Lecture material summary

Purpose of this document:

Teaching material for lecturers in Architecture and Civil Engineering. Can be used as a whole or as separate sections

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- Prof. Pedro Vellasco (Universidade do Estado do Rio de Janeiro, Brazil)

Contents

Stainless Steel Development Associations Worldwide: where you can find free information & downloads

Association	Website	Country/Region	Social media
ISSF	worldstainless.org	Global	LinkedIn, Twitter, YouTube, Facebook
Abinox	abinox.org.br	Brazil	LinkedIn, Twitter, Facebook
ASSDA	assda.asn.au	Australia	LinkedIn, Twitter, Facebook
BSSA	bssa.org.uk	United Kingdom	LinkedIn, Twitter, Facebook
Cedinox	cedinox.es	Spain	
Centro Inox	centroinox.it	Italy	Facebook
IMINOX	iminox.org.mx	Mexico	Twitter, Facebook, Instagram
ISER	edelstahl-rostfrei.de	Germany	LinkedIn, Facebook
ISSDA	stainlessindia.org	India	LinkedIn, Twitter, Facebook
JSSA	jssa.gr.jp	Japan	
KOSA	kosa.or.kr	Korea	LinkedIn, Twitter, Facebook

Stainless Steel Development Associations Worldwide: where you can find free information & downloads

Association	Website	Country/Region	Social media
NZSSDA	nzssda.org.nz	New Zealand	
PASDER	pas-der.com	Turkey	
SASSDA	sassda.co.za	South Africa	
SSINA	ssina.com	North America	
CSSC	cssc.org.cn	China	
SSN	stalenierdzewne.pl	Poland	
Swiss Inox	swissinox.ch	Switzerland	
TSSDA	tssda.org	Thailand	
USSA	ussa.su	Russia	
ICDA	icdacr.com	Global	
IMOA	imoa.info	Global	
Nickel Institute	nickelinstitute.org	Global	

Stainless Steel Development Associations Worldwide: where you can find free information & downloads

Association	Website	Country/Region	Social media
Construiracier	construiracier.fr	France	
Team Stainless	Stainlessconstruction.com	Global	
Stainless Steel Training Portal	issftraining.org	Global	

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A quiz in which you can test your knowledge of stainless steel is now available:
https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 01

Art

Location:
Falkirk, Scotland
Material:
Structural Steel
Cladded with type 316L (S31603) Stainless Steel
Dimensions:
30 metres high
Weight:
300 tonnes each
Year created:
2013

Andy Scott: The Kelpies [1, 2]

Andy Scott: "The original concept of mythical water horses was a valid starting point for the artistic development of the structures. I took that concept and moved with it towards a more equine and contemporary response, shifting from any mythological references towards a socio-historical monument intended to celebrate the horse's role in industry and agriculture as well as the obvious association with the canals as tow horses."

Location:
Brussels, Belgium
Material:
Polished 1.4404 (316L) stainless steel
Dimensions:
102 meters high with each of the nine spheres having a diameter of 18m
Weight:
2400 tons
Year created:
1958

Design: A. Waterkeyn Architects: A. and J. Polak: Atomium [3, 4]

The Atomium was constructed for the 1958 Brussels World Fair. Its nine spheres are connected so that the whole forms the shape of a unit cell of an iron crystal magnified 165 billion times. It was renovated between 2004 and 2006. The renovations included replacing the faded aluminium sheets on the spheres with stainless steel. CNN named it Europe's most bizarre building! It is one of the major attractions of Brussels .

Location:
St. Louis, MO, USA
Material:
AISI 304 Stainless Steel Cladding
Dimensions:
192m tall
Weight:
4164 tonnes
Year created:
1965

Designer: E. Saarinen Engineer: H. Bandel: Gateway Arch [5, 6]

Intended to be "*A suitable and permanent public memorial to the men who made possible the western territorial expansion of the United States….*", the gateway Arch in St Louis, MO, USA, is 192m tall, the world's tallest arch, and has become the symbol of St Louis. The arch weighs 4164T, of which 803T of AISI 304 stainless steel cladding.

Location:
Chicago, USA
Material:
Highly polished 316 stainless steel plates
Dimensions:
10 by 20 by 13 m
Weight:
110 tonnes
Year created:
2004

Sir Anish Kapoor: Cloud Gate [7, 8]

Cloud Gate is British artist Anish Kapoor's first public outdoor work installed in the United States. The 110-ton elliptical sculpture is forged of a seamless series of highly polished stainless steel plates, which reflect Chicago's famous skyline and the clouds above. A 12-foot-high arch provides a "gate" to the concave chamber beneath the sculpture, inviting visitors to touch its mirror-like surface and see their image reflected back from a variety of perspectives. Inspired by liquid mercury, the sculpture is among the largest of its kind in the world.

Location:
Normandy, France
Material:
2205 and 316L stainless steel
Dimensions:
9m high
Weight:

Year created:
2004

Anilore Banon: Les Braves [9 - 11]

This memorial stands on the beach known as Omaha Beach in the village St. Laurent-sur-Mer in Normandy, France and commemorates the soldiers that fell on the beaches of Normandy on D-Day, June 6, 1944. The memorial was dedicated on June 5 2004, for the 60th anniversary of the landing.

Location:
Toledo Museum of Art, Toledo, OH, USA
Material:
Painted stainless steel
Dimensions:
377 x 235 x 245 cm each
Weight:

Year created:
2010

Jaume Plensa: Mirror I and II [12, 13]

The principal concept in this piece is that of dialogue. The two figures face one another as if in perpetual, silent conversation. The title, *Mirror*, is the act that the figures perform for one another — standing as reflections of the other's thoughts and dreams. There is room enough between the two figures for the viewer to stand and "enter" the conversation. The figures are modeled in letters from eight alphabets – Arabic, Chinese, Greek, Hindi, Hebrew, Japanese, Latin and Russian. The artist considers this dialogue and interaction as central to learning, and more importantly to understanding, between people and cultures.

Location:
Guggenheim Museo, Bilbao, Spain
Material:
Bronze, marble, and stainless steel
Dimensions:
9mx10mx12m
Weight:

Year created:
1999

Louise Bourgeois: Maman [14]

The title *Maman* enhances dynamic contradictions at the heart of the sculpture. Why the spider? *"Because my best friend was my mother and she was deliberate, clever, patient, soothing, reasonable, dainty, subtle, indispensable, neat, and as useful as a spider. She could also defend herself, and me, by refusing to answer 'stupid', inquisitive, embarrassing, personal questions"*

Location:
Helsinki, Finland
Material:
600 Stainless Steel Tubes
Dimensions:
8.5 m high, 10.5m in length, and 6.5m in depth
Weight:
24 tonnes
Year created:
1967

Eila Hiltunen: Sibelius Monument (1967) [15]

The Sibelius Monument in Helsinki, Finland, is dedicated to the Finnish composer Jean Sibelius. Weighing around 24 tonnes, the sculpture is made up of more than 600 stainless steel tubes, welded together in a wave-like formation which resembles the shape of organ pipes.

Location:
Oslo, Norway
Material:
stainless steel and glass panels
Dimensions:
12 by 17 by 16 m
Weight:

Year created:
2010

Monica Bonvicini: Hun Ligger (She Lies) [16]

It is a permanent installation, floating on the water in the fjord on a concrete platform next to the Oslo Opera House, 12m above the water surface. The sculpture turns on its axis in line with the tide and wind, offering changing experiences through reflections from the water and its transparent surfaces.

Location:
Jerusalem
Material:
Polished Stainless Steel
Dimensions:
5m tall and 5m in diameter
Weight:

Year created:
2010

Sir Anish Kapoor: Turning the world upside down [17]

The stainless steel piece is 5 m tall and 5 m in diameter and flips the whole city of Jerusalem into the sky, signifying the spiritual importance of Jerusalem as a heavenly city.

Location:
Reykjavík, Iceland
Material:
Stainless Steel
Dimensions:
9 m x 18 m x 7 m
Weight:

Year created:
1990

Jon Gunnar Arnason: Sun Voyager [18]

"Sun Voyager is a dreamboat, an ode to the sun. Intrinsically, it contains within itself the promise of undiscovered territory, a dream of hope, progress and freedom". The sculpture is located by Sæbraut, by the sea in the centre of Reykjavík, Iceland.

Location:
Trentham Gardens, UK
Material:
Stainless Steel Wire
Dimensions:

Weight:

Year created:

Robin Wight: Fantasywire [19]

UK sculptor Robin Wight creates dramatic scenes of wind-blown fairies clutching dandelions, clinging to trees, and seemingly suspended in midair, all with densely wrapped forms of stainless steel wire. The artist currently has several pieces on view at the Trentham Gardens.
http://www.fantasywire.co.uk/

Location:
Tuxtla Gutierrez, Mexico
Material:
Coated Stainless Steel
Dimensions:
48m (62m with the base)
Weight:
2000 tonnes
Year created:
2007

Architect Jaime Latapi Lopez: Cristo de Chiapas [20]

The "Cristo de Chiapas" is an impressive cross, which is coated with gold-colored stainless steel accentuating the figure of Christ and shines in the reflection of the lights of the sun.

Location:
Versailles, France
Material:
Stainless Steel
Dimensions:
3m x 1.5m x 4m
Weight:

Year created:
2009

Joana Vasconcelos: Marylin (2009) [21]

Marilyn takes the form of an elegant pair of high-heeled sandals, whose enlarged scale results from the use of saucepans and their respective lids. The unlikely yet assertive association between the saucepans and high-heeled sandals, two paradigmatic symbols of Woman's private and public dimensions, proposes a revision of the Feminine in the light of the practices of the contemporary world. The recourse to saucepans, sign to which one would associate the traditional domestic sphere of Woman, in order to reproduce an enormous high-heeled sandal, symbol of beauty and elegance demanded by social conventions, contradicts the impossibility of the dichotomic relation of the Feminine in the domestic and social spheres. The represented object thus emerges as panegyric of the feminine duality, insinuating the full realization of individuality through the subversion of the social norm.

Location:
New York, USA
Material:
High chromium stainless steel with transparent color coating
Dimensions:
357 x 218 x 121 cm
Weight:

Year created:
1 of 5 unique versions 1994–2007

Jeff Koons: Sacred Heart Red/Gold …[22]

"….acidly comments on the commercial debasement of emotional and religious experience."

(NY Times)

Location:

Material:
316L Stainless Steel
Dimensions:
71 cm x 41 cm x 41 cm
Weight:

Year created:

Gil Bruvel: Dichotomy [23]

Inspired by the complexities of living fully in all worlds at once, Dichotomy meditates on and celebrates the dual nature of existence. Composed of “ribbons of energy” that seek to capture the process of engaging all levels of being in order to be fully human, the sculpture reflects the natural strength and quiet majesty inherent in integrating the various levels of existence. As a result, the figure inhabits a serene meditative space, fully embracing a dichotomy of existences: anima and animus, male and female, conscious mind and unconscious mind, waking and dreaming.

Location: Charlotte, NC, USA
Material: stainless steel
Dimensions: Height 8m
Weight: Uses 14T of stainless steel
Year created: 2011

David Černý: Metamorphosis [24]

The structure is comprised of seven separate layers that rotate intermittently, dissecting the sculptures features. Custom-written programs control motors embedded within the structure to orchestrate choreographed sequences. Every motor has a feedback switch so the computer knows where each piece is at any given moment, allowing for random motion within the sequences. This movement is controlled via the Internet by David himself and represents a continuation of his work that incorporates mechanical engineering and computers as an integral part of the design. Live streaming video of the sculpture in motion can be viewed online at www.metalmorphosis.tv

Location:
Midway between Oslo and Trondheim, Norway
Material:
Polished 316 Stainless Steel
Dimensions:
H: 10.3m
L: 11,5m
Weight:

Year created: 2015

Linda Bakke: The Big Elk [25]

The Big Elk, which was designed by Norwegian artist Linda Bakke, stands on the Bjøråa picnic area in Stor-Elvdal municipality midway between Oslo and Trondheim in Norway. This landmark, apart from its being inherently beautiful, is to attract drivers attention and increase road safety as it invites drivers to stop and stretch their legs and rest, thereby combatting fatigue.
The Big Elk has also focused attention on the animals and has become a regional symbol.
Sparebanken Hedmark art fund provided NOK 2 million (207,000 euros) to produce the sculpture.
http://lindabakke.webs.com/sculptureskulptur.htm

Location: Paris
Place Augusta Holmes

Materials:
Stainless steel, glass and plastic

Dimensions:

Weight:

Year created:
2008

Chen Zhen: La danse de la fontaine émergente [26]

The fountain, designed by the French Chinese artist is designed to resemble a dragon winding its way around the square, emerging and submerging from the pavement. The dragon's transparent skin shows the water flowing within.

The fountain is in three parts. An opaque bas-relief dragon appears to emerge from the water-supply plant wall and plunge underground. The transparent second and third parts show the dragon seeming to arch out of the pavement. Water under pressure flows within and is illuminated at night. The fountain was commissioned by the City of Paris in 1999 and inaugurated on February 6, 2008. Although the artist died in 2000, he left sketches showing how the fountain should look like and was completed by Xu Min, the sculptor's spouse and collaborator. The fountain did cost 1,2M€, largely financed by the City of Paris and the Ministry of Culture of France.

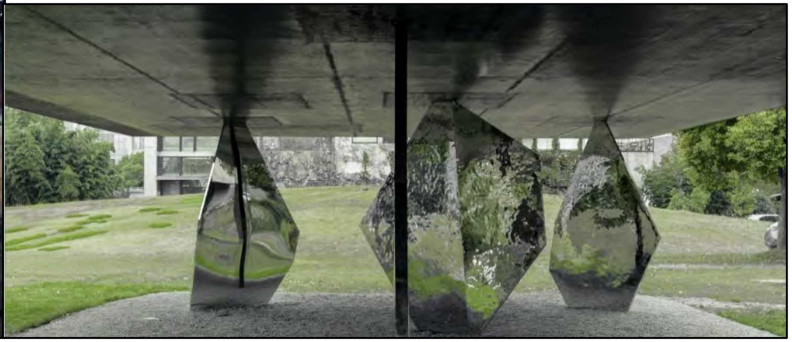
Sources: Wikipedia and https://www.parisladouce.com/2013/03/paris-la-danse-de-la-fontaine-emergente.html

Location: Barcelona, Spain
Material: stainless steel
Dimensions: H 38m
L: 58m
Weight: unavailable
Year created: 1992

Frank Gehry: The golden fish [27]

El Peix d'Or is a mesh sculpture in the form of an open-mouthed undulating fish. It is made of stone and steel. Its **copper-colored stainless steel scales** shine under the Mediterranean sun and change appearance depending on the angle of the sun and the current weather conditions, accentuating the organic form of this vast sculpture.
The Golden Fish called El Peix d'Or in Catalan, was designed for Barcelona's 1992 Olympic village and port. The golden coloured steel structure serves as a canopy for the commercial area which links the luxurious Hotel Arts to the seafront near the Olympic Marina. It is one of the best-loved and most striking iconic landmarks on Barcelona's seafront.
http://www.barcelonaturisme.com/wv3/en/page/1232/peix-fish-frank-gehry.html

Location: Shanghai, China
Material: stainless steel
Dimensions: H 8m **L:** 12m
Weight: unavailable
Year created: 2015



Zhan Wang + Atelier Deshaus: Blossom Pavilion [28]

The starting point for the project was the stainless steel sculptures of Zhan Wang's Rockery Series, which the artist has been working on since 1995. Atelier Deshaus reinterpreted these forms as structural elements, aiming to create a pavilion modelled on a rock garden. Six slender rock-shaped columns support a solid steel roof, which is topped by plants and flowers. The reflective columns are arranged randomly, rather than at the most structurally efficient points, to reinforce the idea of a rockery.

https://www.archdaily.com/792211/blossom-pavilion-atelier-deshaus/5799b693e58ece81bd00004a-blossom-pavilion-atelier-deshaus-photo

Material: stainless steel
Dimensions: lifesize
Weight: unavailable
Year created: -

Martin Debenham: mermaid 3 [29]

British contemporary sculptor Martin Debenham creates stainless steel wire sculptures inspired by fantasy and nature. Working with a malleable material that has endless potential, the self-taught artist's growing collection of wire art features impressive structures rendered from intricate twists, bends, and expert welding.

Appearing as though they're three-dimensional line drawings, most of Debenham's metal masterpieces are made for outdoor display. When placed into natural environments, they seem to evoke mythical narratives as they glimmer in the sunlight. For example, in one piece, a wire-sculpted mermaid sits on a rock by a lily pond, positioned as though she's contemplating going for a swim. Each strand of wire is sculpted into curves that follow the form of the female body, then flow into a long mermaid tail.

https://mymodernmet.com/wire-sculptures-martin-debenham/

Location:

Material:
polished & colored stainless steel

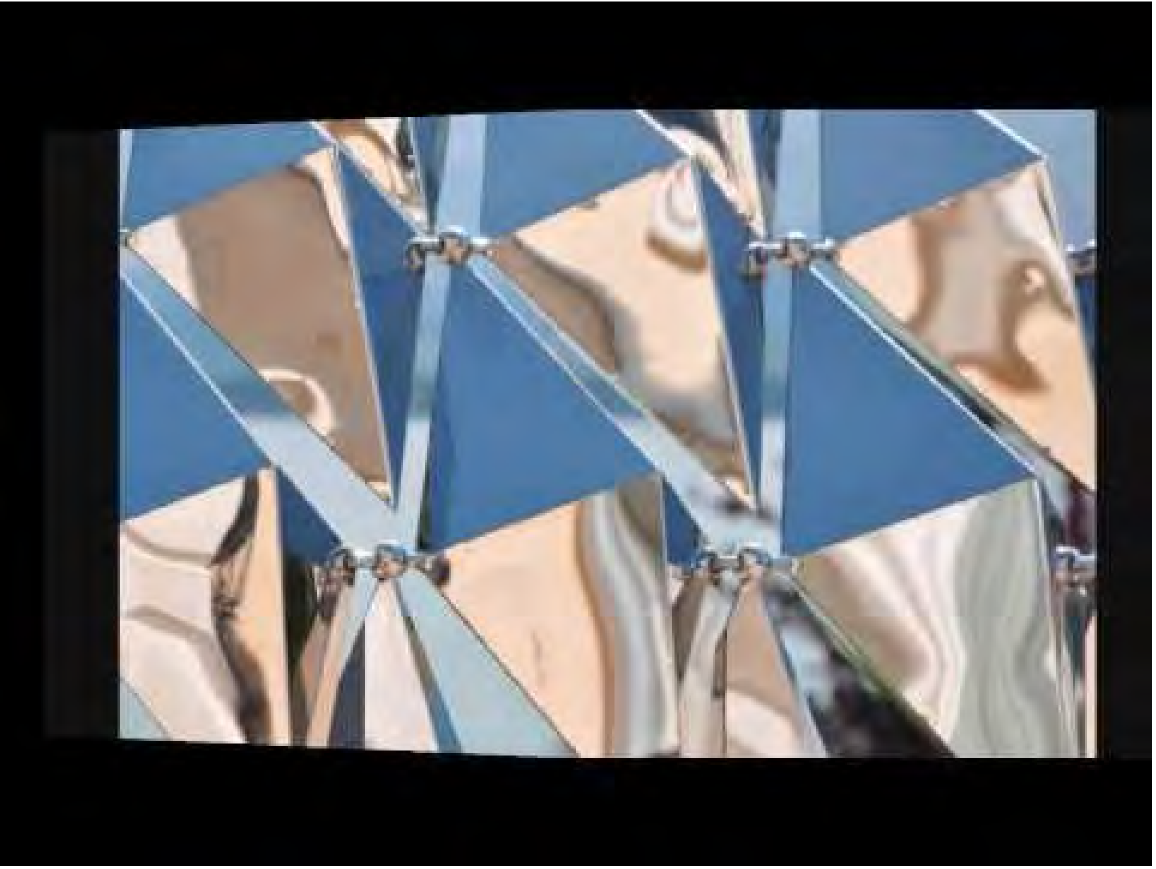
Dimensions:
3 panels of 1mx1m each

Weight:

Year created:
2011

Robert Gahr: Surge [30]

Wall Sculpture



Location:

Material:

Dimensions:
2.1m tall

Weight:

Year created:

Ralfonso Karo: #1 Kinetic Wind Sculpture [31]

25 diamond shaped stainless steel elements connect, self-balance and move independently in the wind. Click here for video (4’:51’’)

Location: S. Korea

Materials: painted stainless steel

Dimensions: 273x160x95cm

Weight:

Year created: 2017

NEW 2019!

Sun Hyuk Kim: Forgotten Memory [32, 33]

Artist Sun-Hyuk Kim takes inspiration from complex root systems found in nature to construct the human form. Each sculptural figure sprouts a branch or sometimes a small tree, appearing to be some type of human-botanic hybrid. The large, stainless steel sculptures feature fragments of faces, headless bodies, and figures crouching towards the ground as if they are overcome by a great weight on their backs.

Kim's minimalist sculptures allow us to project ourselves onto each of his pieces. They communicate fragility. We all know how it feels to be pulled in different directions and the often-uncomfortable state of growth and change. But in having this knowledge, it connects us together and reminds us that the human experience is vast and ever-changing—just like that of a tree.




And there is a lot more !

http://www.worldstainless.org/applications/art

If you have other remarkable works of art in mind, please let us know!




References (1/3)

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5. http://www.gatewayarch.com/
6. http://en.wikipedia.org/wiki/Gateway_Arch
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26. https://www.parisladouce.com/2013/03/paris-la-danse-de-la-fontaine-emergente.html
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References Art (3/3)

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31. http://www.ralfonso.com
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33. https://www.sunhyuk.com/sculpture

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https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Module 02A:

Applications - Architecture

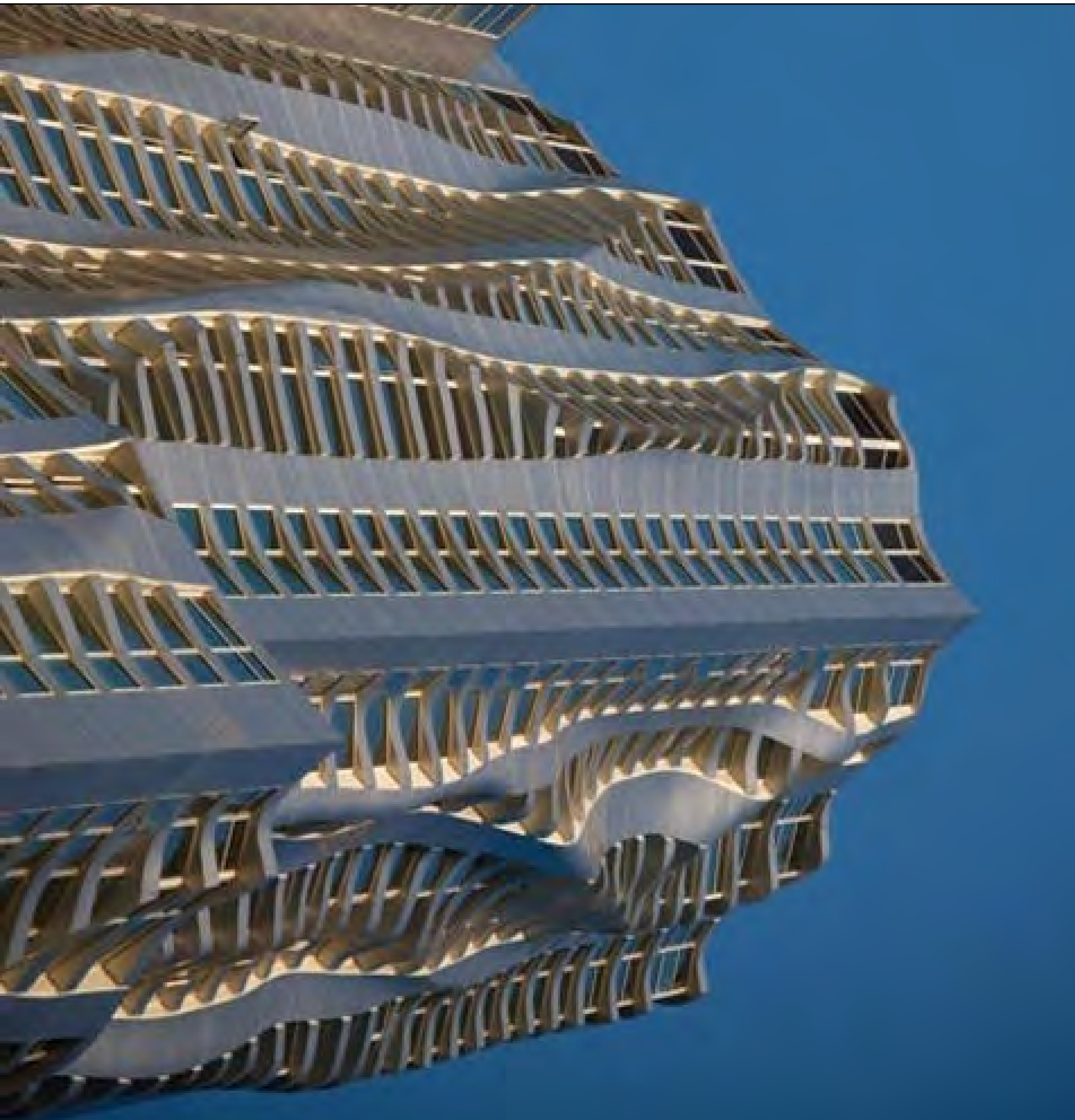
Contents

1. Facades

Clockwise, from top left:

1. Westfield Doncaster shopping center facade in Victoria, Australia [4]
2. Sunbreaker Stainless mesh ion a school facade near Whashington, DC, USA. Reduces glare,saves energy offers good visibility[6]
3. Stainless mesh canopy over courtyard, Arizona, USA. Maximizes sun blockage while allowing air flow[6]
4. Lou Ruvo medical Research Center designed by Frank Gehry, Las Vegas, USA[5]

Stainless facade of 285m-high apartment building, New York, USA.
Architect: Frank Gehry[7]



Reflective stainless steel inserts in a concrete wall for an archive building, Bure-Saudron (51), France[8]

F. R. Weismann Art Museum, Minneapolis, USA (1993)
Architect: Frank Gehry[9]

Gehry: "I always have felt that architecture was about materials. Watching my artist friends work directly with materials – the right product is something that seems right and real and acceptable and not contrived."

For the Weisman, Gehry chose stainless steel… Its shiny, reflective, but extremely durable surface has given the building its unique identity.

Kauffman Center of Performing Arts, Kansas City, ISA (2011)
Architect: Moshe Safdie; Engineering: Arup[10]

The north elevation of the building, which faces downtown Kansas City, features a series of arched walls sheathed in stainless steel that rise from the ground like a wave. From its crest a curved glass roof sweeps down towards the low-rise Crossroads neighborhood to the south and cascades into a 65-foot high by 330-foot wide glass wall, which provides the Kauffman Center's Brandmeyer Great Hall with panoramic views of Kansas City. This dramatic glass facade and roof are anchored by 27 high-tension steel cables, reminiscent of a stringed instrument.

Len Lye Centre, New Plymouth, NZ
Architect: A. Patterson[11]

14 m high facade made of 32 tons of highly polished grade 316 stainless steel

Delhi Metro Rail Corporation Headquarters, India
Architect: Raj Rewal & Associates[12]

Architect Raj Rewal & Associates designed stainless steel cladding for the building in New Delhi, involving stainless steel tubular truss with stainless steel panels interspersed with toughened glass panels.

District heating facility, Torino,Italy
Architect: JP Buffi[13]

The heating facility has been clothed by curved screens.

The copper-coloured stainless strips are arranged to provide gaps for a glimpse through to the facility.

Capital gate Tower (2010), Abu Dhabi RMJM, Architects[14-16]

The distinctive stainless steel ‘splash’ that descends from the 19th floor, is a design element and a shading device that eliminates over 30 percent of the sun’s heat before it reaches the Capital Gate building. The splash also twists around the building towards the south to shield the tower as much as possible from direct sunlight.

The ‘splash’ is made of 580 panels for a total of ~5000 m^2 of stainless steel mesh

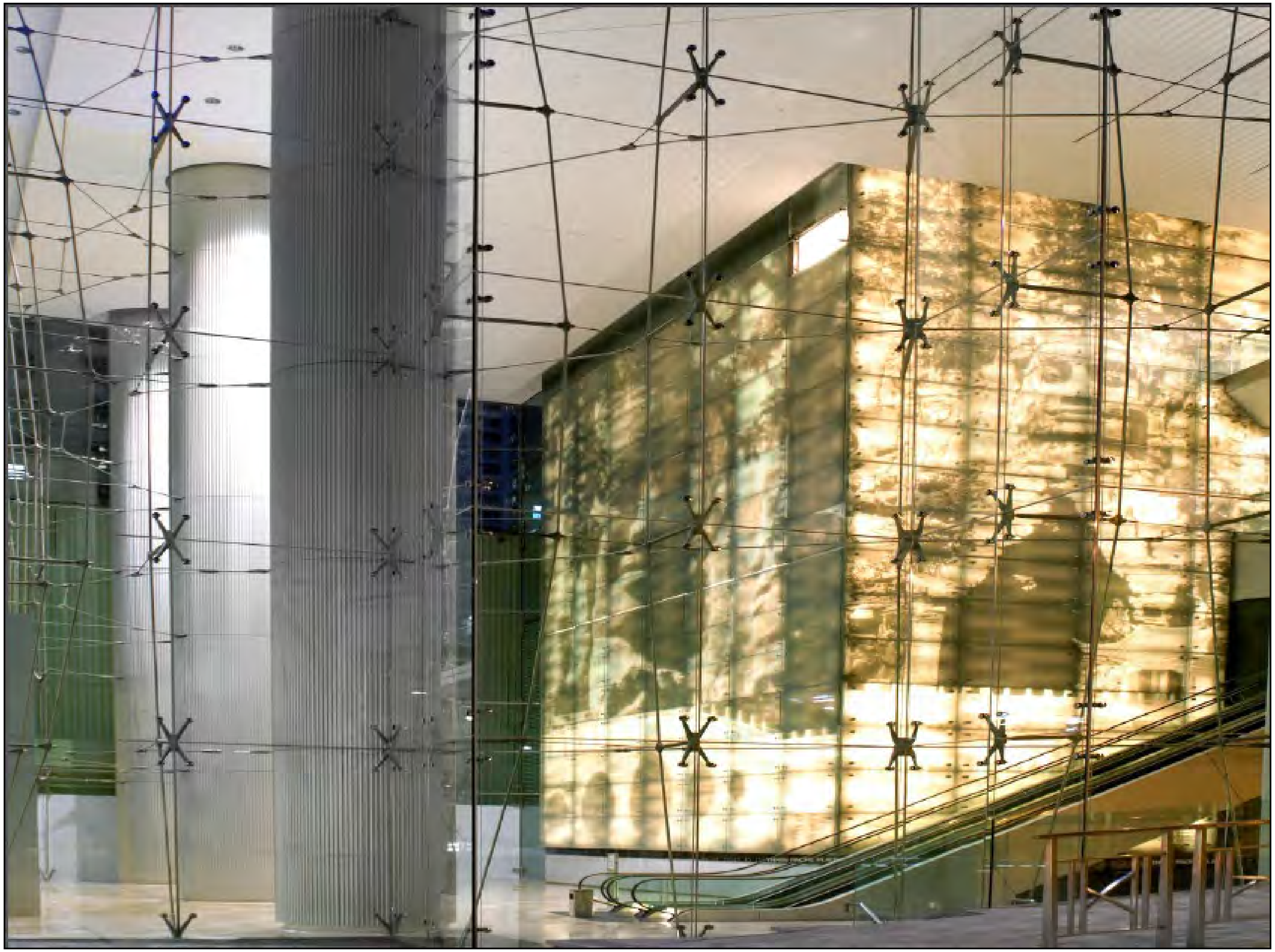
Glass facade[17]

A web of stainless steel tie-bars linked by nodes holds the glass facade, maximizing open light area, including corners

Glass facade, Paris [18]

The glass facade is supported by a light, high strength stainless steel structure

The sphere in the background is the «Geode», a unique stainless steel clad 360° movie theater, part of the «Cité des Sciences et de l’industrie»



Glass facade, Paris[19]

Office building mesh facade, Utrecht, Netherlands[20]
Architects: Cepezed

This 3000 m² stainless steel mesh facade holds transparent plastic disks.

Wind causes the mesh to vibrate and the disks to move, resulting in ripples and light effects.

Energy saving building, Nantes, France [21]
Architects: FORMA 6 & B. Dacher

Intricate laser cut shapes of the stainless steel facade give this building an outstanding look.

McGowan Academic center, Washington, DC, USA
Sunshade mesh[6]

McGowan Academic Center is a classroom building community college.

The building design provided for an atrium area integrated with an exterior ventilated façade, in the center of the building that faced directly east in the morning hours.

The stainless sunshade reduces the daytime glare and the amount of air conditioning required to cool the space in the summer months. Typical metal sunshade products could not be used for this application as visibility was crucial. They simply didn't offer enough open area.

Rehab of Château de Rentilly, France[22-23]

Left: Before
Below: After

A contemporary art building in the park of a château. The facade has been clad with mirror-finish stainless steel plates

Xavier Veilhan, architect:
«… the building was a shadow of what it was…. I wanted walls that would reflect the surrounding park… »

St Guy Hospital , London[24]
Architect: T. Heartherwick

The Boiler Suit, a unique façade designed to encase the boiler house which powers Guy's Hospital. It is made up of 108 undulating tiles of woven stainless steel braid and is illuminated at night to provide a distinctive welcoming beacon for staff and visitors arriving at hospital in the dark.

American Airlines Arena, Miami, USA

Made from 3,400 square feet of a high-grade architectural woven stainless steel mesh fabric with interwoven LED profiles, Miami's Mediamesh® screen, provides visitors to the Arena with unobstructed viewing from the interior and visually engaging digital media content on the exterior. Standing three-stories tall (42 feet high by 80 feet wide), Miami's Mediamesh façade is four times the size of an average billboard. The arena host more than 1.3 million guests per year for concerts, family and sporting events.

Facades References (1/2):

UPDATED 2019!

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3. http://www.archiexpo.com/architecture-design-manufacturer/stainless-steel-facade-cladding-2964.html more examples here!
4. http://www.steelcolor.com.au/westfield-doncaster/
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11. http://pattersons.com/civic/len-lye-contemporary-art-museum/
12. http://www.stainlessindia.org/UploadPdf/SI_Mar08.pdf
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Facades References (2/2):

UPDATED 2019!

15. http://www.dailymail.co.uk/travel/article-1284591/Abu-Dhabi-Capital-Gate-skyscraper-leans-times-Tower-Pisa.html
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21. http://www.reseaux-artistes.fr/dossiers/beatrice-dacher/architecture-sully-2006-2010
22. http://www.marneetgondoire.fr/les-albums-photos/album-photos-490/le-chateau-de-rentilly-renaissance-en-2013-230.html?cHash=d2d475c49fe75ee015495efb35c04460
23. http://www.marneetgondoire.fr/le-parc/les-espaces-1705.html
24. http://www.dezeen.com/2007/08/20/boiler-suit-by-thomas-heatherwick
25. http://www.gkdmediamesh.com/blog/the_role_of_metallic_mesh_in_transforming_stadium_architecture.html

2. Green Walls

About Green Walls

Green Facades are an emerging architectural element, providing an enormous amount of benefits to a building through occupant amenity, thermal control and improving air quality.

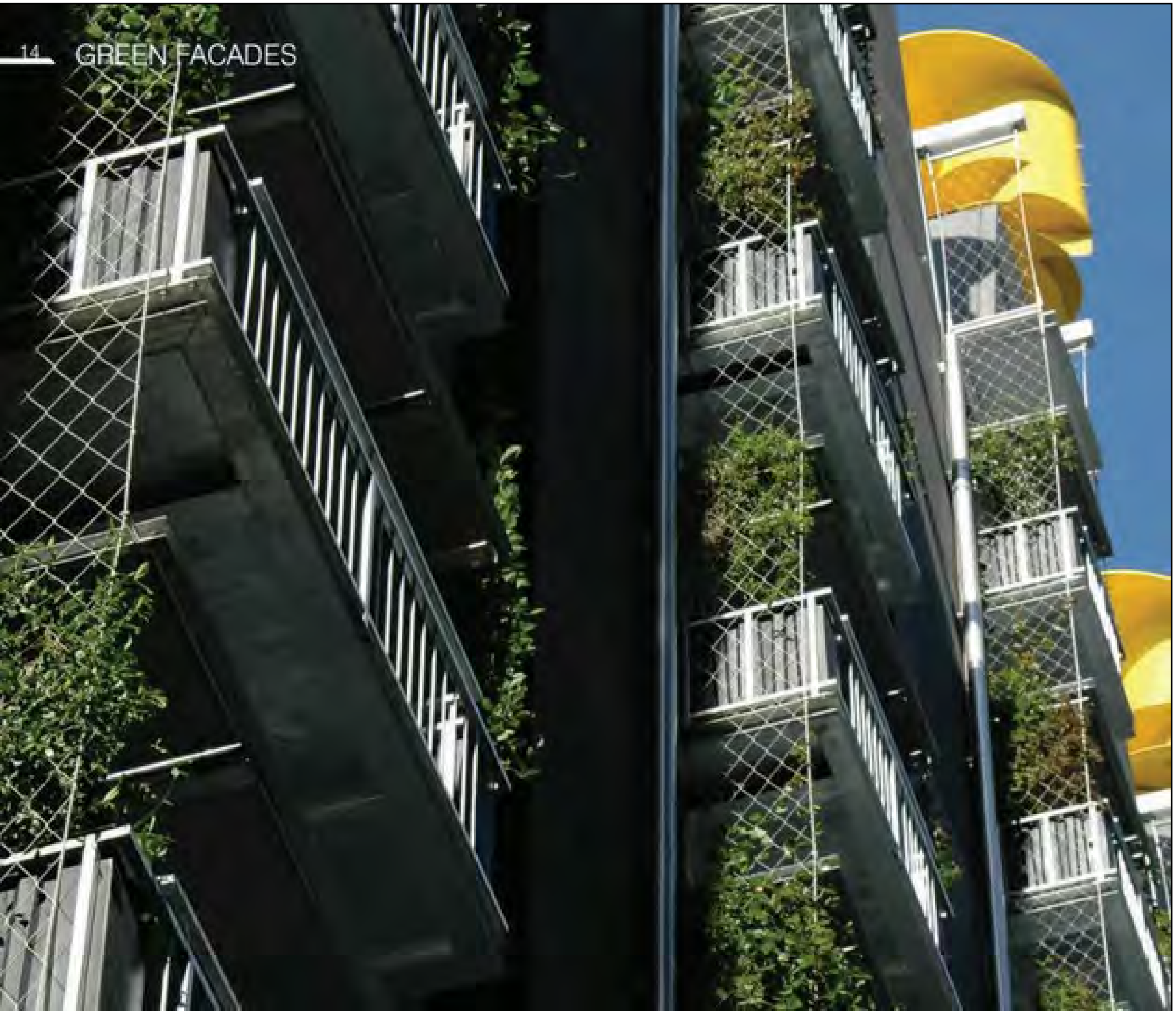
Using stainless steel cables, rods and mesh to train climbing plants up a building facade provides an alternative to the traditional planted green wall.

Retro-fitting a green facade to existing structures is easily achieved.

Green facade[1]

Electric transformer building, Barcelona. Stainless fasteners and cables support the plants.

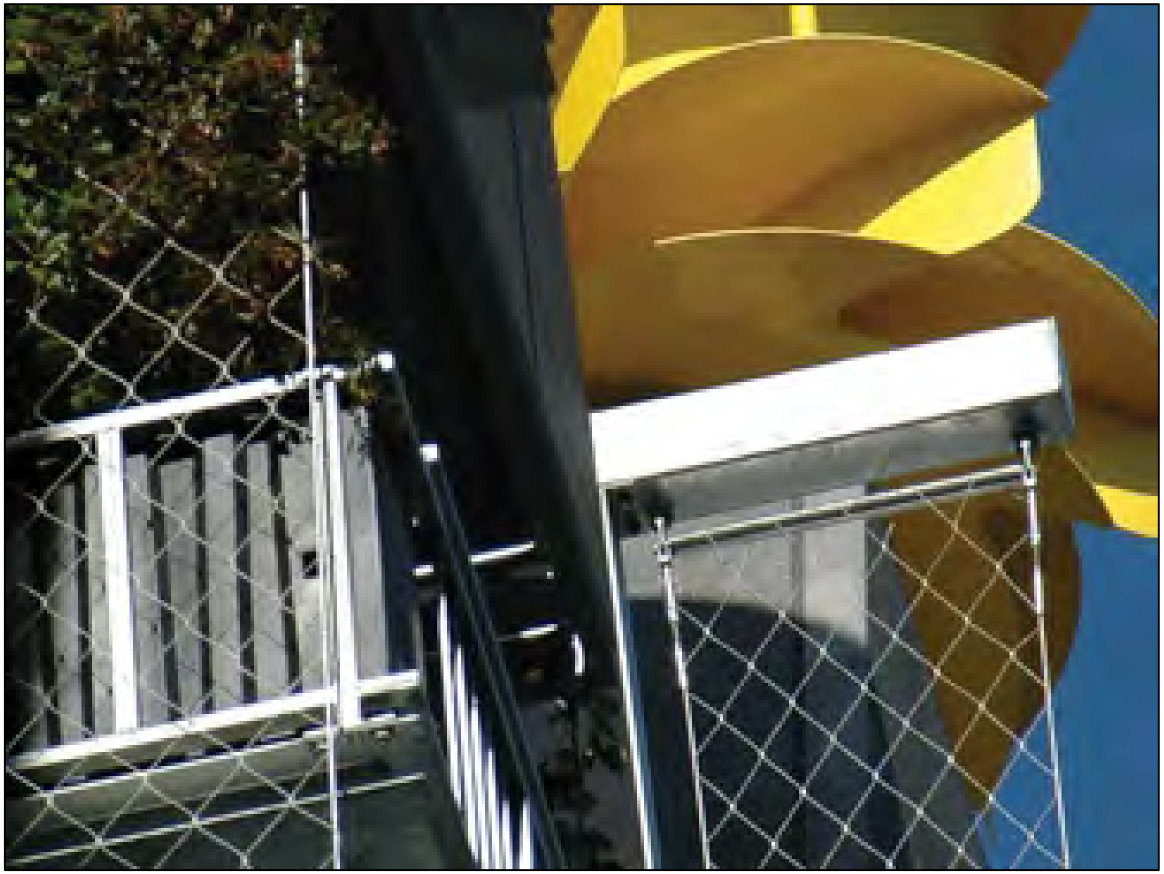
Green walls for apartment buildings[2] (affordable everywhere!)



Advantages :

- Improved insulation
- Noise damping
- Cooler micro-climate
- Enhanced biodiversity
- Better air quality pollutants filtration)
- Aesthetics
- Psychological well-being
- Positive social and economic fallout

Stainless cables and anchors



Green walls for apartment buildings[2]

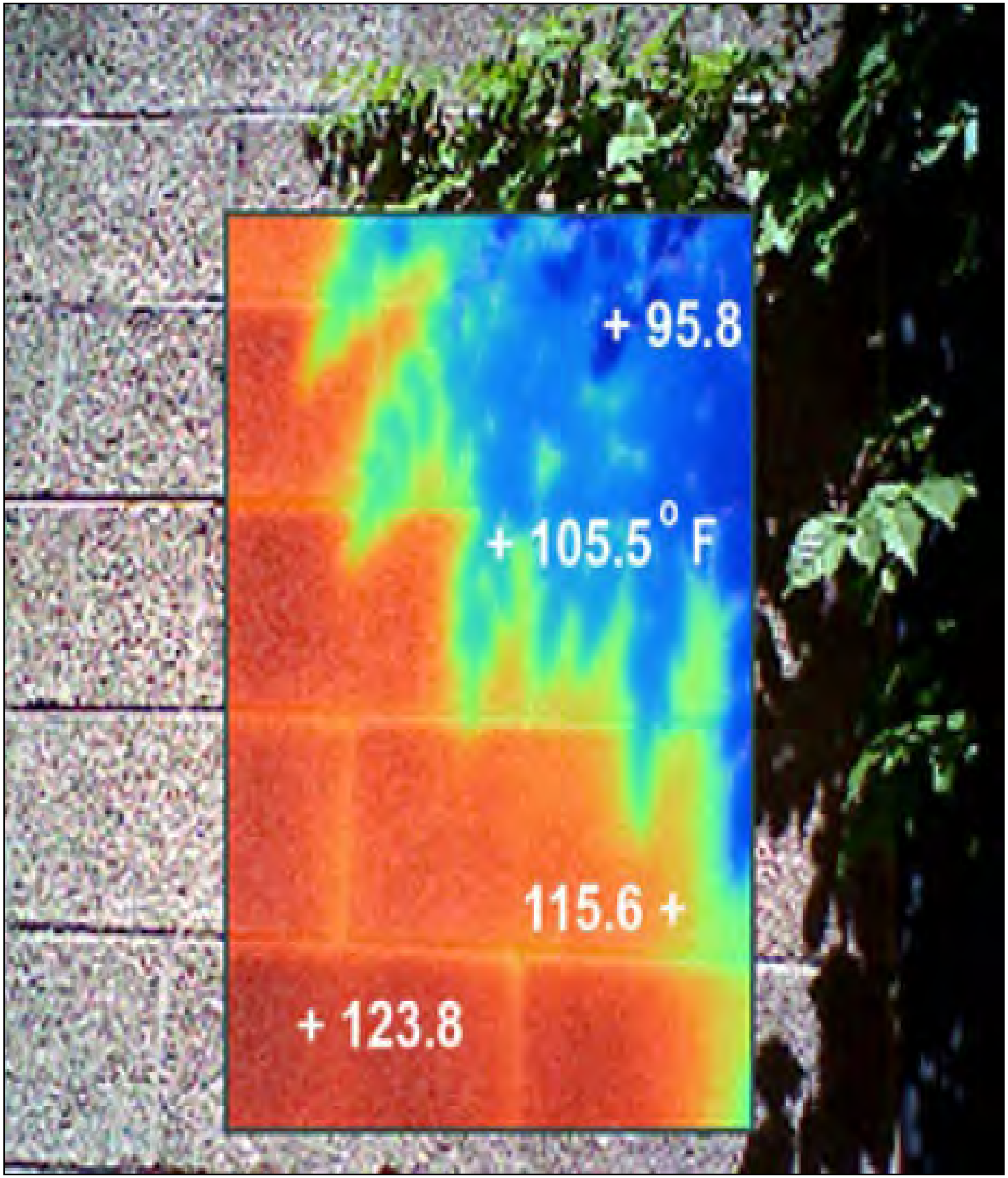
The benefits of re-introducing Mother Nature to an increasingly unnatural environment are so apparent that the Australian Government has established the Green Building Council of Australia (GBA) to advocate sustainable property development.

Vertical Landscaping

Melbourne City Council Chambers: The stainless steel trellising systems and components provide essential climbing structure for the plant life, and transform the hard heat retaining surfaces into vibrant vertical gardens.

Green wall[3]

Infrared photography demonstrating temperatures of the building surface, Tampa, AZ. °F, from ref. 4.



Anchors and cables

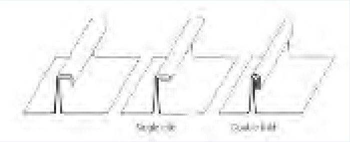
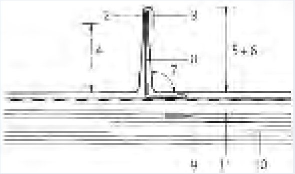
Stainless steel systems are easy to install

Green Walls References

1. https://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/VertGardens_EN.pdf
2. http://www.ronstantensilearch.com/melbourne-city-council-chambers-northern-green-facade/
3. http://www.jakob.co.uk/information/image-galleries/greenwall-systems-gallery/large-scale-greenwall-systems.html
4. http://drum.lib.umd.edu/bitstream/1903/11291/1/Price_umd_0117N_11876.pdf
5. http://www.architectureartdesigns.com/30-incredible-green-walls/

3. Roofs

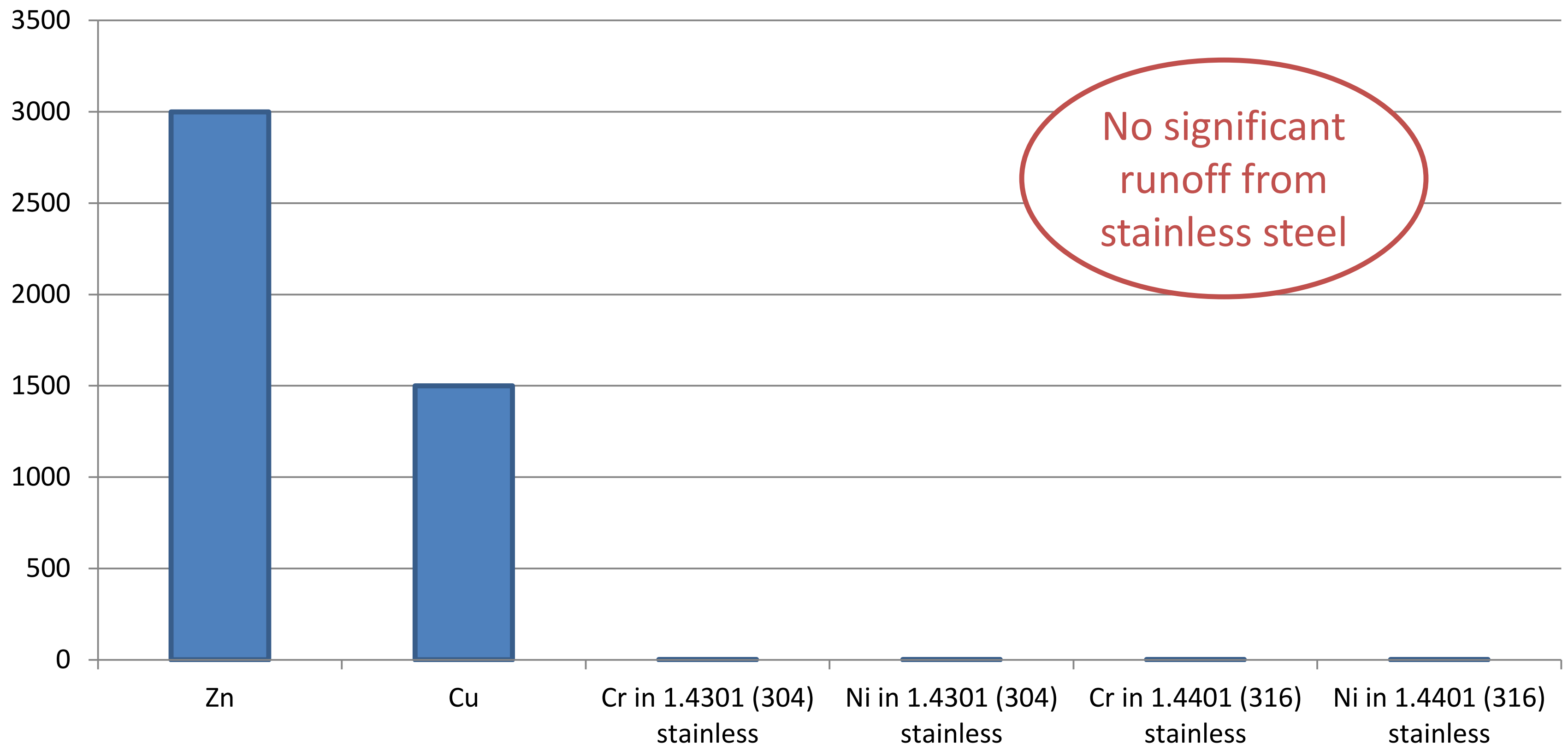
Usual characteristics of stainless steel roofs[1-4]

	Inclined (>3%)	Flat
Material	Ferritics 1.4509 1.4510	Ausenitics 1.4301 1.4401
Joining	Mechanical	Welding (for water tightness)
		 1 Stainless steel strip 2 Continuous seam weld 3 Folded top of standing joint 4 Height to seamweld about 15 mm 5 Height of joint before folding about 30 mm 6 Height of joint after folding about 20 mm 7 Angle of about 92° 8 Sliding cleat 9 Stainless fastener 10 Acoustic/protective membrane 11 Supporting structure
Surface Finish	Matte or terne coating (Sn)*	Matte or 2B (when there is a top layer)
Thickness	0.5mm; 0.4 mm for rainwater goods Allows a lightweight structure	
Life expectancy	Will last the life of the building	
Other		Suitable for green roofs In renovation can be placed directly on the bitumen roof

* In some areas Cu or Zn are restricted as being eco-toxic and leaching into the rainwater

A new concern, metal runoff in rainwater[5]

Mostly in northern Europe ... Stems from demands on water quality, availability and re-use



The Delhi Parliament Library[6-7]
Architect: Raj Rewal Associates

1. Left: Overview, with the Parliament in the back.

2. Right: View of central focal dome

The library, ~ 55,000 m^2, had its height restricted to avoid obstructing the Parliament House. The central focal dome comprises a lattice of stainless steel tubular members and cables converging at key tension cast nodes. The second dome containing stainless steel tubes , known as the VIP dome, has a diameter of 16 m and a height of 2.5 m.

Clockwise, from top left:[1]

1. Stainless church roof, Leicester, UK

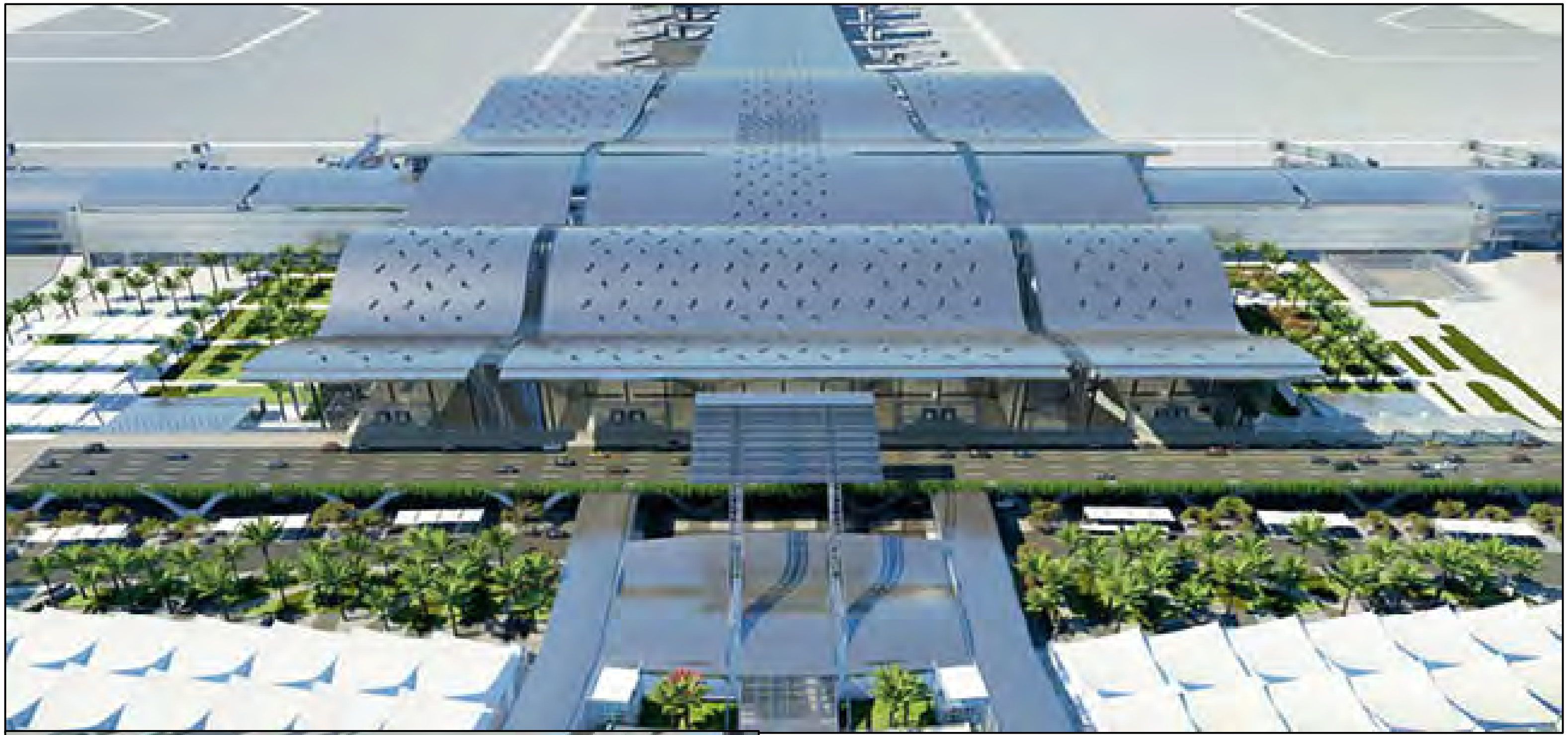
2. School restaurant, Oyonnax, France

3. Universum Science centre, Bremen, Germany

UAE Pavilion at the Shanghaï Expo[8]
Architects: Foster & Partners

The dune-like structure is made of triangulated lattice covered with flat stainless steel panels. It has been designed to be demounted.

New Doha airport, Qatar[9-10]
Architects: HOK



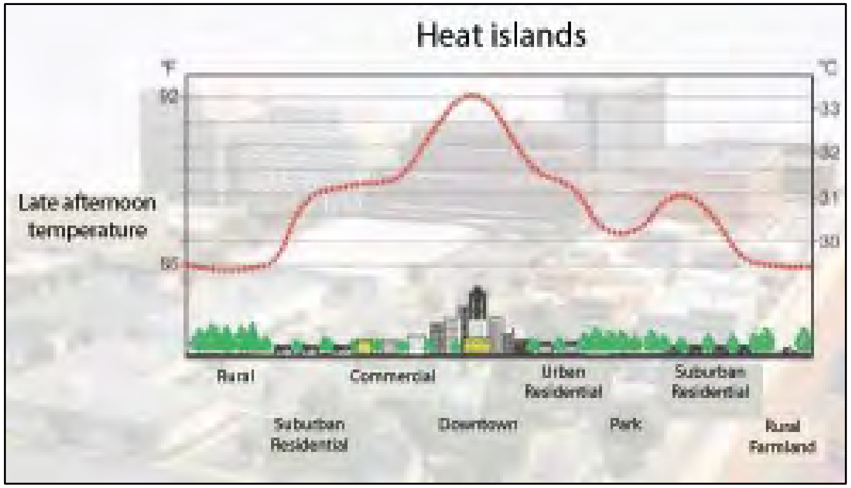
The undulating roof is said to be the largest stainless steel roof in the world (195000m²).

It features a non-directional, low gloss, uniformly textured stainless steel finish.

A lean duplex grade was selected.

No maintenance is required.

Green Roofs[1-4, 11-12]



Advantages

Mitigate heat islands
Reduce dust
Promote biodiversity
Provide insulation
Reduce flood risks
Reduce noise
Absorb CO_2
Aesthetics
Psychological well-being
Positive social and economic fallout

Limits

Requires a sturdy structure
Needs a proper know-how
May need watering in summer
Some maintenance is required
More expensive

High Reflectance Roof

Austin Hall Sam Houston State University Huntsville, Tx, USA (1851)
Low glare*, high reflectance stainless steel roof [11,13]

High Reflectance (Albedo) roofs mitigate heat islands in cities.

Solar Reflectance is now included in LEED (Leadership in Energy and Environmental Design)

SRI of Proprietary finishes > 100

Product	Temperature Rise, at C (F)	Solar Reflective Index
Stainless Steel, bare	27 (48 F)	39-60
Galvanized steel, bare	30 (55 F)	46
Aluminum, bare	27 (48 F)	56
Any metal, white coating	9 (16 F)	107
Clay tile, red	32 (5 8F)	36
Concrete tile, red	39 (71 F)	17
Concrete tile, white	12 (21 F)	90
Asphalt, generic white	36 (64 F)	26
Asphalt, generic black	46 (82 F)	1
Wood shingle, brown	37 (67 F)	22
Wood shingle, white	6 (10 F)	106

* The surface must provide a diffuse light reflection (i.e. avoid mirror-like reflection). Highly polished surfaces are not suitable.

Sunbreakers[15]

University of Arizona Medical Research Building & Thomas Keating Bioresearch Building

Canopy-type shading

Mesh with 43% open area: maximises sun blockage while allowing air to pass between the panels.

Roofs References

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2. http://ssina.com/download_a_file/roofing.pdf
3. https://youtu.be/ZQledV2QFRY
4. http://www.bssa.org.uk/cms/File/The%20Growing%20Market%20for%20Stainless%20Steel%20Roofing.pdf
5. O. Wallinder and C. Leygraf ASTM Special Technical Publication N°1421, « Outdoor Atmospheric Corrosion » pp 185-199
6. https://www.worldstainless.org/Files/issf/non-image-files/PDF/Structural/Parliament_Library_Building_Domes.pdf
7. http://www.architectureweek.com/2003/1022/design_1-3.html
8. http://www.fosterandpartners.com/projects/uae-pavilion-shanghai-expo-2010/
9. http://www.hok.com/design/service/engineering/hamad-international-airport/
10. https://www.rigidized.com/exteriorscmt.php
11. a) http://www.stainlessindia.org/UploadPdf/Dec%202011%20wshop%20Part-I.pdf
    b) http://www.wbdg.org/resources/cool-metal-roofing
12. http://www.constructalia.com/repository/transfer/en/01921518ENLACE_PDF.pdf
13. http://www.rigidized.com/saveenergy.php
14. http://www.stainlessindia.org/UploadPdf/Dec%202011%20wshop%20Part-I.pdf
15. www.cambridgearchitectural.com/

4. Decoration

Clockwise, from top left:

1. Wood and stainless stairs (unspecified location)
2. Curved wire mesh ceiling (Louisiana State University)
3. Restaurant in Finland with transparent room divider
4. Door handle

Banque de France, Paris, France[4]
Architects: Moati -Rivière

Mirror finish EN 1.4301 (AISI 304)

Metro station L5 El Carmel, Barcelona, Spain[5]

Woven stainless steel mesh wall panels

Mosteiro da Batalha, Portugal[6]

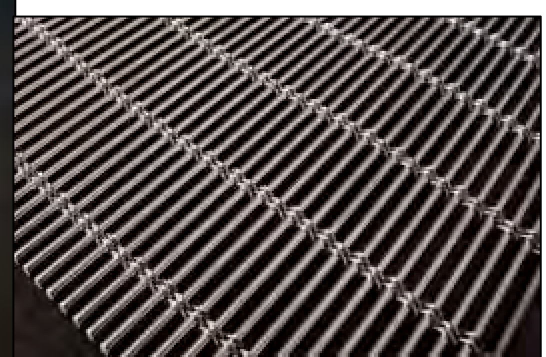
Stainless steel mesh curtain

Open Area 36 %
Weight 0.25 kg/m^2
Rod diameter 0.05 mm.
Wire pitch 0.13 x 0.13 mm.

Home curtain/safety banister[7]

Stainless steel

Open area 44 %
Weight 5,2 kg/m^2
Cable diameter 4 x 0.75 mm.
Rod diameter 1.5 mm.
Cables pitch 26.4 mm.
Wire pitch 3 mm.



Museum of contemporary art & planning exhibition, Shenzhen, China (under construction)
Architect: CoopHimmelblau[8]

Decoration References

1. http://www.seoic.com/cable_railing.htm
2. http://cambridgearchitectural.com/projects/louisiana-state-university-lsu-student-union-theater
3. http://www.twentinox.com/projects/item/36/Transparent+stainless+steel+curtain+panels
4. http://www.uginox.com/fr/node/180
5. http://www.cedinox.es
6. http://www.archilovers.com/projects/58425/mosteiro-da-batalha.html
7. http://www.theinoxincolor.com/portfolio_category/decorative-mesh-projects/
8. http://www.coop-himmelblau.at/architecture/projects/museum-of-contemporary-art-planning-exhibition

5. Stainless Steel Plumbing

Clockwise, from top left:

1. Sanitary piping
2. Press-fitted tubes
3. Kitchen faucet
4. Shower head with light

Stainless piping system

Stainless Steel Plumbing References

1. https://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/PressFittingSystems_EN.pdf
2. http://www.nickelinstitute.org/~/media/Files/TechnicalLiterature/StainlessSteelPlumbing-color-EN_11019_.ashx
3. https://nickelinstitute.org/library/?opt_perpage=20&opt_layout=grid&searchTerm=pipes%20for%20buildings&page=1
4. http://www.bssa.org.uk/cms/File/BSSA%20PLUMBING%20P.1-4.pdf
5. https://www.grohe.de/de_de/badezimmer.html

6. Escalators and elevators

Clockwise, from top left:

1. Elevator (unspecified location)
2. Escalator (Prague Metro)
3. Moving sidewalk (Brussels Metro)

Mesh-clad elevator[3]

Kraaiennest metro station entrance, Amsterdam, NL[4]

References:

1. https://www.forms-surfaces.com/elevator-ceilings
2. http://commons.wikimedia.org/wiki/File:Metro_bruxelles_laufband.jpg
3. http://cambridgearchitectural.com/projects/ft-lauderdale-hollywood-international-airport-rental-car-center
4. http://www.cabworks.com/

7. Airports


SORTIE EXIT
C D
SORTIE EXIT
C
E F

Airports References

Stainless steels are used everywhere, as the requirements are materials are expected to be used by the public 365 days a year while retaining an excellent aesthetic appearance:

- roofs,
- urban furniture,
- counters,
- drinking fountains,
- partitions,
- ventilation equipment
- handrails
- elevators, escalators, moving sidewalks
- baggage delivery carousels
- pushcarts
- fasteners
- etc…

8. Urban furniture

Clockwise, from top left:

1. Fence near school in Budang, Korea. Grades: STS439 / STS304 Finish: 2B / HL / polishing
2. Handail in Gijòn, Spain. Grande: 316L   Finish: Polished
3. Handrail, India
4. Lower Manhattan's South Ferry Subway Terminal “See it split, see it change” by by Doug and Mike Starn

Clockwise, from top left:

1. Bench in Paulinia (SP), Brazil. Grade: 304 STS304 Satin Finish
2. Butterfly bench in San Luis Potosi, Mexico
3. Bench with woven mesh, France
4. Lamp post, Seoul, Korea Grades: STS439 / STS304 / STS304N1 Finish: 2B / BA / Polishing

Clockwise, from top left:

1. Bus Stop, Istanbul, Turkey. Grades: AISI 304 and AISI 316 Finish: 2B / BA / Brushed / Scotch Brite
2. Bicycle rack, Albenga, Italy. Grade: EN 1.4301 (AISI 304)
3. Sculpture, « Invisible City » , Wellington, New Zealand
4. Joana Vasconcelos's sculpture entitled « Marylin » and made of stainless pots






Urban Furniture References

1. https://www.worldstainless.org/applications/architecture-building-and-construction-applications/street-furniture/
2. http://norcor.free.fr/piazza_superbe_inox.jpg
3. http://listraveltips.com/wellington-street-art-stainless-steel-braille-sculpture/

9. Restoration

Left: Stainless steel entrance pavilion to the the crypt of the St Martin-in-the-Field Church, London

Right: Stainless and Glass Pyramide du Louvre, Paris

Opera theatre in Verona, Italy

The great Roman monument, dates back to the first half of the 1st Century AD and has been known as the most important open air opera theatre. Recent restoration work involved the construction of new covering for the central pit, where the orchestra sits, the underground room and the underground sewage tunnels. The new covering slab is supported by a system of roof struts and post tension tie rods. The post tension system used, comprising stainless steel bars, guarantees structural safety, quality and durability.

Roman Theater, Frejus, France

Restoration of the open air roman theater with teck and perforated 3 mm thick EN 1.4571 stainless steel sheet

Restoration References

1. https://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/New_meets_Old_EN.pdf

10. Arenas

Clockwise, from top left: [1-3]

1. Handrail in VIP entrance staircase, Wembley, UK; 2. Turnstile; 3. Lockers; 4. Stainless canopy and handrail on Bourke St pedestrian bridge to Melbourne's Colonial stadium, Australia

Yamuna Stadium, Delhi, India [4]
Architects: Peddle Thorb

On the occasion of the Commonwealth Games 2010, a multifunctional stadium was created in New Delhi. With its shining façade made of stainless steel mesh, the stadium symbolises sport as a means for modern and sustainable human interaction. The stainless steel cladding with an open area of 53 percent shields spectators from the fierce subtropical climate and provides effective sun protection.

Castelão Stadium, Fortaleza, Brazil[5,6]
Architect: Vigliecca & Associados

The façade was entirely made of stainless steel expanded sheets. In addition to the external frame, stainless steel was used on railings, handrails at VIP areas, lavatories and locks of the stadium. "We have made an option for the durability stainless steel provides, which is essential to areas like the façade that required a corrosion-resistant material, and for its noble appearance, required in the hospitality sector", says architect Ronald Fiedler, responsible for the Project.

Allianz Park Palmeiras Stadium, Sao Paulo, Brazil[7]
Architect: Edo Rocha Arquitetura

This is one of the most beautiful arenas in the world. Stainless Steel is intensively used in its façade. Stainless Steel is intensively used in its façade. The sheets of stainless steel have holes in them to facilitate the circulation of air.

Media Facade, Lille stadium, France[8]
Architects: Valode Pistre and Ferret

Stainless steel mesh media facade.

The mesh supports a high power, versatile LED system which permits individually programmable lighting effects, ranging from simple graphics to video content.

Arenas References

1. http://www.cmf.co.uk/products/products.asp?id=92&product_id=4
2. http://www.assda.asn.au/blog/223-stainless-welcome-for-sports-fans
3. http://www.controlledaccess.com/
4. https://gkd-india.com/metalfabrics/yamuna-sports-stadium
5. http://www.vigliecca.com.br/en/projects/castelao-arena#gallery;%20
6. http://www.copa2014.gov.br/en/noticia/see-details-castelaos-architecture-project
7. http://edorocha.com.br/portfolio/allianz-parque/
8. https://www.osram.com/ls/projects/grand-stade-lille/index.jsp

11. Swimming Pools

Clockwise, from top left:

1. Olympic-size, stainless steel-lined swimming pool, Vichy, France
2. Custom stainless roof spa
3. Stainless steel handrail

Stainless Waterslide

Made from a single streamlined curve shape, the foot of the curve constitutes the steps that take the user to the top of the slide. The slide itself then loosens and turns in on itself.. To create a contrast, the designers used a mirror-polished finish on the interior while the exterior is brushed

"*Polished stainless steel doesn't get too hot to touch, even in sunny climates,*" the UK-based designers explained. "*In fact, it actually reflects sunlight and thermal energy as it doesn't oxidise like other metals.*"

Swimming Pools References

1. http://www.imoa.info/molybdenum-uses/molybdenum-grade-stainless-steels/architecture/french-pool-liner-article.php
2. http://www.constructalia.com/repository/transfer/fr/02163065ENLACE_PDF.pdf
3. http://www.awt-eisleben.de/en/swimming-pools-136.html

Thank you

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 02B:

Applications - Infrastructure

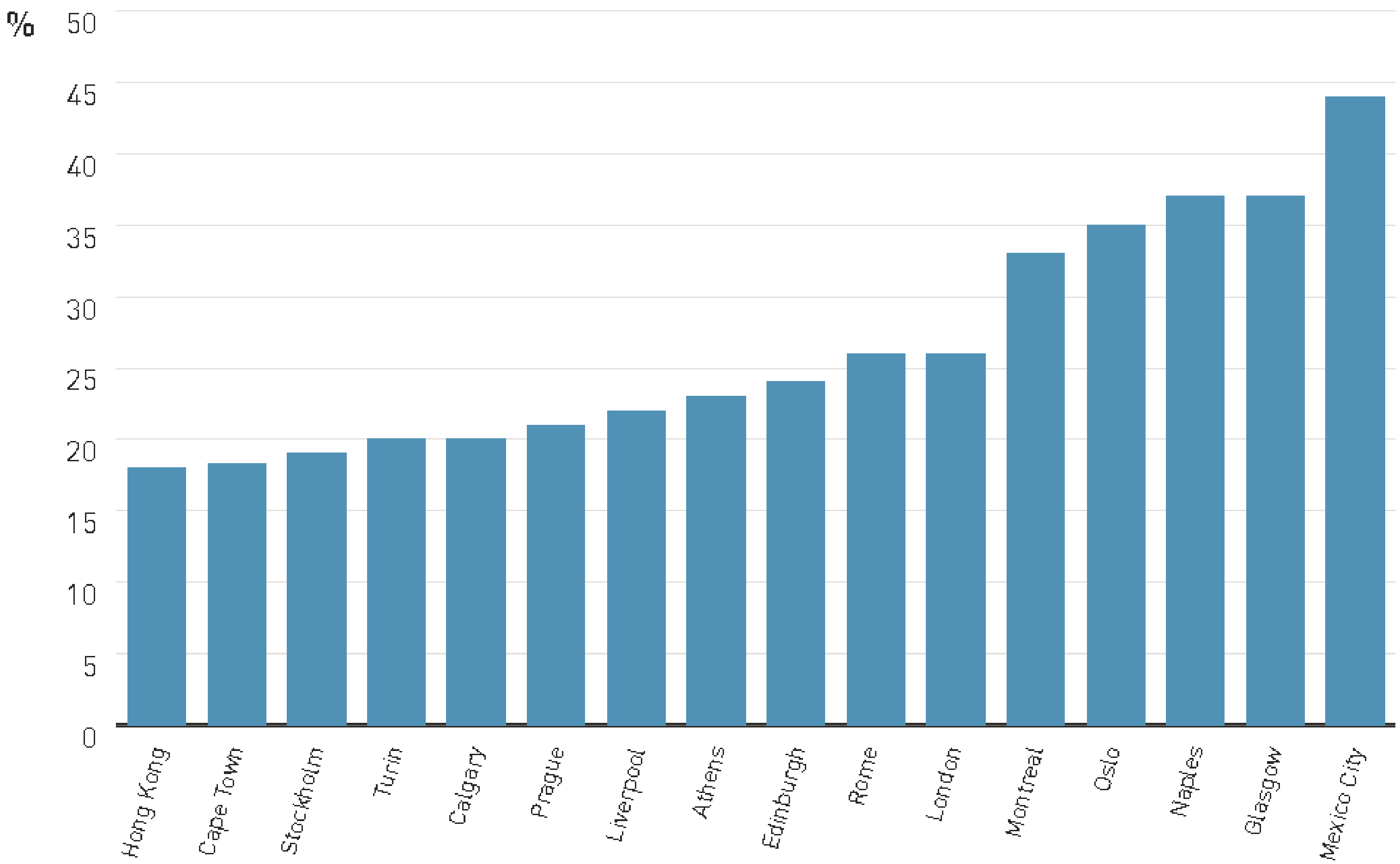
Contents

1. Water distribution

Why are stainless steels used?

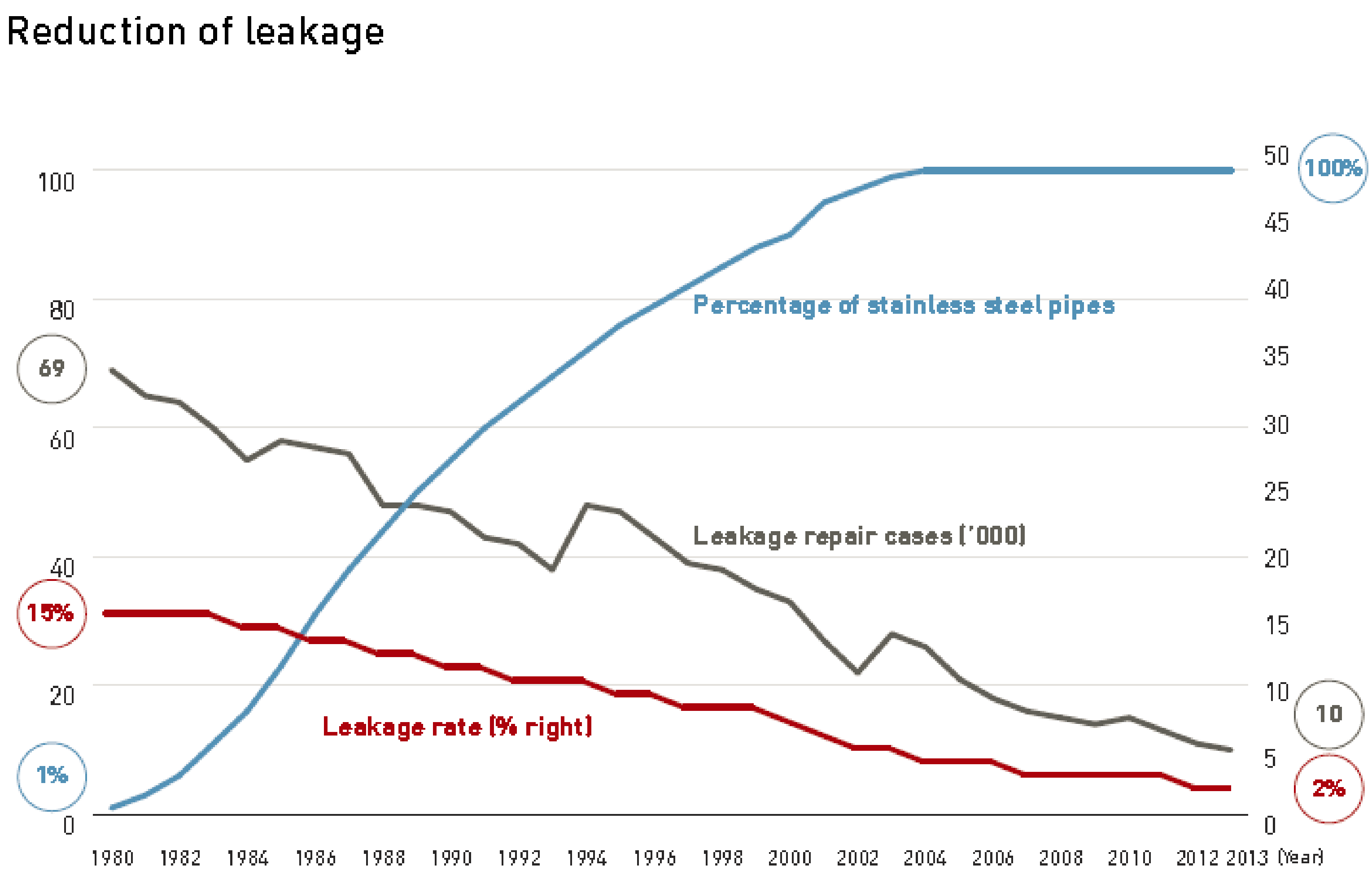
- Low Leakage Rates: Stainless Steels do not suffer from uniform corrosion like their ductile iron or steel counterparts, which can result in the rupture and failure of pipelines. Stainless valves never seize. With proper design, stainless distribution can operate safely in earthquake-prone areas
- Hygienic: Stainless Steels are basically inert in potable waters, which maintains water quality and drinking water integrity.
- Extended Service Life: Stainless steel components can provide 100 years of service due to their excellent corrosion resistance. They resist corrosion in most soils and do not require coatings or electrochemical protection systems
- Recyclable: Unlike cement lined and non-metallic pipe, Stainless Steels are easily recycled and their alloy content is highly valued
- Stainless is used for new large capacity reservoirs, new or for retrofitting existing ones

Water leakage rate in some major cities (2014) [1]

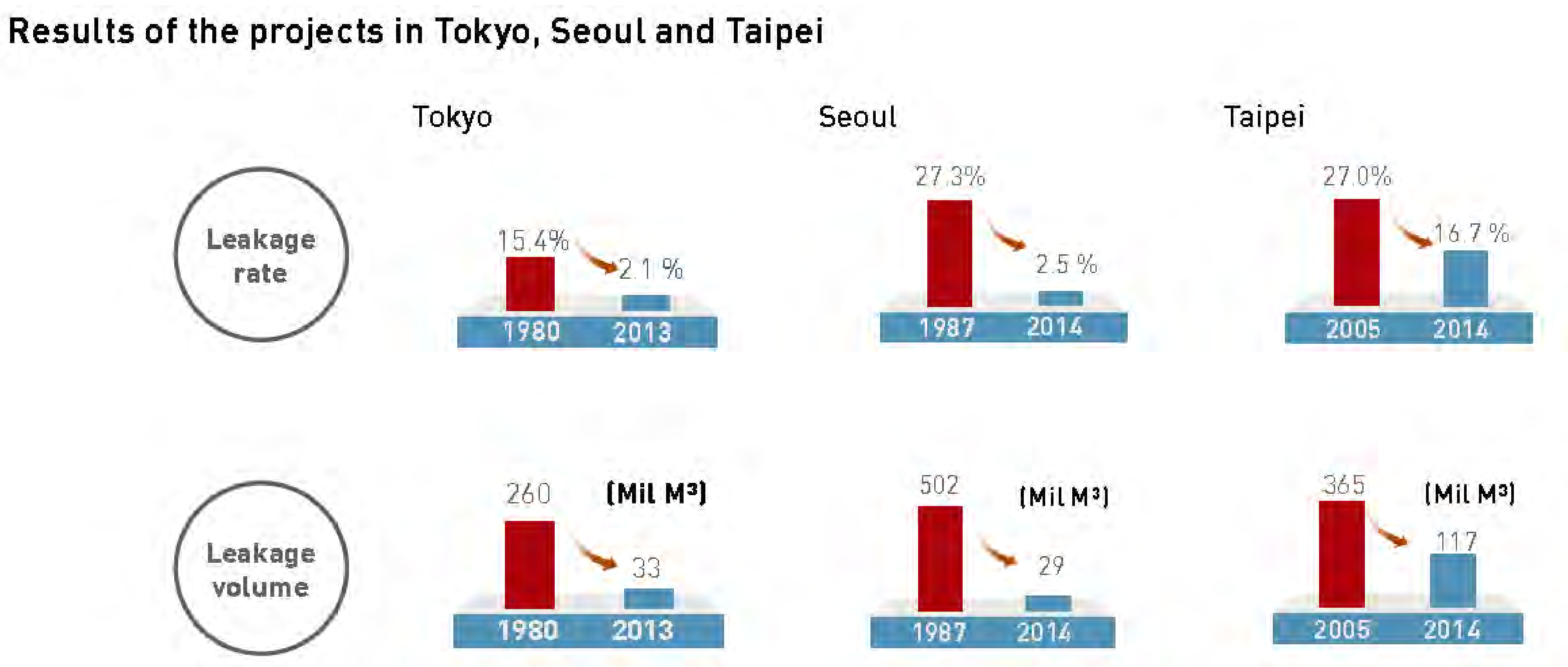


Leakage rate in major cities
Source: OECD (Water Governance in Cities, 2014)

Reduction of leaks vs stainless steel pipe use in Tokyo[1]



Reduction of water leakage with the replacement of old water pipes with stainless steel [8]




9000
8000

Water reservoir before repairs, Gangneung-City, Korea[2]

The corrosion and deterioration of concrete is visible on the picture and causes water leakage.

Epoxy coating was rejected as not lasting .

Retrofitting with a Stainless steel lining was selected for corrosion resistance, durability, no maintenance and no bacterial growth.

BEFORE

Same after new stainless steel lining

Duplex Stainless steel Grades STS329LD and STS329J3L are used.

Panels are welded together and anchored into the concrete.

AFTER

Water distribution References

1. http://www.nickelinstitute.org/en/NickelUseInSociety/MaterialsSelectionAndUse/Water/Distribution.aspx
2. http://www.imoa.info/download_files/stainless-steel/Stainless_Steel_Pipe.pdf
3. https://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/Cutler_water_EN.pdf
4. https://www.worldstainless.org/Files/issf/non-image-files/PDF/ISSF_A_workable_solution.pdf
5. Source: POSCO, Korea (http://www.posco.com)
6. https://www.worldstainless.org/Files/ISSF/non-image-files/PDF/ISSF_Stainless_Steel_in_Drinking_Water_Supply.pdf
7. https://worldstainless.org/applications/applications-for-the-protection-of-the-environment-and-human-health/protection-of-water/
8. https://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/CorrResist_SoilsConcrete_EN.pdf
9. https://www.nickelinstitute.org/~/Media/Files/TechnicalLiterature/FieldCorrosionResistanceTestOnStStPipingForBuildingService_12012_.pdf
10. https://worldstainless.org/applications/applications-for-the-protection-of-the-environment-and-human-health/protection-of-water/

NEW!

2. Bridges

NEW!

Many Bridges are in a poor condition

- A lot of them were built after World War 2
- For a projected life of 60 years plus
- Traffic has been heavier than planned
- Cutting maintenance costs has been a frequent practice

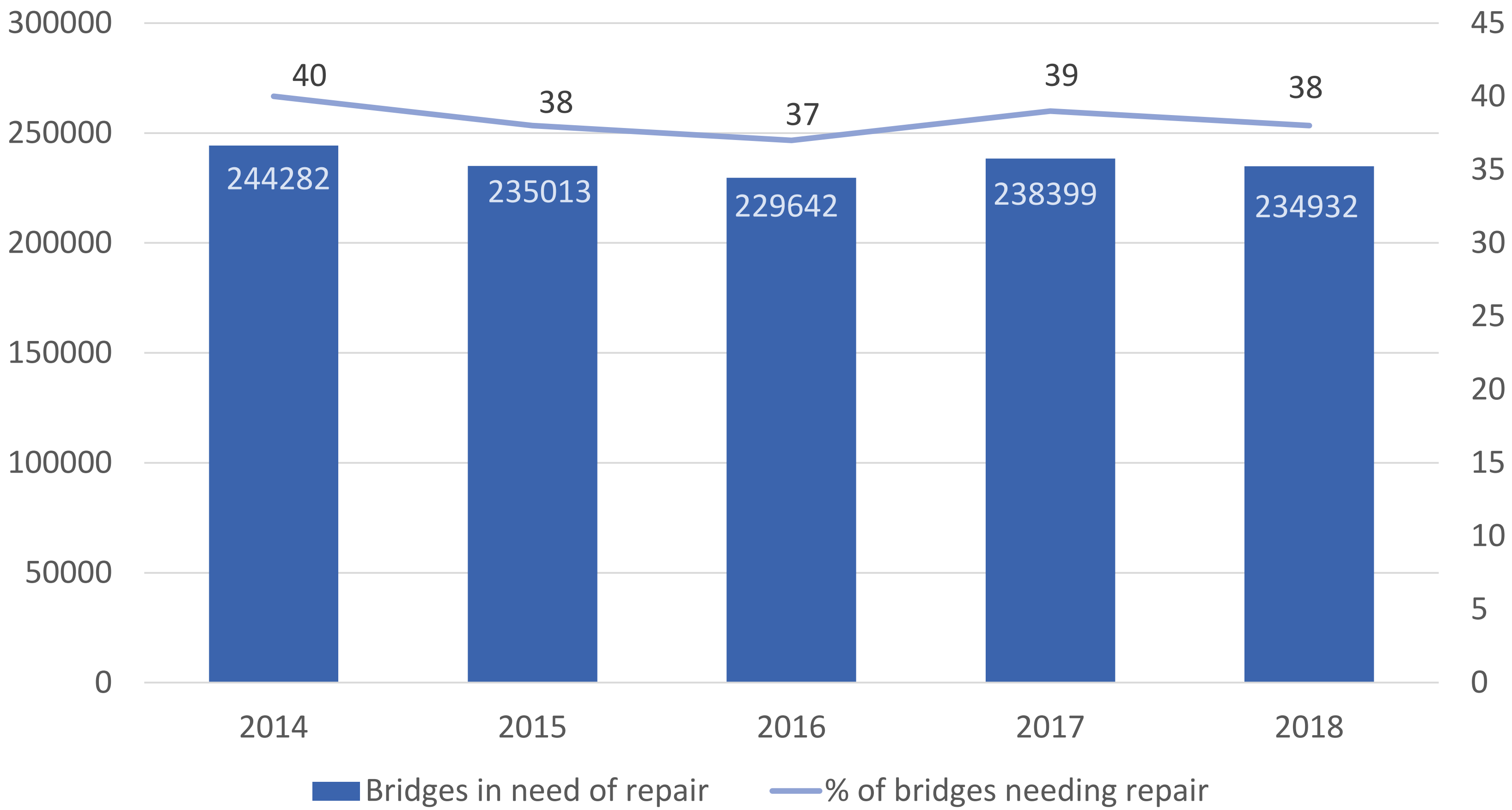
NEW!

Situation in the European Union

- There is no comprehensive report published
- Varies from country to country
- Germany: 12.5 percent of Germany's motorway bridges are in good condition, while 12.4 percent are in poor condition
- France: a recent report concluded 1/3 of the bridges are in a bad condition
- etc…

The US Situation

Number of US bridges in need of replacement or rehabilitation, including structurally deficient bridges



NEW!

Stainless steel in bridges

Some examples

Stonecutter's, Hong Kong

NEW!

This heavily-trafficked iconic bridge is located in an urban area, and has been designed to withstand tropical weather conditions, urban pollution, sea mist, wind, typhoons, accidental loads due to ship impacts and seismic loading.

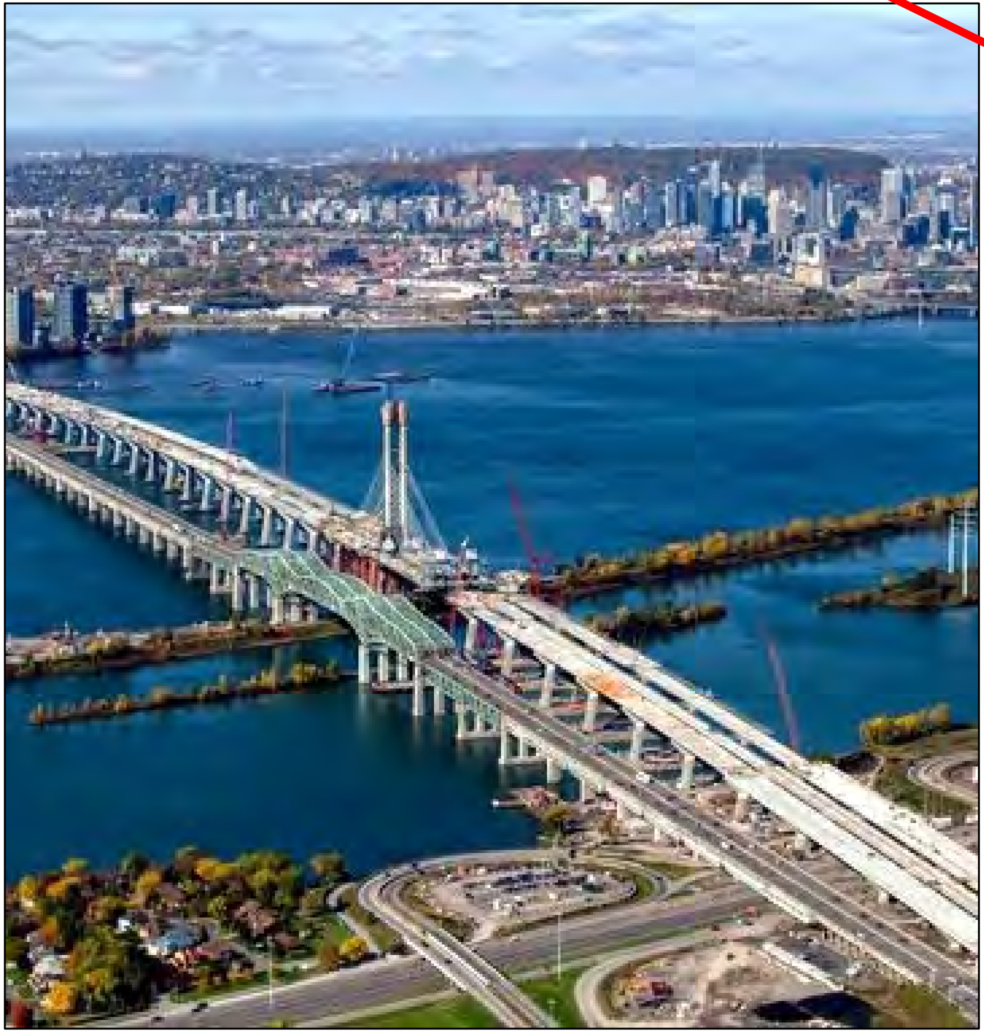
It was at the time (2009) the first cable-stayed bridge exceeding a 1km span and has an expected lifetime of 120 years. Duplex stainless steel UNS S32205 (EN1.4462) was used as skin around concrete for the upper part of the towers, for the cable-stay anchorage and for reinforcing bar of the foundations and lower parts of the towers.

NEW!

Champlain, Montreal

The new bridge (2019), which replaces the old one that was failing due to corrosion, will resist severe freeze-thaw cycles with temperatures as low as -25°C to up to 30°C. It is 3.4km long, spans over the St. Lawrence river and the seaway and will carry over 50 millions vehicles per year. It features a 4-lane highway, a commuter rail line, bicycle tracks and lookouts for sightseeing. Over 15000T of stainless steel S32305 (EN1.4362) were used in the critical parts of the structure.

The old bridge opened in 1962. In spite of extensive maintenance it had to be replaced. The new bridge costs about 4200Million CAD. In addition, de-construction of the old one will cost 400Million CAD.



NEW!

Hong Kong, Zhuhai, Macau

The bridge is a part of a 50km link consisting of a series of three cable stayed bridges, one 6.7 km undersea tunnel, and 3 artificial islands. The bridge was constructed over 9 years, at an estimated cost of $20 billion for a lifetime of 100 years and was completed in 2018.

Over 10000T of duplex stainless steel were used in the critical areas

NEW!

Fort Worth, Texas

This is the world's first arch bridge made of precast elements, 12 in total and was completed in 2013. The innovative feature is the load-bearing angled hanger bars that connect the top and the bottom of the arch bridge. They provide stability and structural performance.

They are made of duplex stainless steel grade S32205 (EN1.4462). The overall design is structurally very efficient, very elegant and ensures long-term durability.

NEW!

Cala Galdana, Menorca

This stainless steel bridge, commissioned in 2005, replaces a carbon steel reinforced concrete structure.

Duplex grade S32205 (EN1.4462) was selected over carbon steel for its higher mechanical properties and corrosion resistance. The minimum Yield strength specified was 460Mpa, for a measured value of 535MPa, while the specified value for Carbon steel was only 355Mpa.

NEW!

Helix, Singapore

Its unique double helix structure, 280m long, supporting a walkway is made of tubes and plates of duplex S32205 (EN1.4462). This grade has been selected for its strength and corrosion resistance in a tropical maritime environment. The life cycle cost of the bridge will be lower than that of a carbon steel solution. The white light at night is particularly beautiful, enhanced by the surface finish of the stainless steel.

NEW!

Lyon, France

Located in an area that underwent a major upgrading and close to the new Musée des Confluences, this duplex stainless steel pedestrian bridge opens up to allow the passage of ships entering the docks. It is elegant, aesthetic and requires no maintenance.

NEW!

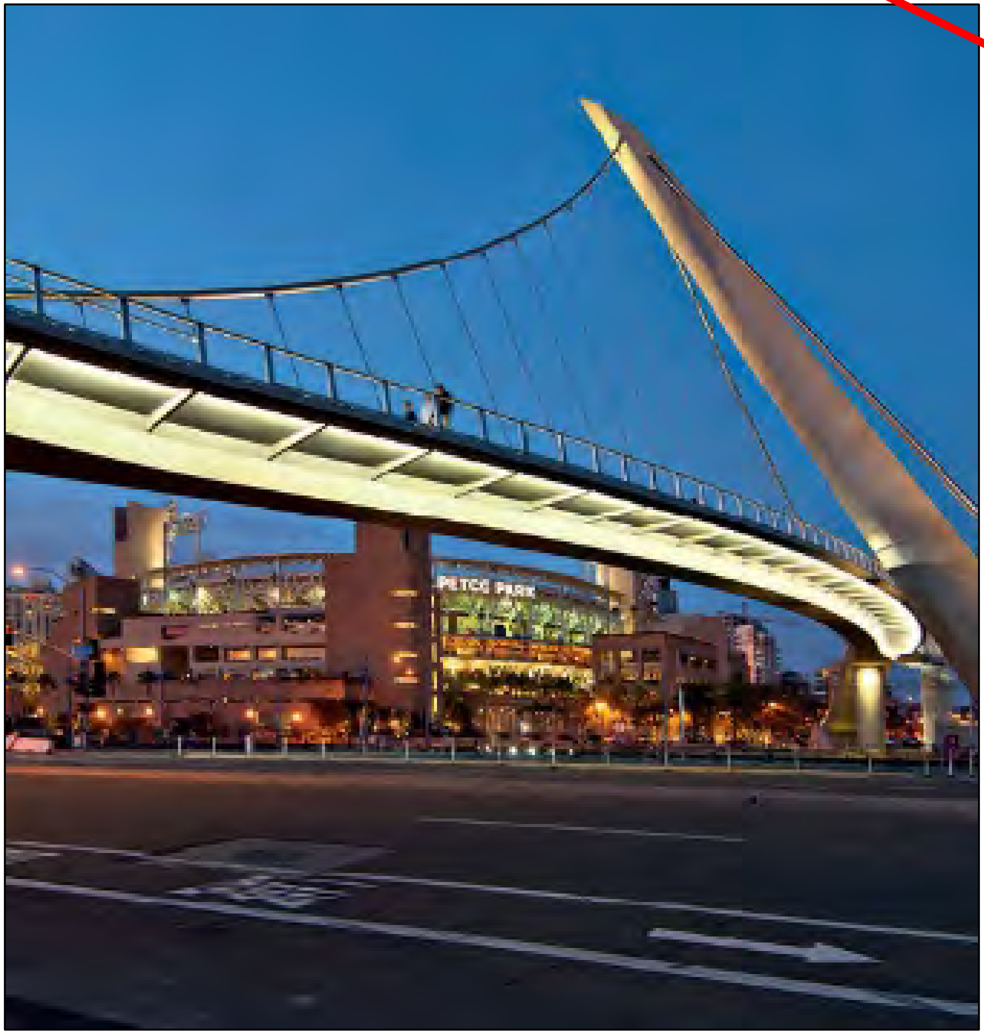
Trumpf, Germany

This footbridge over the heavily trafficked Gerlinger Strasse connects two work sites at the TRUMPF Headquarters in Ditzingen, Germany.
Made of thin, strong , corrosion resistant duplex grades S32205 (EN1.4462) cut with TRUMPF laser technology, it has a very original shape that everyone remembers.
It demonstrates that duplex is not for iconic structures only.

NEW!

San Diego Harbor, California

This self-anchored suspension structure, 168m long, is strikingly beautiful. The curved deck is supported by stay cables attached to a single inclined pylon, resulting in a very simple and attractive design. Duplex stainless steel grade S31803 and austenitic 317L have been selected for structural parts, railings, cables and connectors. The expected life time will exceed 100 years in this marine environment.



NEW!

Progreso Pier, Mexico

On the left, what remains of a pier which was built in 1970. The marine environment made the carbon steel rebar corrode – the structure failed.

On the right, the neighbouring pier erected in 1937 – 1941 using 304 stainless steel reinforcement which has been maintenance free and remained in pristine condition.

NEW!

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NEW!

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NEW!

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NEW!

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NEW!

3. Coastal Infrastructure

37% of the world's population lives within 100km of the coast

NEW!

Climate change and coasts

A few consequences:

- Oceans are rising at a rate of about 3mm/year…and will not go back! Some land is already/will be flooded
- Extreme meteorological events are more frequent (such as class 5 hurricanes, super typhoons…), adding to coastal damage
- Major changes on coastal ecosystems, mostly destruction, are taking place
- Human populations and activities are threatened with a huge human and economic cost.

NEW!

Flooding (Southwest France)

Coastal damage (location unknown)

NEW!

NEW!

Coastal adaptation options

- Managed retreat (e.g. movable structures, inland flood defences, flood warning systems)
- Accommodation (e.g. reservoir relocation, dune management, rain/waste-water management)
- Protection (includes a wide array of technologies available to coastal engineers to stabilize a coastline, including soft technologies such as beach nourishment as well as hard structures such as sea walls, revetments, groynes)

Source: www.unfccc.int/resource/docs/tp/tp0199.pdf
https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/working-regional-seas/coastal-zone-management

NEW!

Some structures for protection that use stainless steel

Sea Wall, Cromer, UK

NEW!

Cromer is a beautiful North Norfolk seaside resort from the Victorian times. Protection against the sea is achieved by a concrete sea wall and by timber groynes. Following a major storm in 2013, large and expensive repairs had to be carried out, not only to maintain the actual level of defense, but also to anticipate 100 years of predicted sea level rise.

In this project, over 300 MT of S32304 (EN1.4362) duplex stainless steel rebar were used.

Breakwater, Bayonne, France

NEW!

The breakwater, built in the 1960s, protects the entrance of the Bayonne harbor against storms. It features a wall and a platform wide and strong enough to bear a heavy duty crane. This crane replaces the 40T concrete blocks that dissipate the energy of the incoming waves on the sea side as they wear out.

As the platform itself eventually started to show cracks, it has been repaired using high strength S32205 (EN1.4462) duplex stainless steel rebar (Yield stress min 750Mpa), allowing a significant reduction of tonnage. In the end only 130 Tons of rebar were needed.

NEW!

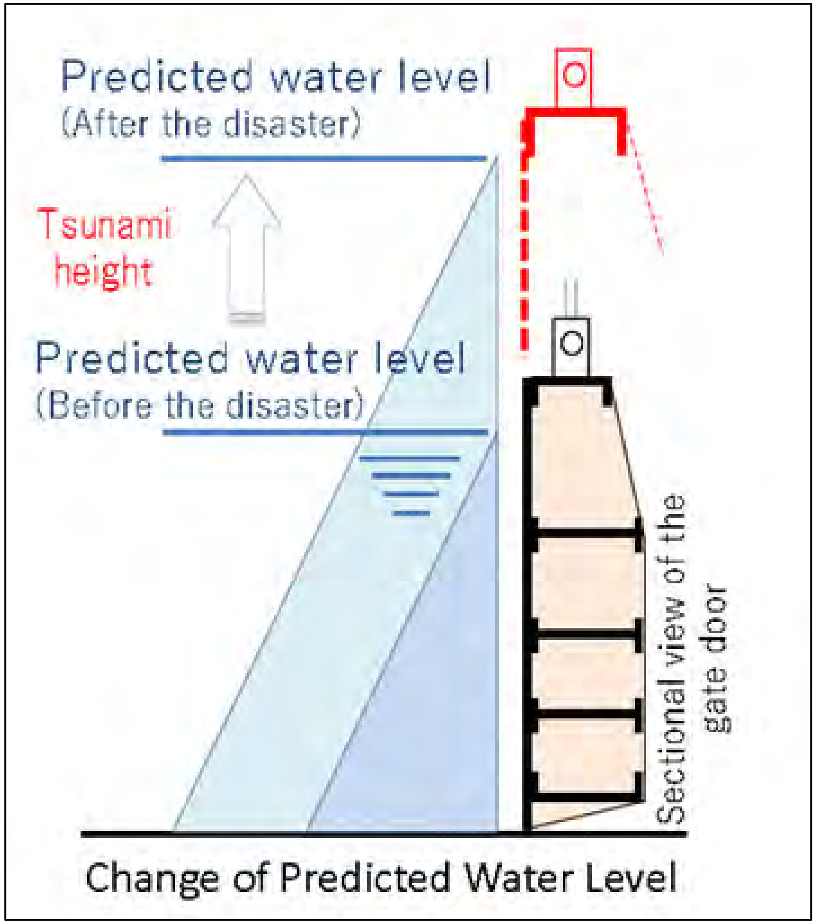
Safety measures in Japan

Contribution to reconstruction of the disasters and the national resilience

The number of deaths caused by the Great East Japan Earthquake in March 2011 was approximately 16,000, and more than 90% of those killed by tsunami, which was exceptionally large.

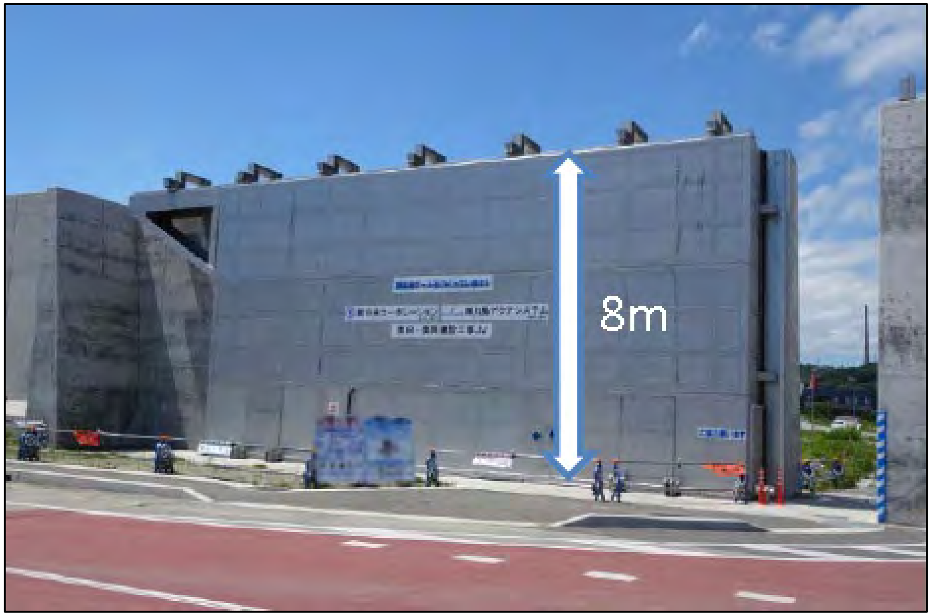
After the Earthquake, Japanese Government changed the specification of the height of the water gates from 5m to 8m. This upsizing led the increase of water pressure and it was required to increase the strength of the gates with additional the design.

Solution: NIPPON STEEL Stainless Steel Corporation proposed Alloy-Saving Duplex Stainless Steel (ASDSS), which enabled reducing its weight and simplifying the design by its strength.



Source: NIPPON STEEL Stainless Steel Corporation

Examples of water gates in Japan

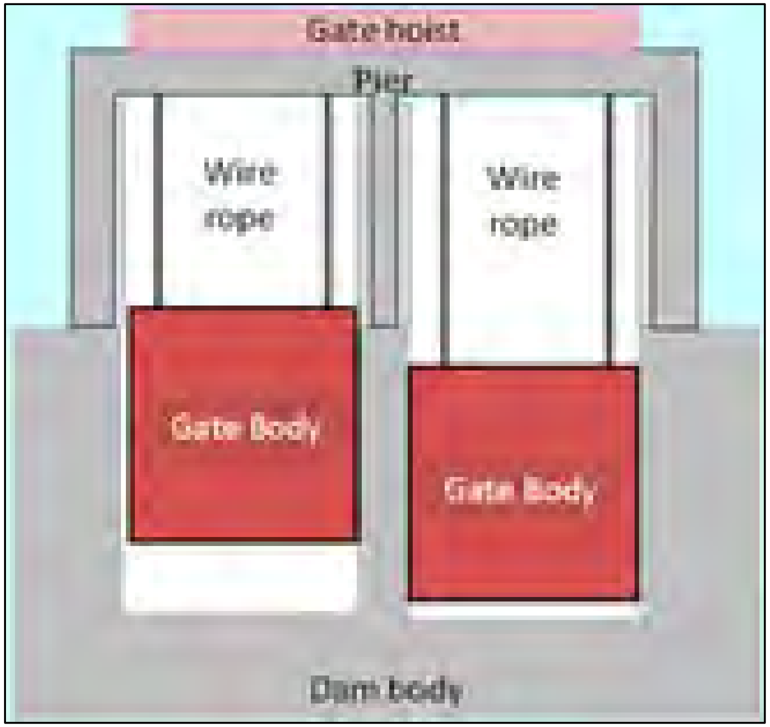


Slide gate
Height: 8.2 m x Width 15 m

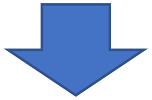
Water gate
Height: 6.2 m x Width 15 m

Source: NIPPON STEEL Stainless Steel Corporation

Weight reduction of water gates achieved by Lean Duplex stainless steel



Grades	Carbon steel (SM490)	Conventional SS (SUS 304)	ASDSS (NSSC2120)
Total weight	16.1 (t/gate)	14.7 (t/gate)	12.1 (t/gate)



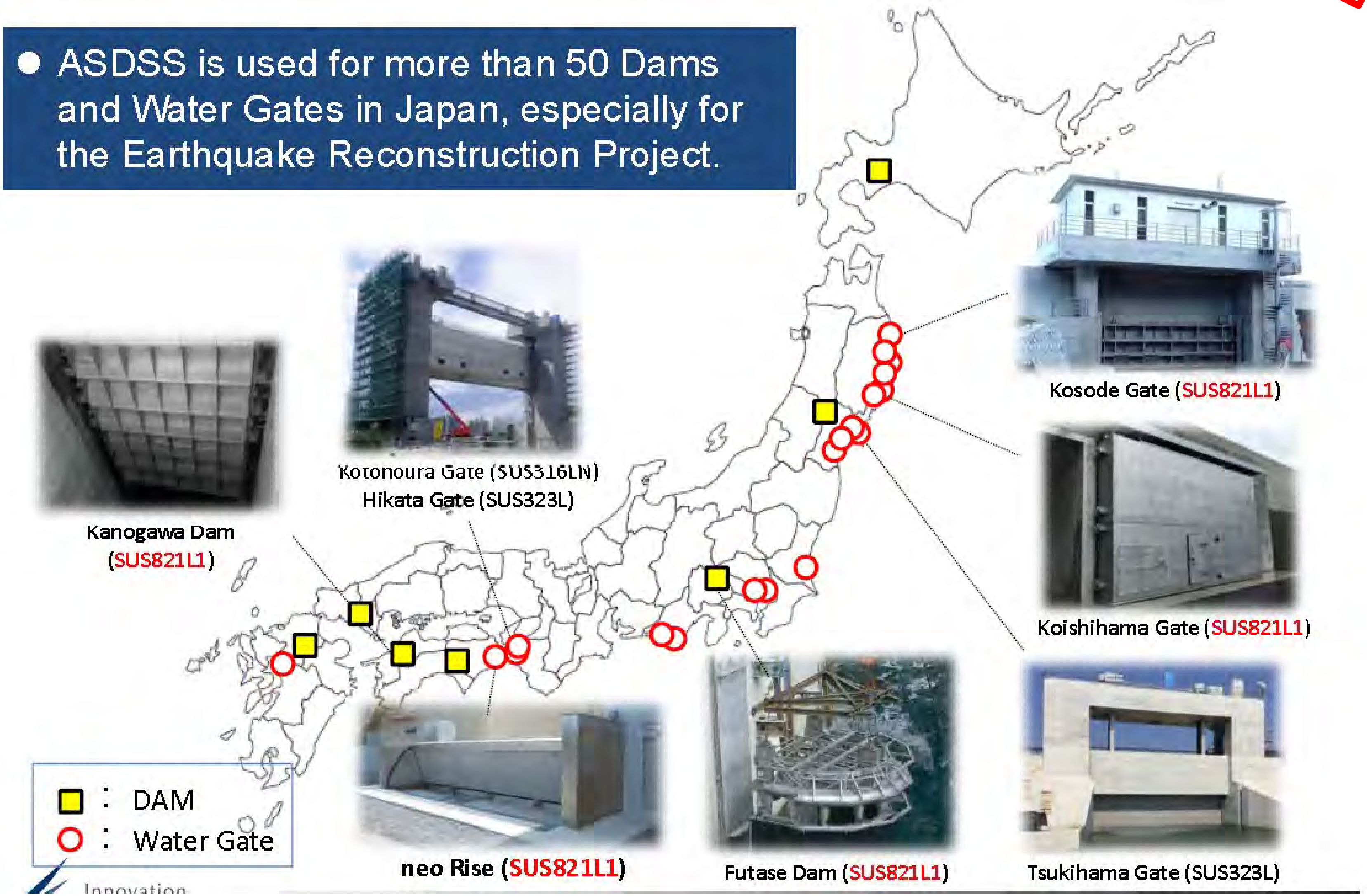
25% weight reduction

Design comparison (dam discharging gate 7m x 7.8m = 54.6m²)

Source: Electric power civil engineering (2016.9)

Some of the major projects in Japan

NEW!



NEW!

Kamihirai gate, Japan

A view of the gate being built

NEW!

Mont Saint Michel, France

NEW!

Mont Saint Michel, France

- Mont Saint Michel is one of the most visited tourist spots of France. The tiny island with its cloister and with an angel on top is located in a bay. Over time, stilting of the bay was slowly taking place, changing the landscape.
- Gates were built to store the water of the incoming stream during the incoming tides and release it at low tides, thereby taking away some sediments back to the sea twice per day. The eight sets of sluice gates clad were built using 36 T of S32205 (EN 1.4462) duplex stainless steel, selected for its good corrosion and abrasion resistance.
- Mont Saint Michel now returns to the sea.

Monaco Extension over the sea

The Principauté (principalty) de Monaco, on the Mediterranean coast, is expanding its tiny territory ($2km^2$) over the sea to build a huge 600 000m^2 new city development, for an estimated cost of 2 billion Euros.

The technical challenges are huge: creating a temporary dam to build the enclosure; erecting the concrete wall capable of lasting at least 100 years, filling up the new space gained over the sea and preparing it for multi storey residential buildings, minimizing the impact on marine life, etc.

Over 4000MT of duplex S32304 (EN1.4362) stainless steel rebar will be used to reinforce the concrete walls and protect them against the corrosion by sea water.

NEW!

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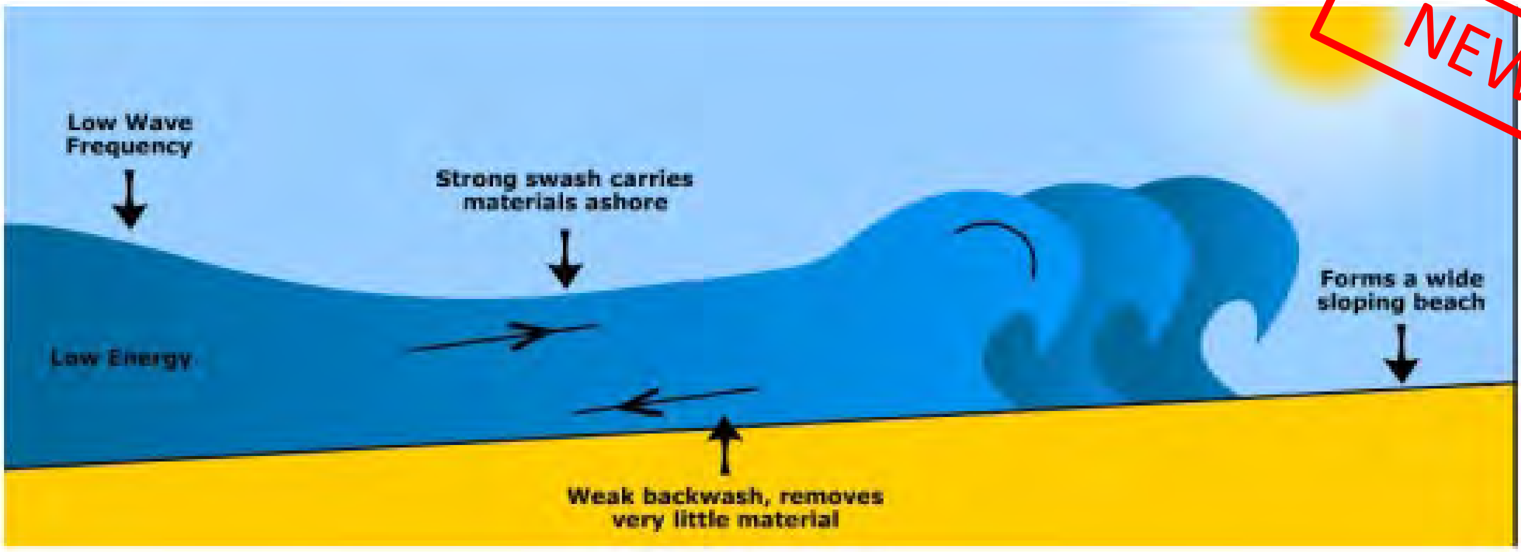
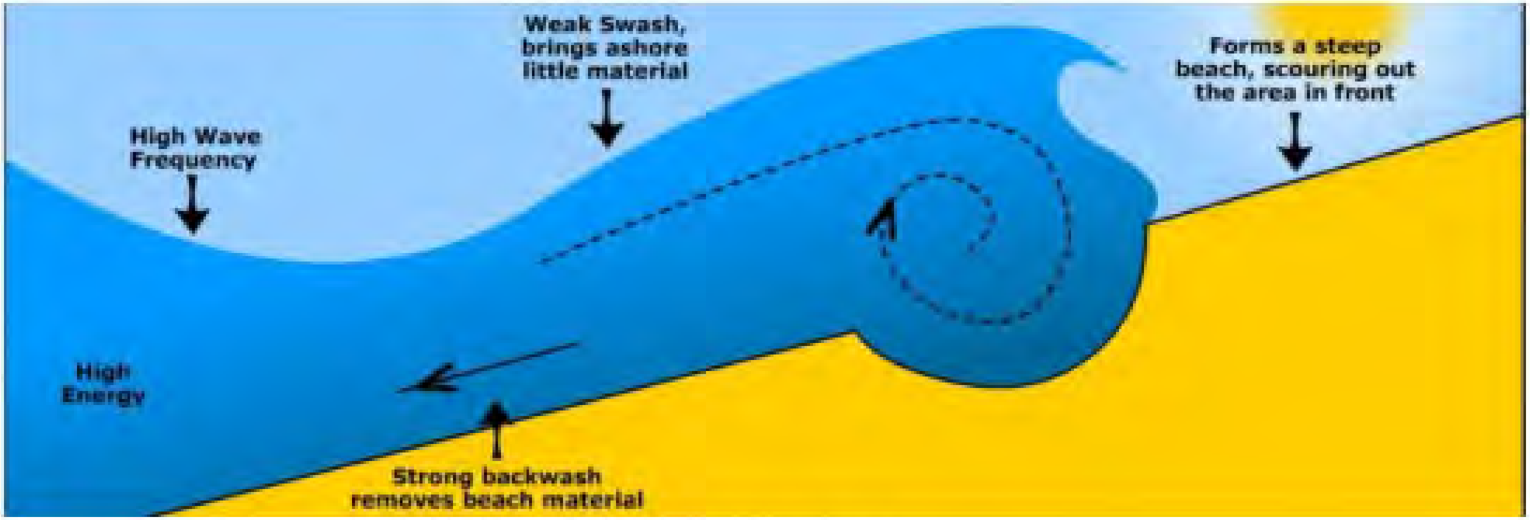
NEW!

Waves construct and destruct the coastlines [1]

NEW!



Constructive Waves



Destructive Waves

https://coastal-environments.weebly.com/landforms-and-processes.html

Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 03

Why stainless steels?

Introduction

Main materials used in architecture, building and construction

Relative use of the main building materials today

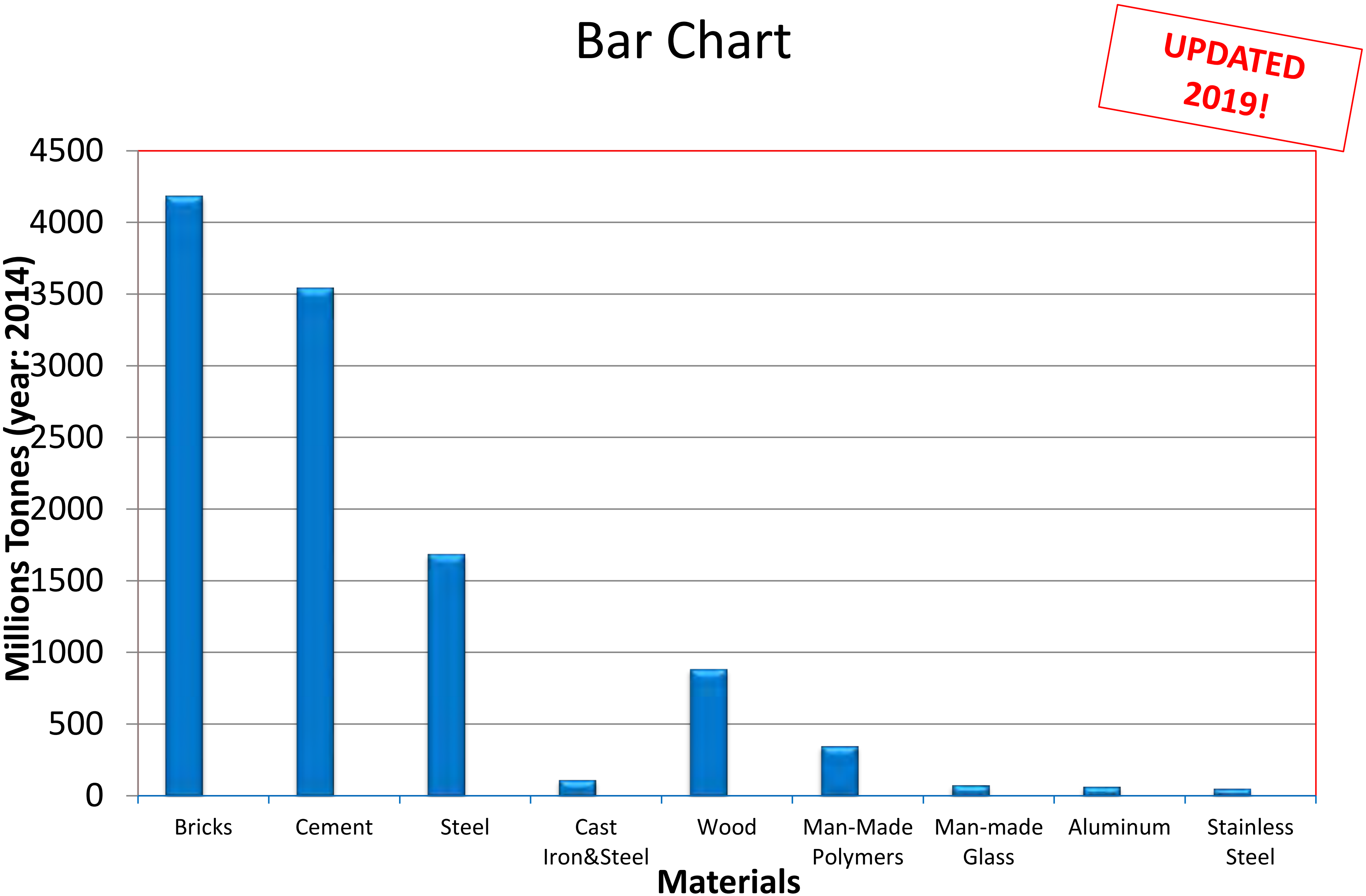
UPDATED 2019!

Materials	World Production *	Average Density	Remarks
Rammed earth, *pisé*	na		Was used for traditional houses in Africa mostly. Some renewed interest for its environmental properties
Bricks [2] Traditional production is very polluting and unhealthy	4185	2,0	Year 2017 Of which 87% in Asia
Cement [3]	3545	2,4**	(To obtain the figure for concrete multiply by 3-4) **Concrete density - 2018 figures
Steel [4a]	1690	7,8	(Crude Steel production 2018) –Includes stainless steel 14% goes into infrastructures - half as rebar [10] 42% goes into buildings [12]
Cast Iron and Steel[4b]	110	7,8	2017 Figures
Wood [5] Deforestation keeps gaining ground	887	0,56	Sawn wood+wood-based panels only (2016 figures) Excluding pulpwood (about 656) Excluding wood fuel (1860) & other wood products
Man-Made Polymers [6]	348	1,1	Some Natural Polymers: Cellulose, Rubber, Silk, Chitin 2017 figures
Man-made Glass [7]	75	2,6	Flat glass only (80% of total glass market) 2018 figures Main other markets: Automotive, Solar energy Glass
Aluminum [8]	64	2,7	(Primary Aluminum Production in 2018) 24% goes into construction [10]
Stainless Steel [9]	51	7,8	2018 figures 17% goes into construction [11]

na: not available

* in Millions Metric Tons

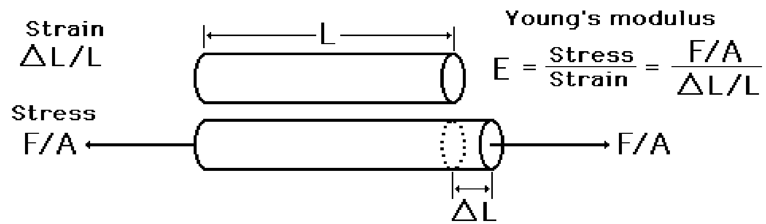
Relative use of the main building materials today: Bar Chart



Young's modulus E of various materials[12] (stiffness)

Material	Young's Modulus E (GPa)
Steels	~210
Stainless steels	~210
Copper alloys	~130
Titanium Alloys	~100
Aluminum alloys	~70
Concrete	~40
Wood	~10
Plastics	~4

Stainless steels are as stiff as steel



Strength/weight ratio[13] of architectural metals

Stainless steels offer a strength/weight ratio comparable to steels and to Al alloys

Material	Strength (YS)/Specific Weight	Yield, Stress, Mpa	Ultimate Tensile Strength, Mpa	Specific wt (Kg/dm³)	Min Elongation, %
Stainless 304 or 316, annealed	26	205	515	7,8	35
Stainless 304 or 316, work-hardened CP 350	45	350	-	7,8	-
Stainless 304 or 316, work-hardened CP 500	62	480	-	7,8	-
Duplex 2205	64	500	700/950	7,8	20
Stainless 630, aged	103	800	950/1150	7,8	10
C-steel commercial sheet, Hot rolled	30	234	317	7,8	35
Structural Steel (plate and bar)	32	250	400/550	7,8	23
HSLA Steel	49	380	460	7,8	25
Engineering Steel 4140 Q&T	96	750	930/1080	7,8	12
Aluminum Alloy 3003- H14	37	145	150	2,7	40
Aluminum Alloy 3105- H14	38	150	170	2,7	5
Aluminum Alloy 5005- H16	44	170	180	2,7	5
Aluminum Alloy 6061- T6	71	275	310	2,7	12
Aluminum Alloy 6063- T5	37	145	185	2,7	12
Copper	23	195	250	8,3	30

Simplified overview of different materials[14]

	Properties	Stainless Steels: EN 1.4521 AISI 444	Stainless Steels: EN 1.4301 AISI 304	Stainless Steels: EN 1.4401 AISI 316	Copper	Aluminum	Carbon Steel	Plastics
Physical	Density	-	-	-	- -	+	-	+ +
Physical	Linear expansion	+ +	0	0	0	-	+	- -
Physical	Electrical Conductivity	- -	-	-	+ + +	+ +	0	- - -
Physical	Ferromagnetism	YES	NO	NO	NO	NO	YES	NO
Mechanical	Stiffness (Young's modulus)	+ + +	+ + +	+ + +	+	-	+ + +	- - -
Mechanical	Tensile	+	+ +	+ +	0	-	+ / + +	- -
Mechanical	Elongation	+	+ + +	+ + +	+ + +	+ +	0	- - / + + +
Other	Fabrication	+ +	+ +	+ +	+	0	+ +	-
Other	High temperatures	+ +	+ +	+ + +	0	-	+	- - -
Other	Low temperatures	-	+ + +	+ + +	+	0	-	-
Other	Corrosion resistance	+ + +	+ + +	+ + + +	+ +	+	- -	+

Symbols + Advantage - Weakness (relative to the other materials)

Stainless steel remains a « young » material

New materials have appeared in the course of history Stainless steel is the most recent*

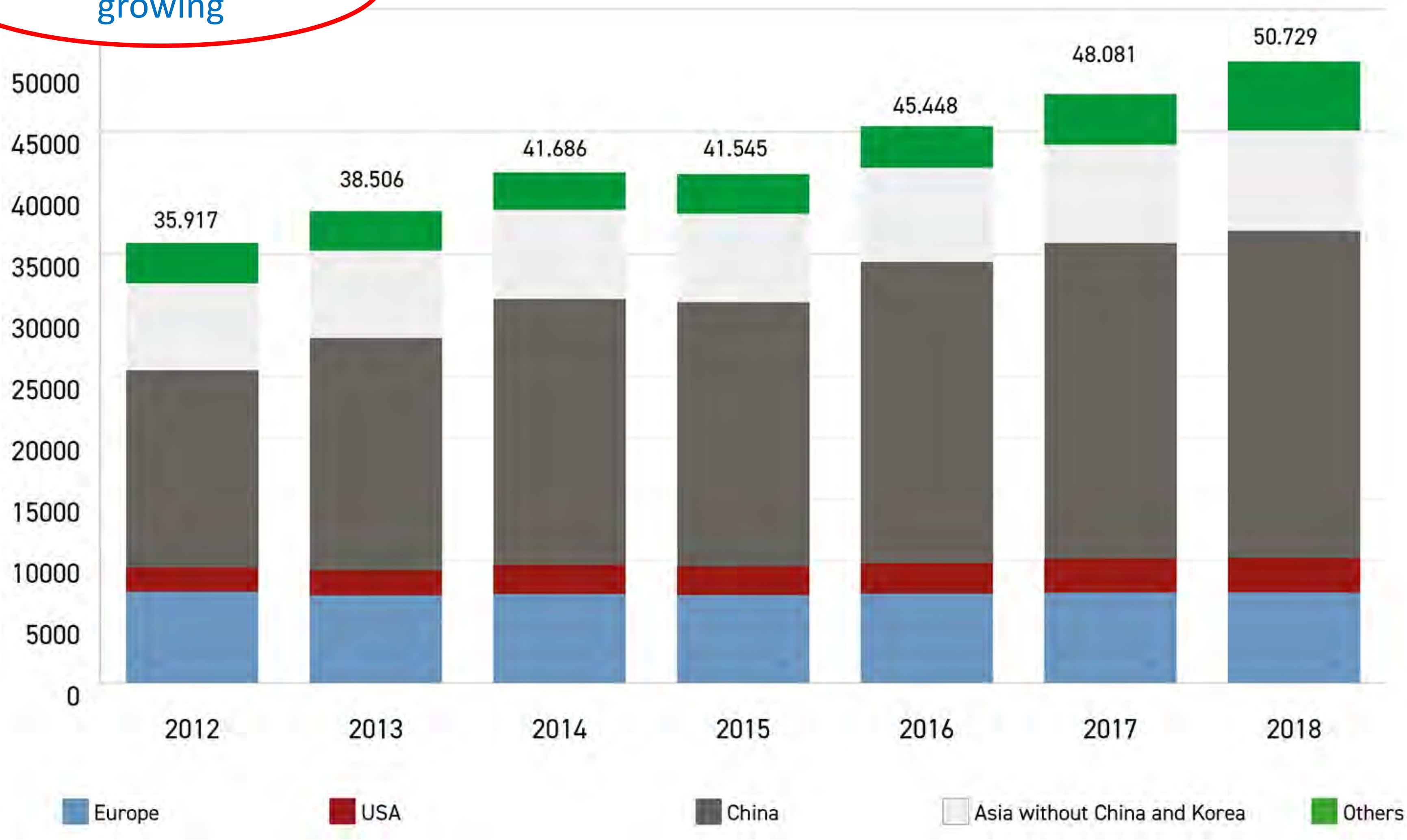
Materials	Timeframe	
Rammed earth, *pisé*		Has been used since the dawn of mankind!
Wood [15]		Has been used since the dawn of mankind!
Brick [15]	7500 BC 4500 BC	Fired bricks/ceramics
Steel [15]	4000 BC 1858	Blacksmiths' shops Bessemer Process
Man-made Glass [15]	3500 BC 100 BC 1950	First glassmaking Clear Glass Pilkington (Float Glass) Process
Aluminum [15]	1825 1886	Oersted discovers Aluminum The Hall –Heroult process
Reinforced Concrete [15]	1850 1885	But cement is much older Rotary Kiln Process
Man-Made Polymers [15]	1846 1907 1939	Celluloïd Bakelite Nylon
Stainless Steel [2]	1912-1913 1954 1955	Early alloys AOD Process Hot Strip Rolling

* There are newer materials, of course, but not used in significant quantities

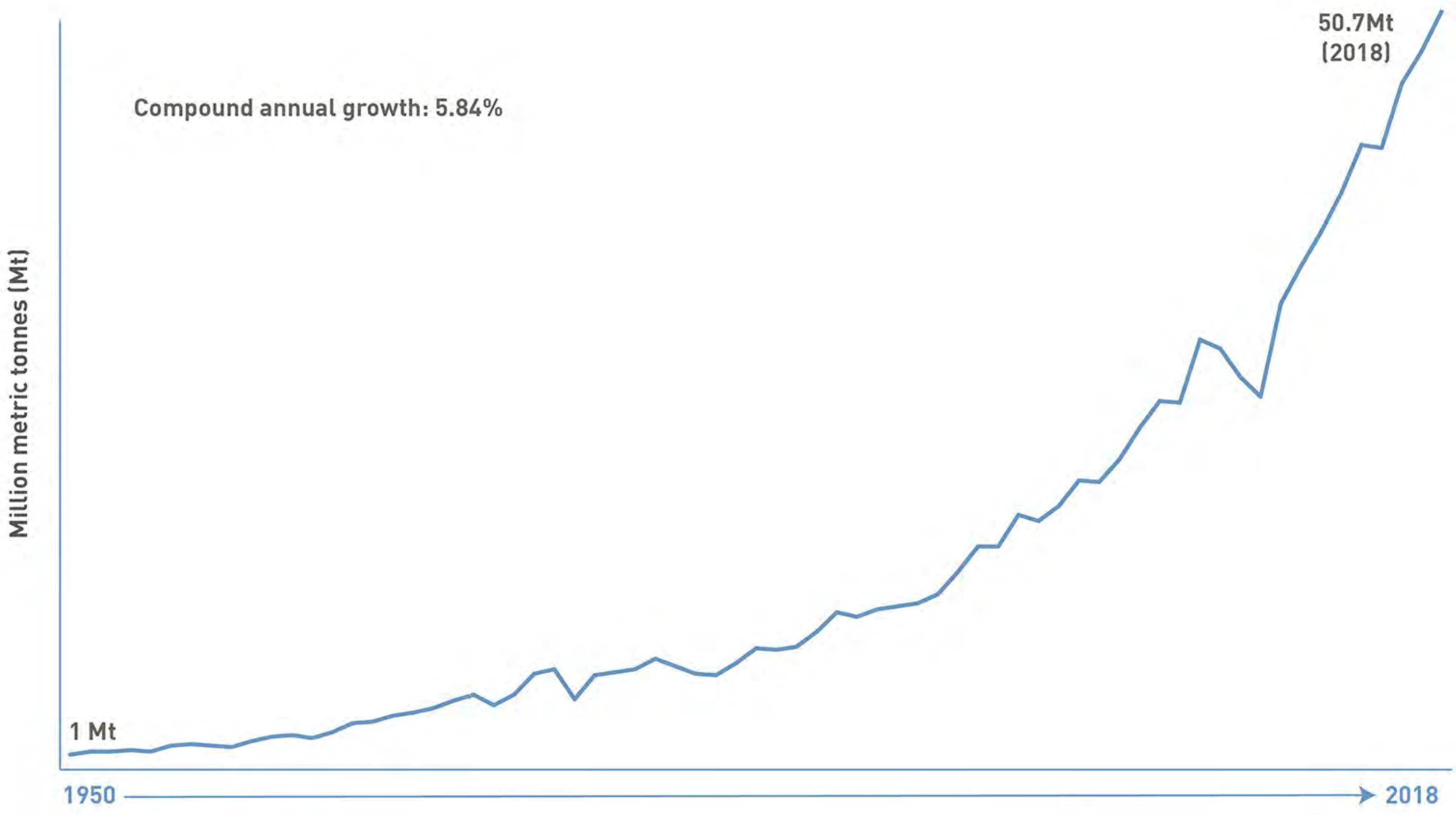
UPDATED 2019!

World Stainless Steel Production by area

Demand keeps growing



Compound annual growth of world Stainless Steel meltshop production[22] (Millions of Metric tons)



Why Stainless steel?

Because of an outstanding set of properties

1. **Corrosion resistance** (see chapter 3)
   - In all environments: tropical to polar, sea or desert, polluted or not…
   - Self-repairing, unlike coatings
2. **Lasting forever** with little or no maintenance
3. **Wide range of mechanical properties** allowed by several stainless families(Cr-Ni Austenitics – Cr-Mn Austenitics – Cr Ferritics – Duplex – Cr C Martensitics) and now built into the major building codes. Plus an excellent fire resistance (see Chapters 4 and 5)
4. **Aesthetics**: Large selection of surface finishes à colors available (see chapter 6). Plus resistance to damage in public areas
5. **Easy fabrication/joining** (see chapter 7)
6. **Excellent sustainability** (see chapter 9)
   - allows a long service life with no or little maintenance,
   - 100% recyclable (and more than 85% recycled) at the end of life into stainless steel without loss of properties
7. **Safe and Hygienic**: Inert, no contamination, easy to clean & disinfect
8. **Specific properties**: magnetic/non magnetic, ….

What limits the use of stainless steels: the price

Stainless Steels are expensive: True? Or False?

Answer: Yes and No

Yes:

If the initial material cost is all what matters (usually because of limited funding…)

But then a bad choice may be very expensive:

- Stainless steel usually represents a small part of the project
- Untimely repairs and maintenance may add huge direct and indirect costs

No:

if

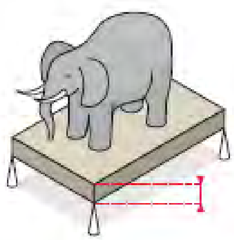
- the Life Cycle Cost (the « real » cost) is taken into account, i.e. if maintenance, service life and recycling issues are factored in*
- the design is optimized: thin sheets, profiled into complex shapes can result, in strong, stiff structures that use little material.

*The owner's best interest is always to make choices based on LCC analysis

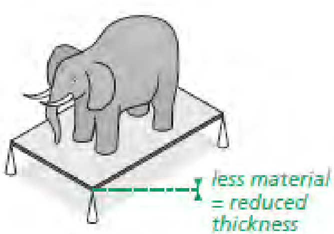
Stainless (and other metals) use less material[16]

DOING MORE WITH LESS

Due to their high strength, metals can bear high loads with less material or be used to reinforce other materials.



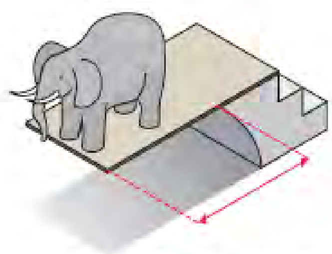
non-metallic material



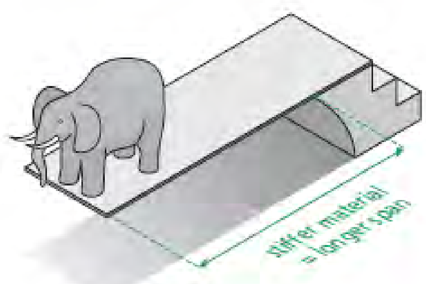
metal

FREEDOM FOR DESIGNERS

Thanks to their high stiffness, metals can span greater distances, allowing more design freedom.



non-metallic material

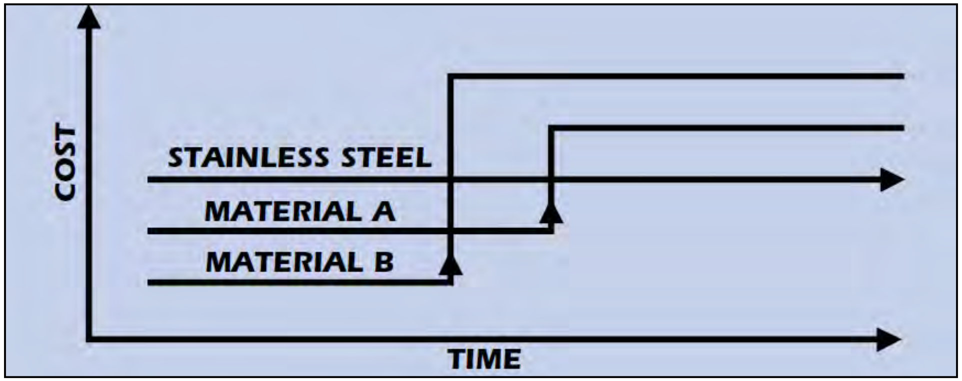


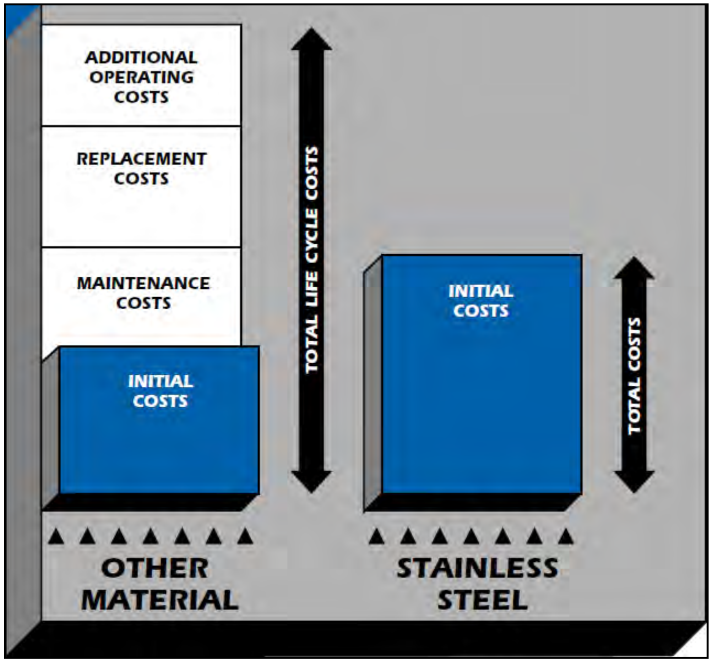
metal

Thin gauge 0,4mm and 0,6mm thick stainless steel sheets are commonly used. Weight: 3,12Kg and 4,68Kg respectively per m^2 only!

Why stainless steel is not expensive if the life cycle cost is taken into account

The cost of structures made of other materials substantially increases over time while the cost of stainless steel structures normally remains constant.





The Cost of corrosion exceeds 276 Billions $ in the USA alone [17]

Life Cycle Cost Comparison of 2 old structures[18,19]

Structures	Completed	Material	Height	Maintenance
Eiffel Tower – Paris * 	1889 	Wrought iron	324m	Every 7 years. Every painting campaign lasts for about a year and a half (15 months). 50 to 60 tons of paint, 25 painters, 1500 brushes, 5000 sanding disks and 1500 sets of work clothes.
Chrysler Building (Roof and Entrance) – New York 	1930 (roof 1929) 	Austenitic Stainless Steel (grade: 302)	319m	Twice in 1951, 1961, 1995. The 1961 cleaning solution is unknown. A mild detergent, degreaser and abrasive was used in 1995.

* The Eiffel tower was built before stainless steel was invented…and it was supposed to be a temporary structure, but the public loved it !

Example:

Comparison of the maintenance of 2 very well known bridges[20, 21]

- Golden Gate Bridge in San Francisco
- Stonecutter's Bridge in Hong Kong

In the next 2 slides

The Golden Gate bridge (1937), San Francisco

<- Maintenance

“a rugged group of **13 ironworkers** and **3 pusher ironworkers** along with and **28 painters**, **5 painter laborers**, and **a chief bridge painter** battle wind, sea air and fog, often suspended high above the Gate, to repair corroding steel. Ironworkers replace corroding steel and rivets with high-strength steel bolts, make small fabrications for use on the Bridge, and assist painters with their rigging. Ironworkers also remove plates and bars to provide access for painters to the interiors of the columns and chords that make up the Bridge. Painters prepare all Bridge surfaces and repaint all corroded areas.” [20]

Stonecutter's bridge (2009), Hong Kong

<- Maintenance

Project details : 1,596m-long dual 3-lane high-level cable-stayed bridge, with a clear span of 1,018m. Typhoon resistant.

Material : Stainless Steel EN1.4462 (Duplex) plate with 450MPa yield stress used for the towers above +175m to top (+295m) and for towers skin.

Why stainless rather than C-steel: designed for 120 years life in a hot and polluted seawater environment. Designed for no maintenance. [21]

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22. https://www.worldstainless.org/Files/issf/non-image-files/PDF/ISSF_Stainless_Steel_in_Figures_2019_English_public_version.pdf

Thank you

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

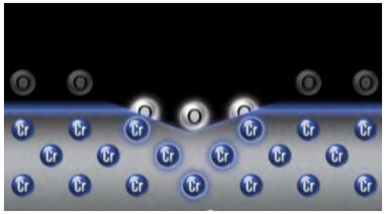
Chapter 04

What are the stainless steels?

Videos

100 Years of Stainless Steel
https://youtu.be/E-GcuxtWcnc

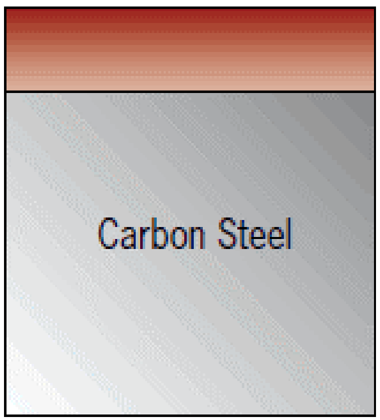
Alloyed for Lasting Value
https://youtu.be/l4Z1UVWm3DE



Self-repairing for Lasting Value
https://youtu.be/ngnT6dYo-M0

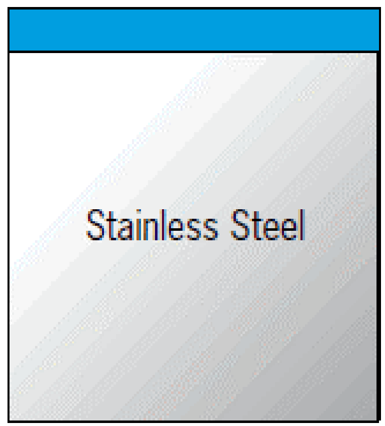
Stainless steels are Iron-base alloys containing at least 10.5% chromium

Surface Oxide (rust)
> 20µm thick



< 11% Chromium

Surface Passive film
~ 2nm thick

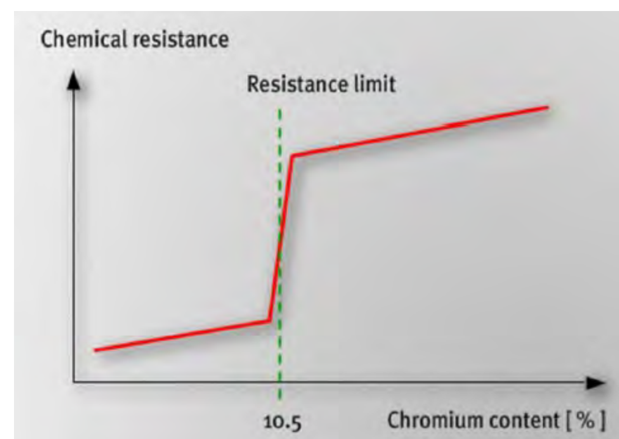


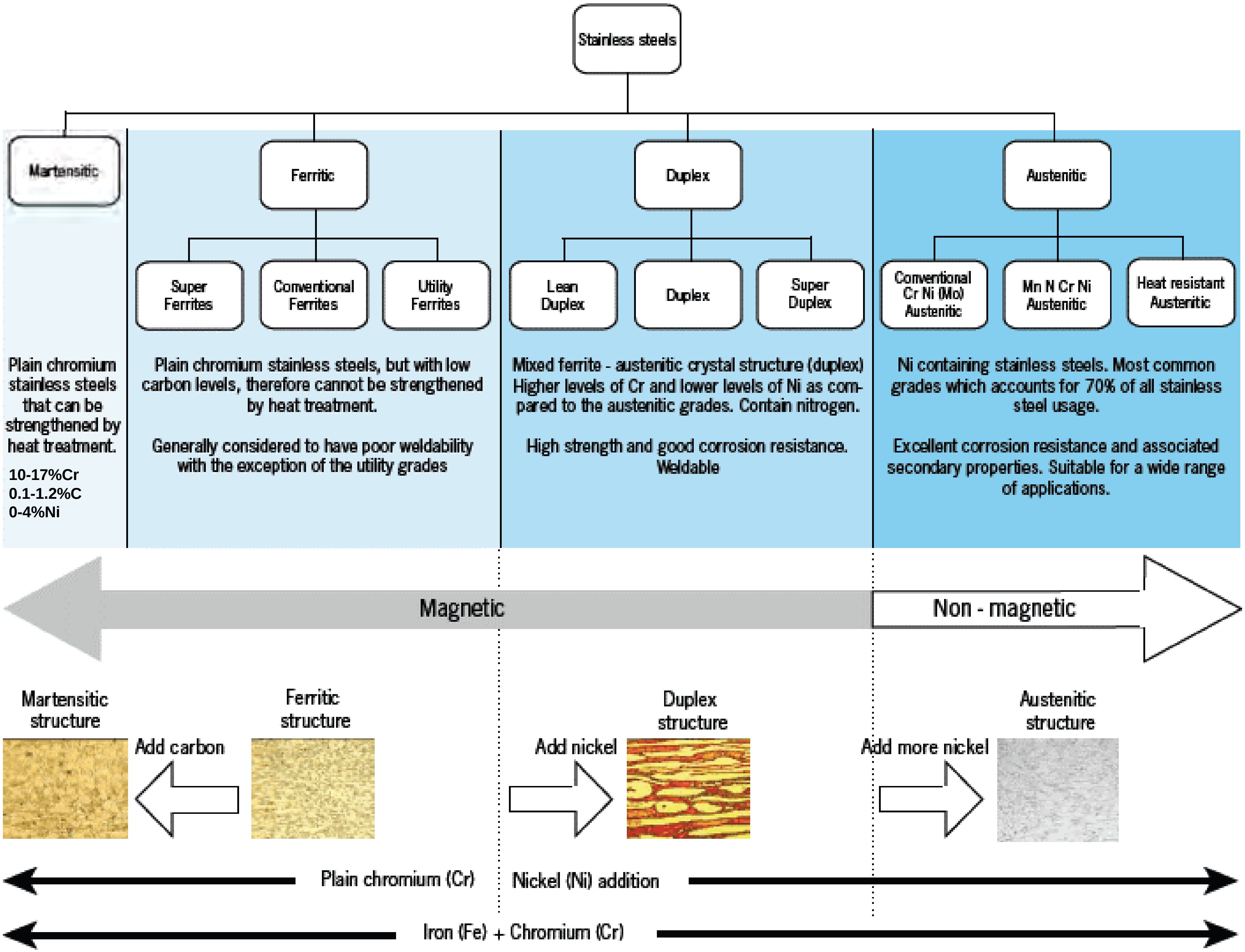
>11% Chromium

→ **corrosion resistance**

The passive film forms in a few minutes

Increasing Cr content increases the effectiveness of the passive film… but there are other important factors that influence the corrosion resistance
(see Chapter 5)




Stainless steels
Martensitic
Ferritic
Duplex
Austenitic
Super Ferrites
Conventional Ferrites
Utility Ferrites
Lean Duplex
Duplex
Super Duplex
Conventional Cr Ni (Mo) Austenitic
Mn N Cr Ni Austenitic
Heat resistant Austenitic
Plain chromium stainless steels that can be strengthened by heat treatment.
10-17%Cr
0.1-1.2%C
0-4%Ni
Plain chromium stainless steels, but with low carbon levels, therefore cannot be strengthened by heat treatment.
Generally considered to have poor weldability with the exception of the utility grades
Mixed ferrite - austenitic crystal structure (duplex) Higher levels of Cr and lower levels of Ni as compared to the austenitic grades. Contain nitrogen.
High strength and good corrosion resistance. Weldable
Ni containing stainless steels. Most common grades which accounts for 70% of all stainless steel usage.
Excellent corrosion resistance and associated secondary properties. Suitable for a wide range of applications.
Magnetic
Non - magnetic
Martensitic structure
Add carbon
Ferritic structure
Add nickel
Duplex structure
Add more nickel
Austenitic structure
Plain chromium (Cr)
Nickel (Ni) addition
Iron (Fe) + Chromium (Cr)

Cr-Ni Grades (Austenitics)[4]

Sub-groups:					
▪ Cr-Ni	Typically EN 1.4301/AISI 304	Cr: 18	Ni: 9		Fe: Balance
▪ Cr-Ni-Mo	Typically EN 1.4401/AISI 316	Cr: 18	Ni 10	Mo: 2.5	Fe: Balance

Common Properties:

- Very good corrosion resistance, increases with alloy content
- ... but can be susceptible to SCC in hot chloride environment (e.g. swimming pools)

- High ductility and impact resistance at all (including very low) temperatures
- Strength can be increased by cold working (but not by heat treatment)
- Very good fire resistance

- Very good cold and hot forming properties (ductility, elongation)
- Easy to weld (TIG, MIG)

The best known and still the most used today

Colour code: ▪ Corrosion resistance ▪ Mechanical properties ▪ Fabrication

Cr-Mn Grades (Austenitics with Manganese)[5]

Typical grade:

- Cr-Mn-Ni-N Typically EN 1.4372/AISI 201 Cr: 17 Mn: 7 Ni: 4 N:0.15 Fe: Balance

Common Properties:

- Lesser corrosion resistance
- ... but far more susceptible to SCC and to pitting, particularly at low Ni and Cr levels

- Higher strength

- Poor cold forming properties due to high work-hardening
- Poor machinability
- More difficult to weld

- Cost less than Cr-Ni Austenitics ... but more than Cr ferritics

Used mostly in India and China

Colour code: ▪ Corrosion resistance ▪ Mechanical properties ▪ Fabrication

Cr Grades (Ferritics)[6]

Sub-groups:					
▪ Cr	Typically EN 1.4016/AISI 430	Cr: 17			Fe: Balance
▪ Cr-Mo	Typically EN1.4521/AISI 444	Cr: 18	Mo: 2	Ti+Ni: 0.4	Fe: Balance

Common Properties:

- Insensitive to Stress Corrosion Cracking

- Good ductility (lower than austenitic grades, though)
- Not suitable for use at very low temperatures
- Strength can be somewhat increased by cold working (but not by heat treatment)

- Very good cold forming properties: (less springback, lower tool wear but lower elongation requires a different deep drawing process compared to austenitics)
- Stabilized grades (i.e. with Nb and/or Ti) are easy to weld (TIG, MIG)

Offer an optimum performance/cost for many applications and are increasingly used

Colour code: ▪ Corrosion resistance ▪ Mechanical properties ▪ Fabrication

Cr Grades (Martensitics)[7]

Sub-groups:

▪ C-Cr	Typically EN1.4021/AISI 420	Cr: 13	C:0.2		Fe: Balance
▪ C-Cr-Ni	Typically EN1.4057/AISI431	Cr: 16	Ni: 2	C: 0.2	Fe: Balance
▪ Precipitation Hardening	Typically EN1.4542/AISI630	Cr: 17	Ni: 4	Cu:4	Fe: Balance

Common Properties:

- Fair to good corrosion resistance, increases with alloy content

- High strength obtained by heat treatment (not by cold work). Limited elongation.
- Not suitable for use at very low temperatures

- Not suitable for forming, often processed by machining
- Can be welded (TIG, MIG), but require usually post-weld heat treatment

Are used as engineering steels with corrosion resistance

Colour code: ▪ Corrosion resistance ▪ Mechanical properties ▪ Fabrication

Duplex (Austenitic-Ferritic)[8]

Sub-groups:						
▪ Cr-Ni	Typically EN1.4362	Cr: 23	Ni: 4		Fe: Balance
▪ Cr-Ni-Mo	Typically EN1.4462	Cr: 22	Ni: 5	Mo: 3	Fe: Balance

Common Properties:

- Excellent corrosion resistance, increases with alloy content
- Insensitive to Stress Corrosion Cracking

- High strength, good ductility
- Strength can be increased by cold working (but not by heat treatment)

- Good cold and hot forming properties (ductility, elongation)
- Weldable (TIG, MIG)

Offer the best combination of corrosion resistance and mechanical properties

Colour code: ▪ Corrosion resistance ▪ Mechanical properties ▪ Fabrication

Physical properties[9, 10]

Materials	Modulus of Elasticity Gpa	Thermal Expansion Coefficient 10^{-6}°K-1	Thermal Conductivity W m^{-1}°K^{-1}	Ferro-Magnetism	Density Kg/dm³
Cr-Ni Austenitics	**210**	18	**15**	No	7.8
Cr-Mn Austenitics	**210**	17	15	No	7.8
Cr Ferritics	**220**	11	23	Yes	7.7
Cr-Ni (Mo)-N Duplex	**210**	14	**15**	Intermediate	7.8
Cr-C Martensitics	**215**	11	30	Yes	7.7
Carbon Steel	**210**	12	18	Yes	7.8
Copper	135	17	380	No	8.3
Aluminum	70	22	230	No	2.7
Glass	65	9	1,7	No	2.5
Concrete	48	10	1	No	2.5

Standards on Stainless Steels

Main World Standards:

ISO EN ASTM/AISI UNS JIS

Notes:
Most countries refer to the above standards, which are widely accepted.
A lot of the grades are very similar in all of the above standards.

List of the American Standards: ref 11
List of European Standards: ref 12

Correspondance tables are available: refs 13 - 15

Main grades in Architecture Building and Construction: EN 10088-4 (for sheet/plate/strip)[16, 17]

Grade	ASTM UNS	C Wt%	Cr Wt%	Ni Wt%	Mo Wt%	Other Wt%	Typical use [3,4]
4003	S40977	0,02	11,5	0,5	-	-	heated and unheated interiors
4016	430	0,04	16,5	-	-	-	decorative interior cladding
4509 4510	S43932 439	0,02 0,02	18 17	- -	- -	Nb Ti Ti	inland roofing and rainwater goods - often Tin-coated for patina
4521	444	0,02	17,8	-	2,1	Ti	domestic plumbing market
4301 4307 4306	304 304L 304L	0,04 0,02 0,02	18,1 18,1 18,2	8,1 8,1 10,1	- - -	- - -	building interiors and exteriors in normal industrial atmospheres away from the coast
4401 4404 4571	316 316L 316Ti	0,04 0,02 0,04	17,2 17,2 16,8	10,1 10,1 10,9	2,1 2,1 2,1	- - Ti	permanently wet applications, locations in a coastal atmosphere, polluted industrial atmospheres or near roads where de-icing salts can be an issue
4529 4547	N08926 S31254	0,01 0,01	20,5 20,0	24,8 18,0	6,5 6,1	N, Cu N, Cu	road tunnels and indoor swimming pools

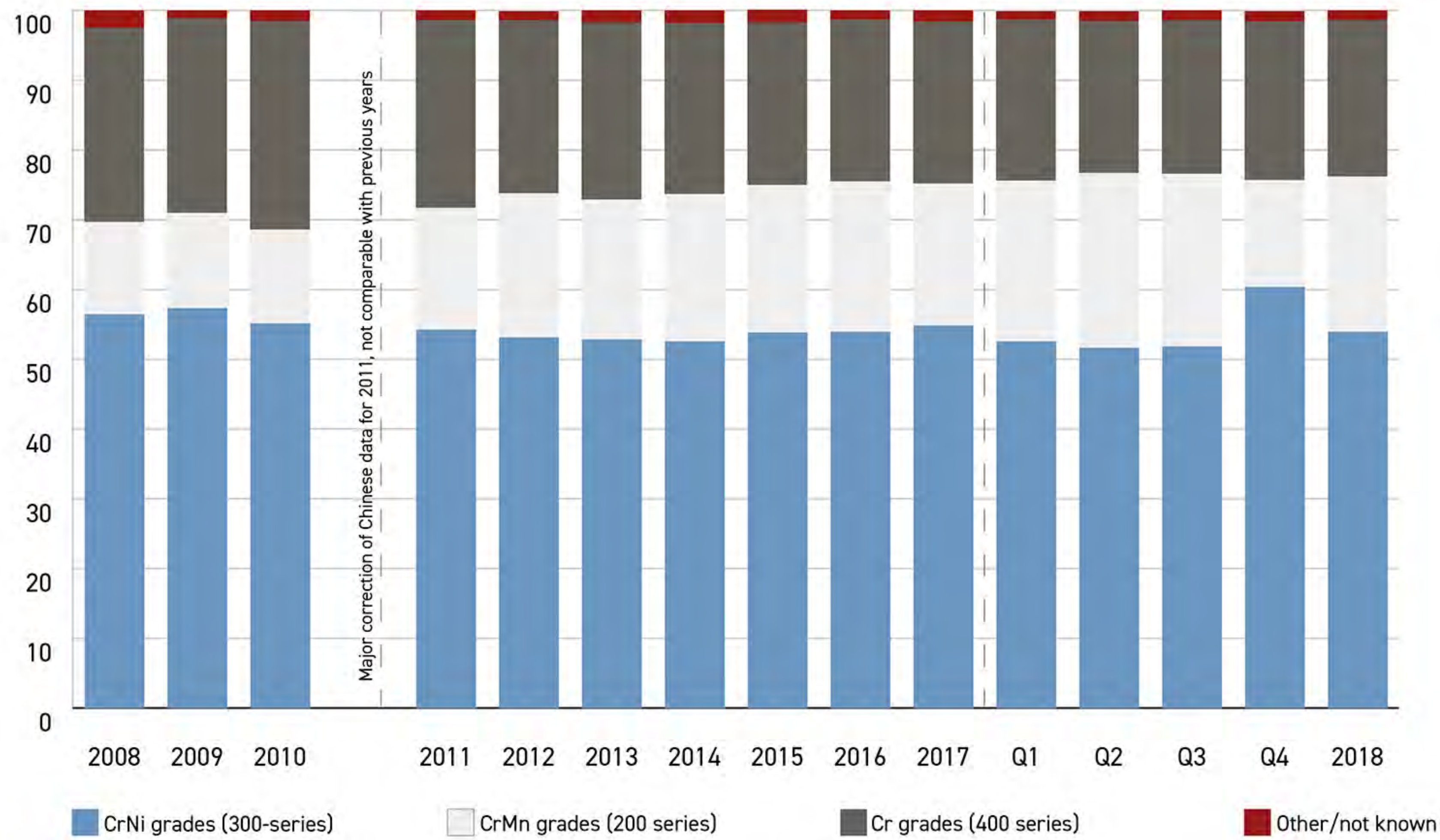
ABC = Architecture, Building and Construction

Main grades in Architecture Building and Construction: EN 10088-5(for bars/wires/sections)[18]

Grade	ASTM UNS	C Wt%	Cr Wt%	Ni Wt%	Mo Wt%	Other Wt%	Typical use [6]
4003	S40977	0,02	11,5	0,5	-	-	
4016	430	0,04	16,5	-	-	-	Slate hooks
4542	630	0,04	16,0	4,0		Cu,Nb	Tie bars
4301 4307 4311 4567	304 304L 304N 304Cu	0,04 0,02 0,02 0,02	18,1 18,1 18,1 17,1	8,1 8,1 8,6 8,6	- - - -	- - N Cu	Rebar A2 fasteners
4401 4404 4429	316 316L « 316LN »	0,05 0,02 0,02	16,6 16,6 16,6	10,1 10,1 11,1	2,1 2,1 2,6	- - N	Building interiors and exteriors in normal industrial atmospheres away from the coast, Rebar
4529 4547	« 926 » S31254	0,01 0,01	20,5 20,0	24,8 18,0	6,5 6,1	N, Cu N, Cu	Road tunnels and indoor swimming pools
4362	S32304	0,02	22,5	3,6	0,3	N, Cu	Rebar and mechanical components
4462	S32205	0,02	21,5	4,6	2,8	N	Rebar and mechanical components

Breakdown of the stainless steel production worldwide by family

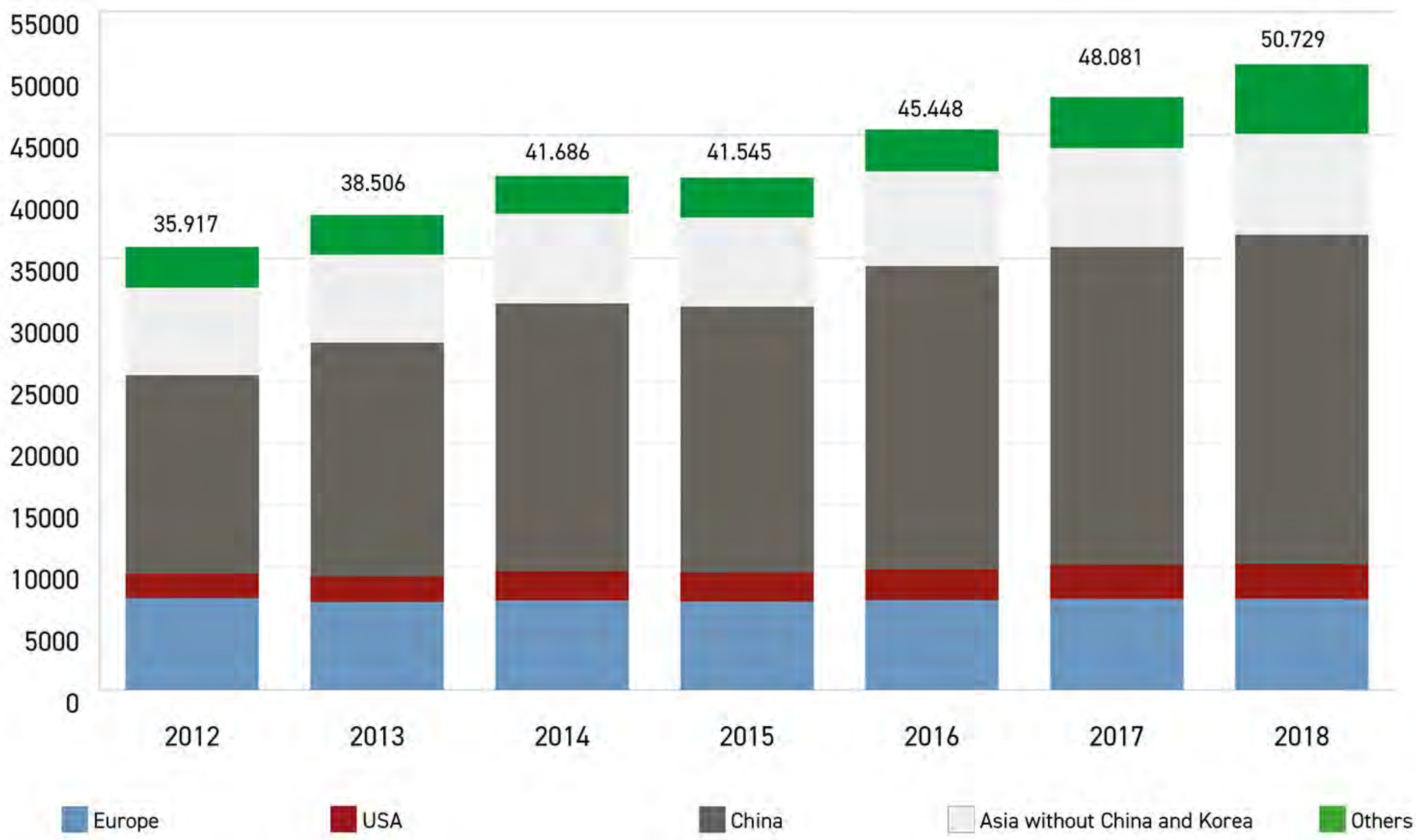
Breakdown of the world production by family[19]



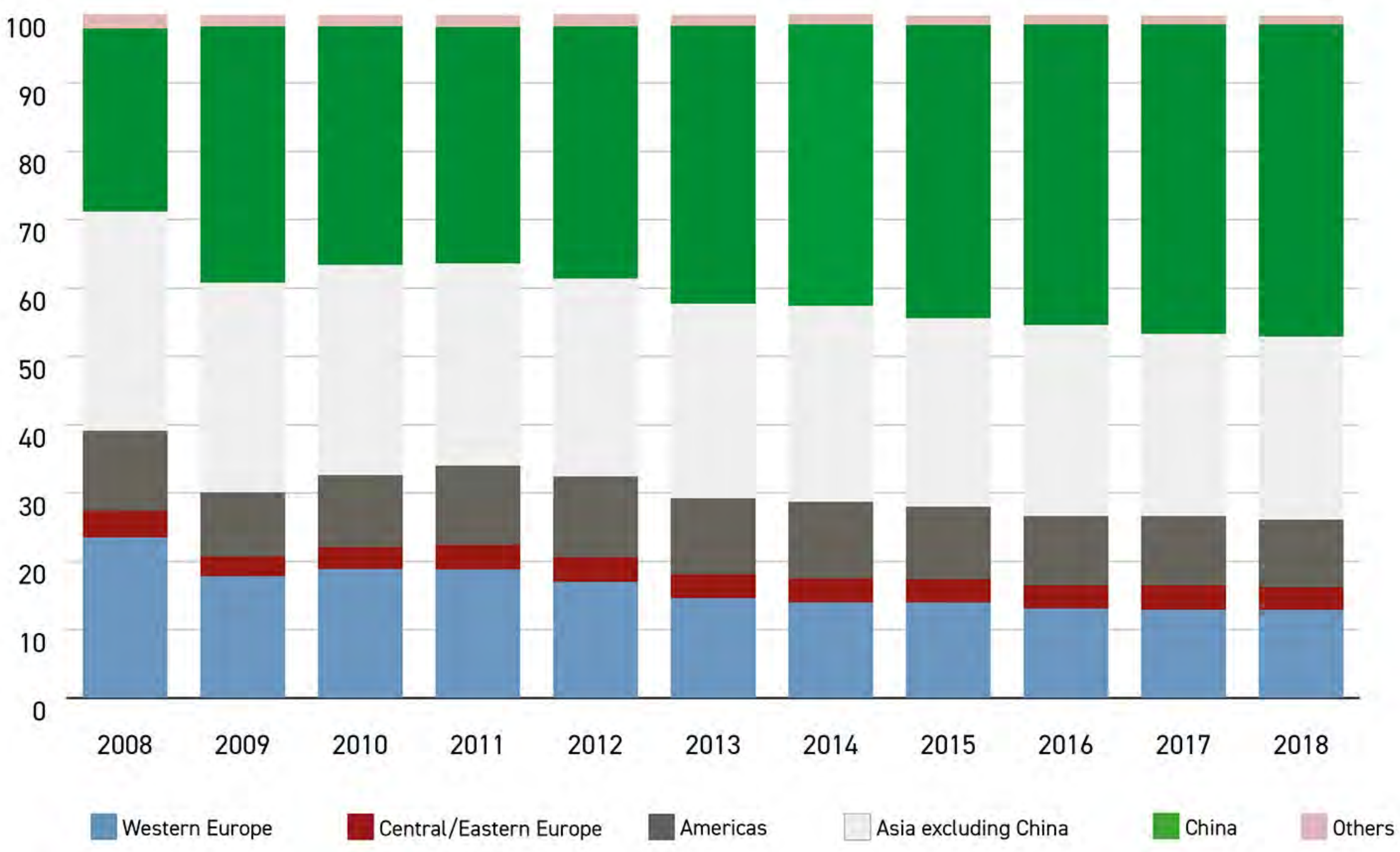
High Ni prices favour the replacement of popular CrNi grades by Cr-Mn or Cr Grades
Duplex grades marginal today, are expected to grow in the future

World stainless meltshop production (slab/ingot equivalent)

UPDATED 2019!



Apparent stainless use by region



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Thank you!

Test your knowledge of stainless steel here:

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Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 05:
Corrosion Resistance of Stainless Steels

Contents

1. Most materials decay over time

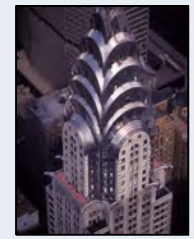
Most materials decay over time

Material	Wood	Steel	Concrete
			
Type of decay	Fungi Insects Sun+rain	Rust	Cracking/ Spalling
Mitigating actions	Chemicals Paint/varnish	Galvanising Painting	Corrosion resistant rebar

Most materials decay over time

Material	Stone	Glass	Polymers
			
Type of decay	Wear Damage by Pollution	Breaks	Become brittle under UV light
Mitigating actions	Usually none taken	Tempered glass	Improved polymer grades

Most materials decay over time

Material	Aluminum*	Copper	Stainless
			
Type of decay	Pitting over time, possible galvanic corrosion	Forms a green patina over time	No decay
Mitigating actions	Galvanic corrosion can be prevented	None	None required

* Aluminum forms a thin protective oxide just like stainless, but with a much lower corrosion resistance

Corrosion in concrete
(corrosion problems are not limited to outside surfaces !)

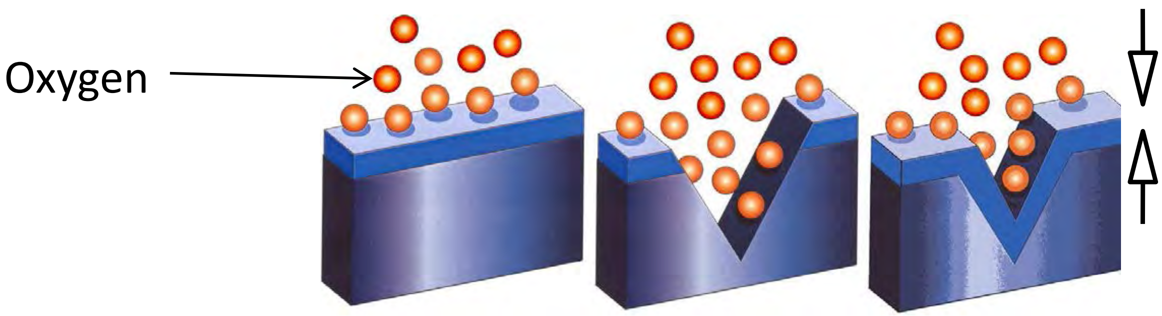
Stainless steel provides both strength and corrosion resistance inside the concrete, providing a long, maintenance-free service life of the structure.

- Corrosion of unprotected carbon steel occurs even inside reinforced concrete structures as chlorides present in the environment (marine/deicing) diffuse through the concrete.
- Corrosion products (rust) have a higher volume than the metal, create internal tensions causing the concrete cover to spall.
- Mitigating the corrosion of steel reinforcing bar in concrete is a must.
- Various techniques are used: thicker concrete cover; cathodic protection; membranes, epoxy coating … **and stainless steel** rather than C-Steel.

2. Why does stainless steel resist corrosion

Passive Layer vs. Coatings

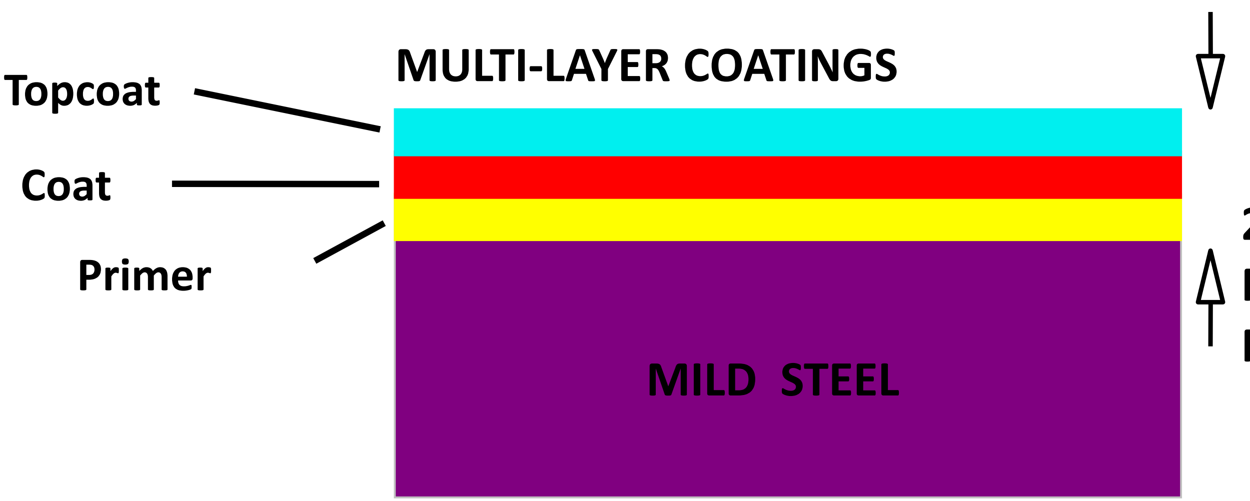
PASSIVE FILM on STAINLESS STEEL:
Oxy-hydroxides of Fe and Cr



2-3 nm thick
(0,002-0,003 µm)

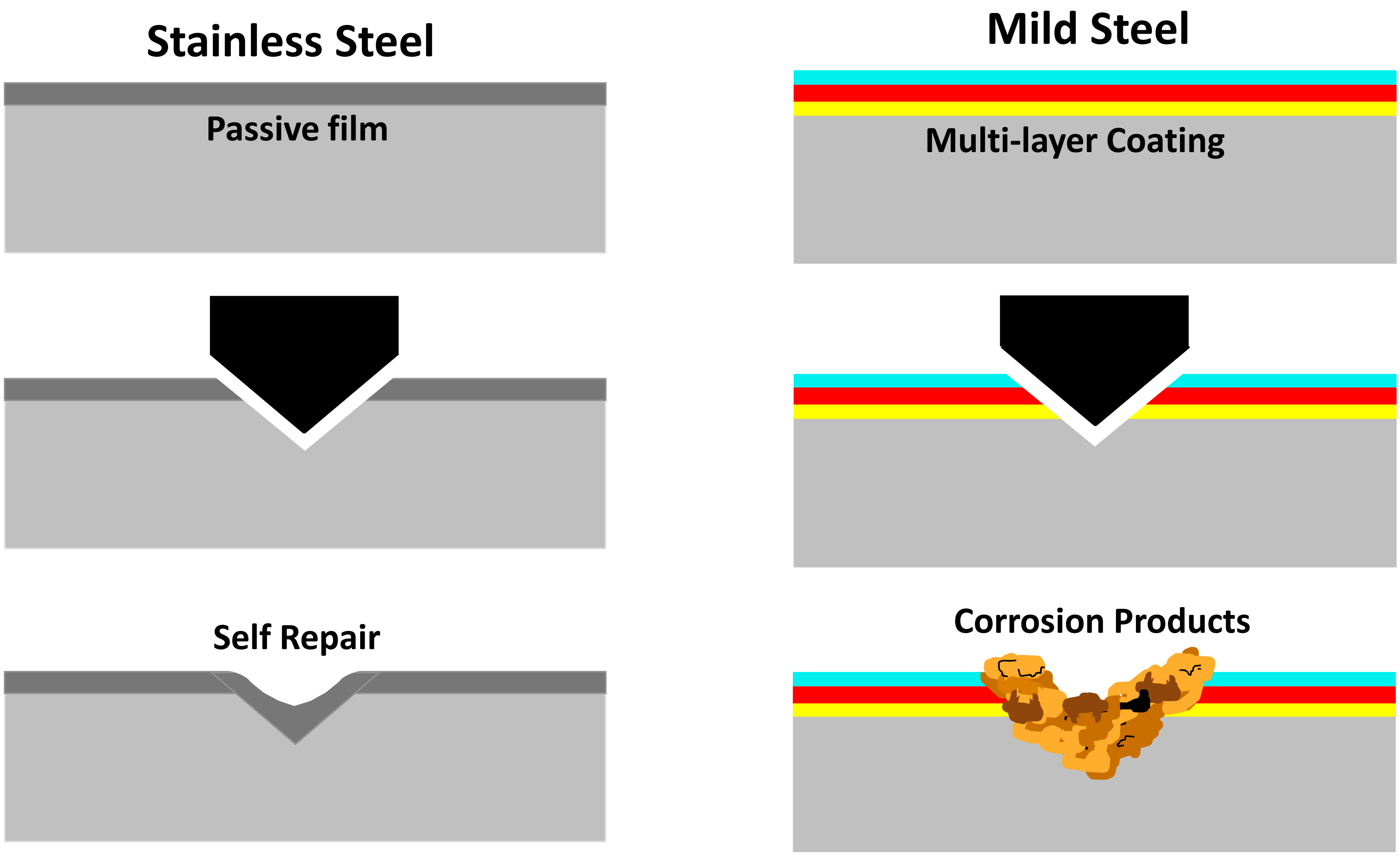
Transparent
Adherent
Self repairing

MULTI-LAYER COATINGS



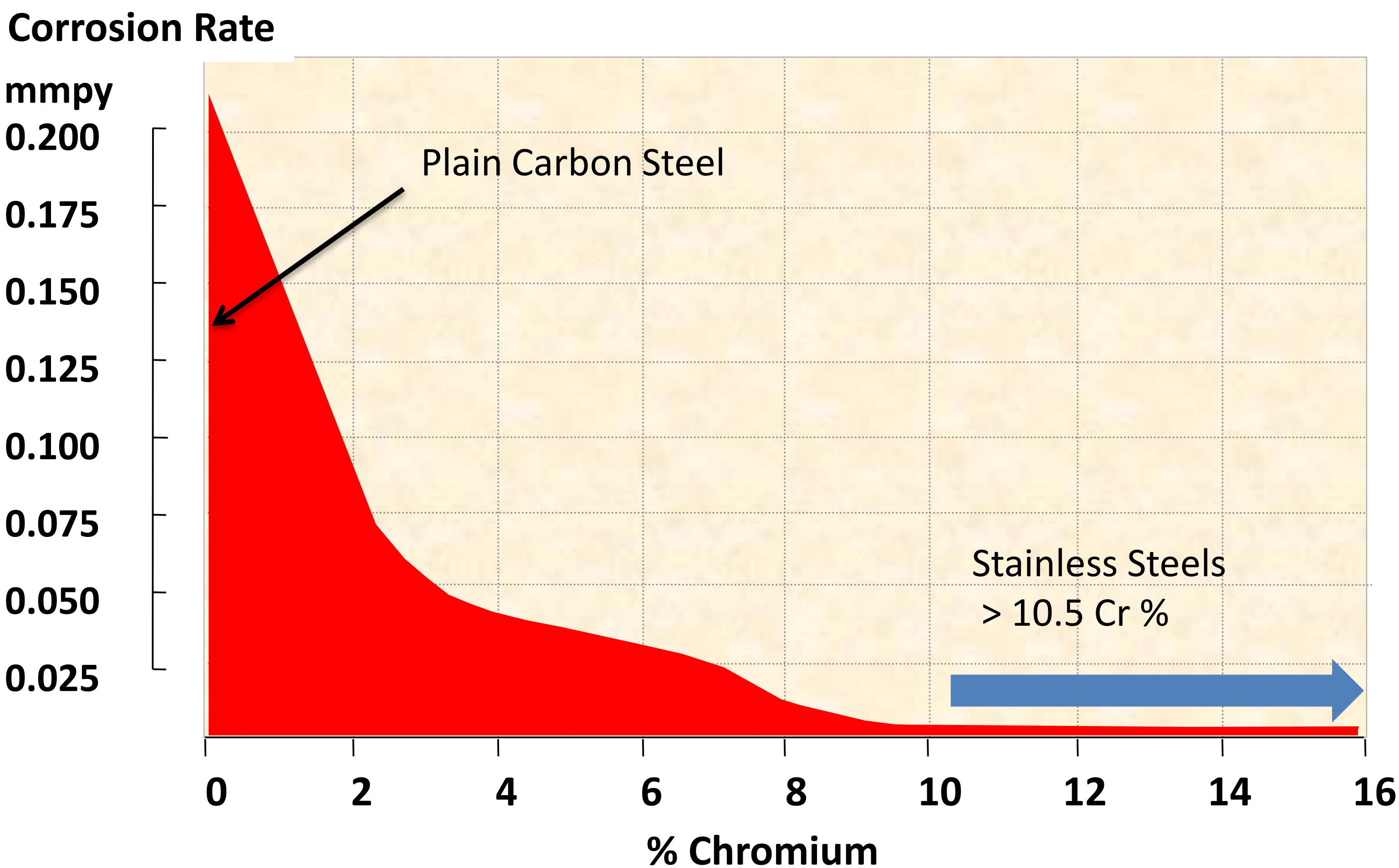
Typically
20-200 µm thick
May peel off
Not self-repairing

Damage to protective layer



3. Types of corrosion of stainless steels

Effect of Chromium Content on Atmospheric Corrosion Resistance (uniform corrosion)



When the selection of the stainless steel grade has not been properly made, corrosion may occur

…no material is perfect!

think of it as selecting the right vehicle
for the intended use

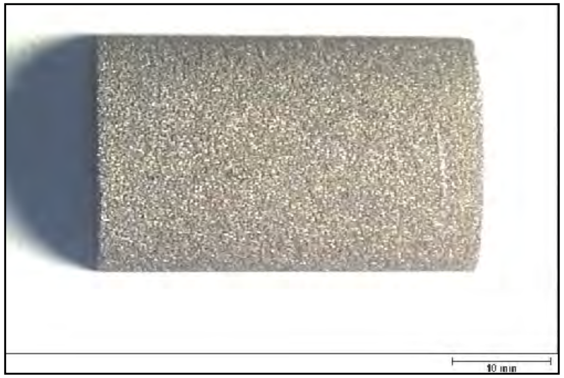
Types of corrosion on stainless steels

a) Uniform
b) Pitting
c) Crevice
d) Galvanic
e) Intergranular
f) Stress corrosion cracking

See Reference 1

a) What is uniform corrosion?

- When the passive film is destroyed by the aggressive environment, the whole surface corrodes uniformly and metal loss can be expressed as µm/year
- This is typical of unprotected Carbon steels.
- This does not occur on stainless steels in the building industry, as the corrosion conditions are never that aggressive (it requires typically immersion in acids)



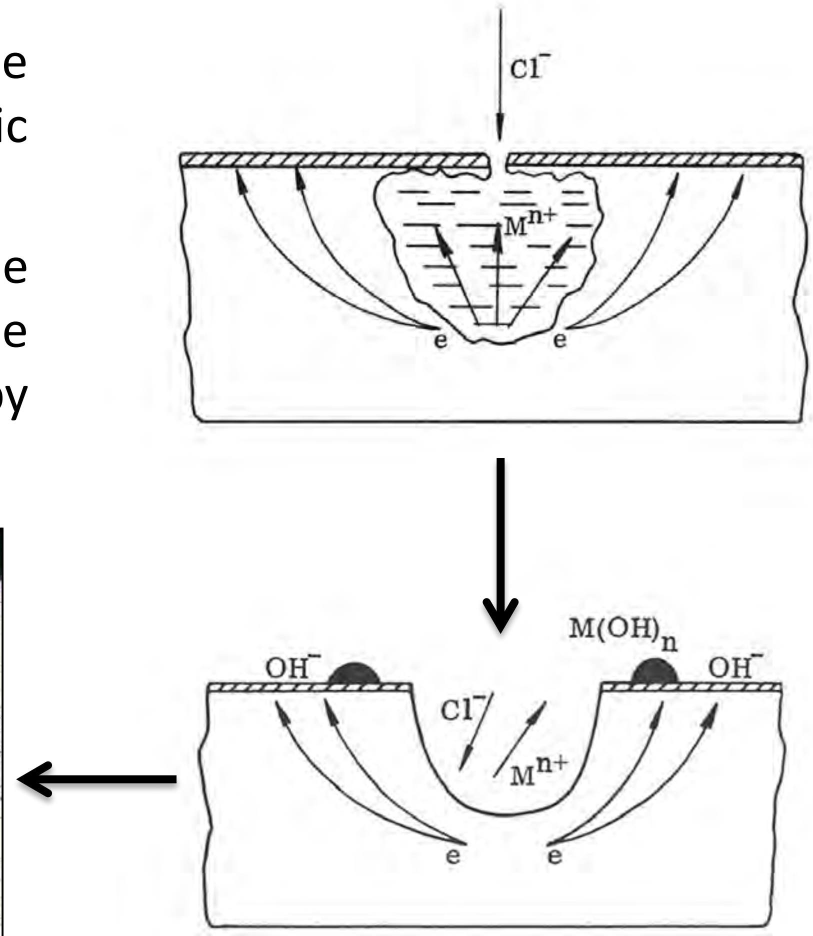
b) What is pitting corrosion[1,2,3,7]?

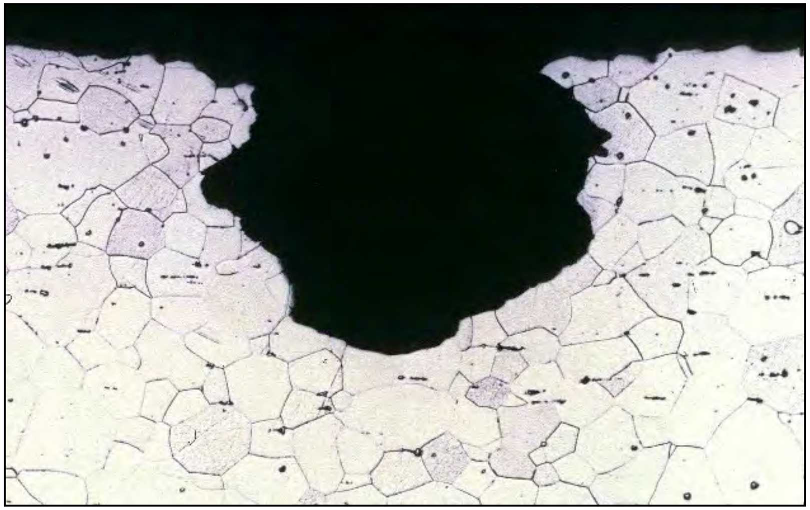
Pitting corrosion, or pitting, is a form of extremely localized corrosion that leads to the creation of small holes in the metal.

This picture shows pitting of stainless steel EN1.4310 (AISI 301) resulting from insufficient corrosion resistance in a very aggressive chlorinated environment.

Pitting corrosion mechanisms

1. Initiation on a very small surface irregularities or non-metallic inclusions
2. Propagation as the electrochemical reactions in the pit cavity are not prevented by re-passivation

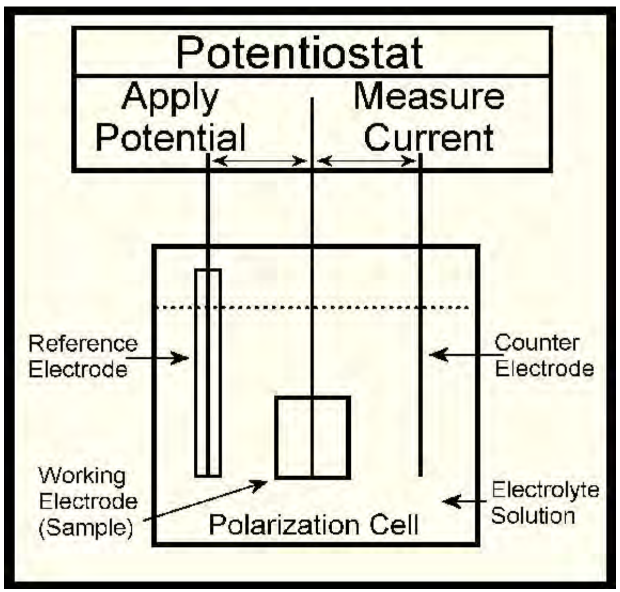




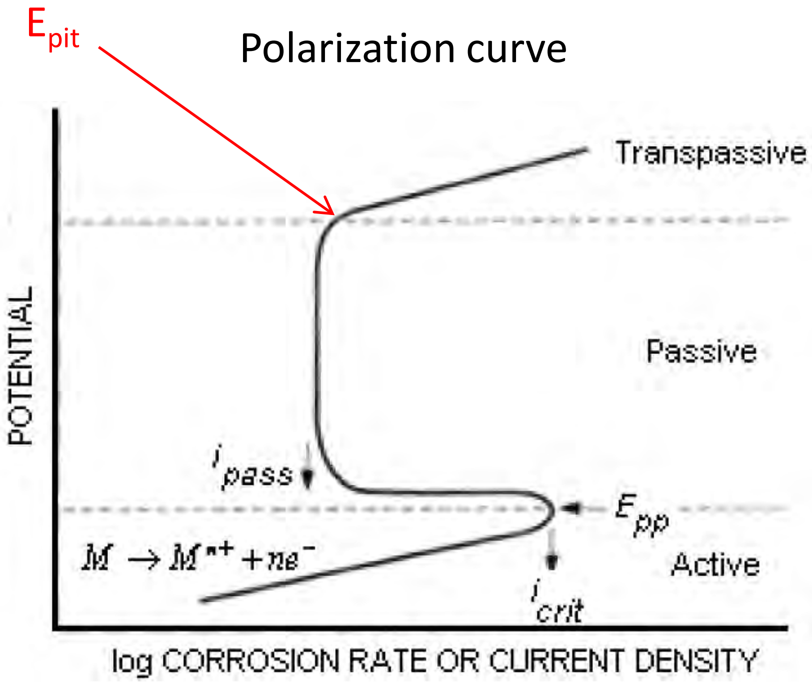
Pitting can be reproduced in an electrochemical cell[4]

- Corrosion involves the dissolution of metal, i.e. an electrochemical process with
  a) electrochemical reactions at the surface of the metal and
  b) a current between the corroding metal (anode) and a cathodic part
- These processes can be simulated in an electrochemical cell, a device that allows the study of corrosion processes

Electrochemical cell



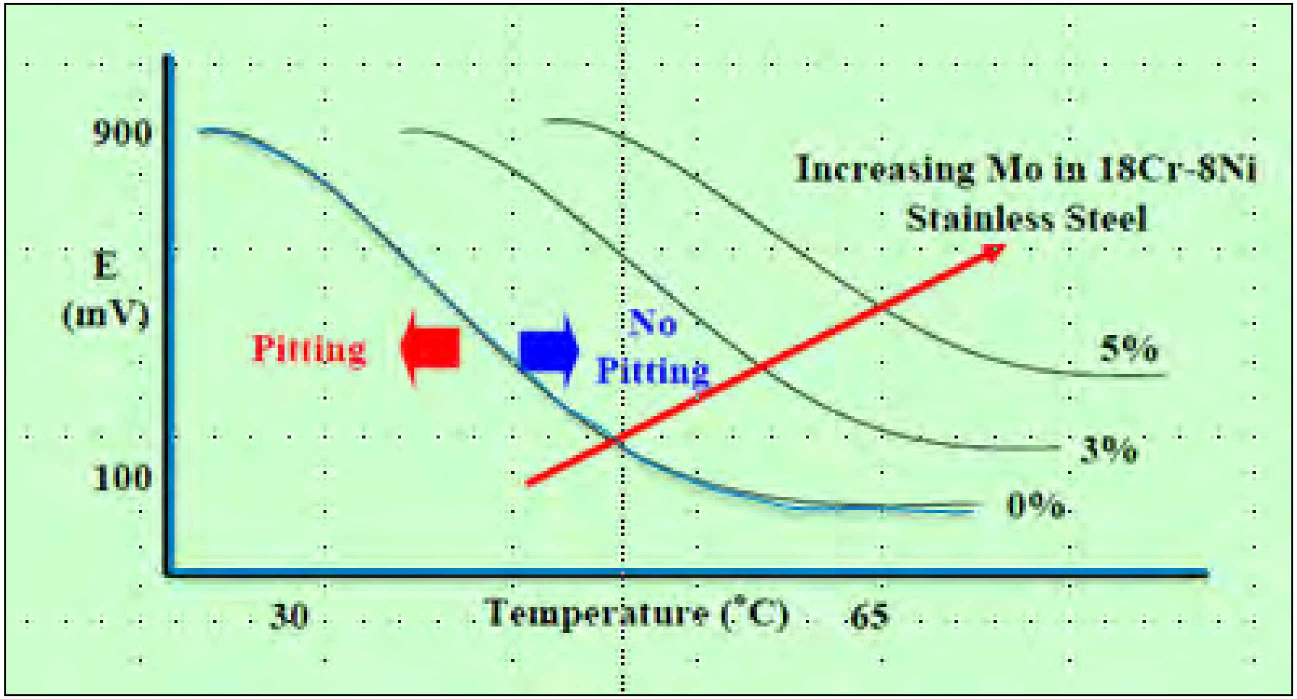
Polarization curve



Major factors that influence pitting corrosion[1]

(the pitting potential E_{pit} is generally used as the criterion for pitting)

1. Temperature



Increasing the temperature reduces drastically the resistance to pitting.

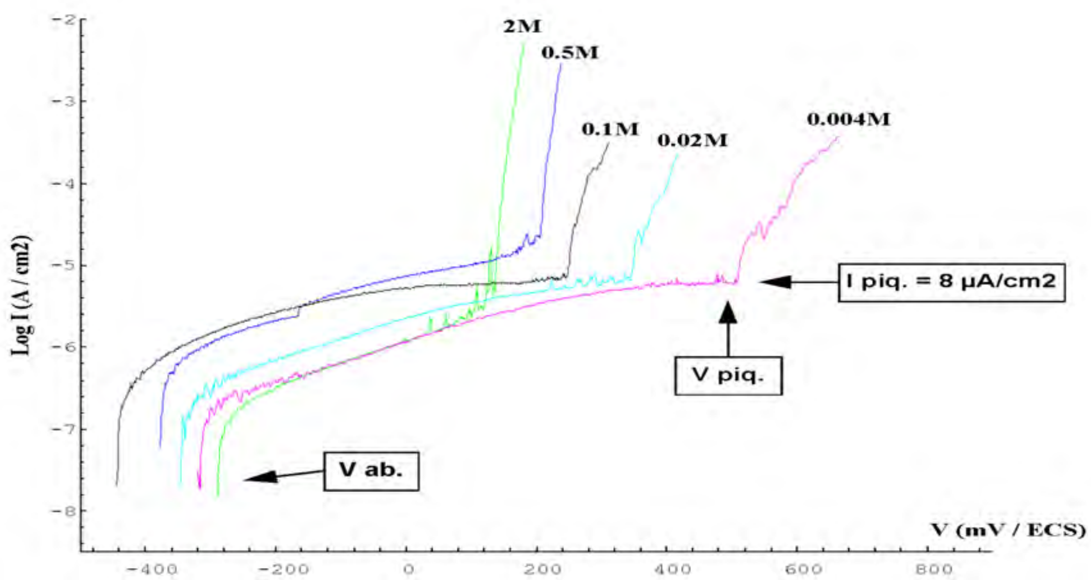
Major factors that influence pitting corrosion[5]

(the pitting potential E_{pit} is generally used as the criterion for pitting)

2. Chloride concentration

The pitting resistance decreases a the Cl^- concentration increases (the log of the Cl^- concentration)

$$E_{pit} = A \log [Cl^-] + B$$

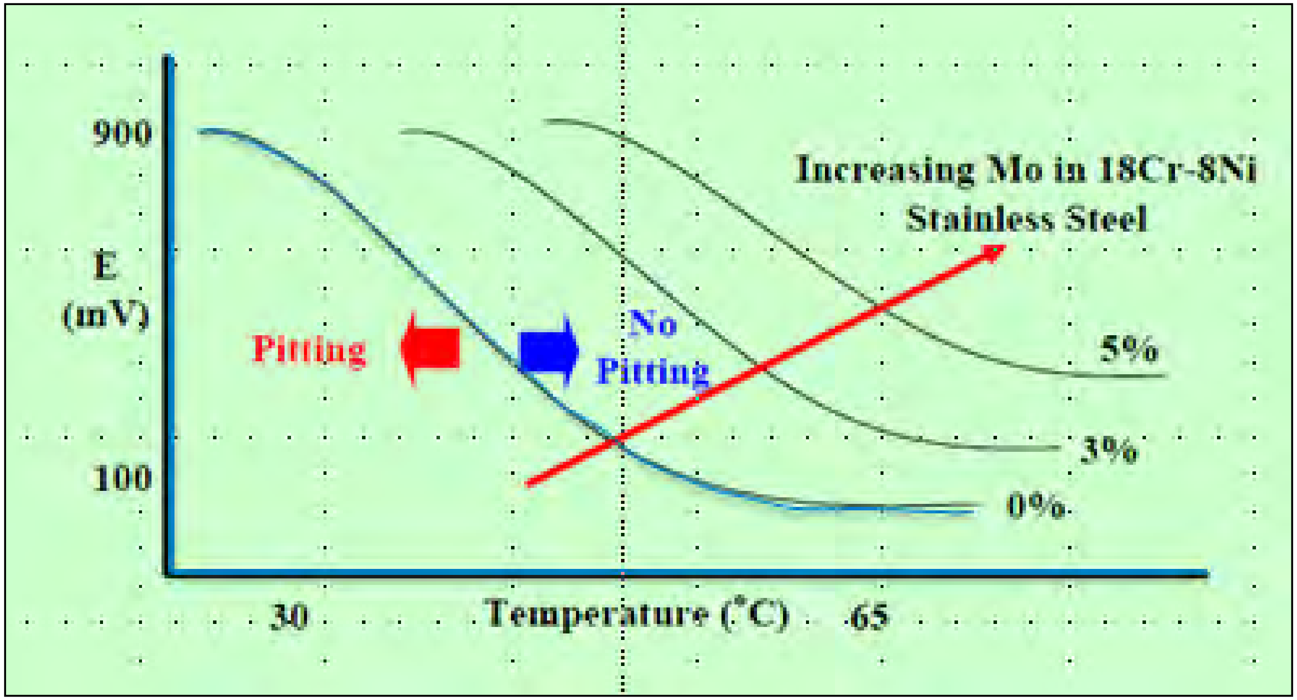


Major factors that influence pitting corrosion[1]

(the pitting potential E_{pit} is generally used as the criterion for pitting)

3. Stainless steel analysis

The pitting resistance increases strongly with some alloying elements: N, Mo, Cr



The role of the alloying elements is described by the PREN (Pitting Resistance Equivalent Number)

Pitting Resistance Equivalent Number (PREN)[6]

Updated!

- By calculating the PREN it is possible to compare stainless steel grades resistance against pitting. The higher the number the better the resistance.
- Obviously the PREN alone cannot be used to predict whether a particular grade will be suitable for a given application

PREN = Cr + 3.3Mo + 16N, where

Cr = Chromium content

Mo = Molybdenum content

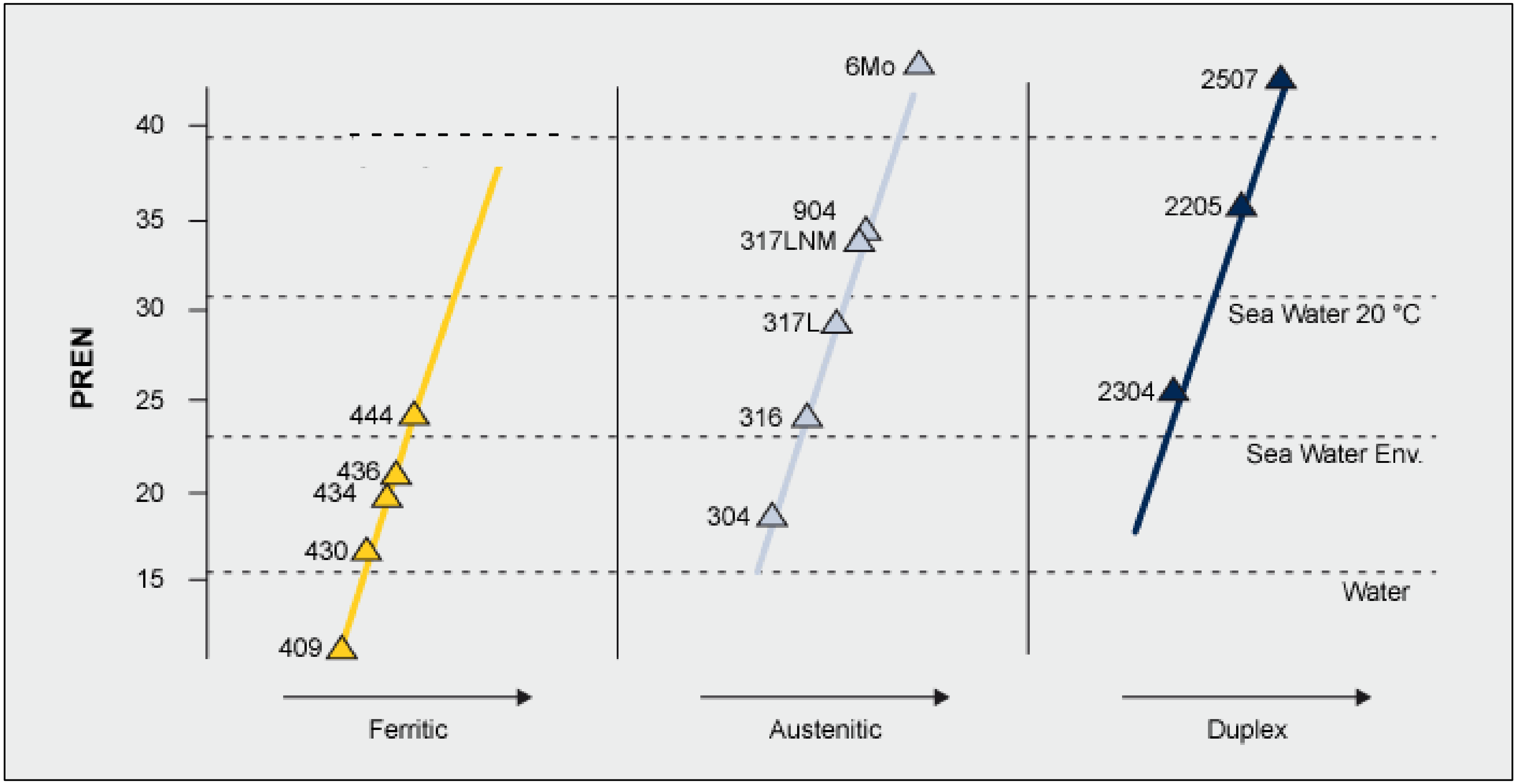
N = Nitrogen content

EN	AISI	PREN
1.4003	-	10.5 - 12.5
1.4016	430	16.0 - 18.0
1.4301	304	17.5 - 20.8
1.4311	304LN	19.4 – 23.0
1.4401/4	316/L	23.1 – 28.5
1.4406	316LN	25.0 – 30.3
1.4439	317L	31.6 – 38.5
1.4539	-	32.2 – 39.9
1.4362	-	23.1 – 29.2
1.4462	-	30.8 – 38.1
1.4410	-	40
1.4501	-	40

Please note that the PREN does not involve Ni.
The resistance to pitting corrosion does not depend upon the Ni content of the stainless steel. See next slide

PREN of some common grades[9]

Updated!



Ferritic stainless steels can match 304 and 316 austenitic stainless steels in pitting corrosion resistance.

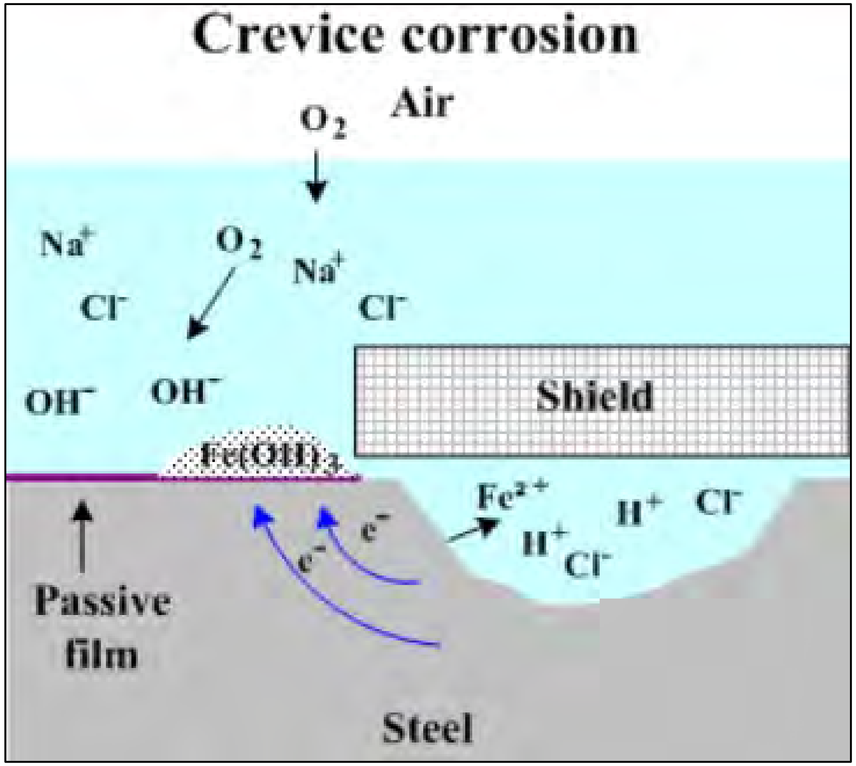
Note: Please see Appendix for EN standards designations

c) What is Crevice Corrosion[1]?

Crevice corrosion refers to corrosion occurring in confined spaces to which the access of the working fluid from the environment is limited. These spaces are generally called crevices. Examples of crevices are gaps and contact areas between parts, under gaskets or seals, inside cracks and seams, spaces filled with deposits and under sludge piles.

Mechanism of Crevice Corrosion

- Initially, no difference between the cavity and the whole surface
- Then things change when the cavity becomes depleted in oxygen
- A set of electrochemical reactions occurs in the crevice, with the result of increasing Cl- concentration and decreasing the local pH, to the extent that passivation cannot occur
- Then the metal in the crevice undergoes uniform corrosion



Critical Pitting Resistance Temperature (CPT)
Critical Crevice Corrosion Temperature (CCT)
of various austenitic & duplex grades[8]

Note: The higher the Temperature, the better the corrosion resistance

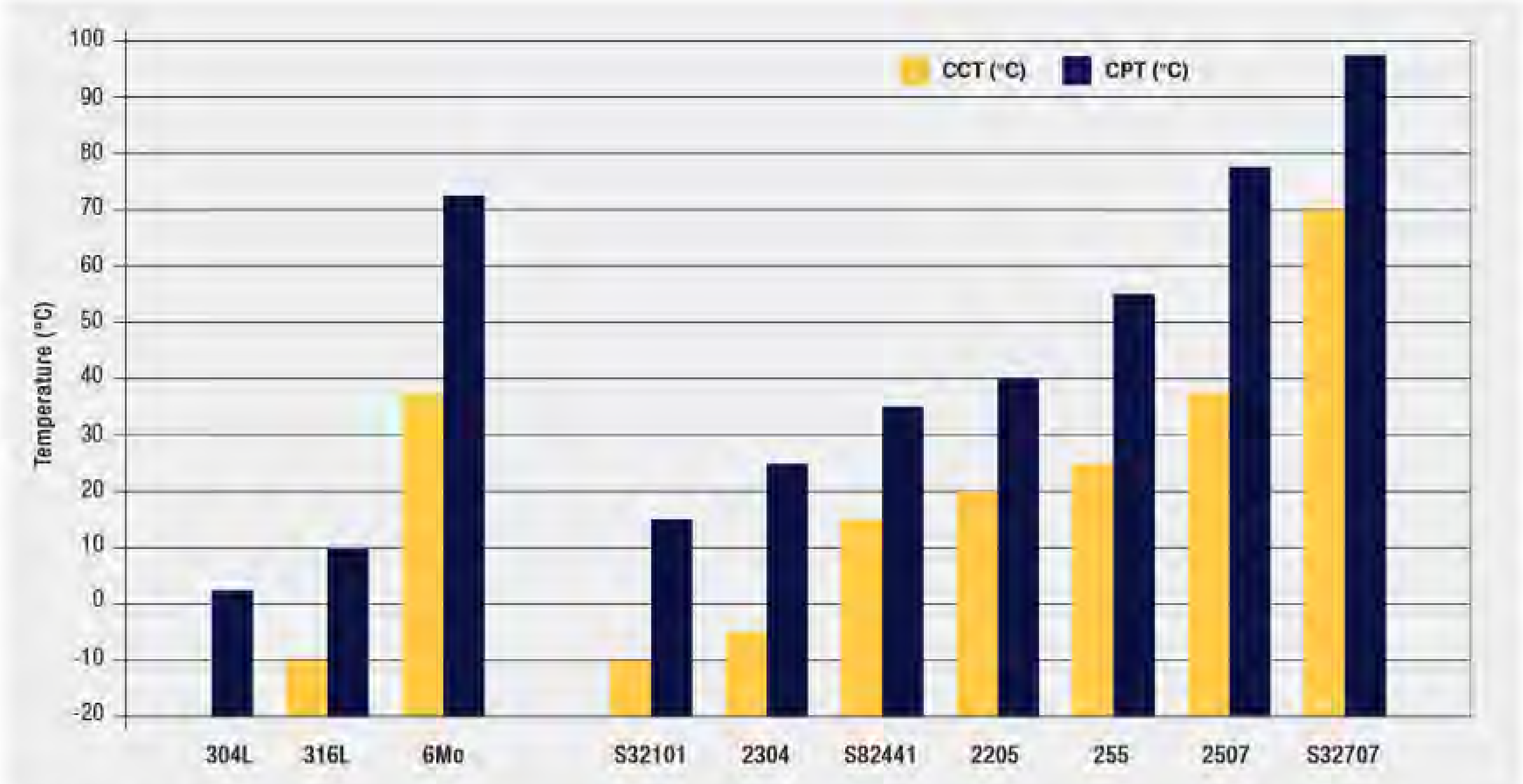


Figure 9: Critical pitting and crevice corrosion temperatures for unwelded austenitic stainless steels (left side) and duplex stainless steels (right side) in the solution annealed condition (evaluated in 6% ferric chloride by ASTM G 48).

Note: Please see Appendix for EN standards designations

How to avoid crevice corrosion

1. Optimize design:
   a) Use welded parts.
   b) Design vessels for complete drainage.
2. Clean to remove deposits (whenever possible)
3. Select a suitably corrosion resistant stainless steel (see part 4 of this chapter)

d) What is Galvanic Corrosion[1]? (also known as bimetallic corrosion)

Corrosion that can occur when 2 metals with very different galvanic potentials are in contact.

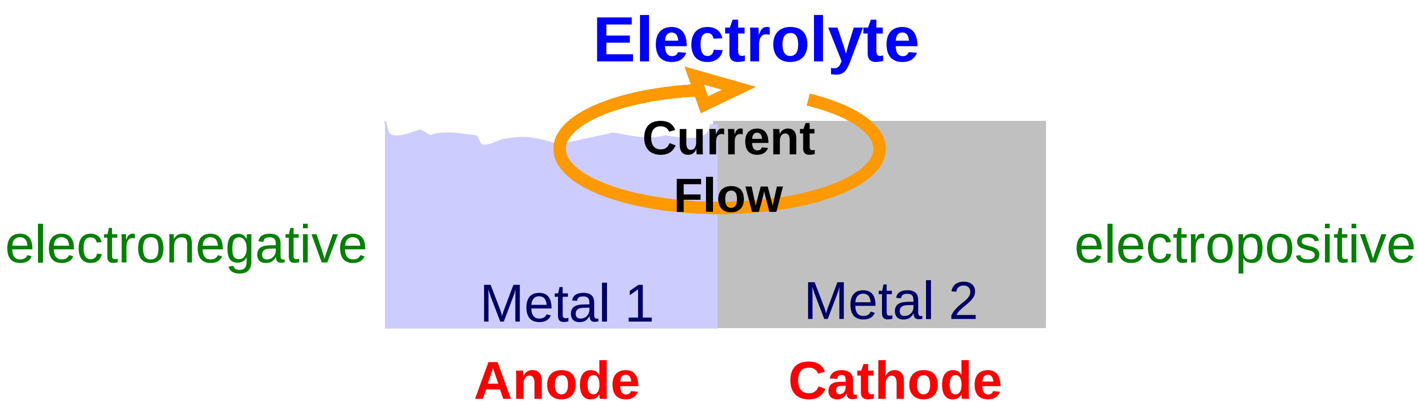
The most anodic metal is attacked

Example on the picture on the left: The stainless steel plate was secured to a stainless steel vessel, using mild steel bolts – resulting in galvanic corrosion of the bolts in presence of humidity, (=electrolyte)

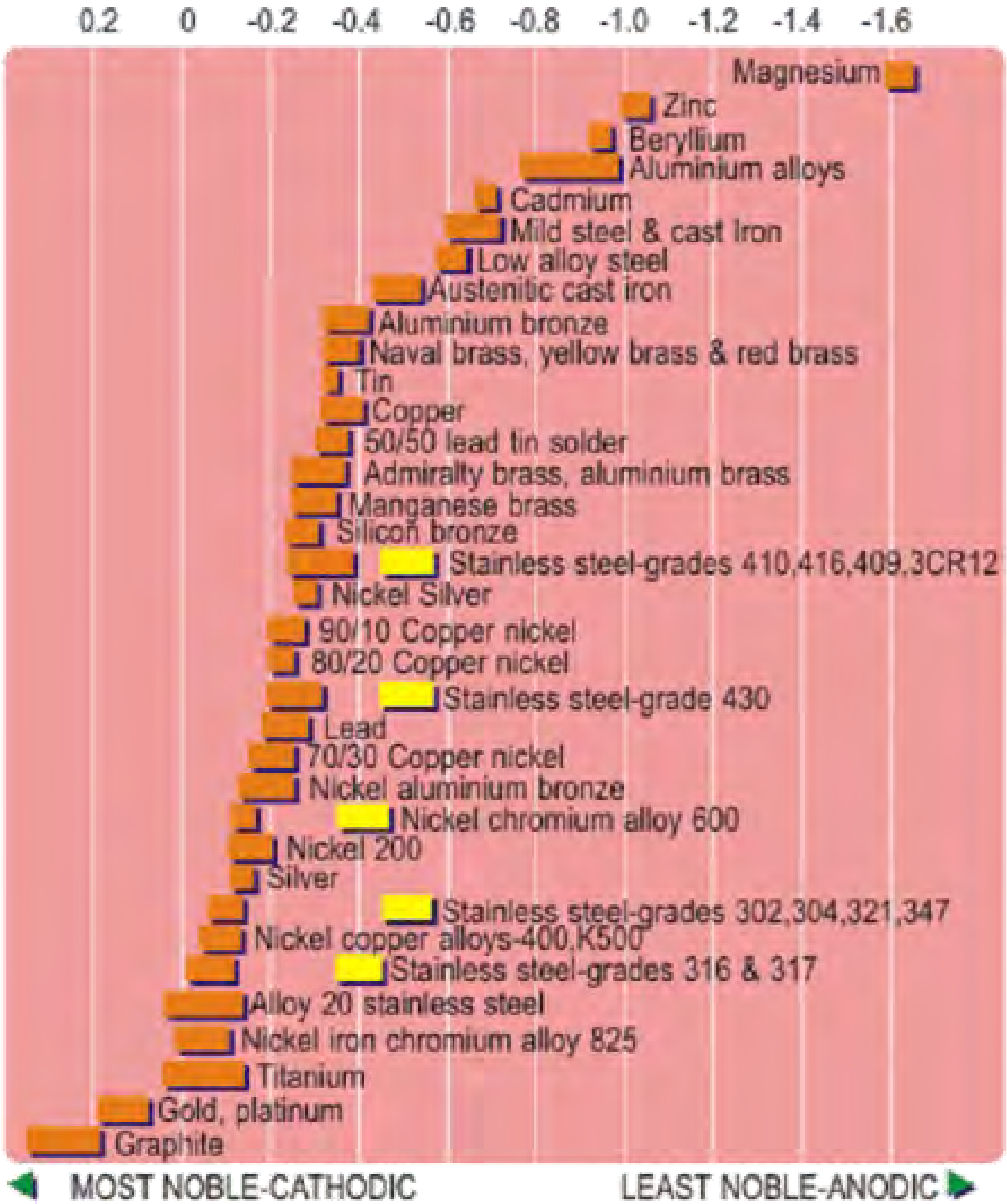
See Reference 11

Mechanism of galvanic corrosion

- Each metal has a characteristic potential when immersed in an electrolyte (measured against a reference electrode.)
- When 2 metals are connected with a conducting liquid (humidity is enough):
- And when the 2 metals have very different potentials
- A current will flow from the most electronegative (anode) to the most electropositive (cathode).
- If the anode area is small it will show dissolution of the metal



Galvanic series for metals in flowing sea water.



Updated!

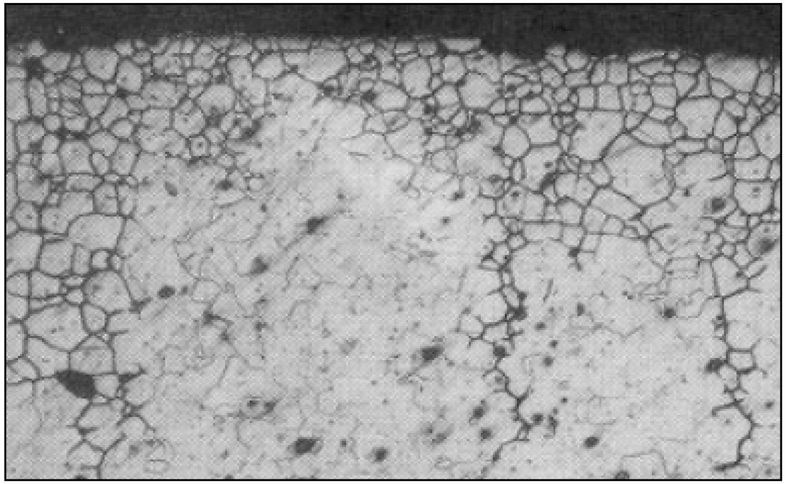
Basic rules on how to avoid galvanic corrosion

- Avoid situations of dissimilar metals
- When dissimilar metals are in contact make sure that the less noble metal (anode) has a much larger surface area than the more noble metal (cathode)
- Examples:
  - Use Stainless steel fasteners for Aluminum products (and never Aluminum fasteners for stainless)
  - Same between stainless steel and carbon steel

In concrete (high pH) contaminated with chlorides, stainless steel rebar DOES NOT INCREASE SIGNIFICANTLY the corrosion rates of carbon steel rebar by galvanic coupling
References are given in www.stainlesssteelrebar.org

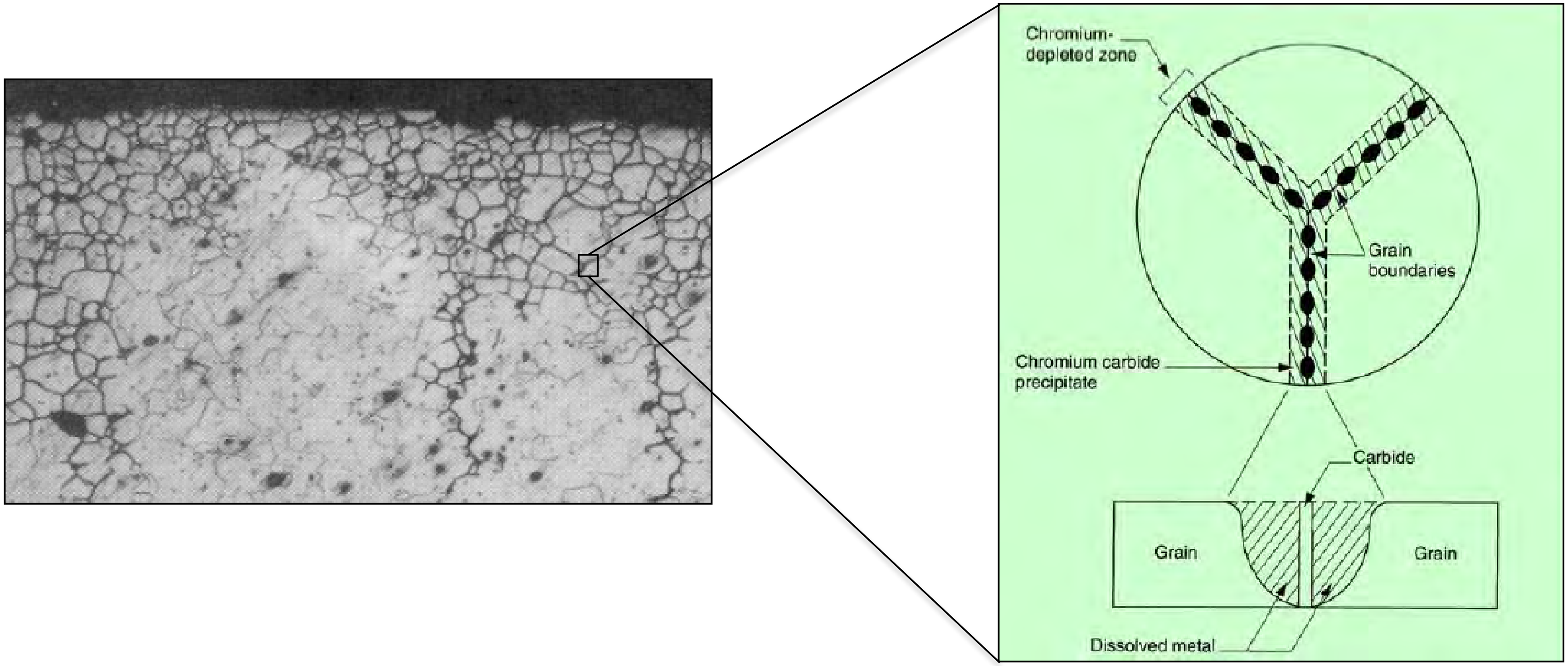
e) What is Intergranular Corrosion[1]?

Intergranular attack is caused by the formation of chromium carbides (Fe,Cr)23C6 at grain boundaries, reducing the chromium content and the stability of the passive layer.



In the above micrographs, stainless steels speciments were polished then etched with a stong acid medium. The network of black lines corresponds to a strong chemical attack of the grain boundaries which exhibit a much lower corrosion resistance than the grains themselves.

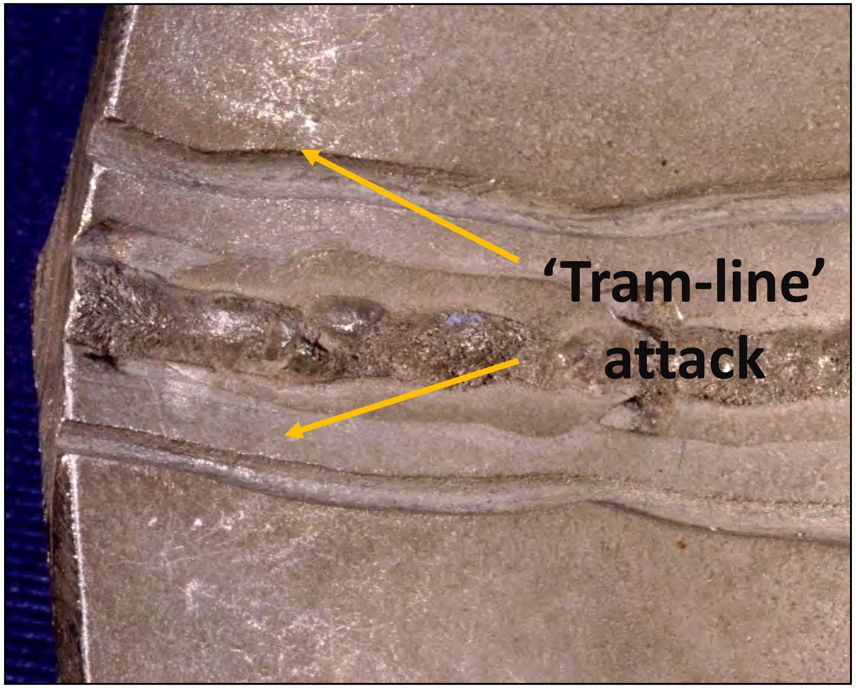
Schematic view of Cr depletion at grain boundaries



When does Intergranular Corrosion occur?

- Properly processed stainless steels are not prone to IC
- May occur in the Heat Affected Zone of a weld (either side of a weld bead) when
  - The Carbon content is high
  - and the steel is not stabilized (by Ti, Nb, Zr * which “trap” the carbon in the matrix, making it unavailable for grain boundary carbides)

* This is why there are grades containing Ti and/or Nb and/or Zr, grades qualified as “stabilized”



Weld Decay

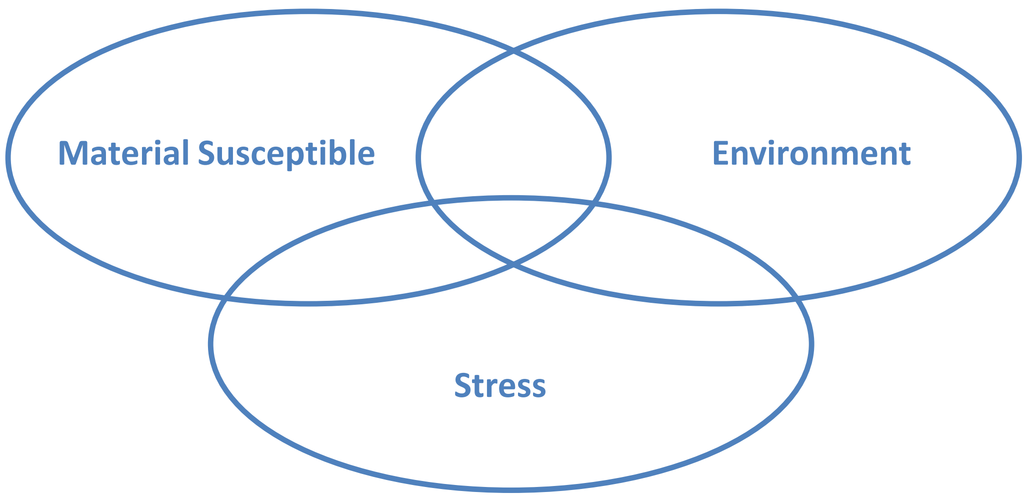
To find out more about welding and other joining methods, please go to Module 09

How to avoid Intergranular Corrosion

- Use low carbon grades, below 0,03% for austenitics
- Or use stabilized grades for ferritics and austenitics
- Or on austenitics, carry out a solution annealing treatment (at 1050°C all the carbides are dissolved) followed by quenching. (This is usually impractical, however).

f) What is Stress Corrosion Cracking[1] (SCC)?

- Sudden cracking and failure of a component without deformation.
- This may occur when
  - The part is stressed (by an applied load or by a residual stress)
  - The environment is aggressive (high chloride level, temperature above 50°C)
  - The stainless steel his not sufficiently SCC resistant

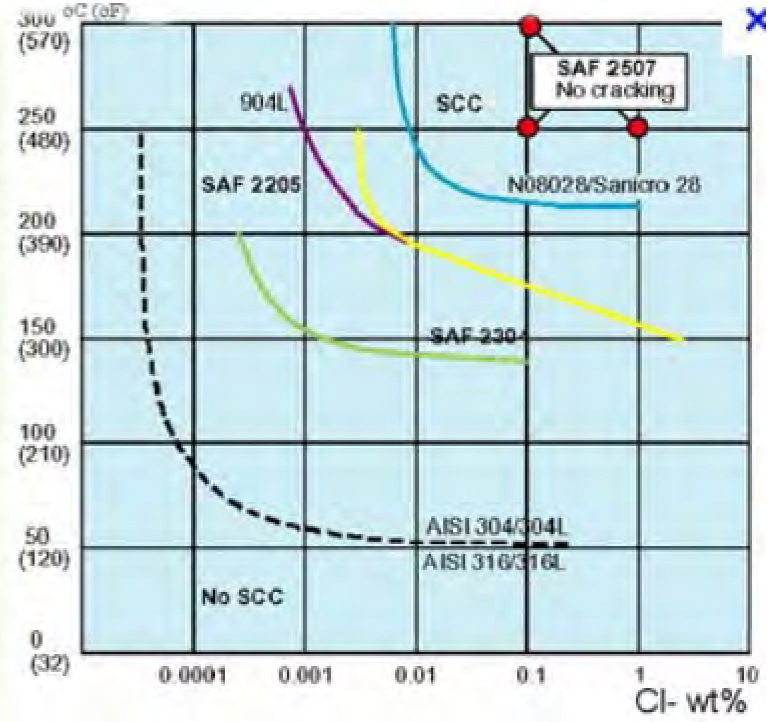


Ferritic and duplex (i.e. austenitic-ferritic) stainless steels are immune to SCC

Mechanism of Stress corrosion cracking (SCC)

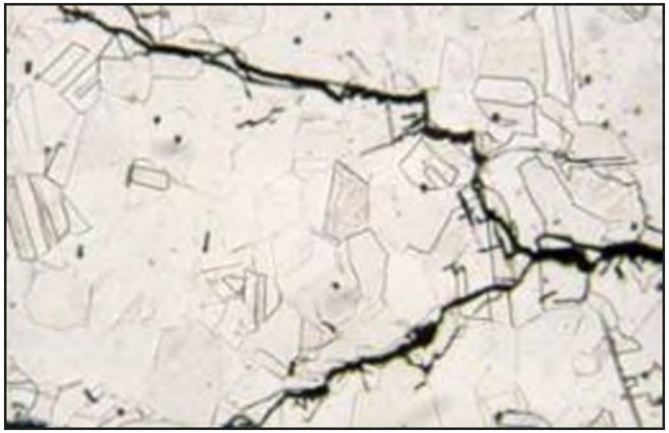
The combined action of environmental conditions (chlorides/elevated temperature) and stress - either applied, residual or both develop the following sequence of events:

1. Pitting occurs
2. Cracks start from a pit initiation site
3. Cracks then propagate through the metal in a transgranular or intergranular mode.
4. Failure occurs



Note: Please see Appendix for EN standards designations

Avoiding SCC – two choices



Chloride induced stress corrosion cracking in standard austenitic stainless steels, viz. 1.4301/ 304 or 1.4401 /316

+Ni
+Mo

1.4539
1.4547 (6Mo)

Select austenitic stainless steels with higher content of Ni and Mo (higher corrosion resistance)

+Cr

Select duplex grades, more price stable (less nickel)

1.4462
1.4410
1.4501

Ferritic and duplex stainless steels are immune to stress corrosion cracking (because the ferrite phase, unlike the austenite phase is not sensitive to this type of corrosion).

For more information on these grades, please go to Module 04

4. How to select the right stainless steel for adequate corrosion resistance

Two different situations:

1. Structural applications [10a]
2. Other applications [10b]

4 - 1 Structural Applications

Eurocode 1-4 provides a procedure for selecting an appropriate grade of stainless steel for the service environment of structural members. (Please note that at the present time – i.e. nov 2014 – the recommendations of the Evolution Group for EN 1993-1-4 have not been yet enforced)

This procedure is presented in the next slides

It is applicable to:

- Load bearing members
- Outdoor use
- Environments without frequent immersion in sea water
- pH between 4 and 10
- No exposure to chemical process flow stream

How the procedure works

1. The environment is assessed by a Corrosion Resistance Factor (CRF) made of 3 components (CRF= F1+F2+F3) where
   a) F1 rates the risk of exposure to chlorides from salt water or deicing salts
   b) F2 rates the risk of exposure to sulphur dioxide
   c) F3 rates the cleaning regime or exposure to washing by rain
2. A matching table indicates for a given CRF the corresponding CRC class
3. The stainless steel grades are placed in corrosion resistance classes (CRC) I to V according to the CRF value

The tables are shown in the next 4 slides

F_1 Risk of exposure to Cl (salt water or deicing salts)		
Note: M is distance from the sea and S is distance from roads with deicing salts		
1	**Internally controlled environment**	
0	**Low risk of exposure**	M > 10 km or S > 0.1 km
-3	**Medium risk of exposure**	1 km < M ≤ 10 km or 0.01 km < S ≤ 0.1 km
-7	**High risk of exposure**	0.25 km < M ≤ 1 km or S ≤ 0.01 km
-10	**Very high risk of exposure** Road tunnels where deicing salt is used or where vehicles might carry deicing salts into the tunnel	
-10	**Very high risk of exposure** North Sea coast of Germany All Baltic coastal areas	M ≤ 0.25 km
-15	**Very high risk of exposure** Atlantic coast line of Portugal, Spain, France Coastline of UK, France, Belgium, Netherlands, Southern Sweden All other coastal areas of UK, Norway, Denmark and Ireland Mediterranean Coast	M ≤ 0.25 km

F_2 Risk of exposure to sulphur dioxide

Note: for European coastal environments the sulphur dioxide value is usually low. For inland environments the sulphur dioxide value is either low or medium. The high classification is unusual and associated with particularly heavy industrial locations or specific environments such as road tunnels. Sulphur dioxide deposition may be evaluated according to the method in ISO 9225.

0	**Low risk of exposure**	(<10 μg/m³ average deposition)
-5	**Medium risk of exposure**	(10 – 90 μg/m³ average deposition)
-10	**High risk of exposure**	(90 – 250 μg/m³ average deposition)

F_3 Cleaning regime or exposure to washing by rain

(if $F_1 + F_2 = 0$, then $F_3 = 0$)

0	Fully exposed to washing by rain
-2	Specified cleaning regime
-7	No washing by rain or No specified cleaning

Matching Table

Table A.2: Determination of Corrosion Resistance Class CRC	
Corrosion Resistance Factor (CRF)	Corrosion Resistance Class (CRC)
CRF = 1	I
0 ≥ CRF > -7	II
-7 ≥ CRF > -15	III
-15 ≥ CRF ≥ -20	IV
CRF < -20	V

Corrosion resistance classes of stainless steels

Updated 2019

Table A.3: Grades in each Corrosion Resistance Class CRC				
	Corrosion resistance class CRC			
I	II	III	IV	V
1.4003	1.4301	1.4401	1.4439	1.4565
1.4016	1.4307	1.4404	1.4539	1.4529
1.4512	1.4311	1.4435	1.4462	1.4547
	1.4541	1.4571		1.4410
	1.4318	1.4429		1.4501
	1.4306	1.4432		1.4507
	1.4567	1.4578		
	1.4482	1.4662		
		1.4362		
		1.4062		
		1.4162		

Ferritics (1.4003, 1.4016, 1.4512); Std Austenitics (1.4301, 1.4307, 1.4311, 1.4541, 1.4318, 1.4306, 1.4567); Mo Austenitcs (1.4401, 1.4404, 1.4435, 1.4571, 1.4429, 1.4432, 1.4578); Lean duplex (1.4482, 1.4662, 1.4362, 1.4062, 1.4162); Super Austenitics (1.4439, 1.4539, 1.4565, 1.4529, 1.4547); Duplex/super duplex (1.4462, 1.4410, 1.4501, 1.4507)

Notes: Please see the appendix for EN standards designations
This does not apply to swimming pools

4 -2 Other applications

- No specific regulations are applicable
- Grade selection must be adequate for the expected performance
- Three ways to do this:
  - Ask an expert
  - Get help from stainless steel development associations
  - Find out successful cases with similar environments (usually available)

Grade Selection Guide for Architecture[10]

Caution: NOT applicable when

- Appearance does not matter
- Structural integrity is the primary concern (Then go to 4 – 1)

How the procedure works

- An evaluation score must be computed
- For each score a list of recommended stainless steel grades is provided

Criteria used in the evaluation score (see the next slides):

i. Environmental Pollution
ii. Coastal exposure or Deicing salts exosure
iii. Local weather pattern
iv. Design considerations
v. Maintenance schedule

i. Environmental pollution

Points	
	Rural
0	Very low or no pollution
	Urban pollution (Light industry, automotive exhaust)
0	Low
2	Moderate
3	High *
	Industrial pollution (Aggressive gases, iron oxides, chemicals, etc.)
3	Low or moderate
4	High *

* Potentially a highly corrosive location. Have a stainless steel expert evaluate the site.

ii. A) Coastal exposure

Points	
	Coastal or Marine Salt Exposure
1	Low (>1.6 to 16 km (1 to 10 miles) from salt water) **
3	Moderate (30m to 1.6 km (100 ft to 1 mile) from salt water)
4	High (<30m (100 ft) from salt water)
5	Marine (some salt spray or occasional splashing) *
8	Severe Marine (continuous splashing) *
10	Severe Marine (continuous immersion) *

* Potentially a highly corrosive location. Have a stainless steel corrosion expert evaluate the site.
** This range shows how far chlorides are typically found from large salt water bodies. Some locations of this type are exposed to chlorides but others are not.

ii. B) Deicing salts exposure

Points	
	Deicing Salt Exposure (Distance from road or ground)
0	No salt was detected on a sample from the site and no change in exposure conditions is expected.
0	Traffic and wind levels on nearby roads are too low to carry chlorides to the site and no deicing salt is used on sidewalks
1	Very low salt exposure (≥10 m to 1 km (33 to 3,280 ft) or 3 to 60 floors) **
2	Low salt exposure (< 10 to 500 m (33 to 1600 ft) or 2 to 34 floors) **
3	Moderate salt exposure (< 3 to 100 m (10 to 328 ft) or 1 to 22 floors) **
4	High salt exposure (<2 to 50 m (6.5 to 164 ft) or 1 to 3 floors) * **

* Potentially a highly corrosive location. Have a stainless steel corrosion expert evaluate the site.

** This range shows how far this chloride concentration has been found from small rural and large high traffic roads. Test surface chloride concentrations.

Note: if both coastal exposure and deicing salts are present, please ask an expert

iii. Local weather pattern

Points	
-1	Temperature or cold climates, regular heavy rain
-1	Hot or cold climates with typical humidity below 50%
0	Temperature or cold climate, occasional heavy rain
0	Tropical or subtropical, wet, regular or seasonal very heavy rain
1	Temperature climate, infrequent rain, humidity above 50%
1	Regular very light rain or frequent fog
2	Hot, humidity above 50%, very low or no rainfall ***

*** If there is also salt or pollution exposure, have a stainless steel corrosion expert evaluate the site.

iv. Design Considerations

Points	
0	Boldly exposed for easy rain cleaning
0	Vertical surfaces with a vertical or no finish grain
-2	Surface finish is pickled, electropolished, or roughness ≤ R_a 0.3 μm (12μin)
-1	Surface finish roughness R_a 0.3 μm (12μin) < X ≤ R_a 0.5 μm (20μin)
1	Surface finish roughness R_a 0.5 μm (20μin) < X ≤ R_a 1 μm (40μin)
2	Surface finish roughness > R_a 1 μm (40μin)
1	Sheltered location or unsealed crevices ***
1	Horizontal surfaces
1	Horizontal finish grain orientation

*** If there is also salt or pollution exposure, have a stainless steel corrosion expert evaluate the site.

About Ra: https://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/RoughnessMeasurement_EN.pdf

This table shows that corrosion resistance depends also on surface finish.
For more information on the available finishes, please go to Module 08

v. Maintenance schedule

Points	
0	Not washed
-1	Washed at least naturally
-2	Washed four or more times per year
-3	Washed at least monthly

Stainless Steel selection scoring system

Total score	Stainless Steel Selection
0 to 2	Type 304/304L is generally the most economical choice
3	Type 316/316L or 444 is generally the most economical choice
4	Type 317L or a more corrosion resistant stainless steel is suggested
≥ 5	A more corrosion resistant stainless steel such as 4462, 317LMN, 904L, super duplex, super ferritic or a 6% molybdenum super austenitic stainless steel may be needed

Note: please see the appendix for EN standard designations

Proper selection of the stainless steel grades will lead to a long, maintenance-free, service life with a low life cycle cost and an excellent sustainability

For more information sustainability, please go to Module 11

Conclusion

- Proper selection of the right stainless steel grade for the application and the environment deserves attention.
- When this is done, stainless steel will provide unlimited service life without maintenance.

You will find in Module 2 a wide range of successful applications of stainless steels, and in Module 1 timeless art, worldwide!

5. References

1. An excellent course on corrosion. Please look at chapters 7 (Galvanic Corrosion), 8 (intergranular corrosion), 11 (crevice corrosion) 12 (pitting) 14 (Stress corrosion cracking) and 15 (stress corrosion cracking of stainless steels) Original source: http://corrosion.kaist.ac.kr Dowloads available from: https://www.worldstainless.org/Files/issf/Education_references/Zrefs_on_corrosion.zip
2. Some basics on corrosion from NACE http://corrosion-doctors.org/Corrosion-History/Course.htm#Scope
3. An online course on corrosion http://www.corrosionclinic.com/corrosion_online_lectures/ME303L10.HTM#top
4. Information on electrochemical testing http://mee-inc.com/esca.html
5. Ugitech: private communication
6. BSSA (British Stainless Steel Association) website " Calculation of pitting resistance equivalent numbers (PREN)" http://www.bssa.org.uk/topics.php?article=111
7. On Pitting corrosion https://kb.osu.edu/dspace/bitstream/handle/1811/45442/FrankelG_JournalElectrochemicalSociety_1998_v145n6_p2186-2198.pdf?sequence=1
8. http://www.imoa.info/download_files/stainless-steel/Duplex_Stainless_Steel_3rd_Edition.pdf
9. http://www.imoa.info/molybdenum-uses/molybdenum-grade-stainless-steels/steel-grades.php
10. http://www.imoa.info/download_files/stainless-steel/IMOA_Houska-Selecting_Stainless_Steel_for_Optimum_Perormance.pdf
11. http://en.wikipedia.org/wiki/Galvanic_corrosion
12. http://www.bssa.org.uk/topics.php?article=668
13. http://www.stainless-steel-world.net/pdf/SSW_0812_duplex.pdf
14. http://www.outokumpu.com/en/stainless-steel/grades/duplex/Pages/default.aspx
15. http://www.aperam.com/uploads/stainlesseurope/TechnicalPublications/Duplex_Maastricht_EN-22p-7064Ko.pdf
16. http://www.bssa.org.uk/topics.php?article=606
17. a) 通用不锈钢板材EN 10088-2的化学组成: http://www.bssa.org.uk/topics.php?article=44 b) 通用不锈钢长材EN 10088-3的化学成分: http://www.bssa.org.uk/topics.php?article=46

Appendix: Designations[17]

EN Designation		Alternative Designations			
Steel name	Steel number	AISI	UNS	Other US	Generic/ Brand
Ferritic stainless steels - standard grades					
X2CrNi12	1.4003		S40977		3CR12
X2CrTi12	1.4512	409	S40900		
X6CrNiTi12	1.4516				
X6Cr13	1.4000	410S	S41008		
X6CrAl13	1.4002	405	S40500		
X6Cr17	1.4016	430	S43000		
X3CrTi17	1.4510	439	S43035		
X3CrNb17	1.4511	430N			
X6CrMo17-1	1.4113	434	S43400		
X2CrMoTi18-2	1.4521	444	S44400		
Martensitic stainless steels - standard grades					
X12Cr13	1.4006	410	S41000		
X20Cr13	1.4021	420	S42000		
X30Cr13	1.4028	420	S42000		
X3CrNiMo13-4	1.4313		S41500	F6NM	
X4CrNiMo16-5-1	1.4418				248 SV
Martensitic and precipitation-hardening steels - special grades					
X5CrNiCuNb16-4	1.4542		S17400		17-4 PH

EN Designation		Alternative Designations			
Steel name	Steel number	AISI	UNS	Other US	Generic/ Brand
Austenitic stainless steels - standard grades					
X10CrNi18-8	1.4310	301	S30100		
X2CrNi18-9	1.4307	304L	S30403		
X2CrNi19-11	1.4306	304L	S30403		
X2CrNiN18-10	1.4311	304LN	S30453		
X5CrNi18-10	1.4301	304	S30400		
X6CrNiTi18-10	1.4541	321	S32100		
X4CrNi18-12	1.4303	305	S30500		
X2CrNiMo17-12-2	1.4404	316L	S31603		
X2CrNiMoN17-11-2	1.4406	316LN	S31653		
X5CrNiMo17-12-2	1.4401	316	S31600		
X6CrNiMoTi17-12-2	1.4571	316Ti	S31635		
X2CrNiMo17-12-3	1.4432	316L	S31603		
X2CrNiMo18-14-3	1.4435	316L	S31603		
X2CrNiMoN17-13-5	1.4439	317L			
X1NiCrMoCu25-20-5	1.4539		N08904		904L
Austenitic-ferritic stainless steels-standard grades					
X2CrNiN22-2	1.4062		S32202		DX 2202
X2CrMnNiMoN21-5-3	1.4482		S32001		
X2CrMnNiN21-5-1	1.4162		S32101		2101 LDX
X2CrNiN23-4	1.4362		S32304		2304
X2CrNiMoN12-5-3	1.4462		S31803/ S32205	F51	2205

Note: This is a simplified table. For special grades, please look at reference 17.

Thank you

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Part A:

Structural Applications of Stainless Steel Reinforcing Bar

See also: stainlesssteelrebar.org

Wrong choice of materials can lead to big problems




A textbook case: Corrosion of the Turcot highway interchange in Montreal [1,2]

- A key interchange between Decarie (North-South) and Ville Marie (East-West) highways, built in 1966.
- Over 300,000 vehicles per day
- Made of reinforced concrete, badly corroded today by deicing salts

It had to be replaced

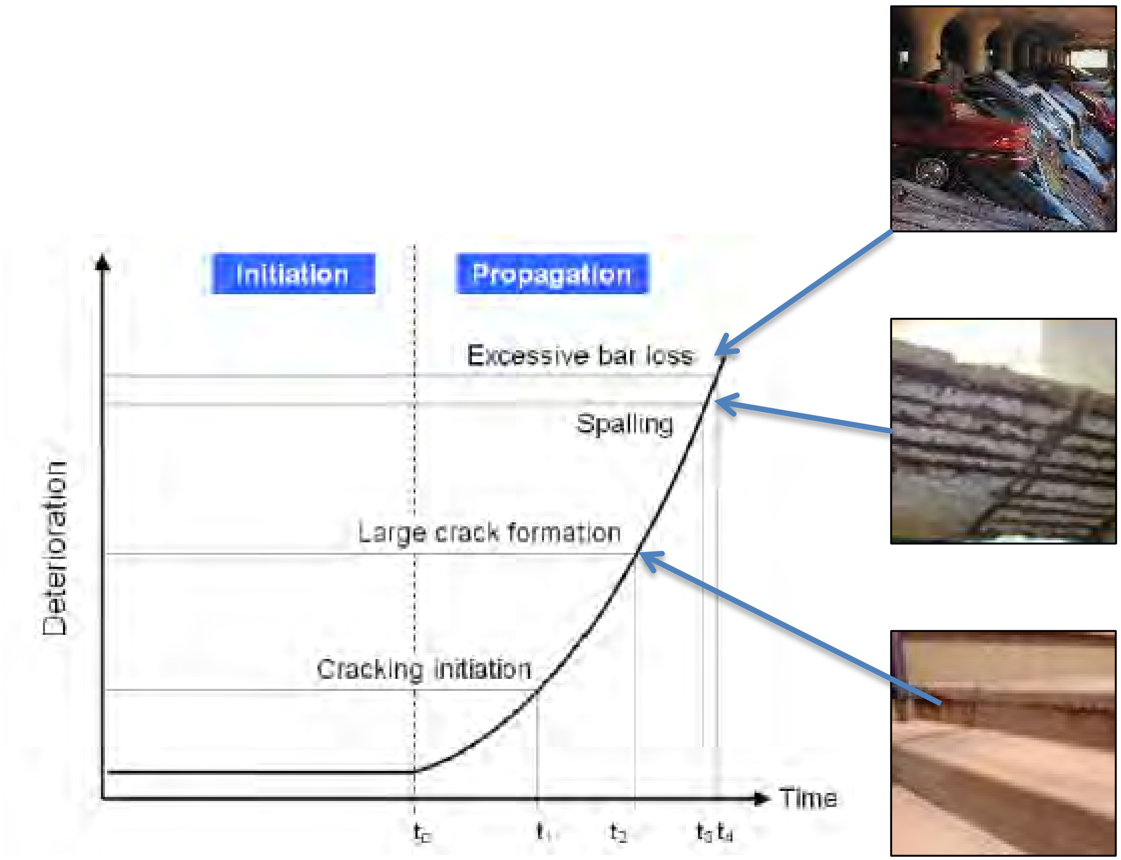
- In spite of constant supervision and repairs, it had to be replaced,
  - Cost CAD 3000M.
  - Moreover, CAD 254M had to be spent to ensure safety until its replacement in 2018
- Lifespan of the structure was only 50 years!

How reinforced concrete can be damaged by corrosion

Diffusion of corrosive ions (usually chlorides) into concrete:

Steps[3]:

1. Once corrosive ions reach the carbon steel rebar (t0), corrosion begins
2. Corrosion products, which occupy a greater volume than steel, exert an outwards pressure
3. Concrete cracking occurs (t1), opening easy access to chlorides
4. Concrete cover cracks (spalling) (t3), exposing the rebar
5. If unattended, corrosion continues until the rebar cannot bear the applied tensile stresses and the structure collapses (t4)



Corrosion of rebar in concrete [21]

- In the high pH of concrete, in the absence of chlorides, carbon steel rebar is in a passive state (i.e. does not corrode)
- A low chloride content is sufficient to activate corrosion of carbon steel
- Stainless steel properly specified never corrodes.
- Galvanic coupling between stainless steel rebar (anode) and carbon steel rebar (cathode) contributes only to ~1% of the overall corrosion rate*. It is therefore negligible.
- Type of concrete, temperature, exposure conditions, distance between carbon steel rebar and surface, etc… have a strong influence on the corrosion rate of the carbon steel rebar

* Specific references are provided at the end of the presentation

Cracks in concrete accelerate corrosion [4]

Concrete often exhibits cracks, though which corrosive ions reach quickly the steel.

Here are some causes of crack formation.

Please note that cracks do not take place immediately, and will also occur in concealed areas, where they cannot be repaired.

Type of cracking	Form of crack	Primary Cause	Time of Appearance
Plastic settlement	Above and aligned with steel reinforcement	Subsidence around rebar; excessive water in the mix	10 minutes to three hours
Plastic shrinkage	Diagonal or random	Excessive early evaporation	30 minutes to six hours
Thermal expansion and contraction	Transverse (example: across the pavement)	Excessive heat generation or temperature gradients	One day to two or three weeks
Drying shrinkage	Transverse or pattern	Excessive water in the mix; poor joint placement; joints over-spaced	Weeks to months
Freezing and thawing	Parallel to the concrete surface	Inadequate air entrainment; non-durable coarse aggregate	After one or more winters
Corrosion of reinforcement	Above reinforcement	Inadequate concrete cover; ingress of moisture or chloride	More than two years
Alkali-aggregate reaction	Pattern cracks; cracks parallel to joints or edges	Reactive aggregate plus moisture	Typically, over five years, but may be much sooner with highly reactive aggregate
Sulfate attack	Pattern cracks	External or internal sulfates promoting the formation of ettringite	One to five years

Major civil engineering structures must last over 100 years now

Haynes Inlet Slough Bridge, Oregon, USA 2004[7,8]

An unusual arch-hinged bridge with 400 tons of stainless steel reinforcing bar in its deck.

The 230m-long link over Haynes Inlet Slough is expected to last 120 maintenance-free years.

Although stainless steel costs a lot more than average steel, the bridge life-cycle cost will be greatly reduced.

Broadmeadow Bridge, Dublin, Ireland (2003)[10]

A new construction built over the estuary using 105MT of stainless steel reinforcement in the columns and parapets.

Dam repair [11] Bayonne, France

Aerial view

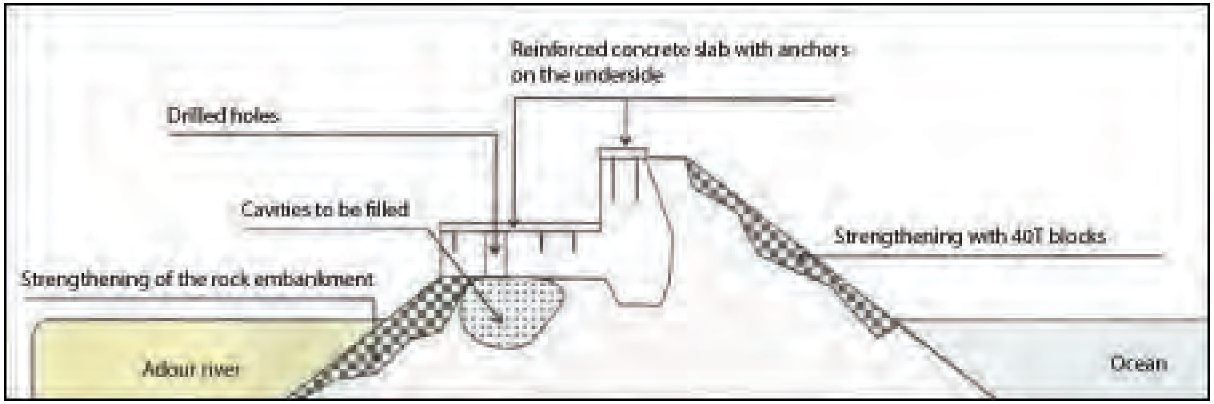
Dam built in the 1960s to protect the entrance to the harbour

The ocean side is higher and protected by 40T blocks which must be replaced as the storms wear them

On the river side a 7m wide platform allows the heavy-duty cranes to lift the blocks

Cracks on the deck and wall required repairs

Section through the sea wall



Sea wall repair Bayonne, France

Platform and sea wall have been reinforced with lean duplex stainless steel (EN 1.4362)[11]

Sea wall repair under way

Early 2014 gale over the dam

Belt Parkway Bridge, Brooklyn, USA (2004)[14]

To assure long-term (100 years) durability and resistance to the corrosive attack of the area's marine environment and road salt, the bridge units and parapet barriers were reinforced with stainless steel grade 2205 rebar.

When should stainless steel rebar be considered [15-20]:

- In corrosive environments:
- Sea water and even more in hot climates
  - Bridges
  - Piers
  - Docks
  - Anchors for lampposts, railings,….
  - Sea walls
  - …..
- Deicing salts
  - Bridges
  - Traffic overpasses and interchanges
  - Parking garages
- Waste water treatment tanks
- Desalination plants
- In structures with a very long life
  - Repairs of historic structures
  - Nuclear waste storage
- In unknown environments in which
  - inspection is impossible,
  - Repairs are almost impossible or very expensive

Comparison of stainless rebar with alternative solutions[15-20]

	Advantages	Drawbacks
Epoxy coating	Lower initial costs	▪ cannot be bent without cracking ▪ Requires careful handling to avoid damaging it during installation
Galvanizing	Lower initial costs	▪ cannot be bent without cracking ▪ No longer effective when the zinc coating has been corroded
Fiber-reinforced Polymers	Lower initial costs	▪ Cannot be bent without cracking ▪ No heat resistance and poor impact resistance in harsh winters ▪ Lower stiffness than that of steel ▪ Cannot be recycled
STAINLESS STEEL	Low Life Cycle cost: • Design similar to C-steels • Mixed C-steel/stainless reinforcements work well • Easy installation, insensitive to poor worknanship • No maintenance • No life limit • Allows a thinner concrete cover • Better fire resistance • 100% Recycled to premium stainless	▪ Higher initial cost, but no more than a few % when ✓ Stainless is selected for the critical areas ✓ Lean duplex grades are selected

Comparison of stainless rebar with alternative solutions[15-20]

	Advantages	Drawbacks
Cathodic protection	Lower initial costs ? Often used for repairs	▪ Requires careful design for overall protection ▪ Requires careful installation to maintain proper electrical contacts ▪ Requires a permanent source of current (which must be monirored and maintained) or sacrificial anodes that require monitoring & replacement
Membranes/ sealants	Lower initial costs?	▪ Require careful installation (bubbles) ▪ Cannot be installed in any weather ▪ Performance over time debatable ▪ Limited to horizontal surfaces

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NEW !

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Thank you

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Part B

Structural Applications of Stainless Steel Plates, Sheets, Bars, ….

Structural Stainless Steel
Designing with stainless steel

Barbara Rossi, Maarten Fortan
Civil Engineering department,
KU Leuven, Belgium

Based on a previous version prepared by Nancy Baddoo
Steel Construction Institute, Ascot, UK

Outline

- Examples of structural applications
- Material mechanical characteristics
- Design according to Eurocode 3
- Alternative methods
- Deflections
- Additional information
- Resources for engineers

Section 1

Examples of structural applications

Station Sint Pieters, Ghent (BE)

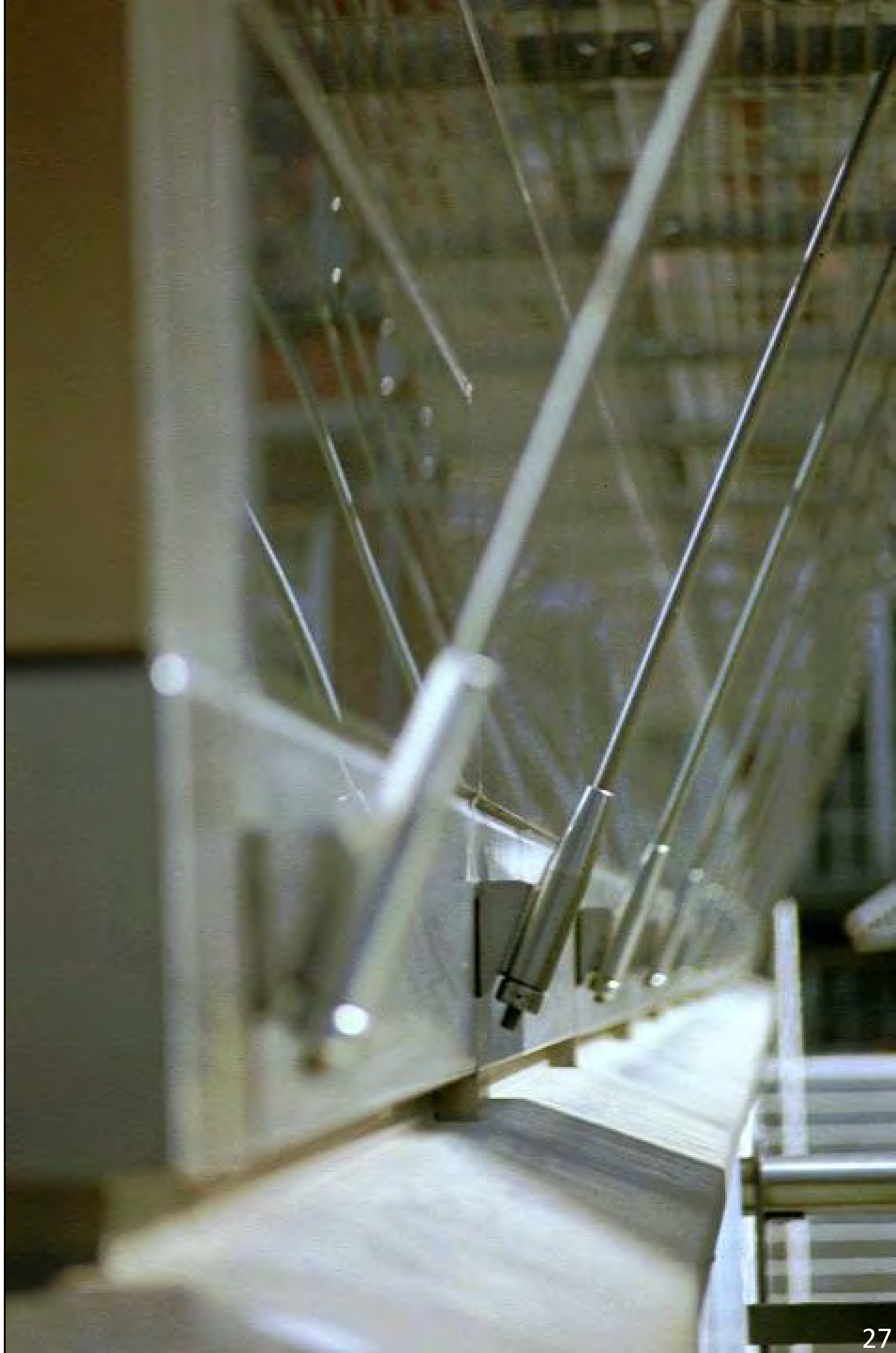
Arch : Wefirna

Eng. Off.: THV Van Laere-Braekel Aero

Military School in Brussels

Arch : AR.TE

Eng. Off.: Tractebel Development



La Grande Arche, Paris

Arch : Johan Otto von Spreckelsen

Eng. Off.: Paul Andreu

Villa Inox (FIN)

La Lentille de Saint-Lazare, Paris, (France)

Arch: Arte Charpentiers & Associés

Eng. Off.: Mitsu Edwards

Station in Porto (Portugal)

Torno Internazionale S.P.A. Headquarters Milan, (IT), Stainless steel grade: EN 1.4404 (AISI 316L)

Architect : Dante O. BENINI & Partners Architects

Photography: Toni Nicolino / Nicola Giacomin

Stainless steel frames in nuclear power plant

Photography: Stainless Structurals LLC

Stainless steel façade supports, Tampa, (USA)

Photography: TriPyramid Structures, Inc.

Stainless steel I-shaped beams, Thames Gateway Water Treatment Works, (UK)

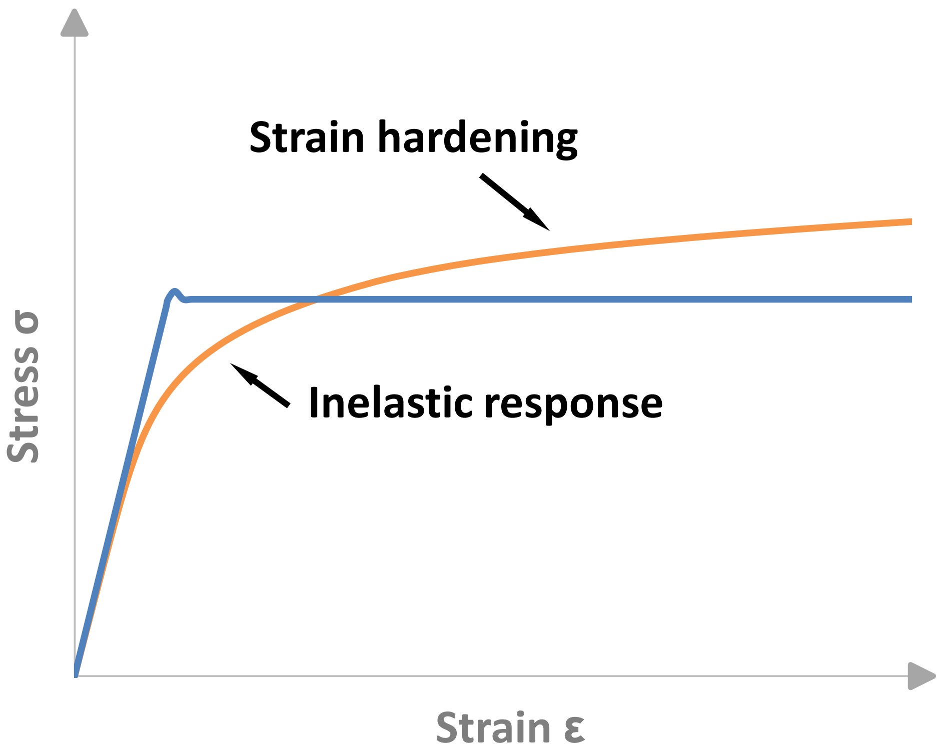
Photography: Interserve

Section 2

Material mechanical characteristics

Stress-Strain characteristics: Carbon steel vs stainless steel

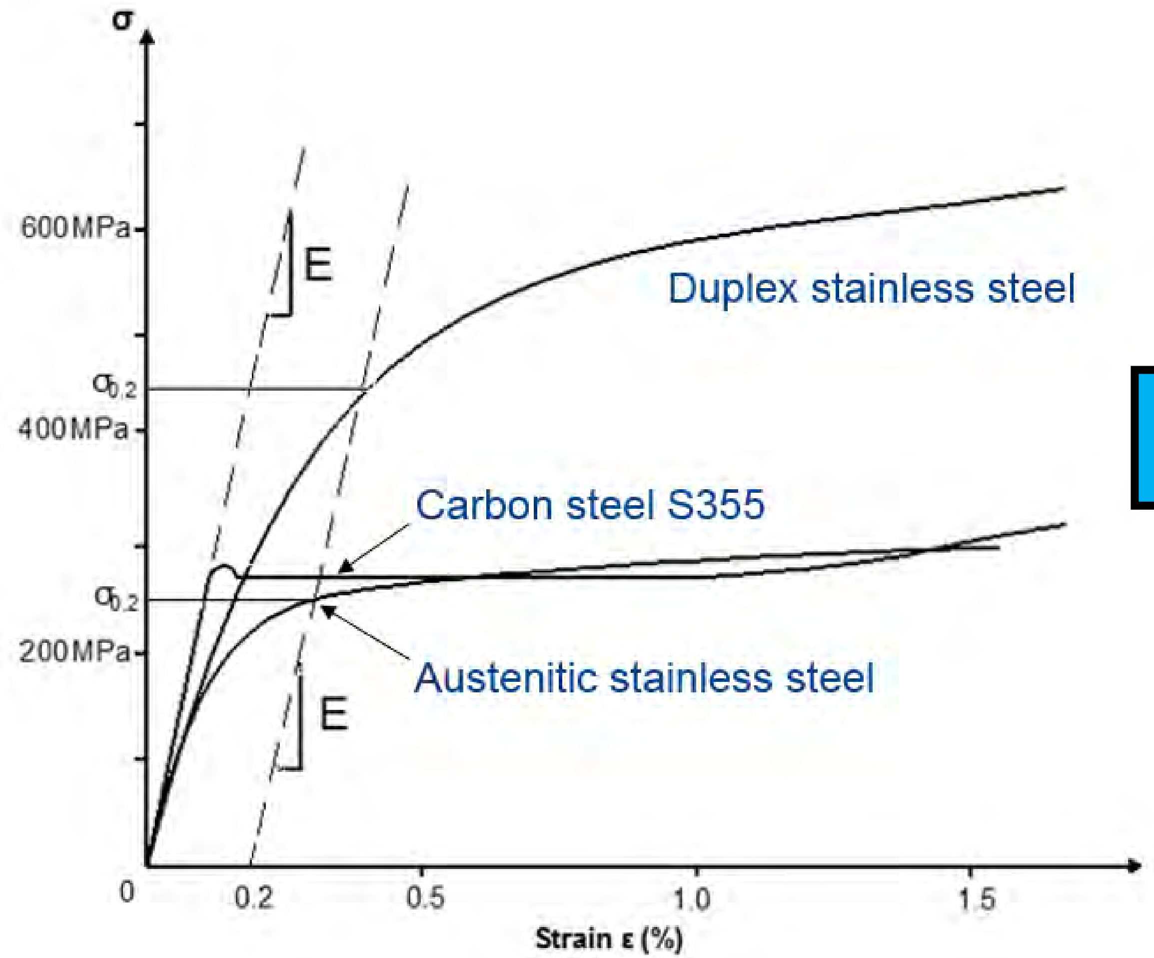
Stainless steel exhibits fundamentally different σ-ε behaviour to carbon steel.



Carbon steel has a sharply defined yield point with a plastic yield plateau.

Stainless steel exhibits gradually yielding behaviour, with high strain-hardening.

Stress-strain characteristics – low strain



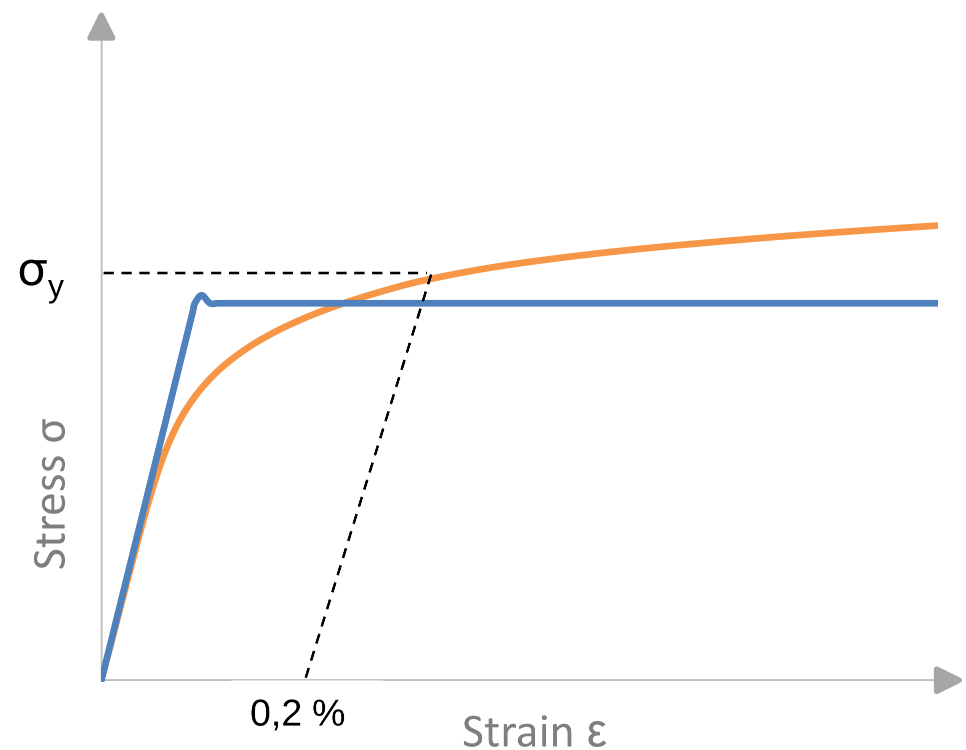
Stress-strain response depends on the family.

Design strength of stainless steel

Minimum specified 0.2% proof strength are given in EN 10088-4 and -5

Austenitics: f_y = 220-350 MPa
Duplexes: f_y = 400-480 Mpa
Ferritics: f_y = 210-280 MPa

Young's modulus: E=200,000 to 220,000 MPa



Design strength of stainless steel

Grade	Family	Yield strength (N/mm^2) 0.2% proof strength	Ultimate strength (N/mm^2)	Young's Modulus (N/mm^2)	Fracture strain (%)
1.4301 (304)	Austenitic	210	520	200000	45
1.4401 (316)	Austenitic	220	520	200000	40
1.4062	Duplex	450	650	200000	
1.4462	Duplex	460	640	200000	
1.4003	Ferritic	250	450	220000	

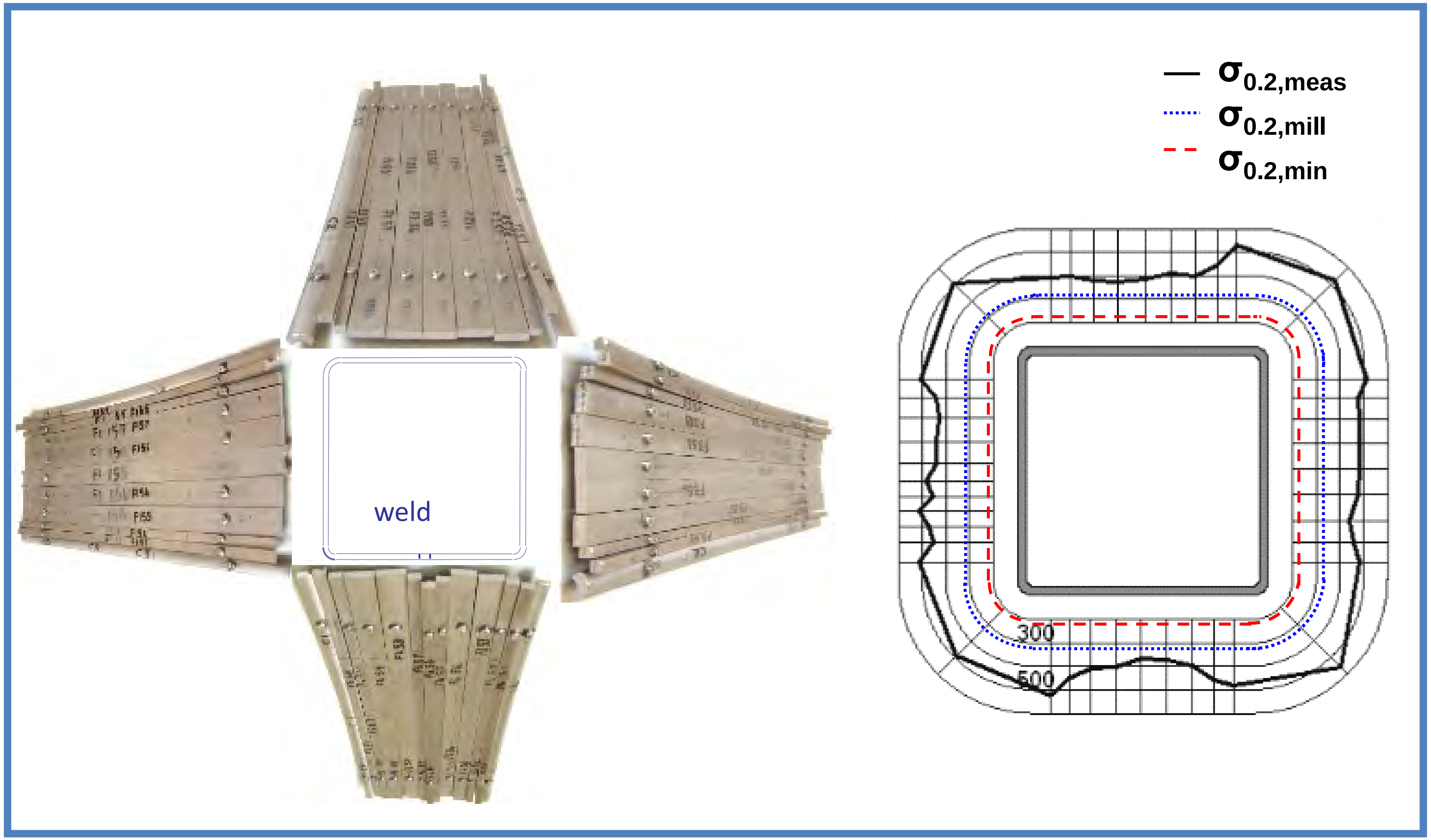
Strain hardening
(work hardening or cold working)

- Increased strength by plastic deformation
- Caused by cold-forming, either during steel production operations at the mill or during fabrication processes

During the fabrication of a rectangular hollow section, the 0.2% proof strength increases by about 50% in the cold-formed corners of cross sections!

Strain hardening
(work hardening or cold working)

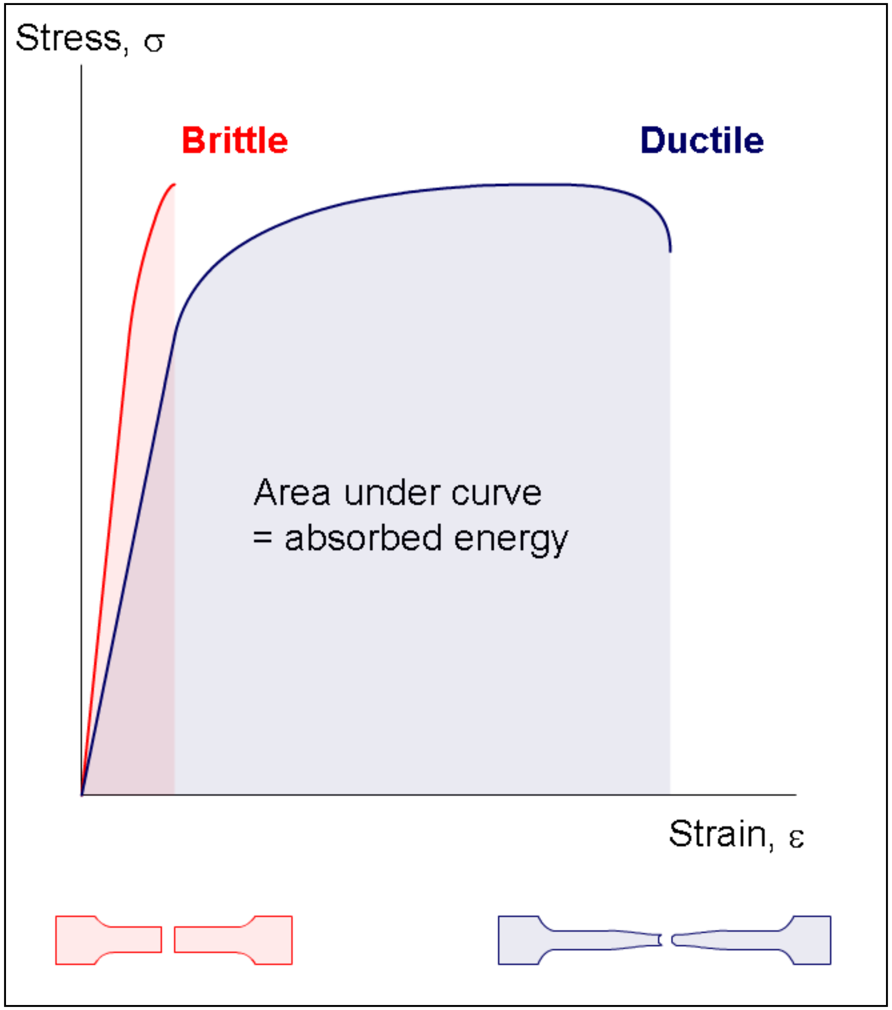
- **Strength enhancement during forming**



Strain hardening – not always useful

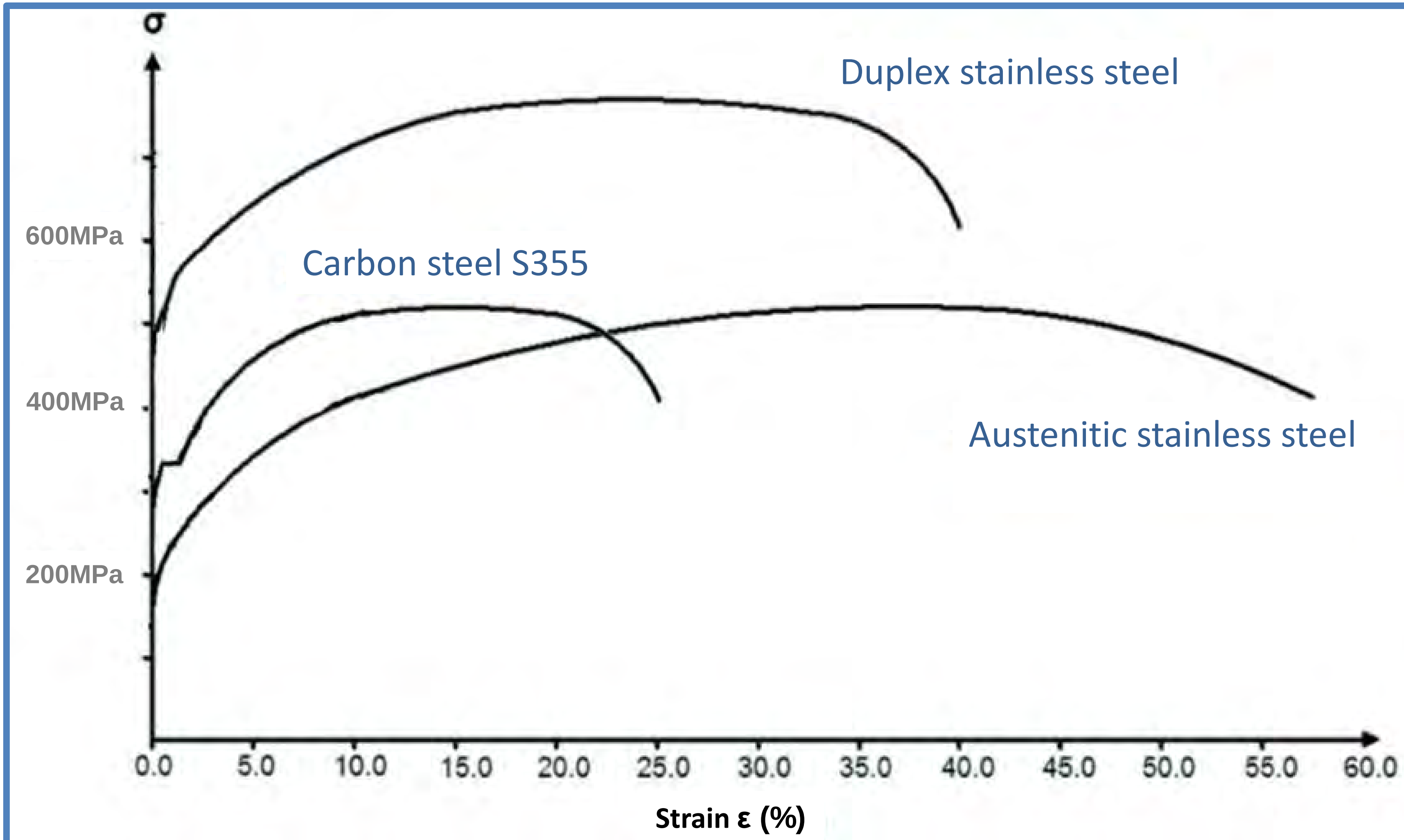
- Heavier and more powerful fabrication equipment
- Greater forces are required
- Reduced ductility (however, the initial ductility is high, especially for austenitics)
- Undesirable residual stresses may be produced

Ductility and toughness



- **Ductility** - ability to be stretched without breaking
- **Toughness -** ability to absorb energy & plastically deform without fracturing

Stress-Strain Characteristics – high strain



Blast/impact resistant structures

Security bollard

A trapezoidal blast resistant wall being fabricated for the topsides of an offshore platform

Stress-strain characteristics

Nonlinearity...........leads to

– different limiting width to thickness ratios for local buckling

– different member buckling behaviour in compression and bending

– greater deflections

Impact on buckling performance

- **Low slenderness**
  columns attain/exceed the squash load

  ⇒ **benefits** of strain hardening apparent
  ss behaves at least **as well as** cs

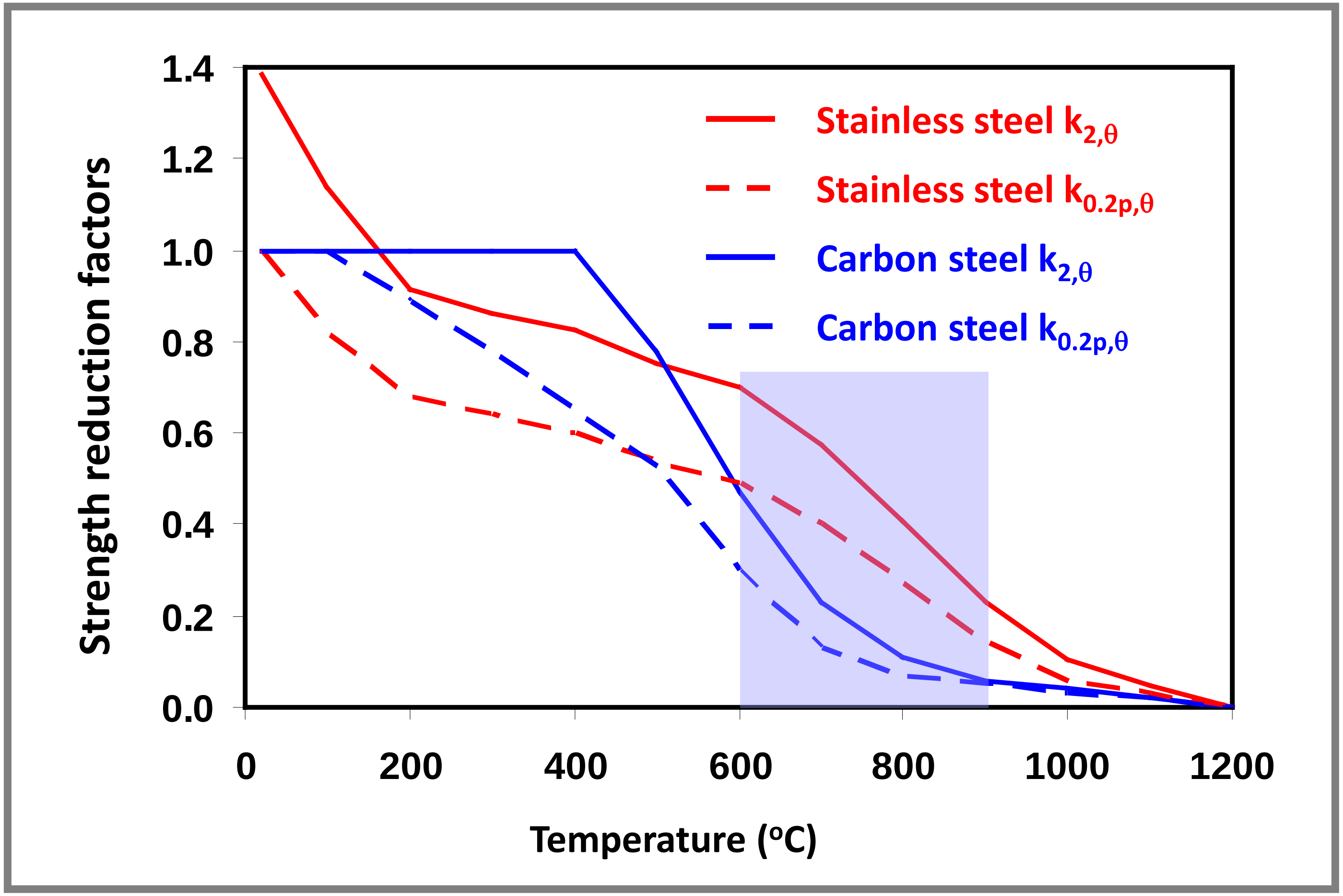
- **High slenderness**
  axial strength low, stresses low and in linear region

  ⇒ ss behaves **similarly** to cs, providing geometric and residual stresses similar

Impact on buckling performance

- **Intermediate slenderness**
  average stress in column lies between the limit of proportionality and the 0.2% permanent strain,
  ss column **less strong** than cs column

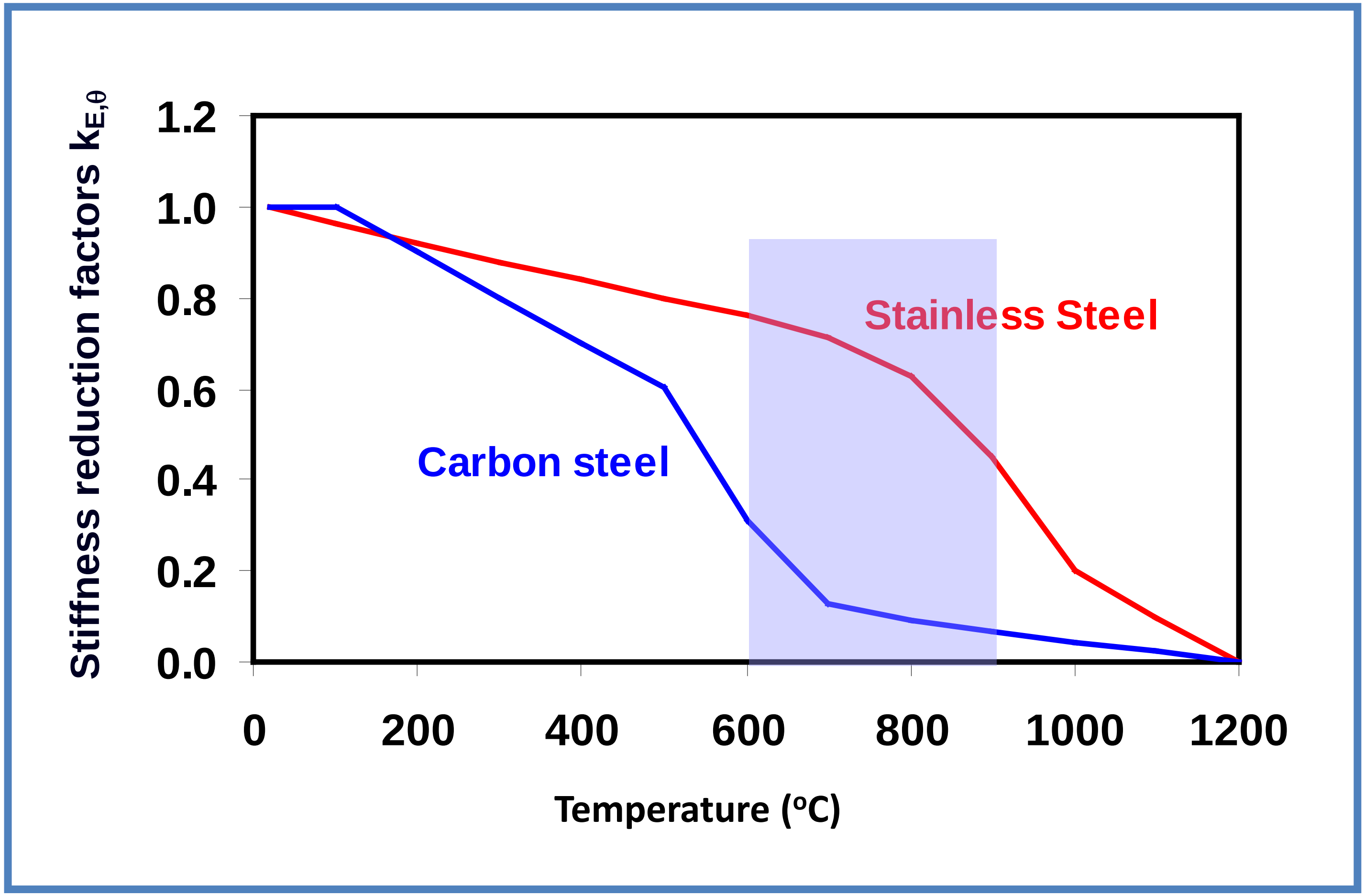
Material at elevated temperature



$k_{0.2p,q}$ = strength reduction factor at 0.2% proof strain

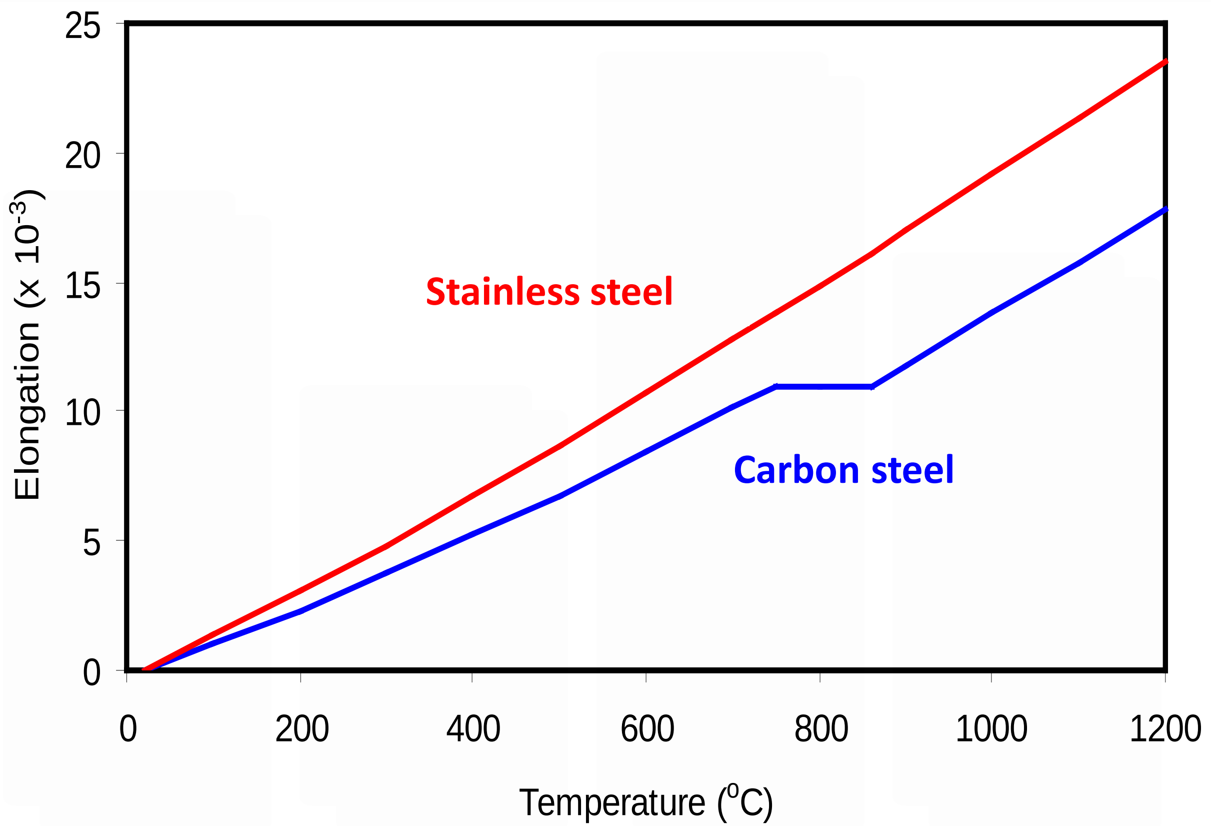
$k_{2,q}$ = strength reduction factor at 2% total strain

Material at elevated temperature



Stiffness reduction factor

Material at elevated temperature



Thermal expansion

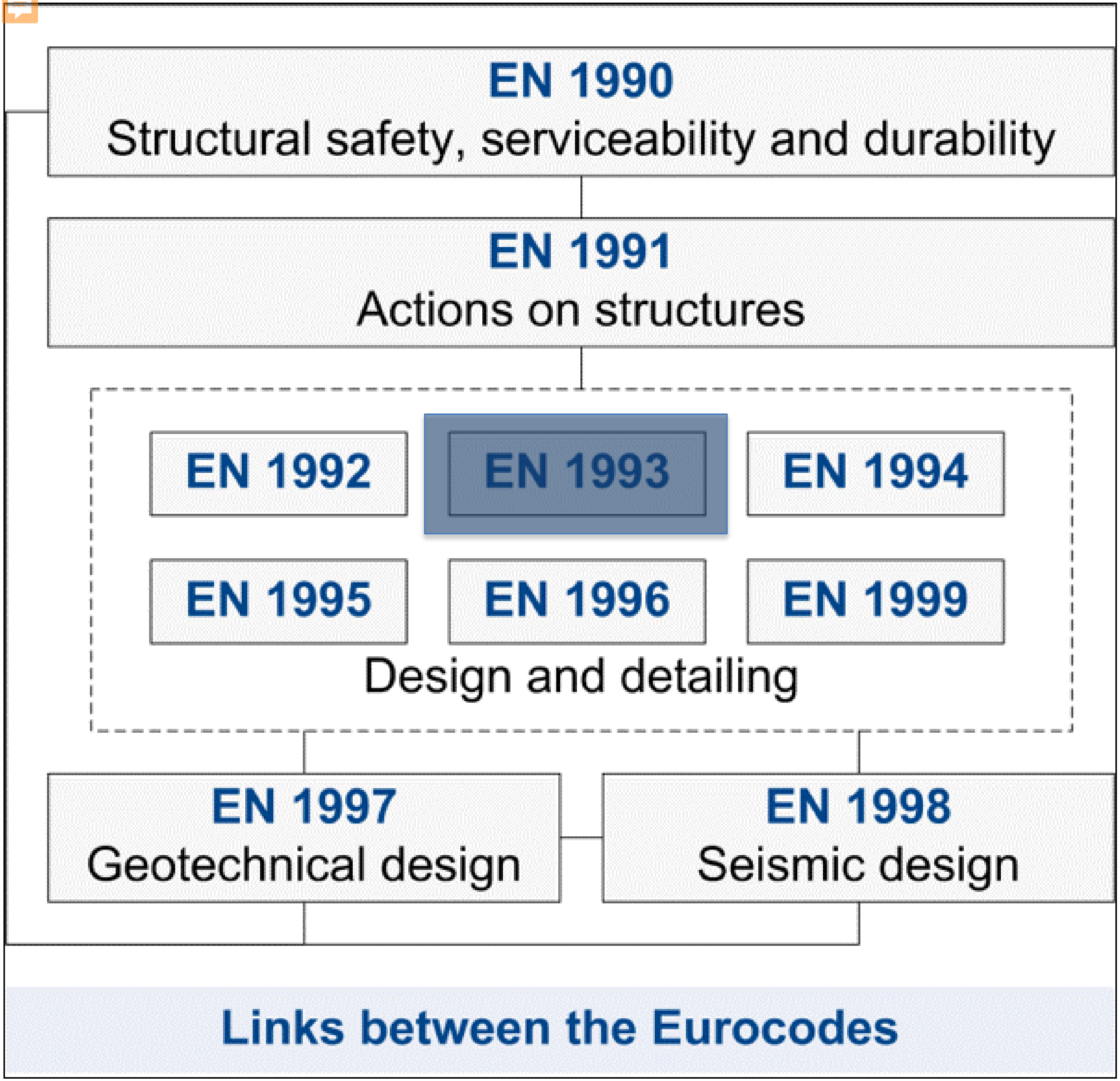
Section 4

Design according to Eurocode 3

International design standards

What design standards are available for structural stainless steel?

Hamilton Island Yacht Club, Australia



Eurocodes are an Integrated suite of structural design codes covering all common construction materials

Eurocode 3: Part 1 (EN 1993-1)

EN 1993-1-1 General rules and rules for buildings.

EN 1993-1-2 Structural fire design.

EN 1993-1-3 Cold-formed members and sheeting .

EN 1993-1-4 Stainless steels.

EN 1993-1-5 Plated structural elements.

EN 1993-1-6 Strength and stability of shell structures.

EN 1993-1-7 Strength & stability of planar plated structures transversely loaded.

EN 1993-1-8 Design of joints.

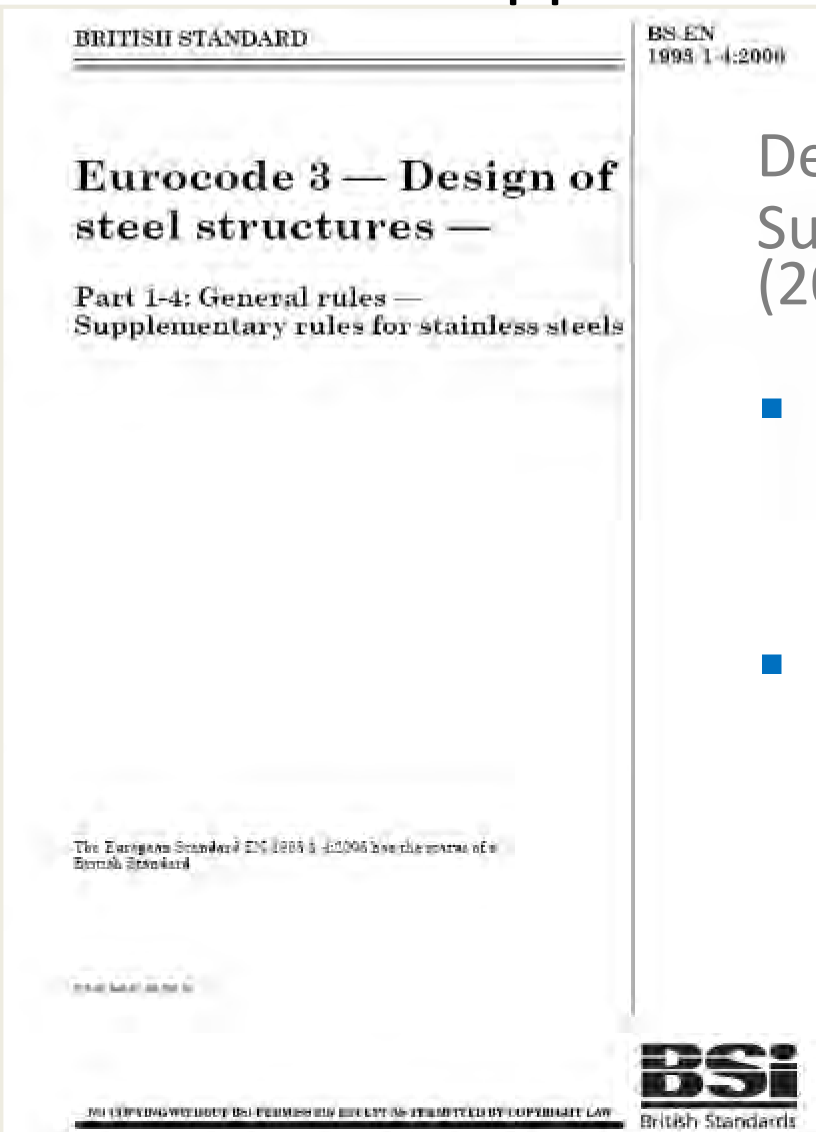
EN 1993-1-9 Fatigue strength of steel structures.

EN 1993-1-10 Selection of steel for fracture toughness and through-thickness properties.

EN 1993-1-11 Design of structures with tension components

EN 1993-1-12 Supplementary rules for high strength steels

Eurocode 3: Design of Steel Structures, Part 1.4 Supplementary rules for stainless steels


BRITISH STANDARD

BS EN 1993-1-4:2006

Eurocode 3 — Design of steel structures —

Part 1-4: General rules — Supplementary rules for stainless steels

The European Standard EN 1993-1-4:2006 has the status of a British Standard

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British Standards

Design of steel structures. Supplementary rules for stainless steels (2006)

- Modifies and supplements rules for carbon steel given in other parts of Eurocode 3 where necessary
- Applies to buildings, bridges, tanks etc

Eurocode 3: Design of Steel Structures, Part 1.4 Supplementary rules for stainless steels

- Follow same basic approach as carbon steel
- Use same rules as for carbon steel for tension members & restrained beams
- Some differences in section classification limits, local buckling and member buckling curves apply due to:
  - non-linear stress strain curve
  - strain hardening characteristics
  - different levels of residual stresses

Eurocode 3: Design of Steel Structures, Part 1.4 Supplementary rules for stainless steels

Types of members

- Hot rolled and welded
- Cold-formed
- Bar

Number of grades

Family	EC3-1-4	Future revision
Ferritic	3	3
Austenitic	16	16
Duplex	2	**6**

Scope

- Members and connections
- Fire *(by reference to EN 1993-1-2)*
- Fatigue *(by reference to EN 1993-1-9)*

Other design standards

- **Japan** – two standards: one for cold formed and one for welded stainless members
- **South Africa, Australia, New Zealand** - standards for cold formed stainless members
- **Chinese** - standard under development
- **US** - ASCE specification for cold-formed members and AISC Design Guide for hot rolled and welded structural stainless steel

Eurocode 3: Design of Steel Structures, Part 1.4 Supplementary rules for stainless steels

What are the design rules for stainless steel given in EN 1993-1-4 and the main differences with carbon steel equivalents?

Blast resistant columns in entrance canopy,
Seven World Trade Centre, New York

Section classification & local buckling expressions in EN 1993-1-4

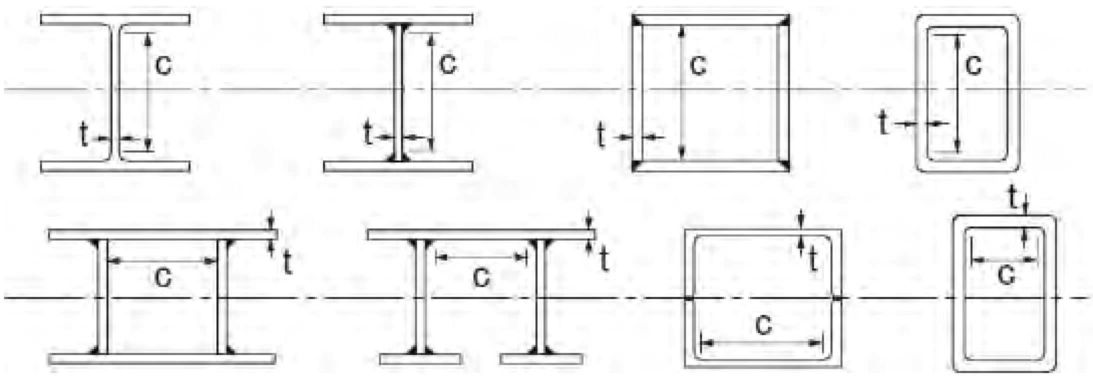
- Lower limiting width-to-thickness ratios than for carbon steel
- Slightly different expressions for calculating effective widths of slender elements

However…

The next version of EN 1993-1-4 will contain less conservative limits & effective width expressions.

Section classification & local buckling expressions in EN 1993-1-4

- Internal compression parts

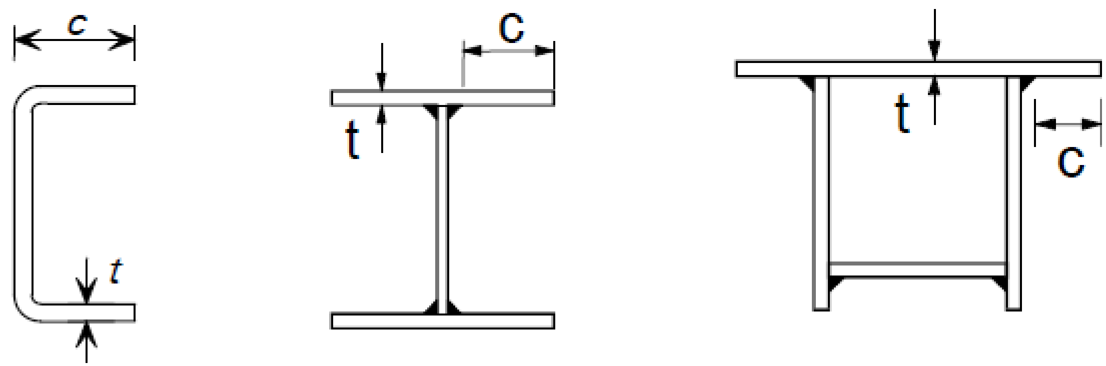


$$\varepsilon = \sqrt{\frac{235}{f_y}\frac{E}{210000}}$$

	EC3-1-1: carbon steel		EC3-1-4: stainless steel		EC3-1-4: Future revision	
Class	**Bending**	**Compression**	**Bending**	**Compression**	**Bending**	**Compression**
1	c/t ≤ 72ε	c/t ≤ 33ε	c/t ≤ 56ε	c/t ≤ 25,7ε	c/t ≤ 72ε	c/t ≤ 33ε
2	c/t ≤ 83ε	c/t ≤ 38ε	c/t ≤ 58,2ε	c/t ≤ 26,7ε	c/t ≤ 76ε	c/t ≤ 35ε
3	c/t ≤ 124ε	c/t ≤ 42ε	c/t ≤ 74,8ε	c/t ≤ 30,7ε	c/t ≤ 90ε	c/t ≤ 37ε

Section classification & local buckling expressions in EN 1993-1-4

- External compression parts



$$\varepsilon = \sqrt{\frac{235}{f_y}\frac{E}{210000}}$$

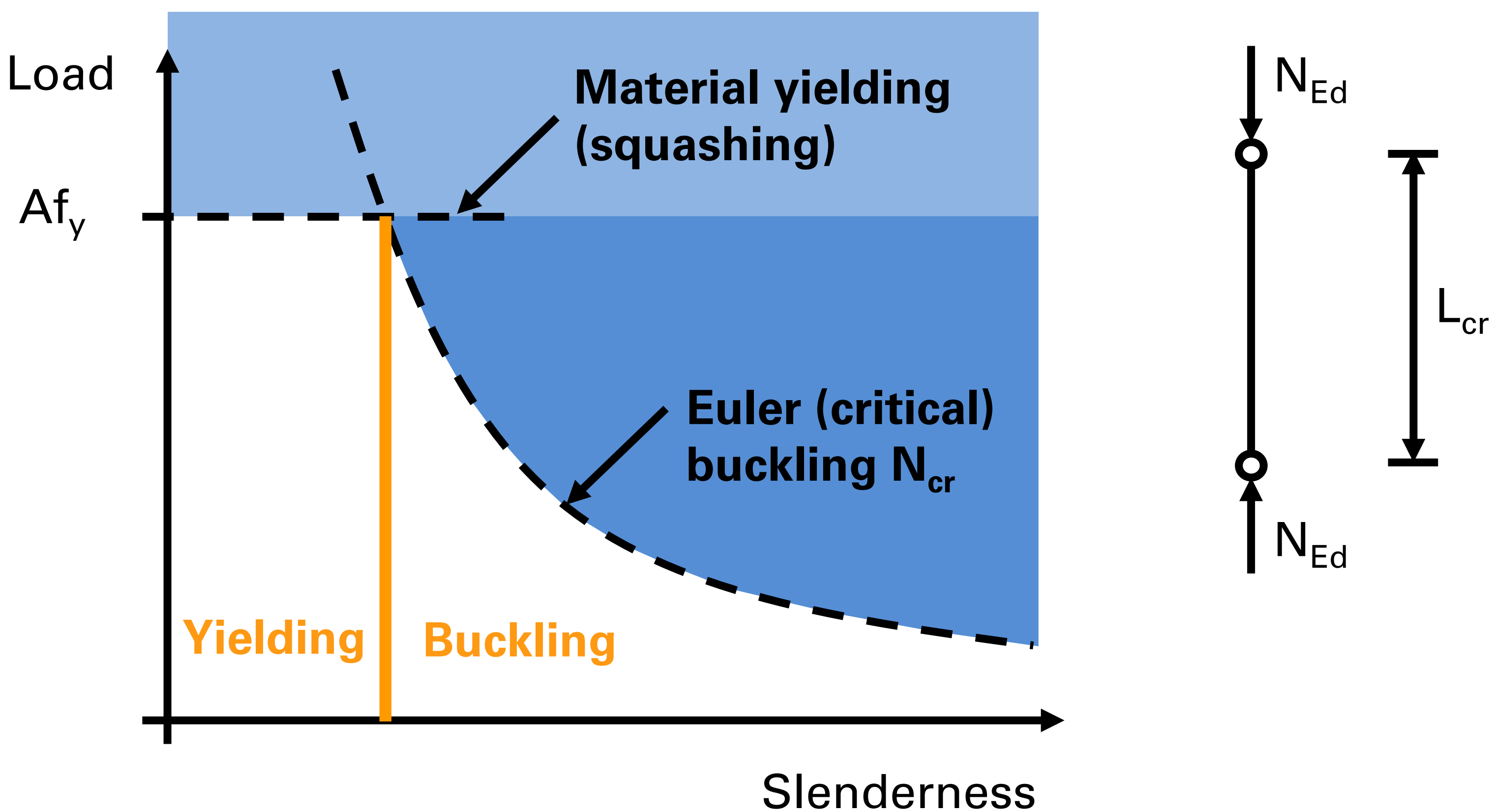
	EC3-1-1: carbon steel	EC3-1-4: stainless steel		EC3-1-4: future revision
Class	**Compression**	**Compression Welded**	**Compression Cold-formed**	**Compression**
1	c/t ≤ 9ε	c/t ≤ 9ε	c/t ≤ 10ε	c/t ≤ 9ε
2	c/t ≤ 10ε	c/t ≤ 9,4ε	c/t ≤ 10,4ε	c/t ≤ 10ε
3	c/t ≤ 14ε	c/t ≤ 11ε	c/t ≤ 11,9ε	c/t ≤ 14ε

Design of columns & beams

- In general use same approach as for carbon steel
- But use different buckling curves for buckling of columns and unrestrained beams (LTB)
- Ensure you use the correct f_y for the grade (minimum specified values are given in EN 10088-4 and -5)

"Perfect" column behaviour

Two bounds: Yielding and buckling:



Column buckling

Compression buckling resistance $N_{b,Rd}$:

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}}$$

for Class 1, 2 and 3

Reduction factor

$$N_{b,Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}}$$

for (symmetric) Class 4

Column buckling

Non-dimensional slenderness: $\bar{\lambda}$

$$\bar{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}} \quad \text{for Class 1, 2 and 3 cross-sections}$$

$\bar{\lambda}$

$$= \sqrt{\frac{A_{eff} f_y}{N_{cr}}} \quad \text{for Class 4 cross-sections}$$

N_{cr} is the elastic critical buckling load for the relevant buckling mode based on the gross properties of the cross-section

Column buckling

Reduction factor: χ

$$\chi = \frac{1}{\phi + (\phi^2 - \bar{\lambda}^2)^{0,5}} \leq 1$$

$$\phi = 0,5\left(1 + \alpha(\bar{\lambda} - \lambda_0) + \bar{\lambda}^2\right)$$

Imperfection factor

Plateau length

Column buckling

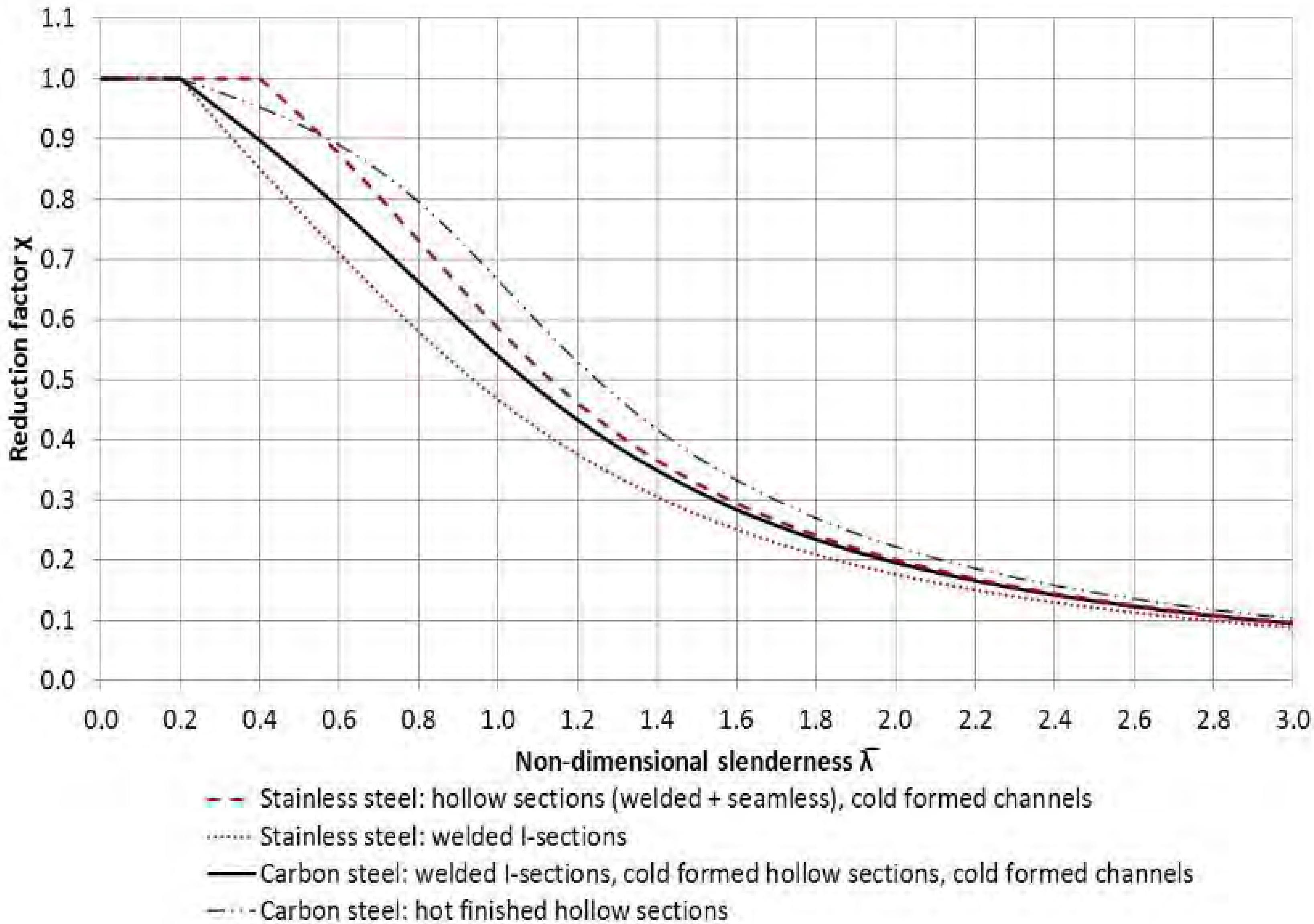
- Choice of buckling curve depends on cross-section, manufacturing route and axis

Table 5.3: Values of α and $\bar{\lambda}_0$ for flexural, torsional and torsional-flexural buckling

Buckling mode	Type of member	α	$\bar{\lambda}_0$
Flexural	Cold formed open sections	0,49	0,40
	Hollow sections (welded and seamless)	0,49	0,40
	Welded open sections (major axis)	0,49	0,20
	Welded open sections (minor axis)	0,76	0,20
Torsional and torsional-flexural	All members	0,34	0,20

Extract from EN 1993-1-4

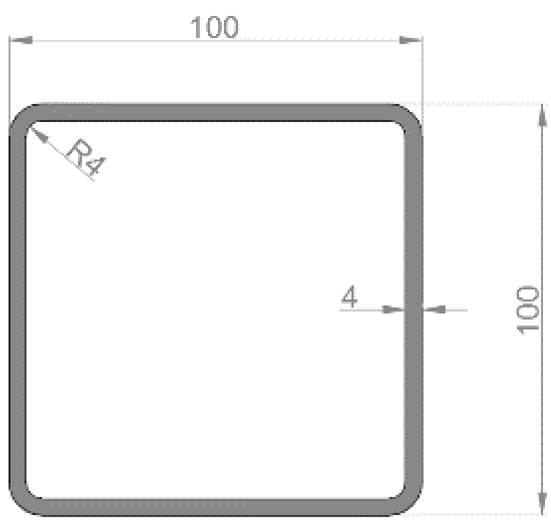
Eurocode 3 Flexural buckling curves

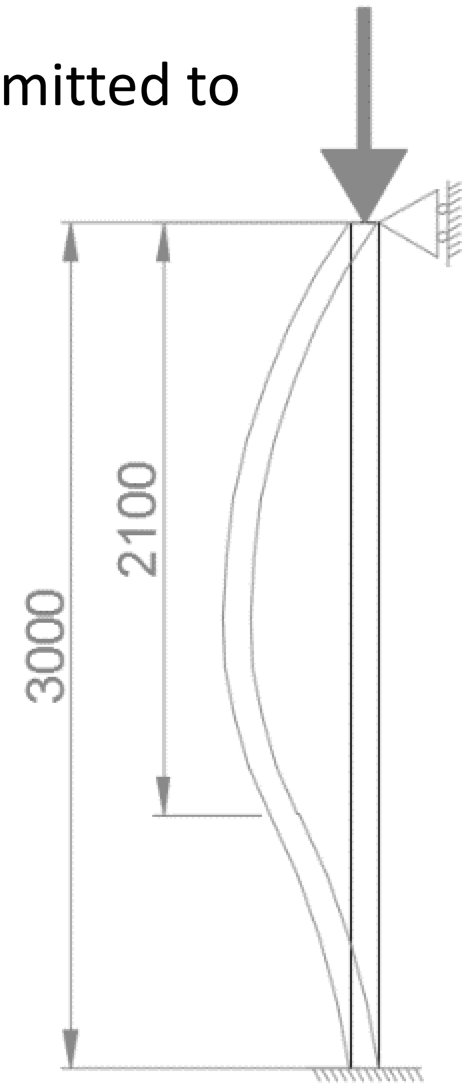


Eurocode 3 Flexural buckling example

- Cold formed rectangular hollow section submitted to concentric compression

	Carbon steel	Austenitic stainless steel
Material	S235	EN 1.4301
f_y [N/mm²]	235	230
E [N/mm²]	210000	200000





Eurocode 3 flexural buckling example

EC 3-1-1: S235

- Classification

$$\varepsilon = \sqrt{\frac{235}{f_y}} = 1$$

  - All internal parts

    $c/_{t} = 21 < 33 = 33\varepsilon$

    Class 1

Cross-section = class 1

EC 3-1-4: Austenitic

- Classification

$$\varepsilon = \sqrt{\frac{235}{f_y}\;\frac{E}{210000}} = 0{,}99$$

  - All internal parts

    $c/_{t} = 21 < 25{,}35 = 25{,}7\varepsilon$

    Class 1

Cross-section = class 1

Eurocode 3 flexural buckling example

	EC 3-1-1: S355	EC 3-1-4: Duplex
A [mm²]	1495	1495
f_y [N/mm²]	**235**	**230**
γ_{M0} [-]	**1**	**1,1**
$N_{c,Rd}$ [kN]	**351**	**313**
L_{cr} [mm]	2100	2100
λ_1 [-]	93,9	92,6
$\bar{\lambda}$ [-]	0,575	0,583
α [-]	0,49	0,49
$\bar{\lambda}_0$ [-]	0,2	0,4
ϕ [-]	0,76	0,71
χ [-]	0,80	0,89
γ_{M1} [-]	**1**	**1,1**
$N_{b,Rd}$ [kN]	**281**	**277**

Eurocode 3 flexural buckling example

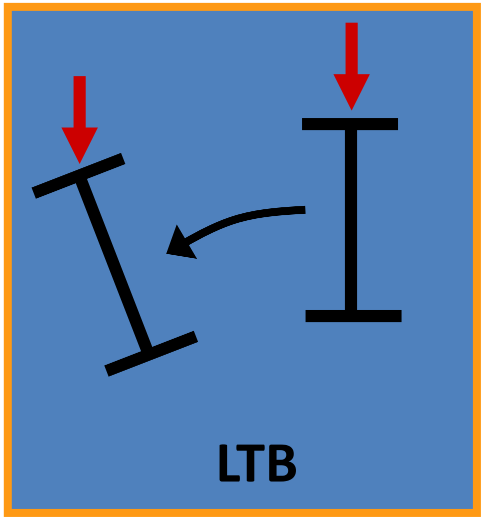
- Comparison

	EC 3-1-1: S235	EC 3-1-4: Austenitic
f_y [N/mm²]	235	230
γ_{M0} [-]	1,0	1,1
γ_{M1} [-]	1,0	1,1
Cross-section $N_{c,Rd}$ [kN]	351	313
Stability $N_{b,Rd}$ [kN]	281	277

– In this example, cs and ss show similar resistance to flexural buckling
⇒ **benefits** of strain hardening not apparent
EC3 1-4 doesn't take duly account for strain hardening

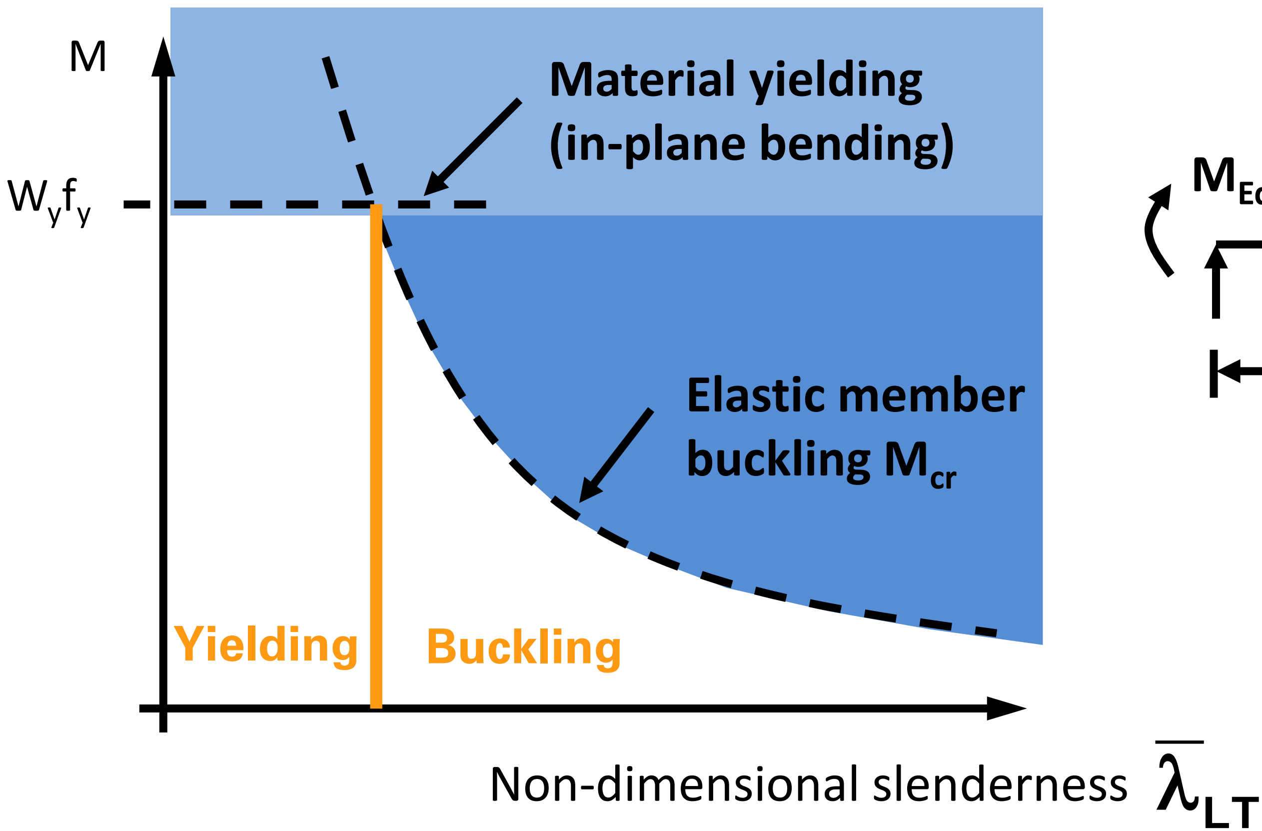
Lateral torsional buckling

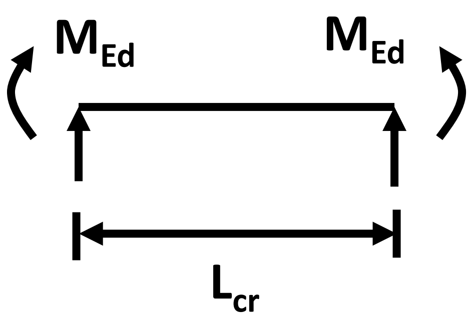
- Can be discounted when:
  - Minor axis bending
  - CHS, SHS, circular or square bar
  - Fully laterally restrained beams
  - $\overline{\lambda}_{LT} < 0.4$



Lateral torsional buckling

- The design approach for lateral torsional buckling is analogous to the column buckling treatment.





Lateral torsional buckling

- The design buckling resistance $M_{b,Rd}$ of a laterally unrestrained beam (or segment of beam) should be taken as:

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}}$$

Reduction factor for LTB

Lateral torsional buckling

- Lateral torsional buckling curves are given below:

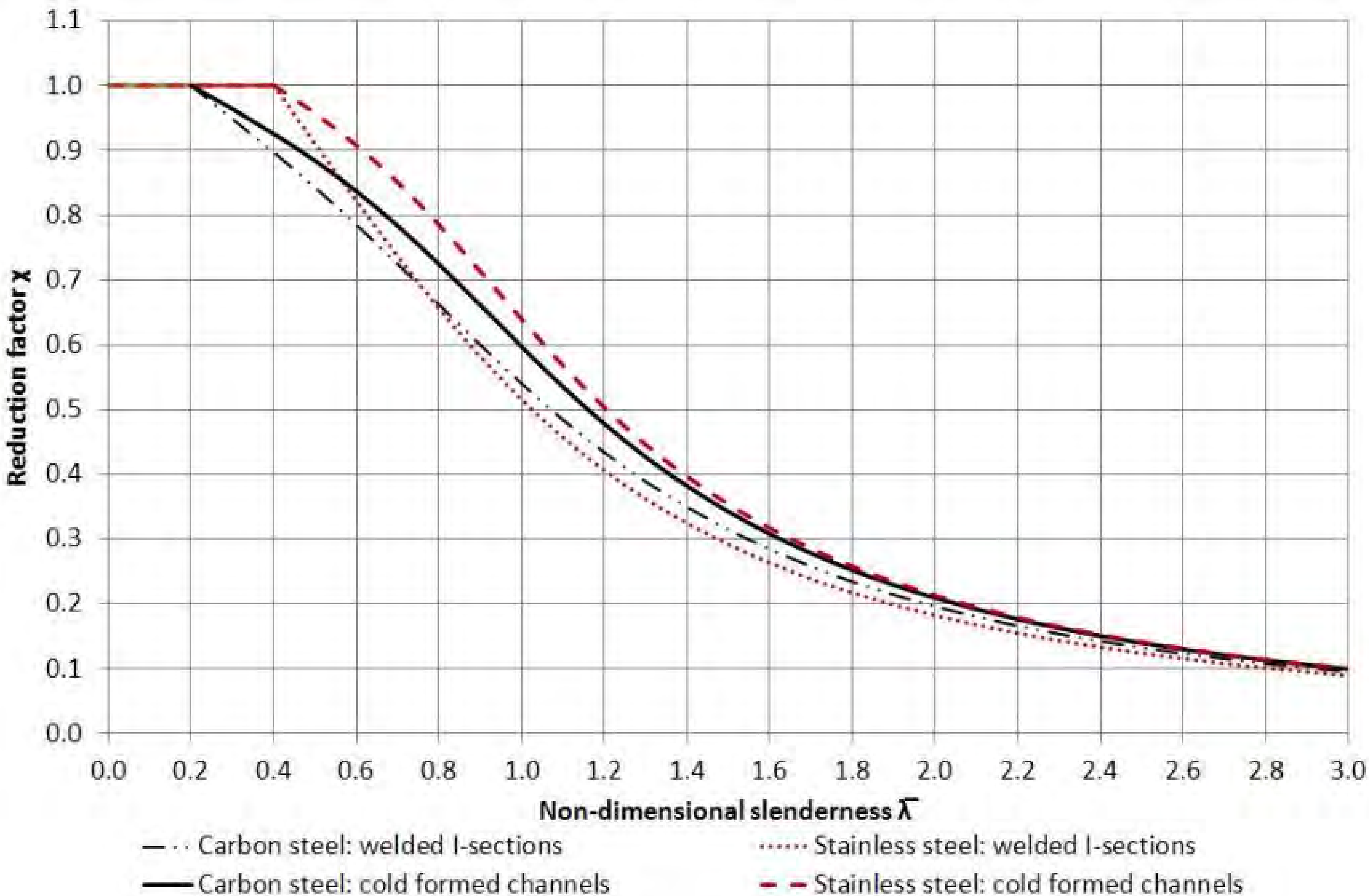
$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \bar{\lambda}_{LT}^2}} \quad \text{but } \chi_{LT} \leq 1.0$$

$$\Phi_{LT} = 0.5[1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0.4) + \bar{\lambda}_{LT}^2]$$

Imperfection factor

Plateau length

Eurocode 3 Lateral torsional buckling curves



Non-dimensional slenderness

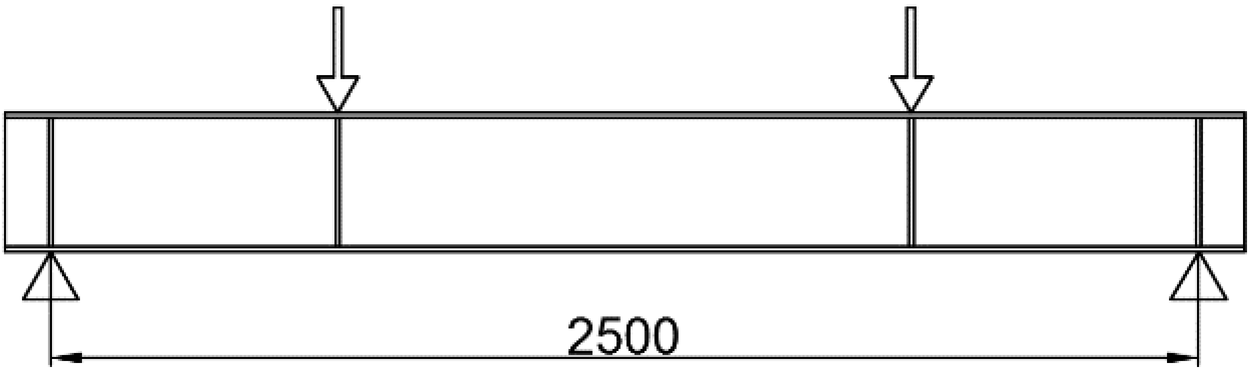
- Lateral torsional buckling slenderness:

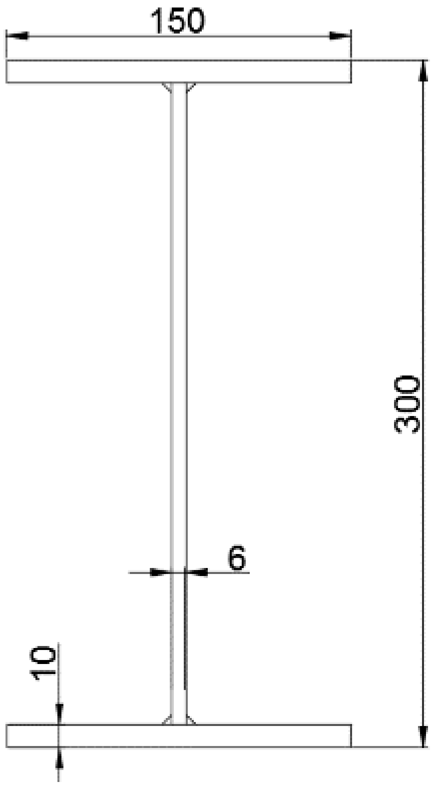
$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}}$$

  - Buckling curves as for compression (except curve a_0)
  - W_y depends on section classification
  - M_{cr} is the elastic critical LTB moment

Eurocode 3 Lateral torsional buckling example

- I-shaped beam submitted to bending





	Carbon steel	Duplex stainless steel
Material	S355	EN 1.4162
f_y [N/mm²]	355	450
E [N/mm²]	210000	200000

Eurocode 3 Lateral torsional buckling example

EC 3-1-1: S355

- Classification

$$\varepsilon = \sqrt{\frac{235}{f_y}} = 0{,}81$$

  - Flange

    $c/t = 6{,}78 < 7{,}3 = 9\varepsilon$

    Class 1
  - Web

    $c/t = 45{,}3 < 58{,}3 = 72\varepsilon$

    Class 1

Cross-section = class 1

EC 3-1-4: Duplex

- Classification

$$\varepsilon = \sqrt{\frac{235}{f_y}\,\frac{E}{210000}} = 0{,}71$$

  - Flange

    $c/t = 6{,}78 < 7{,}76 = 11\varepsilon$

    Class 3
  - Web

    $c/t = 45{,}3 < 58{,}3 = 72\varepsilon$

    Class 3

Cross-section = class 3

Eurocode 3 Lateral torsional buckling example

EC 3-1-1: S355

- Ultimate moment
  - *Class 1*

$$M_{c,Rd} = \frac{W_{pl}.f_y}{\gamma_{M0}} = 196\ kNm$$

EC 3-1-4: Duplex

- Ultimate moment
  - Class 3

$$M_{c,Rd} = \frac{W_{el}.f_y}{\gamma_{M0}} = 202\ kNm$$

Revision EC 3-1-4:

- Classification limits: closer to carbon steel
  - Cross-section = class 2

$$M_{c,Rd} = \frac{W_{pl}.f_y}{\gamma_{M0}} = 226\ kNm$$

Eurocode 3 Lateral torsional buckling example

Elastic critical buckling moment:

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{(k_z L)^2} \left\{ \sqrt{\left[\left(\frac{k_z}{k_\omega} \right)^2 \frac{I_\omega}{I_z} + \frac{(k_z L)^2 G I_T}{\pi^2 E I_z} + \left(C_2 z_g \right)^2 \right]} - C_2 z_g \right\}$$

	EC 3-1-1: S355	EC 3-1-4: duplex
C_1 [-]	1,04	1,04
C_2 [-]	0,42	0,42
k_z [-]	1	1
k_w [-]	1	1
z_g [mm]	160	160
I_z [mm^4]	$5{,}6.10^6$	$5{,}6.10^6$
I_T [mm^4]	$1{,}2.10^5$	$1{,}2.10^5$
I_w [mm^6]	$1{,}2.10^{11}$	$1{,}2.10^{11}$
E [MPa]	210000	200000
G [MPa]	81000	77000
M_{cr} [kNm]	**215**	**205**

Eurocode 3 Lateral torsional buckling example

Lateral torsional buckling resistance

	EC 3-1-1: S355	EC 3-1-4: Duplex	EC 3-1-4: Future revision
W_y [mm³]	**5,5.10⁵**	**4,9.10⁵**	**5,5.10⁵**
f_y [N/mm²]	355	450	450
M_{cr} [kNm]	215	205	205
$\bar{\lambda}_{LT}$ [-]	0,96	1,04	1,10
α_{LT} [-]	0,49	0,76	0,76
$\bar{\lambda}_{LT,0}$ [-]	0,2	0,4	0,4
ϕ_{LT} [-]	1,14	1,29	1,37
χ_{LT} [-]	0,57	0,49	0,46
γ_{M1} [-]	1,0	1,1	1,1
$M_{b,Rd}$ [kNm]	**111**	**99**	**103**

Eurocode 3 Lateral torsional buckling example

- Comparison

	EC 3-1-1: S355	EC 3-1-4: Duplex	EC 3-1-4: Future revision
f_y [N/mm²]	355	450	450
γ_{M0} [-]	1,0	1,1	1,1
γ_{M1} [-]	1,0	1,1	1,1
Cross-section $M_{c,Rd}$	196	202	226
Stability $M_{b,Rd}$	111	99	103

  - In this example, cs and ss show similar resistance to LTB
  - However: Current tests and literature show that the EC3-1-4 results should be adapted to be closer to reality
    ⇒ **too conservative**
    (This will be shown in the example on finite element methods)

Section 4

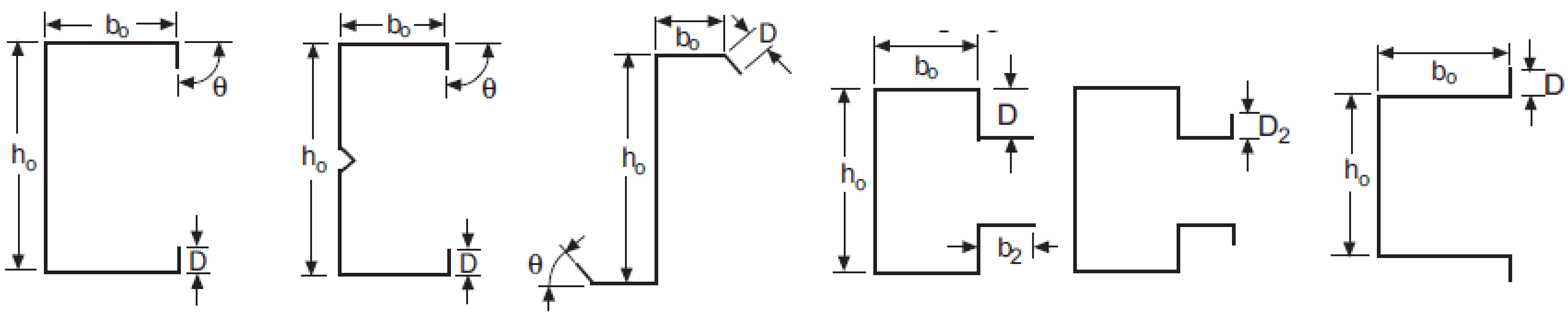
Alternative methods

Alternative methods

- Direct strength method (DSM)
  - Part of the American code
  - For thin-walled profiles
- Continuous strength method (CSM)
  - Includes the beneficial effects of strain hardening
- Finite element methods
  - More tedious
  - Can include all the specificities of the model

Direct strength method

- AISI Appendix 1
- Very simple and straightforward method
- Used for thin-walled sections

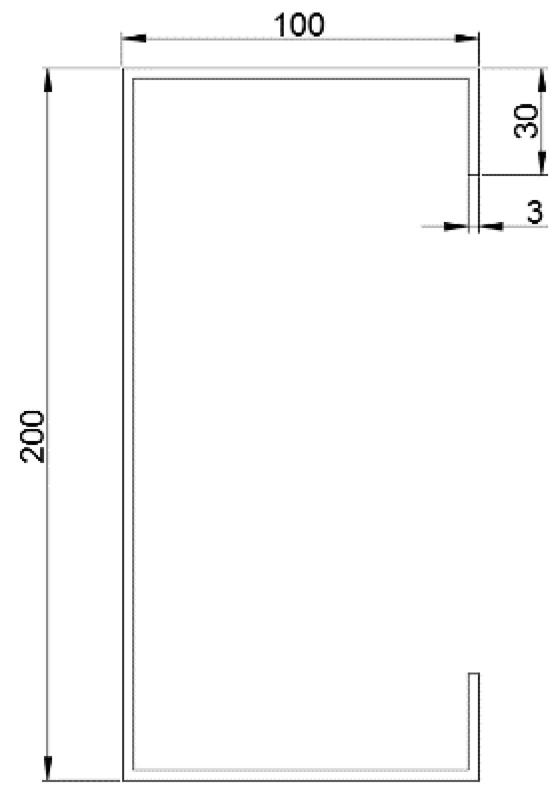


- But requires an “Elastic buckling analysis”
  - Theoretical method provided in the literature
  - Finite strip method (for example CUFSM)
- More info : http://www.ce.jhu.edu/bschafer/

Direct strength method – example

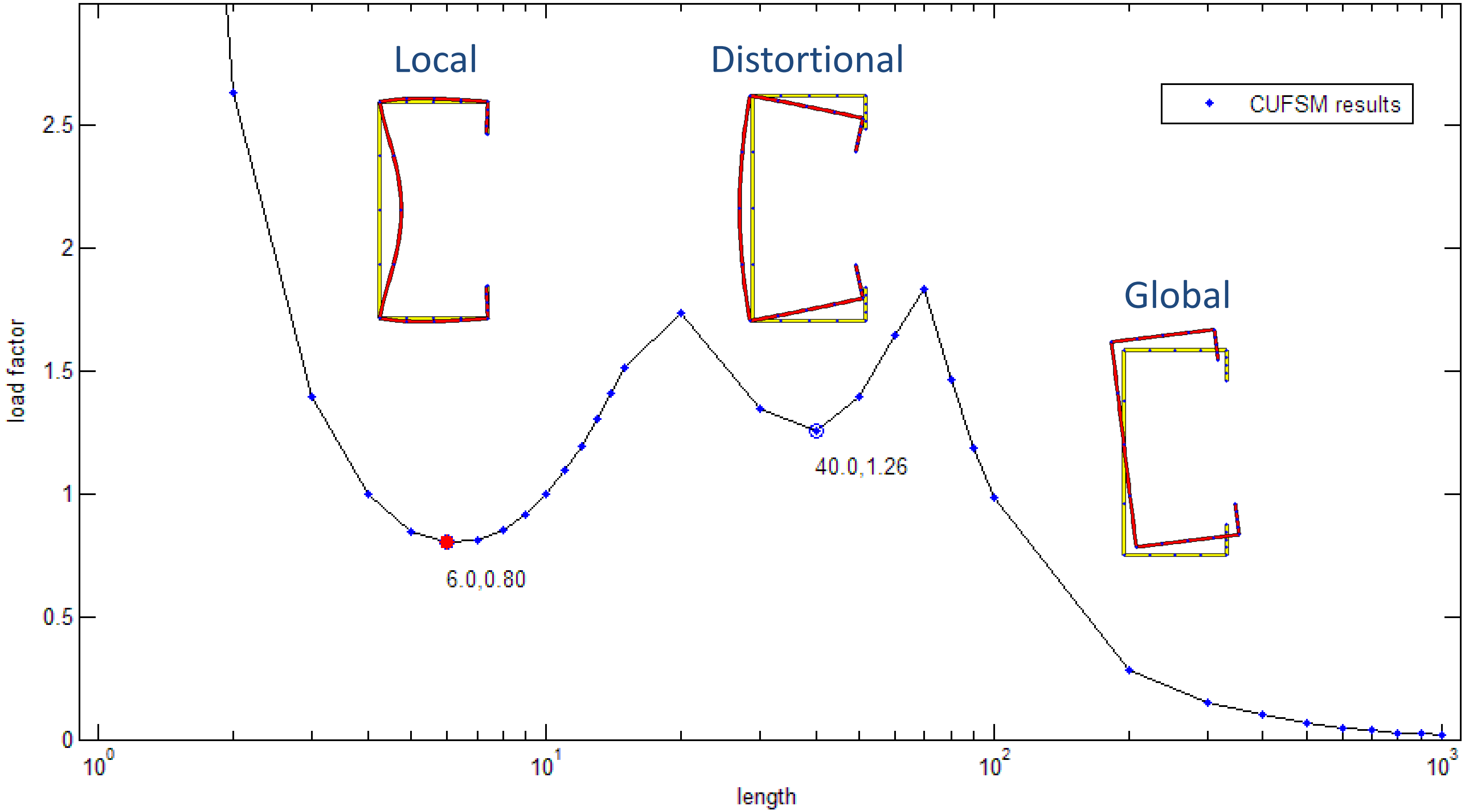
- Lipped C-channel submitted to compression
  - Simply supported column
  - Column length: 5m

	Ferritic stainless steel
Material	EN 1.4003
f_y [N/mm²]	280
f_u[N/mm²]	450
E [N/mm²]	220000



Direct strength method example

- First step: Elastic buckling analysis



Direct strength method – example

- Output of the analysis = "Elastic critical buckling load"
  - In the example, the load factor from elastic buckling analysis equals:
    - For local buckling: 0,80
    - For distortional buckling: 1,26
    - For global buckling: 0,28
- Second step: Calculation of the nominal strengths for
    - Local buckling ⇨ one equation
    - Distortional buckling ⇨ one equation
    - Global buckling ⇨ one equation

Direct strength method example

- Nominal global buckling strength P_{ne}
  - $\lambda_c = \sqrt{P_y / P_{cre}} = 1{,}88$
  - $P_y = Af_y = 376 \text{ kN}$
  - $P_{cre} = 0{,}28 * 376 = 107\ kN$

For $\lambda_c \leq 1{,}5$ $\quad P_{ne} = \left(0{,}658^{\lambda_c^2}\right) P_y$

For $\lambda_c > 1{,}5$ $\quad P_{ne} = \left(\frac{0{,}877}{\lambda_c^2}\right) P_y$

- $P_{ne} = 93{,}81\ kN$

Direct strength method example

- Nominal local buckling strength P_{nl}
  - $\lambda_l = \sqrt{P_{ne}/P_{crl}} = 0{,}56$
  - $P_{crl} = 0{,}80 * 376 = 302\ kN$

For $\lambda_l \leq 0{,}776$ $\qquad P_{nl} = P_{ne}$

For $\lambda_l > 0{,}776$ $\qquad P_{nl} = \left[1 - 0{,}15\left(\frac{P_{crl}}{P_{ne}}\right)^{0{,}4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0{,}4} P_{ne}$

- $P_{nl} = 93{,}81\ kN$

Direct strength method example

- Nominal distortional buckling strength P_{nd}
  - $\lambda_d = \sqrt{P_y / P_{crd}} = 0{,}89$
  - $P_{crd} = 1{,}26 * 376 = 473\ kN$

For $\lambda_d \leq 0{,}561$ $\qquad P_{nd} = P_y$

For $\lambda_d > 0{,}561$ $\qquad P_{nd} = \left[1 - 0{,}25\left(\frac{P_{crd}}{P_y}\right)^{0{,}6}\right]\left(\frac{P_{crd}}{P_y}\right)^{0{,}6} P_y$

- $P_{nd} = 344{,}56\ kN$

Direct strength method – example

- Third step : The axial resistance is "just" the minimum of the three nominal strengths

  - Local: P_{nl} = 93,81 kN
  - Distortional: P_{nd} = 344,56 kN
  - Global: P_{ne} = 93,81 kN

$$\Rightarrow P_n = 93{,}81 \text{ kN}$$

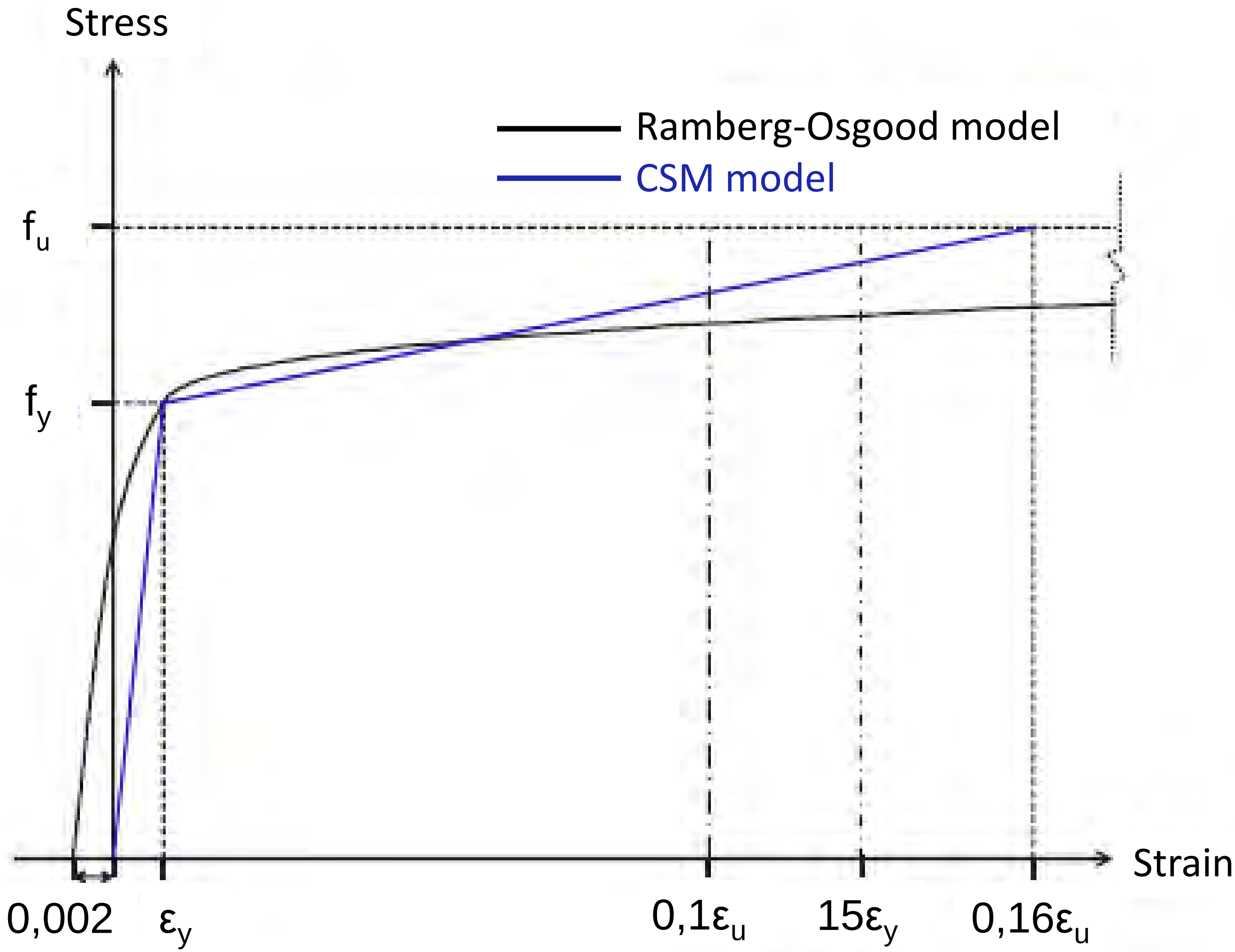
Continuous strength method

- Stainless steel material characteristics:
  - Non-linear material model
  - High train hardening
  - Conventional design methods not able to take into account the full potential of the cross-section

The Continuous strength method uses a material model which includes strain hardening

Continuous strength method

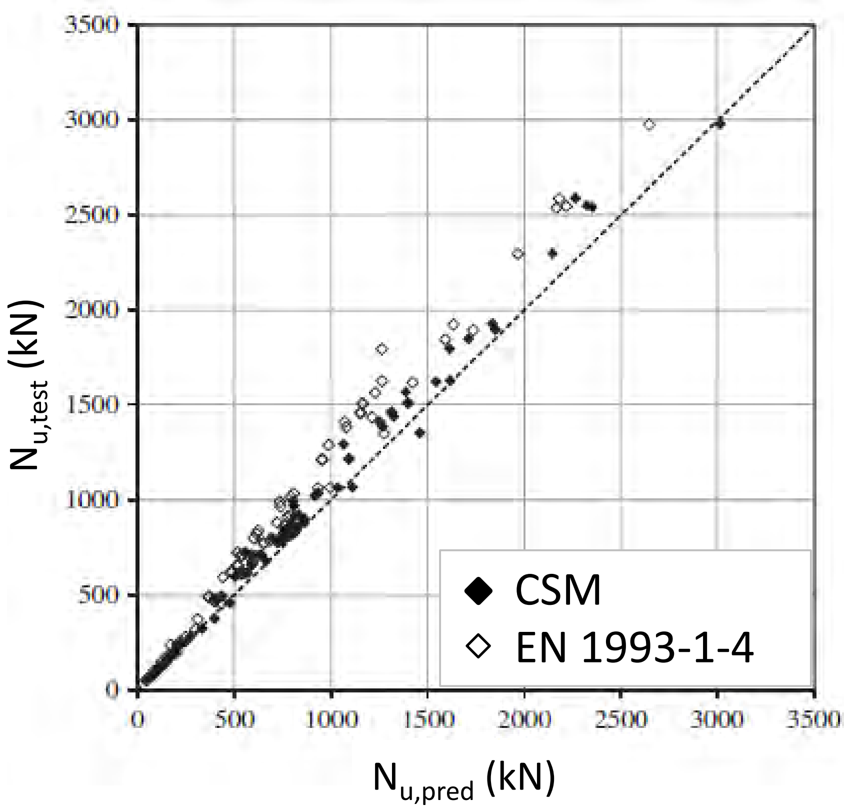
- Material model considered in the CSM:



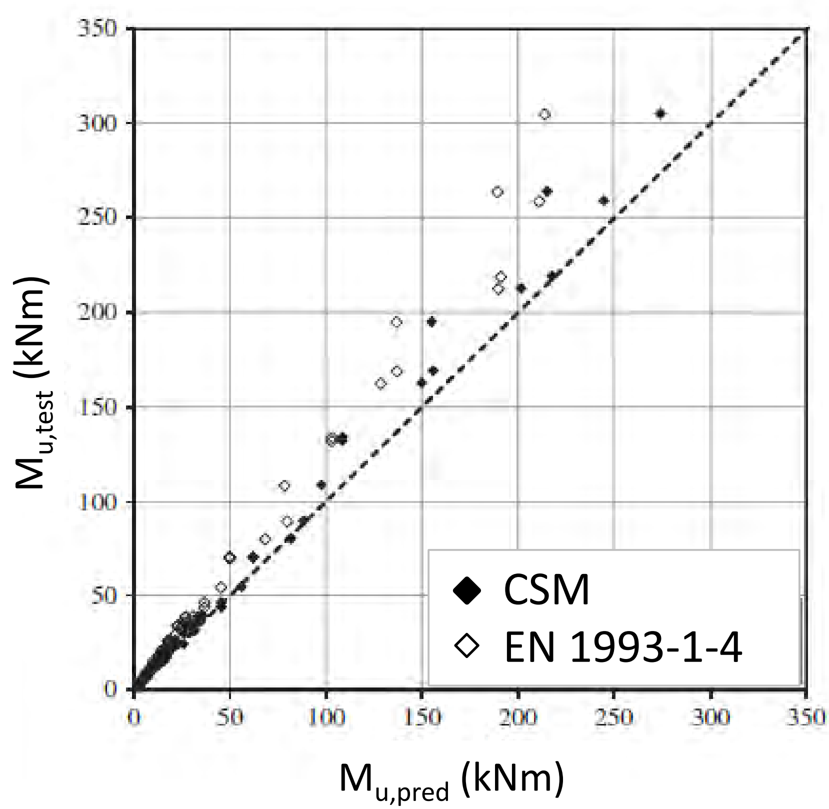
Continuous strength method

- Comparison between EC3 and CSM predictions versus tests:

In compression



In bending

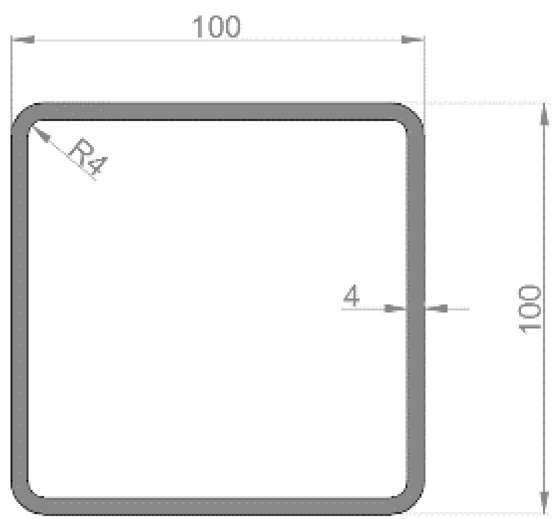


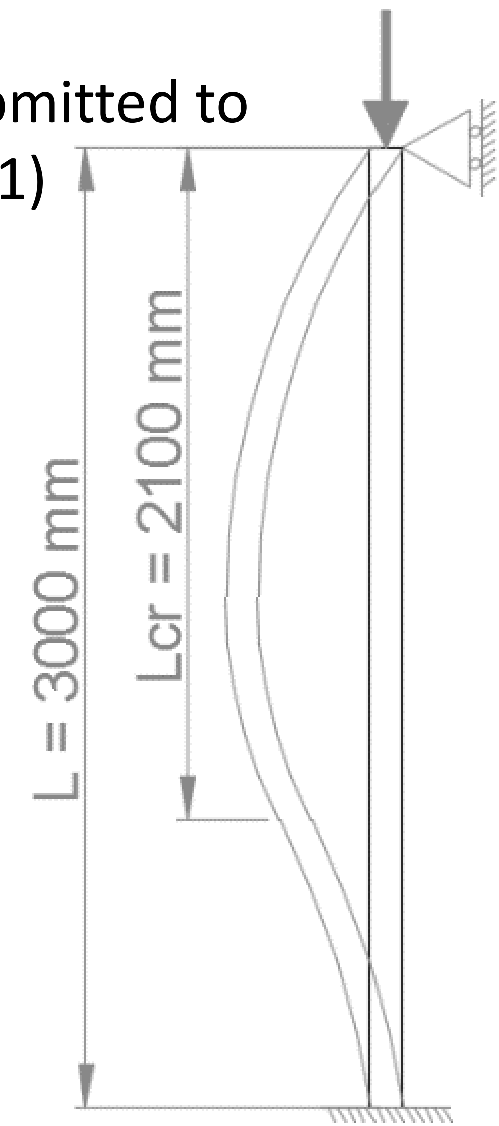
The CSM is able to accurately capture the cross-section behaviour

CSM: Flexural buckling example

- Cold formed rectangular hollow section submitted to concentric compression (example of slide 51)

	Austenitic stainless steel
Material	EN 1.4301
f_y [N/mm²]	230
E [N/mm²]	200000





CSM: flexural buckling example

$f_y = 230 \, {}^{N}/_{mm^2}$

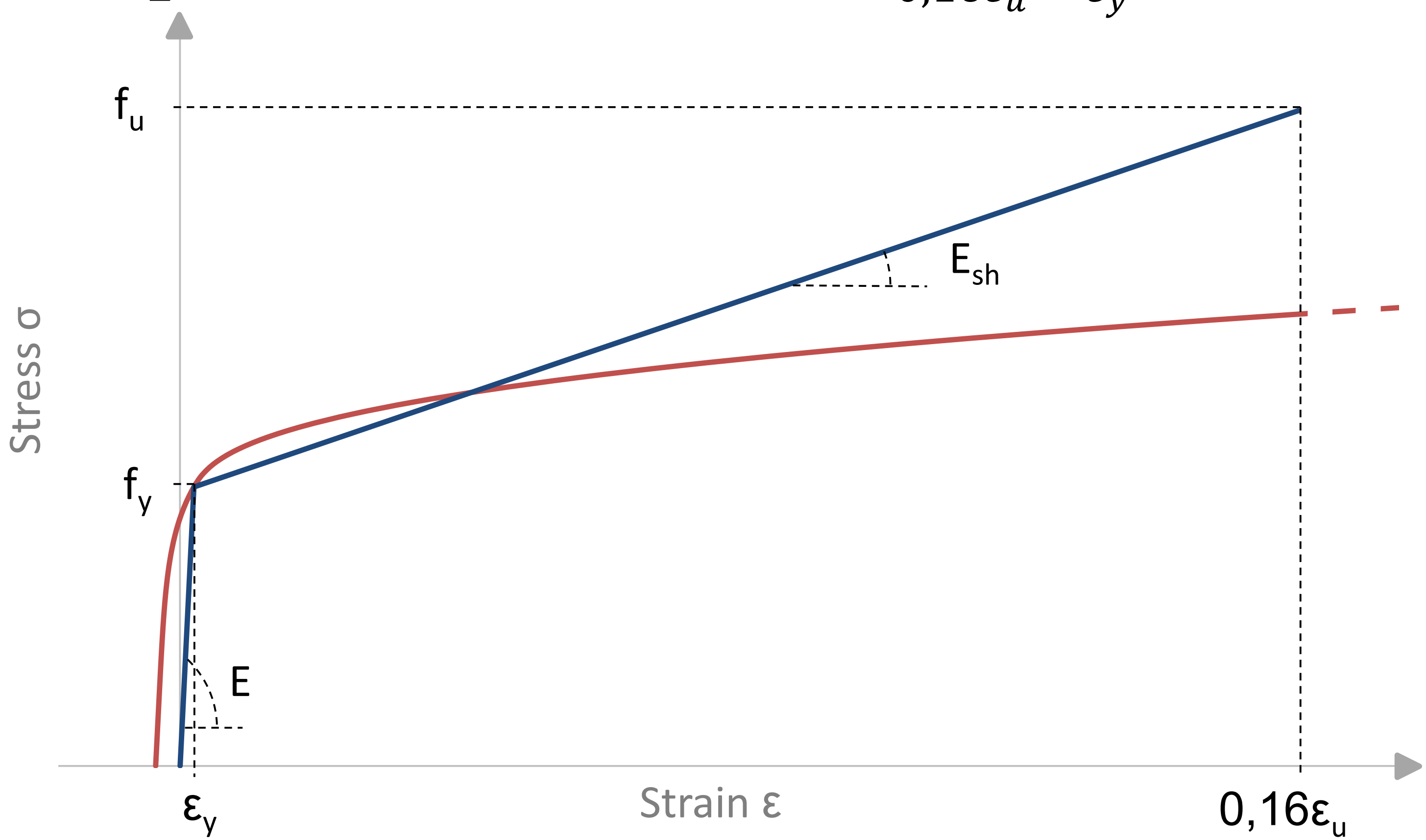
$E = 200000 \, {}^{N}/_{mm^2}$

$\varepsilon_y = {}^{f_y}/_{E} = 0{,}0012$

$f_u = 540 \, {}^{N}/_{mm^2}$

$0{,}16\varepsilon_u = 0{,}16(1 - {}^{f_y}/_{f_u}) = 0{,}0919$

$$E_{sh} = \frac{f_u - f_y}{0{,}16\varepsilon_u - \varepsilon_y} = 3418 \, {}^{N}/_{mm^2}$$



CSM: flexural buckling example

$f_y = 230 \, {}^{N}/_{mm^2}$

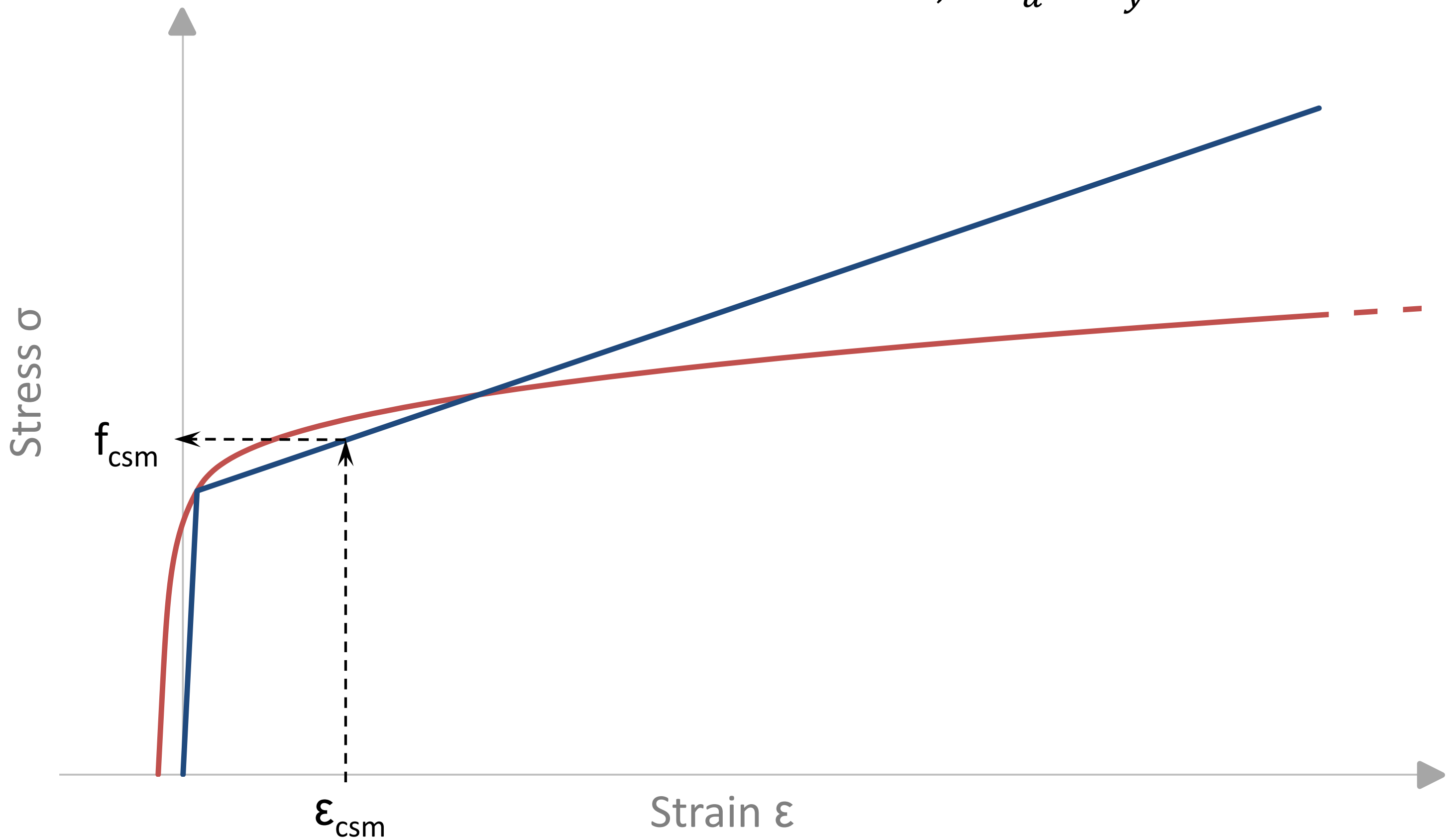
$E = 200000 \, {}^{N}/_{mm^2}$

$\varepsilon_y = {}^{f_y}/_{E} = 0{,}0012$

$f_u = 540 \, {}^{N}/_{mm^2}$

$0{,}16\varepsilon_u = 0{,}16(1 - {}^{f_y}/_{f_u}) = 0{,}0919$

$E_{sh} = \dfrac{f_u - f_y}{0{,}16\varepsilon_u - \varepsilon_y} = 3418 \, {}^{N}/_{mm^2}$



CSM: flexural buckling example

- $\bar{\lambda}_p = \sqrt{\frac{f_y}{\sigma_{cr,cs}}} = 0{,}60$
  - $\sigma_{cr,cs}$= elastic buckling stress of the full cross-section allowing for element interaction
- $\frac{\varepsilon_{csm}}{\varepsilon_y} = \frac{0{,}25}{\bar{\lambda}_p^{\;3{,}6}} = 5{,}27$
- $f_{csm} = f_y + E_{sh}\varepsilon_y\left(\frac{\varepsilon_{csm}}{\varepsilon_y} - 1\right) = 247\ {}^{N}/_{mm^2}$
- $N_{c,Rd} = \frac{Af_{csm}}{\gamma_{M0}} = 335\ kN$

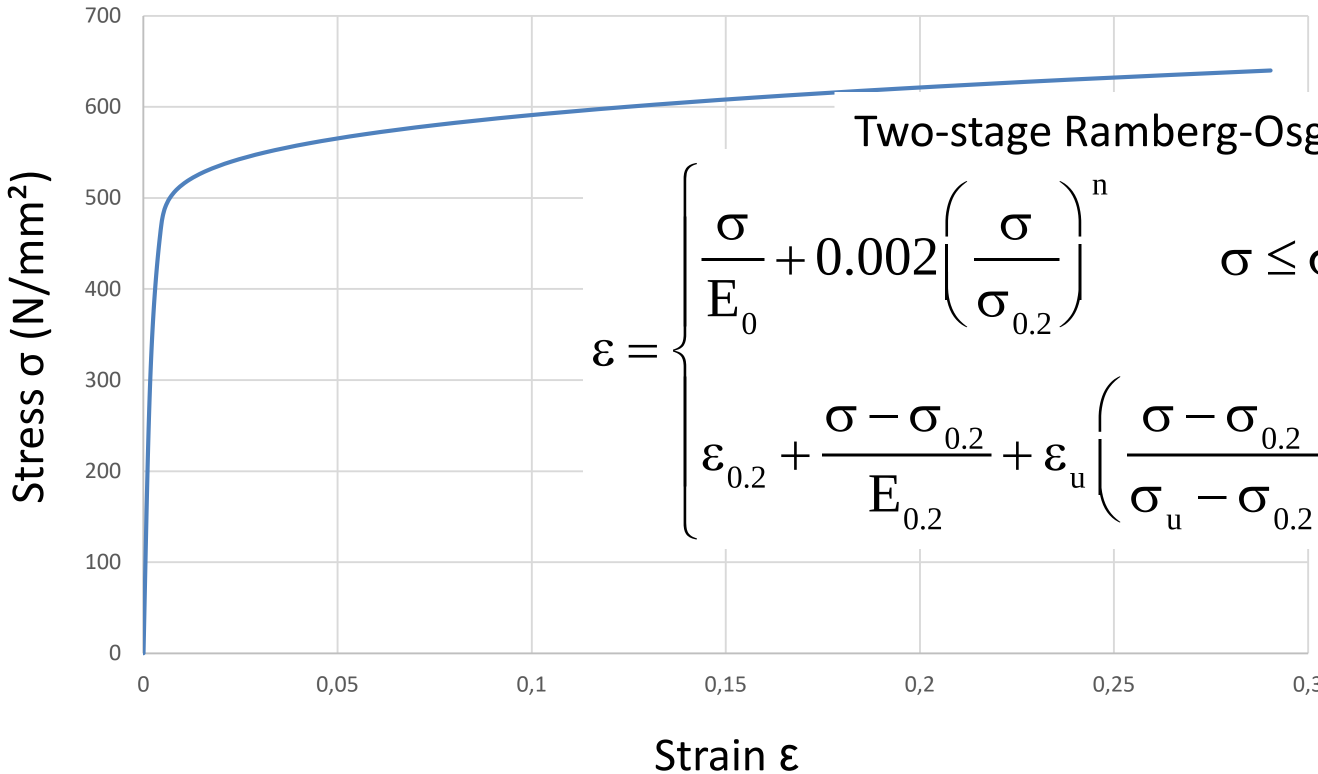
CSM: flexural buckling example

- $\bar{\lambda} = \sqrt{\frac{Af_{csm}}{N_{cr}}} = 0{,}60$
- $N_{b,Rd} = \chi \frac{Af_{csm}}{\gamma_{M1}} = 294\ kN$

	EC 3-1-1: S235	CSM: Austenitic	EC 3-1-4: Austenitic
f_y [N/mm²]	235	230	230
γ_{M0} [-]	1,0	1,1	1,1
γ_{M1} [-]	1,0	1,1	1,1
Cross-section $N_{c,Rd}$ [kN]	**351**	**335**	**313**
Stability $N_{b,Rd}$[kN]	**281**	**294**	**277**

Finite element model

- The material stress-strain curve can be accurately modeled (for example by using Ramberg-osgood material law or “real” measured tensile coupon tests results)



Two-stage Ramberg-Osgood model:

$$\varepsilon = \begin{cases} \frac{\sigma}{E_0} + 0.002\left(\frac{\sigma}{\sigma_{0.2}}\right)^n & \sigma \le \sigma_{0.2} \\ \varepsilon_{0.2} + \frac{\sigma - \sigma_{0.2}}{E_{0.2}} + \varepsilon_u\left(\frac{\sigma - \sigma_{0.2}}{\sigma_u - \sigma_{0.2}}\right)^m & \sigma > \sigma_{0.2} \end{cases}$$

Finite element model

- The nonlinear parameters are given by the following expressions (according to Rasmussen's revision):

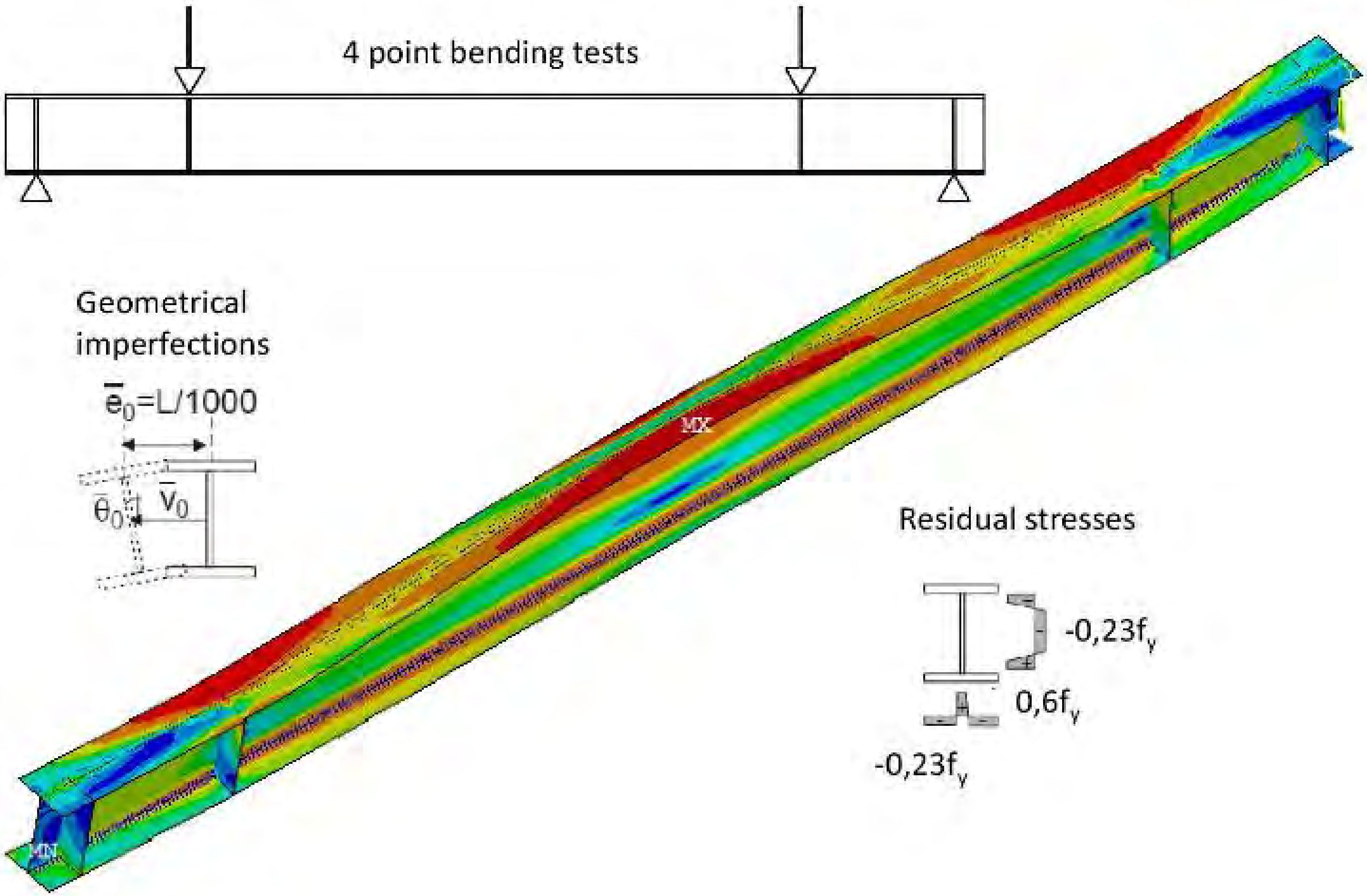
$$n = \frac{\ln(20)}{\ln\left(\frac{\sigma_{0.2}}{\sigma_{0.01}}\right)} \qquad m = 1 + 3.5\frac{\sigma_{0.2}}{\sigma_u} \qquad E_{0.2} = \frac{E_0}{1 + 0.002n\frac{E_0}{\sigma_{0.2}}}$$

$$\varepsilon_u = 1 - \frac{\sigma_{0.2}}{\sigma_u}$$

$$\frac{\sigma_{0.2}}{\sigma_u} = \begin{cases} 0.2 + 185\frac{\sigma_{0.2}}{E_0} & \text{for austenitic and duplex} \\ \dfrac{0.2 + 185\frac{\sigma_{0.2}}{E_0}}{1 - 0.0375(n-5)} & \text{for all stainless steel alloys} \end{cases}$$

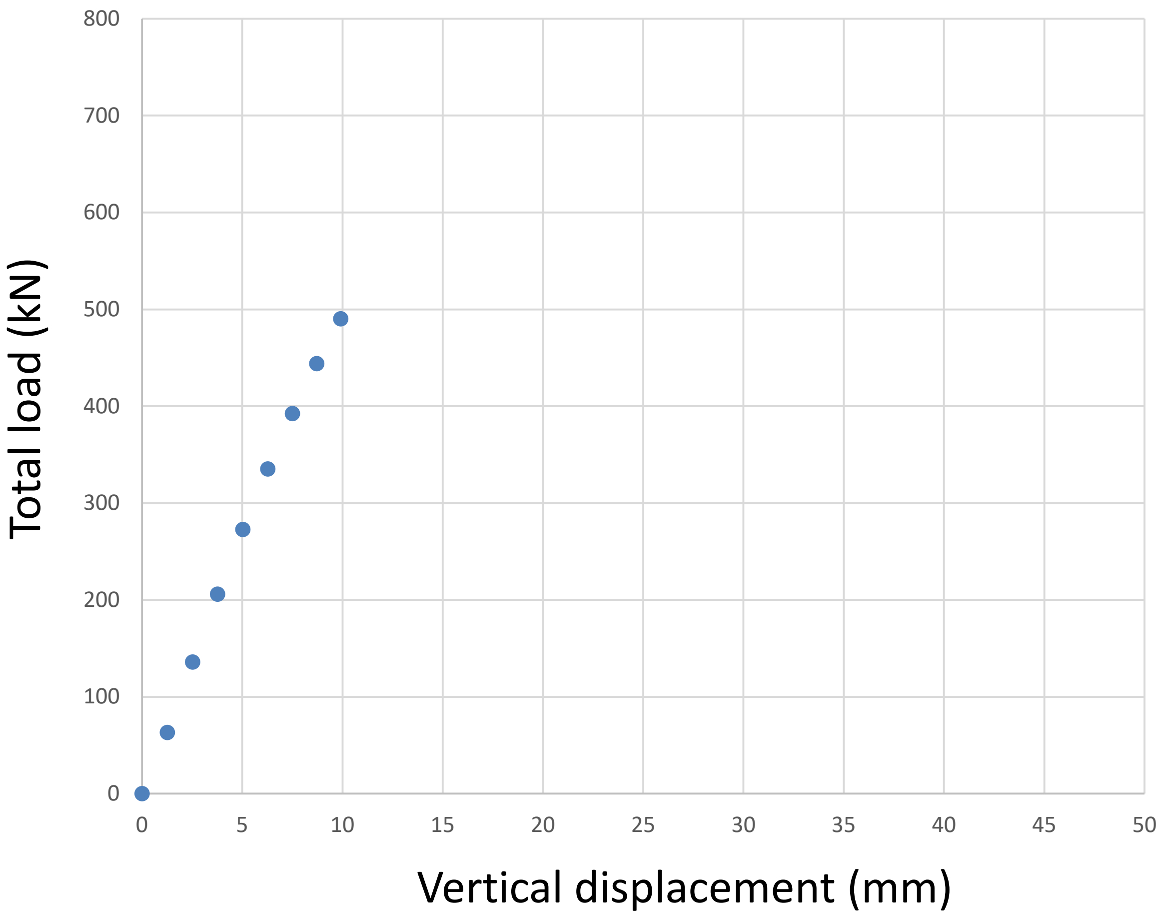
Finite element model

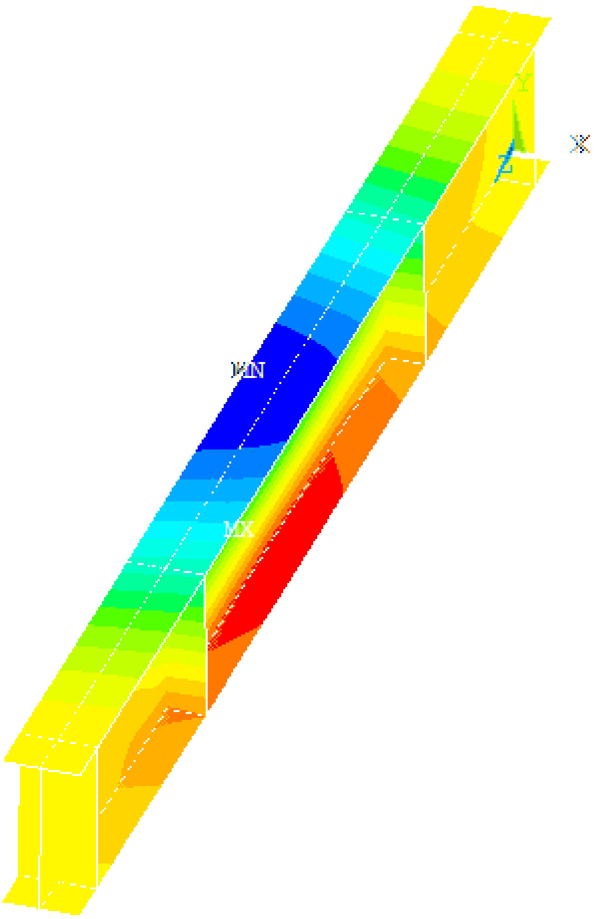
- I-shaped beam submitted to bending suffering lateral torsional buckling : all imperfections can be modelled



Finite element model

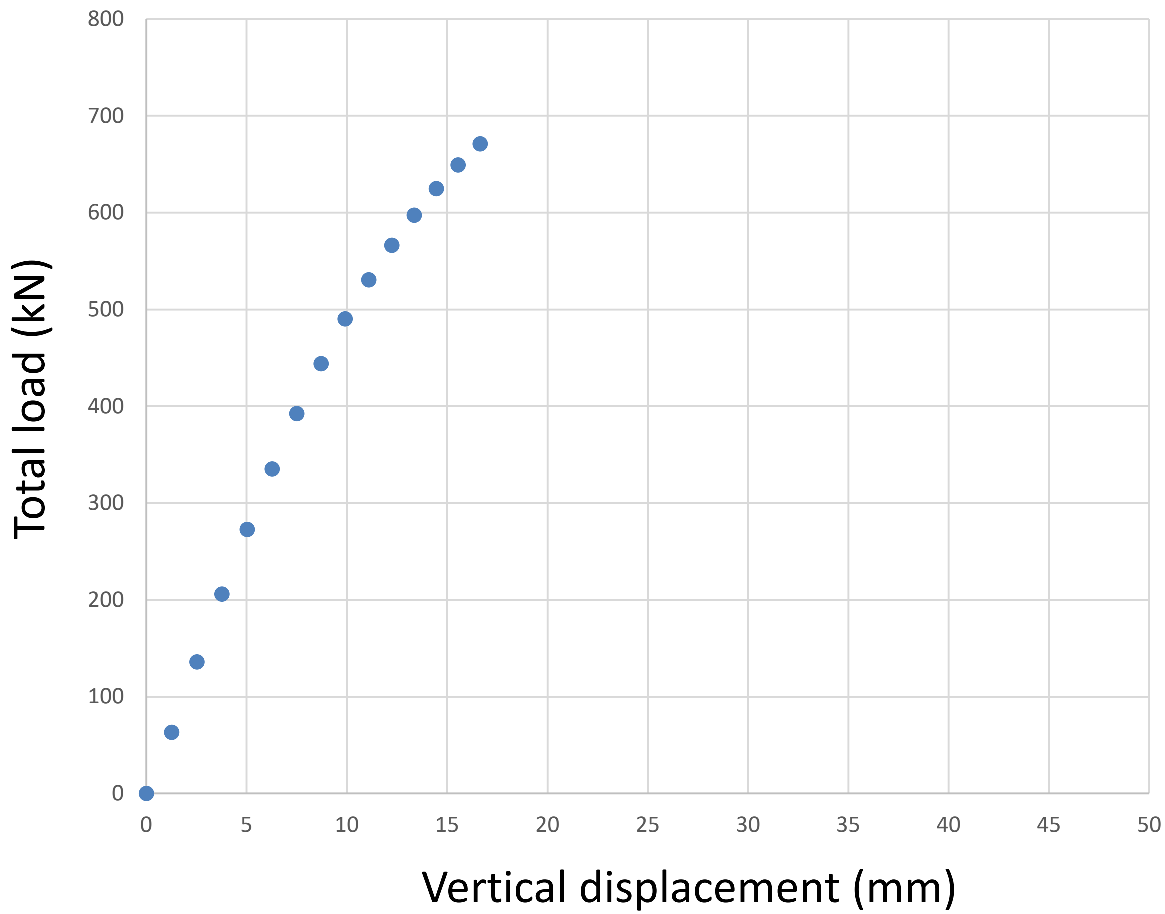
- The load-deflections curve can be calculated
  - Results: elastic behaviour and first yielding

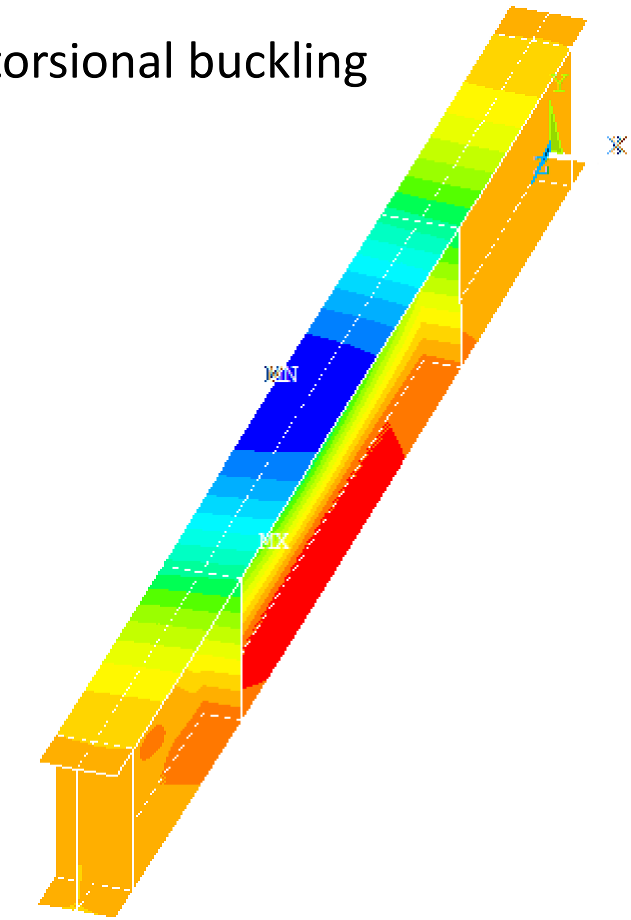




Finite element model

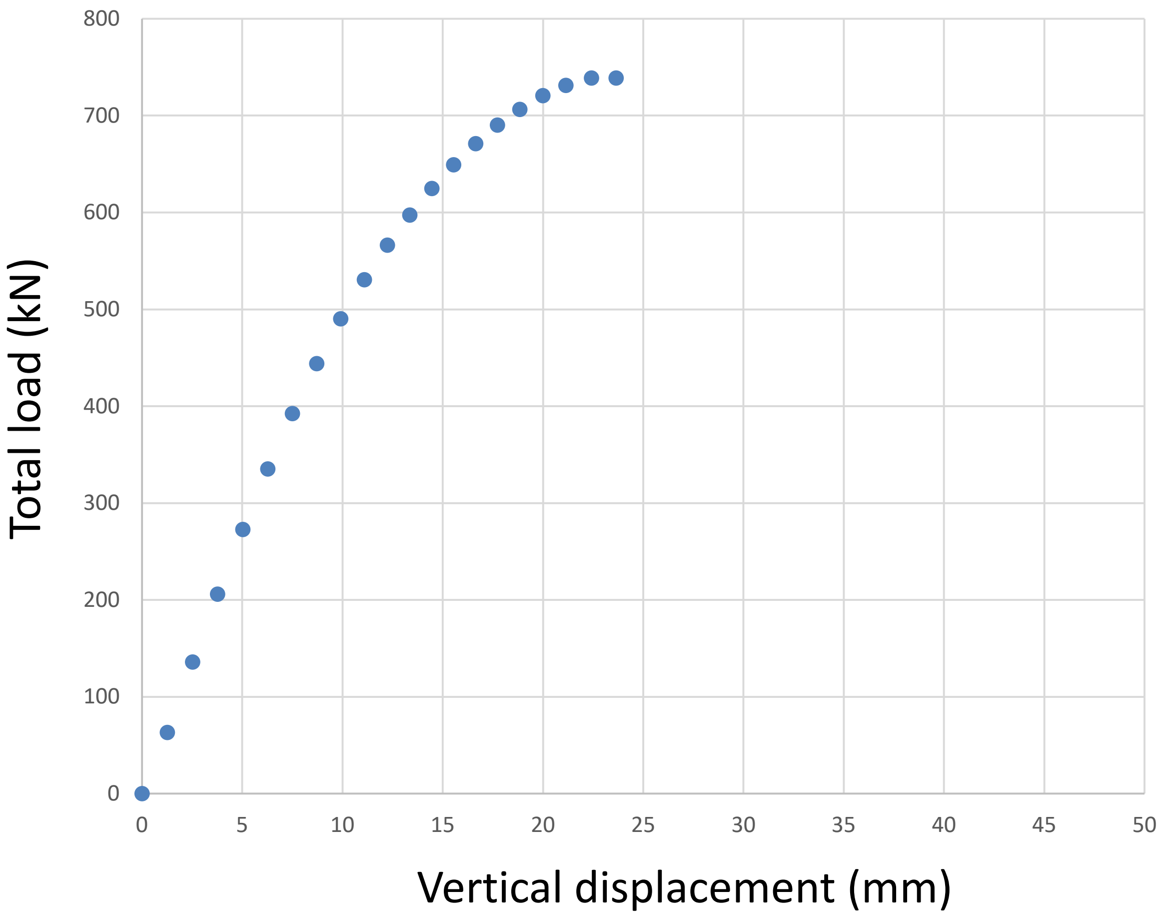
- The load-deflections curve can be calculated
  - Results: instability phenomenon => Lateral torsional buckling

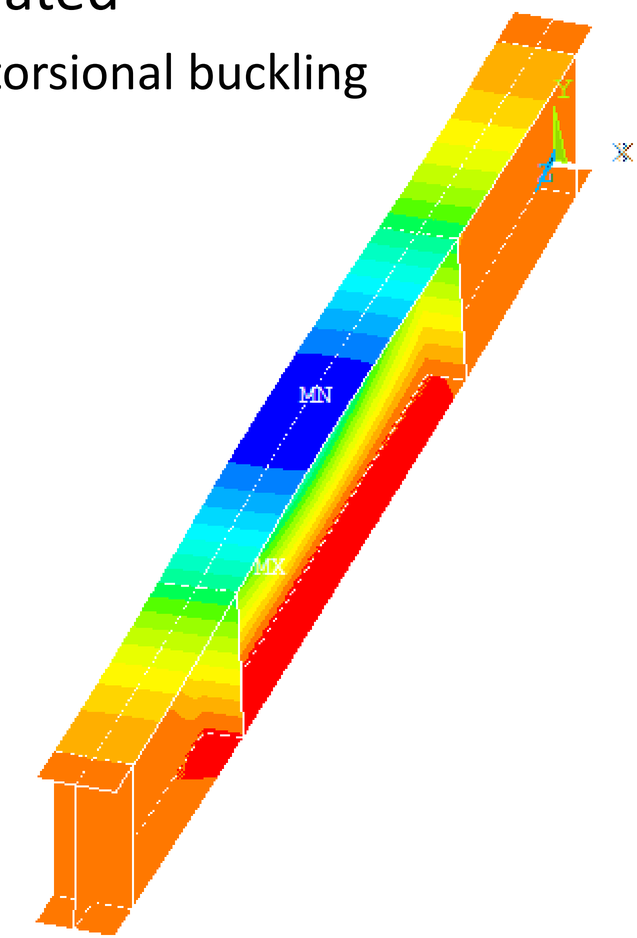




Finite element model

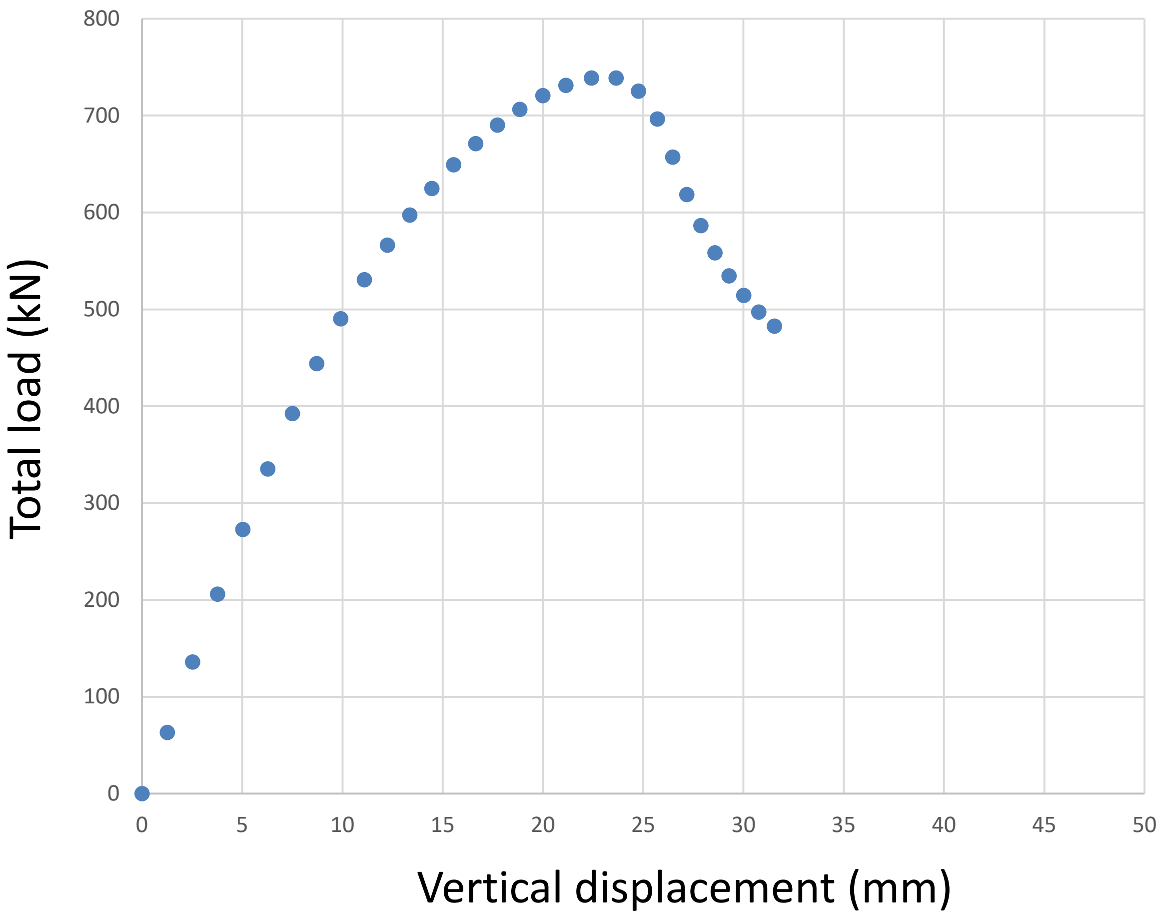
- The load-deflections curve can be calculated
  - Results: instability phenomenon => Lateral torsional buckling

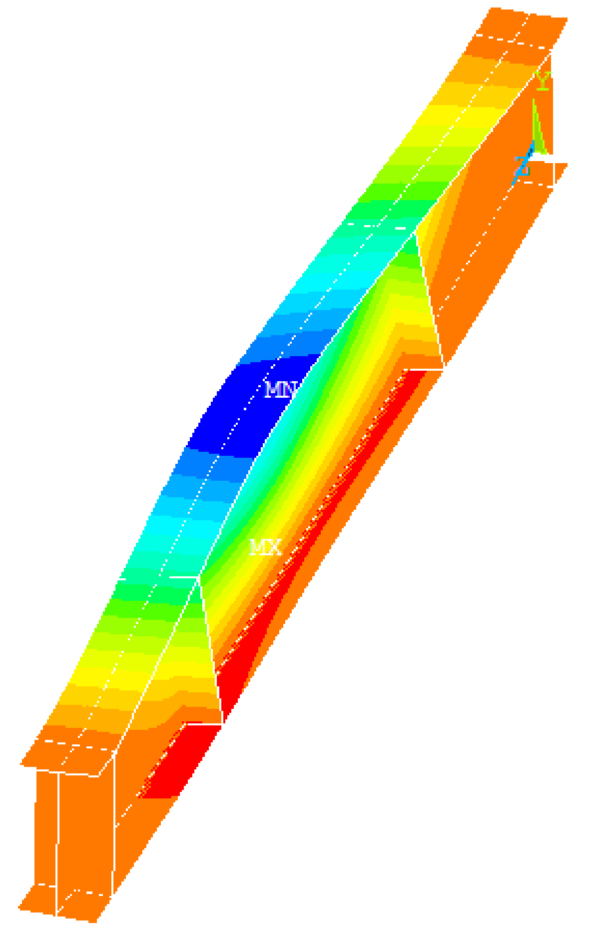




Finite element model

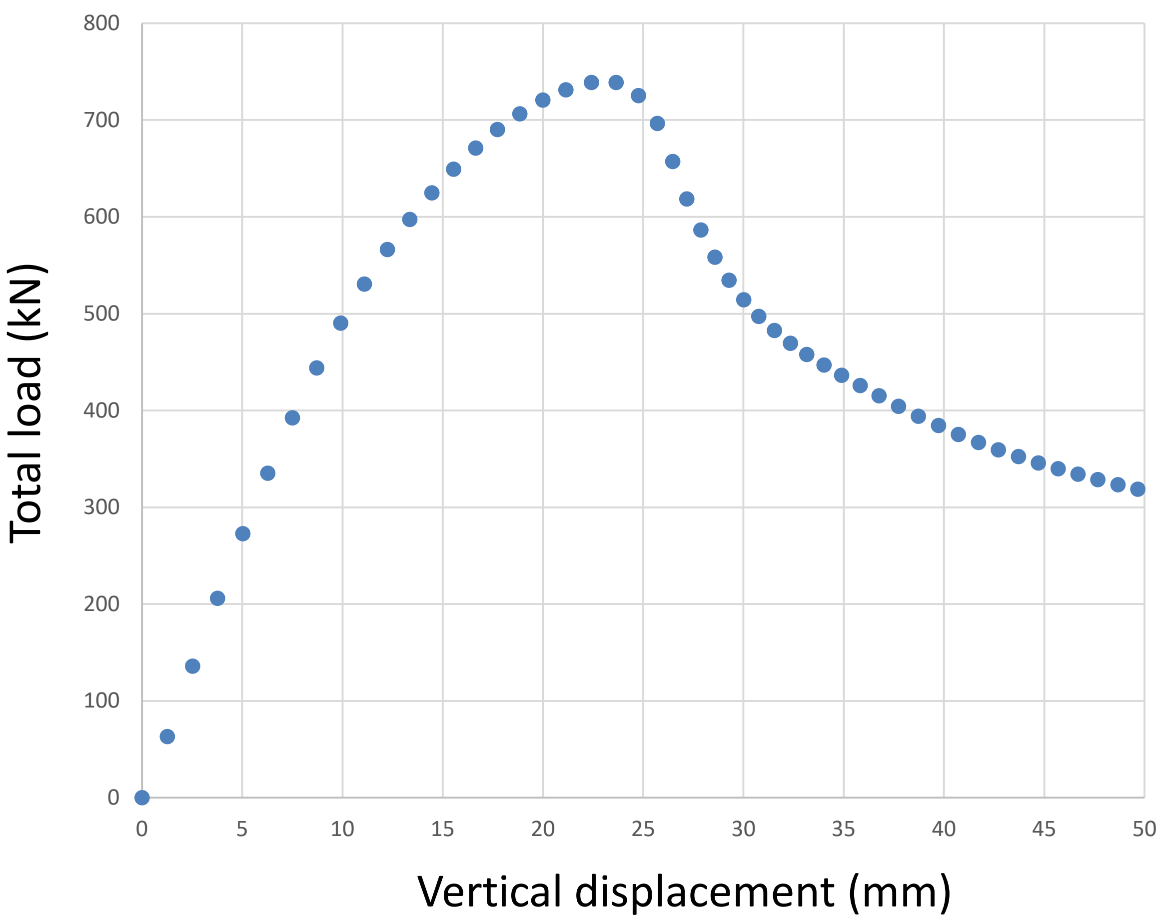
- The load-deflections curve can be calculated
  - Results: post buckling behaviour

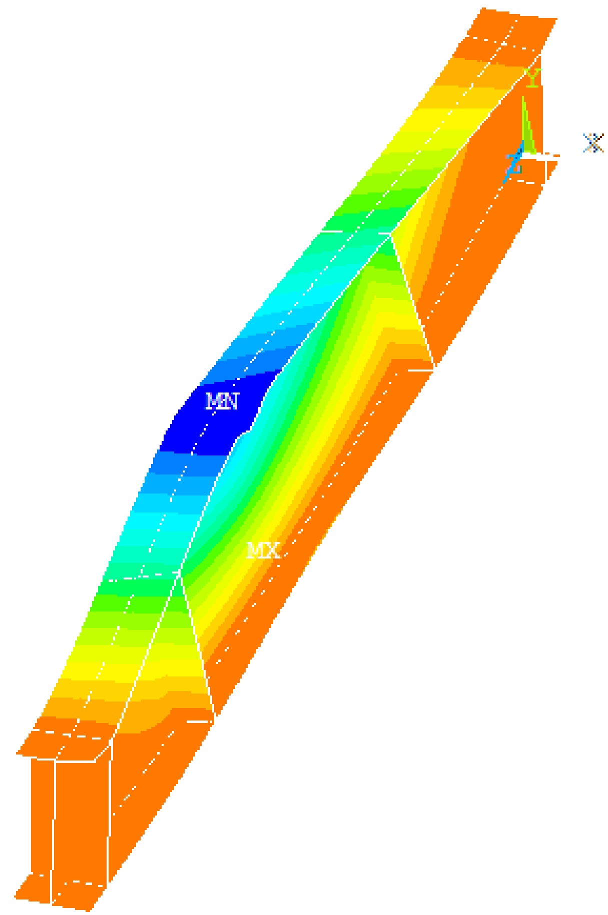




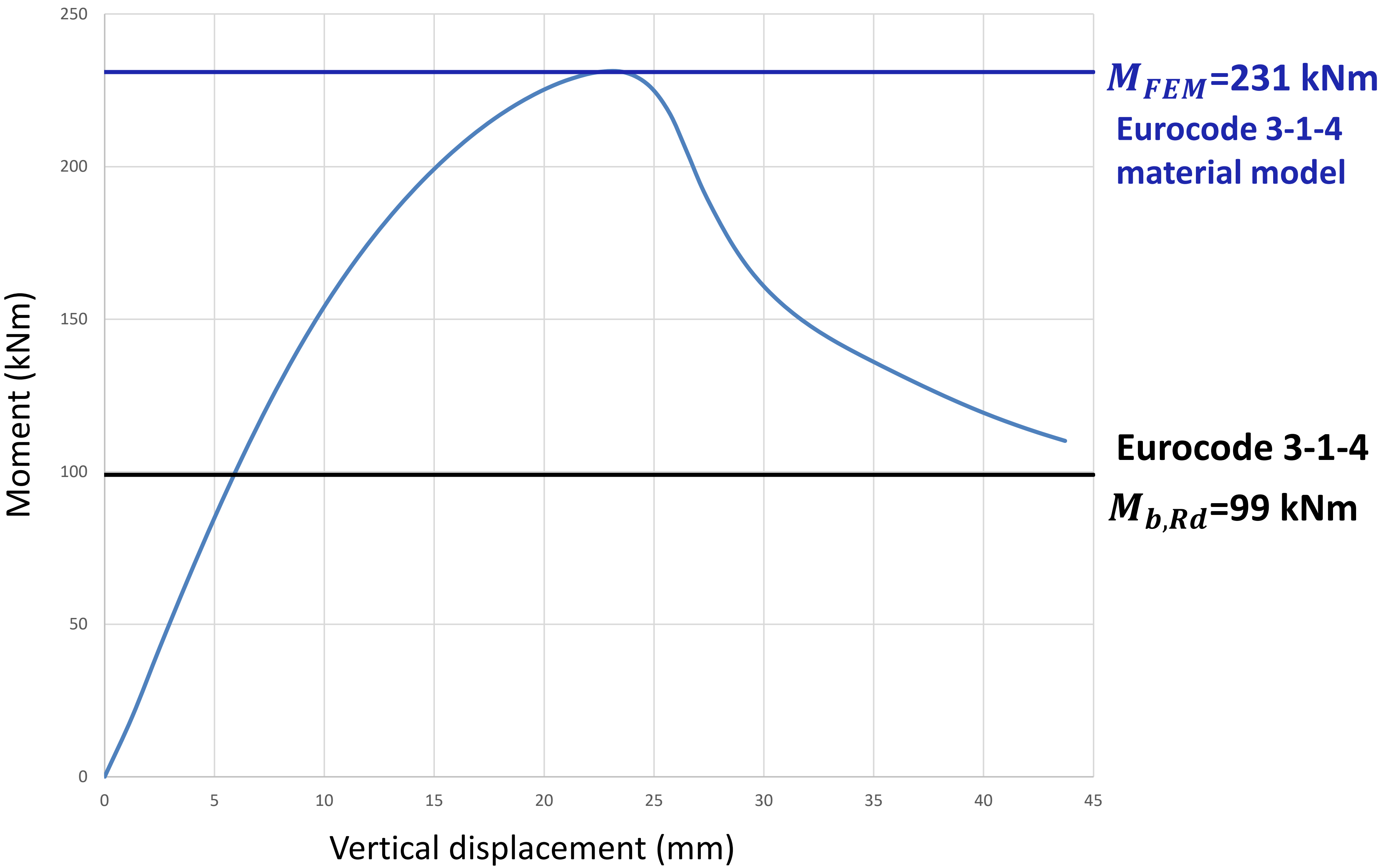
Finite element model

- The load-deflections curve can be calculated
  - Results: post buckling behaviour

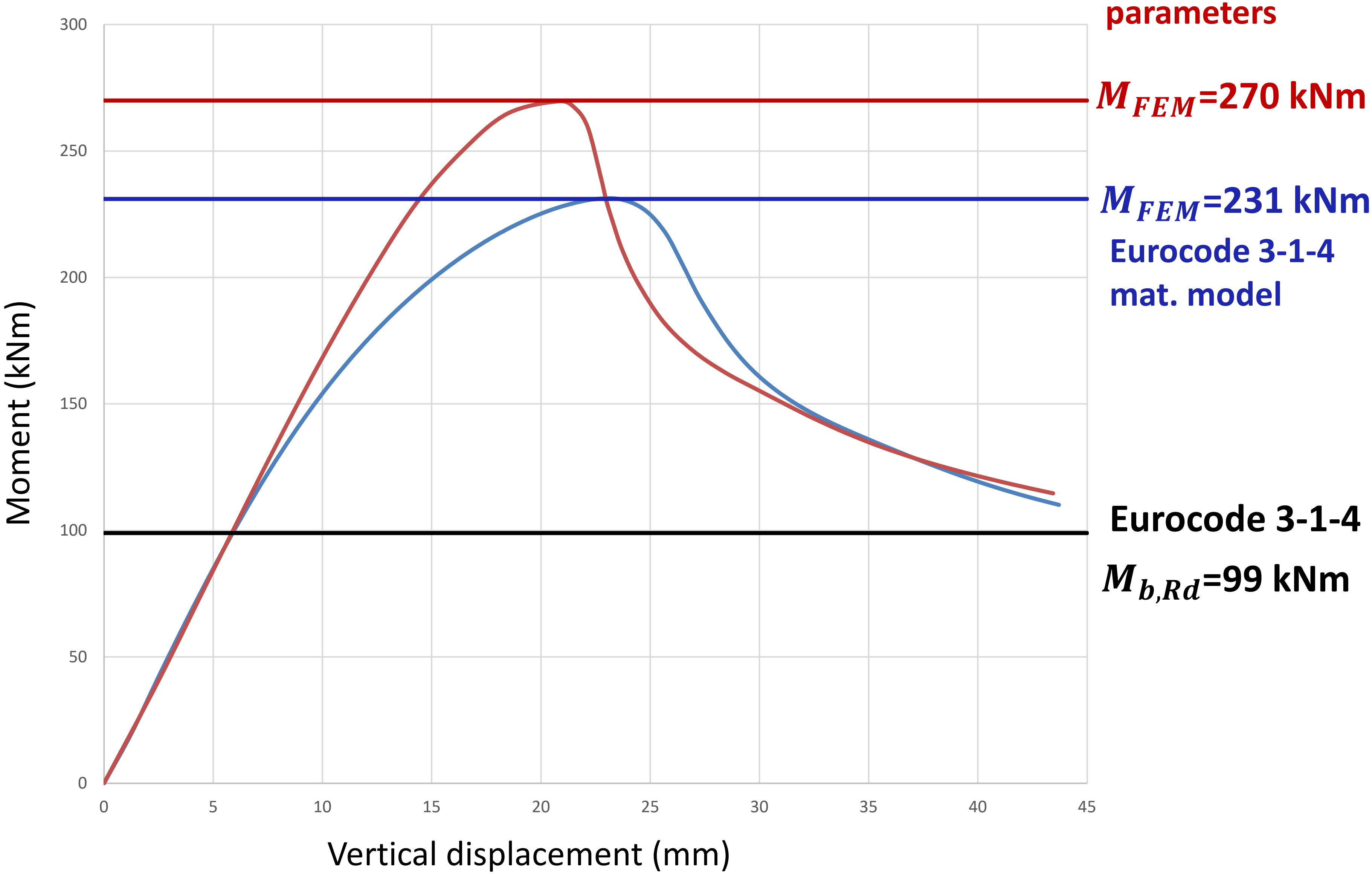




Finite element model



Finite element model



Section 5

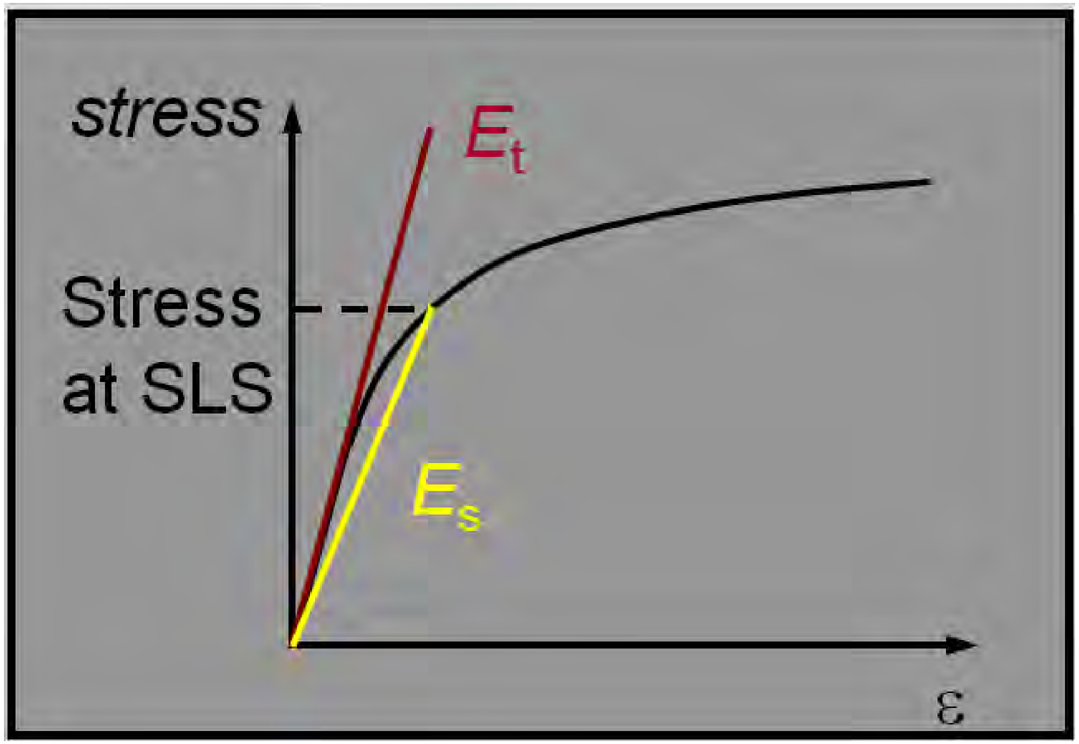
Deflections

Deflections

- Non-linear stress-strain curve means that stiffness of stainless steel ↓ as stress ↑
- Deflections are slightly greater in stainless steel than in carbon steel
- Use secant modulus at the stress in the member at the serviceability limit state (SLS)

Deflections

Secant modulus E_S for the stress in the member at the SLS



Deflections

Secant modulus ES determined from the Ramberg-Osgood model:

$$E_S = \frac{E}{1 + 0.002 \frac{E}{f} \left(\frac{f}{f_y} \right)^n}$$

f is stress at serviceability limit state

n is a material constant

Deflections in an austenitic stainless steel beam

Stress ratio f/f_y	Secant modulus, E_S N/mm^2	% increase in deflection
0.25	200,000	0
0.5	192,000	4
0.7	158,000	27

f = stress at serviceability limit state

Section 6

Additional information

Response to seismic loading

- Higher ductility (austenitic ss) + sustains more load cycles
  → greater hysteretic energy dissipation under cyclic loading
- Higher work hardening
  → enhances development of large & deformable plastic zones
- Stronger strain rate dependency –
  → higher strength at fast strain rates

Design of bolted connections

- The strength and corrosion resistance of the bolts and parent material should be similar
- Stainless steel bolts should be used to connect stainless steel members to avoid bimetallic corrosion
- Stainless steel bolts can also be used to connect galvanized steel and aluminium members

Design of bolted connections

- Rules for carbon steel bolts in clearance holes can generally be applied to stainless steel (tension, shear)
- Special rules for bearing resistance required to limit deformation due to high ductility of stainless steel

$$f_{u,red} = 0.5 f_y + 0.6 f_u < f_u$$

Preloaded bolts

Useful in structures like bridges, towers, masts etc when:

- the connection is subject to vibrating loads,
- slip between joining parts must be avoided,
- the applied load frequently changes from a positive to a negative value

- No design rules for stainless steel preloaded bolts
- Tests should always be carried out

Design of welded connections

- Carbon steel design rules can generally be applied to stainless steel
- Use the correct consumable for the grade of stainless steel
- Stainless steel can be welded to carbon steel, but special preparation is needed

Fatigue strength

- Fatigue behaviour of welded joints is dominated by weld geometry
- Performance of austenitic and duplex stainless steel is at least as good as carbon steel
- Follow guidelines for carbon steel

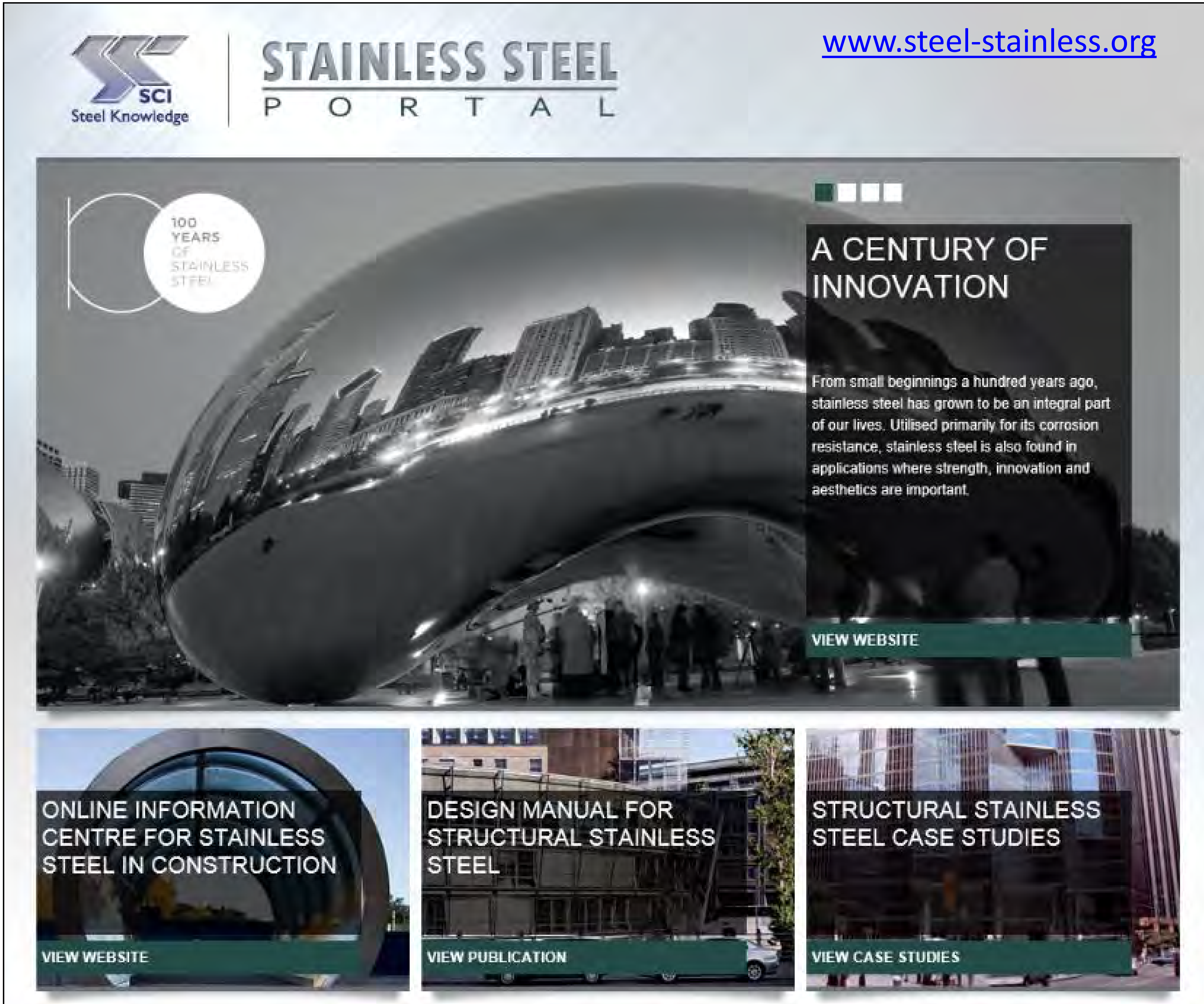
Section 7

Resources for engineers

Resources for engineers

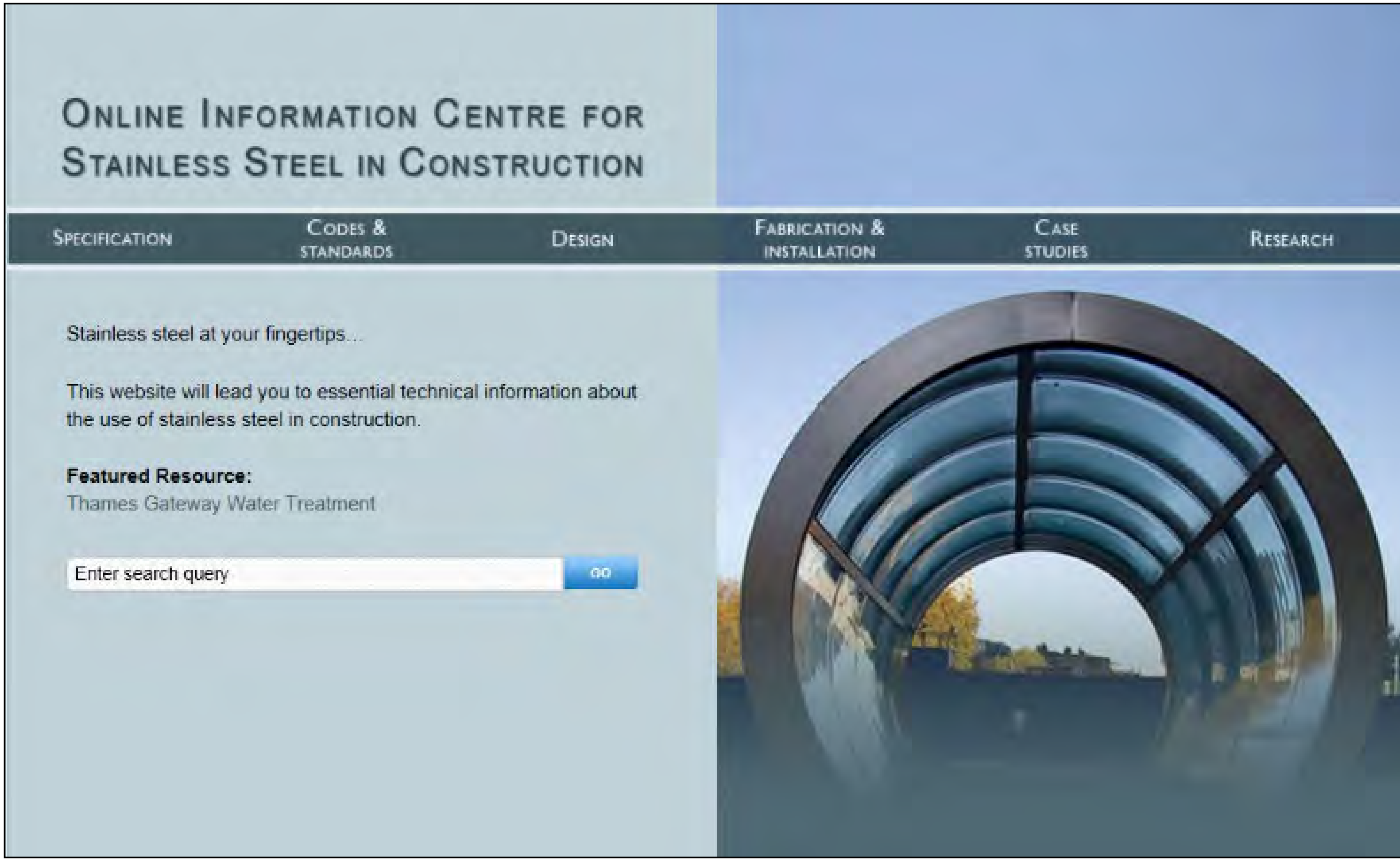
- Online Information Centre
- Case studies
- Design guides
- Design examples
- Software

www.steel-stainless.org



Stainless in Construction Information Centre

www.stainlessconstruction.com



12 Structural Case Studies

www.steel-stainless.org/CaseStudies


SCI Steel Knowledge

Structural Stainless Steel Case Study 01

Stonecutters Bridge Towers

Stonecutters Bridge, Hong Kong, is a cable stayed structure with a total length of 1596 m and a main span of 1018 m. The bridge crosses the Rambler Channel and is the main entrance to the busy Kwai Chung Container Port. It is visible from many parts of Hong Kong Island and Kowloon. The most striking features of the bridge are the twin tapered mono towers at each end supporting the 50 m wide deck. These tapered towers rise to 295 m above sea level; the lower sections are reinforced concrete while the upper 115 m are composite sections with an outer stainless steel skin and a reinforced concrete core.

Material Selection

Figure 1: General view of Stonecutters Bridge

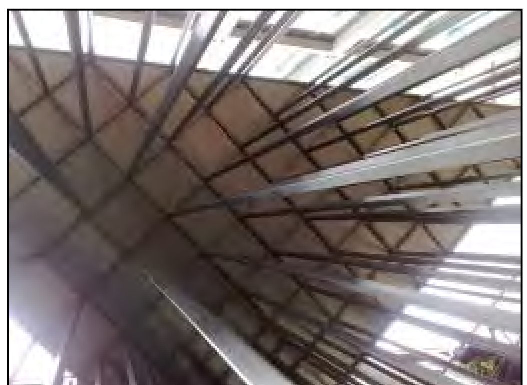
The design life of the bridge is 120 years. A highly durable material was required for the upper sections of the bridge towers because of the harsh marine and polluted environment. Additionally, post-construction maintenance on the towers will be extremely difficult due to the live traffic beneath. Stainless steel was chosen for the skin of the composite section of the upper tower because of its durability and also its attractive appearance. Carbon steel would have required protective coatings that would have needed recoating after an estimated 20-30 years.

Standard molybdenum-alloyed austenitic steel grades were initially considered but discounted because of their relatively low design strength (220 N/mm²) and uncertainty regarding corrosion performance, given the roughness of the desired surface finish. Higher alloyed austenitics with better corrosion resistance, e.g. 1.4539 (N08904) and 1.4439 (S31726), were not considered in detail as they would not have met the requirements for cost, availability and strength. Duplex steel 1.4462 (S32205) was chosen as it has high strength (460 N/mm²) with good corrosion resistance and tolerance of surface finish.

Figure 2: Mono tower and stay cables

A polished [illegible] finish (as defined in EN 10088 Part 2 [illegible]) was specified for all exposed surfaces, with an average surface roughness R_a of 0.5 µm. A slightly textured, non-directional, low reflective appearance was then created by shot peening the surface with a mixture of aluminium oxide and glass beads.

Structural Stainless Steel Case Study 01 Page 1



Design Guidance to Eurocodes

www.steel-stainless.org/designmanual

- Guidance
- Commentary
- Design examples

Online design software:

www.steel-stainless.org/software

Summary

- Structural performance:
  similar to carbon steel but some modifications needed due to non-linear stress-strain curve
- Design rules have been developed
- Resources (design guides, case studies, worked examples, software) are freely available!

References

- EN 1993-1-1. Eurocode 3: Design of steel structures – Part1-1: General rules and rules for buildings. 2005
- EN 1993-1-4. Eurocode 3: Design of steel structures – Part1-4: Supplementary rules for stainless steel. 2006
- EN 1993-1-4. Eurocode 3: Design of steel structures – Part1-4: Supplementary rules for stainless steel. Modifications 2015
- M. Fortan. Lateral-torsional buckling of duplex stainless steel beams - Experiments and design model. PhD thesis. 2014-…
- AISI Standard. North American specification Appendix 1: Design of Cold-Formed Steel Structural Members Using the Direct Strength Method. 2007
- B.W. Schafer. Review: The Direct Strength Method of cold-formed steel member design. Journal of Constructional Steel Research 64 (2008) 766-778
- S.Afshan, L. Gardner. The continuous strength method for structural stainless steel design. Thin-Walled Structures 68 (2013) 42-49

Thank You

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Maarten Fortan – maarten.fortan@kuleuven.be

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 08

Stainless Steel Surfaces

Contents

1 - Stainless steel finishes [1,2]

- Mill Finishes
- Mechanically Polished andBrushed Finishes
- Patterned Finishes
- Bead Blasted Finishes
- Electro-Polished Finishes
- Coloured Finishes
- Electrolytically Coloured Finishes
- Electrolytically Coloured and Patterned Finishes
- Organic Coatings
- Specialist Decorative Finishes

Many finishes are available

Ex-mill cold rolled finishes [1,3]

EN 10088-2 cold rolled finishes from table 6 of the standard, with a guide to typical Ra values

Symbol	Finishing Process Route	Notes	Typical (Ra) µm
2B	Cold rolled, heat treated, pickled, skin passed	Most common 'cold rolled' finish available. Non-reflective, smooth finish, good flatness control. Thickness range limited by manufactures' skin passing rolling capacity.	0.1-0.5
2C	Cold rolled, heat treated, not descaled	Smooth with scale from heat treatment, suitable for parts to be machined or descaled in subsequent production or where the parts are for heat resisting applications.	-
2D	Cold rolled, heat treated, pickled	Thicker sheet size ranges. Smoothness not as good as 2B, but adequate for most purposes.	0.4-1.0
2E	Cold rolled, heat treated, mechanically descaled	Rough and dull. Usually applied to steels with a scale which is very resistant to pickling solutions	-
2H	Cold rolled, work hardened	"Temper" rolling on austenitic types improves mechanical strength. Smoothness similar to 2B	-
2R	Cold rolled, bright annealed	Highly reflective "mirror" finish, very smooth. Often supplied with plastic coatings for pressings. Manufactured items usually put into service without further finishing	.05-0.1
2Q	Cold rolled, hardened and tempered, scale free	Only available on martensitic types (e.g. 420). Scaling avoided by protective atmosphere heat treatment or descaling after heat treatment	-

More on Ra:
http://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/RoughnessMeasurement_EN.pdf

These are the most common ones

Most common mill finishes

2B This is produced as 2D, but a final light rolling using highly polished rolls gives the surface a smooth, reflective, grey sheen. This is the most widely used surface finish in use today and forms the basis for most polished and brushed finishes.

2D This is achieved by cold rolling, heat treating and pickling. The low reflective matt surface appearance is suitable for industrial and engineering needs but, architecturally, is suitable for less critical aesthetic applications.

2R By bright annealing under Oxygen-free atmospthetic conditions following cold rolling using polished rolls, a highly reflective finish, that will reflect clear images, is obtained. This ultra-smooth surface is less likely to harbour airborne contaminants or moisture than any other mill finish, and it is easy to clean.

Special Finishes [1,3]

EN 10088-2 special finishes from Table 6 of the standard, with a guide to typical Ra

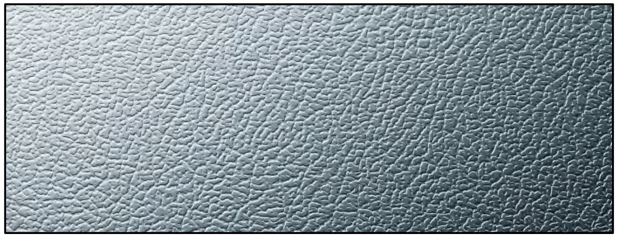
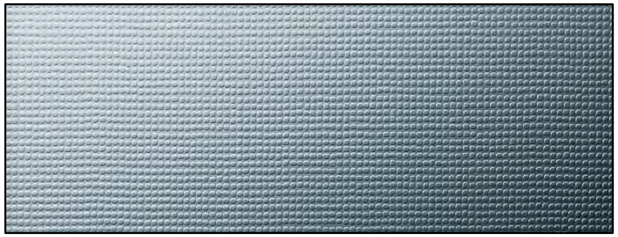
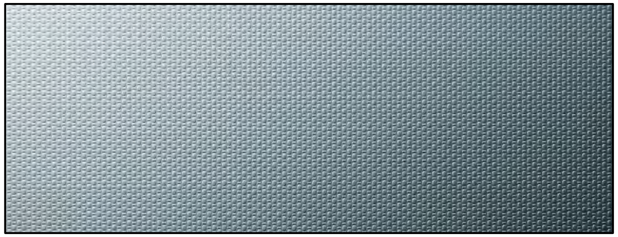
Symbol	Finishing Process Route	Notes	Typical (Ra) µm
1G or 2G	Ground	Can be based on either '1' or '2' ex-mill finishes*. A unidirectional texture, not very reflective	-
1J or 2J	Brushed or dull polished	Can be based on either '1' or '2' ex-mill finishes*. Smoother than "G" with a unidirectional texture, not very reflective	0.2-1.0
1K or 2K	Satin polished	Can be based on either '1' or '2' ex-mill finishes*. Smoothest of the special non-reflective finishes with corrosion resistance suitable for most external applications.	< 0.5
1P or 2P	Bright polished	Can be based on either '1' or '2' ex-mill finishes*. Mechanically polished reflective finish. Can be a mirror finish.	< 0.1
2F	Cold rolled, heat treated, skin passed on roughened rolls	Uniform non-reflective matt surface, can be based on either 2B or 2R mill finishes	-
1M or 2M	Patterned	Can be based on either '1' or '2' ex-mill finishes*. One side patterned only. Includes "chequer" plates ("1" ex-mill finish) & fine textures finishes ("2" ex-mill finish)	-
2W	Corrugated	Profile rolled (e.g. trapezoidal or sinusoidal shapes)	-
2L	Coloured	Applied to flat (2R, 2P or 2K type fishes) or patterned (2M) sheet base finishes in a range of colours	-
1S or 2S	Surface coated	Can be based on either '1' or '2' ex-mill finishes . Normally coated on one side only with a metallic coating, such as tin, aluminium or titanium	-

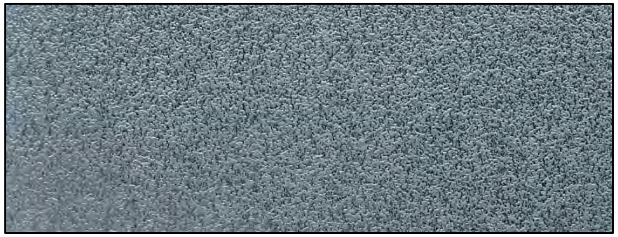
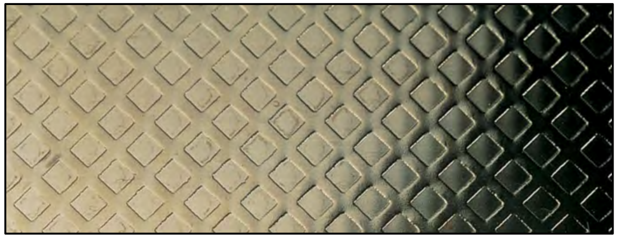
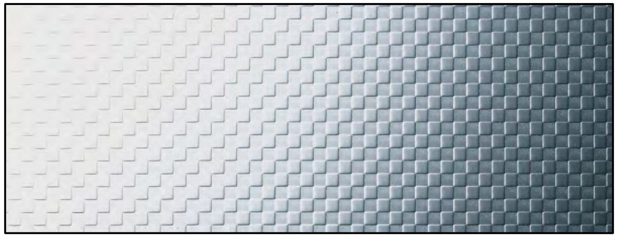
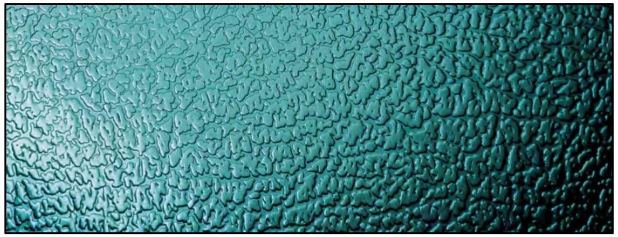
* 1 finishes are for hot-rolled products, 2 finishes for cold rolled

There is a very wide choice of special finishes

Patterned Finishes [4,5,7]

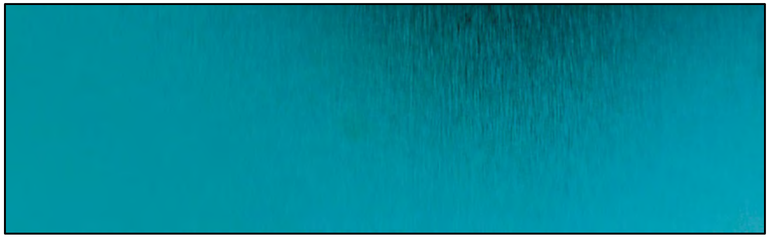
These few examples illustrate the use of sheets patterned on one side only, classified as 2M. A wide variety of patterns are available

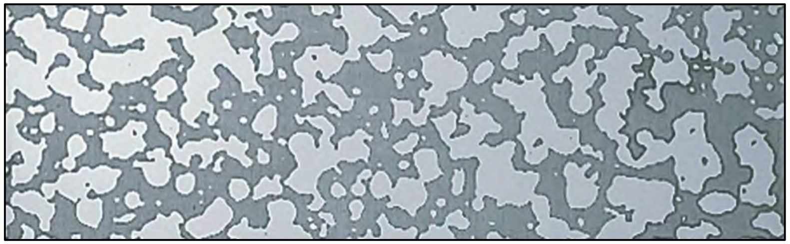
Coloured finishes[4, 5,7]

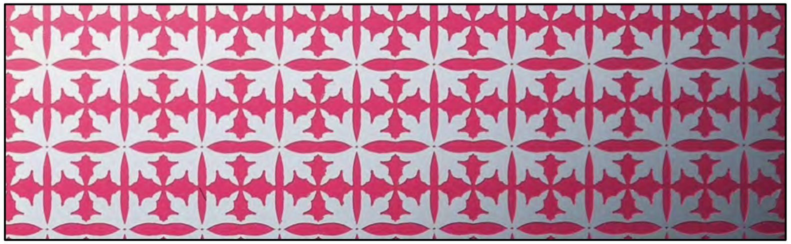
This is only a selection of the colour effects that can be produced by electrolytically colouring stainless steel

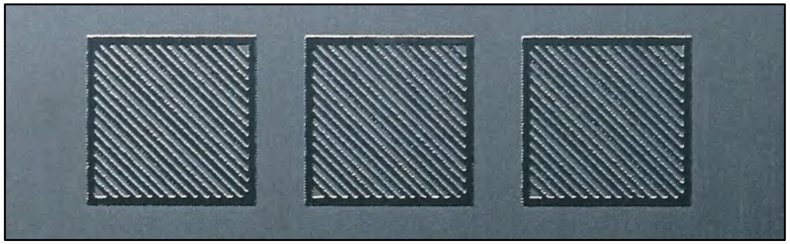


Etched Patterns[4,5,7]

Silk screen and photoresist processes have been developed to transfer any pattern onto stainless steel, the surface of which is then acid etched to reveal the pattern. Acid etching is a process which removes a small amount of surface material. Etched surfaces have a dull and a slightly coarse appearance which contrast well with polished or satin finished un-etched surfaces. Electro-chemical colour can be given to etched surfaces before or after etching.

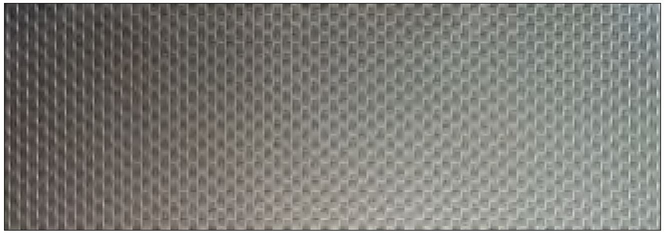






Proprietary finishes [4,5]

Many specific & custom finishes are available from specialized companies
Some examples are shown below



Electropolishing [6]

Produces bright reflecting surfaces which feature

- Optimum corrosion resistance for any grade
- Easier disinfection and cleanability
- Easier removal of graffiti

However

- Irregular surfaces are more visible
- As well as damage from scratches and mechanical damage

Bead Blasting [8]

The appearance can be altered by different blasting materials, e.g. glass bead (above) or shredded glass (below)

Please note:

There are many different grades of stainless steel, which offer solutions to a wide range of design problems, from corrosion resistance in even the most aggressive environments, to high strength requirements; and from ease of formability to ease of welding. Similarly, stainless steels offer a wide range of surface finishes which can assist the architect in achieving the aesthetically pleasing appearance he is looking for. Surface finishes range from a plain matte through soft polishing through textured patterns and colours right up to highly polished mirror finishes. These provide the imaginative designer with a wide array of options.

Care should be taken when using glossy surface finishes to ensure that they do not unwittingly create glare or heat reflectivity issues. Especially building fronts facing the sun and concave-shaped areas deserve special attention during the planning phase.

Architects use everyday the palette of surface finishes available on stainless steels [7]

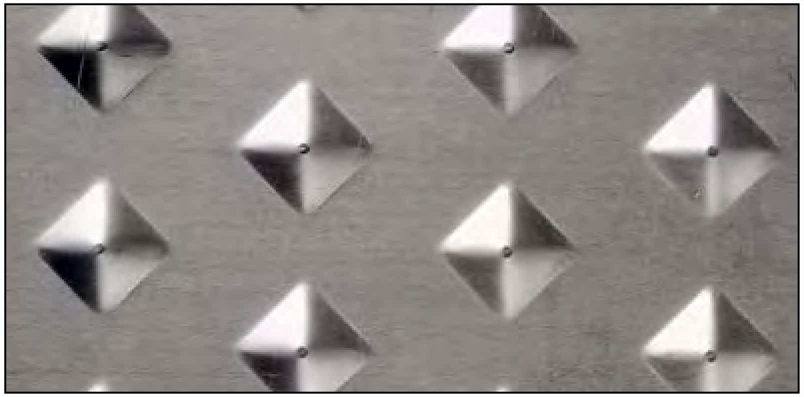
In Chapter 2 you will find some examples of buildings for which the surface finish is essential to the aesthetics

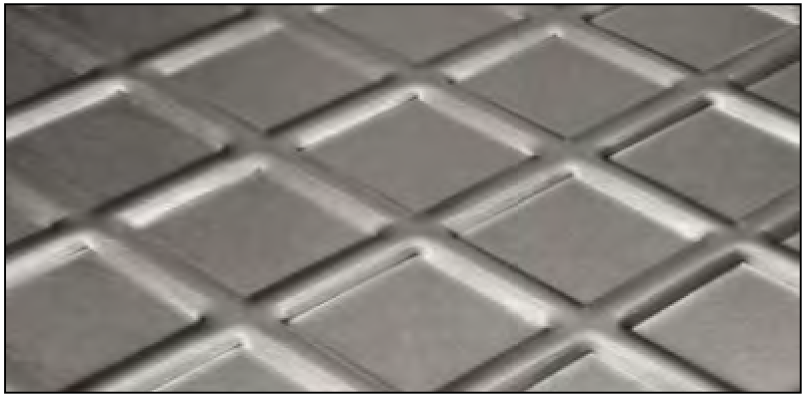
2 - Tridimensional Finishes [9]

i.e. deeper tridimensional features than patterns obtained by embossing, punching, cuttting, profiling, ….

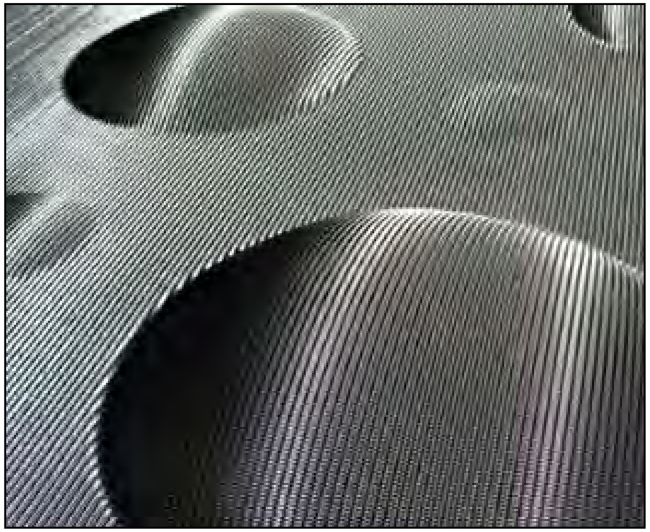
usually carried out on Computer-controlled machines

Embossed patterns [9]

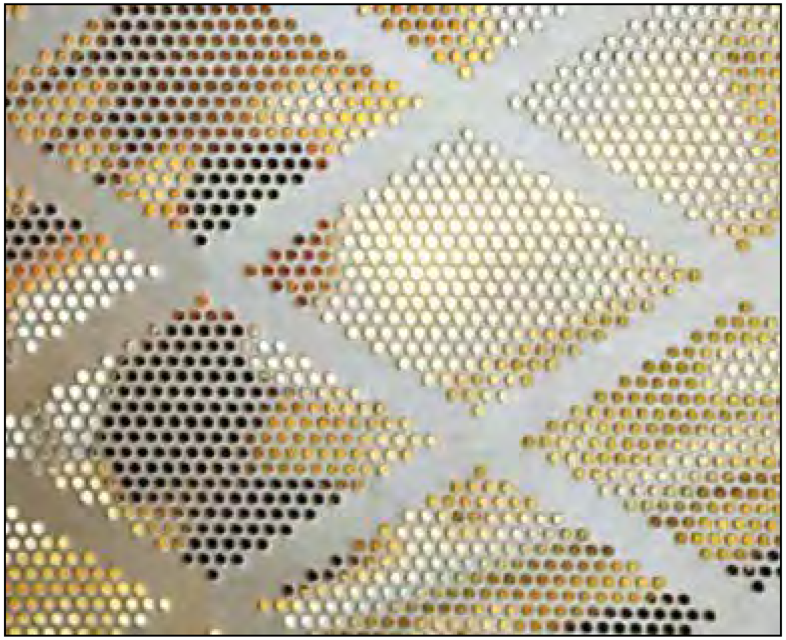


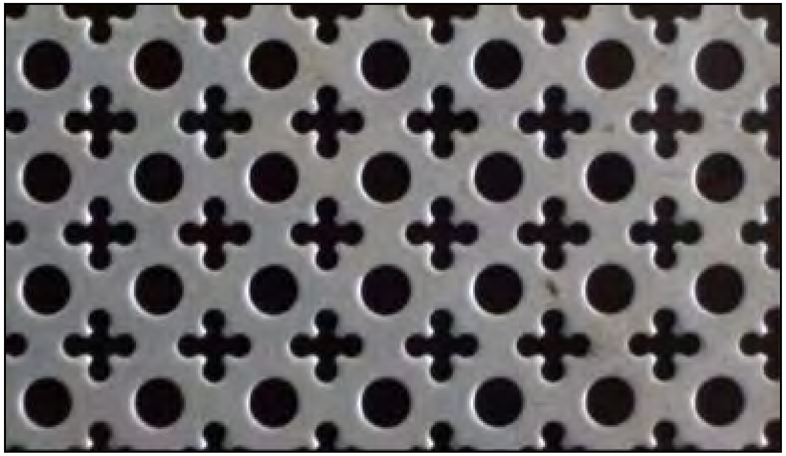


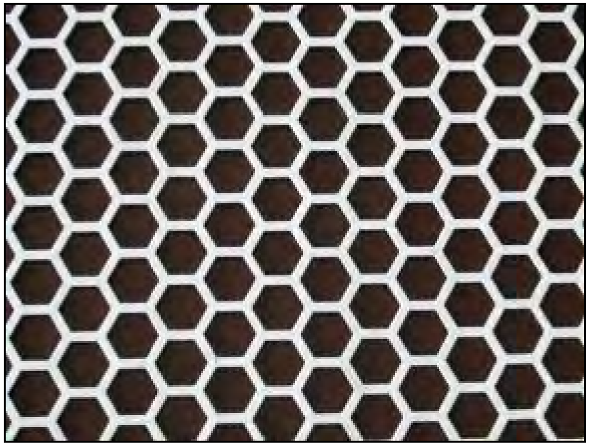
Irregular shapes[9] (fluid forming)



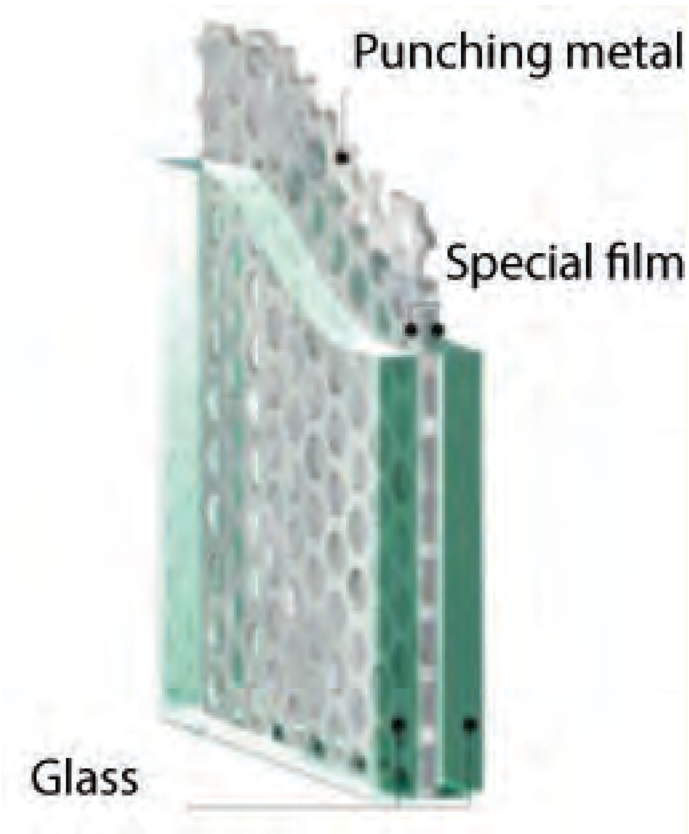
Perforated sheet [9]



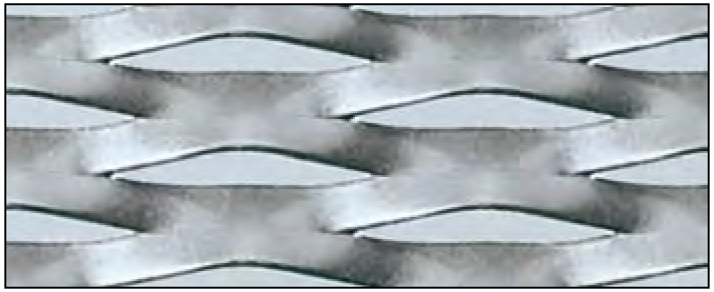




Semi-transparent glass panels with perforated sheet [10]

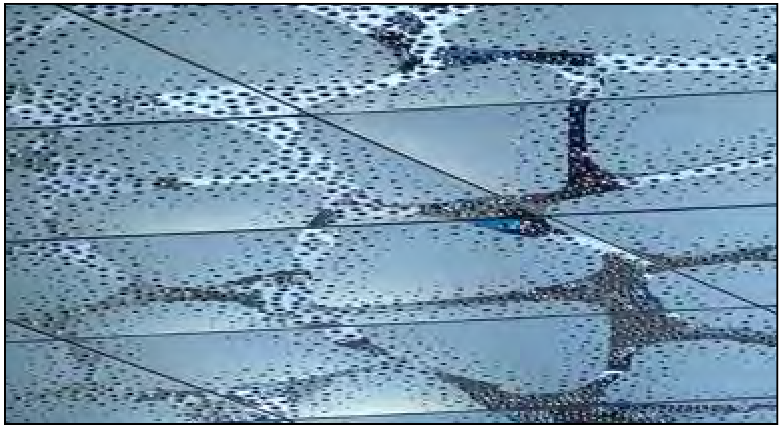


Expanded Sheet



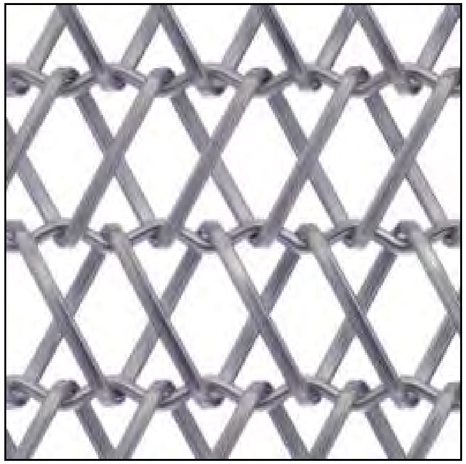
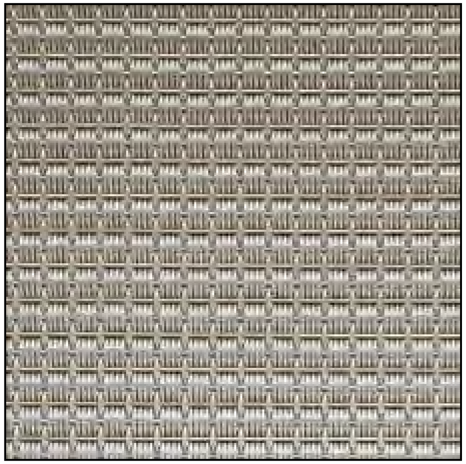
Combination of techniques [11]

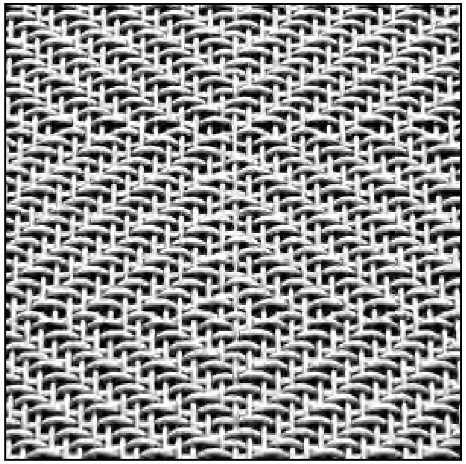
Stockholm Waterfront Building : Perforated and colored stainless steel ceiling that reproduces the image of the melting ice on the lower right



3 – Woven Mesh

Standard [12-14]

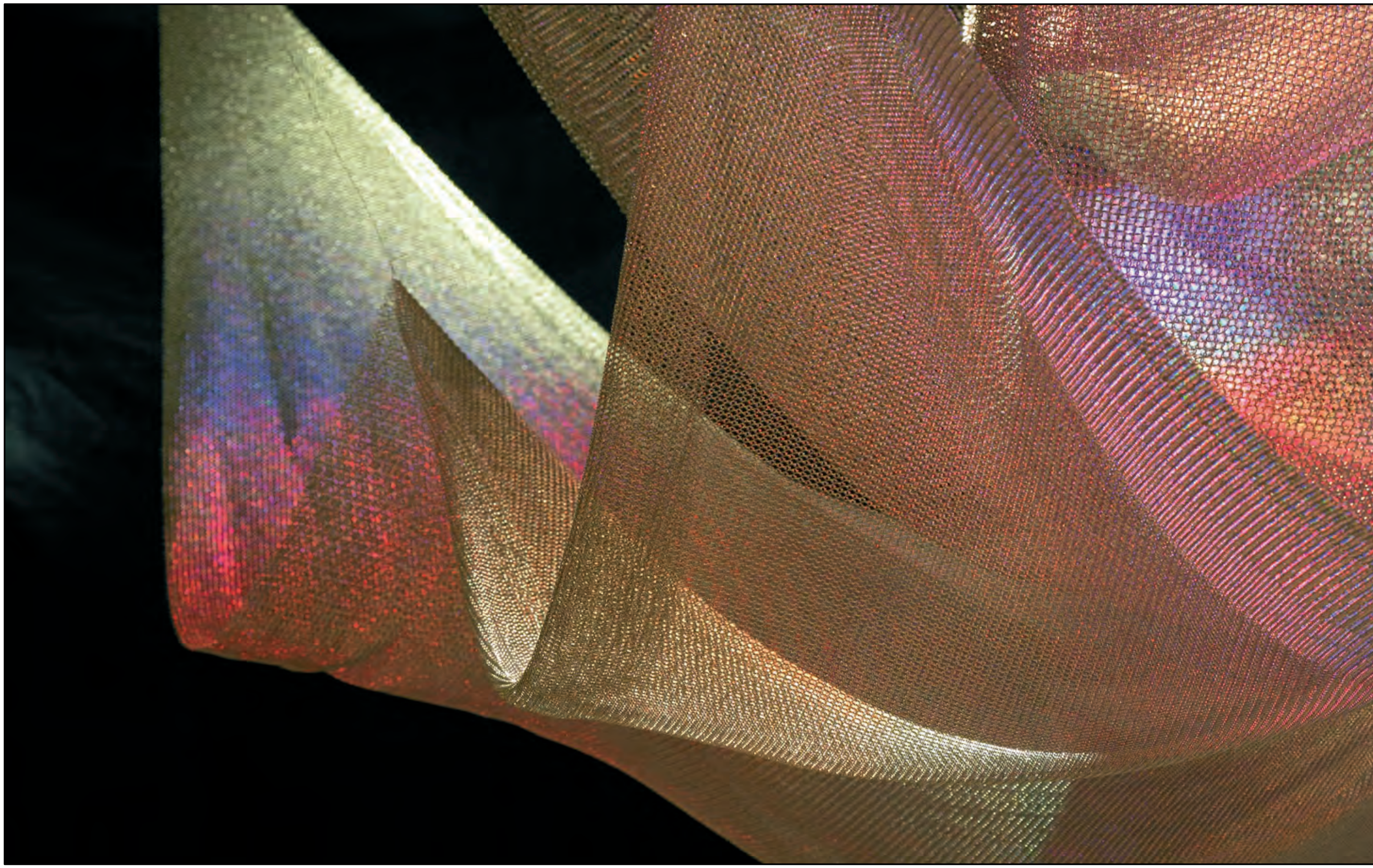





A very wide set of woven shapes and patterns is available, with adjustable

- stiffness
- open area
- light diffusion
- acoustic transparency
- color
- etc…

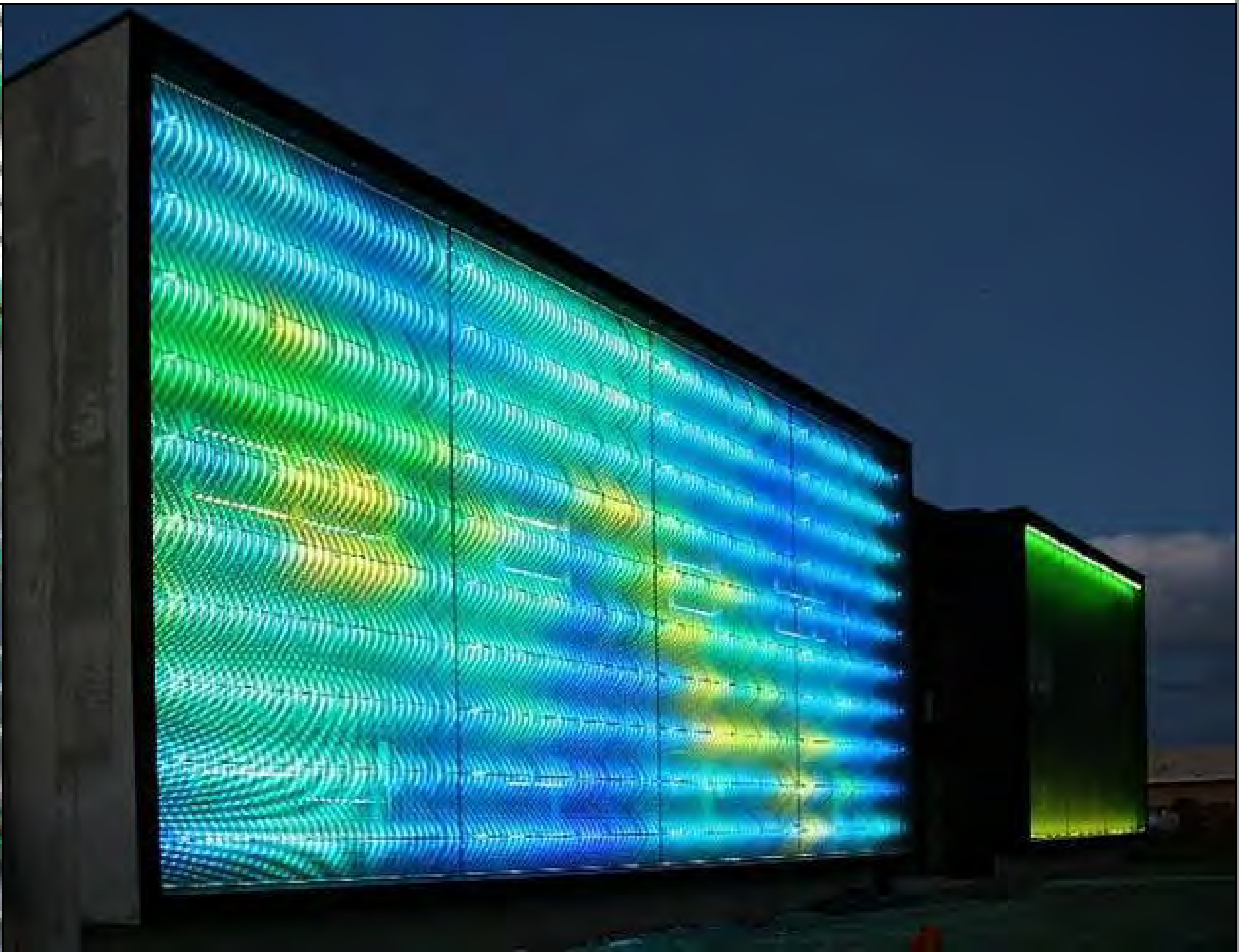
Example of decoration with stainless steel mesh



Outside decoration with Stainless Wire mesh

Stainless wire mesh is widely used for decoration. It allows special effects such as lights (with LEDs) as shown (Swarovski Building headquarters)

Woven stainless with LEDs [13]



4 - References and sources

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2. http://www.ssina.com/download_a_file/special_finishes.pdf
3. http://www.bssa.org.uk/topics.php?article=47
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9. https://cambridgearchitectural.com/projects/ft-lauderdale-hollywood-international-airport-rental-car-center
10. https://www.exyd.com/waterfront-building.html
11. http://cambridgearchitectural.com
12. https://gkd.de/architekturgewebe/
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Thank you

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 09
Joining & Fabrication of Stainless Steels

Contents

1. Joining
2. Fabrication

1 - Joining
Applicable joining processes: all of them!

Process (Refs)	Videos	Preferred process for
Welding (1-5) (widely used)	MIG Welding TIG Welding Welding robot	High strength of the joints No dismantling
Fastening (widely used)	Webinar	Easy on-site assembly Assembling dissimilar materials (wood, glass…) Dismantling at a later stage
Brazing/Soldering	Soldering	Water tightness (Used mostly in roofing)
Mechanical Press-fitting Folding Other ….	 Press-fit example	Permanent joining of tubes Water tighness
Adhesive Bonding (not used often, but growing)		Surface finish integrity

Arc Welding

Advantages of arc welding

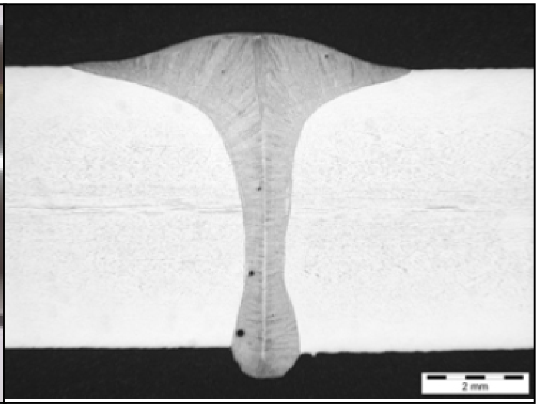
- weld properties equal to that of annealed condition
- provides the strongest joints
- can be done on site or in the shop
- joins thin and thick material of any shape
- joins similar or dissimilar metals (usually carbon steel with proper choice of filler material)
- resists fatigue and cyclic loads
- same corrosion and heat resistance as the annealed base metal

Limitations of arc welding

- not possible with all grades
- require qualified operators and procedures
- may cause heat-induced distortions
- post-weld finishing operations are required for a good-looking finish (such as sand blasting)
- loss of mechanical properties in case of cold-worked material

Arc Welding

[Video: polishing a weld]



Mechanical fastening

Advantages of mechanical fastening

- Can be dismantled
- Ideal for on-site building
- Fast
- No need of qualified operators

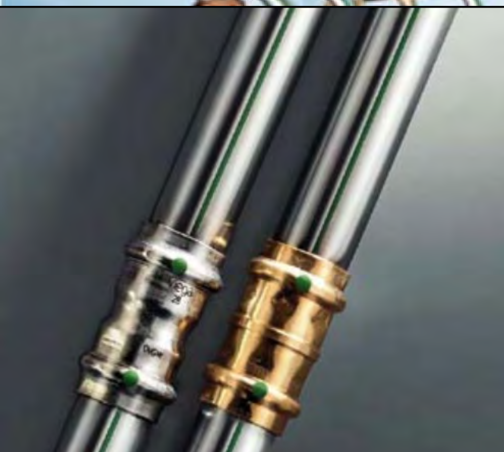
Limitations of mechanical fastening

- Not as strong as welds
- May cause crevice corrosion (see corrosion resistance chapter)

Selecting the appropriate fastener:

The German Institute for Building Technology* has issued recommendations for the selection of fasteners according to the environment. Please read Reference 4, Table 1a (exposure classes) and Table 8 (stainless grades by class)

* Deutsches Institut für Bautechnik (DIBt)



Press fitting

(a process used for tubes only)

Advantages of press fitting

- Perfectly tight for liquid and gases
- Fast
- No flame
- Perfectly clean surfaces
- No need of qualified operators

Limitations of press fitting

- Cannot be dismantled
- Require sleeves for each tube diameter

Adhesive Bonding

Advantages of adhesive bonding

- makes a joint almost invisible, enhancing
- product appearance
- provides uniform distribution of stress and a greater stress-bearing area
- joins thin and thick material of any shape
- joins similar or dissimilar materials
- minimizes or prevents electrochemical (galvanic) corrosion between dissimilar
- materials
- resists fatigue and cyclic loads
- provides joints with smooth contours
- seals joints against a variety of environments
- insulates against heat transfer and electrical conductance
- is free from heat-induced distortions
- dampens vibrations and absorb shocks
- provides attractive strength/weight ratio
- is frequently faster or cheaper than mechanical fastening

Limitations of adhesive bonding

- does not permit visual examination of the bond area
- requires careful surface preparation, often with corrosive chemicals
- may involve long cure times, particularly where high cure temperatures are not used
- may require holding fixtures, presses, ovens and autoclaves, not usually needed for other fastening methods
- should not be exposed to service temperatures above approximately 180 °C
- requires rigid process control, including emphasis on cleanliness, for most adhesives
- depends on the environment to which it is exposed

Adhesive bonding applications

Attaching of banister elements (Delo-Duopox AD895)

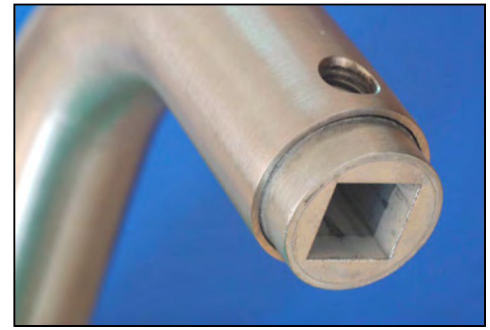
- Fills gaps, suitable for small and large bonding gaps
- Good chemical resistance and aging resistance
- For interior and exterior use
- Efficiency: flexible modular system in banister construction. The additional process steps required for welding, such as grinding or polishing, are avoided

Stainless steel panels (Grade 1.4404) are attached to the outer walls of this 6-storey office building in Hannover (Germany) using an adhesive bonding system without the need for additional mechanical fastening

Table 1. Selection of adhesives for structural bonding [11]

	With stainless steel	Type of adhesive for semi-structural bonding				
		Silicone	Polymer modified with silane	Polyurethane	Acrylic	Epoxy
Stainless steel	yes	●	●	●	○	●
Carbon steel	yes	●	●	○	○	●
Carbon steel/ painted	yes	●	●	X	○	○
Carbon steel/ galvanized	yes	●	●	X	○	○
Aluminium	yes	●	●	○	○	●
Wood	yes	●	●	○	○	●
Glass/ceramic	yes	●	●	X	○	●
Plastic PVC	yes	●	●	X	X	X
Plastic PA	yes	○	●	X	○	
Plastic PP/PE	no	X	X	X	X	X

● highly recommendable - ○ recommendable - X not recommendable



Adhesive bonding is used for the assembly of door handles.

Adhesive bonding is a practical solution in building applications, when stainless steel has to be fastened to masonry or natural stone

References on Joining

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2. http://www.wikihow.com/Weld-Stainless-Steel
3. http://www.nickelinstitute.org/~/Media/Files/TechnicalLiterature/WeldingofStainlesssSteelandotherJoiningMethods_9002_.pdf
4. http://www.edelstahl-rostfrei.de/page.asp?pageID=1590
5. http://www.improve.it/metro/file.php?file=/1/Papers/Metallurgy_of_Welding_Processes/Joint_properties.pdf
6. https://www.worldstainless.org/Files/issf/non-image-files/PDF/Euro_Inox/Adhesive_bonding_EN.pdf
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8. https://www.worldstainless.org/Files/issf/non-image-files/PDF/ISSF_Stainless_Steel_for_Designers.pdf
9. http://www.delo.de/fileadmin/upload/dokumente/en/broschueren/Structural_Bonding.pdf
10. https://www.ellsworth.com/globalassets/literature-library/manufacturer/ellsworth-adhesives/ellsworth-adhesives-white-paper-structural-bonding.pdf
11. http://www.sciencedirect.com/science/book/9781845694357

2 - Fabrication

Very comprehensive documents are available, see the list of references

Ref 1 is a training course dedicated to the fabrication of stainless steels

Chapter 2 lists a number of applications in architecture, building and construction: fabrication of all shapes and finishes is achieved routinely today

Videos on Processes

- Stainless Steel Melting and Rolling https://www.youtube.com/watch?v=5zwgI-pQ6kE
- Shearing and Bending https://www.youtube.com/watch?v=VMu7_W0QE3Y
- Water Jet Cutting http://www.sastainless.com/videos/index.html
- Deep Drawing https://www.youtube.com/watch?v=n-ht_5Ysurc
- Wire Bending Machine https://www.youtube.com/watch?v=kDoSDiiZx6U
- Spring Forming Machine https://www.youtube.com/watch?v=SwY-RT4DBxY
- Roll Forming https://www.youtube.com/watch?v=44XD5mZoM_0
- Machining (milling) https://www.youtube.com/watch?v=LDxNDWObTyg

More videos are readily available on the net

References on Fabrication

1. http://www.issftraining.org/
2. http://www.imoa.info/download_files/stainless-steel/Austenitics.pdf
3. http://www.imoa.info/download_files/stainless-steel/Duplex_Stainless_Steel_3rd_Edition.pdf
4. http://www.worldstainless.org/Files/issf/non-image-files/PDF/ISSF_The_Ferritic_Solution_English.pdf

Thank you

Test your knowledge of stainless steel here:

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Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 10

Forms and availability

Why « Forms and Availability » ?

- Delivery times and costs are major issues for architects & civil engineers
- While all stainless steel products start from a melting shop
  - There are many processing routes for stainless products
  - And stockholders, traders providing service packages
- And therefore Delivery times and Costs may vary widely

Some background information
How stainless steel is produced

- Video: Steelmaking and Hot Rolling of coils
- Video: Hot Rolling of coils
- Video: Cold rolling of coils
- Video: Steelmaking and hot rolling of bars
- Video: Wire rod rolling
- Video: Wire rod rolling

Stainless Steel Supply Chain

SIMPLIFIED

Stainless Steel Mill Ex-mill sales → **Distributors (of which mill-owned)**

	Stainless Steel Mill Ex-mill sales	Distributors (of which mill-owned)
Products	Coils, Sheets, Plates Bars, Wire Reinforcing bar	Customized: Cut to length Cut to shape Polishing …
Service	Minimum weight 1 slab Production on order Lead time 2 – 3weeks Lowest price /Kg	Small orders Available from stock Short delivery times (1-3 days) Price premium for service

Fabricators + Specific finishes (such as color)

Stainless Steel Mill → **Standard Component Manufacturing** → **Distributors (of which mill-owned)**

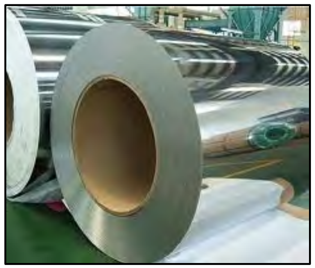
Products
- Fasteners
- Tubes
- Valves
- Fittings

Service
- Available from stock
- Short delivery times (1-3 days)
- Price premium for service

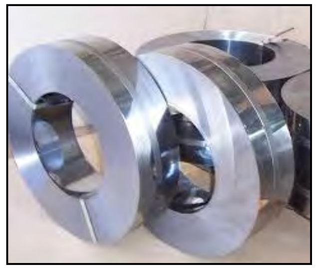
Flat products

Ex-mill

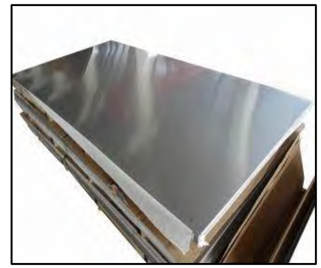
Cold-rolled coil



Cold-rolled strip



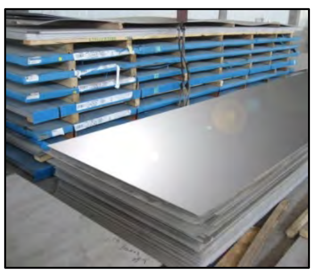
Cold-Rolled polished sheet



Custom

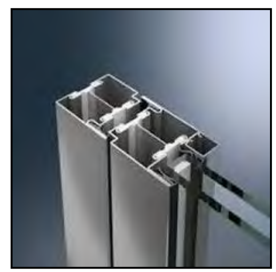
Laser cut shape

Plates



I-beam from plate

Door & Window profiles



Clamps

Standard tubes

Profiled tubes

Tube fittings

Railings

Long Products

Ex-mill

Bars

Tie-bars

Threaded bars

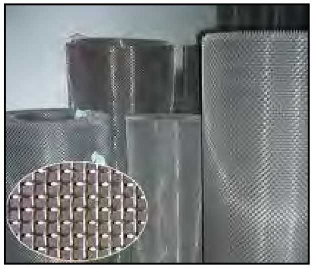
Reinforcing Bar

Cables

Concrete Anchors

Wire Rod

Mesh



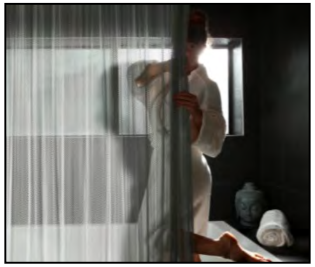
Fasteners

Custom

Handles

Sunbreaker

Mesh shower curtain



Future trends

The urgency of climate change mitigation and of a sustainable economy will drive major changes in the years to come.

A new product offer is likely to appear:

- re-conditioned products. Stainless steel from buildings/ facilities being de-constructed could be re-processed and made available for a new service life without loss of properties.
- Higher strength and thinner products, able to offer the same service performance with less material use. The development of lean duplex grades and of cold-worked austenitic grades is already taking place.

References

Major stainless steel producers
https://www.worldstainless.org/about-issf/issf-members/

Thank you

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https://www.surveymonkey.com/r/3BVK2X6

Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 11

Sustainability of Stainless Steels

Definitions

- **Greenhouse Gas (GHG)**: Emission Tonnes of CO_2-eq /Tonne Steel [1]
- **Global Warming Potential**: no unit Ratio of the abilities of different greenhouse gases (GHG) to trap heat in the atmosphere relative to that of carbon dioxide (CO_2) **[2]**. For instance, the GWP of Methane is **28 over a 100-year period.** The primary GHG emitted in the steelmaking is CO_2.
- **Primary Energy Consumption (GJ/T) GWP also called Energy Intensity** : The energy consumption required to produce 1 tonne of primary material (such as steel). [1]
- **Gross Energy Requirement (GER)**: is the total amount of energy required for a product. [8]
- **Materials Efficiency**: Measures the amount of material not sent for permanent disposal, landfill or incineration, relative to crude steel production. [1]

Definitions

- **Life Cycle Inventory (LCI)**: a structured, comprehensive and internationally standardized method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with the entire life cycle of products. [3]
- **Life Cycle Cost (LCC)**: is a tool for assessing the total cost performance of an asset over time, including the acquisition, operating, maintenance, and disposal costs. [4]
- **Life Cycle Assessment (LCA)**: is a tool to assist with the quantification and evaluation of environmental burdens and impacts associated with product systems and activities, from the extraction of raw materials in the earth to end-of-life and waste disposal. The tool is increasingly used by industries, governments, and environmental groups to assist with decision-making for environment-related strategies and materials selection.

Definitions

Safety Indicators:

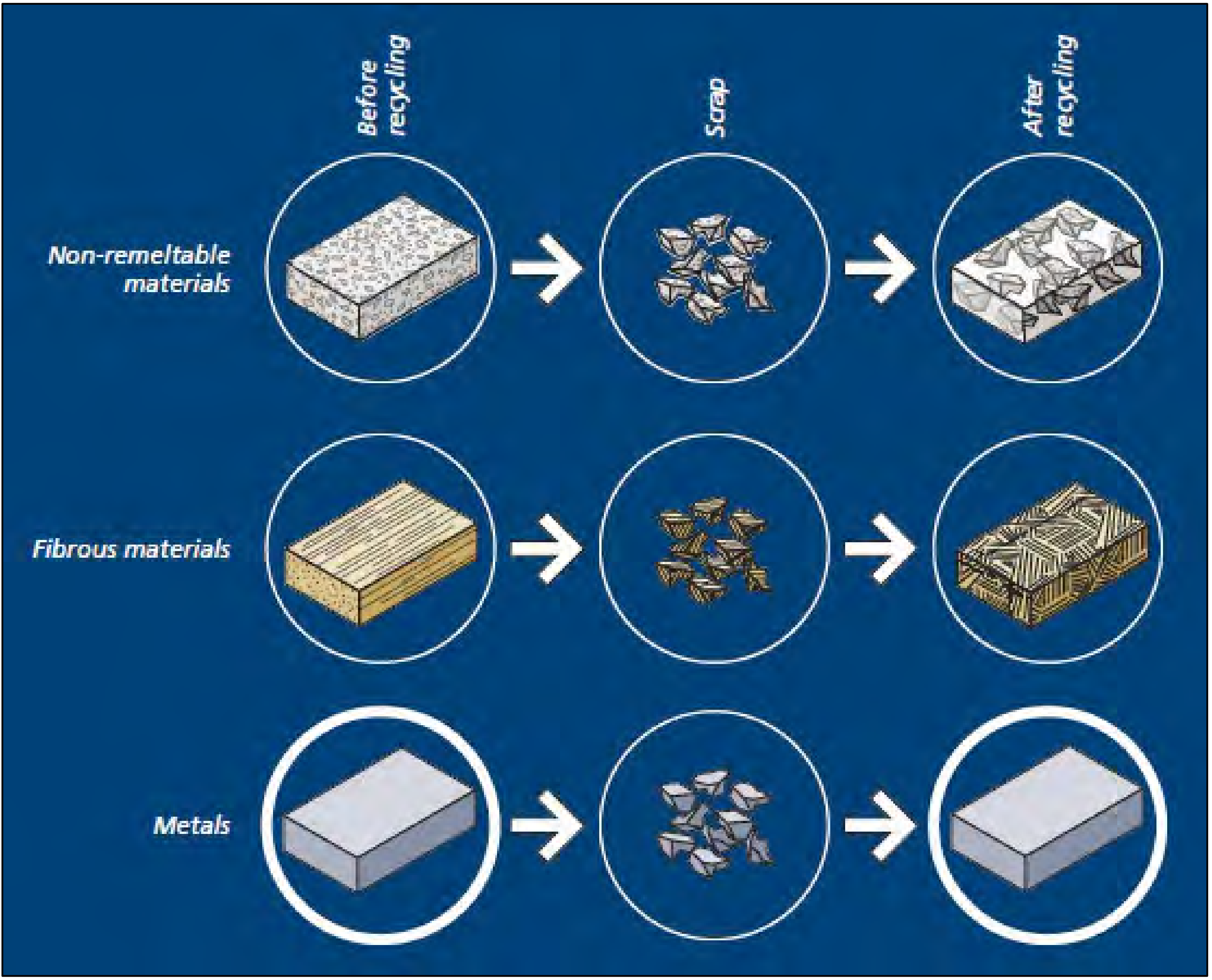
- **Lost–Time Injury**: The lost time injury frequency rate is the number of lost time injuries for each 1,000,000 working hours. [1]

Recycling Indicators:

- **Recycling rate** how much of the end-of-life (EOL) material is collected and enters the recycling chain (as opposed to material that is landfilled). [5]
- **Recycled content** is defined as the proportion, by mass, of post - consumer and pre - consumer recycled material in a product. [6]
- **Solid Waste Burden (SWB):** includes mining waste, tailings, slag and power station ash

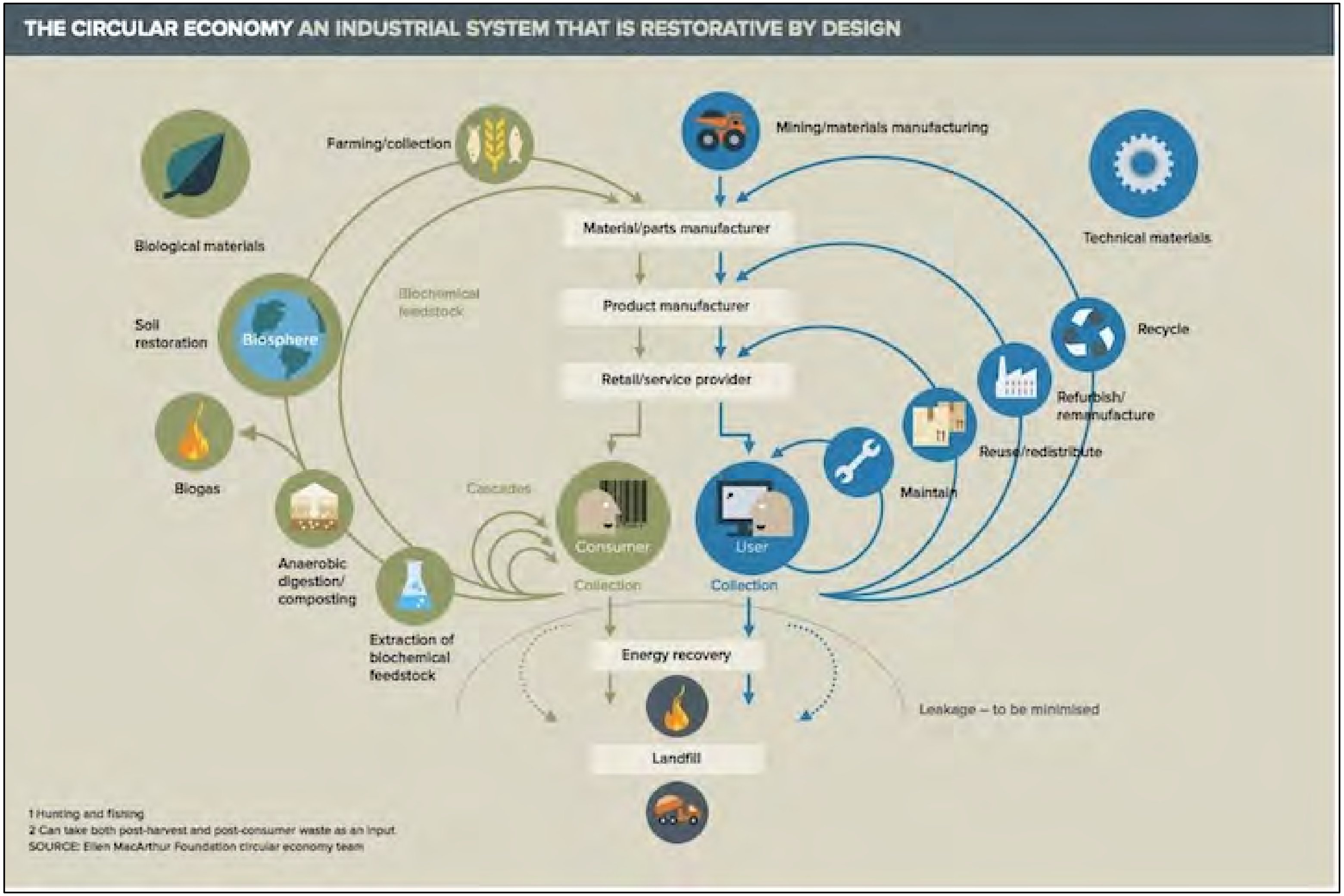
Comments on Indicators:

The recycling indicators do not take into account « downcycling».



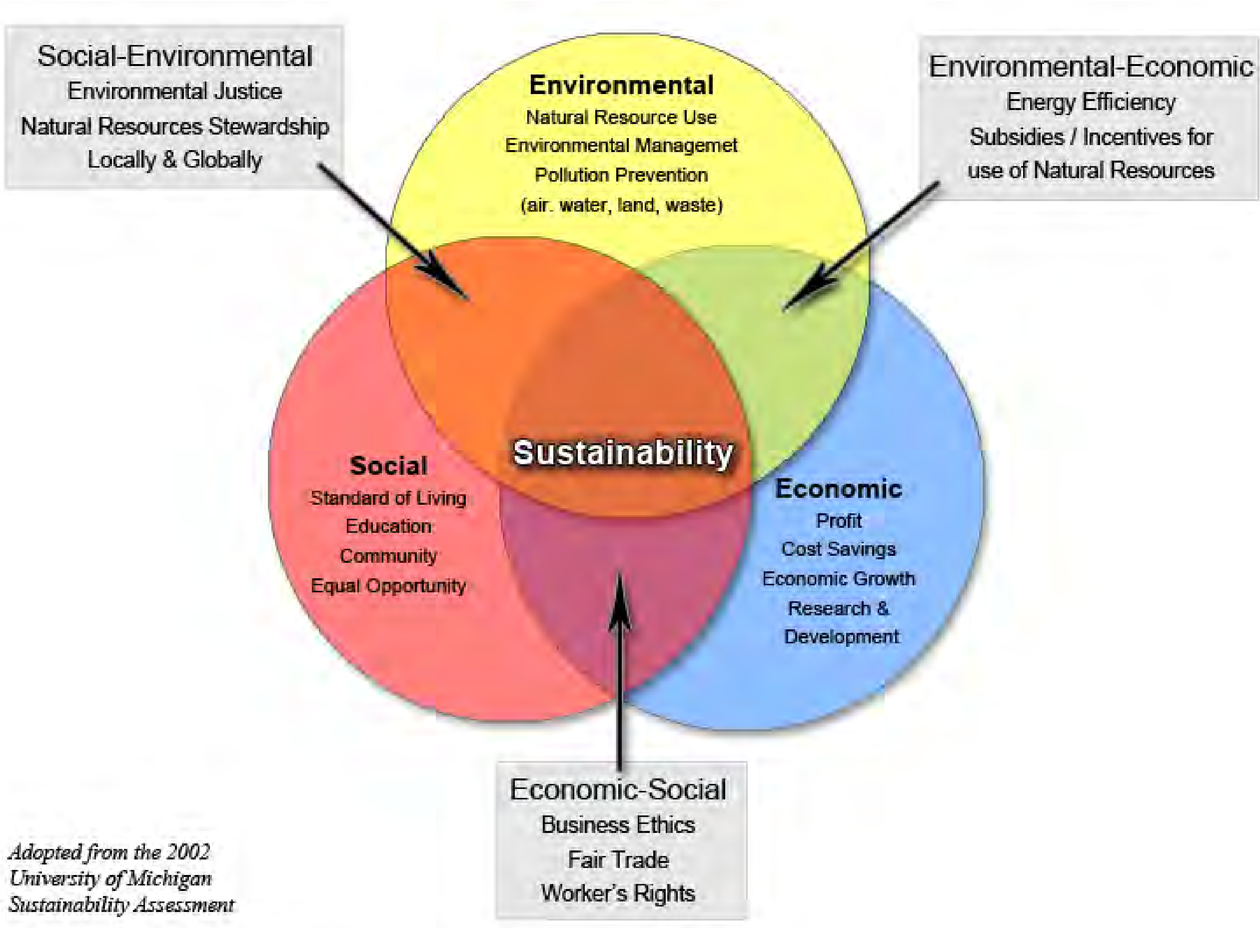
Metals can be recycled without loss of quality.
Because metallic bonds are restored upon resolidification, metals continually recover their original performance properties, even after multiple recycling loops. This allows them to be used again and again for the same application.
By contrast, the performance characteristics of most non-metallic materials degrade after recycling. (45)

Downcycling is better than waste but still a long way from Circular Economy (46,47)



Collecting scrap metal for new metal products is one of the shortest loops

Circular economy is all about closing resource loops, mimicking natural ecosystems in the way we organize our society and businesses.



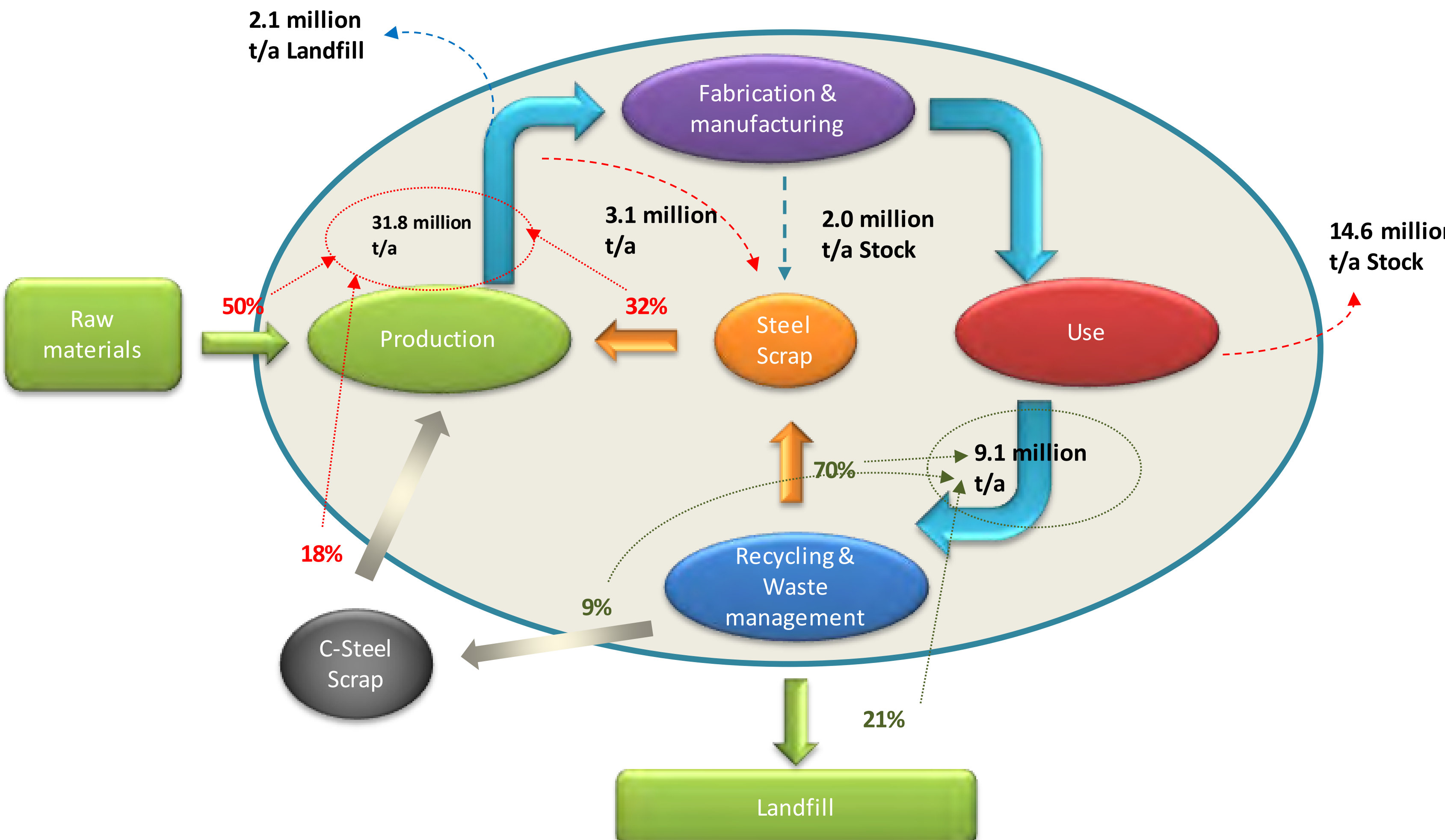
Sustainability

"Sustainability concerns the whole cycle of a product construction i.e. from raw material acquisition, through planning, design, construction and operations, to final demolition and waste management." (Rossi, B. 2012) [9]

Sustainability of stainless steel:

1. Environmental
2. Social
3. Economic

1. Environmental
Production ⇨ Use ⇨ Recycling [15]

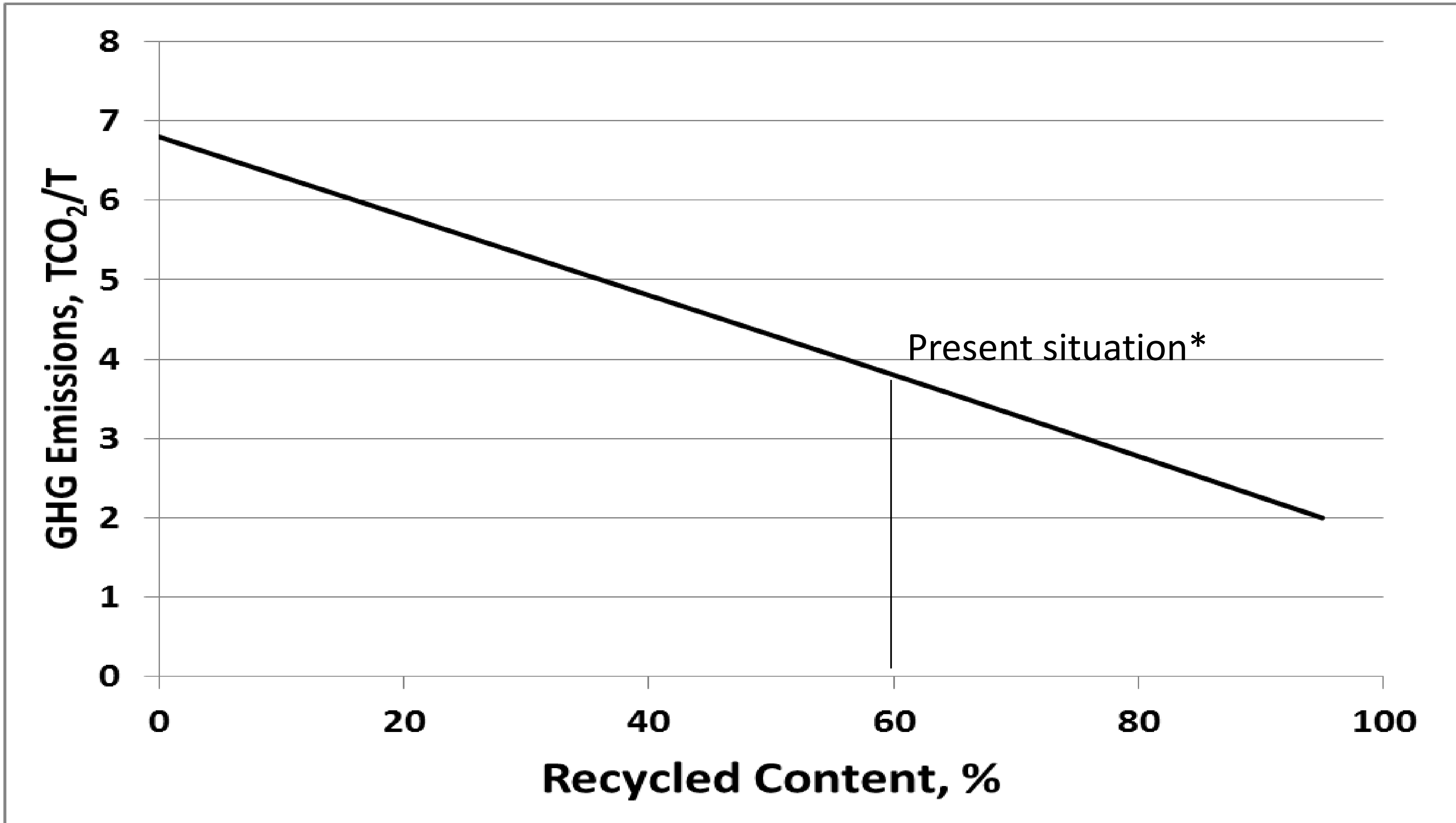


Life cycle of stainless steel
in 2010. (YaleUniversity/ISSF
stainless steel project 2013)

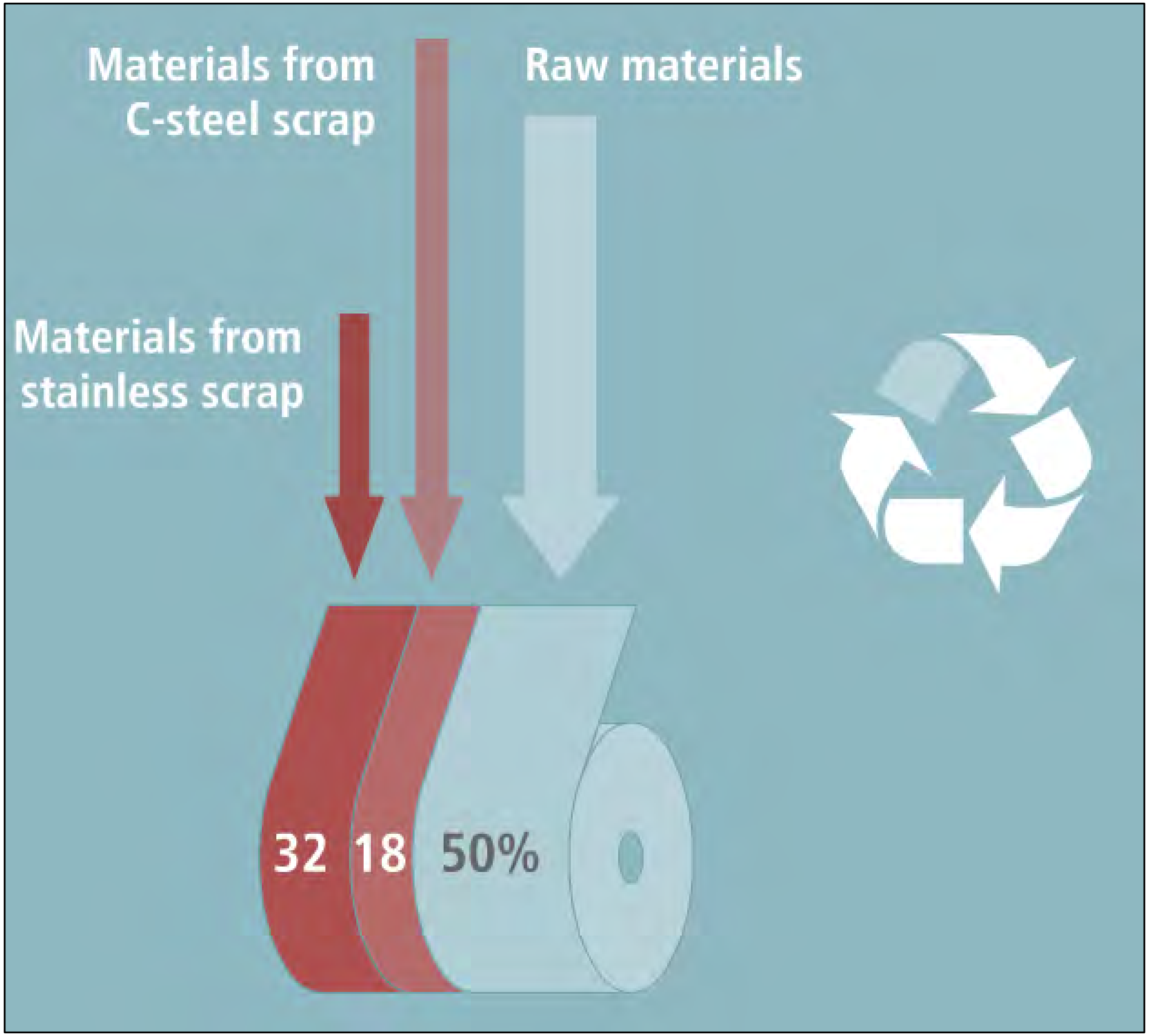
More on Use and Recycling [15, 23-25]

End Use Sector	Average lifetime (in years)	To landfill	Collected for recycling		
			Total	As stainless steel	As carbon steel
Building and infrastructure	50	8%	92%	95%	5%
Transportation (passenger cars)	14	13%	87%	85%	15%
Transportations (others)	30				
Industrial Machinery	25	8%	92%	95%	5%
Household Appliances and Electronics	15	30%	70%	95%	5%
Metal Goods	15	40%	60%	80%	20%

GHG Emissions vs. Recycled content [11, 12, 13, 14]



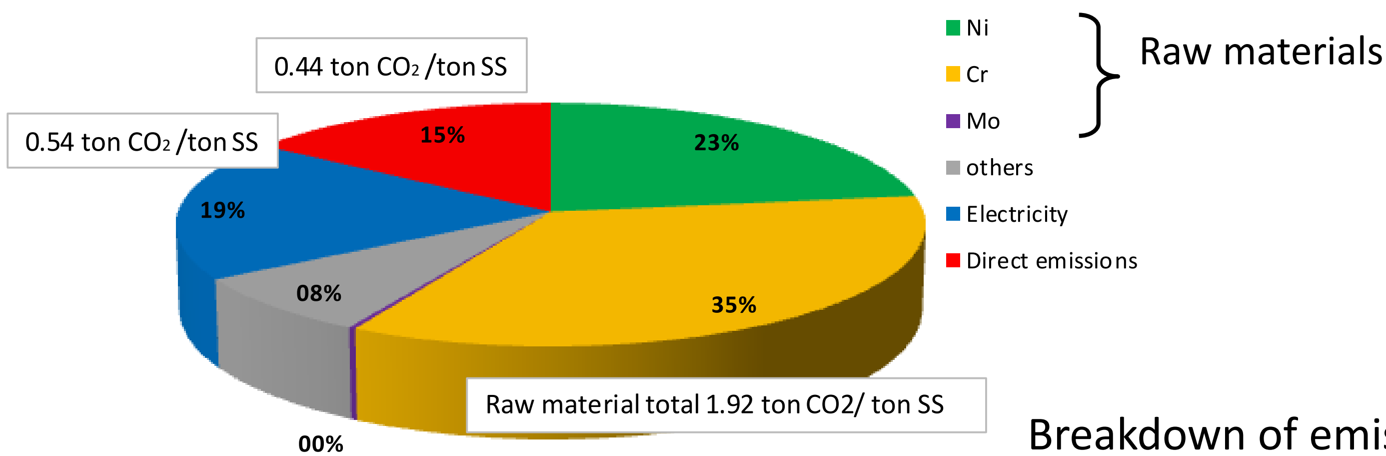
* The recycled content is limited by scrap availability



Recycled content of stainless steel

Greenhouse Gas Emissions for Stainless steel [15]

3.3 ton CO_2/ ton Stainless Steel [16]

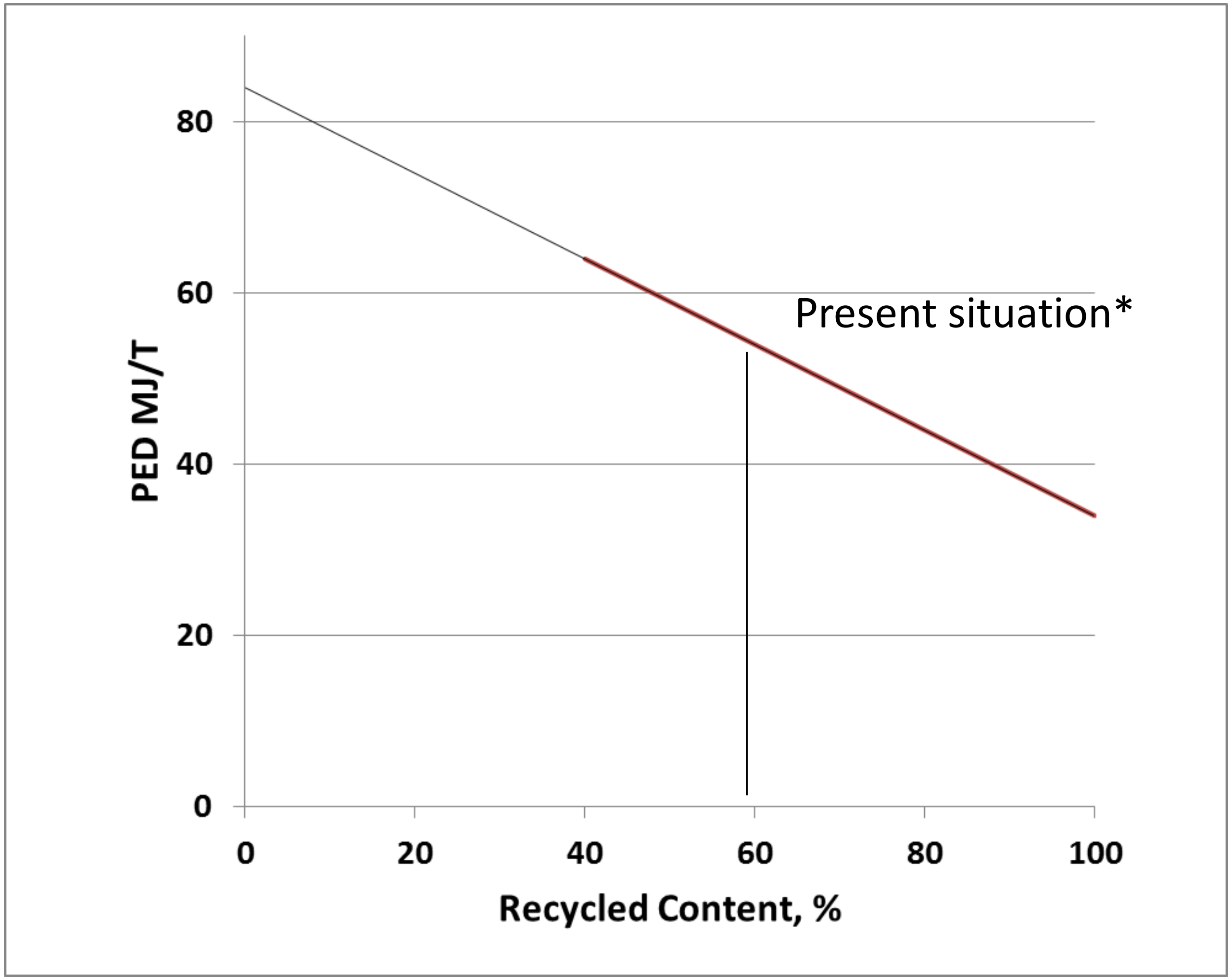


Breakdown of emissions:

- Raw Materials: ~58 %
- Electricity Generation: ~19 %
- Steelmaking: ~15% (17)

Note: This does not take into account Nickel produced by the Nickel Pig Iron Route, for which the figure for Ni is believed to be about 3 times higher. China is currently the only country using Nickel Pig iron

Primary Energy Demand [18]



* The recycled content is limited by scrap availability

Environmental impacts for "cradle-to-gate" metal production [19]

Metal	Process	GER (MJ/kg)	GWP (kg CO_{2e}/kg)	AP (kg SO_{2e}/kg)	SWB (kg/kg)
Stainless Steel	Electric furnace and Argon – Oxygen Decarburization	75	6.8	0.051	6.4
Steel	Integrated route (BF and BOF)	23	2.3	0.020	2.4
Aluminium	Bayer refining, Hall-Heroult smelting	361	35.7	0.230	16.9
Copper	Smelting/converting and electro-refining	33	3.3	0.040	64
	Heap leaching and SX/EW	64	6.2	-	125

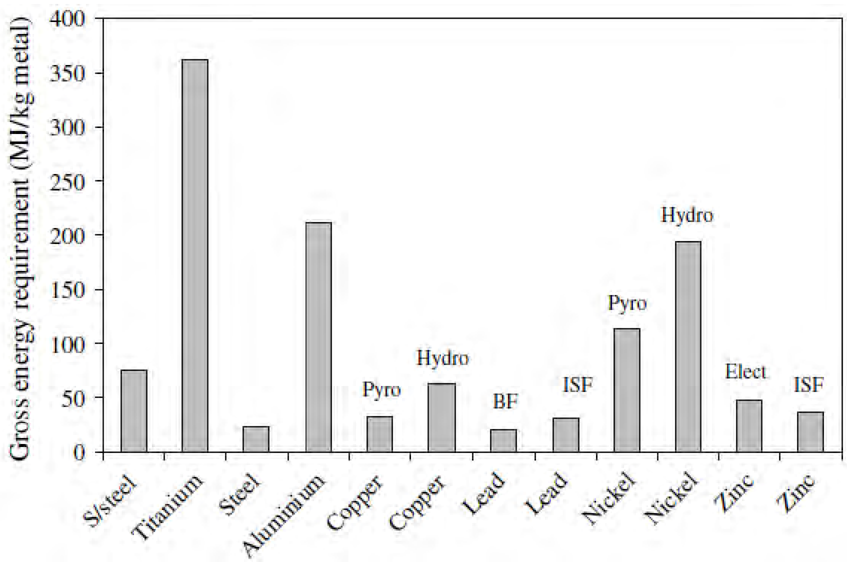
GER: Gross Energy Requirement
GWP: Global Warming
Potential AP: Acidification Potential
SWB: Solid Wast Burden

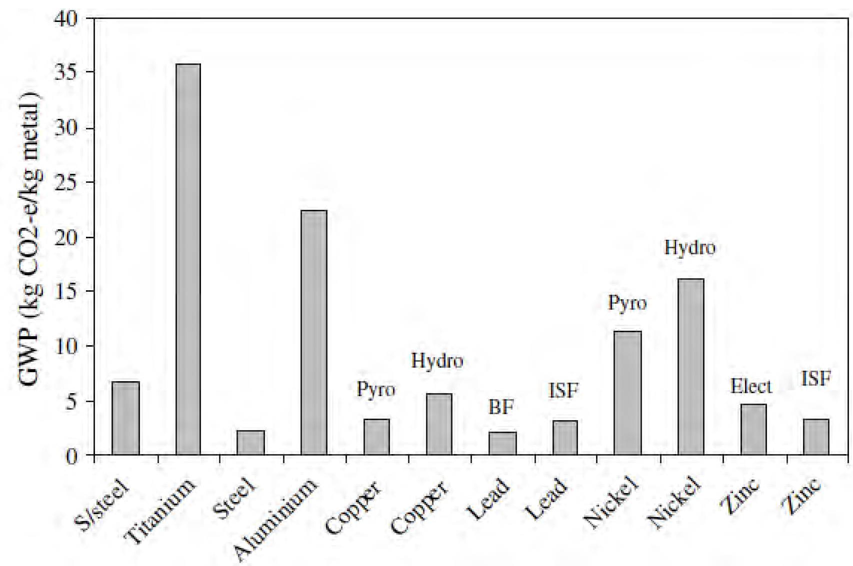
Environmental impacts for "cradle-to-gate" metal production[20]

Gross Energy Requirement for "cradle-to-gate" production of various metals

Global Warming Potential for "cradle-to-gate" production of various metals

(without any recycled content)





Materials are not used in the same quantity for a similar function or service [21]

Example:

Indicative environmental potential impacts for 3 different wall finishes.

Material	PED (MJ/m^2)	GWP ($Kg_{CO_2\text{-eq.}}/m^2$)	End-of-Life (EOL) scenario
High pressure laminate such as Trespa®	759.3	23.9	50% reuse + 50% landfill
Generic stucco	144.2	12.7	Not recycled
Stainless Steel 0.5mm	140.5	7.2	RR = 95%
Stainless Steel 0.8 mm	191.7	11.3	RR = 95%

Materials Efficiency

Reduce:

the quantity of raw material to produce Stainless Steel. (40%), consequently the CO_2 emission decreases.

Reuse:

The durability of stainless steels makes reuse very important.

Examples: Bottles, mugs, cups, straws…

Single use of plastics is increasingly banned

Example: Reuse [22]

The Stainless Steel panels had become dirty and scratched after about 50 years use. During renovation of the lobby, the 50-year old stainless steel panels were removed, cleaned, refinished and reused.

Materials Efficiency

Recycle:

Stainless Steel is 100% recyclable, all the scrap collected (82%) is reused.

Zero-waste stainless steel production ⇨ Slag and dust are the main by-products and waste which result from steelmaking. Example: Slag products can be used in the asphalt for road construction.

LEED* and Stainless LCI Data

- U.S. Green Building Council released "*Leadership in Energy and Environmental Design" version 4 (LEED v4) in 2013
  - New version includes changes that are favorable to stainless:
    - Greater emphasis on service life
    - Tighter requirements on VOC** emissions (a problem for some materials such as plastics)
- U.S. General Services Administration (manages US government buildings and properties) recently endorsed the use of LEED
  - State and local governments increasingly require LEED or similar certifications for new buildings or modifications

** VOC: Volatile Organic Compounds: for Stainless Steel, very small emissions during processing&fabrication (no data available yet) and none during use

Sustainable building with Stainless steel - The David L. Lawrence Convention Center, Pittsburgh (2003) [26]

Stainless steel roof:

- S30400 stainless steel
- Measuring: 280 × 96m
- Sheathed with 23,000m2 of 0.6mm (24-gauge), weighing about 136 tonnes.

Sustainable building with Stainless steel: the Gold LEED status

The Gold **LEED** (Leadership in Energy and Environment Design) status recognizes:

- the centre's brownfield redevelopment
- accommodation of alternative transportation
- reduced water use
- efficient energy performance
- use of materials that emit no or low amounts of toxins
- innovative design

Sustainable Civil Works with Stainless: The Progreso Pier [27]

At Progreso, Mexico, a pier was built in 1970. The marine environment made the carbon steel rebar corrode – the structure failed.

Sustainable Civil Works with Stainless:
The Progreso Pier

The neighbouring pier had been erected in 1937 – 1941 using stainless steel reinforcement.

Sustainable Civil Works with Stainless: The Progreso Pier

Ever since then, it has been maintenance free and remained in pristine condition.

2. Social

A sustainable material does not harm the people working to produce it, or who handle it during its use, recycling and ultimate disposal.

- Stainless steel is not harmful to people during either its production or use. For these reasons, stainless steels are the primary material in medical, foodprocessing, household and catering applications.

- The safety like injury-free and healthy workplace of the employees is the key priority for the stainless steel industry.

- Stainless steel also improves the quality of life by making technical advances possible. For example the installations that provide us with clean drinking water, food and medication would not be nearly as hygienic and efficient as they are without stainless steel.

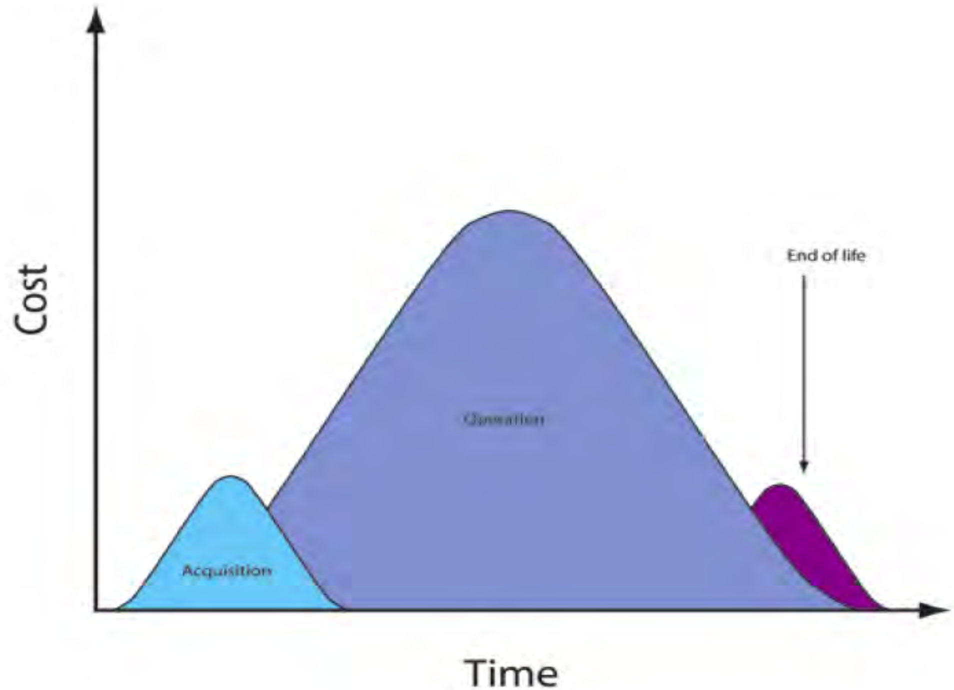
3. Economic

300,000
People directly or indirectly employed in the stainless steel industry worldwide
US$130 billion
Turnover of the global stainless industry, 2010
5,85% average increase in production each year since 1970
100% recyclable forever
45 million tonnes stainless steel fabricated in 2016

Life Cycle Costing (LCC) [30]

- LCC is the cost of an asset throughout its life cycle, while fulfilling the performance requirements (ISO 15686-5).
- LCC is the sum of all cost related to a product incurred during the life cycle:

conception ⇨ fabrication ⇨ operation ⇨ end-of-life



Source: Methodology of life cycle costing, European commission

Life Cycle Costing (LCC)

LCC is a mathematical procedure helping to make investment decisions and/or compare different investment options.

All Costs at Present Value Before Addition:

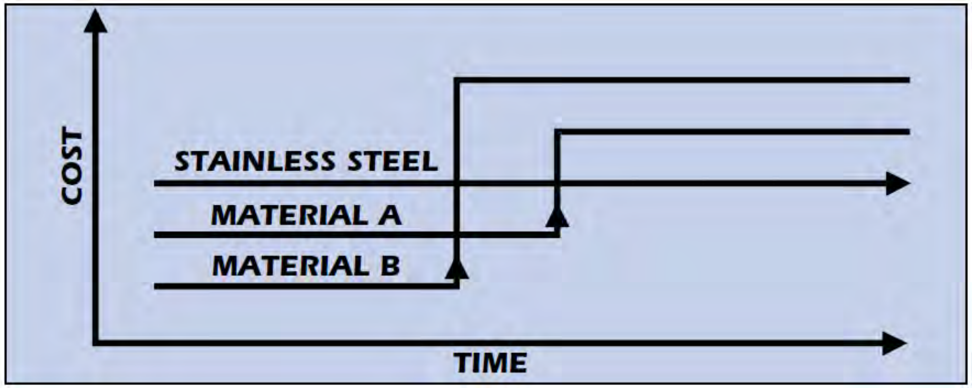
Total life cycle cost (LCC)		Initial materials acquisition costs (AC)		Initial materials installation & fabrication costs (IC)		Operating & maintenance costs (OC)		Lost production costs during down-time (LP)		Replacement materials costs (RC)
LCC	=	AC	+	IC	+	$\sum_{n=1}^{N} \frac{OC}{(1+i)^n}$	+	$\sum_{n=1}^{N} \frac{LP}{(1+i)^n}$	+	$\sum_{n=1}^{N} \frac{RC}{(1+i)^n}$

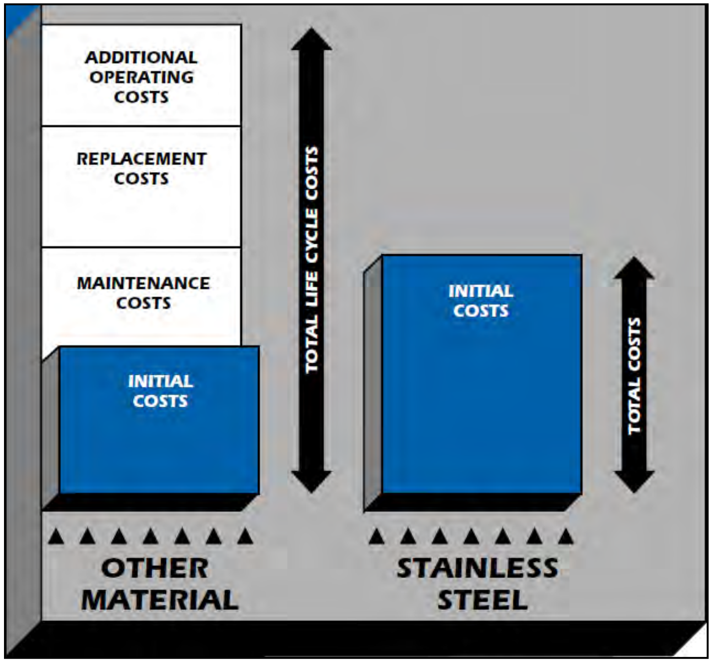
$$LCC = AC + IC + \sum_{n=1}^{N} \frac{OC}{(1+i)^n} + \sum_{n=1}^{N} \frac{LP}{(1+i)^n} + \sum_{n=1}^{N} \frac{RC}{(1+i)^n}$$

Where: **N** = Desired service life **i** = Real interest rate **n** = Year of the event

Stainless steel is not expensive if the life cycle cost is taken into account [31]

The cost of other materials substantially increases over time while the cost of stainless steel normally remains constant.

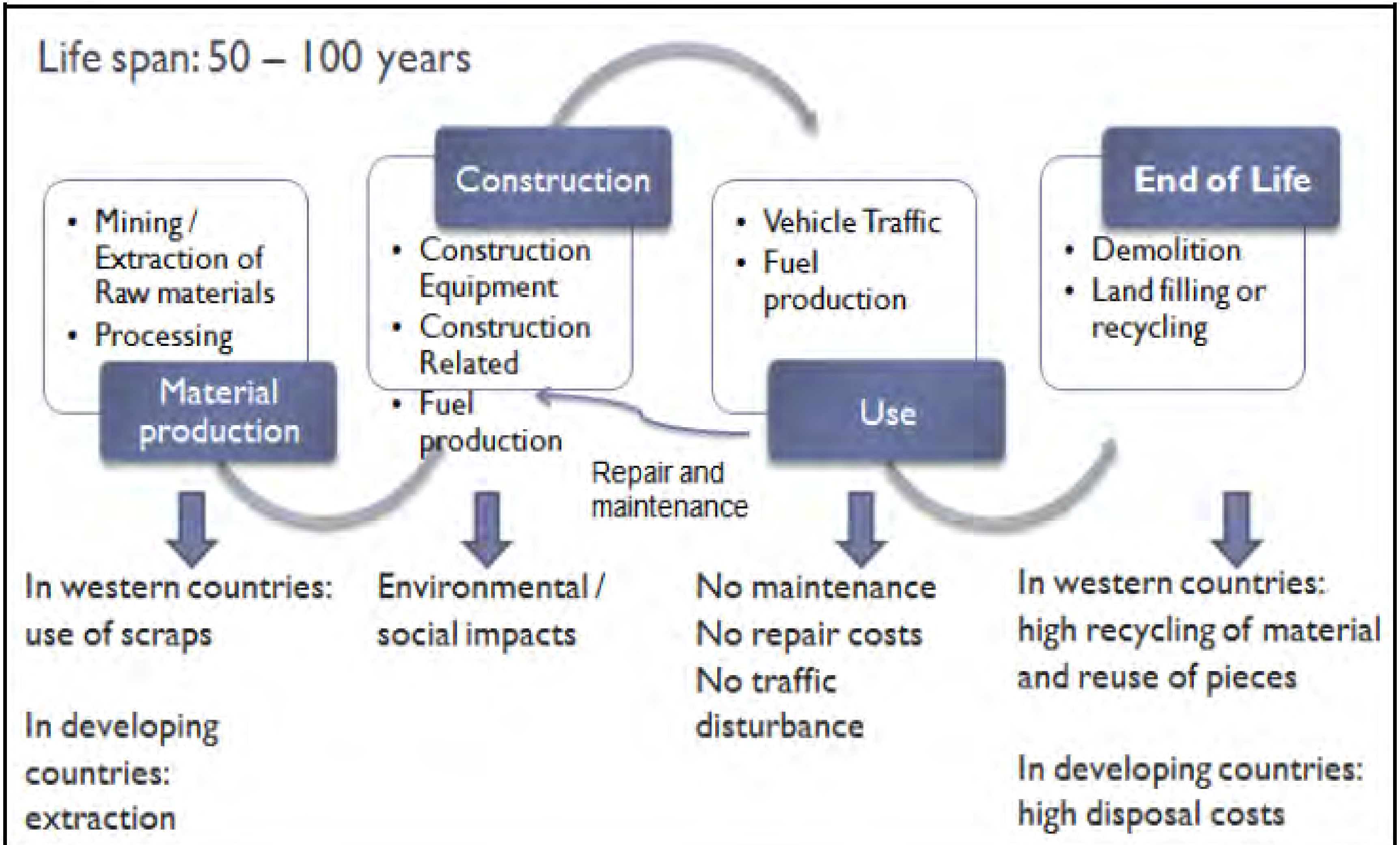




“Corrosion of metals costs the United States economy over $300 billion annually. It is estimated that about one-third of this cost ($100 billion) is avoidable by use of best known technology. This begins with design, selection of anti-corrosion materials like stainless steel, and quantifying initial and future costs including maintenance by Life Cycle Costing/LCC techniques. ”

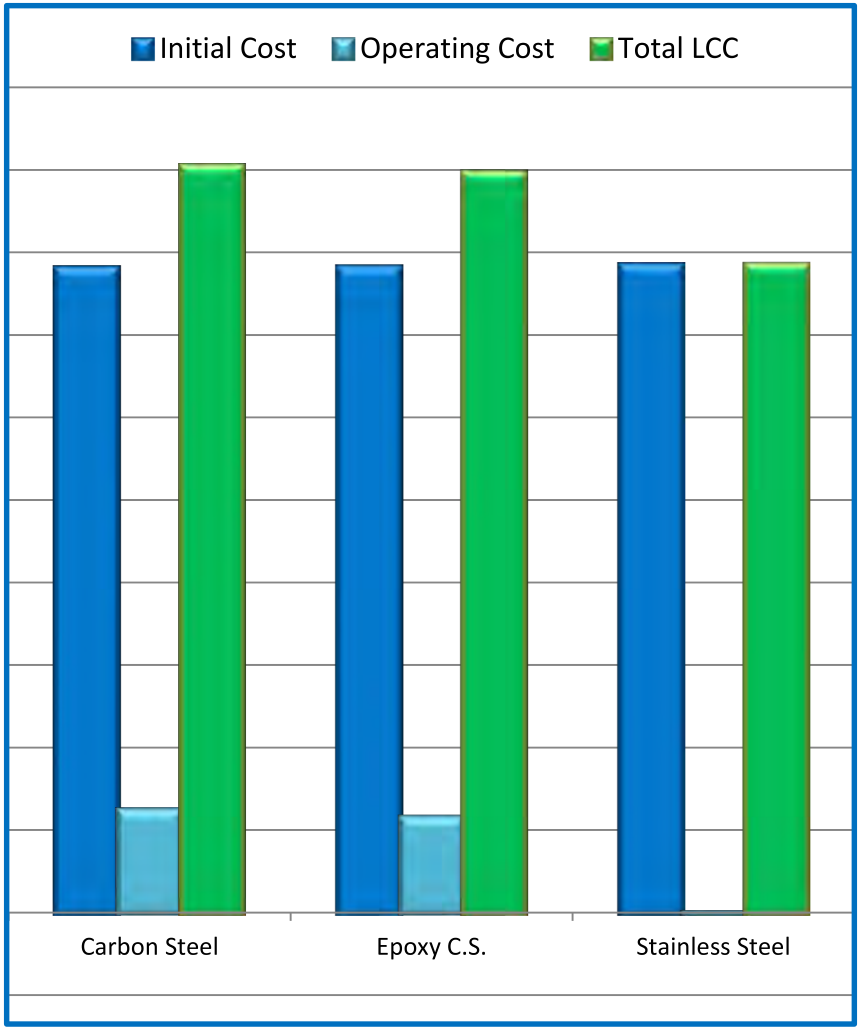
LCC Example: Bridges

Example of stainless steel bridge life cycle phases and its impacts on the environment in different areas of the world



LCC Example: Bridge

Life cycle cost summary of a reinforced concrete highway bridge [32]



Description	Carbon Steel	Epoxy C.S.	Stainless Steel
Material Costs	8,197	31,420	88,646
Fabrication Costs	0	0	0
Other installation costs	15,611,354	15,611,345	15,611,354
Initial Costs	15,619,551	15,642,774	15,700,000
Maintenance	0	0	0
Replacement	256,239	76,872	-141
Lost Production	2,218,524	2,218,524	0
Material related	0	0	0
Operating Costs	2,247,763	2,295,396	-141
Total LCC (USD)	**18,094,314**	**17,937,170**	**15,699,859**

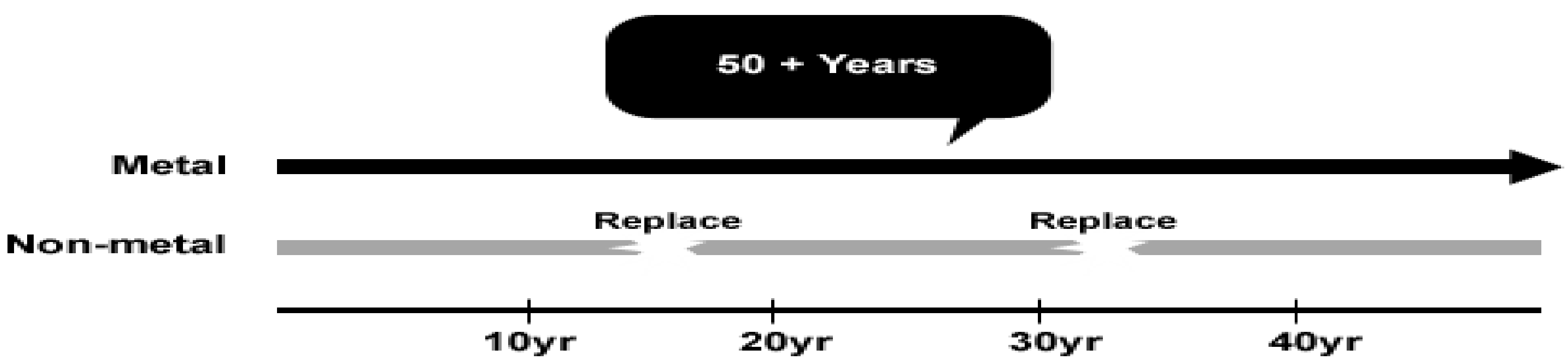
LCC Example: Roofing

Life cycle cost of a roof [33, 34, 35]

Conventional roofing systems, ~30 years

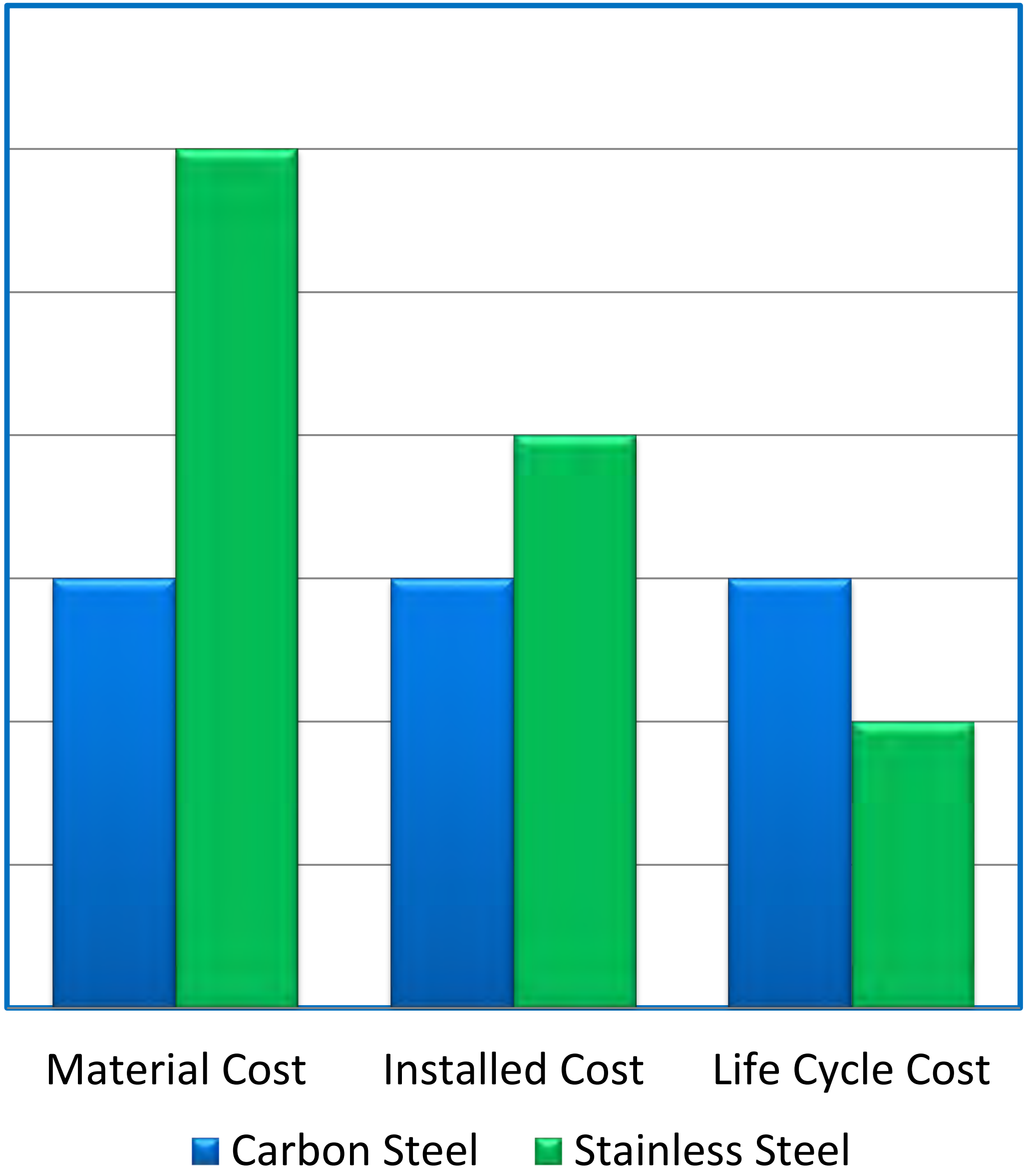
metal roofing system, 40-50 years

Stainless steel roofing system , more than 50 years



LCC Example: Roofing

Cost comparison of 0.6 mm coated galvanised carbon steel and 0.4 mm stainless steel grade 1.4401: Due to the mechanical properties of stainless steels, the material thickness can be reduced to 0.5 or 0.4 mm, providing a lighter weight (4,68 kg/m² for 0.7 mm coated carbon steel, 3,12 kg/m² for stainless steel). While coated carbon steel has a life expectation of 15 to 20 years, the service life of a stainless steel roof is generally that of the building.



Timeless Stainless Steel Architecture[43]

Savoy hotel, London, 1929

Empire State building, New York, 1931

Chrysler Building, New York, 1930

Helix Bridge, Singapore, 2011

Petronas Towers, Kuala Lumpur

Cloud Gate “Jelly Bean”, Chicago, 2008

Comparison of Life Cycle Costing [36, 37, 38, 39, 40]

Monument	Completed	Material	Height	Maintenance
Eiffel Tower – Paris 	1889 	Wrought iron	324m	Every 7 years. Every painting campaign lasts for about a year and a half (15 months). 50 to 60 tons of paint, 25 painters, 1500 brushes, 5000 sanding disks and 1500 sets of work clothes.
Chrysler Building (Roof and Entrance) – New York 	1930 (roof 1929) 	Austenitic Stainless Steel (302)	319m	Twice in 1951, 1961. The 1961 cleaning solution is unknown. A mild detergent, degreaser and abrasive were used in 1995.

What makes Stainless Steel **"Green"**?

Stainless Steel Environmental Evaluation [41]

What is the recycled content?	60%
Is it 100% recyclable?	Yes
Does it provide long life?	Yes (reduces maintenance and disposal frequency)
Is there recycled content?	Yes (both post-consumer and post-industrial)
Is construction waste diverted from landfills?	Yes (high scrap value and product reuse potential)
Can it be salvaged and reused during renovations?	Yes
Is it a low emitting material?	Yes (no coatings = zero emissions)
Can it help to improve indoor air quality?	Yes (no volatile organic compounds (VOCs), bacteria removal, corrosion resistant ductwork)
Does it help to avoid the use of toxic materials?	Yes (long lasting termite barriers, minimal roof run-off)
Can it save energy?	Yes (sunscreens, roofing, balcony inserts)
Can it help generate clean energy?	Yes (solar panels, power plant scrubbers)
Can it conserve water?	Yes (corrosion and earthquake resistant water lines and tanks)
Can reflective panels add natural light?	Yes
Can it extend the life of other materials?	Yes (stone and masonry anchors, fasteners for wood and metals sch as Al)

CONCLUSIONS

- Sustainability is a big and important challenge for the future in the stainless steel industry. Efforts has been done to reduce it Carbon footprint by increasing recyclability and improving processes.
- Stainless steel have a combination of properties which should be taking account in the decision making process at the design state:
  - Mechanical properties
  - Corrosion resistance properties
  - Fire resistance
  - Recyclability
  - Long life
  - Low maintenance costs
  - Neutrality and Hygienic
  - Aesthetics
  - Neutrality to rain water

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Thank you

Appendix
Recycling of other materials

This is a complex issue
This aims at giving a few ideas on other materials,
for comparison purposes
Sources are indicated

More on recycling: Cement and Concrete

www.wbcsdservers.org/wbcsdpublications/cd_files/datas/business-solutions/cement/pdf/CSI-RecyclingConcrete-FullReport.pdf

- 20% maximum of crushed concrete can be used in new concrete.
  - as aggregates only, not as cement
  - the concrete thus produced is a lower quality product, not suitable for all applications
- It seems that most of the concrete after demolition goes into road beds and landfill (no detailed figures are available)
- Crushing old concrete and transportation are the main operations in recycling, to be compared with getting aggregates locally.
- 0verall, recycling involves everytime downcycling.
- Re-using concrete as blocks after demolition is only marginal today, but could provide the shortest route to re-use without downcycling. Not easy to implement, though!

More on recycling: plastics

http://www-g.eng.cam.ac.uk/impee/?section=topics&topic=RecyclePlastics&page=materials

- In-house scrap (generated at the source of production) is near-100% recycled already
- Recycling of used plastics is a big problem:
  - Collection is time-intensive, so expensive
  - Sorting of mixed plastic waste is difficult – contamination is inevitable.
  - Removing labels, print, all but impossible at 100% success rate
  - Contamination of any sort compromises re-use in "hi-tech" applications

=> recycled plastic (apart from in-house) is reused in lower-grade applications (downcycling): PET: cheap carpets, fleeces; PE and PP: block board, park benches.

=> and/or will be eventually burned or worse landfilled or even worse left floating on oceans.

More on recycling: Wood (from ABC*)

- The best recycling option is, of course, to re-use it. It appears that there is a lot of effort going on to collect, recondition and re-manufacture timber and other wood products. How much is re-used is not clear.
- Untreated timber and wood has found an increasing number of new uses: land and horticultural products, animal beddings, equestrian arena surfaces …
- Treated timber& wood (the chemical treatment prevents rot, fungi, insects and UV damage) contains harmful chemicals, which strongly limit their use. The largest use has been so far particle board manufacture, but what happens to these boards at their end of life remains unclear.
- It should be pointed out that the overall deforestation going on on the planet does not speak for unlimited sources of new wood, especailly in northern countries in which it takes a century for a tree to grow to its full size
- Cutting down a forest and re-planting trees leaves the topsoil open to erosion for a while, and destroys the ecosystem in the harvested area possibly beyond self repair.
- Last, it has been argued that the carbon neutrality has been achieved only when the re-planted forest is fully grown….some 30 years or more later!

https://dtsc.ca.gov/toxics-in-products/treated-wood-waste/

https://woodrecyclers.org/about-waste-wood/wood-recycling-information/

http://en.wikipedia.org/wiki/Wood_preservation

http://www.wasteminz.org.nz/wp-content/uploads/Scott-Rhodes.pdf

http://www.brighthub.com/environment/green-living/articles/106146.aspx

*ABC: Architecture, Building and Construction

Thank you!

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6