00	5.33
Traffic control and interruption	0.21	0.84
Total maintenance costs	0.21	6.17
Decommissioning costs (deducted)		
Destroy	-	-
Residual value (deducted)		
Value refunded	0.03	-
LCC		
Total cost containing maintenance	4.596	6.88
Total cost excluding maintenance	4.39	1.15

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