Stronger Steels in the Built Environment

Structural Response & Application of S460 to S700 Hot Rolled & Fabricated Sections

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November 2022

Introducing the Steel Construction Institute (SCI)

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- Product development
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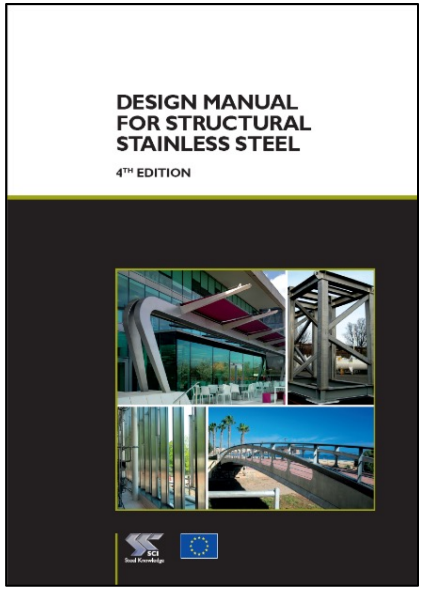
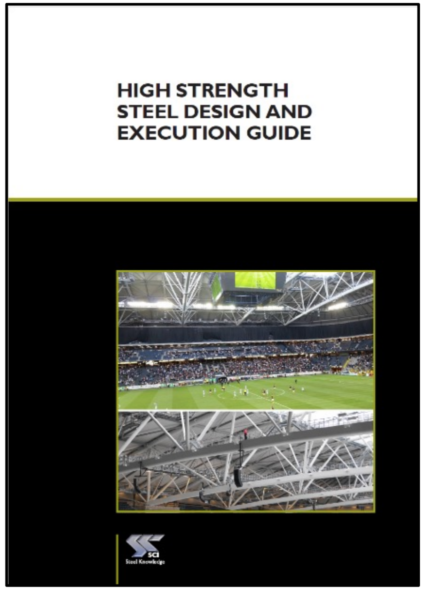
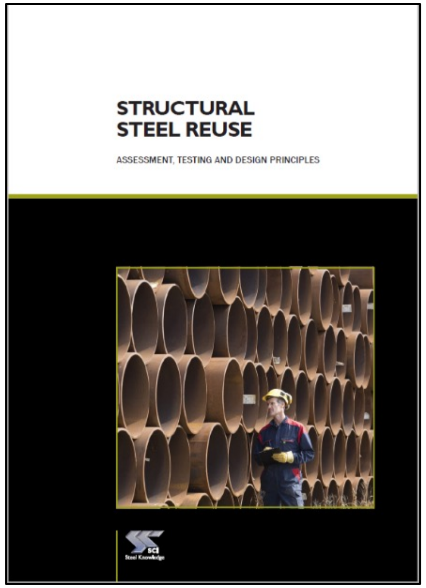
- Research & Testing
- Engineering software
- Advisory Service
- Problem resolution







Outline

- Overview of HSS in construction
- HSS in construction standards
- Outcomes of HSS European Research

In this presentation HSS are steels with f_y > 355 MPa

HSS in structures: Drivers & Challenges

Drivers

- Material (& carbon) savings
- Lighter supporting structure
- Reduced welding effort
- Easier transportation and handling
- More usable space

HSS will be beneficial in certain applications – it is not a solution for everything!

Challenges

- Greater tendency to unstable failure modes
- Deflection and vibration criteria more likely to become critical
- No benefit where fatigue is critical
- Minimum order size/Longer lead times/Limited suppliers

Transitioning to HSS

In the UK….

- 25 years ago, S275 was the steel choice for structural engineers
- Today, S355 is the ‘default’ structural grade
- S275 is not routinely made, and is considered a “special order”
- Market share of S420/S460 is small but growing, especially for columns & in bridges

Change is slow in long supply chains, like construction

New challenges in designing structures: resilience, sustainability, robustness, efficiency

Typical uses of HSS in construction (1/3)

High rise construction

- Columns (low/medium slenderness)
- Lateral stability systems
- Transfer beams
- Bracing
- Hollow filled sections
- Piles

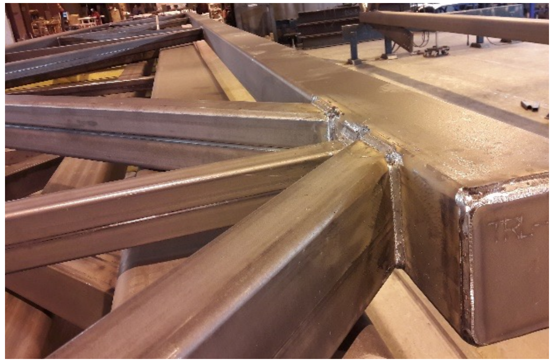
As height increases, vertical forces in columns & foundations increase, HSS resists high loads with minimal footprint

Typical uses of HSS in construction (2/3)

Long span structures (airports, stations, stadia)

- Tension chords
- Tension bracing members in trusses/compression members with short buckling length

- Less stringent deflections limits because the overall height is large, and stiffness can be increased by increasing truss depth
- Structure deadweight is a considerable proportion of the design



16 m span car park roof beams: S235 vs S460:

- 24% reduction in weight
- 17% reduction in cost

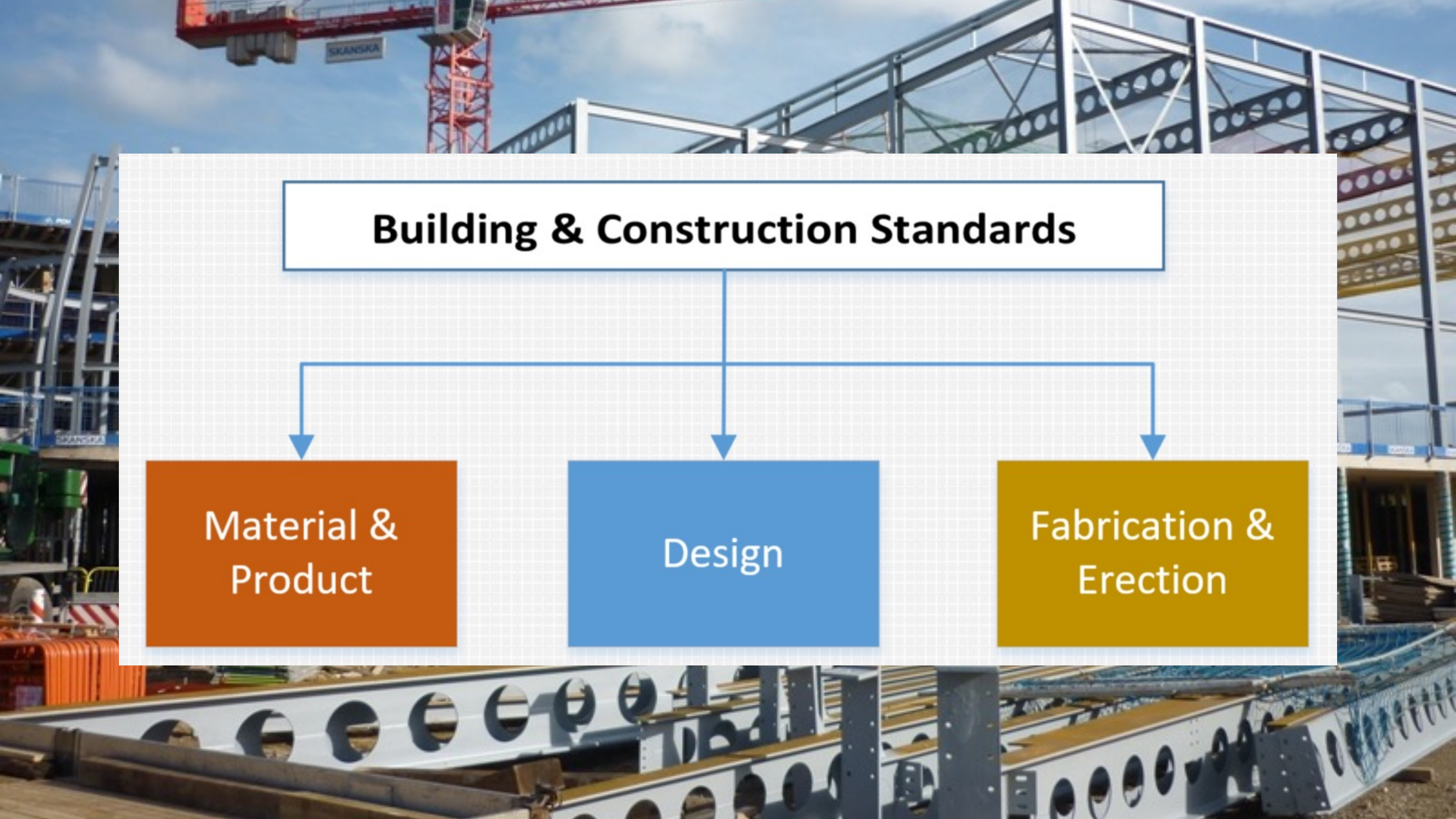
[Sustainable building thanks to high strength steels (arcelormittal.com)]

Typical uses of HSS in construction (3/3)

Bridges

- Tension zones of long spans
- Truss bridges
- Hybrid bridge girders

Reduction in deck weight is a priority for long span bridges (more important than reduction in fabrication costs)


Building & Construction Standards
Material & Product
Design
Fabrication & Erection

What products are available in HSS?

- Hot rolled I shapes, channels, angles:
  S500 (M) EN 10025-4
- Plates:
  S960 (Q) EN 10025-6
- Weathering steel:
  S460W EN 10025-5
- Hollow sections:
  S960 (NH, MH, QH) EN 10210 & EN 10219
- Hot rolled flat products for cold forming:
  S960 (NC, MC) EN 10149

What design rules are available for HSS?

Now:

EN 1993-1-1: S235 to S460

EN 1993-1-12: S500 to S700 ←

- Less strict ductility requirements
- Same column buckling curve as S460
- Restrictions on plastic analysis
- Restrictions on connection design methods utilising large plastic deformations

Second Generation Eurocodes:

EN 1993-1-1 S235 to S700

EN 1993-1-12 S700 to S960

HOCHFEST
€7M German steel research programme:
- 15 core projects
- 31 research institutes

What about composite construction?

What execution rules are available for HSS?

- **EN 1090-2 Technical requirements for execution of steel structures**

  Applicable to structural products ≤ S690

  Vaguely applicable up to S960 *“providing that conditions for execution are verified against reliability criteria and any necessary additional requirements are specified”*

  Amendment underway with specific requirements for HSS:

  - Hot processes (welding, thermal cutting, flame straightening)
  - Cold processes (cold forming, punching)

Stronger Steels in the Built Environment (STROBE)

- 4 year collaborative research project 2017 - 2020
- Part funded by the EU's Research Fund for Coal & Steel (RFCS)

RWTH	Aachen, DE
Imperial College	London, UK
University of Coimbra	Coimbra, PT
Dillinger	Dillingen, DE
Hochtief	Frankfurt, DE
SCI	Ascot, UK

Sponsors:

Objectives of STROBE

- New **ductility and toughness** requirements
- Rules for **plastic design** of HSS beams & frames
- Rules for **stability** of HSS members
- Floor vibration analysis tool to assess **dynamic performance** of HSS floors
- Comparative designs (weight, carbon & cost savings)

But why?

- Conservative design rules
- Construction products are available
- Growing demand for sustainable solutions

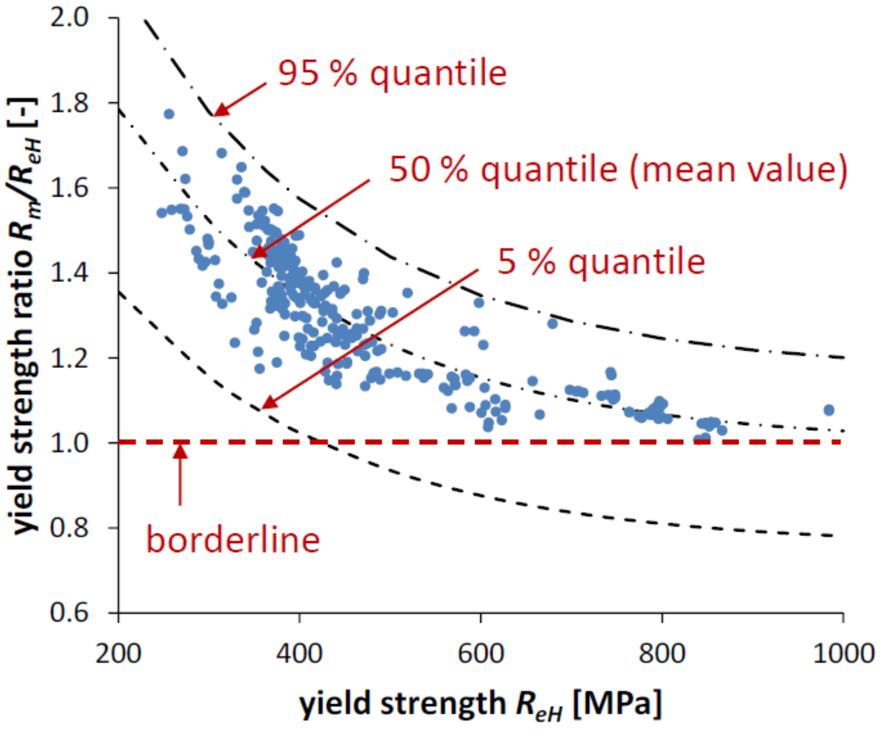
- S460 to S700
- Hot rolled I shapes
- Fabricated I shapes
- Homogeneous & hybrid

Ductility requirements for HSS structures

Database with ca. 300 data sets

- Steel grades S235 - S960
- Thickness t = 4mm – 80mm
- Delivery conditions:
  - non-alloy
  - normalized
  - thermomechanical rolled
  - quenched and tempered

➢ Data:
  - R_{eH}
  - R_m
  - A_u
  - A_L



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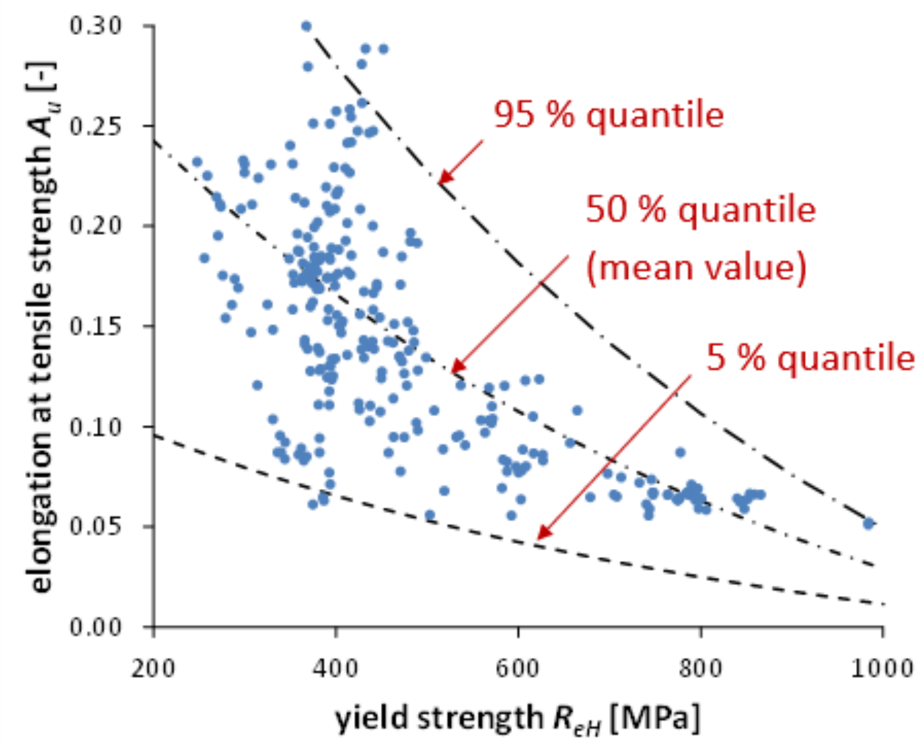

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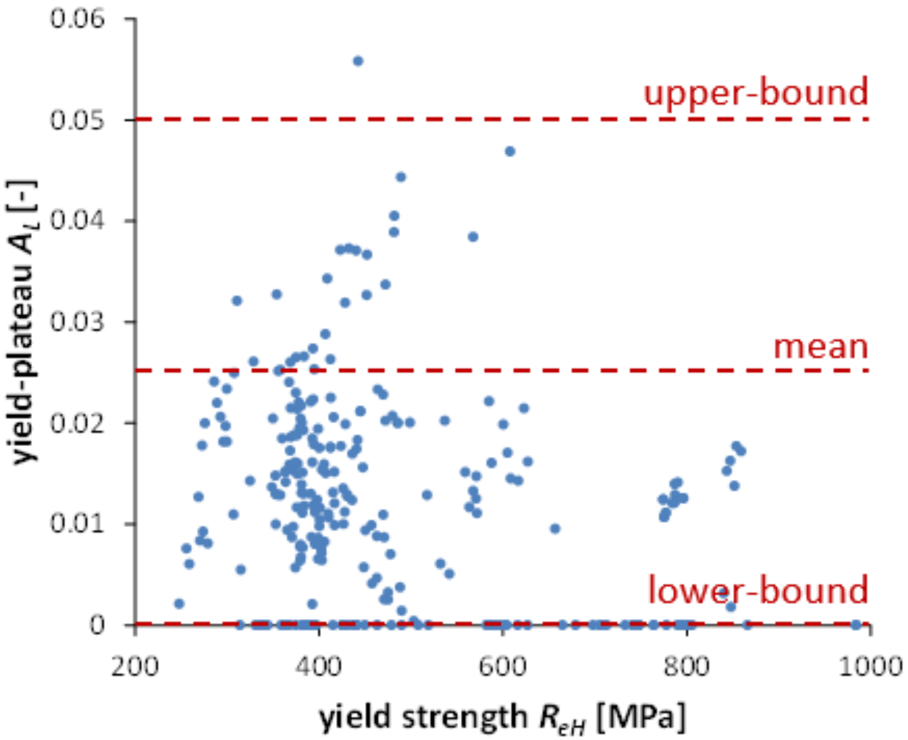


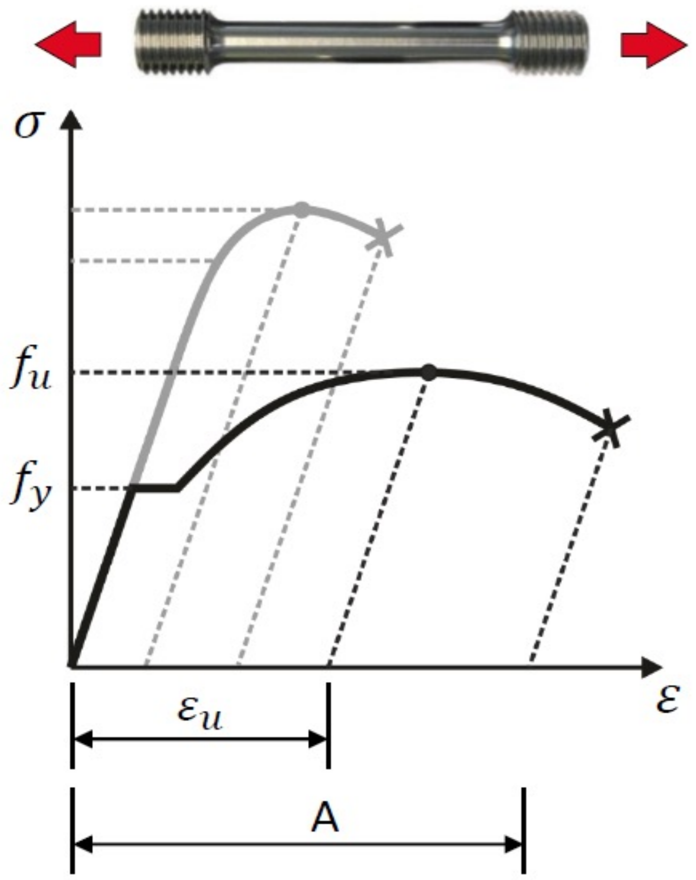
Ductility requirements for HSS structures

Ductility requirements acc. to EC3 (1st Edition)

	≤ S460 (EN 1993-1-1)	≤ S700 (EN 1993-1-12)
f_u/f_y	≥ 1.10	≥ 1.05
A	≥ 15 %	≥ 10 %
ε_u	≥ 15 f_y/E	≥ 15 f_y/E

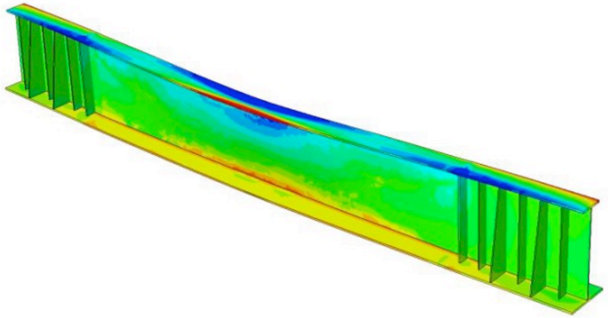
Ductility requirements acc. to EC3 (2nd Edition)

	plastic global analysis	elastic global analysis
f_u/f_y	≥ 1.10	≥ 1.05
A	≥ 15 %	≥ 12 %

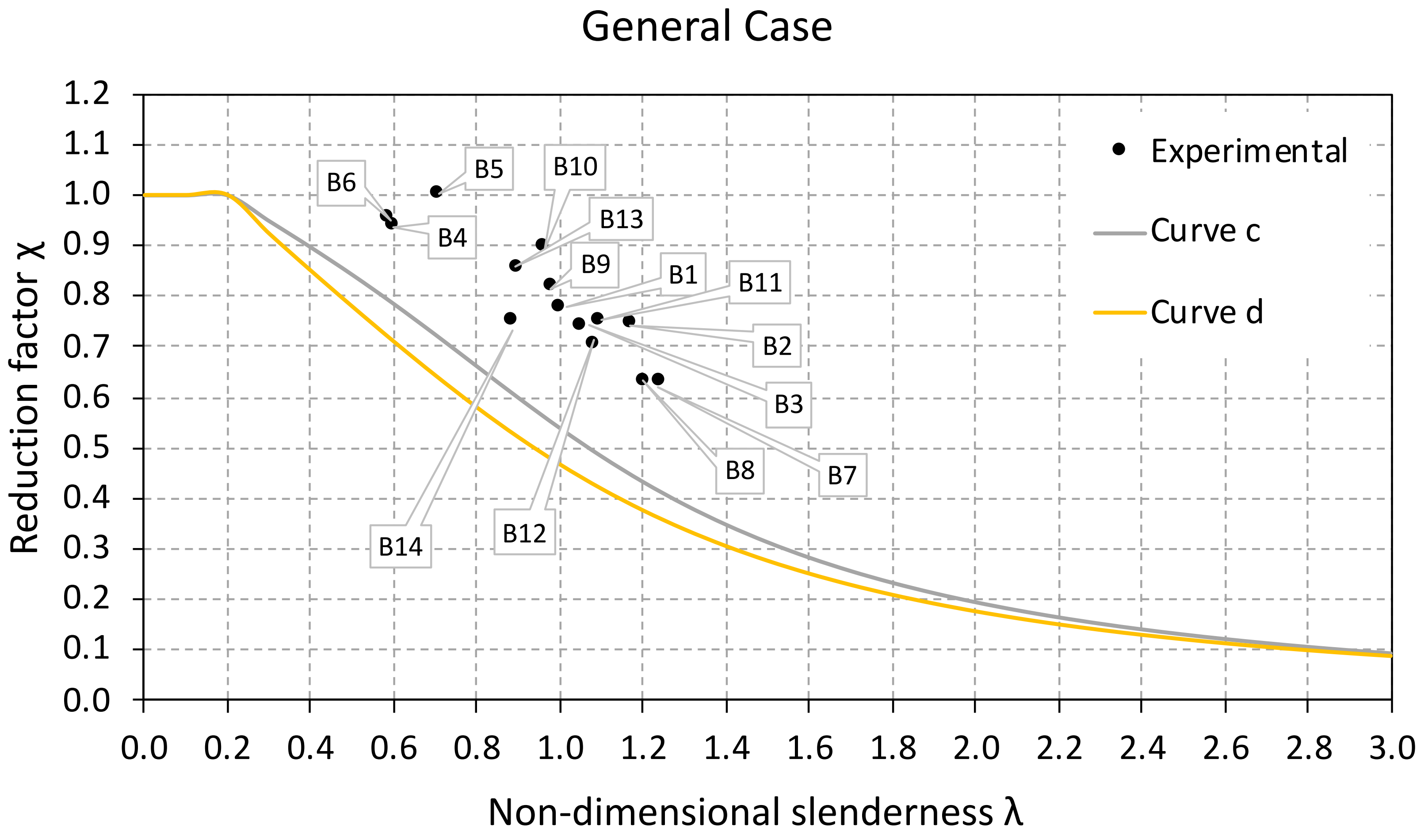


Stability of HSS beams and columns

- Beam and column tests on welded I sections
- Homogeneous and hybrid cross-sections
- Numerical analysis
- Probabilistic reliability analysis
- More general design rules developed and to be included in an amendment to EN 1993-1



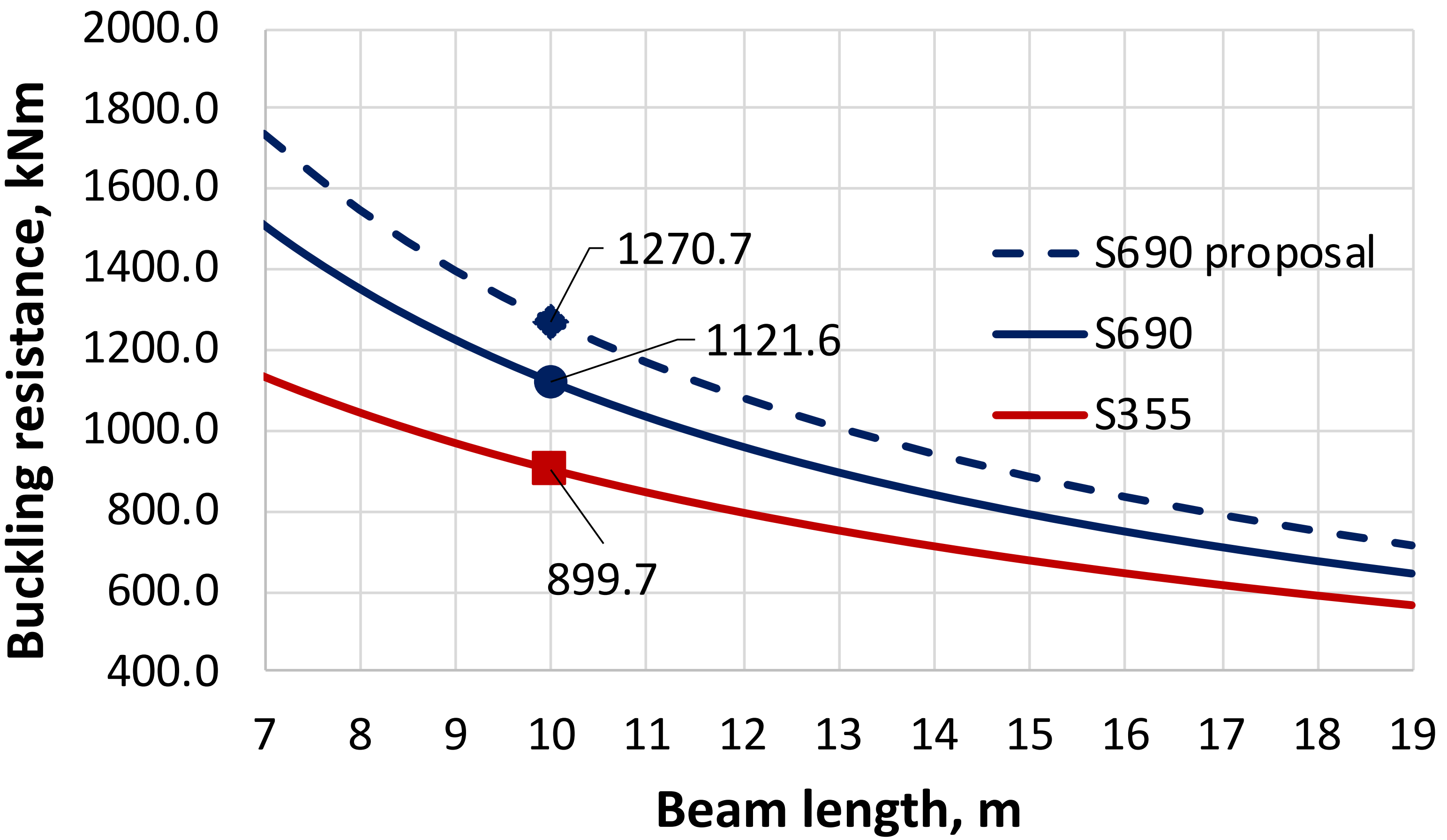
Experimental results - beams

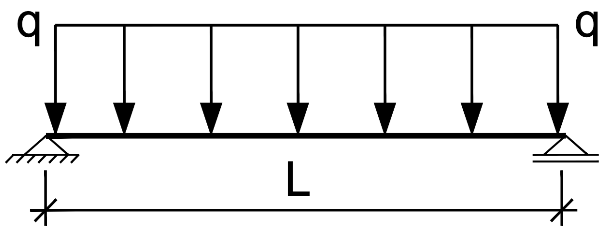


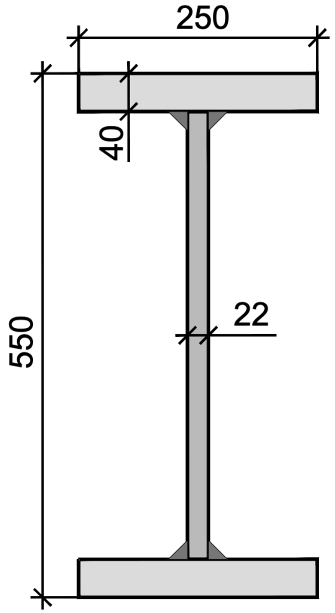
Cross section	Limits	Buckling curve (All)	Recommendation S460 to S700
Rolled I sections	$h/b \leq 2$	a	-
	$h/b > 2$	b	-
Welded Sections	$h/b \leq 2$	c	b
	$h/b > 2$	d	c
Other Sections	-	d	-

STROBE Proposed rules for HSS

Improved design rules for HSS beams







Comparative building designs

- **9m x 9m floor grid in an office building.** *The HSS primary beams are connected to the column flanges and develop partial fixity. They support 2 in-coming S355 secondary beams.*
- **15m x 7.5m floor grid in an office building where the primary beams span support in-coming beams at 3m spacing.** *The HSS primary beams are designed with large web openings and develop partial fixity with the columns. The secondary beams are S355.*
- **15m transfer beams at 6m spacing of 1 to 1.3m depth at first floor level supporting 6 or 8 residential levels above.**
- **4 m tall columns supporting a 9m x 9m floor grid office building 10 and 20 storeys high.**

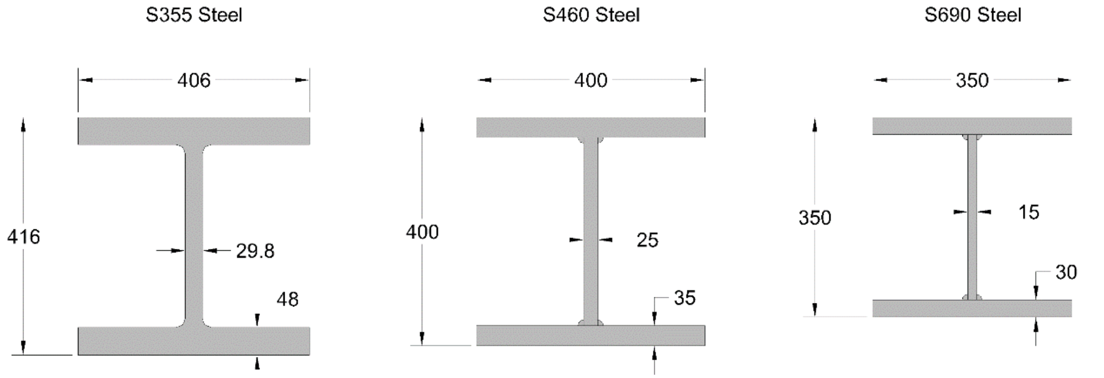
- Weight of steelwork
- Embodied carbon assessment - EN 15804 Modules A, C, D
- Cost - materials, fabrication, transport, erection, construction

S355 - rolled sections and plate girders
S460, S690 - HSS plate girders

- Highly loaded members
- Serviceability not controlling
- Sections relatively stocky so not governed by local buckling

Weight & carbon savings for HSS vs S355 columns in 20-storey 9x9 m office building

	S355 HR	S460 Welded	S690 Welded	S460 HR
Steel material cost	100%	94.8%	87.8%	82.5%
Fabrication cost	100%	173.6%	172.0%	99.5%
Coating cost	100%	95.4%	86.1%	97.5%
Transport cost	100%	73.1%	57.7%	76.9%
Erection cost	100%	100%	100%	100%
Total cost – steelwork	100%	101.2%	94.4%	87.4%
Tonnes	100%	74.6%	56.8%	75.1%
Embodied carbon (module A-C) $kgCO_2e$	100%	87.8%	69.6%	76.4%



HD 400 x 382kg/m
(similar to 356 x 406 x 393kg/m UC)

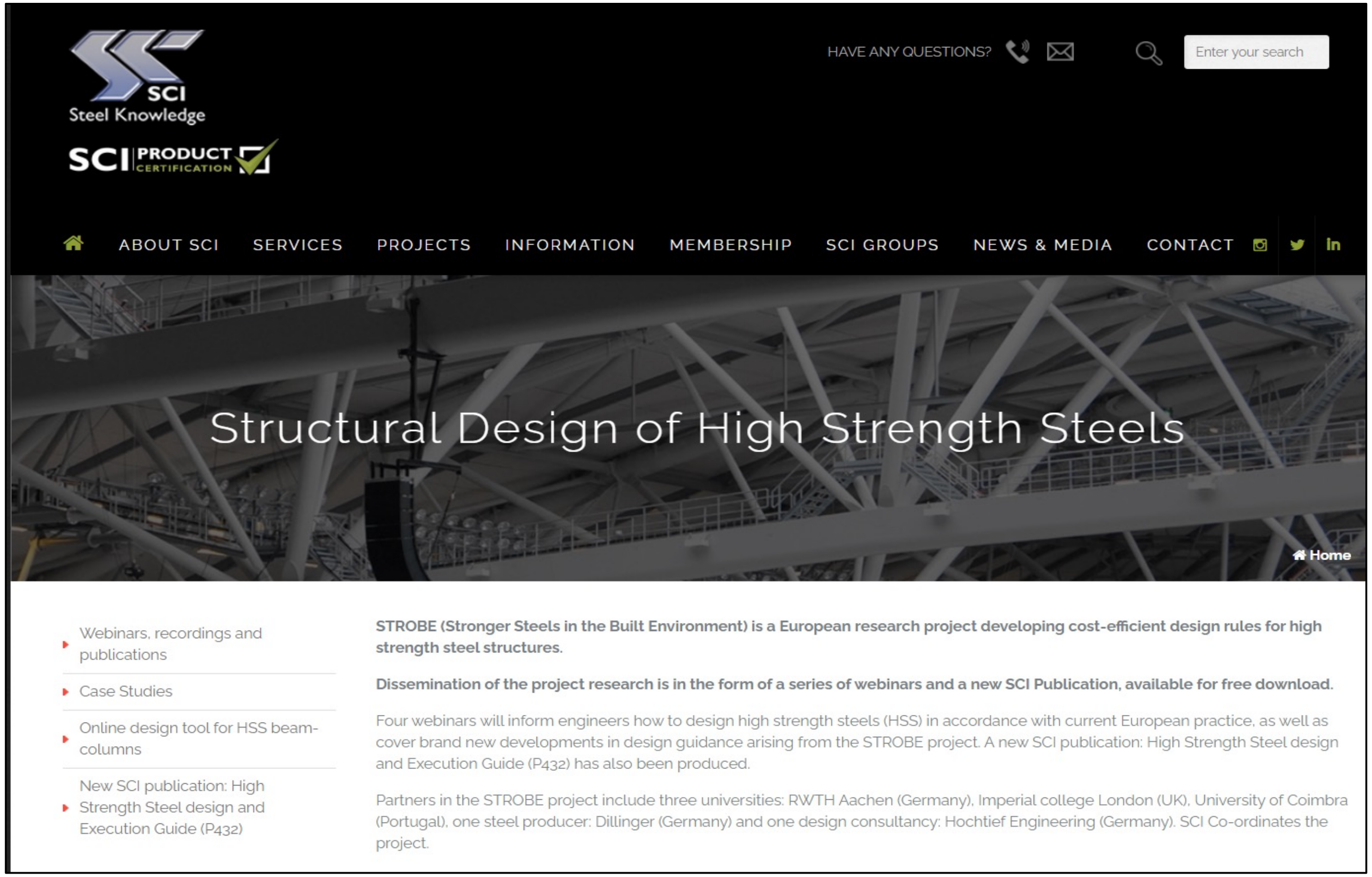
Fabricated Section 285kg/m
(25% reduction)

Fabricated Section 200kg/m
(49% reduction)

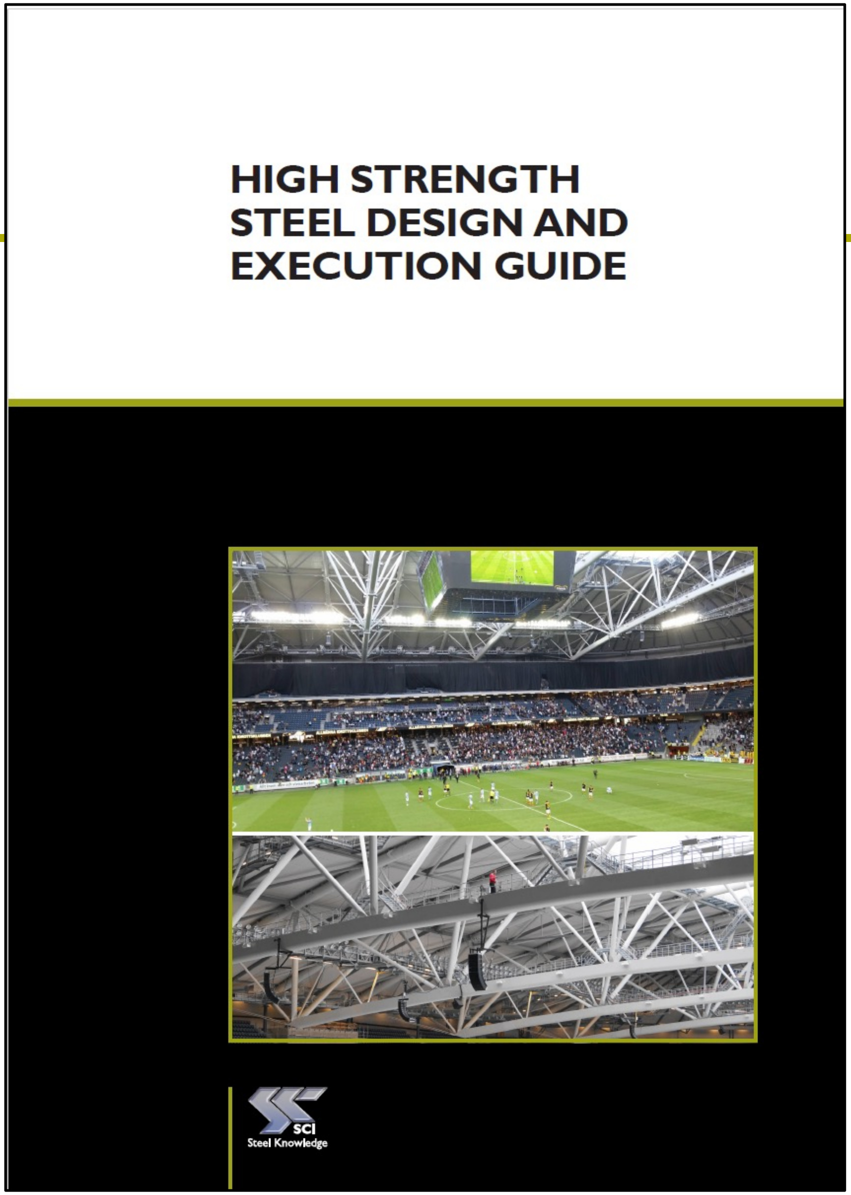
Comparative designs:
Weight and carbon savings relative to S355 (S460 and S690)

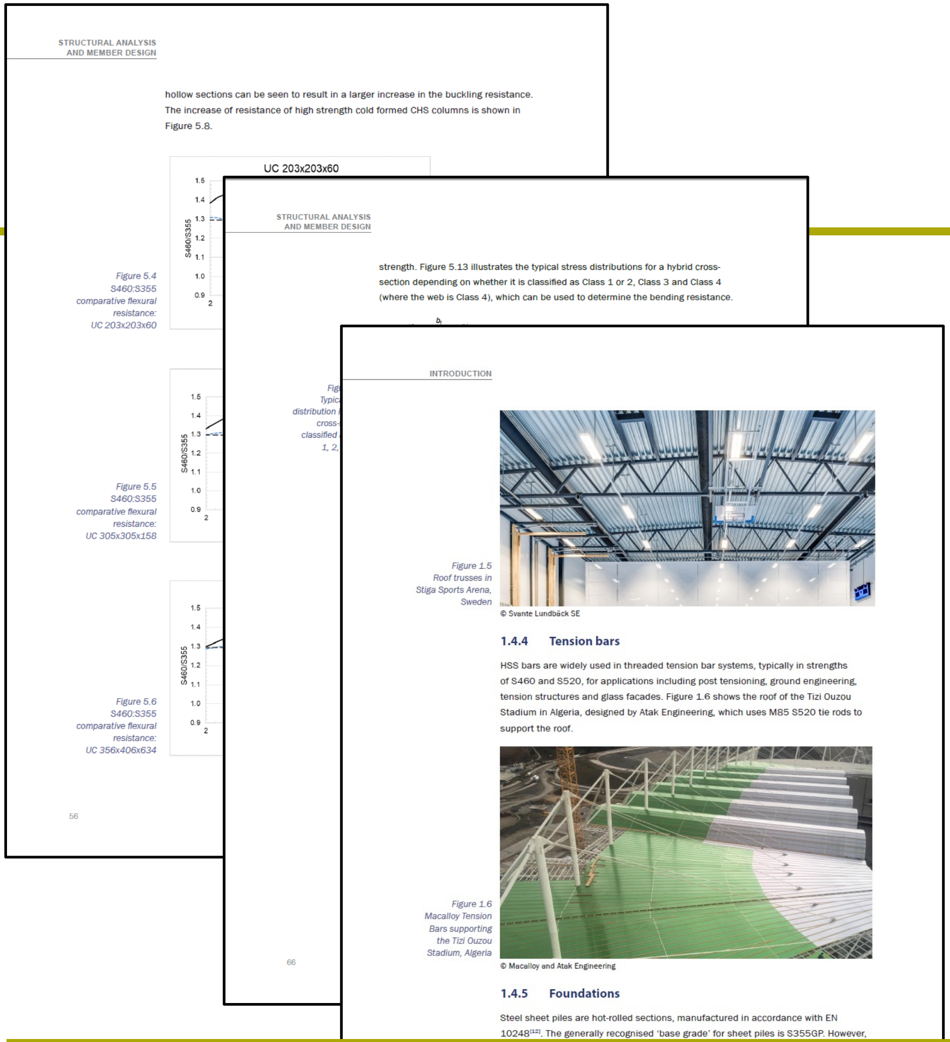
Case No.	Description	Weight saving %	Carbon saving % (Modules A-C)
1	9m x 9m floor grid for an office building	24 – 38	11 – 24
2	15m x 7.5m floor grid for an office building	18 – 31	16 – 27
3	15m span transfer beams for 6 residential levels over a commercial space	21 – 41	19 – 36
4	Columns in a 10-storey building	22 – 39	9 – 26
	Columns in a 20-storey building	25 – 48	12 – 36

STROBE deliverables https://steel-sci.com/sci-projects/



- Reports
- Webinar
- Web tool for designing HSS plate girders
- Case studies




STRUCTURAL ANALYSIS AND MEMBER DESIGN

hollow sections can be seen to result in a larger increase in the buckling resistance. The increase of resistance of high strength cold formed CHS columns is shown in Figure 5.8.

UC 203x203x60

Figure 5.4 S460:S355 comparative flexural resistance: UC 203x203x60

Figure 5.5 S460:S355 comparative flexural resistance: UC 305x305x158

Figure 5.6 S460:S355 comparative flexural resistance: UC 356x406x634

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STRUCTURAL ANALYSIS AND MEMBER DESIGN

strength. Figure 5.13 illustrates the typical stress distributions for a hybrid cross-section depending on whether it is classified as Class 1 or 2, Class 3 and Class 4 (where the web is Class 4), which can be used to determine the bending resistance.

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INTRODUCTION

Figure 1.5 Roof trusses in Stiga Sports Arena, Sweden

© Svante Lundbäck SE

1.4.4 Tension bars

HSS bars are widely used in threaded tension bar systems, typically in strengths of S460 and S520, for applications including post tensioning, ground engineering, tension structures and glass facades. Figure 1.6 shows the roof of the Tizi Ouzou Stadium in Algeria, designed by Atak Engineering, which uses M85 S520 tie rods to support the roof.

Figure 1.6 Macalloy Tension Bars supporting the Tizi Ouzou Stadium, Algeria

© Macalloy and Atak Engineering

1.4.5 Foundations

Steel sheet piles are hot-rolled sections, manufactured in accordance with EN 10248[12]. The generally recognised 'base grade' for sheet piles is S355GP. However,

Free to download from SCI bookshop and Steelbiz

https://portal.steel-sci.com/shop.html

Conclusion

- HSS are beneficial in certain applications,
  e.g., highly loaded members
- Savings on weight, cost and carbon are readily achievable relative to S355 or lower strength steels
- Procurement obstacles
  e.g. limited sources of supply, inexperienced fabricators,
  will reduce as demand grows