

# Structural stainless steel

Decorative stainless steel panels are widely used in façades, roofs and elevators because they are attractive and long-lasting. Increasingly, engineers now use stainless steel for load-bearing structures in challenging environments. In many cases stainless steel is cost-effective if the whole life cycle of the installation is considered.

More than half of the annual production of steel worldwide is used in construction. Typically I-beams, plates and reinforcing bars in buildings and bridges are made of affordable carbon or low-alloy structural steel. Unfortunately, these grades of steel rust easily. This has an enormous economic and environmental impact on the world's infrastructure, affecting roads, bridges, buildings and systems that distribute oil, gas, water and waste water.

The annual cost of corrosion to industrialized countries is 3 to 4% of their GDP according to numerous studies. This figure includes only the direct cost of replacing damaged material and components. Indirect costs, such as loss of production, environmental impact, transportation disruptions, injuries and fatalities are estimated to be just as high.

Standard structural steels must be painted or covered with metallic coatings to minimize corrosion. In addition to the initial cost of such protection, coated steels require costly inspection, maintenance, and sometimes replacement over a structure's life. The indirect cost of maintenance such as loss of production and revenue can also be high. Sometimes it is simply impossible to access components of a structure to carry out inspection and maintenance.

## Comparing life-cycle costs

Designers increasingly take into account the costs of a structure throughout its whole life, not only its initial cost. When life-cycle costs are considered, stainless steel becomes viable, particularly for structures requiring durability or where inspection

and maintenance are impossible or very costly.

This is true even though stainless steel is significantly more expensive than carbon steel. There are ways to reduce the gap in material costs, however. Eliminating coatings decreases installed cost, and when using the higher-strength duplex stainless steel, it may be possible to trim section sizes (and weight) to further lower the initial investment.

When it comes to maintenance cost over an installation's life, the use of stainless steel eliminates coating maintenance costs and component replacement due to corrosion. Stainless steel construction may also provide a more sustainable solution, reducing emissions, resource depletion and waste.

## Designing with structural stainless steel

Design codes and specifications for conventional structural carbon steel cannot be used with stainless steel, because the mechanical properties (specifically the stress-strain behavior) of the two materials are fundamentally different. Stainless steel therefore needs its own set of design rules.

In Europe, Part 1.4 of Eurocode 3, EN 1993-1-4 *Design of steel structures, Supplementary rules for stainless steels*, was published in 2006<sup>1</sup>. It is based on many years of research carried out around the world and covers hot-rolled, welded and cold-formed structural sections. ➤

Minimum specified values of design strength  $f_y$  for structural stainless steel hot-rolled plate

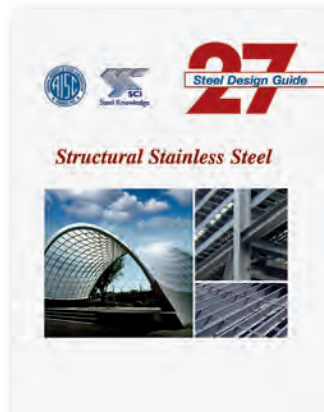
Type of stainless steel	US Specification			European Specification	
	Grade		Design strength <sup>a</sup>	Grade	Design strength <sup>b</sup>
	Common name	UNS designation	$f_y$ MPa	EN designation	$f_y$ MPa
Austenitic, without Mo	304	S30400	205	1.4301	210
	304L	S30403	170	1.4307	200
Austenitic, 2% Mo	316	S31600	205	1.4401	220
	316L	S31603	170	1.4404	220
Duplex, <0.5% Mo	2101	S32101	450	1.4162	450
Duplex, <0.5% Mo	2304	S32304	400	1.4362	400
Duplex, 3% Mo	2205	S32205	450	1.4462	460

a ASTM 240 and A276    b EN 10088

1 EN 1993-1-4:2006 Eurocode 3 Design of steel structures Part 1-4: General rules. Supplementary rules for stainless steels

In the US, guidance on design with lighter gauge stainless steel sections has been available for years<sup>2</sup>, but there was no design specification covering hot-rolled and welded stainless steel structural sections. This required designers to work from first principles or use rules for carbon steel with additional safety factors, a significant obstacle. Moreover, the lack of a design standard required building enforcement officials to approve each application individually.

IMOA, in cooperation with stainless steel producers and other industry associations, initiated a project in 2009 to develop design rules for heavier stainless steel structural sections. The effort resulted in the publication of AISC Design Guide 27: *Structural Stainless Steel*, authored by Nancy Baddoo of the Steel Construction Institute in September 2013<sup>3</sup>. The guide can be downloaded from AISC's website at [www.aisc.org/dg](http://www.aisc.org/dg).



The Design Guide is a comprehensive document covering design rules for structural members and connections at ambient temperatures and in fire. It discusses material properties, grade selection and durability, and gives guidance on fatigue, fabrication and erection.

As always with stainless steels, grade selection is crucial. Molybdenum provides the improved corrosion resistance of grades like Type 316 (2% Mo, austenitic) or 2205 (3% Mo, duplex). These grades are, therefore, often specified in corrosive environments such as coastal regions, or where there is exposure to de-icing salts, heavy pollution or chemicals. Duplex stainless steels like 2205 are twice as strong as most austenitics, giving them an additional advantage in load-bearing applications.

### Structural stainless steel applications

The key advantages of stainless steel for load-bearing applications include corrosion resistance and hence durability even in corrosive environments, better retention of strength in fires compared to carbon steel, high impact resistance, good cleanability and a pleasing appearance.



The Passerelle Mobile footbridge in Lyon-Confluence, designed by PCCP and ALTO, has 2205 duplex stainless steel structural members. Their strength allowed a considerable reduction of the size and thickness of the sections and the weight of the bridge. © ALTO and PCCP

2 American Society of Civil Engineers (2003) Specification for the Design of Cold-Formed Stainless Steel Structural Members, SEI/ASCE 8-02, Reston, VA

3 Baddoo, N R, AISC Design Guide 27: Structural Stainless Steel, AISC, September 2013



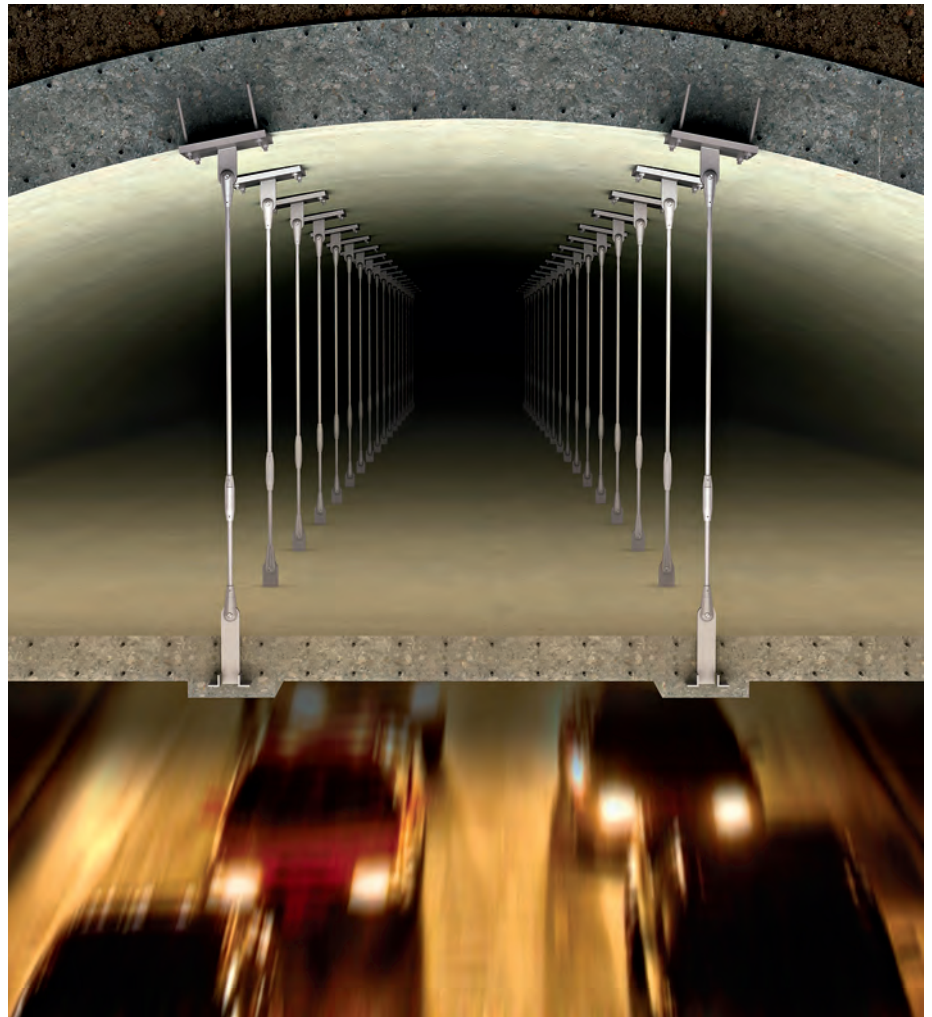
2205 duplex stainless steel escape tunnel on a floating production, storage and offloading (FPSO) vessel. © BP p.l.c.

Among the most iconic structural applications are monuments such as Arlington's Air Force Memorial, Dublin's Spire or St. Louis' Gateway Arch, and sculptures like the Cloud Gate (known as "The Bean") in Chicago. Pedestrian bridges like The Helix in Singapore and San Diego's Harbor Drive Bridge, both previously covered in MolyReview, also have high visibility.

Stainless steel structural components are often used in commercial buildings to support glass curtain walls. For example, the smallest connections in New York's 5<sup>th</sup> Avenue Apple Cube are almost invisible, allowing nearly unobstructed views. Like stainless steel canopies, handrails and street furniture, connectors require little maintenance. Fasteners, anchoring systems and support angles for wood, stone and masonry are often inaccessible or difficult to replace and benefit from structural stainless steel's good corrosion resistance. Wood and masonry can themselves be corrosive to other metals and are likely to absorb moisture and corrosive chemicals over time.

Road tunnels are harsh environments for materials. Maintenance costs are high and a structural failure or fire can have severe consequences. Stainless steel is therefore deployed in tunnel construction for linings and their support frames, maintenance walkways, fixings and fasteners, lighting and signage supports and ground-support rock anchors. The CLEM7 Tunnel under the Brisbane River, the longest road tunnel in Australia, has many advanced safety features. In the event of a fire or explosion, a high-tech ventilation system comprising 100 jet fans will rapidly extract smoke to a longitudinal duct high above the road deck. A duplex 2205 stainless steel system suspends the massive concrete slabs, which form the duct in the highly corrosive environment.

Stainless steel is also used for explosion- and impact-resistant structures such as blast and security walls, gates, security



Tunnel ceiling suspended from a duplex stainless steel system, North-South Bypass Tunnel, Brisbane, Australia. © Ancon

barriers and bollards. It can absorb considerable impact without fracturing due to its excellent ductility and strain-hardening characteristics.

On offshore structures, escape routes are required for personnel in the event of explosion and fire. They can vary from semi-open walkways to fully enclosed high-integrity fire- and blast-rated tunnels, an example of which is the escape tunnel suspended on the side of the Skarv FPSO (Floating production, storage and offloading) vessel. The tunnel is over 200 meters long and comprises an inner carbon steel truss and an outer 2205 duplex stainless steel envelope.

The water treatment, pulp and paper, nuclear, biomass, chemical, pharmaceutical, and food and beverage industries make extensive use of stainless steel in platforms, barriers, gates, ladders, stairs, cable trays and equipment supports.

Engineers are increasingly selecting stainless steel for load-bearing applications that benefit from its durability, attractive appearance, strength, ductility, toughness and formability. The broader availability of design guides makes it easier to specify stainless steel for applications that require durable, resilient and sustainable structures and go beyond decorative panels. (Nancy Baddoo)

# Structural stainless steel case study: UK's first desalination plant

London is a surprising location for a desalination plant considering its cool, wet climate. Predictions based on climate change and population expansion, however, indicated that London water demand could outstrip existing freshwater supply in the next few years. Therefore, the UK's first desalination plant, the Thames Gateway Water Treatment Works in East London, was opened in 2010. The plant treats brackish Thames River water to produce up to 150 million liters of clean drinking water each day, enough to supply up to one million Londoners. It will be used to supplement supplies during extended periods of low rainfall, maintain supplies in the event of incidents at other water facilities and support future demand growth.

**Plant design with carbon steel** – The Gateway plant utilizes the world's first high-efficiency four-step, rather than the more common two-step, reverse osmosis desalination process. Brackish river water passes four times through semipermeable membranes to achieve a high level of salt removal.

The water first passes through lamella clarifiers, containing a coarse filter medium, to remove solid particles. The clarifiers are large open tanks, supported by a framework of 78 I-beams. These beams need good strength and stiffness.



Desalination Plant at Thames Gateway Water Treatment Works, East London. © Interserve



A framework of duplex stainless steel beams support the lamella clarifiers. © Interserve

They also must be highly corrosion resistant, not to be compromised throughout the 60-year design life of the plant. The beams were initially specified as epoxy-coated carbon steel, but it was recognized that there would be a high risk of damage to the coating during installation and maintenance. This would have resulted in rusting of the carbon steel beams and subsequent damage to the £7 million desalination membranes.

**Using molybdenum-containing stainless steel instead** – Unlike carbon steel, the surface of stainless steel is protected from corrosion by an adherent layer of chromium-rich oxide that reforms immediately if damaged, self-healing the surface. Thus, the engineers, concerned about the durability of the epoxy-coated beams, specified 2205 duplex stainless steel instead. This grade has high strength, requires little maintenance and is durable in brackish

water without coating, thanks to the addition of 3% molybdenum. This grade is also approved for contact with drinking water by the Drinking Water Inspectorate (DWI), the independent regulator of drinking water in England and Wales.

**Minimizing costs** – Simply replicating the carbon steel beams in stainless steel would have led to a 74% cost increase, so several measures were undertaken to reduce cost. Firstly, the superior strength properties of duplex stainless steel were exploited. A web depth of 500 mm was selected for the fabricated beams, to be cut from 2-meter wide plate, reducing offcut wastage. The flange dimensions were sized to optimize bending strength, while keeping beam deflection within acceptable limits. As a result, the total weight of the stainless steel beams was reduced from 140 tonnes to 75 tonnes, allowing considerable cost savings. (Nancy Baddoo)