STAINLESS STEEL INFRASTRUCTURE

A lifetime of savings

Nickel
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“Quality is remembered long after the price is forgotten.”

Stainless steel enjoys a strong and enduring reputation for structural durability, corrosion resistance and visual appeal in a wide range of applications and environments. While it may require an initial higher investment when compared with other materials, stainless steel’s unique properties deliver long-term performance and economic benefits including minimum downtime, reduced maintenance costs and reduced environmental impacts.

This publication looks beyond initial project costs and takes account of the total cost of ownership over the life of an asset. The value proposition of stainless steel is demonstrated by a selection of international case studies.

**Life cycle cost considerations**

Life cycle costing assesses all costs an owner incurs over the lifespan of an asset, to help maximise cost efficiency and return on investment. Cost considerations include acquisition, installation, operation, downtime and residual value.

More information regarding life cycle costing principles, components, calculation methods and where to find information can be found in Appendix 1.

**About stainless steel**

Stainless steels are a group of iron alloys with a minimum chromium content of 10.5% (by weight) and a maximum of 1.2% carbon. This content is necessary to ensure the build-up of a self-healing oxide layer — known as the passive layer — which provides the alloy’s corrosion resistance.

The composition of the alloying elements greatly influences the metallurgical structure of stainless steel and defines four main families of stainless steel of which the austenitic stainless steels are by far the most widely used. The most commonly used stainless steel grades are Type 304 (18% chromium and 8% nickel) and Type 316 (16.5% chromium, 10% nickel and 2% molybdenum). Austenitic stainless steels (also named “300-series”) exhibit the following properties: corrosion resistance, aesthetic appeal, heat resistance, low life-cycle cost, full recyclability, biological inertness, ease of fabrication, high strength-to-weight ratio and excellent commercial availability of all product forms.

More information about properties and applications of stainless steels can be obtained from the Nickel Institute at [www.nickelinstitute.org](http://www.nickelinstitute.org).
The benefits of stainless steel

The efficient operation of public infrastructure has a strong effect on the quality of our daily lives. Reliable access to energy and drinking water; the ease of travelling by road, rail, air or water; the safe disposal of waste and sewage—all determine how we live and work. In these sectors, stainless steel plays an important but often unnoticed role.

Proper material selection is a decisive factor for the durability and lifespan of infrastructure. It is the key to maximum availability and low maintenance costs.

The benefits of stainless steel include:

- **Corrosion resistance**
- **100% recyclable**
- **Strength**
- **Durability**
- **High and low temperature resistance**
- **Ease of fabrication**
- **Aesthetic appeal**
- **Hygienic properties**

**Overall cost saving**
High material costs per kg, but usually less material is needed.

**Installation**
Less material, easy on-site installation, no finishing operations needed...

**Recycling**
High value of scrap, high recycling rate

**Operational cost saving**
Sustainable operation

**Lost production**
Minimized lost production costs, no additional society costs
Stainless steel is the material of choice when life cycle costs are considered. These are benchmarked against the material’s unique properties:

**Acquisition**
When compared with mild or galvanized steel for example, stainless steel often has a higher purchasing cost per unit of weight. However, its mechanical and corrosion resistant properties make it possible to use less of the material in many project applications. The cost advantages of specifying stainless steel may not be apparent upfront, however its material benefits deliver the return on investment when whole-of-life project costs are considered.

**Installation**
Stainless steel delivers high quality, durable and lightweight structures. Substantial cost savings around transportation, constructability and man hours per tonne can be realised when less material is used. For example, the use of stainless steel reinforcement bar in bridge structures can significantly reduce the thickness of concrete cover required due to its corrosion resistance and relatively higher tensile strength. This results in a lighter weight structure and easier on-site installation.

**Operation**
Efficient operation of infrastructure is key to the success of any project. Maintenance closures due to poor corrosion performance and disruptions to public accessibility are some important considerations when determining the materials selection at the design and specification stage of a project.

Stainless steel delivers many benefits with its high resistance to corrosion at the forefront. This is due to a chromium-rich oxide film that is formed on the surface of the steel. If the film is scratched or damaged, it rapidly self-repairs in the presence of oxygen, restoring its protective coating.

Mild steels and other materials are often coated or plated for surface protection, however this does not offer the self-repairing mechanism of stainless steels.

**Downtime**
Downtime is an unwanted situation in the operational period of any project. Experience shows stainless steel requires less maintenance and repair than alternative materials, reducing overall downtime.

**Residual value**
Stainless steel is 100% recyclable and has an attractive scrap value due to the presence of nickel and other alloying elements in its composition. There are multiple examples of building refurbishments where stainless steel has been repurposed and reused. The lobby of William Penn Place in Pittsburgh USA, for example, was refurbished 50 years after its construction. Replacing the original stainless steel proved unnecessary.
Case study

Tokyo main-to-meter water line

Non-revenue water (NRW) is a significant problem in the majority of the world’s cities. The total cost of NRW to water utilities is an estimated $39 billion per year. Water scarcity, high water cost, increase in population, droughts and climate change are key drivers for change in many parts of the world.

The water losses, which for many cities are around 20 to 35%, contribute to the depletion of precious water resources. The losses are also costly to the consumer due to intensive water leak detection efforts, required repairs, lost process and pumping energy, wasted water treatment and follow-on costs such as road cave-ins and traffic disruptions. Because of leakage, the whole water infrastructure footprint of a city from intake to storage, pumping and treatment has to be larger (by more than the percentage lost) than what is needed to simply fulfil the water demand. Cost-effective, innovative and sustainable solutions are being called for by the global drinking water sector.

Type 316 stainless partially corrugated tube was first developed as a solution for leakage in Japan.

The corrugated parts offer flexibility of installation, leak-free joints and resistance to seismic effects (where relevant). The stainless solution is helping large cities to significantly reduce NRW and annual maintenance costs. Tokyo, Taipei and Seoul have replaced their service lines on a large scale and some 35+ other Asian cities are following their lead.

Tokyo, for example, reduced its water loss from 15% to 3% after it replaced nearly all its service lines over a twenty-year period. While Tokyo has also taken other measures to reduce water loss, including replacement of water mains, improved detection techniques and speedy repairs, the utility credits the switch to stainless steel service lines for most of the water and cost savings.

Service pipe made of partially corrugated stainless steel (©ISSF, Philippe De Putter)
Tokyo has about 2.2 million connections, distributing 1.54 billion m$^3$ of water in 2018. It was determined that 97% of their repair cases were service line related.

Since the early 1980s, Tokyo has implemented a program using stainless flexible service lines (which was changed to stainless partially corrugated tubes in 1998) and seismic resistant ductile iron mains, as well as improving leak detection, to reduce their water loss rate. The program resulted in:

- reduction from 260 million m$^3$ (15.4%) in 1980 to 50 million m$^3$ (3.2%) of water loss in 2018
- reduction of repair cases from 69,000 per year to 8,000 per year.

The total savings correspond to more than 500 million USD per year, based on the following assumptions: 210 million m$^3$ water saved x USD 2/m$^3$ = USD 420 million / year plus 61,000 fewer repair cases x USD 2,500 / case means USD 152.5 million / year.

The Tokyo case is a key example of how careful material selection (despite being more expensive at the acquisition stage), determined by including all cost aspects over the whole service life, makes a sustainable material such as stainless steel the preferred option. This is not tantamount to being the cheapest material. Moreover, it can be pointed out that the cost of material becomes insignificant, compared to the annual gains.
With a population of 1.3 billion and a land area of around 3 million km², there is no end to the growth and innovation of transport modes in India. Since the first journey in 1853 in India, railways have become one of the most important modes of transportation.

With 16 railway zones and more than 60,000 mainline railcars running, the opportunity for new developments in railcars is immense. Four state-owned coach factories and one public sector coach factory meet India’s entire manufacturing requirements. Awareness regarding high maintenance cost of the existing rolling stock reinforces the need for a long lasting, low maintenance material of construction. A weathering steel similar to COR-TEN® was used since the 1950s. Frequent breakdowns, cost and time for repair as well as shortage in availability of coaches for running trains were the key issues to look for a better coach design.

The Indian government took decisions based on input from the railway organization. Corrosion repair was the main argument for considering stainless steel. A technical know-how agreement was made with a renowned stainless steel based coach maker and the national stainless steel development association (ISSDA). Domestic mills organized ‘know how’ sessions with railways and also organized fabrication workshops with railway coach manufacturers.

With around 5,500 mainline coaches made of stainless steel between 2002 and 2017, the production switched to 100% stainless steel in 2018 at a rate of approximately 6,000 coaches each year. Stainless steel rolling stock now connects a very large country, virtually maintenance-free.

There are considerable savings to be made in terms of Life Cycle Costs (LCC). Appreciable cost benefits arise from: increased life expectancy; increased material strength, providing an inherently higher level of passenger safety; and, most importantly, a higher fire safety. Stainless steel maintains its mechanical properties better at higher temperatures, thus providing enhanced fire resistance.

The most corrosion prone components, like roofs, trough-floors, toilet inlays, bio-toilet digesters, water storage tanks and entrance gangways, are all made in nickel-containing austenitic stainless steel. Only the side and end panels are in painted low nickel-containing utility stainless steel. The use of austenitic stainless steel for the side panels, offering savings on painting, time and maintenance, is under consideration. For export markets, India has also manufactured all-austenitic stainless steel coach shells.

In a mainline coach shell around three tons of austenitic stainless steel and four tons of utility stainless steel are used, which account for 20% of the total coach weight.

Case study

The growth of railway cars in India

Vande Bharat High Speed stainless steel Train (©ISSDA)
These new generation stainless steel coaches weigh less per meter length, can take more passengers, withstand higher speed (160 to 180 km/h), and have a longer life. Safety is increased by reducing the risk of coaches climbing over one another in case of accident. Periodic overhaul is required only once every two years due to the use of stainless steel for the coach shell.

New generation stainless steel coaches have the Head-On Generation (HOG) system for power collection, thus saving energy. More weight saving opportunity is offered by the use of stainless steel instead of weathering steel. As the table details, coaches made of weathering steel weigh 47 tons, whereas coaches that use stainless steel weigh significantly less. This weight reduction originates from the absence of a corrosion allowance on the wall thickness and from better strength offered by stainless steel. The latter property also made it possible to increase coach length.

The use of stainless steel results in energy savings of 7,500 USD / 100 km / coach, as detailed in the table. The 12,000 stainless steel coaches that have been added in 2018 and 2019 enable fuel savings of 90 million USD, just by selecting stainless steel.

The gains obtained from selecting stainless steel for mainline coach shells have been so convincing that the same approach has been used for metro-line passenger cars. In the last 18 years a new avenue for stainless steel rail cars emerged in the form of city metro lines. With most major cities in the country being heavily congested, metro construction has been moving on the fast track. All major cities in India today have metro rail projects in operation or in various stages of construction. The metro coach shells (2,500 by the year 2020) are made in unpainted austenitic stainless steels.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stainless steel</th>
<th>Weathering steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight per coach</td>
<td>40 t</td>
<td>47 t</td>
</tr>
<tr>
<td>Length of coach</td>
<td>23 m</td>
<td>21 m</td>
</tr>
<tr>
<td>Weight per unit length (/m)</td>
<td>1.74 t</td>
<td>2.24 t</td>
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<tr>
<td>Fuel saving per 100 kg per 100 km (international norm)</td>
<td>0.7 litre</td>
<td></td>
</tr>
<tr>
<td>Weight reduction per m length</td>
<td>500 kg</td>
<td></td>
</tr>
<tr>
<td>Fuel saving per coach</td>
<td>500 kg x 0.7 x 23 m = 8,050 litres</td>
<td></td>
</tr>
<tr>
<td>Saving in USD per coach</td>
<td>8,050 x INR 70/75 = USD 7,500</td>
<td></td>
</tr>
</tbody>
</table>

Energy savings in stainless steel coach vs earlier weathering steel coach (ISSDA)
Bridge design from Canada

Transportation authorities spend billions of dollars annually to address concrete bridge deterioration. A key factor is the corrosion of the embedded reinforcement elements caused by de-icing chemicals or marine spray. Design engineers facing the challenge to build better bridges with extended service lives have the option of using more effective corrosion-resistant reinforcement materials such as stainless steel reinforcement bar (rebar).

The long term cost effectiveness of constructing with more durable materials such as stainless steel rebar can be validated with time dependent “life cycle” valuation tools, proving that spending more initially with purpose is beneficial.

The new 3.4 km long Champlain Bridge located in Montreal opened in July 2019. It is a lifeline for residents and businesses carrying over 50 million vehicles a year which represents 25% of the total local river crossings. The original structure, dating back to 1962, was not adequately designed to resist the severe chloride conditions, necessitating frequent repairs. During the period of 2015 to 2017, a total of CAD 250 million was spent rehabilitating the bridge. Traffic disruptions were frequent and lengthy, resulting in significant delays to users. Truck payloads were restricted. There was ample proof of the consequences of using materials poorly suited to the exposure conditions.

Infrastructure Canada did not want to repeat the poor reliability performance of the structure. The objective was to ensure a secure, dependable and long-lasting quality structure. As such, and given the economic importance of the Champlain Bridge, the design service life was set at 125 years. To ensure that the service life was achieved, construction materials with the appropriate durability for the service conditions were required, including the concrete reinforcement.

To determine the most suitable type of concrete reinforcement material for the bridge, material “life-cycle” probabilistic modelling was employed to assess the time-to-corrosion initiation as a function of the chloride loading, concrete mix design, effectiveness of surface treatments and environmental factors.

Three types of steel reinforcement were selected for the probabilistic assessment based on availability and viability:

- stainless
- galvanized
- black carbon

The corrosion modelling concluded that stainless steel rebar had a substantially greater capacity to resist initiation of corrosion than the other types of reinforcement analyzed. The analysis confirmed that the bridge design would ensure a 125 year service life.

A key criterion of the design affecting the reliability performance Infrastructure Canada wanted to achieve was the specification of...
non-replacement of specific bridge elements for 125 years without major planned repairs. This extended service life requirement which was assured by the use of stainless steel reinforcement bar has significant long term “life-cycle” benefits due to cost savings, and greater economic impacts relative to designs with lesser corrosion resistant materials.

The long term operating “life-cycle” cost savings with stainless steel rebar are significant. Designing for durability with stainless steel reinforcement bar may call for a small initial quality “investment”. However the avoidance of the burdensome effort and cost of planning and executing frequent repairs and maintenance to the structure is well in excess of this initial investment. For most applications, the amount of stainless steel rebar represents a very small proportion of the total amount of reinforcement required.

The economic benefits of the new Champlain Bridge include the substantial user costs now averted, which would otherwise be caused by traffic delays from roadway construction had non-stainless steel rebar been used. In addition, the dependability of an open roadway for decades to come has vastly increased the private vehicle and truck traffic capacity, generating substantial economic advantages to the local economy.

The 125-year condition of “non-replacement”, without major planned repairs, was specified for the more exposed zones of the bridge which includes the road deck. The decks were constructed of precast deck panels using stainless steel in the top and bottom mats. Stainless steel was especially important for the more vulnerable “cold joints” of the cast-in-place closure-pour concrete between the panels.

Other parts of the bridge with stainless steel include:

- areas near the expansion joints
- splash zones on the piers and abutments, and
- the cable stay tower above the roadway.
Life Cycle Cost (LCC) analysis helps to determine the most economic material for the fabrication of a product. In almost every capital expenditure decision, the material is selected for a given application based only on price. Over the years, awareness has grown that the cheapest purchase price may not be the most economic choice when the additional costs are considered such as installation, regular maintenance, replacement and decommissioning of the product. In many cases (think of a road bridge), the cost of (scheduled or unscheduled) down-time to industry (lost manufacturing time, wages) and to society (idling vehicles, environmental impact) must be included too.

The “time value” of money (often called the “discount rate”) is a key factor in making LCC analysis. That is why future expenditure (of e.g. maintenance or replacement) is calculated back to “today’s” value. This time value factor is determined by the prevailing interest rate and (indirectly) the inflation rate, accounting for the attractiveness of borrowing (today’s) or saving (tomorrow’s) money. The discount rate is variable over time.

LCC analysis should not be confused with Life Cycle Assessment, which is a similar technique that looks at aspects other than costing. LCA focuses on the environmental impact of the different materials of construction under comparison.

The stainless steel industry offers various online tools for making LCC comparisons between materials. These range from a more intuitive checklist (as offered by the International Stainless Steel Forum (ISSF)), to simple interactive calculation tools (as offered by the Stainless Steel Industry of North America (SSINA) association) or downloadable LCC software (such as offered by the South African Stainless Steel Development Association (SASSDA)).
Appendix 2

About the selection of stainless steels

Efficient grade selection relies on adequate knowledge of the performance required of the steel, cost and available supply. Suppliers can often assist with a successful selection.

For infrastructure exposed to atmospheric conditions, factors such as weather, rainfall, surfaces being exposed or not, minimal requested lifetime, maintenance intervals, availability and price all determine which type of stainless steel is the most suitable for a given application. Although grade selection is not the core subject of this publication, some comments about the materials used in the examples can be offered.

Tokyo’s water distribution service lines are made of Type 316, which contains 10% nickel. This choice offers more corrosion resistance in a wide range of soils than Type 304 would. Tokyo expects service life to be in excess of 100 years. Type 316 stainless steel is essentially inert in potable water, with negligible leaching of alloying elements, and therefore does not affect the water.

The Champlain Bridge in Montreal relies on duplex 2304, which contains 4% nickel. Three possible stainless steel alloys were specified as being acceptable for the intended service. All three alloys would provide sufficient corrosion resistance for 125 years as they all include sufficient levels of chromium and nickel. Type 2304 was selected for cost and availability reasons at the time of bidding.

Indian Rail used Types 304 and 301LN, containing 8% and 7% nickel respectively, for their work hardening potential, offering optimal strength per unit of weight in turn. These grades are easy to work with too.

Since the railcar body is subject to frequent inspection and overhaul, exterior cladding does not require a long service life. This is why exterior cladding is made of painted, nickel-containing Type 409M.