

ArcelorMittal Europe - Long Products
Sections and Merchant Bars



ArcelorMittal

High-rise buildings

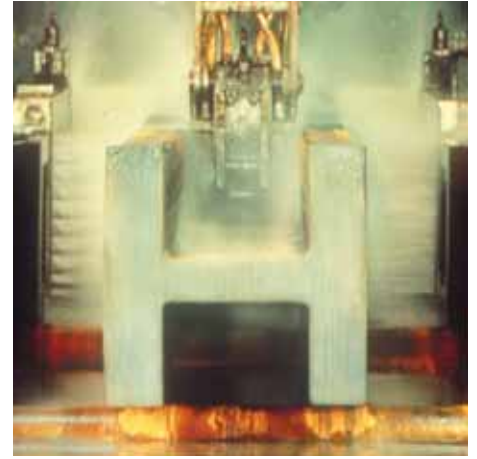




Electric arc furnace



Rolling process



Quenching and Self-Tempering (QST) process for HISTAR® steel



Shanghai World Financial Center, Shanghai, China

© Antony Wood / CTBUH



D2 Tower, Courbevoie, France

Agence d'architecture Anthony Béchu - Tom Sheehan, © Pierre-Élie de Pibiac

Dear Customer,

We are delighted to present you the high-rise buildings brochure. It features suggestions and advices about the optimal use of hot-rolled shapes in tall buildings.

We offer the widest range of structural shape sizes & steel grades and here, you will find a comprehensive information about their properties as well as their advantages and applications in high-rise buildings.

Since we operate a policy of continuous product development, this brochure will be subject to changes. In order to remain up-to-date with our latest developments, we invite you to regularly consult our website: sections.arcelormittal.com.

In addition to this brochure, our commercial teams and technical advisory are at your disposal to answer any question you may have: sections.tecom@arcelormittal.com.

Kind regards,

A handwritten signature in black ink, appearing to read 'Tapas Rajderkar', with a stylized flourish at the end.

Tapas Rajderkar

ArcelorMittal Europe - Long Products
CEO Sections and Merchant Bars

Dear Reader,

This ArcelorMittal publication, focusing on high-rise buildings, was produced with the assistance and guidance of the Council on Tall Buildings and Urban Habitat (CTBUH), the world's leading resource for professionals focused on the inception, design, construction and operation of tall buildings and future cities. The Council's research department is spearheading the investigation of the next generation of tall buildings by aiding original research on sustainability and key development issues. Part of this research includes examining the optimal structural solutions for tall buildings.

This ArcelorMittal publication highlights how structural steel can be used in tall buildings and directly references the Outrigger Design for High-Rise Buildings and Recommendations for Seismic Design Technical Guides developed by CTBUH Working Groups. The Life Cycle Assessment of Tall Building Structural Systems and Composite Megacolumns Research Reports, which were made possible through research grants provided by ArcelorMittal, are also discussed in this publication.

Furthermore, CTBUH hosts the world's premier free database on tall buildings, The Skyscraper Center (skyscrapercenter.com), which is updated daily with detailed information, images, data and news. This database houses information on more than 25 000 buildings, with ArcelorMittal providing steel services for over 150 of the buildings featured on this site.

We hope this publication provides you with useful information on the application of steel in tall structures.

Sincerely,

A handwritten signature in black ink that reads "Antony Wood". The signature is written in a cursive, flowing style with a large initial 'A'.

Antony Wood

CTBUH Executive Director

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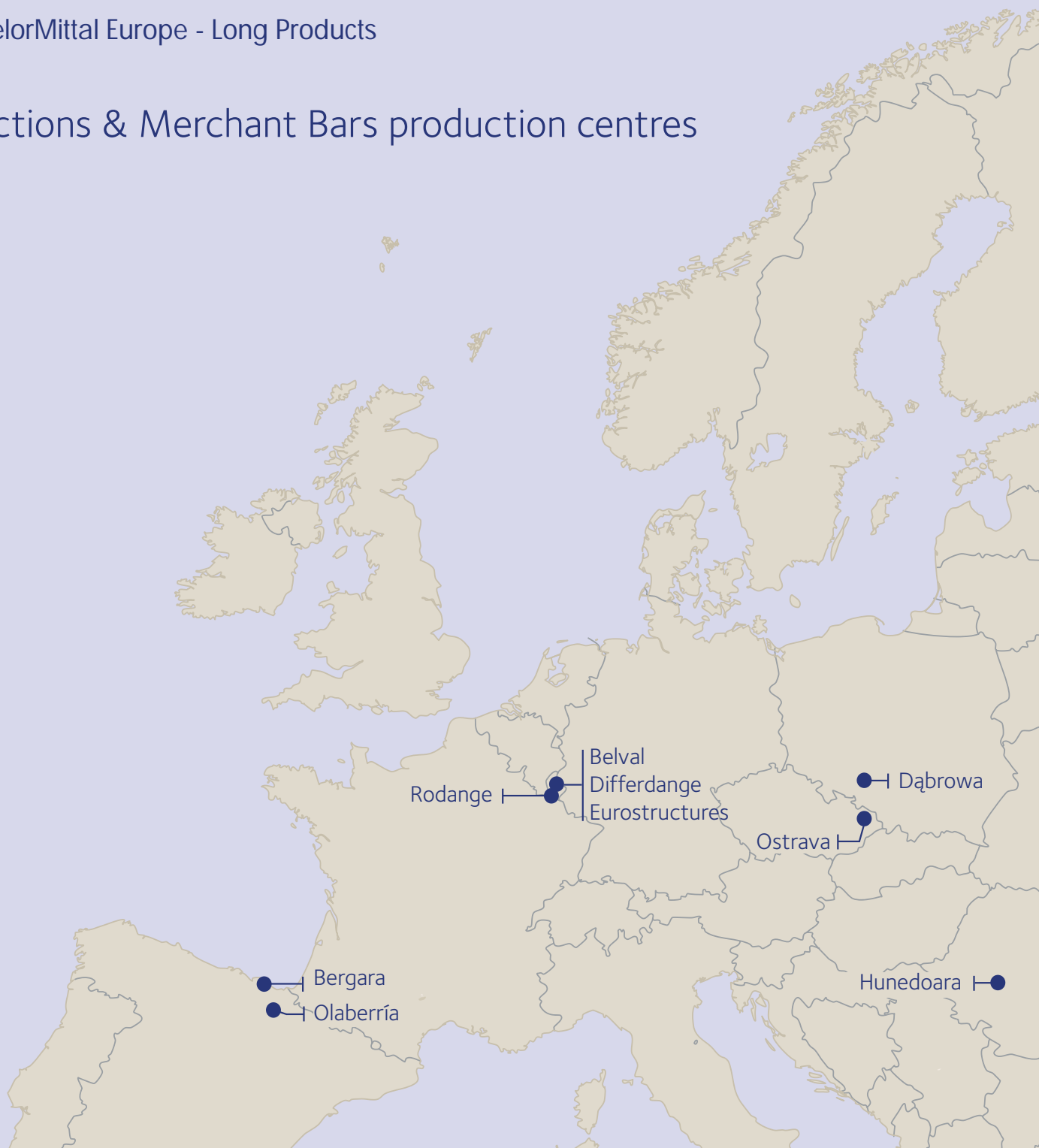
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

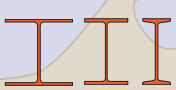































The term "high-rise building" refers in this brochure to buildings with a minimum height (height understood as height to tip) of about 150m including super tall buildings (300 metres high) and mega tall buildings (600 metres high). The number of floors is understood as the number of floors above ground.

Brochure values expression: decimal separator: coma; thousands separator: thin space.

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Sections & Merchant Bars production centres



Sections and Merchant Bars				
Sections				Merchant Bars
Beams	Columns	Bearing Piles	Channels	  
				
<div><div> HE 100 - 1000</div><div> HL 920 - 1100 / HLZ</div><div> IPE 80 - 750</div><div> UB 127 x 76 - 1100 x 400</div><div> W 6 x 4 - 44 x 16</div><div> GOST 10B1 - 50B3</div><div> IPN 80 - 600</div><div> J 76 - 152</div><div> S 3 - 24</div></div>	<div><div> HD 260 - 400</div><div> UC 152 x 152 - 356 x 406</div><div> W 4 x 4 .. 14 x 16</div><div> GOST 20K1 - 40K5</div></div>	<div><div> HP 200 - 400</div><div> UBP 203 x 203 - 356 x 368</div><div> HP 8 - 14</div></div>	<div><div> UPE 80 - 400</div><div> PFC 100 - 430</div><div> UPN 50 - 400</div><div> C 8 - 12</div><div> MC 6 - 18</div><div> GOST 8Y - 30Y</div></div>	
				<div><div> L 35 x 35 - 300 x 300</div><div> L 100 x 65 - 250 x 90</div><div> L 1 3/4 - 12</div><div> FL 20 - 180</div><div> SQ 90 x 90 - 160 x 160</div><div> R 10 - 150</div></div>

Introduction

ArcelorMittal

ArcelorMittal is the world's leading steel and mining company, with around 199 000 employees in more than 60 countries. ArcelorMittal is the leader in all major global steel markets, including automotive, construction, household appliances and packaging, with leading R&D and technology, as well as sizeable captive supplies of raw materials and outstanding distribution networks. An industrial presence on four continents exposes the company to all major markets, from emerging to developed. We are the largest producer of steel in the EU, North & South America and Africa, a significant steel producer in the CIS region, and have a growing presence in Asia, including investments in China and India.

ArcelorMittal Europe – Long Products

Long Products operates at 15 integrated and mini-mill sites in 10 countries. Long products include sections, merchant bars, wire rod, special quality bars, rebar, rails, sheet piles, special sections, billets, and blooms. ArcelorMittal Europe – Long Products is a leader in sections, sheet piles, rails and quality wire rod. It offers the widest range from small sections to jumbo beams according to many standards and covering the full range of applications.



ArcelorMittal office building (AOB), Esch-sur-Alzette, Luxembourg



Electric arc furnace, Luxembourg

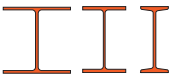



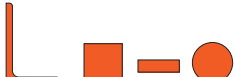
We are the largest recycler of steel in the world notably thanks to the electric arc furnace technology. ArcelorMittal's facilities of Differdange can provide sections with unique dimensions in the world, including finishing from Eurostructures if requested.





Technical support








ArcelorMittal provides free technical advice to assist designers in using its unique products and materials to their full potential. The technical advisory team is available to answer questions about structural shapes, merchant bars, design of structural elements, construction details, surface protection, fire safety and welding.





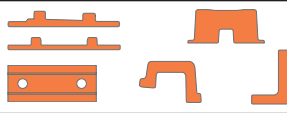

The team of technical specialists is readily available to support projects throughout the world.



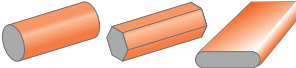
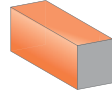
ArcelorMittal also offers free software and technical documents to support designers. These tools can be downloaded at: sections.arcelormittal.com or upon request at sections.tecom@arcelormittal.com

Sections and Merchant Bars				
Sections				Merchant Bars
Beams	Columns	Bearing Piles	Channels	
				
<ul style="list-style-type: none"> HE 100 - 1000 HL 920 - 1100 / HLZ IPE 80 - 750 UB 127 x 76 - 1100 x 400 W 6 x 4 - 44 x 16 GOST 10B1 - 50B3 IPN 80 - 600 J 76 - 152 S 3 - 24 	<ul style="list-style-type: none"> HD 260 - 400 UC 152 x 152 - 356 x 406 W 4 x 4 - 14 x 16 GOST 20K1 - 40K5 	<ul style="list-style-type: none"> HP 200 - 400 UBP 203 x 203-356 x 368 HP 8 - 14 	<ul style="list-style-type: none"> UPE 80 - 400 PFC 100 - 430 UPN 50 - 400 C 8 - 12 MC 6 - 18 GOST 8Y - 30Y 	<ul style="list-style-type: none"> L 35 x 35 - 300 x 300 L 100 x 65 - 250 x 90 L 1 3/4 - 12 FL 20 - 180 SQ 90 x 90 - 160 x 160 R 10 - 150

Sheet Piles			
AZ®-Section	U-Section	Combi-wall HZ®-M/AZ®	Flat Sheet Pile AS 500®
			
AZ 18 - 800 - AZ 27 - 800 AZ 28 - 750 - AZ 32 - 750 AZ 12-770 - AZ 52-700 AZ 18 - AZ 50	AU™ 14 - AU™ 25 PU 12 - PU 32 GU 6N - GU 33N	HZ 680M LT - HZ 880M A - C HZ 1080M A - D - HZ 1180M A - D	AS 500 9.5-13 I.S. max = 6000 kN/m

Rails						
Transport Rails and Rails for Crossovers			Crane & Light rail			
Vignole Type	Grooved & Block Type GI	Rails for Crossovers	Crane rails	Girder Crane rails	Conductors	Light Rails
						
EN 13674-1, EN 13674-2, AS 1085. 1, GOST P51685, ASCE, IRS, ArcelorMittal Specifications, AREMA	EN 14811, 2006 +A1, ArcelorMittal Specifications	EN 13674-3	DIN 536, ASTM, MRS, AS, CR, CRS, JKL, SP, RG, ArcelorMittal Specifications	GCRD42, GCRD45, GCRD108, GCRD183	STR40, STR74, ArcelorMittal Specifications	DIN 5901, DIN 17100, EN 13674-4, DIN 20501, PN-79/H, ASTM, BS11, ZN 2004

Special Sections					
Cathode bars	Track Shoes	Mining		Other special sections	
		Mining sections	Mining Accessories	Rail Accessories	Flanges
					
Square Rectangular	Single grouser Double grousers Triple grousers	TH 16.5 - TH 44, P 28, SV 29, K 21 - K 24, V 25 - V 36	GTHN 29, J21 - J36, A 36 CLAMP, E 74 V.S	Ribbed baseplates, Tie plates standard, Tie plates Type Pandrol, Guiding bar for Metro Cross hearts Fishplates	Rectangular L shape T shape

Bars and Rods			
Rebars	Wire Rod	SBQ	Semis
			
Bars : ø 8 - 50 mm Coils : ø 6 - 20 mm	Round : ø 5 - 52 mm Hexagon : ø 14,3 - 42,5 mm Mesh, Low and High carbon steels, Cold heading, Welding, Free-cutting, Spring, Steel cord, Bearing	Round : ø 15 - 170 mm Hexagon : ø 14,3 - 70,4 mm Round corner square : □ 63 - 200 mm² Leaf Spring: up to □ 56 x 100	Round billets: ø 130 - 400 mm Square billets : □ 115² - 320² mm Rectangular billets: □ 190 x 220; 265 x 385; 280 x 300; 400 x 280

Sections & Merchant Bars: sections.arcelormittal.com

Rebars, Mesh & Pre-Stressed concrete: barsandrods.arcelormittal.com

Steel Decks: ds.arcelormittal.com/construction

Facades & Claddings: industry.arcelormittal.com/steelenvlope

Partitions: ds.arcelormittal.com/construction

Sheet piles and Bearing piles: sheetpiling.arcelormittal.com

All products for construction: constructalia.arcelormittal.com

Visit us on:

1. Steel advantages

The main advantages of steel are:

- stiffness, ductility and resistance
- prefabrication and speed of construction
- flexibility
- sustainability (reusability & indefinitely recyclable)
- reliability



Figure 1.1: Tour D2, half of the weight is carried by exterior steel diagrid, Courbevoie, France

- increased usable "carpet" area (the footprint of a column is approximatively 10 times smaller in steel than in concrete)
- lighter columns (about 3 to 6 times lighter than concrete columns)
- lower loads transferred to foundations (total building weight is more than 2 times lighter in steel than in concrete)
- long span

Example: Comparison between concrete and steel columns

Load = 15000kN (\approx 25 floors), Buckling length = 4m

Class / Grade	Concrete C60	HISTAR® 460
Dimensions / Section	650 x 650mm	HD 400 x 314
Weight	1060kg/m	314kg/m
Column area	0,42m ²	0,04m ²

• Stiffness & resistance

Steel is the most efficient material for columns thanks to its stiffness and resistance. Steel solutions are 5 to 8 times stiffer and about 10 times more resistant than concrete.

Steel has a very high strength to weight ratio, leading to :

- minimum construction dimensions

It is widely acknowledged that steel structures inherently offer superior performance in earthquakes compared to masonry or reinforced concrete.



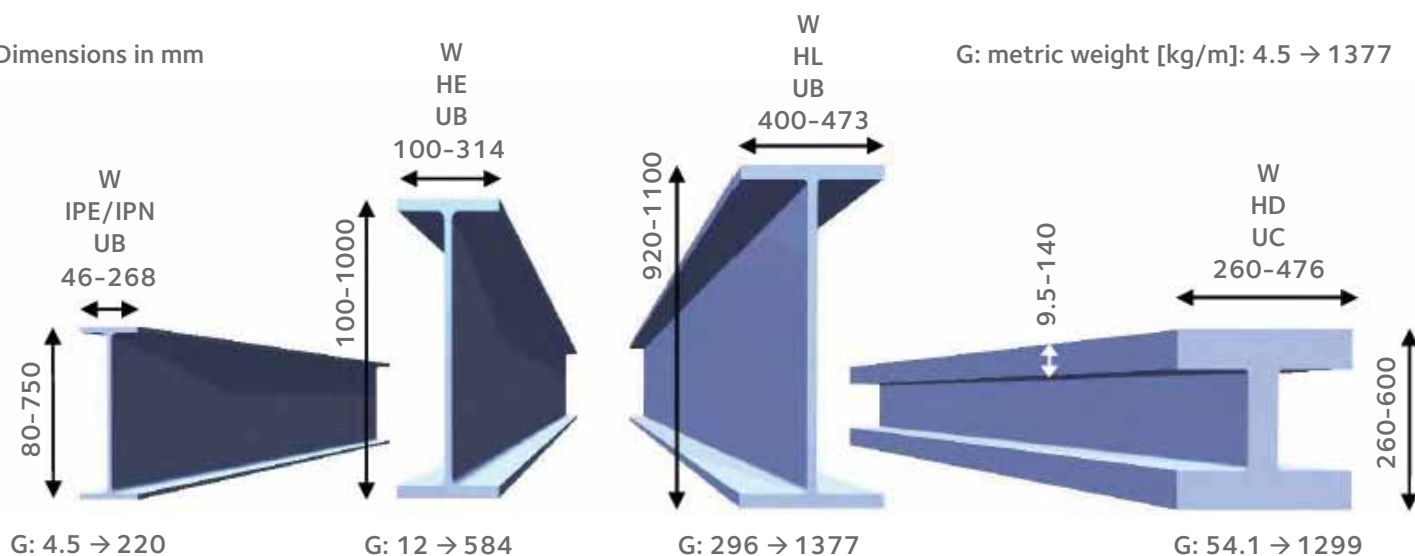
Figure 1.2: Broad J57 Tower, 19 days for 57 storeys, Changsha, China

• Fabrication and speed

Fabrication of steel elements is carried out in a workshop, leading to:

- less material and waste on-site
- minimum disruptions to the surroundings (e.g. less noise)
- ease of construction
- reduced workforce on-site
- higher level of safety for the workers
- reduced management costs on-site
- optimised construction time
- earlier pay-back of investments

Dimensions in mm



ArcelorMittal offers the widest range of beams – also available with fabrication

• Flexibility

Structural steel can be combined with other materials to achieve the desired look, properties or functionalities. Steel is the material “par excellence” when it comes to inventing new structures and forms. All solutions are possible, from the very simplest to the most challenging ones. No other material is used to make structures which are so slender, light and transparent. Forms can be created using different structural effects and envelopes with pure or finely sculpted curves.



Figure 1.3: Emirates Tower One, Dubai, UAE

Steel provides the flexibility needed to enable a building to evolve throughout its working life. The building can be initially designed in order to facilitate future evolutions:

- Modification of applied loads due to change of the building's usage
- Floor plan layout
- Possibility to create new openings in façade or slab

• Sustainability

It is ArcelorMittal's corporate approach to produce safe and sustainable steel reflecting our commitment to protect and improve the environment in which we live and work. We constantly work to develop clean practices in steel production. More than 1400 research engineers are constantly trying to develop cleaner and greener processes to produce steel.

One example is the development of the modern high strength steel HISTAR®. By increasing the strength of the steel, less material is needed. For example, HISTAR® which has been used in buildings such as One World Trade Center in New York and Emirates Tower One in Dubai, can reduce CO₂ emissions during construction phase by as much as 30%.

Steel is an especially sustainable material as it can indefinitely be recycled, without quality loss. Thanks to this property, it surpasses other materials and saves millions of tonnes of resources worldwide.



Figure 1.4: Scrap yard, Belval, Luxembourg

• Reliability

All structural steel products made by ArcelorMittal are manufactured using automated and computerised industrial processes. Finished products are subjected to high levels of quality controls to ensure the best finished quality.

2. Steel grades for high-rise buildings

In order to classify various steels by their composition and physical properties, a number of standards organisations have created specific steel grades. ArcelorMittal offers a large number of the grades specified by standards.

• Conventional steel

ArcelorMittal manufactures I-sections, H-sections, channels, steel angles and bars. The product range includes all dimensions for European standards, and a large number of dimensions from the American and Russian standards. Upon request, sections can also be produced according to custom dimensions and geometries (Figure 2.1).

Rolled sections are delivered in grades complying with European, American, Russian and Chinese standards. Other grades (e.g. Canadian CSA standards) can be supplied upon request. In Europe, ArcelorMittal offers conventional S235, S355, S460 and S500 steel (see table below). S355 is becoming the base grade for all kinds of applications for steel. S500 is feasible and

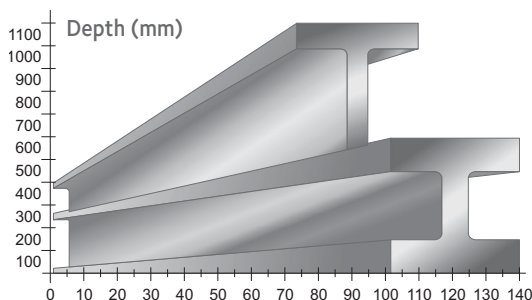


Figure 2.1: Range of dimensions

will be available as soon as it will be included in the EN product standard.

• HISTAR®/ASTM A913 & products standards

In addition to conventional steel, ArcelorMittal offers HISTAR® 355 & 460, HISTAR®/ASTM A913 Grade 50, Grade 65 and Grade 70 steels, which exceed standard requirements. HISTAR® steels are advanced thermo-mechanical structural steels that are manufactured with the in-line QST (Quenching and Self-Tempering) process. They are low-alloyed, high-strength thermo-mechanical fine-grained construction steels with excellent weldability and good toughness values. An outstanding feature of these high strength steels is their low-carbon equivalent values, allowing easier processing for fabricators. As such, preheating before welding can usually be avoided and lead to substantial time and cost savings. HISTAR® grade steel products are available for multiple European, British and American dimensions standards (see table on the following page).



Figure 2.2: HISTAR® in Shanghai World Financial Center

Product standards for steel grades

Class / Grade		Europe		USA			China
Yield Strength [MPa]	HISTAR®	EN10025 - 2	EN10025 - 4	ASTM A913	ASTM A992	ASTM A572	GB/T 33968-2017
355	355	S355 J0/JR/J2/K2	S355M/ML	Grade 50	Grade 50	Grade 50	Q345QST
460	460	S450J0/JR/J2/K2	S460M/ML	Grade 65		Grade 60	Q460QST
500		S500 J0/J2	S500M/ML	Grade 70			Q485QST

Dimensions standards for HISTAR® grades

Class / Grade	European Standards	British Standards	American Standards
Parallel flange beams	IPE 550 on request, IPE 600 - IPE 750	UB 610 x 229 - UB 838 x 292	W 24 - W 36
Wide flange beams	HE 260 - HE 280 on request, HE 300 - HE 1000		
Extra wide flange beams	HL 920 - HL 1100	UB 914 x 305 - UB 1016 x 305	W 36 - W 44
Wide flange columns	HD 260 - HD 400	UC 152 x 152 - UC 356 x 406	W 10 - W 14
Wide flange bearing piles	HP 200 - HP 400	UBP 203 x 203 - UBP 356 x 268	HP 10 - HP 14

— Benefits of HISTAR®

The yield strengths of HISTAR® grades are superior across the entire range of material thickness compared to standard structural steels (Table 2.3). Engineers around the world are taking advantage of HISTAR® steel in elements such as gravity columns, long span trusses, belt trusses and outriggers. HISTAR® is the steel “par excellence” for the high-rise buildings columns even in severe earthquake conditions, as seen in the Shanghai World Financial Center (Figure 2.2). There are countless advantages to using HISTAR® steel products, notably:

- **material savings:** HISTAR® steels with higher strength values can significantly reduce the amount of materials used. This results in up to 30% savings in total cost when compared to S355 construction elements.

- **Less weld deposits** as smaller sections are used.
- **Less surface to protect** against corrosion and fire.
- **Less CO₂ emissions:** it reduces carbon emissions by about 30%.
- **Lightness:** due to the high yield strength, the steel tonnage of any element designed by stress can be reduced by around 30% - in some cases even more. Thanks to the lighter construction process, transportation costs are automatically lowered. Depending on the location and availability of equipment on the construction site, smaller cranes or hoists can also be used.

So, HISTAR® steel solutions are always more economic.

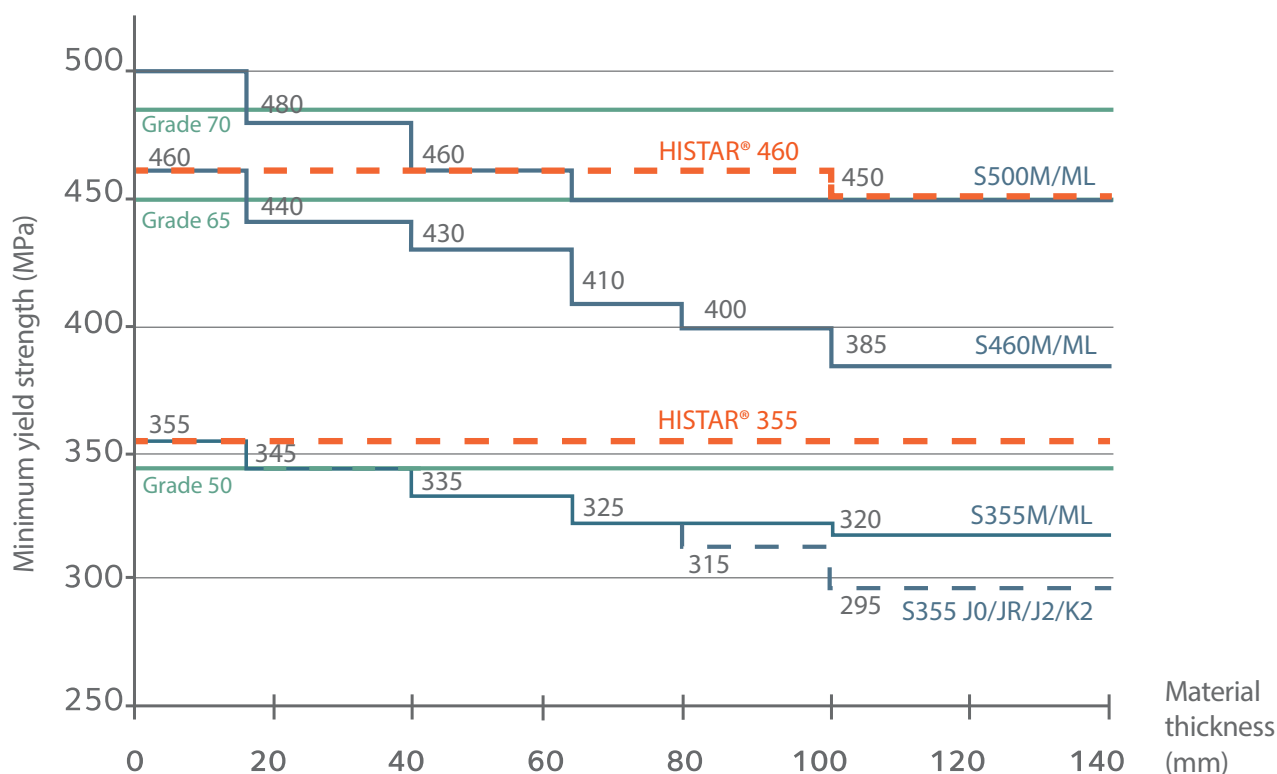


Table 2.3: Minimum yield strength according to material thickness for HISTAR® steels and European grades

— Welding

Provided that the general rules of welding and fabrication are respected (see EN1090-2, EN1011-2 or local codes), HISTAR® grades also offer good weldability for all manual and automatic processes. Due to their low carbon equivalent content, it is generally not necessary to preheat under the following conditions (Figure 2.4):

- Heat input Q ranges 10-60kJ/cm
 - Temperature of the product is > 5 °C
 - Electrodes with low carbon equivalent and low hydrogen content, typically with a diffusible hydrogen content ≤ H10 for HISTAR® 355 and ≤ H5 for HISTAR® 460, are used.
- This is illustrated in Figure 2.5, where the welding of a Jumbo beam of 140mm flange thickness in HISTAR® 460 was welded without preheating with a filler metal with low hydrogen content ≤ H5.

Additional cost savings can be achieved using HISTAR®. The volume to be welded can significantly be reduced by 35-40% in function of the groove detail. This induces a total welding time saving by 40% to 50% in function of the welding process and the preheating. Energy consumption can also be further saved. Moreover, under normal conditions, fabrication such as machining, thermal cutting, stress relieving, flame straightening and cold forming can be performed under the same conditions as structural steels with the same level of tensile strength.

Nevertheless, some preheating* may be required in case of:

- ambient $T^{\circ} < 5^{\circ}\text{C}$
- high hydrogen content
- high restraint conditions (leading, for example, to high tri-axial shrinkage stresses)
- low heat input
- special applications.

* More information can be found within the ArcelorMittal HISTAR® brochure, and for further questions, contact sections.tecom@arcelormittal.com.

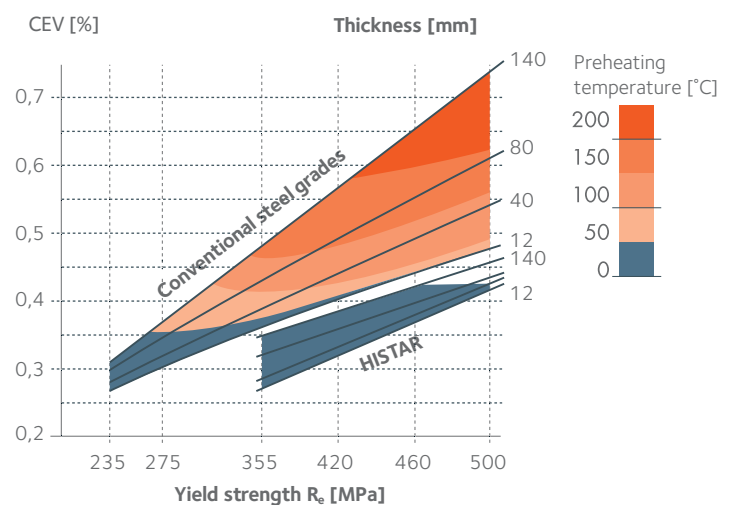


Figure 2.4: Preheating temperatures for conventional structural steel grades and HISTAR® grades.

No preheat conditions* for HISTAR® grades :

- For $R_e < 460$: $H_2 \leq 10\text{ml} / 100\text{g}$
- For $R_e \geq 460$: $H_2 \leq 5\text{ml} / 100\text{g}$
- $Q > 10 \text{ kJ/cm}$

$$\text{CEV (\%)} = C + \frac{\text{Mn}}{6} + \frac{(\text{Cr} + \text{Mo} + \text{V})}{5} + \frac{(\text{Cu} + \text{Ni})}{15}$$



Figure 2.5: Welding of HISTAR® structural steel grades without preheating* (CJP_Complete Joint Penetration_splice of HD400 x 1299 in HISTAR® 460)

3. Columns

Steel is the most efficient material for slender columns thanks to its stiffness and resistance. Compared to concrete, steel is 5 to 8 times stiffer and 10 times more resistant in compression. This makes steel sections the ideal material for columns in tall buildings.

- **Steel sections**

The example in Figure 3.1 shows how a typical 185m high office building of 50 storeys, with a reinforced concrete core, can use HISTAR® columns for the majority of the internal and façade columns (HISTAR® 460 in this case). In this example, the floor's dead and live loads are 5kN/m² and 3kN/m², respectively, and the span between the columns is between 10 and 12 meters.

Combined with the high-strength steel HISTAR® 460, HD 400 / UC 356 / W14 x 16 series enable coverage of almost the whole height of the building. Sizes for an internal column are shown in Figure 3.2. HD/W/UC steel columns have the advantage of having the same distance h_i between the flanges. In this way two HD/UC/W columns can be piled up on each other so that they can easily be spliced (Figure 3.2).

- **Jumbos and SuperJumbos**

To accommodate additional loads, Jumbo and SuperJumbo sections can be used. Jumbos ($G > 500$ kg/m) and Super Jumbos ($G > 1000$ kg/m) are very heavy rolled wide flange sections, due to a significant increase in flange thickness. The example (Figure 3.2) shows HD 400 with flange thickness up to 140mm (5.5in.) and with weight up to 1299kg/m (873lbs/ft). In larger sections, such as the HL 920 series, the weight can go up to 1377kg/m (925lbs/ft). Actually, ArcelorMittal has the record of the heaviest and the thickest rolled shape in the world (see page 10). When loads are too heavy for the strongest single SuperJumbo such as in the first three floors of the example (Figure 3.2), optimised section such as **HD Box** can be used (Figure 3.3).

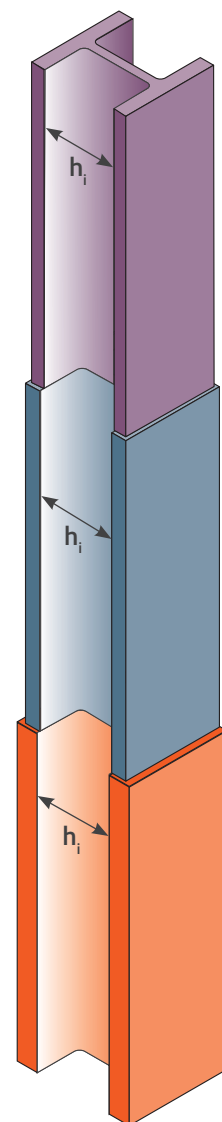
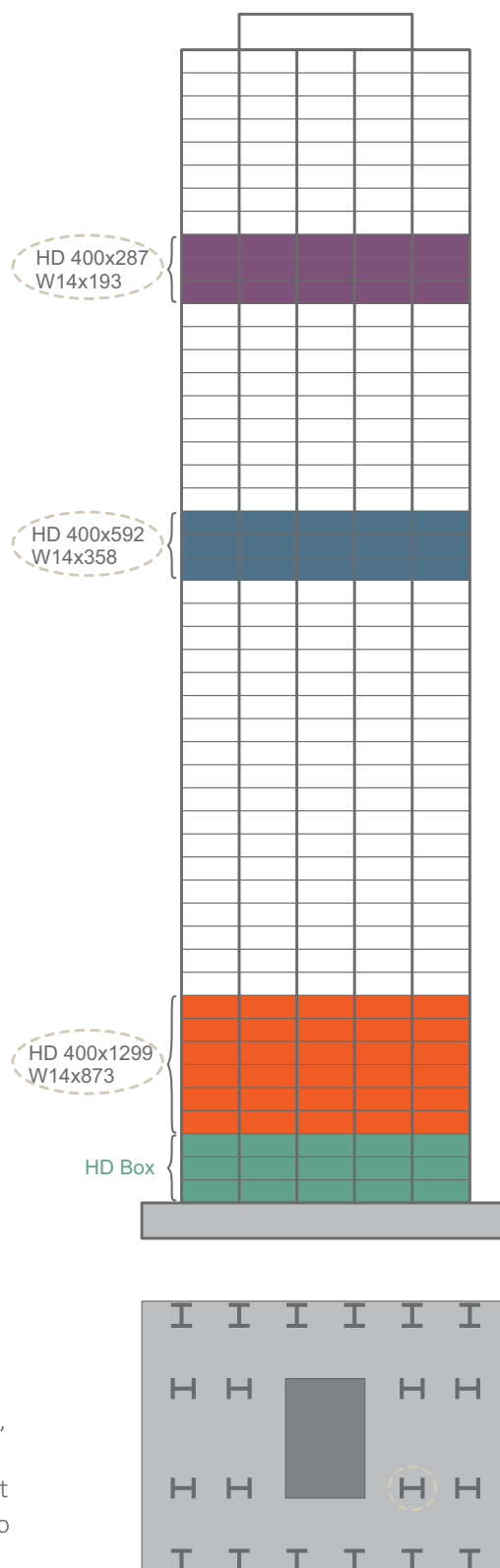


Figure 3.2: Stacking up HD 400 columns.

h_i is constant within a family of sections

Figure 3.1: 185m high office building

- **Optimised built-up sections**

Optimised sections can provide more design flexibility. ArcelorMittal supplies numerous varieties of these welded sections, such as HD Box (Figure 3.3), cruciform section (Figure 3.4), sections with cover plates (Figure 3.5) and

several different welded sections (Figure 3.6). Pages 24 and 25 show design tables for specific HD Box & cruciform sections made of HD/HL/W sections to which two tees, split from the same sections, are welded.



Figure 3.3: HD Box

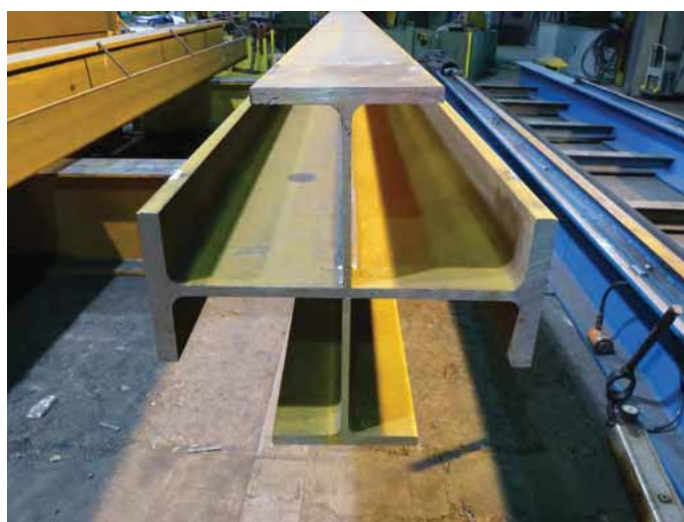


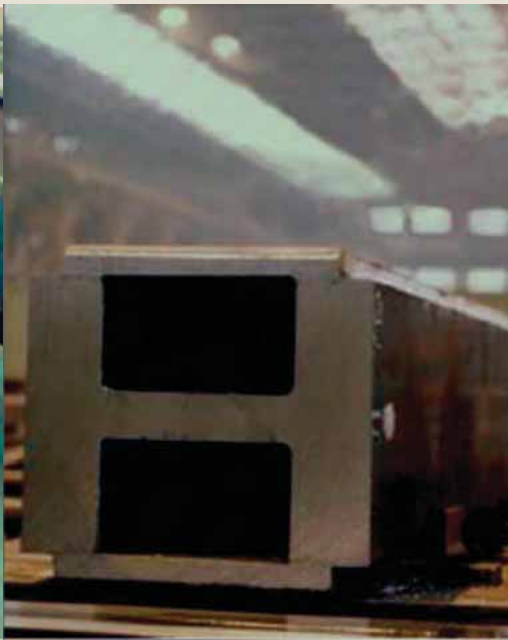
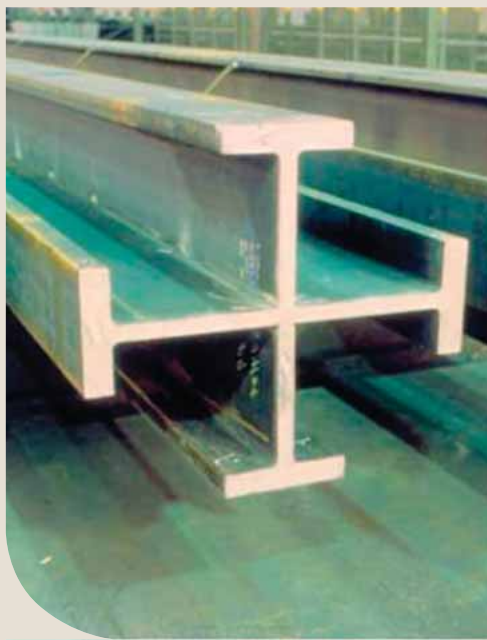
Figure 3.4: Cruciform section



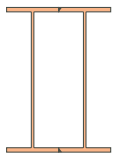
Figure 3.5: Rolled section with coverplates



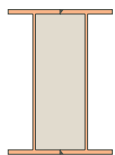
Figure 3.6: Welded sections,
Two heavy sections welded together



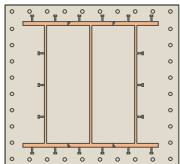
See optimised solution Megacolumn below



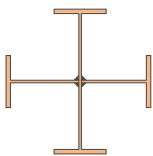
Box section welded from two sections



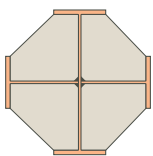
Composite column: box section welded from two sections section with concrete filling



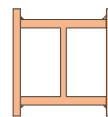
Composite column: box section welded from three sections encased in concrete



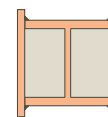
Cruciform section made out of one rolled section and two T-sections



Composite column: cruciform beam with concrete filling



Wide flange beam boxed with two plates



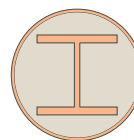
Composite column: wide flange beam boxed with two plates filled with concrete



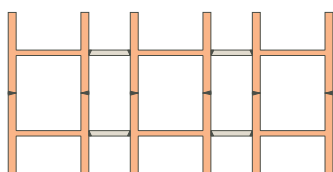
Box HD section made out of one rolled section and two T sections



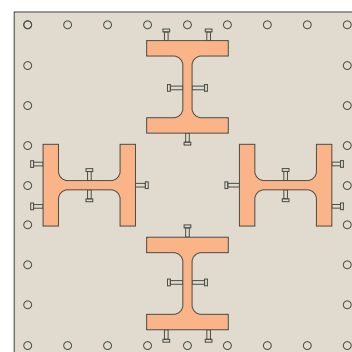
Partially encased composite beam or column



Composite column: wide flange sections encased in concrete filled steel tube



Mega column built up from 6 wide flange beams and 4 connection plates



Megacolumn without connection plates

• Using HISTAR® grade steel for columns

Thanks to the high yield strength of HISTAR® beams, it is a great advantage to substitute most heavy and complicated, built-up columns with these hot rolled beams. Combining Jumbos & Super Jumbos with the high strength steel HISTAR® 460 also allows to:

1- Reduce weight

- less material, transportation, erection and fabrication costs
- lower construction weight
 - lower stabilisation efforts
 - lower foundation loads
- smaller sections or less columns
 - less surface to treat
 - lighter connections
 - smaller footprint
 - gain in usable surface area

2- Save time

- shorter fabrication time
- shorter execution time
- quicker return on investment

Significant reductions in weight not only lead to economic savings in the production process but also in the construction process (see below).

For example: Instead of using two UC356x406x509 in S355M for plunge columns (= king post piles) applications



only one UC356x406x1299 in HISTAR® 460 is used, which



allows a weight reduction of 20% and easier assembly.

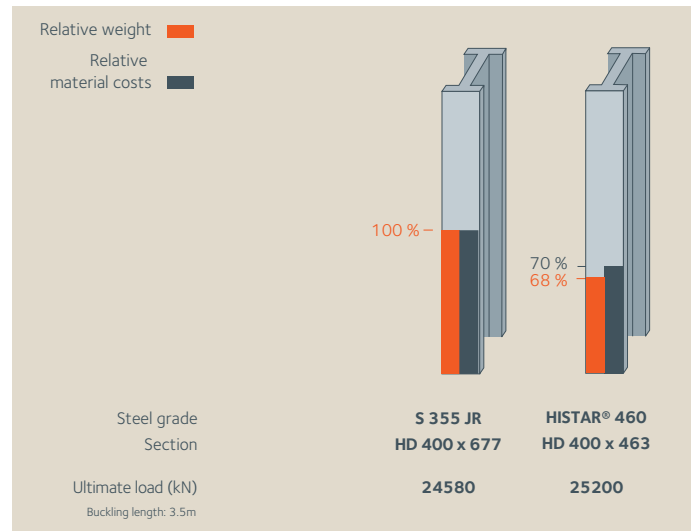


Figure 3.7: Economical use of HISTAR®: heavy columns

Heavy columns:

Gains, when using HISTAR® 460 instead of S355 JR steel:

- 32% weight savings
- 30% costs savings

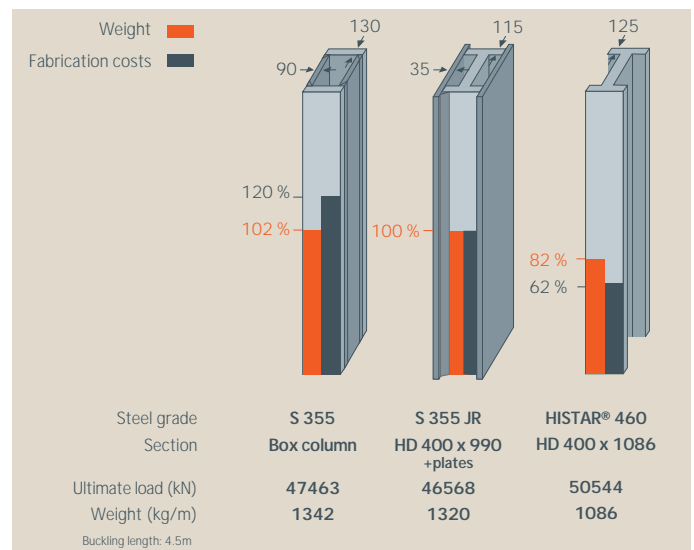


Figure 3.8: Economical use of HISTAR®: built-up sections

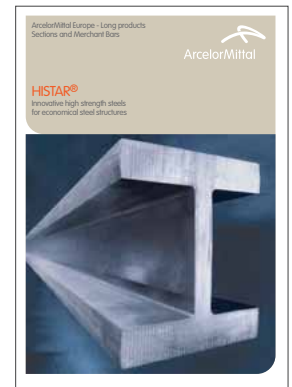
Built-up sections:

Gains, when using S355 cover plated column compared to S355 Box column:

- 2% weight savings -> 20% costs savings

Gains, when using HISTAR® 460 Super Jumbo compared to cover plated S355 JR Jumbo:

- 18% weight savings -> 38% costs savings



• **Predesign tools, design tables:**

Different design tables exist according to different standards (European, British, American etc.). Here are some examples.


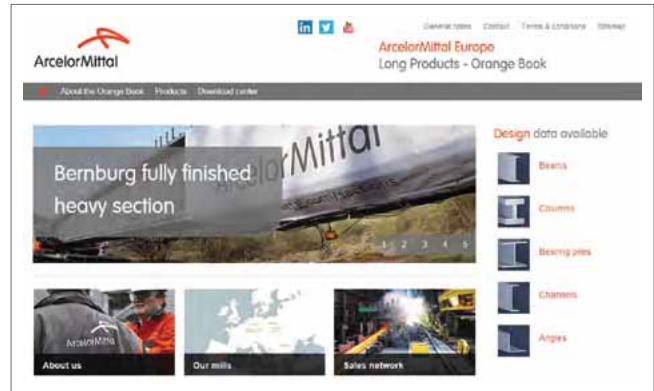
	Axis	Buckling length [m]																
		1	1,5	2	2,5	3	3,5	4	5	6	7	8	9	10	11	12	13	14
HD 400 x 1299	N _{b,y,Rd}	74300	74300	74300	74300	74100	73600	73000	71800	70500	69000	67400	65500	63300	60800	57900	54700	51200
	N _{b,z,Rd}	74300	74300	73300	71700	70000	68300	66500	62400	57700	52400	46700	41200	36000	31500	27600	24300	21500
HD 400 x 1202	N _{b,y,Rd}	68900	68900	68900	68900	68700	68100	67600	66400	65100	63700	62100	60300	58100	55600	52800	49600	46300
	N _{b,z,Rd}	68900	68900	67800	66300	64800	63200	61400	57500	53000	48000	42700	37500	32700	28600	25000	21900	19400
HD 400 x 1086	N _{b,y,Rd}	62400	62400	62400	62400	62200	61700	61200	60100	59000	57700	56200	54500	52600	50300	47700	44800	41700
	N _{b,z,Rd}	62400	62400	61300	59900	58500	56900	55300	51600	47300	42600	37600	32800	28500	24800	21700	19000	16800
HD 400 x 990	N _{b,y,Rd}	56800	56800	56800	56800	56600	56100	55600	54600	53600	52300	50900	49300	47400	45200	42700	40000	37100
	N _{b,z,Rd}	56800	56800	55800	54500	53100	51700	50100	46700	42700	38300	33700	29300	25500	22100	19300	16900	14900
HD 400 x 900	N _{b,y,Rd}	51700	51700	51700	51700	51400	51000	50600	49600	48600	47400	46100	44500	42700	40600	38200	35600	32900
	N _{b,z,Rd}	51700	51700	50700	49500	48200	46900	45500	42300	38500	34400	30200	26200	22700	19700	17100	15000	13200
HD 400 x 818	N _{b,y,Rd}	48000	48000	48000	48000	47700	47200	46800	45900	44900	43800	42400	40900	39000	36900	34500	32000	29400
	N _{b,z,Rd}	48000	48000	47300	46600	45800	45000	44000	41700	38600	34700	30400	26200	22400	19200	16600	14400	12600
HD 400 x 744	N _{b,y,Rd}	43600	43600	43600	43600	43300	42900	42500	41600	40700	39600	38300	36900	35100	33100	30800	28400	26100
	N _{b,z,Rd}	43600	43600	43000	42300	41600	40800	39900	37700	34800	31200	27200	23300	19900	17100	14700	12800	11200
HD 400 x 677	N _{b,y,Rd}	39700	39700	39700	39700	39400	39000	38600	37800	37000	35900	34700	33300	31600	29700	27500	25300	23100
	N _{b,z,Rd}	39700	39700	39100	38500	37800	37100	36300	34200	31500	28200	24500	20900	17800	15300	13100	11400	9970
HD 400 x 634	N _{b,y,Rd}	37200	37200	37200	37200	36800	36500	36100	35400	34500	33500	32400	31000	29400	27500	25500	23400	21300
	N _{b,z,Rd}	37200	37100	36600	36000	35400	34700	33900	31900	29300	26100	22600	19300	16500	14100	12100	10500	9180
HD 400 x 592	N _{b,y,Rd}	34700	34700	34700	34700	34400	34100	33700	33000	32200	31300	30100	28800	27300	25500	23500	21600	19600
	N _{b,z,Rd}	34700	34700	34200	33600	33000	32300	31600	29700	27300	24200	20900	17800	15200	12900	11100	9650	8440
HD 400 x 551	N _{b,y,Rd}	32300	32300	32300	32200	31900	31600	31300	30600	29800	28900	27900	26600	25100	23400	21600	19700	17900
	N _{b,z,Rd}	32300	32200	31700	31200	30600	30000	29300	27500	25200	22300	19300	16400	13900	11900	10200	8840	7730
HD 400 x 509	N _{b,y,Rd}	29900	29900	29900	29800	29500	29200	28900	28300	27600	26700	25700	24500	23100	21500	19700	18000	16300
	N _{b,z,Rd}	29900	29800	29300	28900	28300	27700	27100	25400	23200	20500	17700	15000	12700	10900	9340	8090	7070
HD 400 x 463	N _{b,y,Rd}	27100	27100	27100	27000	26800	26500	26200	25600	25000	24200	23200	22100	20700	19200	17600	16000	14500
	N _{b,z,Rd}	27100	27100	26600	26200	25700	25200	24500	23000	21000	18500	15800	13400	11400	9690	8320	7210	6300
HD 400 x 421	N _{b,y,Rd}	24700	24700	24700	24600	24400	24100	23900	23300	22700	21900	21000	20000	18700	17300	15800	14300	12900
	N _{b,z,Rd}	24700	24600	24300	23800	23400	22900	22300	20900	19000	16700	14300	12100	10200	8700	7470	6470	5650
HD 400 x 382	N _{b,y,Rd}	22400	22400	22400	22300	22100	21900	21600	21100	20500	19800	19000	18000	16800	15500	14100	12800	11500
	N _{b,z,Rd}	22400	22300	22000	21600	21200	20700	20200	18900	17100	15000	12800	10800	9150	7790	6680	5780	5050
HD 400 x 347	N _{b,y,Rd}	20300	20300	20300	20200	20000	19800	19600	19100	18600	17900	17100	16200	15100	13900	12600	11400	10300
	N _{b,z,Rd}	20300	20300	19900	19600	19200	18800	18300	17100	15500	13500	11500	9730	8220	6990	6000	5190	4530
HD 400 x 314	N _{b,y,Rd}	18400	18400	18400	18300	18100	17900	17700	17300	16700	16100	15400	14500	13500	12400	11200	10100	9110
	N _{b,z,Rd}	18400	18300	18000	17700	17300	16900	16500	15400	13900	12100	10300	8660	7310	6210	5330	4610	4020
HD 400 x 287	N _{b,y,Rd}	16800	16800	16800	16800	16600	16400	16200	15800	15300	14800	14100	13300	12300	11300	10200	9210	8270
	N _{b,z,Rd}	16800	16800	16500	16200	15900	15500	15100	14100	12700	11100	9380	7900	6660	5660	4850	4200	3660
HD 400 x 262	N _{b,y,Rd}	15400	15400	15400	15300	15100	15000	14800	14400	14000	13500	12800	12100	11200	10200	9240	8310	7450
	N _{b,z,Rd}	15400	15300	15100	14800	14500	14200	13800	12800	11600	10000	8500	7150	6030	5120	4390	3800	3310
HD 400 x 237	N _{b,y,Rd}	13800	13800	13800	13700	13600	13500	13300	13000	12600	12100	11500	10800	9970	9090	8200	7360	6600
	N _{b,z,Rd}	13800	13800	13600	13300	13000	12700	12400	11500	10300	8950	7570	6360	5350	4550	3890	3370	2940
HD 400 x 216	N _{b,y,Rd}	12700	12700	12700	12600	12500	12300	12200	11900	11500	11000	10500	9830	9070	8260	7450	6680	5980
	N _{b,z,Rd}	12700	12600	12400	12200	11900	11700	11300	10500	9440	8170	6900	5790	4880	4140	3550	3070	2680

Table 3.1: Eurocode (EN 1993-1-1: 2005) design buckling resistance [kN] of strong and weak axis of HD columns sections in HISTAR® 460.




	Axis	Buckling length [m]																
		1	1,5	2	2,5	3	3,5	4	5	6	7	8	9	10	11	12	13	14
HD 400 x 187	N _{b,y,Rd}	10900	10900	10900	10800	10700	10600	10500	10200	9880	9480	9000	8420	7760	7050	6340	5680	5080
	N _{b,z,Rd}	10900	10900	10700	10500	10300	10000	9750	9040	8090	6970	5880	4920	4140	3510	3010	2600	2270
HD 360 x 196	N _{b,y,Rd}	11500	11500	11500	11400	11300	11200	11000	10800	10400	10000	9490	8880	8190	7440	6700	6000	5360
	N _{b,z,Rd}	11500	11400	11200	11000	10800	10500	10100	9290	8180	6930	5770	4790	4010	3390	2900	2500	2180
HD 360 x 179	N _{b,y,Rd}	10500	10500	10500	10400	10300	10200	10100	9800	9490	9100	8640	8070	7430	6750	6070	5430	4850
	N _{b,z,Rd}	10500	10400	10200	10000	9800	9540	9240	8460	7430	6290	5230	4340	3640	3070	2630	2270	1970
HD 360 x 162	N _{b,y,Rd}	9490	9490	9490	9420	9310	9210	9100	8850	8570	8220	7790	7280	6690	6070	5460	4880	4360
	N _{b,z,Rd}	9490	9420	9240	9060	8850	8620	8340	7630	6690	5660	4700	3900	3270	2760	2360	2040	1770
HD 360 x 147	N _{b,y,Rd}	8640	8640	8640	8570	8480	8380	8280	8060	7790	7470	7070	6600	6060	5490	4920	4400	3930
	N _{b,z,Rd}	8640	8570	8420	8250	8060	7840	7590	6930	6070	5120	4250	3520	2950	2490	2130	1840	1600
HD 360 x 134	N _{b,y,Rd}	7850	7850	7850	7780	7700	7610	7510	7310	7060	6760	6400	5960	5470	4950	4430	3960	3530
	N _{b,z,Rd}	7850	7780	7640	7490	7310	7110	6880	6280	5490	4630	3840	3180	2660	2250	1920	1660	1440
HD 320 x 300	N _{b,y,Rd}	17600	17600	17600	17400	17200	17000	16800	16300	15700	15000	14100	13000	11800	10600	9480	8420	7490
	N _{b,z,Rd}	17600	17300	16900	16400	15900	15300	14500	12600	10300	8270	6660	5430	4490	3770	3200	2760	2390
HD 320 x 245	N _{b,y,Rd}	14400	14400	14300	14200	14000	13800	13700	13200	12700	12100	11400	10500	9470	8470	7520	6670	5920
	N _{b,z,Rd}	14400	14100	13800	13400	13000	12400	11800	10200	8310	6650	5350	4360	3600	3020	2570	2210	1920
HD 320 x 198	N _{b,y,Rd}	11600	11600	11600	11500	11300	11200	11000	10700	10200	9690	9020	8250	7410	6580	5820	5140	4550
	N _{b,z,Rd}	11600	11400	11100	10800	10400	10000	9460	8080	6550	5210	4180	3400	2810	2360	2000	1720	1490
HD 320 x 158	N _{b,y,Rd}	9260	9260	9230	9120	9010	8890	8760	8460	8100	7650	7090	6450	5760	5100	4490	3960	3500
	N _{b,z,Rd}	9260	9070	8850	8600	8300	7930	7480	6350	5110	4060	3250	2640	2180	1830	1550	1330	1160
HD 320 x 127	N _{b,y,Rd}	7420	7420	7390	7310	7210	7110	7010	6770	6470	6090	5630	5090	4540	4000	3520	3100	2740
	N _{b,z,Rd}	7420	7260	7080	6880	6630	6330	5960	5020	4020	3180	2540	2060	1700	1430	1210	1040	904
HD 320 x 97,6	N _{b,y,Rd}	5720	5720	5700	5630	5550	5480	5390	5200	4960	4650	4280	3860	3420	3010	2640	2320	2050
	N _{b,z,Rd}	5720	5600	5460	5290	5100	4860	4570	3830	3060	2410	1930	1560	1290	1080	917	788	684
HD 320 x 74,2*	N _{b,y,Rd}	4220	4220	4200	4150	4090	4030	3970	3820	3640	3410	3120	2800	2480	2170	1900	1670	1470
	N _{b,z,Rd}	4220	4120	4010	3890	3740	3560	3330	2770	2190	1730	1370	1110	918	769	653	561	487
HD 260 x 299	N _{b,y,Rd}	17500	17500	17400	17200	16900	16700	16400	15700	14900	13900	12600	11300	9880	8620	7520	6590	5800
	N _{b,z,Rd}	17500	17100	16600	16100	15400	14600	13700	11200	8840	6930	5510	4460	3670	3070	2610	2240	1940
HD 260 x 225	N _{b,y,Rd}	13200	13200	13100	12900	12700	12500	12300	11700	11000	10100	9100	7990	6940	6010	5220	4550	4000
	N _{b,z,Rd}	13100	12800	12500	12000	11500	10900	10100	8160	6350	4950	3920	3170	2610	2180	1850	1590	1380
HD 260 x 172	N _{b,y,Rd}	10100	10100	9990	9850	9690	9520	9340	8900	8320	7590	6740	5860	5060	4360	3770	3290	2880
	N _{b,z,Rd}	10100	9820	9540	9210	8800	8280	7650	6160	4780	3710	2940	2370	1950	1630	1380	1190	1030
HD 260 x 142	N _{b,y,Rd}	8290	8290	8190	8070	7940	7790	7630	7250	6740	6100	5370	4640	3980	3420	2960	2570	2250
	N _{b,z,Rd}	8260	8050	7810	7530	7180	6730	6190	4930	3800	2940	2330	1880	1540	1290	1090	938	814
HD 260 x 114	N _{b,y,Rd}	6700	6700	6610	6510	6400	6280	6150	5820	5390	4850	4240	3650	3120	2680	2310	2010	1760
	N _{b,z,Rd}	6670	6490	6300	6060	5770	5400	4940	3910	3000	2320	1830	1470	1210	1010	858	736	638
HD 260 x 93,0	N _{b,y,Rd}	5450	5450	5370	5280	5190	5090	4980	4710	4350	3890	3390	2910	2480	2120	1830	1590	1390
	N _{b,z,Rd}	5410	5270	5110	4920	4670	4360	3980	3130	2390	1850	1460	1170	965	806	683	586	508
HD 260 x 68,2	N _{b,y,Rd}	3990	3990	3930	3870	3800	3720	3630	3420	3140	2790	2420	2060	1750	1500	1290	1120	977
	N _{b,z,Rd}	3970	3860	3740	3590	3410	3170	2890	2260	1720	1320	1040	841	690	577	489	419	363
HD 260 x 54,1*	N _{b,y,Rd}	3080	3070	3030	2980	2920	2860	2800	2630	2410	2140	1850	1580	1340	1150	985	854	747
	N _{b,z,Rd}	3050	2970	2880	2760	2620	2430	2210	1720	1310	1010	794	640	525	439	372	319	276

Table 3.1 (continued): Eurocode (EN 1993-1-1: 2005) design buckling resistance [kN] of strong and weak axis of HD columns sections in HISTAR® 460.

* Only available in S460M.


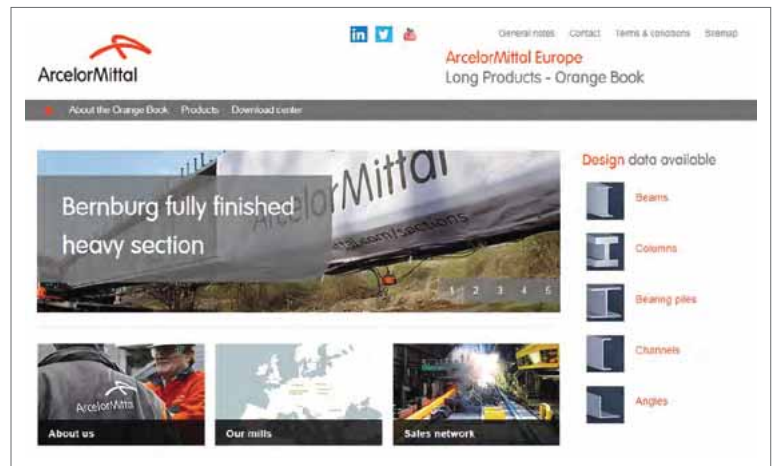
	Axis	Buckling length [m]																
		1	1,5	2	2,5	3	3,5	4	5	6	7	8	9	10	11	12	13	14
UC 356 x 406 x 1299	N _{b,y,Rd}	74500	74500	74500	74500	74400	73800	73200	72000	70700	69200	67600	65700	63500	60900	58000	54800	51300
	N _{b,z,Rd}	74500	74500	73500	71900	70200	68500	66600	62500	57800	52500	46800	41200	36100	31500	27600	24300	21500
UC 356 x 406 x 1202	N _{b,y,Rd}	68900	68900	68900	68900	68700	68200	67600	66400	65200	63800	62200	60300	58100	55600	52800	49600	46300
	N _{b,z,Rd}	68900	68900	67900	66400	64800	63200	61400	57600	53100	48000	42700	37500	32700	28500	25000	21900	19400
UC 356 x 406 x 1086	N _{b,y,Rd}	62400	62400	62400	62400	62200	61700	61200	60100	59000	57700	56200	54500	52500	50300	47600	44800	41700
	N _{b,z,Rd}	62400	62400	61300	59900	58400	56900	55300	51600	47300	42600	37600	32800	28500	24800	21700	19000	16800
UC 356 x 406 x 990	N _{b,y,Rd}	56800	56800	56800	56800	56600	56100	55700	54700	53600	52300	50900	49300	47400	45200	42700	40000	37100
	N _{b,z,Rd}	56800	56800	55800	54500	53100	51700	50200	46700	42700	38300	33700	29300	25400	22100	19300	16900	14900
UC 356 x 406 x 900	N _{b,y,Rd}	51700	51700	51700	51700	51400	51000	50600	49600	48600	47400	46100	44500	42700	40600	38200	35600	32900
	N _{b,z,Rd}	51700	51700	50700	49500	48200	46900	45500	42300	38600	34400	30200	26200	22700	19700	17100	15000	13200
UC 356 x 406 x 818	N _{b,y,Rd}	48000	48000	48000	48000	47700	47300	46800	45900	44900	43800	42400	40900	39000	36900	34500	32000	29400
	N _{b,z,Rd}	48000	48000	47300	46600	45800	45000	44000	41700	38600	34700	30400	26200	22400	19200	16600	14400	12600
UC 356 x 406 x 744	N _{b,y,Rd}	43600	43600	43600	43600	43300	42900	42500	41600	40700	39600	38300	36900	35100	33100	30800	28400	26100
	N _{b,z,Rd}	43600	43600	43000	42300	41600	40800	39900	37700	34800	31200	27200	23300	19900	17100	14700	12800	11200
UC 356 x 406 x 677	N _{b,y,Rd}	39700	39700	39700	39700	39400	39000	38600	37800	36900	35900	34700	33300	31600	29700	27500	25300	23100
	N _{b,z,Rd}	39700	39700	39100	38500	37800	37100	36300	34200	31500	28200	24500	20900	17800	15300	13100	11400	9970
UC 356 x 406 x 634	N _{b,y,Rd}	37100	37100	37100	37100	36800	36500	36100	35400	34500	33500	32400	31000	29400	27500	25500	23400	21400
	N _{b,z,Rd}	37100	37100	36600	36000	35300	34600	33800	31900	29300	26100	22600	19300	16400	14000	12100	10500	9160
UC 356 x 406 x 592	N _{b,y,Rd}	34700	34700	34700	34700	34400	34100	33700	33000	32200	31200	30100	28800	27300	25500	23500	21600	19600
	N _{b,z,Rd}	34700	34700	34200	33600	33000	32300	31600	29700	27300	24200	20900	17800	15200	12900	11100	9650	8440
UC 356 x 406 x 551	N _{b,y,Rd}	32300	32300	32300	32200	31900	31600	31300	30600	29900	29000	27900	26600	25100	23400	21600	19700	17900
	N _{b,z,Rd}	32300	32200	31800	31200	30700	30000	29300	27600	25200	22400	19300	16400	13900	11900	10200	8860	7740
UC 356 x 406 x 509	N _{b,y,Rd}	29900	29900	29900	29800	29500	29200	28900	28300	27600	26700	25700	24500	23100	21400	19700	18000	16300
	N _{b,z,Rd}	29900	29800	29300	28900	28300	27700	27100	25400	23200	20500	17700	15000	12700	10900	9340	8090	7070
UC 356 x 406 x 467	N _{b,y,Rd}	27400	27400	27400	27300	27000	26800	26500	25900	25200	24400	23500	22300	21000	19500	17800	16200	14700
	N _{b,z,Rd}	27400	27300	26900	26400	25900	25400	24800	23200	21200	18700	16000	13600	11500	9800	8420	7300	6370
UC 356 x 406 x 393	N _{b,y,Rd}	23000	23000	23000	22900	22700	22500	22200	21700	21100	20400	19600	18500	17300	16000	14600	13200	11900
	N _{b,z,Rd}	23000	23000	22600	22200	21800	21300	20800	19400	17600	15500	13200	11200	9440	8040	6900	5970	5220
UC 356 x 406 x 340	N _{b,y,Rd}	19900	19900	19900	19800	19600	19400	19200	18700	18200	17600	16800	15900	14800	13600	12400	11200	10100
	N _{b,z,Rd}	19900	19900	19500	19200	18800	18400	17900	16700	15100	13200	11300	9490	8010	6820	5850	5060	4420
UC 356 x 406 x 287	N _{b,y,Rd}	16100	16100	16100	16000	15900	15700	15500	15200	14700	14200	13600	12900	12000	11000	10100	9090	8190
	N _{b,z,Rd}	16100	16000	15800	15500	15200	14900	14500	13600	12300	10800	9220	7790	6590	5610	4810	4170	3640
UC 356 x 406 x 235	N _{b,y,Rd}	13200	13200	13200	13100	13000	12800	12700	12400	12000	11600	11000	10400	9680	8880	8060	7260	6530
	N _{b,z,Rd}	13200	13100	12900	12700	12400	12200	11800	11100	10000	8760	7460	6290	5320	4520	3880	3360	2930

Table 3.2: Eurocode (EN 1993-1-1: 2005) design buckling resistances [kN] of strong and weak axis of UC columns sections in H1STAR® 460.




	Axis	Buckling length [m]																
		1	1,5	2	2,5	3	3,5	4	5	6	7	8	9	10	11	12	13	14
UC 356 x 368 x 202	N _{b,y,Rd}	11300	11300	11300	11200	11100	11000	10900	10600	10300	9910	9450	8890	8250	7540	6830	6140	5510
	N _{b,z,Rd}	11300	11200	11100	10800	10600	10300	10000	9260	8220	7040	5900	4920	4130	3500	2990	2590	2250
UC 356 x 368 x 177	N _{b,y,Rd}	9920	9920	9920	9860	9760	9650	9540	9300	9010	8670	8250	7750	7180	6550	5920	5320	4770
	N _{b,z,Rd}	9920	9860	9690	9500	9300	9060	8790	8090	7170	6120	5120	4270	3580	3030	2600	2240	1950
UC 356 x 368 x 153	N _{b,y,Rd}	8570	8570	8570	8510	8420	8330	8240	8020	7770	7470	7110	6670	6160	5610	5060	4540	4070
	N _{b,z,Rd}	8570	8510	8360	8200	8020	7820	7580	6970	6170	5260	4390	3660	3070	2600	2220	1920	1670
UC 356 x 368 x 129	N _{b,y,Rd}	7230	7230	7230	7180	7100	7020	6940	6760	6540	6280	5970	5590	5160	4690	4220	3780	3390
	N _{b,z,Rd}	7230	7180	7050	6910	6760	6590	6380	5860	5180	4400	3670	3050	2560	2160	1850	1600	1390
UC 305 x 305 x 283	N _{b,y,Rd}	16600	16600	16600	16400	16200	16000	15800	15300	14700	14000	13100	12100	10900	9790	8690	7710	6840
	N _{b,z,Rd}	16600	16300	16000	15600	15100	14600	13900	12200	10100	8170	6600	5400	4470	3760	3200	2750	2390
UC 305 x 305 x 240	N _{b,y,Rd}	13500	13500	13500	13300	13100	13000	12800	12400	12000	11400	10700	9830	8900	7960	7070	6270	5570
	N _{b,z,Rd}	13500	13300	13000	12600	12300	11800	11300	9930	8270	6700	5430	4440	3680	3090	2630	2260	1970
UC 305 x 305 x 198	N _{b,y,Rd}	11100	11100	11100	11000	10800	10700	10600	10200	9820	9320	8700	7980	7190	6400	5670	5020	4450
	N _{b,z,Rd}	11100	10900	10700	10400	10100	9730	9280	8100	6720	5420	4380	3580	2960	2490	2120	1820	1580
UC 305 x 305 x 158	N _{b,y,Rd}	8860	8860	8840	8740	8630	8520	8400	8120	7780	7360	6840	6230	5580	4950	4370	3860	3410
	N _{b,z,Rd}	8860	8710	8510	8290	8040	7730	7350	6370	5240	4210	3390	2770	2290	1920	1640	1410	1220
UC 305 x 305 x 137	N _{b,y,Rd}	7670	7670	7650	7560	7470	7370	7260	7020	6720	6340	5880	5340	4770	4220	3720	3280	2900
	N _{b,z,Rd}	7670	7540	7370	7170	6950	6670	6340	5480	4490	3600	2890	2360	1950	1640	1390	1200	1040
UC 305 x 305 x 118	N _{b,y,Rd}	6610	6610	6590	6510	6420	6340	6240	6030	5760	5430	5020	4550	4060	3580	3150	2780	2450
	N _{b,z,Rd}	6610	6490	6340	6170	5970	5730	5440	4680	3820	3060	2460	2000	1660	1390	1180	1020	883
UC 305 x 305 x 97	N _{b,y,Rd}	5680	5680	5650	5580	5500	5420	5340	5140	4900	4590	4210	3780	3340	2930	2570	2260	1990
	N _{b,z,Rd}	5680	5560	5430	5270	5090	4870	4600	3900	3140	2500	2000	1620	1340	1120	955	821	713
UC 254 x 254 x 167	N _{b,y,Rd}	9370	9370	9270	9140	9000	8850	8680	8290	7770	7120	6350	5550	4800	4150	3600	3140	2750
	N _{b,z,Rd}	9340	9110	8860	8550	8180	7720	7140	5780	4490	3500	2770	2240	1840	1540	1310	1120	973
UC 254 x 254 x 132	N _{b,y,Rd}	7400	7400	7310	7200	7090	6970	6830	6500	6070	5520	4890	4240	3660	3150	2720	2370	2080
	N _{b,z,Rd}	7370	7180	6980	6730	6420	6040	5570	4460	3450	2680	2120	1710	1410	1180	997	856	742
UC 254 x 254 x 107	N _{b,y,Rd}	6000	6000	5920	5840	5740	5640	5520	5240	4870	4400	3870	3340	2870	2460	2130	1850	1620
	N _{b,z,Rd}	5970	5820	5650	5440	5190	4860	4470	3550	2730	2120	1670	1350	1110	927	786	675	585
UC 254 x 254 x 89	N _{b,y,Rd}	4980	4980	4920	4840	4760	4680	4580	4340	4020	3630	3180	2740	2350	2020	1740	1510	1320
	N _{b,z,Rd}	4960	4830	4690	4520	4300	4030	3690	2930	2250	1740	1380	1110	911	762	645	554	480
UC 254 x 254 x 73	N _{b,y,Rd}	4280	4280	4220	4150	4080	4000	3900	3680	3390	3020	2620	2240	1910	1630	1400	1220	1060
	N _{b,z,Rd}	4250	4140	4010	3850	3650	3400	3090	2410	1830	1410	1110	896	736	615	521	447	387

Table 3.2 (continued): Eurocode (EN 1993-1-1: 2005) design buckling resistances [kN] of strong and weak axis of UC columns sections in HISTAR® 460.

Shape		W14 x 16													
lb/ft		873 ^h		808 ^h		730 ^h		665 ^h		605 ^h		550 ^h		500 ^h	
Design		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, ry	0	10000	15030	9260	13920	8370	12580	7630	11470	6930	10410	6310	9480	5720	8600
	11	9340	14030	8630	12970	7760	11670	7060	10610	6400	9610	5810	8730	5260	7900
	12	9210	13850	8510	12790	7650	11500	6960	10450	6300	9470	5720	8590	5170	7780
	13	9080	13650	8390	12610	7530	11320	6850	10290	6200	9310	5620	8450	5090	7640
	14	8950	13450	8260	12410	7410	11130	6730	10110	6090	9150	5520	8300	4990	7500
	15	8800	13220	8120	12200	7270	10930	6600	9930	5970	8970	5410	8130	4890	7350
	16	8640	12990	7970	11980	7140	10730	6470	9730	5850	8790	5300	7970	4790	7190
	17	8480	12750	7820	11750	6990	10510	6340	9530	5720	8600	5180	7790	4680	7030
	18	8320	12500	7660	11510	6840	10280	6200	9310	5590	8410	5060	7610	4560	6860
	19	8140	12240	7500	11270	6680	10050	6050	9100	5460	8200	4930	7420	4450	6690
	20	7960	11970	7330	11010	6520	9810	5900	8870	5320	7990	4810	7220	4330	6510
	22	7590	11410	6970	10480	6190	9310	5590	8410	5030	7560	4540	6820	4080	6140
	24	7200	10830	6610	9930	5850	8790	5270	7920	4730	7120	4260	6410	3830	5750
	26	6800	10230	6230	9360	5490	8260	4950	7430	4430	6660	3980	5990	3570	5370
	28	6400	9620	5850	8790	5140	7720	4610	6940	4130	6200	3700	5570	3310	4980
	30	5990	9000	5460	8210	4780	7180	4280	6440	3820	5740	3420	5140	3050	4590
	32	5580	8390	5080	7630	4420	6650	3960	5950	3520	5290	3150	4730	2800	4210
	34	5180	7780	4700	7070	4080	6130	3640	5460	3230	4850	2880	4320	2550	3840
	36	4780	7180	4330	6510	3740	5620	3320	4990	2940	4420	2620	3930	2320	3480
	38	4390	6600	3970	5970	3410	5120	3020	4540	2660	4000	2360	3550	2090	3130
	40	4020	6040	3620	5450	3090	4640	2730	4100	2400	3610	2130	3200	1880	2830
	42	3650	5490	3290	4940	2800	4210	2480	3720	2180	3280	1930	2900	1710	2570
	44	3330	5000	2990	4500	2550	3830	2260	3390	1990	2990	1760	2650	1560	2340
	46	3040	4570	2740	4120	2330	3510	2060	3100	1820	2730	1610	2420	1420	2140
	48	2800	4200	2520	3780	2140	3220	1900	2850	1670	2510	1480	2220	1310	1960
	50	2580	3870	2320	3480	1970	2970	1750	2630	1540	2310	1360	2050	1200	1810

Shape		W14 x 16													
lb/ft		455 ^h		426 ^h		398 ^h		370 ^h		342 ^h		311 ^h		283 ^h	
Design		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, ry	0	5220	7840	4870	7310	4550	6840	4240	6380	3930	5910	3560	5350	3240	4870
	11	4780	7190	4460	6700	4170	6260	3870	5820	3590	5390	3240	4870	2950	4430
	12	4710	7070	4380	6590	4100	6160	3810	5720	3520	5290	3180	4780	2890	4350
	13	4620	6950	4300	6470	4020	6040	3740	5620	3460	5200	3120	4690	2840	4270
	14	4530	6820	4220	6340	3940	5920	3660	5500	3390	5090	3060	4590	2780	4180
	15	4440	6680	4130	6210	3860	5800	3580	5390	3310	4980	2990	4490	2720	4080
	16	4340	6530	4040	6070	3770	5670	3500	5260	3230	4860	2920	4380	2650	3980
	17	4240	6380	3940	5930	3680	5530	3420	5130	3150	4740	2840	4270	2580	3880
	18	4140	6220	3840	5780	3590	5390	3330	5000	3070	4620	2770	4160	2510	3780
	19	4030	6060	3740	5630	3490	5250	3240	4860	2990	4490	2690	4040	2440	3670
	20	3920	5890	3640	5470	3390	5100	3140	4720	2900	4360	2610	3920	2370	3560
	22	3690	5550	3420	5140	3190	4790	2950	4430	2720	4090	2440	3670	2220	3330
	24	3460	5200	3200	4810	2980	4480	2750	4140	2540	3810	2280	3420	2060	3100
	26	3220	4840	2980	4470	2770	4160	2550	3840	2350	3530	2110	3160	1900	2860
	28	2980	4480	2750	4140	2560	3840	2360	3540	2160	3250	1940	2910	1750	2630
	30	2740	4120	2530	3800	2350	3530	2160	3240	1980	2980	1770	2660	1600	2400
	32	2510	3780	2310	3470	2140	3220	1970	2960	1800	2710	1610	2420	1450	2180
	34	2290	3440	2100	3160	1940	2920	1780	2680	1630	2450	1450	2180	1310	1960
	36	2070	3110	1900	2850	1750	2630	1600	2410	1460	2200	1300	1950	1170	1750
	38	1860	2790	1700	2560	1570	2360	1440	2160	1310	1970	1170	1750	1050	1570
	40	1680	2520	1540	2310	1420	2130	1300	1950	1180	1780	1050	1580	944	1420
	42	1520	2290	1390	2090	1290	1930	1180	1770	1070	1610	954	1430	857	1290
	44	1390	2080	1270	1910	1170	1760	1070	1610	978	1470	869	1310	780	1170
	46	1270	1910	1160	1750	1070	1610	980	1470	895	1350	795	1200	714	1070
	48	1160	1750	1070	1600	984	1480	900	1350	822	1240	730	1100	656	986
	50	1070	1610	983	1480	907	1360	829	1250	758	1140	673	1010	604	908

Table 3.3: American Standard (ANSI/AISC 360-16) design buckling resistance [kips] of W columns in Grade 65.

^h Flange thickness is greater than 2 in. Special requirements may apply per AISC Specification Section A3.1c.

Shape		W14 x 16													
lb/ft		257		233		211		193		176		159		145	
Design		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, KL (ft), with respect to least radius of gyration, ry	0	2940	4420	2670	4010	2410	3630	2210	3320	2020	3030	1820	2730	1660	2500
	11	2670	4010	2420	3630	2180	3280	2000	3000	1820	2740	1640	2460	1500	2250
	12	2620	3940	2370	3560	2140	3220	1960	2950	1780	2680	1610	2420	1470	2210
	13	2570	3860	2320	3490	2100	3150	1920	2890	1750	2630	1570	2360	1440	2160
	14	2510	3780	2270	3420	2050	3080	1880	2820	1710	2570	1540	2310	1400	2110
	15	2460	3690	2220	3340	2000	3010	1830	2750	1670	2500	1500	2250	1370	2060
	16	2400	3600	2160	3250	1950	2940	1790	2680	1620	2440	1460	2190	1330	2000
	17	2330	3510	2110	3170	1900	2860	1740	2610	1580	2370	1420	2130	1290	1950
	18	2270	3410	2050	3080	1850	2780	1690	2540	1530	2300	1380	2070	1260	1890
	19	2200	3310	1990	2990	1790	2690	1640	2460	1490	2230	1330	2010	1220	1830
	20	2130	3210	1930	2890	1730	2610	1580	2380	1440	2160	1290	1940	1180	1770
	22	2000	3000	1800	2700	1620	2430	1480	2220	1340	2010	1200	1810	1090	1640
	24	1850	2790	1670	2510	1500	2250	1370	2050	1240	1860	1110	1670	1010	1520
	26	1710	2570	1540	2310	1380	2070	1260	1890	1140	1710	1020	1530	926	1390
	28	1570	2360	1410	2120	1260	1900	1150	1730	1040	1560	929	1400	844	1270
	30	1430	2150	1280	1930	1150	1720	1040	1570	940	1410	841	1270	763	1150
	32	1290	1940	1160	1740	1040	1560	940	1410	846	1270	756	1140	686	1030
	34	1160	1750	1040	1560	927	1390	841	1260	755	1140	674	1010	610	917
	36	1040	1560	927	1390	827	1240	750	1130	674	1010	601	904	544	818
	38	932	1400	832	1250	742	1120	673	1010	605	909	540	811	488	734
	40	841	1260	751	1130	670	1010	607	913	546	820	487	732	441	663
	42	763	1150	681	1020	607	913	551	828	495	744	442	664	400	601
	44	695	1040	620	933	553	832	502	754	451	678	402	605	364	548
	46	636	956	568	853	506	761	459	690	412	620	368	553	333	501
	48	584	878	521	784	465	699	422	634	379	570	338	508	306	460
	50	538	809	480	722	428	644	388	584	349	525	311	468	282	424

Table 3.3 (continued): American Standard (ANSI/AISC 360-16) design buckling resistance [kips] of W columns in Grade 65.


	Axis	Buckling length [m]												
		2	3	4	5	6	7	8	9	10	11	12	13	14
Box HD 400 x 634	N _{b,y,Rd}	74 204	70653	66891	62958	58793	54402	49863	45315	40913	36791	33029	29661	26680
	N _{b,z,Rd}	74 204	72557	69487	66346	63079	59652	56064	52348	48568	44813	41170	37715	34499
Box HD 400 x 677	N _{b,y,Rd}	79 291	77676	71647	67498	63109	58480	53688	48873	44196	39799	35773	32157	28948
	N _{b,z,Rd}	79 291	75620	74446	71145	67720	64129	60370	56471	52497	48533	44671	40993	37554
Box HD 400 x 744	N _{b,y,Rd}	85178	81587	77451	73146	68603	63811	58832	53793	48855	44165	39829	35902	32393
	N _{b,z,Rd}	85178	83767	80409	76990	73450	69748	65875	61851	57729	53584	49521	45609	41920
Box HD 400 x 818	N _{b,y,Rd}	93706	90006	85548	80920	76043	70900	65545	60105	54740	49613	44844	40499	36598
	N _{b,z,Rd}	93706	92414	88808	85146	81363	77415	73287	68992	64581	60130	55729	51469	47424
Box HD 400 x 900	N _{b,y,Rd}	103232	99424	94614	89629	84385	78857	73093	67213	61384	55779	50532	45724	41386
	N _{b,z,Rd}	103232	102099	98225	94300	90255	86042	81641	77059	72341	67558	62803	58169	53738
Box HD 400 x 990	N _{b,y,Rd}	113385	109542	104380	99046	93446	87546	81384	75074	68783	62690	56945	51645	46836
	N _{b,z,Rd}	113385	112462	108314	104121	99810	95331	90656	85788	80764	75652	70541	65527	60700
Box HD 400 x 1086	N _{b,y,Rd}	124529	120647	115100	109381	103390	97082	90487	83712	76923	70305	64023	58193	52872
	N _{b,z,Rd}	124529	123878	119443	114970	110384	105629	100673	95513	90178	84729	79253	73847	68605
Box HD 400 x 1202	N _{b,y,Rd}	137443	133346	127291	121056	114530	107663	100480	93090	85665	78408	71494	65056	59165
	N _{b,z,Rd}	137443	137162	132412	127633	122746	117693	112435	106963	101297	95491	89624	83795	78099
Box HD 400 x 1299	N _{b,y,Rd}	148230	144267	137898	131358	124528	117350	109837	102084	94254	86547	79151	72214	65824
	N _{b,z,Rd}	148230	148230	143333	138320	133207	127930	122449	116749	110842	104775	98620	92471	86427

Table 3.4: Eurocode (EN 1993-1-1: 2005) design buckling resistance [kN] of strong and weak axis of HD Box columns sections in HISTAR® 460.


	Axis	Buckling length [m]												
		2	3	4	5	6	7	8	9	10	11	12	13	14
Cruciform HL 1100 x 607	N _{b,y,Rd}	71039	71039	71039	70020	68374	66721	65046	63342	61598	59807	57967	56077	54139
	N _{b,z,Rd}	71039	71039	71039	70221	68615	67004	65375	63719	62027	60292	58511	56682	54806
Cruciform HL 1000 x 642	N _{b,y,Rd}	75125	75125	75125	73441	71578	69699	67788	65835	63828	61762	59635	57450	55214
	N _{b,z,Rd}	75125	75125	75125	73708	71899	70078	68229	66343	64408	62419	60373	58270	56116
Cruciform HL 920 x 656	N _{b,y,Rd}	76752	76752	76752	74586	72590	70571	68513	66402	64227	61986	59677	57306	54887
	N _{b,z,Rd}	76752	76752	76752	74891	72958	71008	69022	66991	64901	62750	60534	58258	55931
Cruciform HL 920 x 725	N _{b,y,Rd}	84801	84801	84801	82472	80280	78064	75805	73489	71105	68647	66116	63517	60863
	N _{b,z,Rd}	84801	84801	84801	82846	80731	78598	76429	74210	71929	69581	67164	64681	62141
Cruciform HL 1000 x 748	N _{b,y,Rd}	87605	87605	87605	85771	83624	81461	79264	77019	74713	72342	69901	67393	64826
	N _{b,z,Rd}	87605	87605	87605	86129	84054	81969	79854	77698	75489	73220	70886	68488	66031
Cruciform HL 920 x 787	N _{b,y,Rd}	92071	92071	92071	89638	87278	84893	82464	79975	77413	74773	72054	69262	66410
	N _{b,z,Rd}	92071	92071	92071	90069	87798	85508	83181	80803	78360	75846	73258	70600	67878
Cruciform HL 1000 x 883	N _{b,y,Rd}	103402	103402	103402	101400	98899	96381	93826	91216	88540	85787	82955	80045	77065
	N _{b,z,Rd}	103402	103402	103402	101891	99489	97076	94634	92146	89599	86986	84299	81540	78711
Cruciform HL 920 x 970	N _{b,y,Rd}	111159	111159	111159	108615	105847	103055	100215	97311	94327	91255	88092	84843	81519
	N _{b,z,Rd}	111159	111159	111159	109238	106597	103940	101246	98498	95683	92790	89814	86757	83625
Cruciform HL 1000 x 976	N _{b,y,Rd}	111735	111735	111735	109818	107165	104498	101793	99035	96208	93304	90317	87248	84104
	N _{b,z,Rd}	111735	111735	111735	110389	107851	105305	102730	100111	97434	94689	91870	88975	86007
Cruciform HL 920 x 1077	N _{b,y,Rd}	123331	123331	123331	120665	117625	114562	111448	108266	104997	101634	98172	94616	90975
	N _{b,z,Rd}	123331	123331	123331	121410	118522	115618	112677	109681	106612	103461	100222	96894	93483
Cruciform HL 920 x 1194	N _{b,y,Rd}	136816	136816	136816	134043	130710	127351	123940	120457	116881	113204	109419	105531	101549
	N _{b,z,Rd}	136816	136816	136816	134941	131789	128622	125418	122156	118819	115395	111878	108264	104559
Cruciform HL 920 x 1269	N _{b,y,Rd}	145357	145357	145357	142531	139014	135471	131876	128205	124438	120566	116581	112487	108294
	N _{b,z,Rd}	145357	145357	145357	143525	140208	136878	133510	130084	126580	122987	119297	115506	111620
Cruciform HL 920 x 1377	N _{b,y,Rd}	157652	157652	157652	154264	150383	146471	142495	138432	134260	129966	125547	121007	116359
	N _{b,z,Rd}	157652	157652	157652	155601	151990	148364	144697	140965	137148	133233	129211	125080	120845

Table 3.5: Eurocode (EN 1993-1-1: 2005) design buckling resistance [kN] of strong and weak axis of Cruciform sections in HISTAR® 460.


	Axis	Buckling length [m]												
		2	3	4	5	6	7	8	9	10	11	12	13	14
Box W 360 x 410 x 634	N _{b,y,Rd}	64259	62945	61150	58917	56299	53354	50147	46745	43215	39623	36030	32494	29063
	N _{b,z,Rd}	63684	63684	62432	60859	58990	56855	54488	51923	49200	46356	43429	40457	37475
Box W 360 x 410 x 677	N _{b,y,Rd}	68691	67315	65435	63094	60347	57254	53882	50299	46576	42781	38979	35228	31581
	N _{b,z,Rd}	68104	68104	66805	65170	63227	61004	58537	55861	53015	50038	46968	43845	40705
Box W 360 x 410 x 744	N _{b,y,Rd}	75469	74008	72010	69521	66595	63295	59690	55852	51854	47767	43660	39595	35628
	N _{b,z,Rd}	74858	74858	73487	71761	69706	67354	64738	61896	58867	55691	52410	49061	45685
Box W 360 x 410 x 818	N _{b,y,Rd}	83100	81550	79428	76781	73664	70144	66291	62180	57885	53483	49045	44638	40321
	N _{b,z,Rd}	82471	82471	81030	79213	77049	74567	71802	68793	65578	62199	58699	55116	51493
Box W 360 x 410 x 900	N _{b,y,Rd}	91586	89940	87685	84868	81548	77792	73672	69265	64652	59910	55114	50335	45639
	N _{b,z,Rd}	90942	90942	89429	87520	85243	82628	79710	76527	73120	69531	65802	61974	58091
Box W 360 x 410 x 990	N _{b,y,Rd}	100672	98939	96562	93589	90080	86103	81731	77044	72122	67048	61899	56750	51669
	N _{b,z,Rd}	100009	100009	98426	96428	94041	91296	88229	84876	81280	77482	73526	69454	65310
Box W 360 x 410 x 1086	N _{b,y,Rd}	110572	108744	106236	103096	99383	95168	90526	85538	80288	74859	69333	63789	58298
	N _{b,z,Rd}	109901	109901	108253	106171	103680	100811	97599	94083	90303	86301	82122	77808	73403
Box W 360 x 410 x 1202	N _{b,y,Rd}	122094	120116	117401	114000	109977	105405	100365	94944	89231	83316	77286	71226	65214
	N _{b,z,Rd}	121458	121458	119742	117572	114972	111975	108613	104924	100950	96732	92315	87741	83057
Box W 360 x 410 x 1299	N _{b,y,Rd}	132150	130102	127287	123757	119576	114816	109559	103891	97903	91685	85327	78915	72531
	N _{b,z,Rd}	131503	131503	129734	127495	124810	121711	118230	114405	110276	105886	101278	96496	91585

Table 3.6: American Standard (ANSI/AISC 360-16) design buckling resistance [kN] of W Box columns in Grade 65.


	Axis	Buckling length [m]												
		2	3	4	5	6	7	8	9	10	11	12	13	14
Cruciform W 1100 x 400 x 607	N _{b,y,Rd}	62322	62044	61656	61161	60562	59861	59062	58170	57189	56127	57189	56127	57189
	N _{b,z,Rd}	62333	62068	61699	61227	60656	59988	59226	58374	57436	56417	57436	56417	57436
Cruciform W 1000 x 400 x 642	N _{b,y,Rd}	65873	65536	65068	65536	65068	65536	65068	65536	65068	65536	65068	65536	65068
	N _{b,z,Rd}	65888	65571	65129	65571	65129	65571	65129	65571	65129	65571	65129	65571	65129
Cruciform W 920 x 420 x 656	N _{b,y,Rd}	67273	66897	66373	65706	66373	65706	66373	65706	66373	65706	66373	65706	66373
	N _{b,z,Rd}	67291	66937	66445	65817	66445	65817	66445	65817	66445	65817	66445	65817	66445
Cruciform W 920 x 420 x 725	N _{b,y,Rd}	74332	73921	73349	72620	73349	72620	73349	72620	73349	72620	73349	72620	73349
	N _{b,z,Rd}	74354	73971	73437	72756	73437	72756	73437	72756	73437	72756	73437	72756	73437
Cruciform W 1000 x 400 x 748	N _{b,y,Rd}	76823	76440	75907	76440	75907	76440	75907	76440	75907	76440	75907	76440	75907
	N _{b,z,Rd}	76843	76485	75986	76485	75986	76485	75986	76485	75986	76485	75986	76485	75986
Cruciform W 920 x 420 x 787	N _{b,y,Rd}	80710	80270	79659	78880	79659	78880	79659	78880	79659	78880	79659	78880	79659
	N _{b,z,Rd}	80735	80327	79759	79035	79759	79035	79759	79035	79759	79035	79759	79035	79759
Cruciform W 1000 x 400 x 883	N _{b,y,Rd}	90685	90244	89631	90244	89631	90244	89631	90244	89631	90244	89631	90244	89631
	N _{b,z,Rd}	90712	90305	89738	90305	89738	90305	89738	90305	89738	90305	89738	90305	89738
Cruciform W 920 x 420 x 970	N _{b,y,Rd}	99622	99098	98369	97439	98369	97439	98369	97439	98369	97439	98369	97439	98369
	N _{b,z,Rd}	99659	99181	98515	97666	98515	97666	98515	97666	98515	97666	98515	97666	98515
Cruciform W 1000 x 400 x 976	N _{b,y,Rd}	100177	99697	99029	99697	99029	99697	99029	99697	99029	99697	99029	99697	99029
	N _{b,z,Rd}	100209	99769	99157	99769	99157	99769	99157	99769	99157	99769	99157	99769	99157
Cruciform W 920 x 420 x 1077	N _{b,y,Rd}	110541	109971	109178	108167	109178	108167	109178	108167	109178	108167	109178	108167	109178
	N _{b,z,Rd}	110585	110069	109351	108435	109351	108435	109351	108435	109351	108435	109351	108435	109351
Cruciform W 920 x 420 x 1194	N _{b,y,Rd}	122638	122020	121159	120062	121159	120062	121159	120062	121159	120062	121159	120062	121159
	N _{b,z,Rd}	122690	122136	121365	120380	121365	120380	121365	120380	121365	120380	121365	120380	121365
Cruciform W 920 x 420 x 1269	N _{b,y,Rd}	130301	129653	128751	127600	128751	127600	128751	127600	128751	127600	128751	127600	128751
	N _{b,z,Rd}	130358	129781	128977	127950	128977	127950	128977	127950	128977	127950	128977	127950	128977
Cruciform W 920 x 420 x 1377	N _{b,y,Rd}	141304	140577	139565	138275	139565	138275	139565	138275	139565	138275	139565	138275	139565
	N _{b,z,Rd}	141381	140751	139872	138751	139872	138751	139872	138751	139872	138751	139872	138751	139872

Table 3.7: American Standard (ANSI/AISC 360-16) design buckling resistance [kN] of cruciform columns in Grade 65.



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• Megacolumns

High-rise buildings have been built in recent years all around the world and the majority of their structures are built using reinforced concrete as the core and structural steel as the surrounding frame.

Minimising the size of the vertical structural elements, without compromising the economic feasibility of projects and limiting their impact on tall buildings' floor plans, is a constant challenge. The use of composite structural elements combining high grade concrete and steel is a viable solution.

Currently, concrete filled tubes (CFT) or concrete filled continuous caissons built-up by welding heavy plates are common structural solutions. Their main drawbacks include high costs, the need for skilled labour, complex connections, and requiring welding conditions for heavy plates, such as preheating and repairing.

Megacolumns are composed of more than one structural steel wide flange shape with longitudinal rebar and ties embedded in concrete. These are believed to be a convenient solution in terms of structural behaviour, cost and constructability for the design of tall buildings (incl. towers over 300m). They serve to support gravity loads, as well as axial loads from wind and seismic overturning, and the reinforced concrete surrounding the megacolumns is not only for structural stability, but also protects the steel column from corrosion and fire. This technical solution brings several advantages:

- smaller footprint of the column
- lower prices thanks to the simplicity of the system itself
- safe and reliable (i.e. minimal welding is necessary on site and, fire protection can be achieved utilising the surrounding concrete)
- construction times are decreased dramatically due to off-site fabrication and faster erection
- optimisation of the section using composite action decreases significantly the environmental footprint of the structural system.

• Experimental Testing of Composite Megacolumns

Experimental performance tests on composite megacolumns with encased hot rolled steel sections, which were supported and founded by ArcelorMittal, were carried out between February and September 2015 at the China Academy of Building Research Technologies (CABR) Laboratories and the Laboratories of Tsinghua University, Beijing.

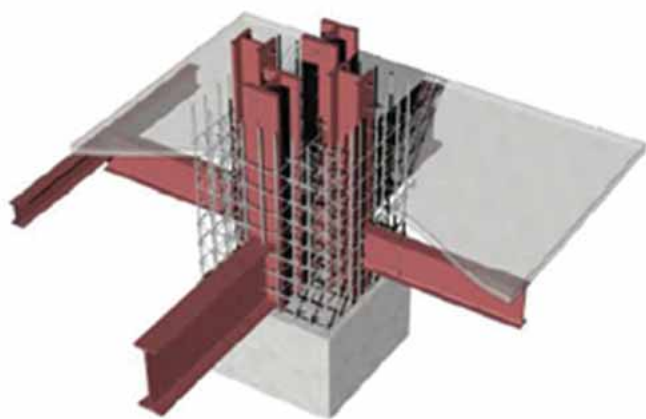
The design office, Magnusson Klemencic Associates, provided background studies on comparative composite megacolumn construction projects, both within China and other international markets and the Council on Tall Buildings and Urban Habitat (CTBUH) assumed the role of project coordinator.



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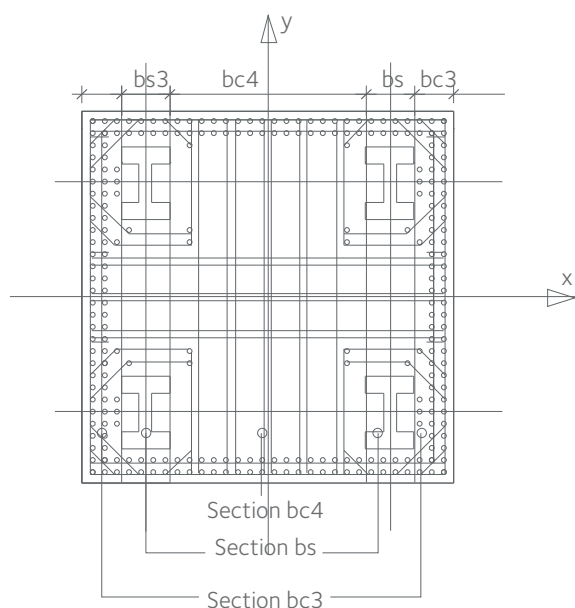
Figure 3.9 Mega-Column scaled (1:4) Specimen tested to failure

The composite megacolumns considered in this testing were defined as vertical structural systems with four hot-rolled steel sections embedded in concrete and subjected to significant vertical loads and secondary bending moments from wind and seismic actions.



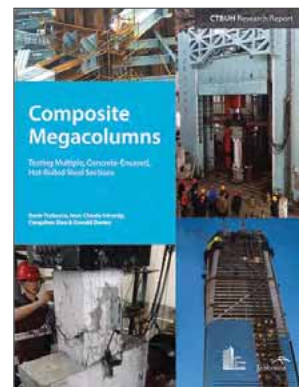
Although codes and specifications do consider composite structural elements, they do not offer specific provisions on the design of composite sections with two or more encased steel sections (American Institute of Steel Construction_AISC_2010 Specifications for instance). The lack of knowledge on the axial, bending and shear behaviour of composite megacolumns, along with the resulting lack of clarity in the codes, is what led to the need for experimental performance tests.

The column specimens' overall layout and geometry were based on suggestions from Magnusson Klemencic Associates and others, with the ultimate goal to be representative of full scale composite columns considered for high-rise buildings. Overall dimensions of the representative full scale columns considered for this testing program are 1800 x 1800mm, with a height of 9m at the lobby level (base of the tower) and 4,5m at the typical floor.



**Figure 3.10: Section layout of reinforcement
Example of the Eurocode 4 Design Method**

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**Figure 3.11: Scaled (1:6)
Specimen tested to failure**

The experimental campaign consisted of two sets of tests that attempt to define the axial load and moment (P-M) interaction curves of the representative columns at failure. Static tests were accomplished by applying 0%, 10% and 15% eccentricity axial loads, on six 1:4 scaled specimens, until failure (Figure 3.9). Quasi-static tests were accomplished by applying 10% and 15% eccentricity axial loads with horizontal forces on four 1:6 scaled specimens, until failure (Figure 3.11).

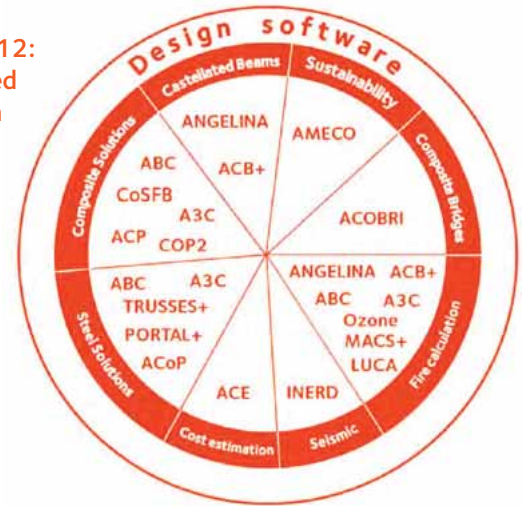
The results of the tests were used to investigate the specimens' maximum capacity, displacements, stress distribution, ductility and stiffness. The experimental results were further validated by the finite element method (FEM) models developed by CABR and ArcelorMittal with Abaqus and Safr software. FEM models also allow for a deeper insight on steel-concrete interaction forces and stress distribution.

• Design rules

Then simplified design methods based on European, Chinese, and US codes were suggested and the results were compared to the numerical and experimental values (Figure 3.10). This proved the simplified structural design methods to be an effective and useful design tool.

A complete description of the research programme, design methods, design examples including all information and data of the experimental campaign can be found at sections.arcelormittal.com or at ctbuh.org/megacolumns.

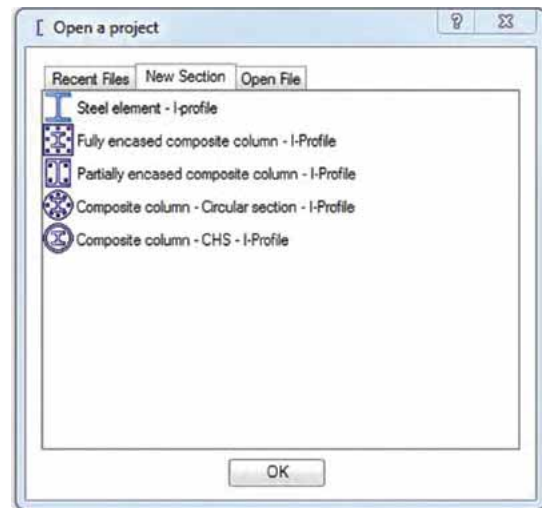
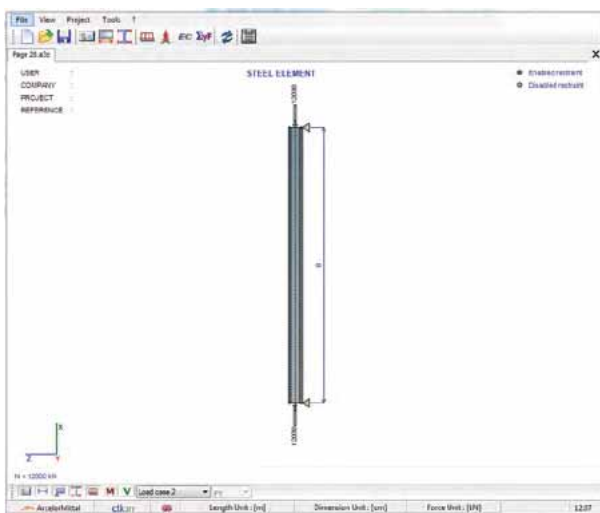
Figure 3.12:
pre-designed
software available on
sections.arcelormittal.com



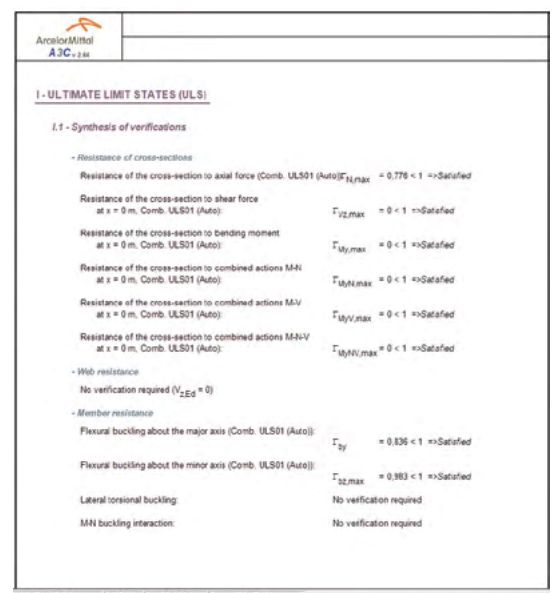
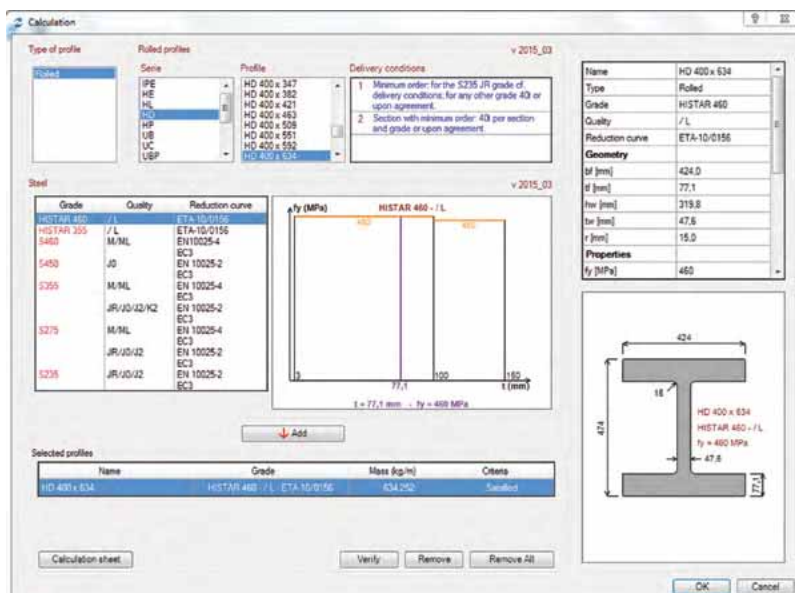
• Predesign tools, software

A3C – Verification of steel and composite (partially or totally encased) columns in cold and fire conditions

A3C Software: This software is available for free at sections.arcelormittal.com in the download centre. The A3C software allows the designer to perform a detailed verification of a single steel member or a composite steel-concrete column (partially encased, fully encased in concrete or in a concrete filled tube) subjected to axial force and/or bending moments according to the rules of the Eurocodes.

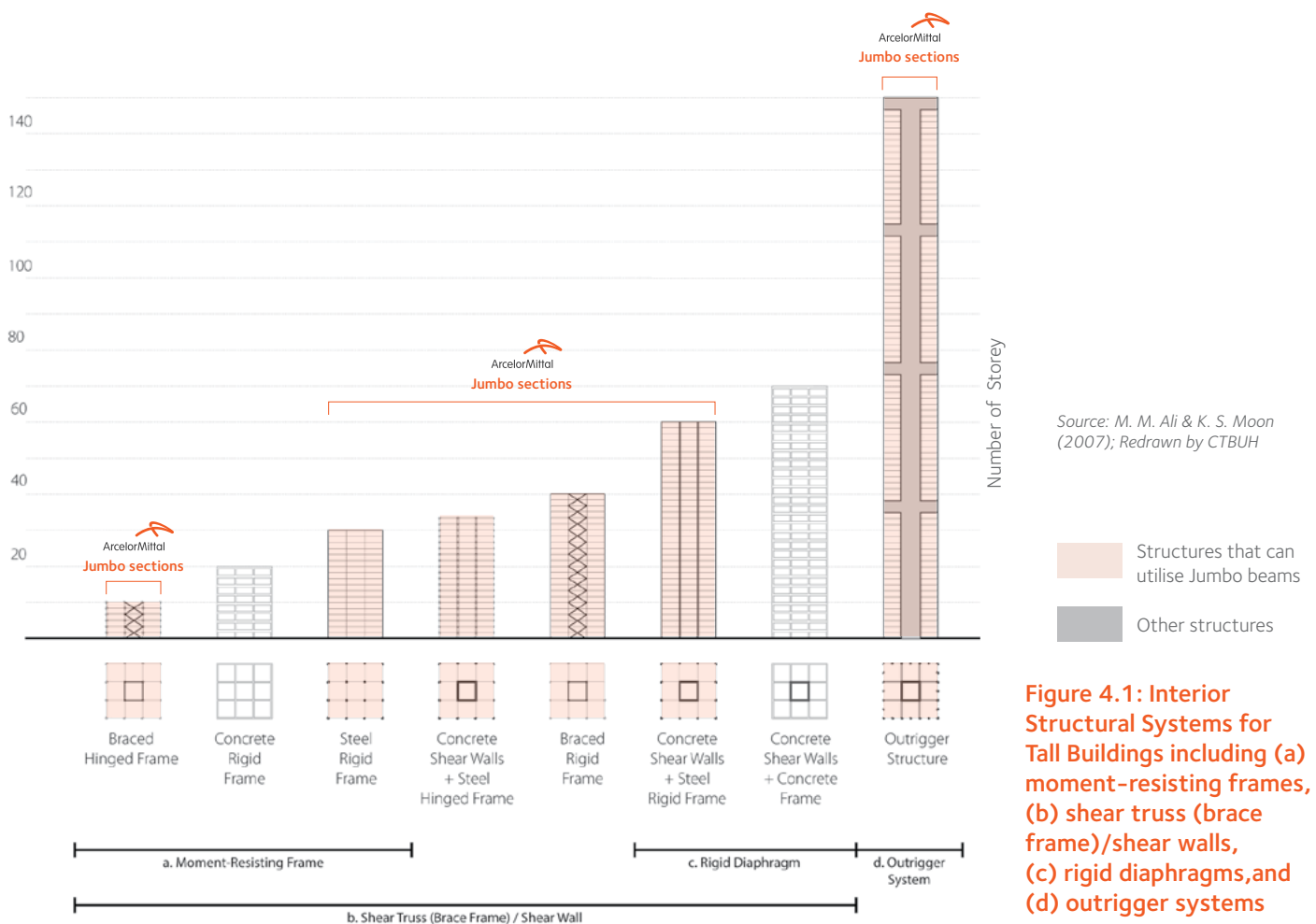


Above, an example of a 6m column under a design axial load of 29000kN is shown. A3C software can define the loads, their combinations as well as the other design parameters such as the fire resistance, the steel sections (i.e. HD 400 x 634) and their steel grade (i.e. H1STAR® 460). With a single click, a resistance check can be performed (see below), additionally the fire protection thickness can also be provided.





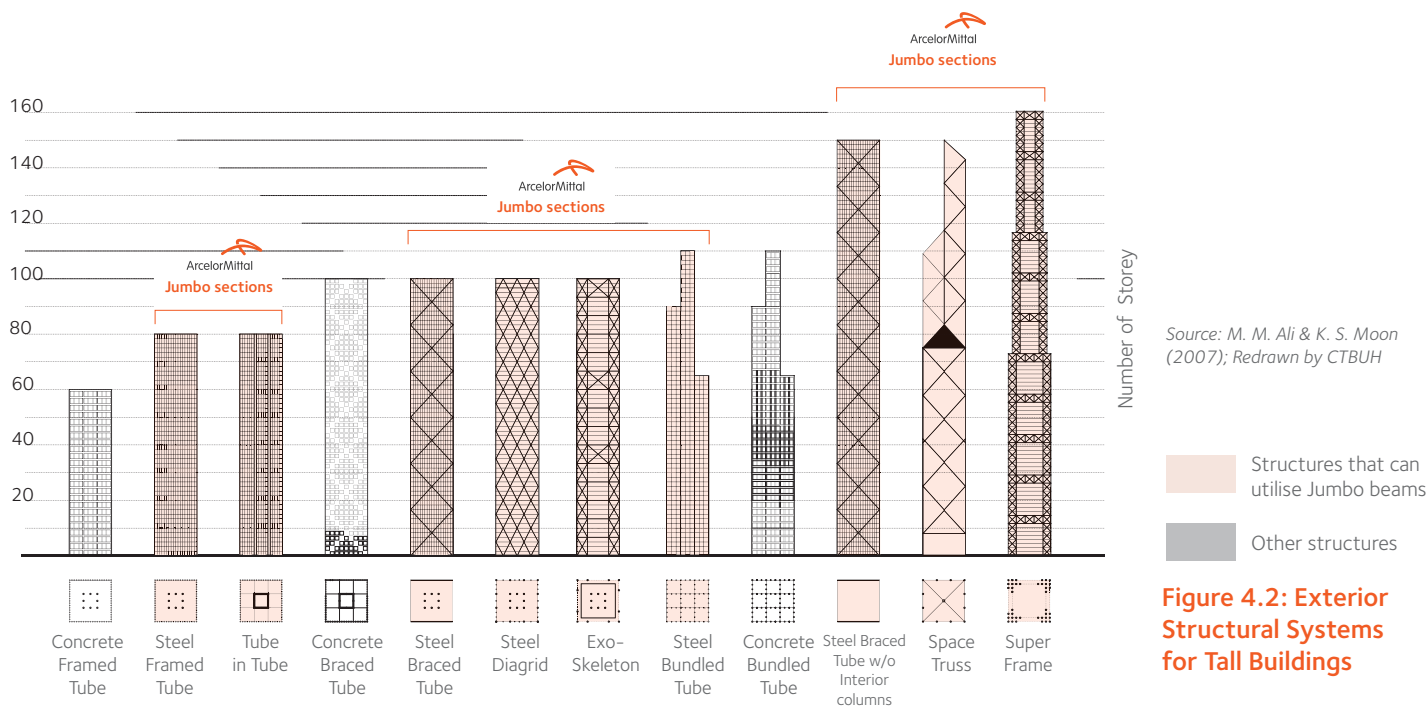
4. Bracing systems



• Structural Systems for Tall Buildings

As height and slenderness of buildings increase, lateral drifts start to control the design of the structure and the stiffness of the components become the dominant factor instead of their strength. Therefore, the need for appropriate structural systems, beyond the simple rigid frame, must be properly addressed in the design of tall buildings, accounting for the prominent loads and forces that differ depending on a building's height.

Lateral forces are usually the driving parameter for the design of a tall building's structural system, and strength, stiffness and damping are the main parameters controlling the limiting factors of displacements (e.g. Building Height/250) and accelerations (e.g. 18 milli-g per 10 year wind return period). Therefore, the ideal structure to withstand the effects of bending, shear and vibrations is a system in which the vertical elements are located at the farthest extremity from the



geometric center of the building, such as in a hollow tube. Here, the parameters that control the efficiency of the structural element's layout are bending and shear rigidity. From the bending rigidity standpoints, the best solution would be to maximise the total moment of inertia of the overall structure, positioning columns at the corners along the outermost perimeter of the building. As far as shear efficiency is concerned, the ideal solution would be a continuous wall without openings.

The existing structural systems used in contemporary tall buildings stem from the basic principles described above. During the last 50 years, rigid frame systems adopted in older tall buildings evolved into different structural families that are used depending on a number of parameters including the size of the building, the magnitude of the external forces, the availability and cost of materials, and labour and stylistic decisions made by the architect and the developer. A common classification of tall buildings structural systems was given by Ali and Moon [2007]* that propose two main categories: interior (Figure 4.1) and exterior (Figure 4.2) (depending if the main lateral resisting system is at the perimeter or not). Each system has a wide variety of application height that depends on several factors (e.g. building stability, aspect ratio (height/width), architectural functions, etc.).

Interior structures (Figure 4.1) are composed of two main systems: moment-resisting frames (Figure 4.1a) and shear truss (braced frame)/shear wall (Figure 4.1b). These systems alone can provide resistance up to 30 storeys, since higher buildings would require deeper elements that are not architecturally and economically feasible. An alternative system is to combine rigid frames with shear truss/shear wall through a rigid diaphragm (Figure 4.1c) and this could lead to buildings up to 70 storeys. The different sway behaviour of the two systems permit the movement to be constrained, making the whole system more rigid (Figure 4.3).

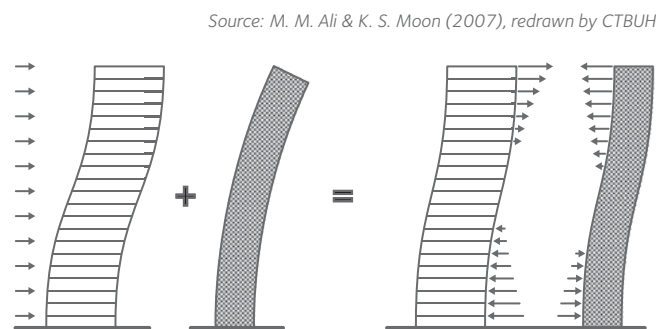


Figure 4.3: Shear Wall-Rigid Frame Interaction

Another alternative solution, becoming popular today for super tall buildings, is the so called outrigger system (Figure 4.1d) that can reach up to 150 storeys or more. The major benefits are to reduce the core overturning moment, storey drifts and floor accelerations (i.e. increasing building comfort). The basis of this structural system is that the overturning moment resistance of the building core is countered through coupling of the compression-tension of the external columns through the help of stiff headers (steel trusses or shear walls, Figure 4.4). This increases the structure flexural rigidity without enhancing the shear rigidity. This system is becoming less efficient if utilised for tube in tube dual systems since the

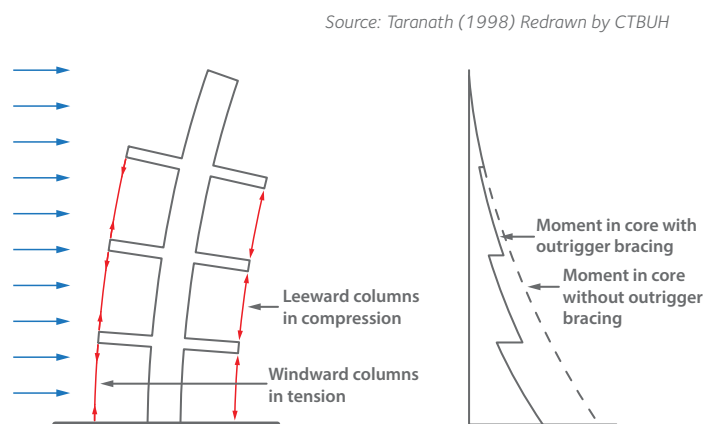


Figure 4.4: Outrigger structural system principles



Figure 4.5: New York Times Tower, New York City, USA

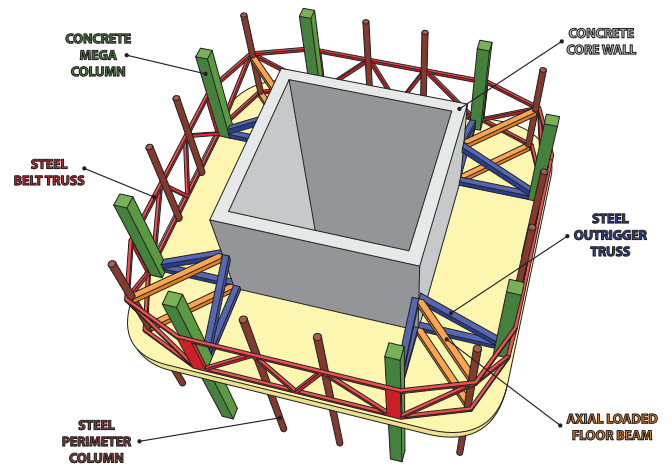


Figure 4.7: Outriggers trusses and belt trusses

lateral response of the two systems is very similar. Outrigger performance is a function of the location through the building height, the presence of belt trusses (to help engaging perimeter columns) or single megacolumns and their structural depth. One of the major issues of outriggers is the differential deformation of core and columns that can create additional forces in the outriggers. For this reason, an alternative solution could be belt trusses in conjunction with rigid diaphragms.

Exterior structures (Figure 4.2) are based on the typical tube structure in which the whole perimeter is designed to resist the lateral loads. This structural system has shear lag problems in which corner columns have larger axial forces due to the intrinsic nature of the system (Figure 4.6), in which shear is carried through columns and beams bending. To overcome these problems different structural solutions have been adopted: braced tube, bundle tube, tube-in-tube systems and diagrids. Particularly, diagrid systems are considered advantageous since they provide both shear and bending rigidity to the building. Alternative solutions, in the exterior category are: space trusses, super frames and exoskeletons.

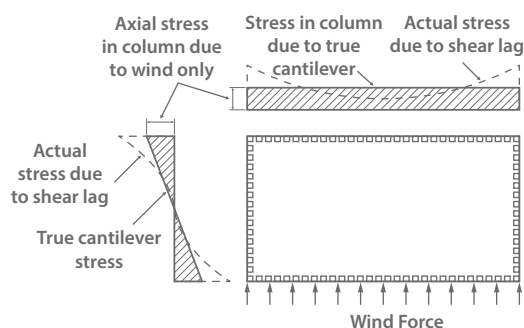


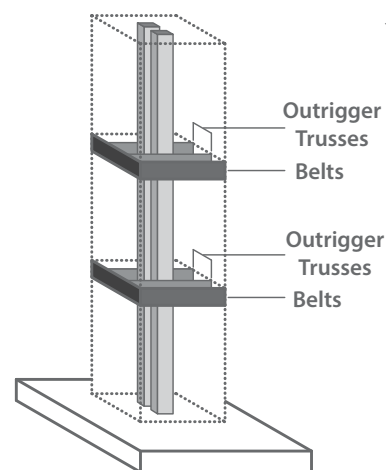
Figure 4.6: Shear lag principles

• Trusses

A truss is essentially a triangulated system of straight interconnected structural elements and they are utilised to increase the lateral stiffness. In high-rise buildings, trusses serve as bracing systems (e.g. belt truss and outriggers) as well as super floors.

• Outriggers and Belt Trusses (Figure 4.7)

Outriggers connect the core to the outer columns through a rigid system (e.g. truss). In addition, at the same outrigger level belt trusses can be utilised to distribute the axial forces in the exterior frames and to provide additional torsional resistance (Figure 4.8). Moreover, belt trusses are efficient in differential elongation and shortening of columns. A gain of 25–30% stiffness can be achieved by combining belt trusses and outriggers trusses, as well as a column-free space leading to an increasing functional efficiency of the building.

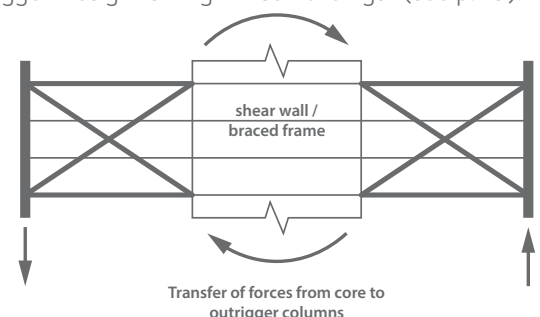


Source: Khanorkar et al. (2016)
Redrawn by CTBUH

Figure 4.8
Outrigger and
belt trusses
location scheme
in a tall building

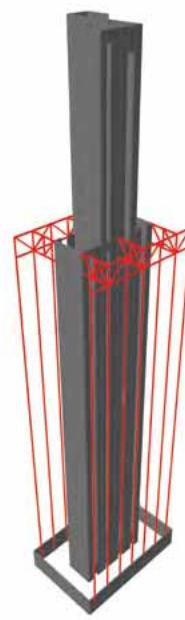
The design principles of outriggers, virtual outriggers and belt trusses are based on the conversion of the core overturning moment into a couple of horizontal forces and then into axial forces in the exterior columns (Figure 4.9). Additional information can be found in the CTBUH Technical Guide “Outrigger Design for High-Rise Buildings” (see p.29).

Figure 4.9:
Force
transfer
using an
outrigger
system





© (CC BY-SA) MusikAnimal



© Magnusson Klemencic Associates

Figure 4.10: 300 North LaSalle, Chicago, USA

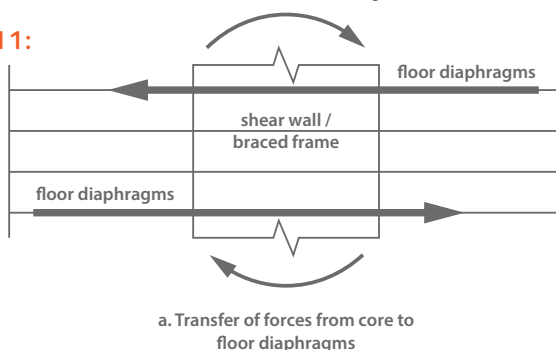
The major benefits of this outrigger-belt truss system are:

- deformation reduction due to increased stiffness
- efficiency in structural usage, lower demands in the core with uniform exterior columns utilisation
- reduction in foundation forces underneath the core
- enhanced torsional stiffness due to belt truss
- enhanced progressive collapse resistance due to the presence of an alternative load path
- architectural flexibility since it permits wide spaced perimeter columns and lower spandrel beam depth.

Instead, the major shortcomings are:

- differential deformation between core and columns that can create additional forces in the outriggers. For this reason, an alternative solution can be belt trusses in conjunction with rigid diaphragms ("Virtual" outriggers (Figure 4.11) [Nair, 1998]*).
- usability of occupied spaces since outriggers interfere with the space usage at the floor they are allocated. In alternative, outriggers can be allocated in mechanical floors or they can serve as super floors for safety and evacuation purposes.
- floor diaphragms stiffness is important since it allows transferring the forces from the core to the exterior column. This is particular relevant for the "virtual" outrigger system (Figure 4.11).
- foundation dishing due to core and perimeter column differential settlement
- change in stiffness between outrigger and adjacent storeys. This can create a sort of "soft" storey behaviour.

Figure 4.11:
Force transfer using a belt truss and a virtual outrigger



• Super Floors

There are ideal locations for outriggers and belt trusses but realities of space planning to suit architectural, mechanical and leasing criteria leave such consideration to be purely academic. Then outriggers are located typically to some of the mechanical or refuge floors (i.e. super floors), which are composed of belt trusses and located at regular intervals in the building. Super floors serve also as alternative load path in case of building partial collapse and as a consequence increase building robustness.

• Connections

Particular care needs to be considered for the outrigger and belt connection since they need to transfer high loads between the core and the exterior columns. There are mainly two

Source: Choi et al. (2016); Redrawn by CTBUH

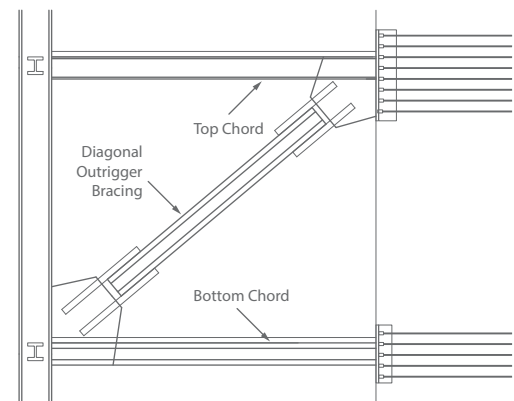
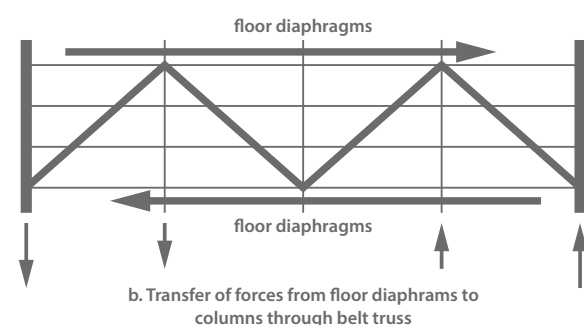


Figure 4.12: Outrigger connection with embedded plates and bar anchors [Choi, 2012] **



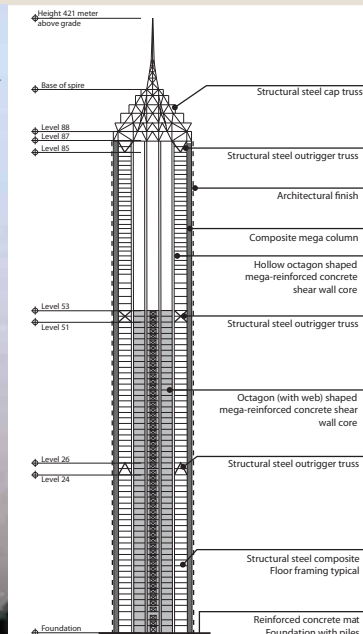


Figure 4.13:
Jin Mao Tower,
Shanghai, China

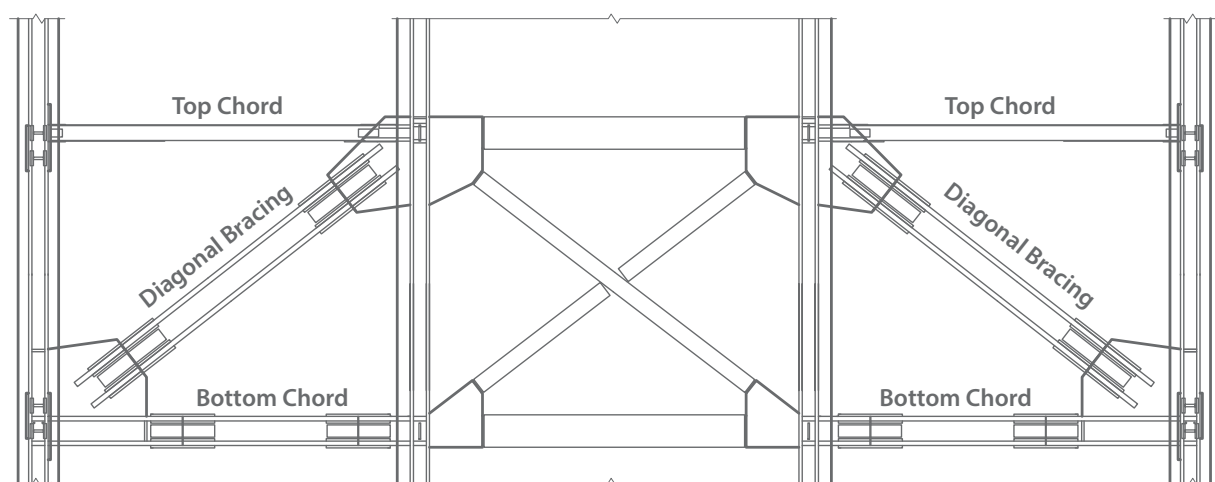


Figure 4.14: Outrigger connections with continuous steel members [Choi, 2012]**

possible connections: continuous steel members (Figure 4.14) and steel to concrete with embedded plates and anchors (Figure 4.12).

• Steel Profiles

Outriggers and belt trusses require large member sizes due to the high axial load. This is caused by the large portion of the building overturning that they need to resist, since they are provided only in few location throughout the building height. Therefore, ArcelorMittal Jumbo profiles are ideal for such applications. In particular, HISTAR®/ASTM A913 steels develop their full potential in the design of tension members in trusses. Here, they allow saving material costs by taking full advantage of the high yield strength and, therefore, also thinner sections and smaller welds, which leads to savings in fabrication costs. Using HISTAR® 460 in truss design will result in direct tonnage savings. Truss compression and tension members will achieve 20-25% weight savings (Figure 4.15).

• Wind Design

Many aspects should be carefully considered when addressing lateral loads, especially in the case of wind: strength and stability, excessive lateral deflections, frequency

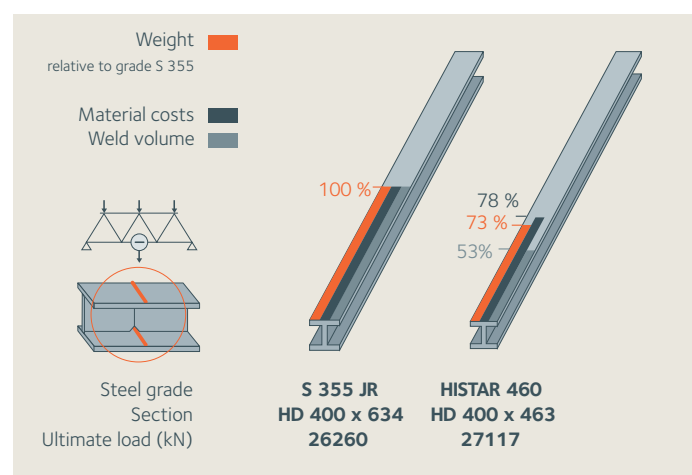


Figure 4.15: HISTAR® in trusses

and amplitude of sway (the resonance of building motions can create problems with an elevator's hoist rope). Additionally, wind can also affect the surroundings of a building. There can be wind acceleration nearby or annoying acoustic disturbances that can be heard from far distances. Overall, it is necessary to consider wind loads when determining the required strength and stiffness of building frames.



Figure 4.16: Shanghai tower, Shanghai, China

The effect of wind on a building can be described as two mechanisms: buffeting and vortex-shedding. The buffeting component acts in the along-wind direction and it can be easily estimated from code approaches. The vortex-shedding component acts mainly in perpendicular direction to the downstream flow and it is less predictable since it induces dynamic loads that are a function of the building forms and relative surrounding. Therefore, in addition to a building's superstructure, information on local wind conditions is required in order to determine the necessary strength and stiffness of wall elements, roof elements and their fastenings. Particularly, for tall buildings one of the critical design aspects is the resonant behaviour to vortex-shedding excitation. This is usually related to vortex-shedding with return periods of 50-100 years that refers to ultimate limit states design wind loads. However, for super tall and slender buildings, this resonant effect is more related to serviceability performance of building that has a critical design return periods between 1-10 years [ASCE, 2015]*. This induces problems with occupancy comfort rather than strength design.

• Seismic Design

Looking at the seismic design of superstructures, as their degree-of-freedom increases, there is a higher number of significant modes to be taken into consideration and the response to seismic excitement becomes more complex. Tall buildings appear to be more flexible than low-rise buildings and thus generally experience lower accelerations (despite bigger displacements demands). On the other hand, when the attenuation of seismic waves is taken into account, long-period components are not attenuated as fast as short-period components with the distance from a fault. Thus, taller buildings can experience more severe seismic loads than low-rise buildings while located at the same distance from a fault. Overall, from a seismic design perspective, while members designed for vertical loads are able to provide the resistance required for the vertical aspect of the seismic loads, a dedicated lateral load-resisting system has to be designed to withstand the inertial forces caused by ground motion.

In particular, steel is an ideal material for seismic design since it is very ductile and it has a great plastic deformation ability that allows the dissipation of seismic energy. In addition, several solutions have been adopted to enhance the seismic performance of steel structures, which is further discussed in Chapter 10.

• Applications

Several applications of outriggers and belt trusses systems are applied to tall buildings worldwide. Some examples are:

- Shanghai Tower, Shanghai, China (Figure 4.16)
- New York Times Tower, New York City, USA (Figure 4.5)
- 300 North LaSalle, Chicago, USA (Figure 4.10)
- Jin Mao Tower, Shanghai, China (Figure 4.13)
- Ref. projects detailed in chap.13 and summarised in Fig. 4.17.

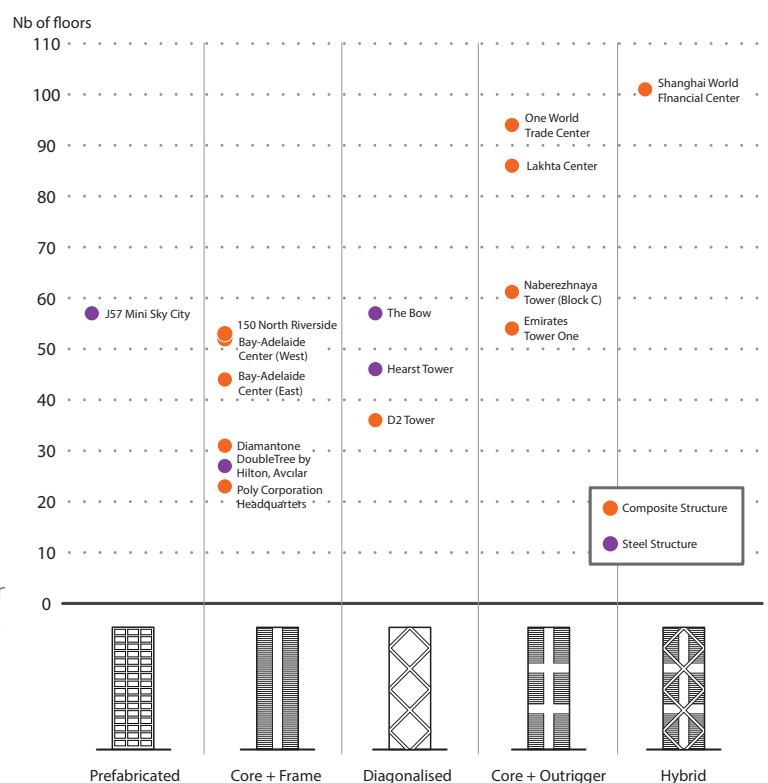
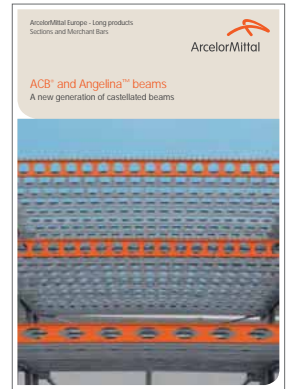


Figure 4.17: Bracing systems of the reference projects



5. Beams and floor systems

• Introduction

Floor systems are generally made of a steel beam supporting a metal deck filled with a poured concrete slab. This is called a composite slab (Figure 5.1). Composite slabs act as a diaphragm, allowing the shear forces between the steel beams and the horizontal load forces on the concrete slabs to transfer to the bracing elements. A range of floor systems are suitable for different spans, but there are specific systems that are suitable for high-rise buildings (Table 5.2).

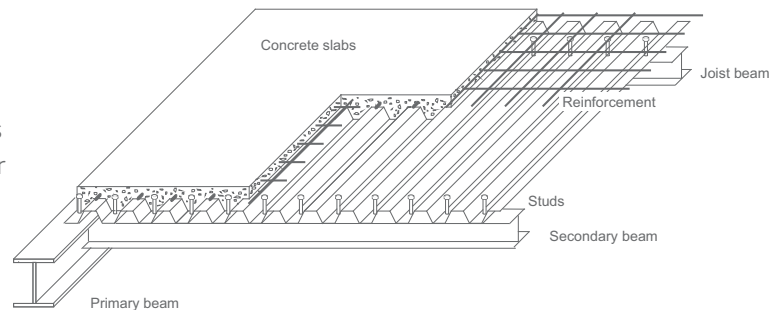
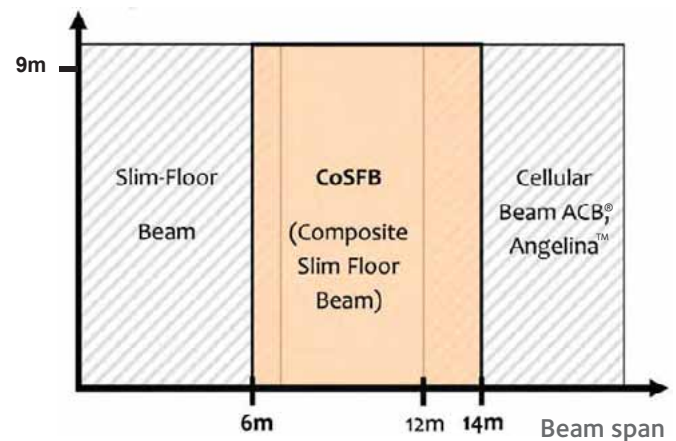


Figure 5.1: Composite floor system

	Span (m)					
	6	8	10	13	16	20
Reinforced concrete flat slab	—	—				
Integrated beams and deep composite slab	—	—	—			
Integrated beams with precast slabs	—	—	—	—		
Composite beams and slab		—	—	—	—	
Fabricated beams with web openings			—	—	—	—
Cellular composite beams			—	—	—	—
Composite trusses				—	—	—

Table 5.2: Slab depending on the span

Slab span



• Floor systems specific for high-rise buildings

In high-rise buildings, floor systems must be light and slim in order to minimise the weight and maximise the usable height of the building. Both requirements can be achieved using castellated beams, which enable an easy integration of building services within the floor system. Another solution which provides minimal floor thickness is the Slim-Floor system, which integrates the slab between the flanges of the steel beam.



Cellular beam

- lighter
- smaller
- cheaper for long spans

• Castellated beams

The use of castellated beams allows a new architectural expression. Structures are lighter and spans are increased, allowing for more open spaces in buildings. These beams are created by subjecting a hot rolled section to longitudinal cuts along its web, following a specific pattern (Figure 5.3). Once divided, the beam can be reassembled with a longer web, taking advantage of the cutting pattern. These cutting patterns can produce a number of different castellated beams, including sinusoidal cut (Figure 5.4), cellular (see above) and octagonal. The cutting pattern also allows openings for technical installations to be integrated within the structure instead of below it, which reduces floor-to-ceiling heights. The reduced castellated beams weight, combined with their high strength, can inspire architects to create new structural forms:

- Angelina™ (sinusoidal cut)
- cellular
- octagonal



Figure 5.3: Flame cutting table for hot rolled sections

The use of castellated beams now provides effective solutions to the demands of project owners. This solution allows large column-free floor areas over a distance from 12 to 18 meters. Additionally, the total floor thickness is 25 to 40cm less than conventional solutions, the beams are about 30% lighter, which allows for more efficient transportation and installation of the beams, and the costs are reduced for spans larger than 10m.



Figure 5.4: Angelina™ beams

Web openings on castellated sizes are typically 60 to 80% of the beam depth. Stiffeners may be required for elongated openings and large openings should be located in areas with low shear forces. Shear or buckling of the web posts can occur between openings, particularly near high point loads or adjacent to elongated openings. In this case, the spacing between openings should be increased or heavier sections should be used.

Angelina™ beams and cellular beams are fabricated in modern workshops at ArcelorMittal's rolling mill for heavy sections in Differdange, Luxembourg. The proximity of these manufacturing plants limits transport, maximises responsiveness, and contributes to the competitiveness of the manufacturing costs.

Beam spacing is function of the floor used.

- For composite floor slabs (steel decks), the distance should be:
 - 2,5 to 3m without propping
 - 3 to 5m with propping.
- With pre-stressed concrete floor elements:
 - 2,7 to 7m with propping when required.

ArcelorMittal's flooring Cofradal 200/230/260 and Cofraplus 220 are suitable for 5 to 7m spans.

Typical chord sizes for cellular secondary beams with a 12 to 18m span, a 130mm slab depth, and 3m spacing are presented in Figure 5.5.



Angelina™ beam with filled openings at support

Design table:

Cellular beam parameter	Typical spans of cellular beam (m) - S355				
	12m	13,5m	15m	16,5m	18m
Opening diameter (mm)	300	350	400	450	500
Beam depth (mm)	460	525	570	630	675
Top chord	IPE 360	IPE 400	IPE 400	IPE 450	IPE 500
Bottom chord	HE 260 A	HE 300A	HE 340B	HE 360B	HE 400M

Variable action = 3kN/m² plus 1kN/m² for partitions
 Slab depth = 130mm; Beam spacing = 3m

Figure 5.5: Sizes of composite cellular beams as secondary beams

• Slim-Floor systems

The “Slim-Floor” system is a fast, innovative and economical solution, which combines precast slabs, such as prestressed hollow core slabs with specific steel beams (see Figures 5.6 and 5.7).



Figure 5.6: Slim-Floor for parking in IFB (Nantes, France)



Figure 5.7: Slim-Floor (Eich Clinic, Luxembourg)

The Integrated Floor Beam (IFB) replaces the lower flange with a wider plate (Figure 5.8), while the Slim-Floor Beam (SFB) attaches a plate wider than the lower flange directly to the bottom of a beam element (Figure 5.9).

The beam is characterised by a lower flange which is wider than the upper flange. This allows the floor slab elements to be put directly onto the lower flange plate of the beam, avoiding downstanding beams and offering working spans of up to 8 meters (Figure 5.8).

ArcelorMittal offers two varieties of Slim-Floor elements, which offer similar advantages.

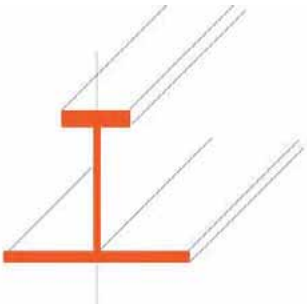


Figure 5.8: IFB system

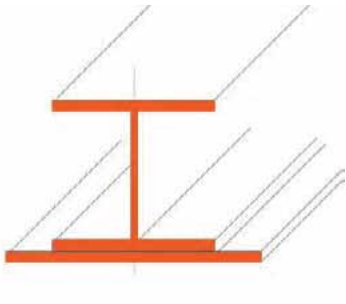
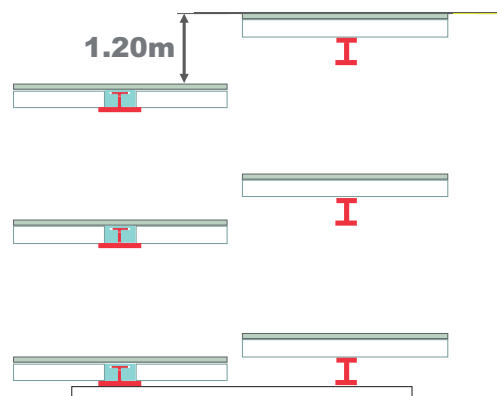


Figure 5.9: SFB system

Advantages of the Slim-Floor (IFB/SFB):

- floor thickness reduction
- lower floor-to-floor height
- lighter structure
- built-in fire resistance
- easy to build
- competitive pricing
- environmentally-sustainable
- easier integration of under-floor technical equipment
- possible solution for constructing floors of variable thickness.

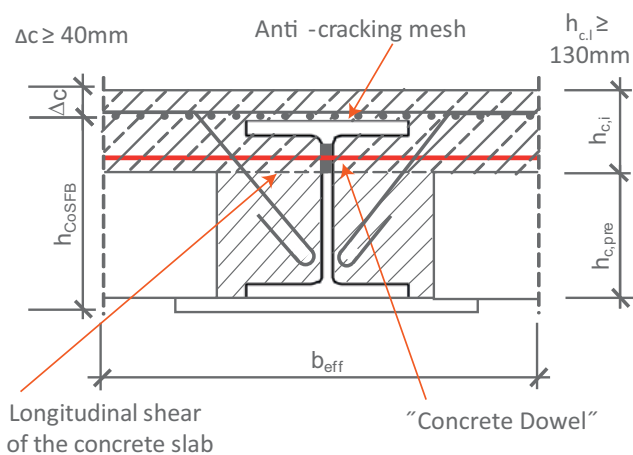


Height advantage with Slim-Floor

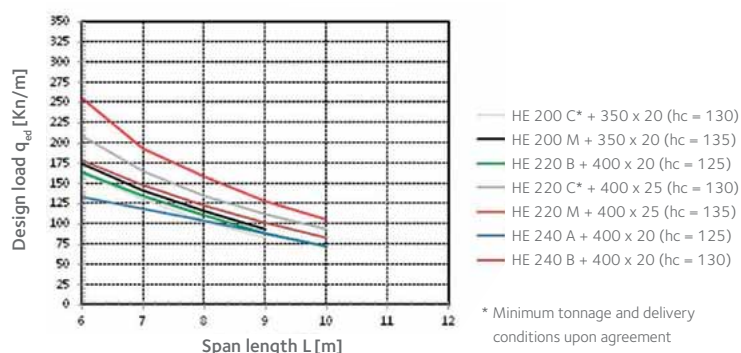
Span of slab (m)	Typical beam size for Slim-Floor beam span - S355			
	5m	6m	7m	8m
5	HE 200 A	HE 240 A	HE 280 A	HE 300 A
6	HE 240 A	HE 280 A	HE 300 A	HE 280 A
7	HE 280 A	HE 300 A	HE 280 B	HE 300 B
8	HE 280 A	HE 280 B	HE 300 B	HE 320 B

Span of slab (m)	Typical beam size for Slim-Floor beam span - S355			
	5m	6m	7m	8m
5	IPE 400	IPE 500	IPE 550	IPE 600
6	IPE 500	IPE 550	IPE 600	HE 500 A
7	IPE 550	IPE 600	HE 500 A	HE 600 A
8	IPE 600	HE 500 A	HE 600 A	HE 600 B

Figure 5.10: Design tables: - S355 - for office buildings; A welded plate - 20mm thick and 150mm wider than the section is used in all cases.



CoSFB - 250mm < Slab thickness ≤ 300mm
Steel S355



CoSFB made up with "concrete dowel" and Slim-Floor beam

• SFB

Application range of SFB :

Typical non-composite Slim-Floor Beams have a limited inertia and stiffness because of their slim construction height.

- the design is mainly driven by the SLS (deflection + vibration)
- typical beam spans are up to ≈ 7m

• CoSFB

The CoSFB is a Slim-Floor beam system where the floor acts **compositely** with the steel beam. Due to the wider lower flange of Slim Beam systems, it allows a seamless integration with hollow core slabs, concrete plants, or prefabricated slab elements produced by ArcelorMittal, such as Cofraplus and Cofradal systems (Figure 5.11 to

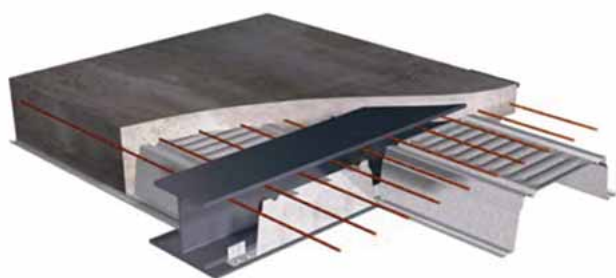


Figure 5.11: CoSFB and Cofraplus 220

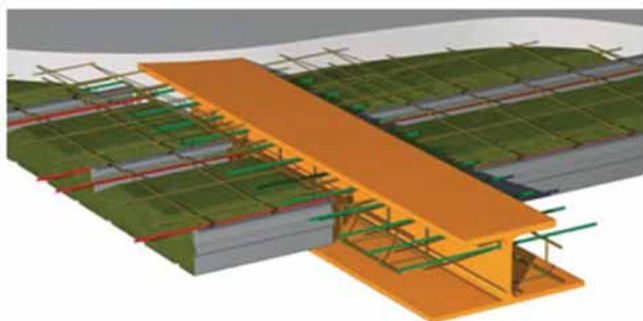


Figure 5.12: CoSFB and Cofradal 260

Figure 5.13). Composite action is ensured by the so-called "concrete dowel" (see Figure above) composed of holes in the web with adequate reinforcement. This system is referred as Composite Slim-Floor Beam or CoSFB systems.

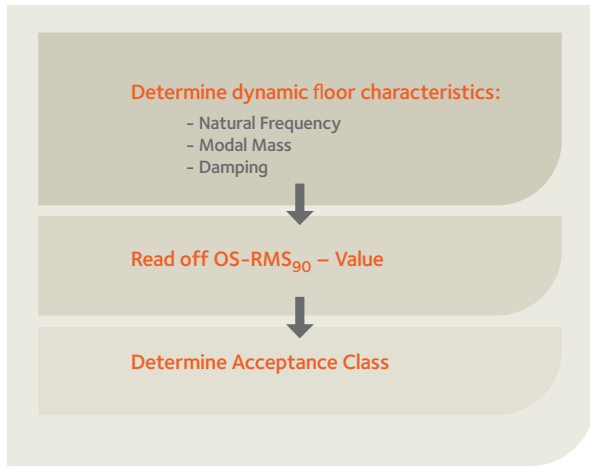
A typical non-composite Slim-Floor beam can only span up to 8m, as their reduced construction height limits the inertia and stiffness of the system. Once a Slim-Floor beam is integrated into a composite system, beams can span from 6 to 14m (even up to 16m in some cases). It also allows for an overall construction height of only 40cm combined with an integrated fire resistance for up to 90 minutes.

Application range of CoSFB:

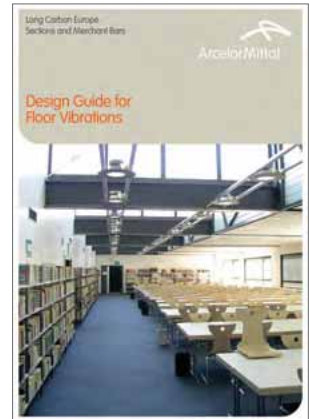
- beam span from 6m up to ≈ 14m (16m possible in some cases)
- beam distance from 5m up to 10m



Figure 5.13: CoSFB



Design procedure for vibrations



• Vibration

Floor structures are designed for ultimate limit state and serviceability limit state criteria:

- ultimate limit states are those related to strength and stability;
- serviceability limit states are mainly related to vibrations and hence are governed by stiffness, masses, damping and the excitation mechanisms.

When developing these floor systems for tall buildings, the ultimate limit states, such as strength and stability, are not the only thing that needs to be taken into account. Serviceability limit states, which are related to floor vibrations, a common trait of tall buildings, must take stiffness, massing, damping and excitation mechanisms into account. The serviceability criteria and required comfort of occupants are likely to govern the design.

The perception of vibrations and the individual's feeling of annoyance depends on several aspects, such as:

- the direction of the vibration,
- the posture of people such as standing, lying or sitting,
- the daily activity of the occupants (persons working in the production of a factory perceive vibrations differently from those working in an office or a surgery),
- age and health of occupants.

Thus the perception of vibrations is a very individual problem that can only be described in a way that fulfills the acceptance of comfort (A→F) of the majority. The design procedure is summarised by the following diagrams:



Class	OS-RMS ₉₀		Function of Floor									
	Lower Limit	Upper Limit	Critical Workspace	Health	Education	Residential	Office	Meeting	Retail	Hotel	Industrial	Sport
A	0.0	0.1	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended
B	0.1	0.2	Critical	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended
C	0.2	0.8	Not recommended	Critical	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended
D	0.8	3.2	Not recommended	Not recommended	Critical	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended
E	3.2	12.8	Not recommended	Not recommended	Not recommended	Critical	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended
F	12.8	51.2	Not recommended	Not recommended	Not recommended	Not recommended	Critical	Recommended	Recommended	Recommended	Recommended	Recommended

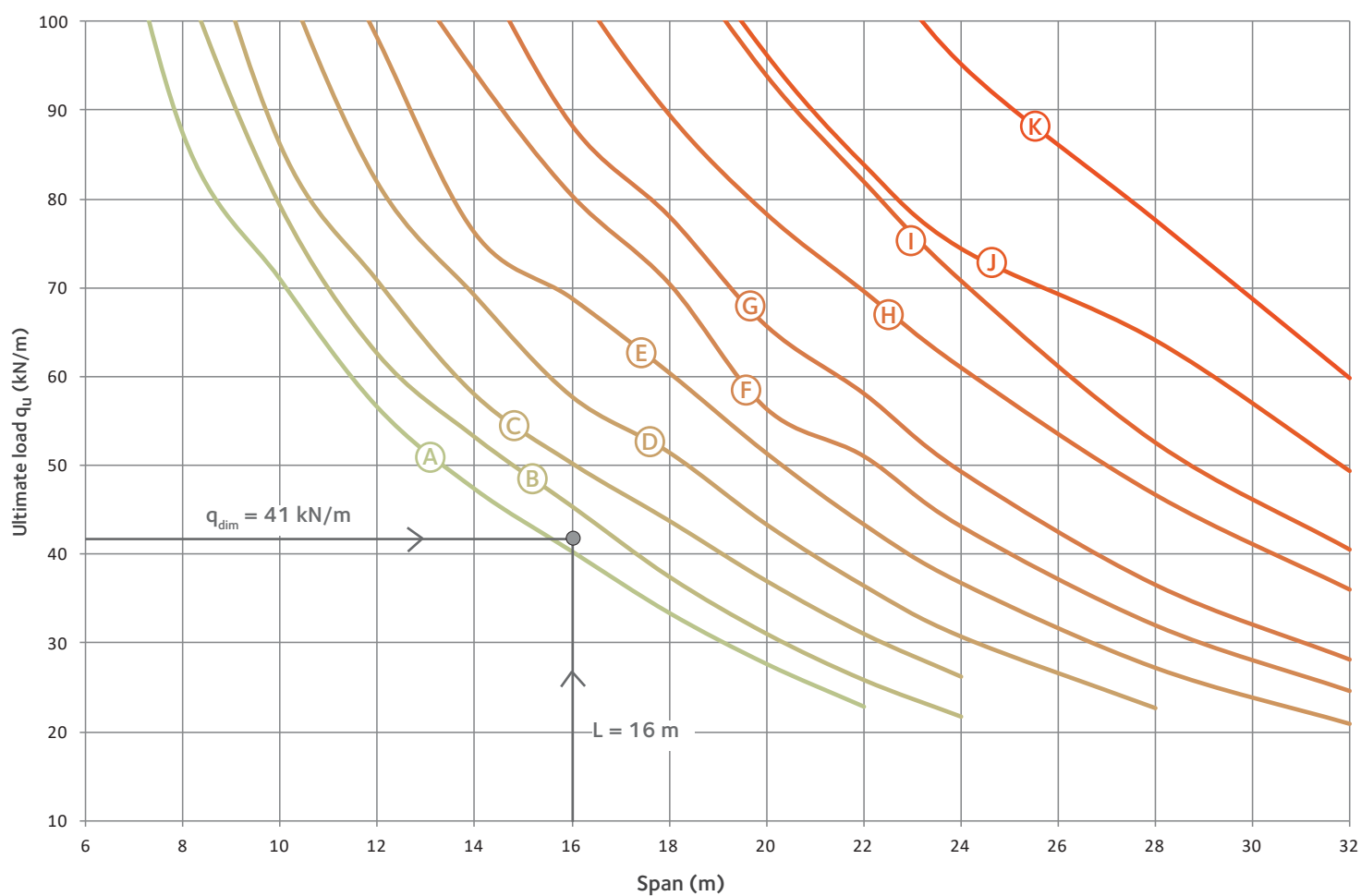
■ Recommended
■ Critical
■ Not recommended

The OS-RMS values correspond to the harmonic vibration caused by one relevant step onto the floor. As the dynamic effect of people walking on a floor depends on several boundary conditions, such as weight and walking speed, their shoes, flooring, etc., the 90% OS-RMS (One Step-Root Mean Square₉₀) value is recommended as assessment value. It represents an effective step velocity of 90% of people walking normally. Detailed description of the methodology is given in the ArcelorMittal brochure "Design guide for Floor Vibrations" available on sections.arcelormittal.com. A summary is provided at the top left of the page.

• Predesign tools

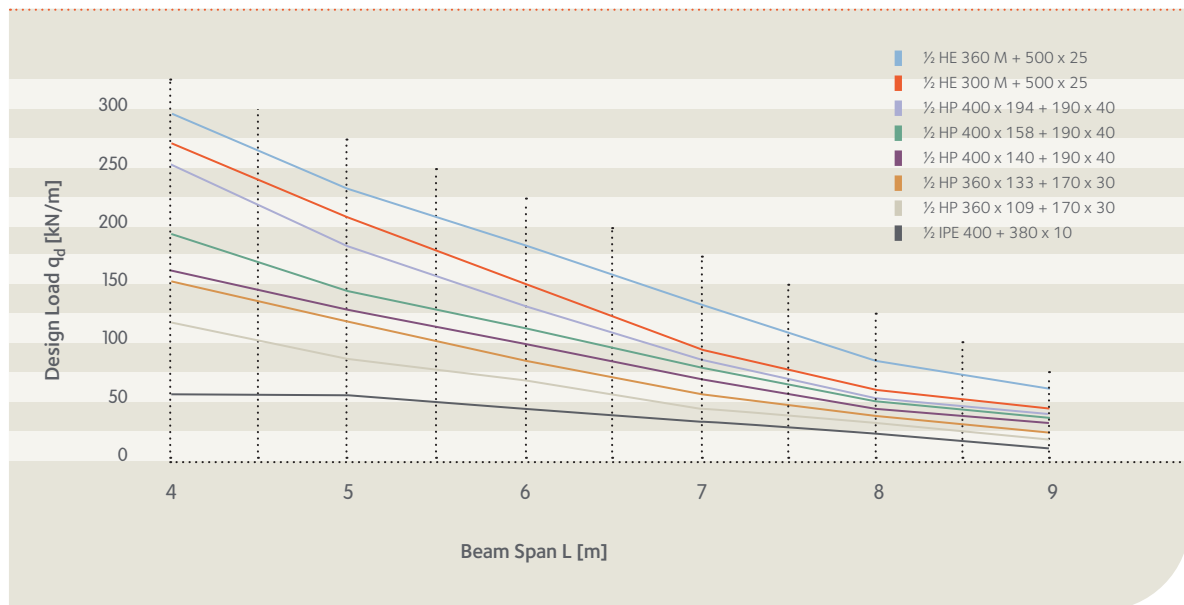
Software and design tables, as well as design guidance are available on sections.arcelormittal.com for all of the floor systems, including castellated beams, Angelina™ beams, Slim-Floor and CoSFB systems.

Predesign chart: Composite Angelina™ based on HEB, S355 with COFRAPLUS 60

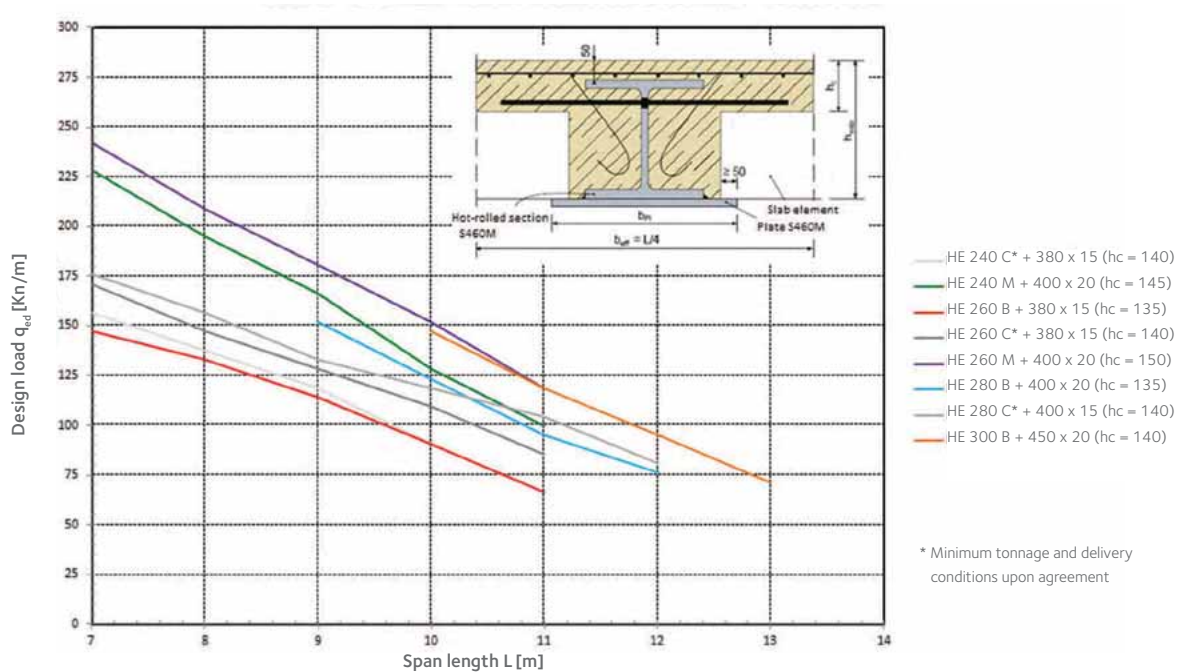


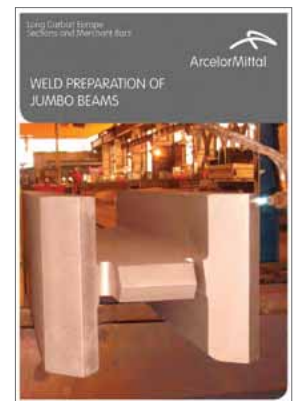
Sections		Dimensions (mm)					Ultimate load q_u (kN/m) according to the span (m)											
		a_0	w	s	e	H_t	6	8	10	12	14	16	18	20	22	24	28	32
(A)	HE 300 B	315	250	315	1130	457,5	129,3	87,5	71,0	56,6	47,4	40,4	33,5	27,7	22,9			
(B)	HE 320 B	335	250	335	1170	487,5	138,5	105,6	79,3	62,6	53,3	45,4	37,5	31,1	25,9	21,7		
(C)	HE 360 B	380	300	380	1360	550		120,6	86,2	70,8	58,0	50,3	43,8	37,0	31,0	26,2		
(D)	HE 400 B	420	300	420	1440	610		137,9	106,4	81,9	69,1	57,7	51,4	43,3	36,4	30,7		
(E)	HE 450 B	475	300	475	1550	687,5		151,5	120,9	98,1	76,2	68,8	60,4	51,3	43,3	36,7		
(F)	HE 500 B	525	300	525	1650	762,5			132,4	111,1	94,3	80,4	70,5	56,4	51,1	43,2		
(G)	HE 550 B	580	300	580	1760	840				130,6	107,7	88,4	78,1	65,7	58,1	49,4	12,6	
(H)	HE 650 B	680	300	680	1960	990				153,2	125,4	104,8	89,5	78,3	69,6	61,0	16,2	11,0
(I)	HE 700 B	730	300	730	2060	1065					154,9	130,7	109,8	94,0	82,0	70,9	20,2	13,7
(J)	HE 800 B	780	300	780	2160	1190						136,3	112,6	96,3	83,9	74,4	25,2	17,1
(K)	HE 900 B	830	350	830	2360	1315							155,9	128,6	109,9	95,2	31,9	21,8

Slim-Floor IFB - Slab thickness < 200 mm



CoSFB - 300 mm < Slab thickness ≤ 350 mm - Steel S460





6. Connections

Steel connections are the structural elements used to hold a steel structure together. The selection of connection depends on many aspects, including the type of loading required, the strength and stiffness required, economy and the level of difficulty for construction. The connection choice can have a direct influence on the cost of a steel structure. For the structural members in previous sections, they are generally more efficient if they adequately serve the structural requirements with less weight and less material, which is not always the case for steel connections. Some connections, although efficient in material use, may still be expensive to erect. Furthermore, additional cost saving can be made if the structural design uses many similar connections, instead of many custom-made connections. Thus, it is imperative that connections are considered early in the structural design process as a means to be economically and structurally efficient, and ArcelorMittal sections offers a number of options for efficient steel connections.

• Columns

In high-rise buildings, gravity columns must be perfectly spliced to each other to ensure that the axial load is correctly transmitted between the end of the columns section and not through the splice plate. Columns sections from ArcelorMittal of the same series have the same distance between the flanges, or an equal chamber size, so that they can easily be stacked on each other. ArcelorMittal also offers the possibility to mill the end of sections to ensure that they will perfectly sit down on each other.

Two types of connections are available for gravity columns:

- Bolted Connections:

Column splices (Figure 6.1) are designed assuming they must resist both the axial compression and, where appropriate, a nominal moment from the connection to the beams. The plates provide the splice with adequate stiffness and tying resistance to ensure that the two ends of the columns are always in compression.

- Welded Connections:

Jumbo and Super Jumbo columns can be connected together by welding (Figure 6.2). The joint detail and joint preparation are two of the most important factors which will affect the quality and cost of the completed weld.

Welding offers a number of advantages:

- product ready-to-install
- weld preparation of steel sections with flange thickness up to 140mm
- surface quality according to EN 1090-2 / ISO 9013 and AISC
- increased processing capability of heavy sections
- time and cost saving for steel fabricators.



Figure 6.1: Bolted connection of two HD/UC/W columns



Figure 6.2: Column joint before welding



Figure 6.3: CJP butt weld preparation for Jumbo column



Figure 6.5: Gusset plates connection in S355 (Gr. 50) with S460 (Gr. 65) beams at Mariner Stadium (Seattle)

Partial Joint Penetration (PJP) welded connections are recommended for gravity columns unless conditions occur which would require Complete Joint Penetration (CJP). PJP welds are groove welds that do not extend completely through the thickness of a column section and are more typical, while CJP (Figure 6.3) welds extend completely through the section and are used when the column is subjected to tension, seismic activity, etc.

- Fit of column compression joints and base plates:

Lack of contact bearing shall not exceed a gap of 2mm, regardless of the type of splice used. If the gap exceeds 2mm and is less than 6mm, it shall be filled with non-tapered steel shims. Shims need not be other than mild steel, regardless of the grade of the column material.

• Truss connections

When designing bracing systems for tall buildings, connection geometries should be designed in order to achieve intersections at the nodal points of sections, which avoid bending moments being introduced into the chord. A truss girder system using I-sections is an efficient and commercially viable alternative to existing solutions, due to the great range of cross sections available. It is a flexible system which allows for large clear span structures without internal columns. Like columns, these connections can be achieved using two different strategies:

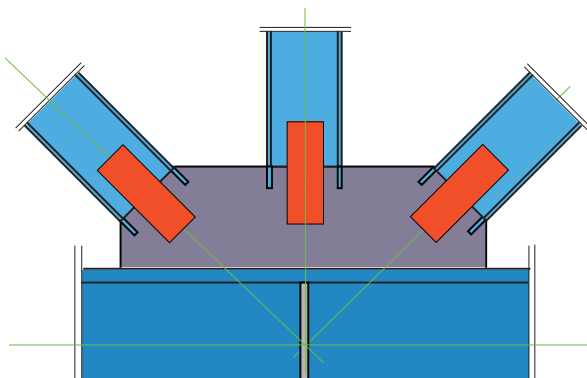


Figure 6.4: Gusset plates connection

- Bolted Connections:

Unlike columns, bracing systems use a web based connection, and through the use of gusset plates and stiffeners, forces from trusses can be adequately transmitted to beams and columns. This can be seen in Figure 6.4 to 6.7, with the I-sections oriented in such a way, through the use of gusset plates, that bending moments are avoided. Widely used in belt and outrigger trusses, this type of connection is well adapted for big trusses supporting the high loads of skyscrapers.

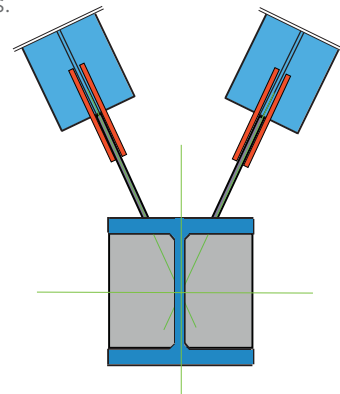


Figure 6.6: Gusset plates connection (cross-sectional view)

- Welded Connections:

By changing the orientation of the I-sections, additional constructional elements (like plates) are no longer required. The function of the gusset plates and stiffeners is taken over by the flanges of the chord and the brace members with the result of a simple and clear-cut form. It is obvious that this solution is more economical than using gusset plates. This statement is supported also by a quantitative comparison: since stiffeners and gusset plates are no longer required, the amount of welding is reduced by 77% and an overall 19% cost reduction. With this method, different shapes can be welded together as long as they have the same chamber* size (See Figure 6.8 to 6.11). HD series sections, especially HD 360 and HD 400, are also suitable. For instance, the 22 sections from the HD 400 series have the same chamber size of 290mm. A truss girder system using I-sections is an interesting and commercially viable alternative to existing solutions,



Figure 6.7: Mariner Stadium close up on gusset plates connection in S355 (Gr. 50) with S460 (Gr. 65) beams

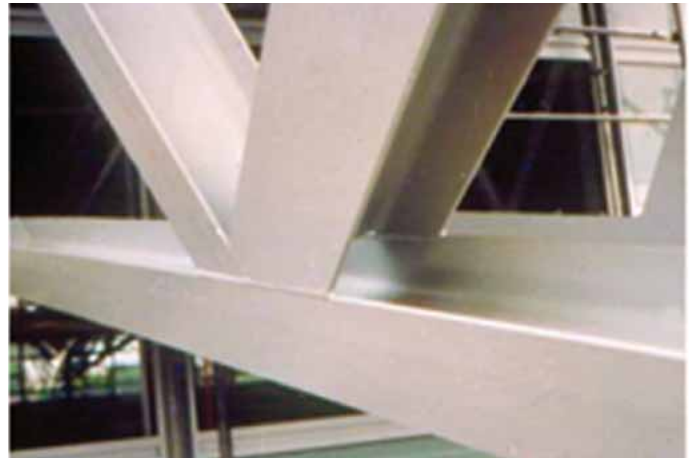


Figure 6.9: Equal chamber* size

due to the great range of cross sections available. It is a flexible system which allows for large clear span structures without internal columns.

European shape	Area		Chamber* size (mm)	Depth (mm)	Width (mm)
	cm ²	%			
IPE 300	53,8	17	278,6	300	150
IPE O 300	62,8	20	278,6	304	152
HE 320 A	94,6	30	279,0	301	300
HP 305 x 88	112,1	35	277,1	301,7	307,8
HP 320 x 88,5	112,7	36	279,0	303	304
HP 305 x 95	121	39	277,1	303,7	308,7
HP 320 A	124,4	40	279,0	310	300
HP 320 x 103	131,0	42	279,0	307	306
HP 305 x 110	140,1	44	277,1	307,9	310,7
HP 320 x 117	149,5	47	279,0	311	308
HE 320 B	161,3	51	279,0	320	300
HP 305 x 126	160,6	51	277,1	312,3	312,9
HP 320 x 147	186,9	59	279,0	319	312
HP 305 x 149	189,9	60	277,1	318,5	316
HD 320 x 158	201,2	64	279,0	330	303
HP 305 x 180	229,3	73	277,1	326,7	319,7
HP 320x184	234,5	75	279,0	329	317
HP 305 x 186	236,9	76	277,1	328,3	320,9
HD 320 x 198	252,3	80	279,0	343	306
HP 305 x 223	284	91	277,1	337,9	325,7
HE 320 M	312,0	100	279,0	359	309

Figure 6.8: Selection of shape according to the rolling programme

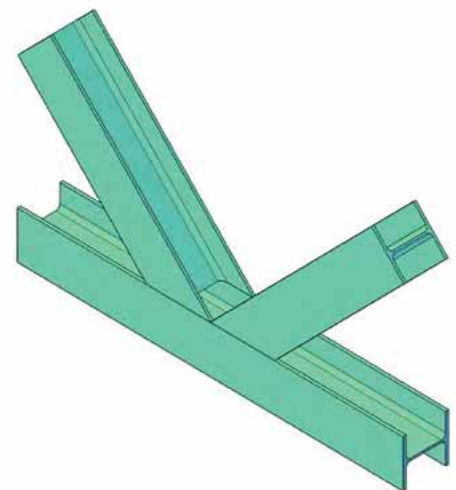


Figure 6.10: Various shapes with equal chamber* size

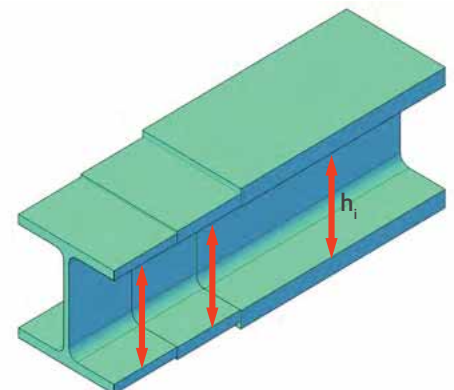


Figure 6.11: Equal chamber* size

*inner distance between flanges



Figure 6.12: Bevel preparation on Jumbo



Figure 6.14: Mistral Residential Tower, Izmir, Turkey

• Beam Finishing Centre

The Beam Finishing Centre, in collaboration with the Commercial Sections Technical Advisory, manufactures customs joints for steel sections. The Beam Finishing Centre offers a complete range of fabrication and finishing operations to improve the technical capabilities for steel sections, including cold sawing, drilling, cambering, bending, oxyacetylene cutting, flame cutting, milling and plasma cutting.

One of the main fabrication capabilities of the finishing centre is bevel preparation, which allows joints of steel sections to be ready for welding, including PJP and CJP welds (Figure 6.12). The joint design and the joint preparation are two of the most important factors which affects the quality and cost of the completed weld. Time spent in preparing the joint properly is more than compensated by higher welding speeds and better quality welds. Correct and accurate edge preparation is essential for the production of quality welds. Edge preparations are required to achieve full penetration to the root of the joint helping the welder to produce quality joints.

All weld access holes required to facilitate welding operations shall have a length (1) from the toe of the weld preparation no less than 1,5 times the thickness of the material in which the hole is made.

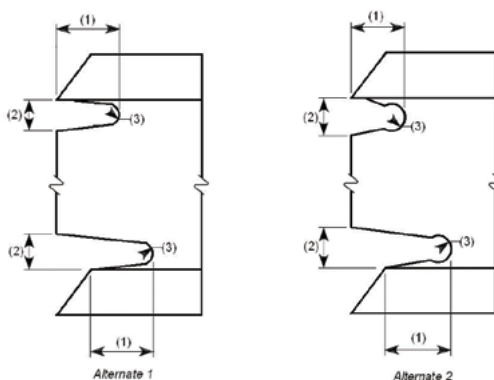


Figure 6.13: Weld access hole geometry

- (1) Length: Greater of $1.5 \times t_w$ or 11/2 in. (38 mm). Tolerance is $\pm 1/4$ in. (6 mm).
 (2) Height: Greater of $1.5 \times t_w$ or 1 in. (25 mm) but need not exceed 2 in. (50 mm).
 (3) R: 3/8 in. min. (8 mm). Grind the thermally cut surfaces of access holes in heavy shapes.

The height (h) of the access hole (Figure 6.13) shall be adequate for deposition of sound weld metal in the adjacent plates and provide clearance for weld tabs for the weld in the material in which the hole is made, but not less than the thickness of the material.

In structural shapes all beam copes and weld access holes shall be shaped free of notches or sharp reentrant corners.

The main structure of the Mistral Tower in Izmir (Figure 6.14), a 200m high building is composed of the HD beams, ranging from 400 x 262 to 400 x 1086. In total, 1 485 tonnes of steel with chamfers, which were flame cut in the ArcelorMittal Beam Finishing Centre, were delivered on time.

- Delivery conditions:

- weld preparation of steel sections with flange thickness up to 140mm
- surface quality according EN 1090-2 / ISO 9013 or AISC 303-05
- the thermally cut surfaces of beam copes and weld access holes are ground to bright metal and inspected by either magnetic particle or dye penetrant methods, if specified.

• Pre-qualified connections

Jumbo profiles can be very appropriate for use in seismic design of high-rise buildings. Amongst other requirements, these structures must be able to develop certain rotation capacity at beam-to-column joints.

In countries such as the US, some combinations of beams and columns, as well as the components in the connection, have been defined such that the joints formed by them are already prequalified as satisfactory to meet the requirements.

For future developments, please refer to chapter 12.

7. Foundations for high loads

For decades, steel bearing piles, plunge columns, and king-post piles have been used as a cost efficient solution for deep foundations, especially when high vertical loads need to be transferred into the foundation soil, which is a common trait of tall buildings. All wide-flange beams are suitable for this and HP steel piles are optimised for this type of application. Compared to normal beams, the radii of gyration of these special, wide-flange beams, which have identical flange and web thicknesses, are distributed more evenly around the two main axes.

- Steel foundation properties

Thanks to the large range of standard sections and HP piles, the design engineer is able to find the ideal solution in terms of bearing capacity and pile driving properties for their tall building project. In addition, high-strength steel grades, such as HISTAR®, can be used to reduce the required amount of steel and maintain the bearing capacity, which will optimise costs. The specific shape of the pile and the properties of

the steel means that HP piles can be used in various soil conditions, and as it is a prefabricated product, the quality can be tested in advance.

Additionally, the piles can be subject to loads immediately after their installation and do not require any time to settle. Once installed, there are various methods for predicting the bearing capacity of the piles. For high-rise projects, static tests or PDA tests (Pile Driving Analyser tests) can be carried out on site to immediately determine the possible bearing capacity and define the safety factor more accurately than when empirical calculation methods are used.

Steel piles generally obtain their bearing capacity through skin friction. In suitable soils, the point bearing pressure can also be considered in addition to the skin friction capacity. There are various ways to further increase the skin friction and point-bearing pressure, including, but not limited to, cased piles with specially designed tips. Also, reinforcement can be added to the base of driven piles to increase the cone friction resistance and provide additional support for high-rise buildings (Figure 7.1).

Rolled sections can be supplied within lengths up to 40 meters, as seen in the Wilhemshaven Power Plant, which uses HE 800 B sections between 33,8 and 38,8m (Figure 7.2). If required, sections over 40 meters can be achieved by means of special fasteners or by welding. As the soil conditions can only be estimated during the initial phases of the project, using steel sections is a great advantage, as it allows to flexibly respond to soil layers and conditions during construction.

- Installation of steel piles

Piles are normally installed using pile hammers, which are so strong and flexible that they can drive piles into extremely compact soils without negatively affecting the surrounding area. Any vibrations and noise can be controlled through various control systems.



Figure 7.1: Driven piles with reinforcement at the base to increase the cone friction resistance and thus provide support for high loads.

There are also other sheet pile driving systems, such as vibratory pile driver or sheet pile presses, which allows for further flexibility in the installation process.

Piles can be used in almost all types of soil. Even if soft layers of soil lie above the compacted, load-bearing soil, piles are still reliable and economic since the soft layers have neither a negative effect on the installation nor on the bearing capacity of the piles. For high-rise projects that require minimal soil movements, a top-down construction method can be used, which can also reduce construction time (Figure 7.3). Furthermore, examinations of steel piles that have been removed from the soil after 50 to 80 years have shown that the total reduction in steel thickness due to corrosion is so minimal that no impairment of their bearing capacity is to be expected.

- Advantages of using steel piles

Finally, it should be mentioned that because of the inherent properties of steel, the piles can be subjected to both compressive and tensile loads. This ability makes them particularly useful for construction that, depending on the load cases (earthquake, water level, etc.), requires the piles to resist to both compressive and tensile forces. Tension piles



Figure 7.2: Use of HE 800 B with lengths ranging from 33,80 to 38,80m for foundations (Wilhemshaven power plant).



Figure 7.3: 26-metre long foundations for the top down construction method with no splicing required.

often present a more optimised and cost-efficient solution, when compared to injection or bored piles. Ultimately, even if high tensions occur (e.g., during pile driving), especially in compact soils, no threat to the stability of the piles occurs.

Bending stress caused by the lateral pressure of soft layers of soil or horizontal loads above the foundation plate can be transferred by the bending capacity of the steel sections. The same is true for horizontal movements caused by earthquakes.

In conclusion, steel piles can be used for a large number of foundation applications in high rise buildings, as they are ideally suited for high vertical loads in most soil conditions.

8. Fire resistance

High-rise buildings present several unique safety challenges that are not found in traditional low-rise buildings; longer egress times and distance, evacuation strategies, fire department accessibility, smoke movement and fire control. Due to advanced structural technologies, buildings are constantly being built taller, which means a greater number of occupants need to travel greater distance in order to evacuate a building during an emergency. During a fire event, the structural members of a building need to be able to withstand heat and open flames long enough to allow all occupants to exit. Steel structural elements, particularly gravity columns, can withstand excessive heating for 90 to 120 minutes, so it is an optimal solution when taking fire safety concerns into account. Several ways to provide steel fire safe solutions exist:

- thermal insulation products (reactive coatings, spray, boards) which delay the time needed for steel to reach the critical temperature
- composite steel-concrete solutions
- fire engineering solutions.

Thermal insulation products

• Intumescent coatings

Intumescent “painting” is a fire protection strategy that is typically used for exposed structural steel elements and can resist high temperatures for 30 to 120 minutes.

before fire



after fire



Figure 8.1: Intumescent coating layer

It is a reactive paint coating that expands under high temperature to provide adequate insulation to the steel member (Figure 8.1). As a paint coating, it offers a number of benefits:

- no augmentation of exterior dimensions
- easy and quick application
- application possible on complex structural details
- some coatings have a fire resistance up to 120 minutes and are resistant to corrosion.

The required Dry Film Thickness (DFT) of the paint depends on the critical temperature and on the section factor (A_p/V value). Small steel beams require a high DFT, and the relative cost of the coating to the cost of the steel sections can be comparable. In Jumbo size steel sections, the DFT can be quite small due to the very low section factor, therefore the reactive coating cost could be less than 10% of the cost of the steel.

• Spray

Spray protection is generally used on non-visible structural elements, located above suspended ceiling, or on complex structural elements like trusses etc. Although not as visually



Figure 8.2: Protection by spraying on ACB® beam

appealing as intumescent paint, it offers the same benefits at significantly lower costs, which makes it an ideal (and economic) solution for non-visible structural elements (Figure 8.2). There are two kinds of spray products available, depending on the required fire resistance: low density products, which is made with mineral fibres, and high density products, which are composed of cement, plaster, etc.

- Boards

Board fire protection is generally applied for visible beams and columns. Board protection advantages are:

- the structural elements can remain visible
- boards have a well defined guaranteed thickness
- no steel preparation needed
- a plaster layer can be applied to improve aesthetics aspects

Board fire protection generally does not suit complex structures (truss), castellated beams or external elements subjected to humidity.

They are either low density products made from mineral fibres or high density products made of plaster, vermiculite and calcium silicate. Boards are fixed with staples, glue, nails or screws. The thickness of the boards depends on the required fire protection and the section factor of the element.

Composite steel/concrete solutions (Figure 8.3, 8.4)

Composite structural solutions that use both steel and concrete are ideal solutions that inherently provide fire protection. Systems, such as optimised composite sections, partially encased (for the top levels; not adequate for heavy sections), fully encased, megacolumns, CoSFB (Chapter 3 and 5) are all exemplar examples of composite structural systems. The fire resistance is built into the system itself, which can save valuable floor area, if composite columns are used, and increase the floor-to-ceiling heights, if composite floor systems are used.

Even a combination of protection solutions can be used, i.e. partially encased columns and sprayed beams.



Figure 8.3: Partially encased



Figure 8.4: Fully encased

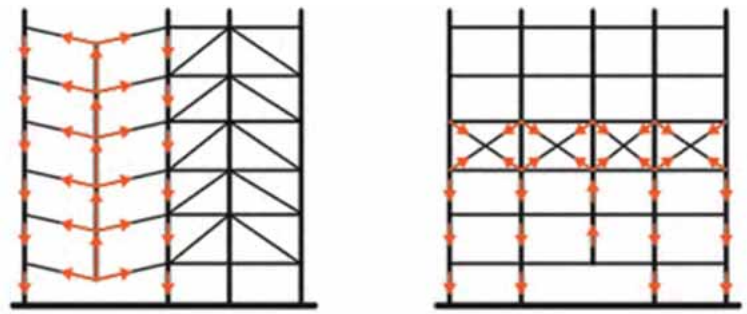
Fire safety engineering studies

Adequate fire protection can be achieved for a reduced cost by applying a number of advanced fire engineering methods, which can optimise or, in some cases, completely avoid passive fire protection. One of the options available is the fracof/membrane effect. This method avoids any passive fire protection measures on secondary beams. Only beams linked to columns require protections (Figure 8.5).

Details regarding this method can be found at: macsfire.eu. Simulation of the fire itself combined with structural calculations can also be used to optimised fire protection. For further information, ArcelorMittal has developed a "Secure with Steel Network", which is an international group of structural fire safety engineering experts, who can provide information regarding the most state-of-the-art practices. Information on this network of professionals can be found at: sections.arcelormittal.com.



Figure 8.5: Fire test on unprotected cellular beams (Fracof)



Progressive collapse resisted through tensile forces in adjacent beams

Belt truss redistribute induced forces due to column loss

Figure 9.1 Column loss scenarios with and without belt truss systems [Eltobgy, 2013]⁽¹⁾ redrawn by CTBUH.

9. Robustness

• Introduction

Robustness is the capacity for a building to avoid damage that is disproportionate to the original cause of failure; such as: fire, explosion, impact or due to human errors (Eurocode 1 [CEN, 2006*]). This design philosophy became even more prominent after the 9/11 disaster which increased the awareness about robustness of structures.

Progressive collapse is a type of disproportionate collapse related with the progressive collapse of different members as a consequence of the load redistribution coming from the failure of a single element or a limited part of a structure. In light of these considerations, the term robustness can be considered as a property of a structure, independent from the type of events that cause the collapse [Val and Val, 2006**].

Structural system reliability is one of the most important concepts for building design since the scope is to minimise the probability of failure. This, however, is a probabilistic value since the properties and the environmental conditions are not determining. For these reasons risk based methodologies are utilised [CEN, 2006*]. Therefore, the main scope is to limit the consequences of local failure due to expected and unexpected causes.

The main design criteria for structural robustness are that, after an event, the structural system residual capacity has to be bigger than the residual demand. Some of the most utilised robustness measures are: redundant elements, ductile detailing, ties, etc. [ASCE, 2010***; CEN, 2006*].

That means alternative load paths are to be provided in case of a member failure (e.g. column and supported beam removal or section of load bearing wall [CEN, 2006*]).

Among all the conventional structural materials, steel can be ideal to provide robustness. Steel has several advantages compared to other structural material: very high yield strength,

ductile fracture, the capacity to work either in tension or in compression, the ability to redistribute the loads through plastic behaviour. All these properties make steel one of the best structural material for tall buildings.

• Alternative load path method

One of the most widely used methods to test robustness is a scenario-based approach that consists in the removal of a key element in the structure to check its vulnerability. In most of the cases, column removal scenario is considered in order to provide an alternate load path. Critical columns should be identified and analysed with this approach. Columns are removed one by one and then the structure is analysed both statically and dynamically.

• Superfloor systems

Progressive collapse resistance capacity of structures with megacolumns and core walls (typical of tall building systems) can be enhanced with the utilisation of outrigger and belt trusses (superfloors). The utilisation of this system can be considered as a mean for increasing robustness in a building. Outriggers and belt trusses improve continuity and interconnect with the structure, creating alternative load path to resist progressive collapse problems. Moreover, this will add redundancy to key elements, such as megacolumns. These floors will allow the distribution of the loads to all of the structure in the case there is a partial collapse of an element. The connection between the core and the columns is critical in order to increase the robustness of the whole building. This will produce an extra-tie consideration in the building performance.

Belt truss locations can then be determined based progressive collapse requirements (as well as drifts). The idea is to locate the belt truss in a specific floor in such a way the load is distributed from the damaged area to adjacent elements. The ideal location of the belt truss is as close as possible to the removed column as shown by Figure 9.1.

* CEN, 2006. Eurocode 1: Actions on Structures – Part 1-7: General Actions – Accidental Actions. ENV 1991-1-7:2006. European Committee for Standardisation.

** Val, D.V., and Val, E.G., 2006. Robustness of Frame Structures. Structural Engineering International, 16(2), 108-112.

*** ASCE, 2010. ASCE 7-10: Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers.

⁽¹⁾ Eltobgy, 2013: Eltobgy Hanan, Optimum belt truss locations to enhance the structural performance of high-rise steel buildings, WULFENIA Journal, Klagenfurt, Austria, Vol 20, No. 6, Jun 2013.

"It is widely acknowledged that steel structures inherently offer superior performance in earthquakes compared to masonry or reinforced concrete."

Georges Axmann

ArcelorMittal Europe – Long Products

Sections and Merchant bars

Head of Technical Advisory and Product Development

10. Earthquake design

Earthquake refers to the earth shaking with a sudden release of energy that creates seismic waves. These events are mainly caused by the rupture of geological faults, but other possible sources are volcanoes and landslides. The point of rupture is called the hypocenter and the point directly above it on the ground is called the epicenter. Usually, the most significant earthquakes are located close to the borders of the main tectonic plates which cover the surface of the globe (Figure 10.1). These plates tend to move relative to one another but are prevented from doing so by friction until the stresses between plates under the epicenter point become so high that a move suddenly takes place. The local shock generates waves in the ground which propagate over the earth's surface, creating movement at the bases (foundations) of structures. The size of the waves reduce with the distance from the epicenter. Therefore, there are regions of the world with more or less high seismic risk, mainly depending on their proximity to the boundaries of the main tectonic plates.

The action applied to a structure by an earthquake is a ground movement/acceleration with horizontal and vertical components (Figure 10.2). The vertical component of the earthquake is usually about 50% of the horizontal component, except in the vicinity of the epicenter where it can be of the same order. Today, minimum building requirements are that structures are designed to withstand these loads without collapse. However, stringent criteria are usually taken into considerations in order to reduce damage to the building thus reducing injuries. This approach is called performance-based design and requires a structure to be designed to achieve higher performance objectives (Figure 10.3). Performance-based design also allows projects to overcome code limitations and to utilise structural systems that are not prescribed by code (such as outriggers and belt trusses, see **CTBUH Performance Based Seismic Design Technical Guide** for more details). Three different levels of intensity are considered by this method: Maximum considered Earthquake

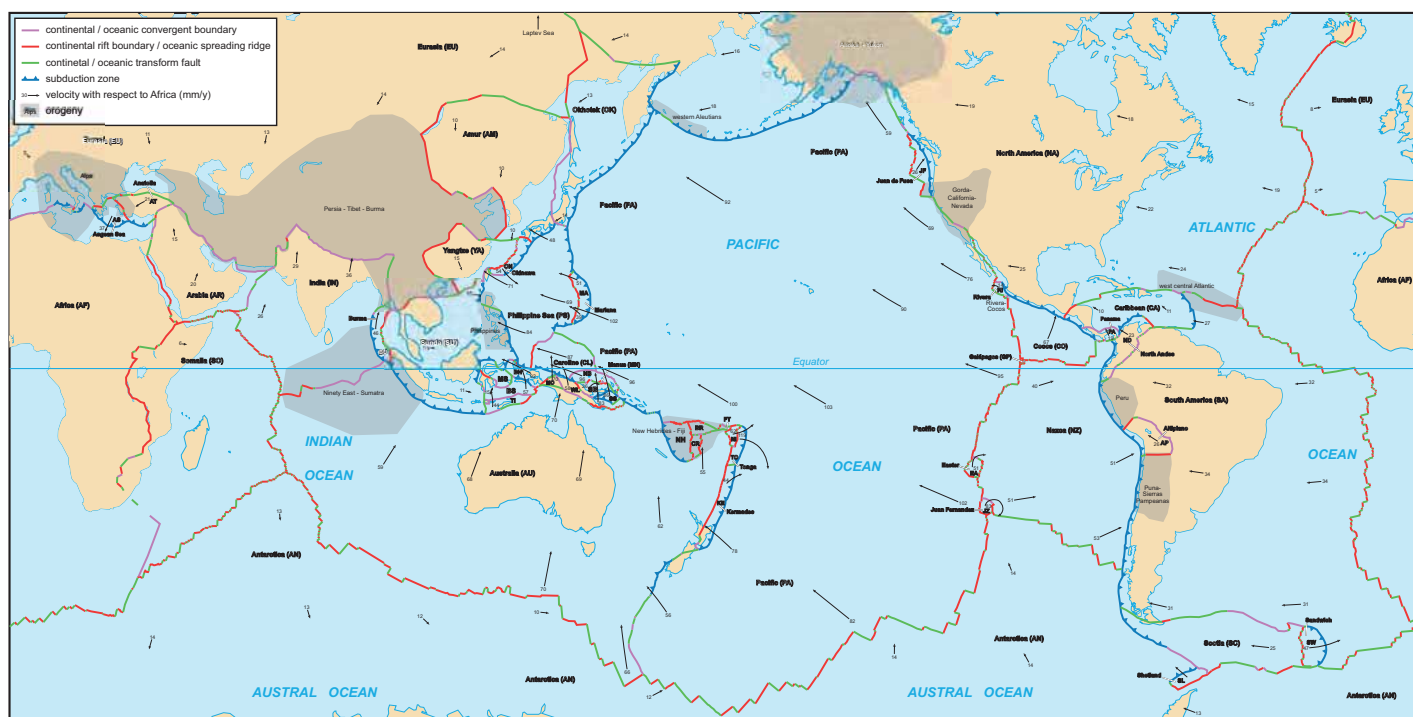


Figure 10.1: World map showing the main tectonic plates. From Bristol University website: www.ideers.bris.ac.uk

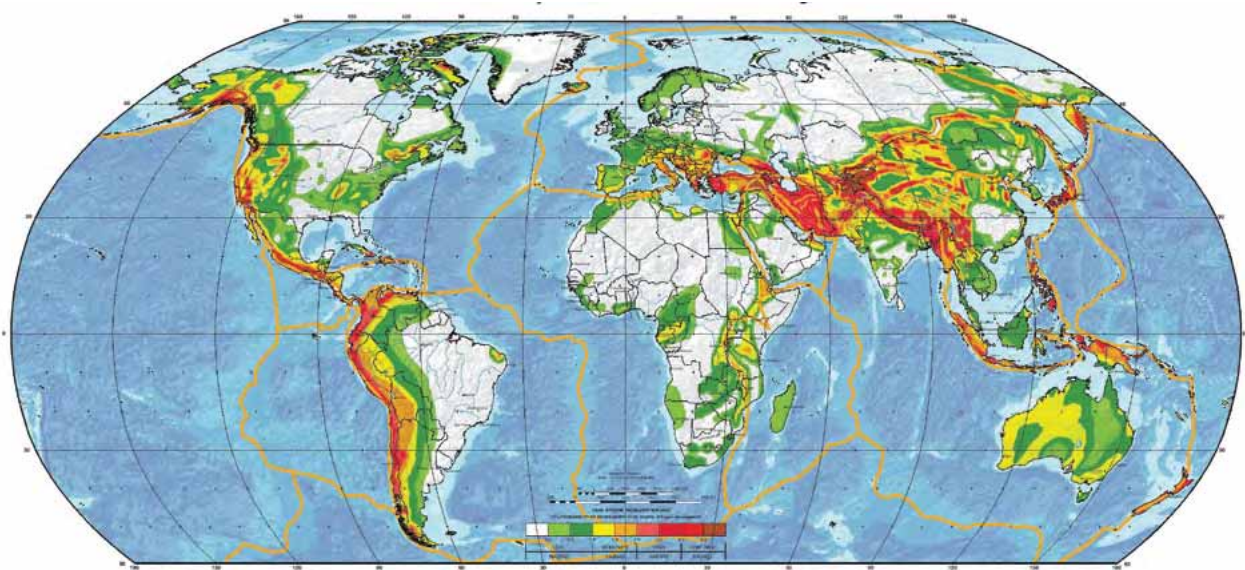
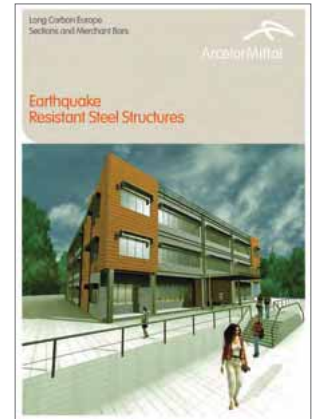


Figure 10.2: Global seismic hazard map, 1999

[produced by the Global Seismic Hazard Assessment Program (GSHAP), a demonstration project of the UN/International Decade of Natural Disaster Reduction, conducted by the International Lithosphere Program. Global map assembled by D. Giardini, G. Grünthal, K. Shedlock and P. Zhang.]

(MCER), Design Earthquake (DE) and Service Level Earthquake (SLE). Furthermore, the acceptable performance levels are defined as: operational, immediate occupancy,

life safety and collapse prevention. The possible relationship between performance level and earthquake intensity at various risk category levels as given in Figure 10.4.

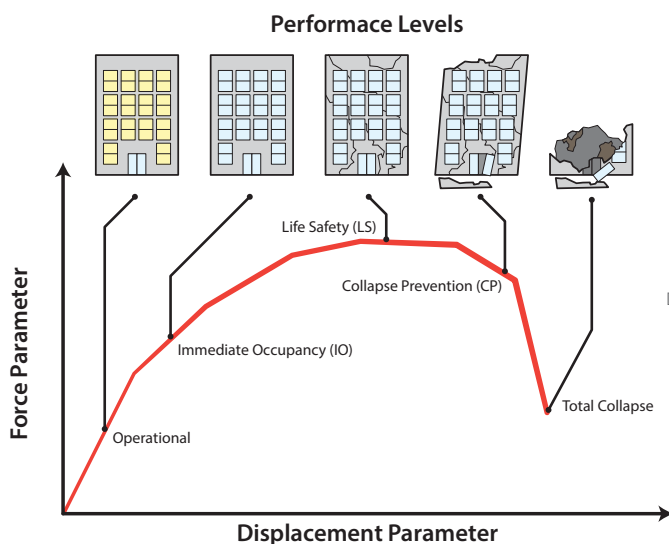


Figure 10.3 Structural Performance Objectives



Figure 10.4. Performance Levels of Code-Based Buildings at Various Risk Category Levels

Means to resist earthquake actions are commonly based on two different approaches:

- Option 1: structures made of sufficiently large sections that they are subject to only elastic stresses.
- Option 2: structures made of smaller sections, designed for ductility (i.e. for inelastic behaviour without strength degradation). In this case, the designer accepts some level of damages to occur in the structural and non-structural elements.

A structure designed to option 1 will be heavier and may not provide a safety margin to cover earthquake actions that are higher than expected, as element failure is not ductile (i.e. low robustness). In this case, the structure's global behaviour is 'brittle'. One example could be a "soft" first storey as shown in 'Concept a' in Figure 10.5. In this case, the building response is not safe since the first inelastic deformations due to the seismic demands are developing on the first floor columns. However, these columns are not designed to undergo these inelastic deformations (no energy dissipation due to cyclic behaviour), and therefore, as the demands increase, the deformations also increase accordingly. This would lead to first floor column failure inducing generally total building collapse.

In a structure designed according to option 2, selected parts of the structure are intentionally designed to undergo cyclic

plastic deformations without failure, and the structure as a whole is designed such that only those selected zones (plastic hinges) will be plastically deformed (as shown in Figure 10.6). The structure's global behaviour is 'ductile' and in this way it can dissipate a significant amount of energy through the formation of globally distributed plastic hinges (as shown in "Concept b" in Figure 10.5). For these reasons, the two design options are said to lead to 'dissipative' and 'non-dissipative' structures, respectively.

Experience shows that steel structures subjected to earthquakes behave well. Severe damages and collapses are mostly associated with structures made from other materials. This may be explained by some of the specific features of steel structures, such as: high ductile and stable hysteretic behaviour under cyclic loading. One of the most common solutions to obtain a ductile behaviour is the utilisation of the strong column – weak beam concept. If this solution is adopted, the inelastic deformations are forced to happen in the beam and not in the column. This would lead to a more ductile behaviour reducing the risk of collapse. The idea of this concept was at the base on the work conducted in 1989 by ArcelorMittal that developed (and patented) a Reduced Beam Section (RBS) or "dog-bone" connection (Figure 10.6 to 10.8). This connection can be

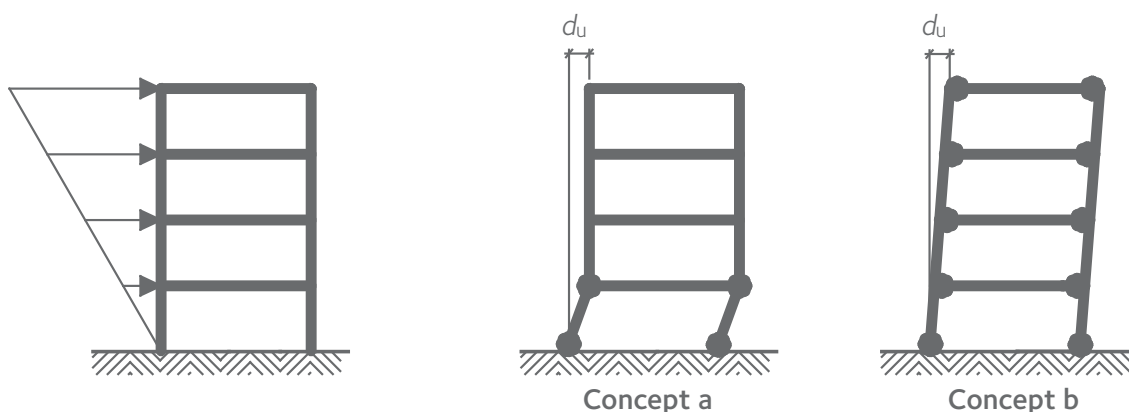


Figure 10.5: Examples of 'Dissipative' and 'Non Dissipative' global behaviours of structures.
"Non-dissipative" structure fails in a soft single storey mechanism

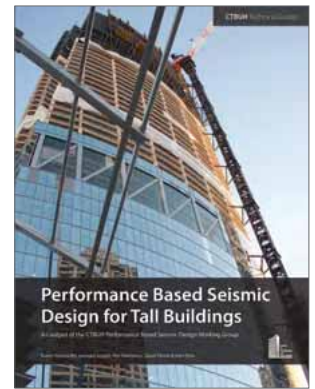


Figure 10.6: RBS: Reduced Beam Section Plasticisation

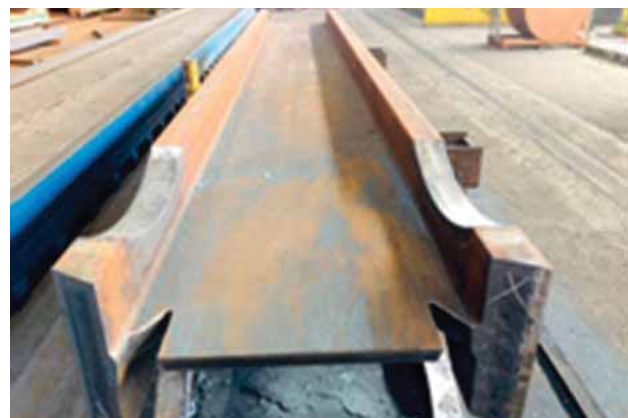


Figure 10.7: Reduced beam

easily developed in the fabrication shop and results in the removal of a portion of the beam's flange material at its connection to supports. Design of such a connection became more critical after the 1994 Northridge earthquake, which exposed several seismic design deficiencies. A number of steel moment frame buildings experienced brittle fractures of beam-to-column connections as a result of the earthquake. The SAC Joint Venture, under contract by FEMA, studied the "strong column – weak beam" design concept (Figure 10.8). When used in conjunction with ArcelorMittal's RBS connection, which was released from patent in 1995, this design concept can facilitate a shift of the plastic deformation from the column to the beam during an earthquake, thereby preventing the connection between the column and the beam from experiencing inelastic deformations. The method was successfully tested by AISC and was included in the FEMA 350 and 353 documents.

As a result of these research projects, the construction industry shifted away from ASTM A36 to Grade 50 steel. Moreover, for ductility purposes, it is often necessary to use higher strength steel in the design of columns. Using ASTM A913 Grades 65 or 70 for column shapes and A913 Grade 50 (with a maximum yield point of 65 ksi) for beams, coupled with the RBS, offers the most economical solution to seismic design available today. In addition, replacing A992 with higher



Figure 10.8: RBS connection

yield A913 can lower material weight and cost, strengthen connections, reduce or eliminate stiffeners in the panel zone and reduce or eliminate the need for double plates (Figure 10.8). Prequalified joints for earthquake resistance as defined in the American code cover almost the whole range of ArcelorMittal sections (see chapter 12).



11. Sustainability

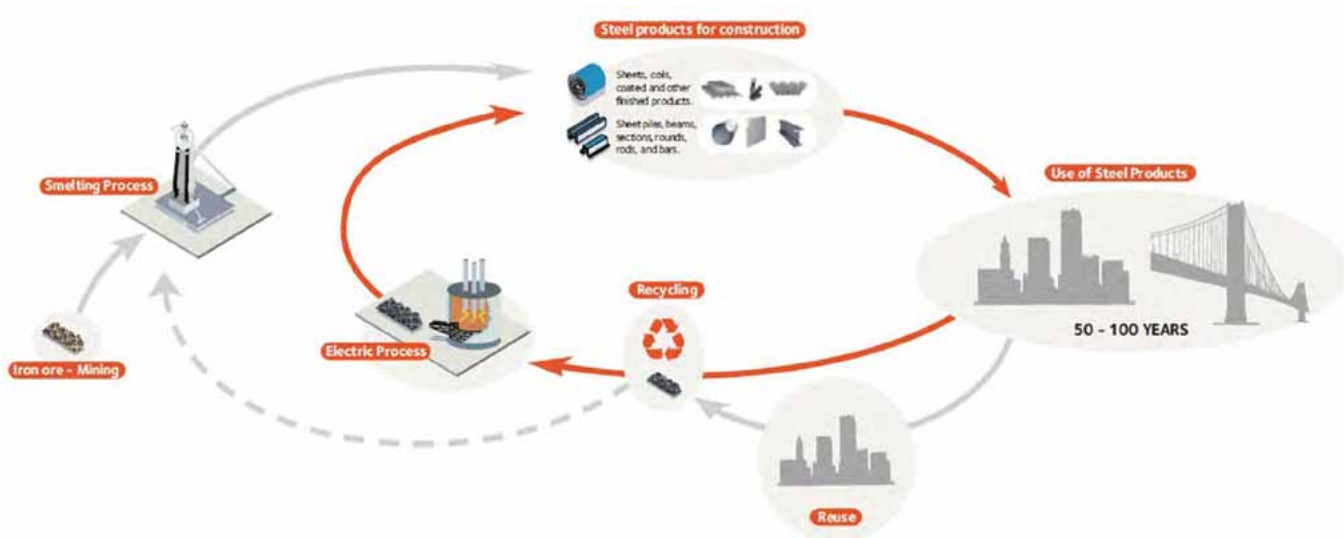


Figure 11.1: 1,2 tonnes of steel recycled by ArcelorMittal each second

Steel can be indefinitely recycled without any loss in quality. This means that the amount of scrap material from job sites or manufacturing plants, in addition to steel elements recovered from demolished building and structures, contribute to the majority of the steel material used in new high-rise structures (Figure 11.1). Steel is the most recycled material in the world.

About 65–70% of all steel needed for reinforcement bars has come from recycled material and 99% of steel beams are developed from recycled steel (approximately 88% recycled and 11% can be reused)*. Recycled steel represents currently about 40% of the steel industry ferrous resource in the world. With 33 million tonnes CO₂ saved each year, ArcelorMittal is the world's largest recycler of steel.

Furthermore, ArcelorMittal is striving to reduce the overall environmental impact in the manufacturing process. Waste generation, water use and air emissions are continually decreasing, as are energy consumption and greenhouse gas emissions. The European steel industry is one of the most

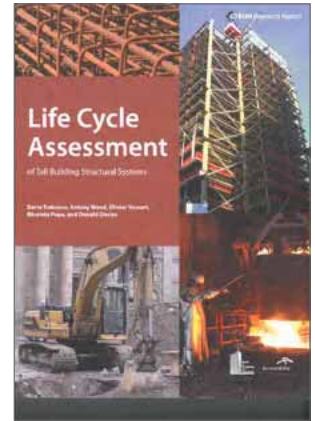
efficient steel industries in the world. European steelmakers have reduced energy consumption and CO₂ emissions per tonne of steel by 50% since 1960 and are now close to the technically feasible minimum**. ArcelorMittal production sites of beams have all reached ISO 14001 certification, the international standard for environmental management systems.

In addition, these sites are BES 6001 certified (Responsible Sourcing). ArcelorMittal is also a proponent for a dry steel construction system and using prefabricated steel elements during construction. This can lead to a shortened total construction time and reduce various risks during the construction phase, as assembly is simpler and less labour is required. Using prefabricated elements also reduces physical environmental impacts to the surrounding land and neighbourhood nuisance. Water use, waste generation, dust emission, traffic, and noise are considerably lower than in traditional construction. Work site management is largely facilitated. All these advantages are especially valuable for congested urban areas.

“It is important to identify the ‘good’ material producers, independently from their distance to the construction site.”

Nicoleta Popa

ArcelorMittal Global R&D – Long Products
Head of Structural Products



• Life Cycle Assessment

Developed during the 1990's, Life Cycle Assessment (LCA) is a methodology aimed at assessing the environmental consequences of human actions, particularly in the production of goods. In the past two decades, LCA analysis has become more and more popular in all disciplines, especially in architecture and engineering. LCA has been used for thousands of research projects analysing the environmental characteristics of materials, components and even entire buildings.

Based on the International Reference Life Cycle Data System Handbook (JRC, 2010)*, a handbook released by the European Union's Joint Research Centre, Institute for Environment and Sustainability, The Council on Tall Buildings and Urban Habitat, in collaboration with ArcelorMittal, produced Life Cycle Assessment of Tall Building Structural Systems, which analysed tall building structures from their inception to demolition. Steel buildings were analysed for their emissions during initial manufacturing, transportation on-site, assembly of structures, and ultimately to the demolition and recycling of the products, which are discussed further in this section.

• Global Warming Potential and Embodied Energy

Due to climate changes that have occurred in recent years as a result of greenhouse gas emissions, many efforts in the tall building industry are focused on reversing this trend. Global Warming Potential (GWP) and Embodied Energy (EE) are seen as indicators to give a general sense of the consequences building materials can have on environmental sustainability.

Energy is the driving force of life on earth, and the cause of many political, military, and strategic decisions internationally. Acknowledging the importance of energy broadens the definition of “sustainability” to account for the social and economic implications of energy consumption beyond purely environmental considerations.

However, energy is profoundly linked to environmental aspects too, as the use of fossil fuels and other non-renewable resources induces large emissions of CO₂ and other greenhouse gasses (Trabucco, et al., 2015)**.



* JRC, E. C. J. R. C. (2010) "ILCD Handbook: International Reference Life Cycle Data System" (First Edition)

** Trabucco, D., Wood, A., Popa, N., Vassart, O. & Davies, D. (2015) Life Cycle Assessment of Tall Building Structural Systems. Council on Tall Buildings and Urban Habitat: Chicago.

Short description	Scenario Number	GWP [kg CO ₂ Eq/m ²]	EE [GJ/m ²]	Building Height [storey]
Normal steel + Concrete Core	1a	222	2,4	60
High Strength + Concrete Core	1b	219	2,4	60
Concrete Core and Composite Frame	1c	216	2,3	60
All Concrete Wide and Shallow Beams	2a	241	2,2	60
All Concrete Narrow and Deep Beams	2b	209	2,0	60
All Steel Diagrid Normal Steel	3a	243	3,0	60
All Steel Diagrid High Strength Steel	3b	226	2,7	60
Composite Diagrid	3c	228	2,6	60

Figure 11.2: 60-Storey Tower scenarios

• Steel structure performances

In order to verify the sustainability of steel as a structural product, 60-storey tower scenarios were developed for different structural arrangements (Figure 11.2).

In this analysis, all-concrete solutions performed worse (on average) than the other scenarios that used steel, in terms of GWP (Figure 11.3).

Consequently, each tall building scenario can benefit from the recyclability of the steel at the end of the building life cycle along varying magnitudes: concrete scenarios benefit from the recyclability of rebar, while steel buildings benefit from

the recycling potential of the majority of the structural material, including steel sections, rebar, steel decks, etc.

Following the in-depth analysis, it was found that some of the environmental impacts occur during the final delivery of the materials to the construction site. The majority of the environmental impact comes from the direct delivery of the structural materials to the constructions site through the use of diesel-powered trucks. When structural materials are shipped internationally, they are traditionally shipped in bulk with ships, barges, trains, etc. This method, although over a

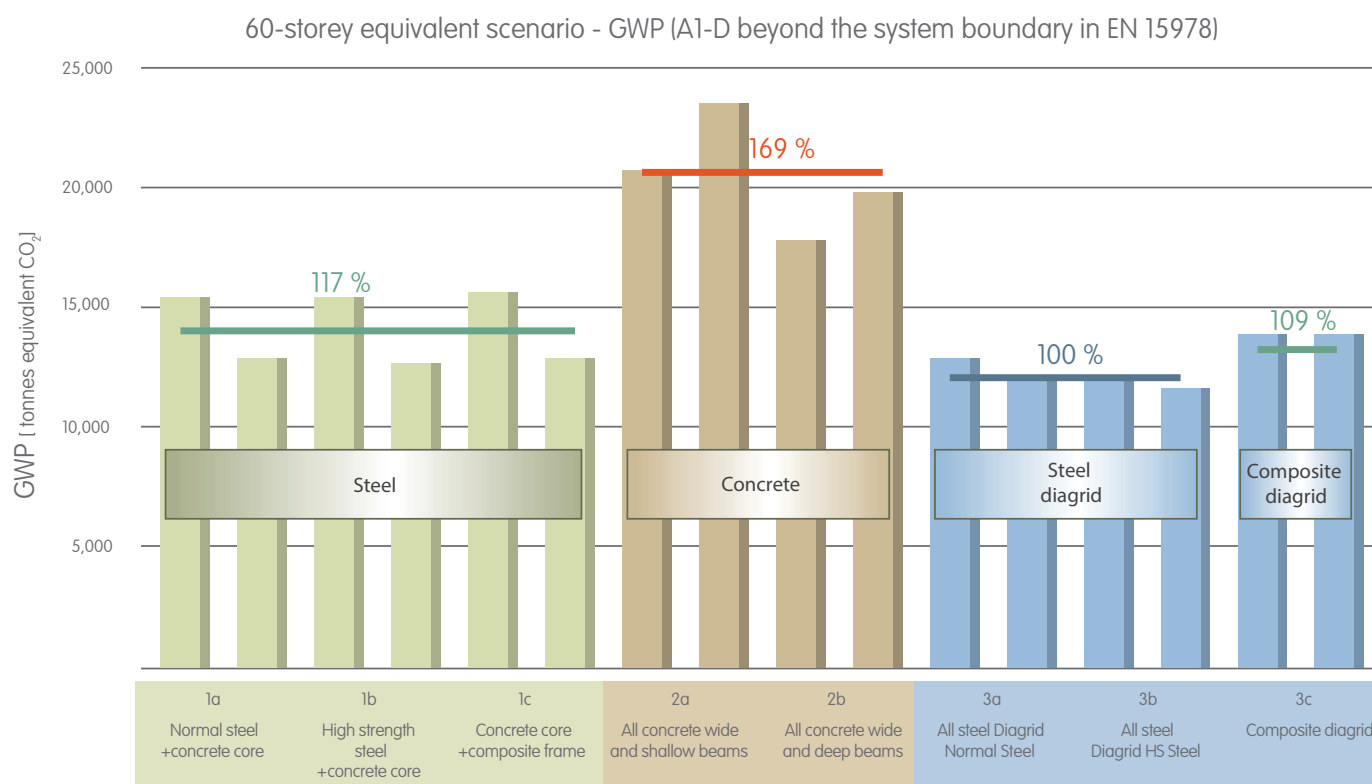
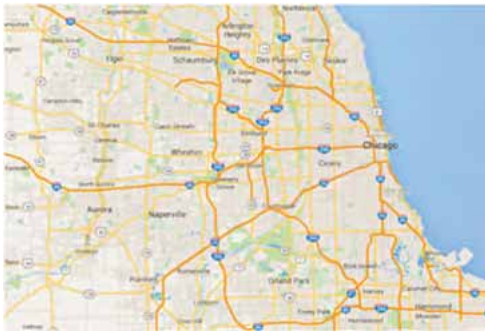


Figure 11.3: LCA of the 60-storey Scenarios Global Warming Potential (CO₂)



versus



avg 1.7% in terms of GWP
avg 1.9% in terms of EE

avg 5% in terms of GWP
avg 6.3% in terms of EE

Figure 11.4: Environmental effect of transport

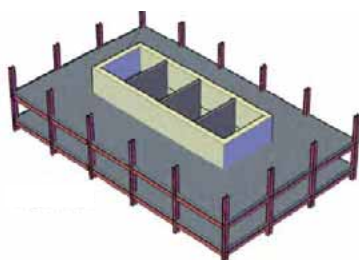
larger distance, does not contribute to significantly more total GWP and EE, when compared the manufacturers that may be closer to the construction site itself (Figure 11.4).

Furthermore, transportation of both construction materials to the site and transportation of demolition material and waste off sites does not account for a significant amount of the total GWP (between 1 and 2,5%) or the total EE (between 0,9 and 3,2%). This means that, in some cases, it is more important to find producers of high-quality, efficient structural material for a successful project, regardless of their distance from the construction site.

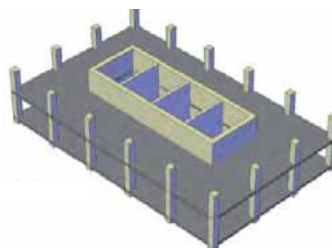
Significant environmental benefits can be realised by choosing

the best material production process, as the same material can have profoundly different environmental properties, depending on the source. For example, steel products produced in ArcelorMittal's Differdange location, such as ASTM A913 profiles are made with predominantly recycled steel scrap, using electric arc furnaces. The environmental properties of such products are less impactful than other conventional building materials (see EPD leaflet for Histar® steel page 56: **Environmental Product Declaration**).

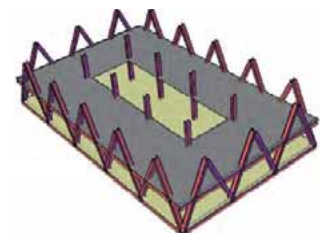
Also, the structures designed with these materials have a significantly lower GWP and EE than structures designed with the average environmental values published by WorldSteel (WorldSteel Association 2011)* (Hammond & Jones 2011)**.



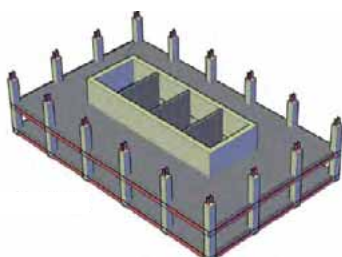
Steel Frame with Concrete Core



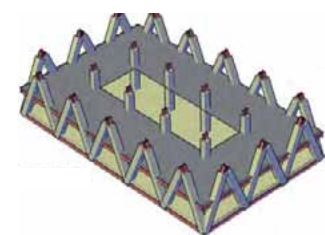
Concrete Structure



Steel Diagrid Structure



Composite Structure



Composite Diagrid Structure

* Worldsteel Association (2011) "Life Cycle assessment methodology report" Worldsteel Association, Brussels, Belgium.

** Hammond, G. & Jones, C. (2011), "Inventory of Carbon and Energy (ICE) Version 2.0", Claverton Down: University of Bath.

12. Future developments: pre-qualified joints

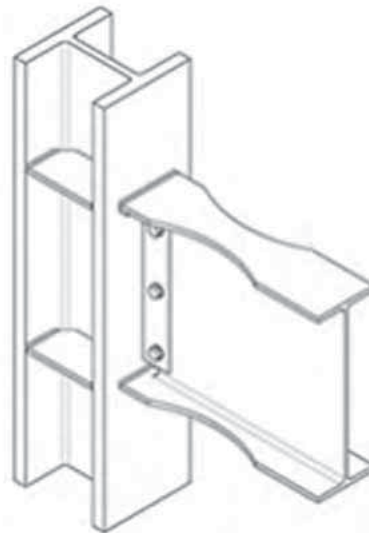
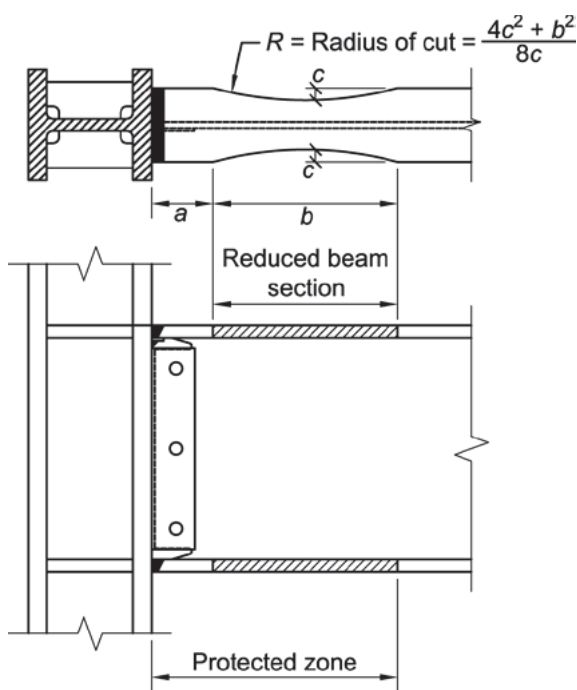


Figure 12.1: Reduced Beam Section type connections being tested

Jumbo profiles can be very beneficial for use in seismic design of high rise buildings. Amongst other requirements these structures must be able to develop certain rotation capacity at beam to column joints, in order to avoid the soft storey failure.

In countries such as the US some combinations of beams and columns, as well as the components in the connection, have been defined such that the joints formed by them are already prequalified as satisfactory to meet this requirement.

ArcelorMittal is currently working on a project to demonstrate that joints connecting Jumbo profiles satisfy the conditions to be prequalified. To achieve this goal numerical and experimental analyses will be performed and are expected to confirm appropriate behaviour of the joints in accordance with AISC-358.

The research focuses on Reduced Beam Section (RBS) type connections (also known as Dog Bone) made of Grade 65 columns and Grade 50 beams and plates (see Figure 12.1).

Four full-scale tests have been designed to cover the full range of Jumbo profiles:

- SP1: W36 × 652 beam / W14 × 873 column
- SP2: W44 × 230 beam / W14 × 233 column
- SP3: W36 × 925 beam / W14 × 873 column
- SP4: W44 × 408 beam / W40 × 593 column

The test frame will be placed horizontally and its layout is shown in Figure 12.2. The forces will be applied by four large deformation/high capacity actuators as rotations of at least 4% are expected. These activators will apply cyclic forces in

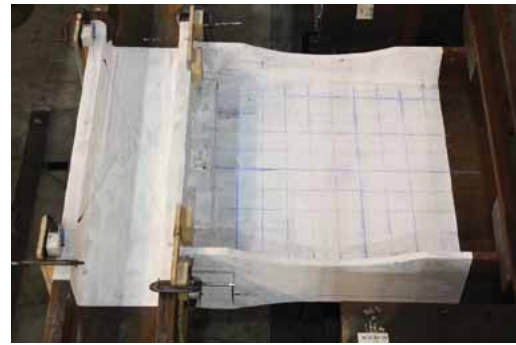
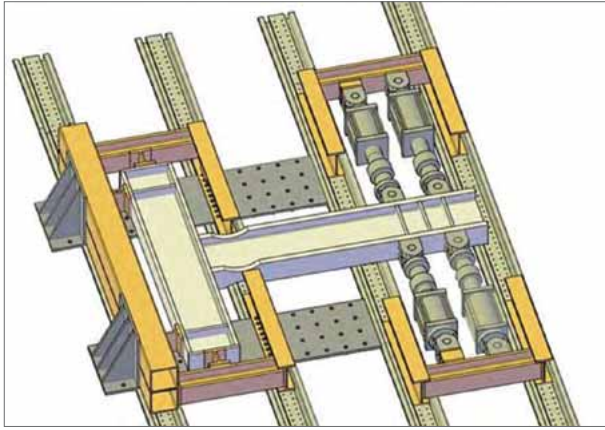


Figure 12.2: Layout of the test frame and specimen in VirginiaTec.

accordance with AISC - 341 - 10 K2 4b, which is shown in Fig. 12.3.

In order to ensure the appropriateness of the selected specimens and foresee the possible results of the tests, all joints have been previously numerically analysed. These analyses show the adequate behaviour of the joints as they provide enough rotation capacity after a number of cyclic forces.

Figures 12.4 and 12.5 show the final stage of the yielding process for one of the connections which confirms the formation of the plastic hinge at the desired location, i.e. the Reduced Beam Section, while the panel zone and reinforcing double plates remain in the elastic range.

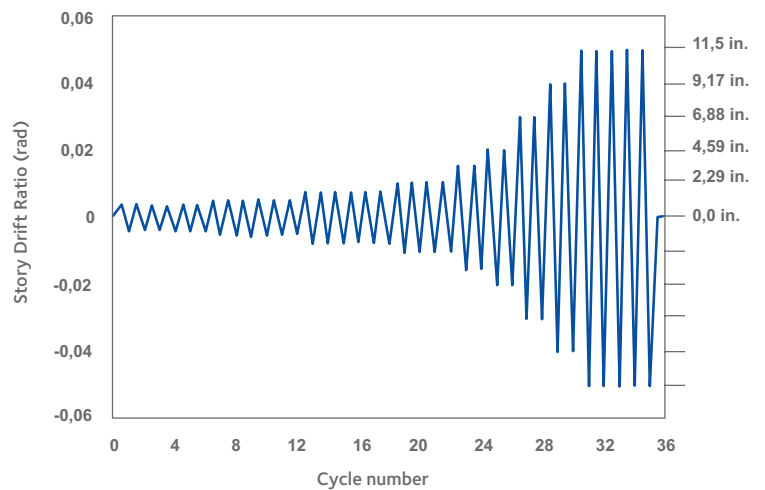


Figure 12.3: Cyclic loading

The first two tests have already been successfully performed on SP2 and SP4. These results will facilitate the prequalification of beams up to W44 (currently limited to W30) and columns up to W40 (currently limited to W36).

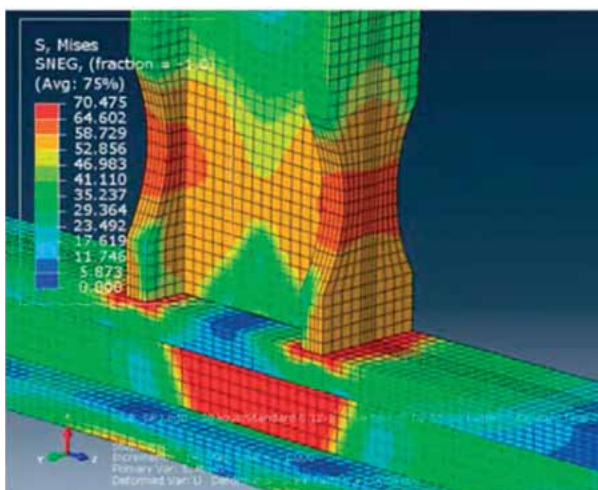
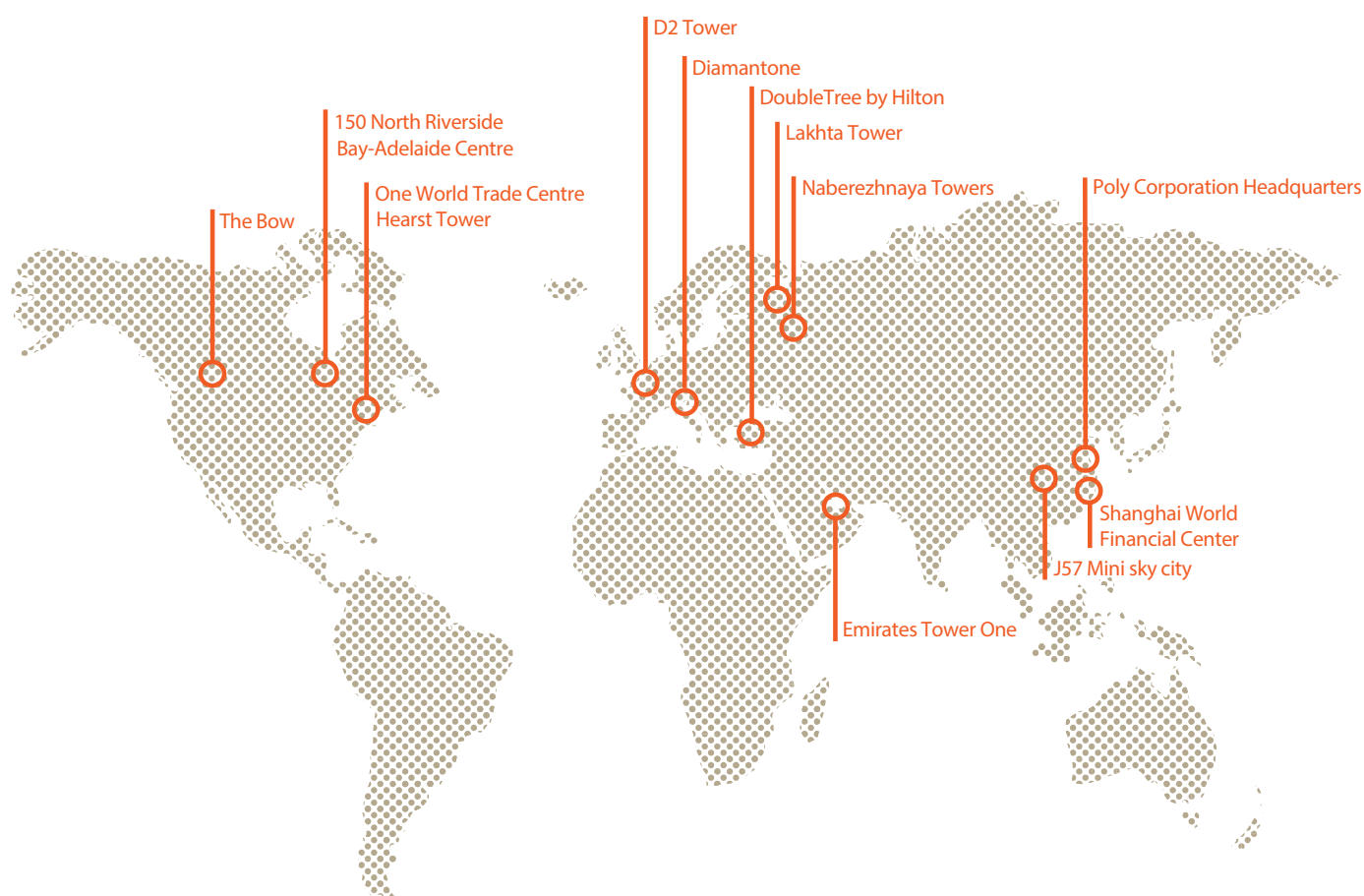


Figure 12.4: Numerical simulation of the specimens

Figure 12.5: Specimen after test

13. Reference projects



Europe

- D2 Tower – Paris, France
- Naberezhnaya Towers – Moscow, Russia
- Diamantone – Milan, Italia
- DoubleTree by Hilton – Istanbul, Turkey
- Lakhta Center – St. Peterburg, Russia

Asia

- Emirates Tower One – Dubai, UAE
- J57 Mini sky city – Changsha, China
- Poly Corporation Headquarters – Beijing, China
- Shanghai World Financial Center – Shanghai, China

America

- Hearst Tower – New York, USA
- The Bow – Calgary, Canada
- One World Trade Center – New York, USA
- 150 North Riverside – Chicago, USA
- Bay-Adelaide Centre – Toronto, Canada

The following case studies are outstanding skyscrapers where **ArcelorMittal products and solutions** have been used and have contributed to an optimum structural efficiency.

The Skyscraper Center
The Global Tall Building Database of the CTBUH

Search Buildings, Companies & Companies

Countries Cities Buildings Companies Interactive Data Lists Search Submit Data

ArcelorMittal

Acquired Arcelor (2006)
Acquired Mittal Steel (2006)
Parent company of Arcelor S.A.

Click a company above to see buildings specifically involving that company. The building list below shows buildings involving ArcelorMittal, Arcelor, Mittal Steel, Arcelor S.A., Aceralis, Arbed, Usinor, International Steel Group, Ispat International N.V.

Buildings

Note: All listed data for proposed or under construction buildings is based on the most reliable information currently available. This data is thus subject to change until the building has completed and all information can be confirmed and ratified by the CTBUH.

Completed Architecturally Topped Out Structurally Topped Out Under Construction On Hold Never Completed Processed Vision Demolished

Search:

Previous 1 2 3 Next

#	Building Name	City	Height (m)	Height (ft)	Floors	Completed	Material	Use
1	Burj Khalifa	Dubai (AE)	828	2,717	163	2010	steel/concrete	office / residential / hotel
2	One World Trade Center	New York City (US)	541.3	1,776	94	2014	composite	office
3	Pentominium Tower	Dubai (AE)	516	1,693	122	-	steel/concrete	residential
4	Shanghai World Financial Center	Shanghai (CN)	492	1,614	101	2008	composite	hotel / office

<http://www.skyscrapercenter.com/company/7007>

Some high-rise buildings with HISTAR® or ASTM A913 steel grades

Project America	Location
33 ARCH STREET	BOSTON, MA
111 HUNTINGTON	BOSTON, MA
EIGHTH AVENUE PLACE	CALGARY, AB
THE BOW	CALGARY, AB
MANULIFE TOWER*	CALGARY, AB
111 SOUTH WACKER	CHICAGO, IL
ONE SOUTH DEARBORN	CHICAGO, IL
300 NORTH LASALLE	CHICAGO, IL
150 NORTH RIVERSIDE*	CHICAGO, IL
155 WACKER	CHICAGO, IL
LURIE HOSPITAL	CHICAGO, IL
HARTFORD 21 / TOWN SQUARE	HARTFORD, CT
LAS VEGAS CLUB TOWER	LAS VEGAS, NV
COSMOPOLITAN	LAS VEGAS, NV
BRICKELL CITY CENTER	MIAMI, FL
250 WEST 55 th STREET	NEW YORK, NY
ONE WORLD TRADE CENTER	NEW YORK, NY
THREE WORLD TRADE CENTER	NEW YORK, NY
FOUR WORLD TRADE CENTER	NEW YORK, NY
217 WEST 57 th STREET*	NEW YORK, NY
425 PARK AVENUE*	NEW YORK, NY
HUDSON YARDS	NEW YORK, NY
4 TIMES SQUARE	NEW YORK, NY
HEARST TOWER	NEW YORK, NY
STANDARD HOTEL	NEW YORK, NY
300 MADISON AVENUE	NEW YORK, NY
TORRE REFORMA 509	MEXICO, ME
PHELPS DODGE TOWER	PHOENIX, CA
ADVANCED EQUITIES PLAZA	SAN DIEGO, CA
BROADWAY 655	SAN DIEGO, CA
555 MISSION STREET	SAN FRANCISCO, CA
RUSSEL INVESTMENTS CENTER	SEATTLE, WA
5 th & COLUMBIA	SEATTLE, WA
BAY ADELAIDE CENTER*	TORONTO, ON
BROOKFIELD PLACE*	TORONTO, ON

Project Europe	Location
REMBRANDT TOWER	AMSTERDAM (NL)
TORRE MAPFRE	BARCELONA (ES)
THE PINNACLE	LONDON (UK)
25 CHURCHILL PLACE	LONDON (UK)
DIAMOND OF ISTANBUL	ISTANBUL (TR)
HILTON DOUBLETREE HOTEL	ISTANBUL (TR)
PUERTA DE EUROPA	MADRID (ES)
TORRE REPSOL	MADRID (ES)
TORRE DE CRISTAL	MADRID (ES)
TORRE BANKIA	MADRID (ES)
DIAMANTONE	MILANO (IT)
DESIO TOWER	MILANO (IT)
NABEREZHNYA TOWER	MOSCOW (RU)
FEDERATION COMPLEX	MOSCOW (RU)
EMBANKMENT TOWER	MOSCOW (RU)
EURASIA TOWER	MOSCOW (RU)
IMMEUBLE BASALTE	PARIS (FR)
D2 TOWER	PARIS (FR)
LAKHTA TOWER	ST PETERSBURG (RU)
DAEWOO TOWER	WARSAW (PL)

Project Asia	Location
POLY CORPORATION HEADQUARTERS	BEIJING (CN)
J57 MINI SKY CITY	CHANGSHA (CN)
EMIRATES TOWER ONE	DUBAI (UAE)
PENTOMINIUM TOWER	DUBAI (UAE)
TRUMP TOWER	MUMBAI (IN)
CMA TOWER	RIYADH (SA)
SHANGHAI WFC	SHANGHAI (CN)
POLY CORPORATION HEADQUARTERS	BEIJING (CN)

*using ASTM A913 Grade 70



Europe

Facts:

Height: 171m (561ft)

Number of Floors: 36

Gross floor area: 54 500m²

Building Function: Office

Structural material: Steel columns and beams with composite floors and a reinforced concrete core

Completion: 2014

Architect: Agence d'architecture Anthony Béchu – Tom Sheehan

Structural Engineer: DVVD; Setec TPI

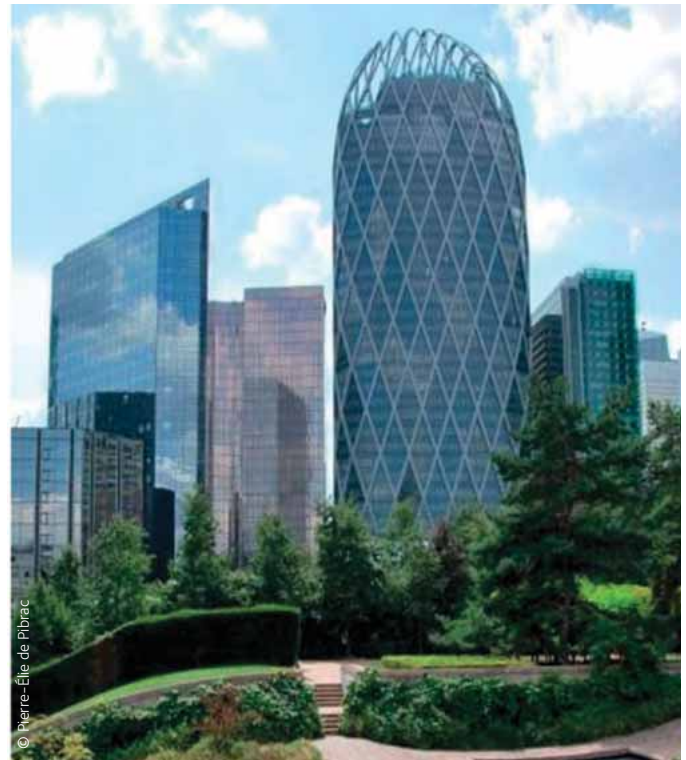
General Contractor: GTM Bâtiment (Vinci group)

ArceleorMittal Steel: 3 000 tonnes of HD 400 sections in HISTAR® 460 and 1 200 tonnes of ACB® beams

D2 Tower (Paris, France)

Located in La Défense, a major business district, in the west of Paris, the D2 Tower is the first high-rise building in France to employ the use of an external steel grid structure. It would have been difficult to adapt a conventional, rectangular floor plan in these dense surroundings so a rounded shape was chosen for the design. To adapt to this design restraint, an external steel diagrid structure was chosen to provide adequate structural stability. This decision proved effective, as the total amount of structural material was 30% less than a conventional tower design. Not only did this allow the design to take advantage of additional interior floor area, but also comply with the French green buildings standard, achieving a "Certification NF-HQE Bâtiments Tertiaires, Passeport Excellent" rating.

In addition to office space, the D2 Tower houses a fitness centre, a panoramic restaurant, a cafeteria and meeting rooms, with the aim of creating a comfortable and functional professional environment. At the top floor, the tower shelters two levels of top management offices and the "Jardin des nuages" (a garden of clouds), including a 45m² putting-green and a "Zen" walk in the middle of trees, offering an exceptional view of the capital and a spot of green foliage accessible to the tower occupants.



• Steel structure

From the beginning, the choice of the material for the structure of the D2 Tower was clear. Steel was chosen for its flexibility and sustainability advantages. The external diagrid structure, which supports half of the horizontal and vertical loads, is connected to a central concrete core through long cellular beams. Through the combination of the diagrid structure with a system of composite floors and cellular beams, the useable total floor area is increased, which creates flexible and modern workspaces, and the structural materials are considerably reduced. The reduction of 30% of the material consumption guarantees a fast construction process, with all steel stock being incorporated into the structure within 3 days of delivery on-site. The ease and speed of construction allowed the project to be built according to the original timetable estimate and meet a consistent, regular cycle of approximately 3 storeys built every 3 weeks.



Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
	Bracing	diagrid	HISTAR® 460		sprayed + protective metal coating
	Columns	internal columns	HISTAR® 460		sprayed/Intumescent coating
	Floor solutions		cellular beams	cellular beams	sprayed



45m² putting-green



Spray fire-protected diagrid



Spray fire-protected beams

• ArcelorMittal Steel

ArcelorMittal supplied 4200 tonnes of steel for the structure: 3 000 tonnes of HISTAR® 460 sections for the external diagrid and 1 200 tonnes of ACB® beams for the floors.

The bracing façade consists of massive hot-rolled steel profiles, mainly HD 400 in the high-strength steel grade HISTAR® 460 sections. These 12-meter-long profiles were pre-fabricated on-site in the shape of a "V", with each element weighting approximately 14 tonnes. Due to the elliptical shape of the tower, the radius of curvature varies and the angles of inclination range from 3 to 15 degrees. Every V-shape is wrapped in an aluminium shell and is integrated with the glazing to compose the curtain wall system. The use of this construction method and the HISTAR® grade steel is what largely contributed to reducing the construction time and the amount of structure material (by 30%).

The ACB® cellular floor beams were selected because the openings in the web simplify the installation of technical equipment and building services and increase the usable floor height. Additionally, these beams were based on IPE 450 and HE 450 A profiles, and due to their excellent strength-to-weight ratio, longer spans than conventional beams can be achieved, which creates open office spaces without column obstructions further reducing the total structural weight.

• Fire Resistance

In order to address fire safety concerns, the entire diagrid structure and cellular beams are protected by a cement spray. This is an effective solution in terms of cost and labour and



through a metallic cowling that covers the diagrid, the desired aesthetics for the exterior structure are achieved.



Europe

Facts:

Height: 268,4m (881ft)
 Number of Floors: 61
 Gross floor area: 136 651m²
 Building Function: Office
 Structural material: Steel perimeter framing and outriggers with composite floors a reinforced concrete core
 Completion: 2007
 Architect: ENKA Design; RTKL
 Structural Engineer: ENKA Design; Thornton Tomasetti
 General Contractor: ENKA
 ArcelorMittal Steel: 13 500 tonnes in HISTAR® 460 for Russian weather conditions

Naberezhnaya Towers (Moscow, Russia)

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
 Bracing		outriggers trusses with concrete core	HISTAR® 460 for Russian weather conditions		sprayed
 Columns		perimeter columns			4 hours concrete encasement
Floor solutions				composite beams	sprayed

Located on plot 10 of the Moscow International Business Centre (MIBC), the Naberezhnaya Towers are an office complex consisting of 3 individual office buildings, interconnected at the basement levels. Block C, the tallest of the three towers at a height of 268,4 meters, achieved the status of the "Tallest Building in Europe" at the time of completion in 2007, before being surpassed by the Capital City Moscow Tower in 2010.

The complex includes shops, a restaurant and the connecting central core public area. Vestibules, reception groups and administrative rooms are on the ground and mezzanine floors. Open-plan offices extend from the 2nd to the 58th floors.

• Steel structure

The majority of the structure consists of steel perimeter columns and composite floor systems with a cast-in-place reinforced-concrete central core. Built-up steel box columns are arranged at the tower's perimeter to resist only vertical loads, and avoid directly transferring lateral loads. At the 26th and 59th floors, outrigger and belt trusses were installed; the outriggers were designed between the core and perimeter columns to restrict lateral displacement of the core under wind effects and the belt trusses were installed between the perimeter columns to distribute the lateral loads that are transferred by outriggers. This structural solution ensures that the maximum allowable lateral drift at the top of the building is limited to only 0,2% of its height.

• ArcelorMittal Steel

The Naberezhnaya Towers are the first projects to use a special high strength steel produced by ArcelorMittal. Extensive tests were conducted to ensure that the toughness



of the steel, even under the extreme Russian weather conditions of -20 °C, still provided adequate structural performance.

• Fire Resistance

Highly effective fireproof compounds with a certified fire safety performance are applied to the surface of the 13 500 tonnes of structural steelwork. The fire protection of the steel columns has been ensured by concrete encasement, which can achieve at least four hours of fire resistance for the steel structure.



Europe

Facts:

Height: 140m (459ft)

Number of Floors: 31

Gross floor area: 290 000m²

Building Function: Office

Structural material : Steel columns with composite floors a reinforced concrete core

Completion: 2012

Architect: Kohn Pedersen Fox Associates Pc

Structural Engineer and Work Supervisor's technical support: ARUP

General Contractor: ATI CMB/UNIECO

ArceleorMittal Steel: 3 800 tonnes

Diamantone (Milan, Italy)

Located in the Centro Direzionale di Milano, a major business district in Milan, the 140-meter Diamantone or Diamond Tower, became the tallest steel structure in Italy, and the country's third tallest building, when it was completed in 2012. Diamantone, named for its irregular, faceted form that references a diamond, is the tallest of the three towers built on this plot, with the additional two buildings known as the Diamantini or the Small Diamonds. They were constructed as part of the extensive urban redevelopment program in Milan, known as the Progetto Porta Nuova.

The use of high strength steel sections contributed to significantly reducing the weight of the whole building. It also allowed column-free office space, enabling a preferential shallow foundation and providing significant advantages in terms of transportation of materials on-site. The challenges of a major construction project in a dense urban environment includes heavy traffic, reduced space for unloading, and virtually no storage space. Through a detailed production and logistics plan, the 3 800 tonnes of steel elements were delivered in 150 separate loads with limited interruptions to regular traffic and only 2 deliveries a day. Through these sustainable and efficient design and construction methods, Diamantone achieved a LEED Gold certification, one of the highest ratings recognised by the Green Building Council.

• Steel structure

Designed with steel columns, composite flooring, and a reinforced concrete core, the building is lighter than a conventional reinforced concrete structure. Furthermore, using load distributing finned walls in the foundation, a more economical shallow foundation with a 2-meter base plate was possible and a pile foundation was avoided; this was a cost effective solution that also reduced the construction time.

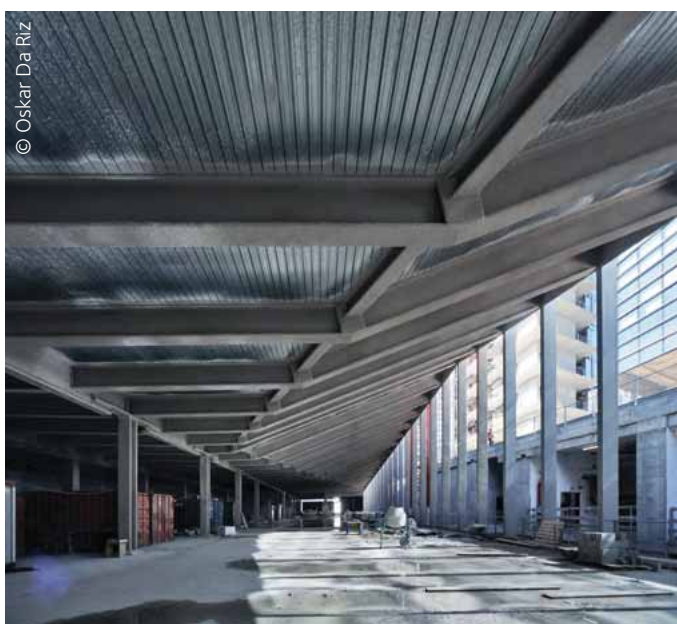
The floors of the building are characterised by column free floor areas, linked to a central core with connecting beams. The concrete core contains all infrastructure and access functions, such as elevators, staircases, and electricity supply and consists of three vertical shafts, which act like a vertical cantilever fixed to the foundation and are integrated with each other through horizontal connecting beams. These beams connect the core walls and ensure the three shafts interact as a cross-bracing system. The connecting beams avoid the relative vertical displacement of the single shafts and transmit the shear loads.

High strength steel was used in the structure, which has a higher yield strength compared to conventional, S235 grade steel. This resulted in up to a 50% reduction in the total material cost. Since the cost of the S460 M grade rolled sections is



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Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
 Bracing		concrete core			sprayed
 Columns		perimeter column:HD360/HD400	S460M		sprayed /board
Floor solutions			S355	composite beams	sprayed



just 10-15 % higher than S235 grade material, 30-40% of the savings could be achieved exclusively in the material costs. The additional savings were achieved through a reduction in the amount of welding material, corrosion protection and transportation costs using less structural material and less surface area.

● ArcelorMittal Steel

The composite beams provided for Diamantone, were S355 grade, IPE and HE sections that contain several openings in the web for the integration of building services and can achieve spans of up to 11 meters. 1 800 IPE and HE composite floor beams were provided, with a total combined length of 13 520 meters. The steel deck of the composite floors had an undercut geometry that contributed to the reinforcement, allowing for a floor thickness of only 15-20cm. A total of 26 000m² of composite decking was used.





Europe

Facts:

Height: 110m (361ft)

Number of Floors: 27

Gross floor area: 25 042m²

Building Function: Hotel

Structural Material: Steel with reinforced concrete at basement levels

Completion: 2012

Architect: Uras x Dilekci Architects

Structural Engineer: Yapı Teknik

General Contractor: Gülermak

ArcelorMittal Steel: 2 683 tonnes of W14 Jumbos columns in HISTAR® 460, primary beams and bracing in S355 and secondary beams in S275

DoubleTree by Hilton (Istanbul, Turkey)

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
	Bracing	concrete core + steel frame	HISTAR® 460		sprayed
	Columns	perimeter columns	HISTAR® 460		sprayed
	Floor solutions		S355 primary beams	composite beams	sprayed

Located in Avcılar, a district in Istanbul, Turkey, the 110-meter DoubleTree by Hilton became the tallest all-steel building in Turkey when it completed in 2012. It was bestowed the “Best Steel Structure High-Rise Building” award by TUSCA in 2013. Originally envisioned as a 14-floor steel and glass auto showroom, the design quickly shifted to 27-floor hotel building that includes an indoor pool, fitness and business centres and restaurants.

• Steel Structure

Steel was chosen as the primary structural material, due to the high amount of seismic activity in the area. Furthermore, as the function and size of the tower changed during the construction process, steel columns reinforced with cast-in-place concrete were used in the basement and an overall refurbishment of the foundation was conducted. This gave the foundation the ability to accommodate the increased stress on the system, without sacrificing the construction work that had already occurred; this is another aspect of this project that could not have been achieved without the use of steel. The primary structure consists of HISTAR® HD columns with a 40 x 40cm cross-section. These columns can accommodate all of the vertical loads and all horizontal loads, from earthquakes and wind, are supported by transverse bracing elements, which are also HISTAR® HD columns. The use of steel for the primary structure, instead of reinforced concrete, also allowed for a smaller worksite (only the backyard and parking lot were used), minimising the impact on the surrounding environment. Furthermore, the use of steel also contributed aesthetically to the design; the thin structural elements help provide the maximum views towards the Sea of Marmara and the Lake of Kucukcekmece.



Sonkar Oto

• ArcelorMittal Steel

A total of 2 683 tonnes of steel was imported on site. All deliveries of the ready-to-erect steel occurred during the night times, which minimised disturbances to the surrounding area and interruptions in regular traffic. HISTAR® 460 Jumbo columns, S355 primary beams and bracing, and S275 secondary beams were used to assemble the structure, due to their flexibility and weldability. The column joints were prepared so that full penetration butt welds could be achieved on-site. The main beams and secondary beams were designed as composite floor elements, coated in concrete, which was

an economic and efficient solution, in terms of the increased spans that were able to be achieved, the minimal amount of material used, and the reduced floor thicknesses. All beam-to-beam and column-to-beam connections were achieved using high-strength 10-grade steel bolts.

• Fire Resistance

In order to achieve adequate fire resistance, all steel sections were coated with an intumescent coating. This was also used due to its aesthetic value, as the bracing elements are exposed in the hotel rooms, and the paint provides a clean, modern finish.



Europe

Facts:

Height: 462m (1 516ft)

Number of Floors: 86

Gross floor area: 330 000m²

Building Function: Office

Structural Material: Composite columns and floors with steel-braced reinforced concrete outriggers and a reinforced concrete core

Completion: 2018

Architect: Gorproject; RMJM

Structural Engineer: Gorproject; Inforceproject

General Contractor: Renaissance Construction Company

ArcelorMittal Steel: 18 309 tonnes in HISTAR® 460 Russia

Lakhta Center (St. Petersburg, Russia)

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished sections	
 Bracing		concrete core + steel frame + outriggers	HISTAR® 460 Russia		composite
 Columns		composite mega-column	HISTAR® 460 Russia	cruciform columns	composite
Floor solutions				composite beams	sprayed

Located in the Primorsky district of St. Petersburg, the Lakhta Center will create a sustainable economic zone by combining the office space of the tower with transportation infrastructure, green space, and several public resources, including a planetarium, sports complex, medical centre, performance hall and a bank. Outside of the building, the planned landscaped spaces consist of a 2 000-seat amphitheatre and a green promenade. The Lakhta Center is seen as the "pilot project" for this area on the outskirts of St. Peterburg, with the view to create a new area for business and living in this area. The building will serve as a major landmark for the area through unique twisted-spire form, which is inspired concepts of extrusion, torsion and tension. Furthermore, once complete, the Lakhta Center expected to become the tallest tower in Europe.

• Steel Structure

The Lakhta Center was originally designed as structure consisting of massive steel columns, with composite floors, reinforced concrete outriggers, and a reinforced concrete core. In order to save time, reduce costs and improve the constructability. The structural design was optimised, taking advantage of the benefits of using steel and concrete together. In addition to optimising the layout of the beams in the composite floors, the columns were adjusted to be more efficient composite columns and the steel outriggers were encased to help connect the columns to the building's core.



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America

Facts:

Height: 182m (597ft)

Number of Floors: 46

Gross floor area: 79 524m²

Building Function: Office

Structural material : A steel diagrid frame supported by concrete-reinforced steel supercolumns, with a steel core and composite floors

Completion: 2006

Architect: Foster + Partners; Adamson Associates

Structural Engineer: WSP Cantor Seinuk

General Contractor: Turner Construction Company

ArcelorMittal Steel: 8 000 tonnes in A913 Grade 65

Hearst Tower (New York, USA)

In 1928, a six-storey, Art Deco building, commissioned by William Randolph Hearst to house his publishing empire, completed construction on New York City's 8th Avenue. Over 70 years later, the hollowed shell of this landmark office building would become the base of the 182-meter Hearst Tower. Completed in 2006, the Hearst Tower became the

first New York City commercial office building to achieve Gold LEED Certification from the US Green Building Council, bettering itself in 2012 with a LEED Platinum rating. The tower presents a distinctive method to create a dialogue between old and new architecture through a completely glass façade that appears to be floating above the base. This individual building is able to embody the historical and modern architecture that defines the entirety of New York City. Upon entering the building, occupants are greeted with a spacious lobby, which occupies the entire space of the original building. The space provides access to all aspects of the building, including the main elevator lobby, the cafeteria, auditorium and meeting areas. Also, the roof of the tower has been design to collect rainwater, harvested in a 64-cubic meter reclamation tank located in the basement of the building. Some of this water is utilised for "Icefall", the grand atrium's water feature, which has the environmental function of humidifying and chilling the atrium lobby as necessary.

• Steel Structure

All four sides of the main tower are formed by a diagonal steel structure wrapping around the perimeter of the tower. This series of 16,5-meter-tall triangulated structural elements form what is commonly referred to as a "diagrid", which is an efficient structural form that reduces the volume of steel required by 20 percent when compared to a conventional moment frame structure. The diagrid system also provides increased structural stability. Furthermore, it contributes aesthetically to the tower; the edges between the diagonals are pulled back giving the tower its distinctive faceted appearance and emphasises its vertical proportions.

The diagrid structure is supported by ten-storey tall concrete-reinforced steel super columns and the entire tower is further reinforced by a steel core. Composite steel and concrete floors are used, with 12-meter interior column-free spans for open-floor-plan offices.



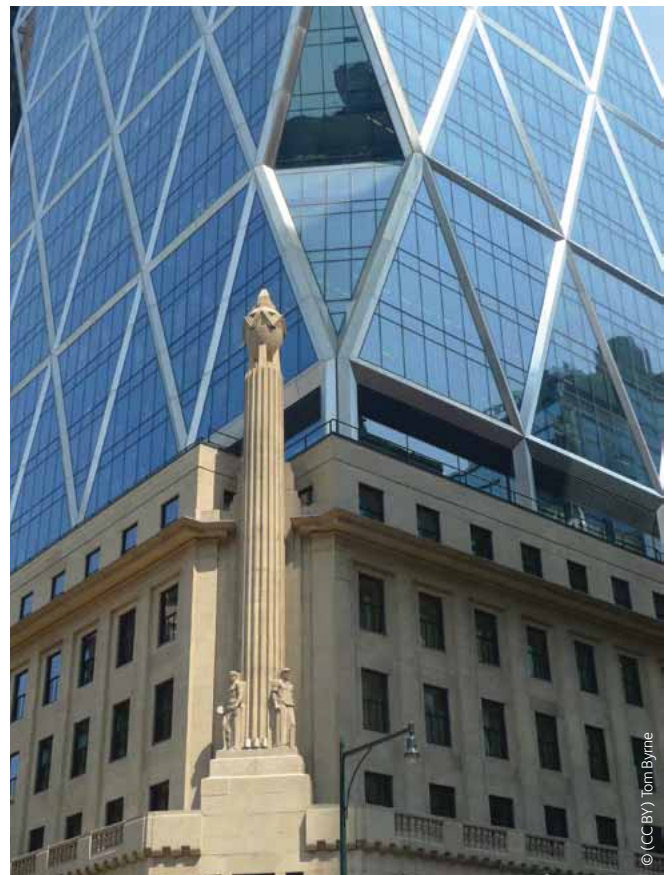
Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
	Bracing	diagrid			sprayed
	Columns	perimeter column:HD360/HD400	A913 - Grade 65		sprayed/Intumescent coating
	Floor solutions		A913 - Grade 50	composite beams	sprayed

• ArcelorMittal Steel

The HISTAR® steel sections in the Hearst Tower were made in Differdange (ASTM A913 grade 65, wide flange structural shapes per ASTM A6), and are used in the wind bracing and gravity load system. These sections make up the diagrid system, visible on the façade of the building, and the inclination of these structural members function simultaneously as the bracing and column system. The external cladding of the diagrid is covered with stainless steel to give it a clean and modern finish. A total of about 10 000 tonnes of structural steel is used in this project.

• Sustainability

This building was built using 85 percent recycled steel and is designed to consume 26 percent less energy than conventional buildings of a similar size and function. Also, since the diagrid frame of the tower contains roughly 20 percent less steel than would a conventional perimeter frame, approximately 2 000 tonnes of steel is saved. In addition to the efficiency of the structural steel, the high-performance low-emission glass façade allows for internal spaces to be flooded with natural light, while keeping out solar radiation causing heat. Light sensors control the amount of artificial light on each floor based on the amount of natural light available at any given time, and motion sensors



allow for light and computers to be turned off when a room is vacant. High-efficiency heating and air-conditioning equipment utilise outside air for cooling and ventilation for 75 percent of the year.

Furthermore, the remaining rainwater collected on the roof that is not used in the fountain, is used to replace water lost to evaporation in the office-air conditioning system. It is also fed into a special pumping system to irrigate plants and trees inside and outside the building. Additionally, electrically actuated faucets reduce potable water use by 25 percent.



America

Facts:

Height: 236m (774,3ft)

Number of Floors: 57

Gross floor area: 199 781m²

Building Function: Office

Structural material: A steel diagrid and braced frame perimeter, with composite floors

Completion: 2012

Architect: Foster + Partners, Zeidler Partnership Architects

Structural Engineer: Halcrow Yolles

General Contractor: Ledcor Construction Limited

ArcelorMittal Steel: 4 900 tonnes of W14 x 16 sections

The Bow (Calgary, Canada)

At 236 meters, Foster + Partners' The Bow is Calgary's highest skyscraper. This bold new landmark on Calgary's skyline consists of an iconic, curved design, formed by an external diagrid structure, which contributes to the building's environmental performance. Its form is derived from an in depth climate analysis: facing south, the tower curves

towards the sun to take advantage of daylight and heat, while maximising the space for offices with views of the Rocky Mountains. Also, by turning the convex façade into the prevailing wind, the structural loads are minimised; in addition to the inherently efficient diagrid system this unique form and climate analysis helps contribute to significantly reducing the volume of structural steel required. The external diagrid structure consists of triangular shaped steel sections that span six storeys. This helps to visually break down the size of the building. Upon completion in 2013, The Bow became Canada's tallest commercial office building outside of Toronto and is the headquarters for the companies Encana and Cenovus.

The internal office floors are pulled back from the south facing curving façade; this allows for three spacious sky gardens, six-storeys in height, and a series of atria. This gives occupants of the building a working environment that promotes sociability and interaction. As each floor has been sized to accommodate a whole business unit, the sky gardens (located at levels 24, 42 and 54) help promote collaboration across the companies; they enable vertical access to the office floors and incorporate trees, seating, meeting rooms, catering facilities and local elevator cores. An auditorium can be found on the top floor.

• Steel structure

Given the design and sustainability goals, the geometry of the building, cladding design, interior and exterior aesthetics and space planning, steel was a natural choice for the building's structure. The use of high strength structural steel offered additional advantages: smaller vertical load carrying members allow the use of lightweight long span floors, larger column free areas for more open spaces and higher flexibility, and more economic foundations due to its reduced weight. The building's distinct perimeter diagrid frame acts as one of its structural systems that make up the hybrid lateral force resisting system (LFRS). The remainder of the perimeter consists of three primary braced frames on the curved south elevation and two on the north elevation, combined with steel moment resisting and braced frames. The three conventional secondary



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Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
	Bracing	diagrid	A913 - Grade 65		sprayed + protective metal coating
	Columns	W14 x 16	A913 - Grade 65		sprayed
	Floor solutions			composite beams	sprayed

bracing systems increase the lateral stiffness of the tower; one is situated around the main elevator core in the centre and two along the core stairs in what is referred to as the building’s “fingers”. Due to its location south of the Bow River, one of the urban guidelines was to keep the building low enough to avoid shadowing the river in the September equinox period. This limitation of height affected its gravity load carrying system: in order to keep the depth of the floor beams low (below 485mm/19in.) a network of interior columns were added.

• ArcelorMittal Steel

It is Canada’s largest steel-framed building: a total of 39 000 tonnes of steel and 900 000 square-foot glass were used. ArcelorMittal supplied 4 900 tonnes of W14 x 16 x 145–730 sections, of which 3 320 tonnes were HISTAR® grade (ASTM A913–65).



• Sustainability

Creating a “green” building was a major goal for the design; its structure as well as its service life is oriented at reducing the building’s environmental footprint. As previously mentioned, due to the building’s form, prevailing winds are deflected, allowing for a lighter structure and thus reducing the material needed and size of the foundations.

Furthermore, the solar heat collected in the atrium is redistributed throughout the year by means of extraction during winter and heat exchange during summer, reducing the load on the mechanical systems. The large glazed areas also reduce the need for artificial lighting.





America

Facts:

Height: 546,2m (1792ft)

Number of Floors: 94

Gross floor area: 325 279m²

Building Function: Office

Structural material: Steel moment frame, with a reinforced high-strength concrete core

Completion: 2014

Architect: Skidmore, Owings & Merrill LLP

Structural Engineer: WSP Group; Schlaich Bergermann und Partner

General Contractor: Tishman Construction

ArcelorMittal Steel: 12 500 tonnes of steel, primarily W14 x 16 in A913 - Grade 65

One World Trade Center (New York, USA)



One World Trade Center was built on ground zero, the site of the former Twin Towers in lower Manhattan, and stands at a symbolic 1 792 feet (546,2m) tall including the spire. With its slender, tapering triangular form, it shimmers in the light and acknowledges the adjacent memorial, as a symbol of renewal and hope. The design of One World Trade Center is an innovative mix of architecture, safety and sustainability and expresses timeless simplicity and clarity of form. It was designed by renowned architect David Childs, of Skidmore, Owings and Merrill LLP, and it sets a new level of social responsibility in urban design by incorporating new architectural and environmental standards. Upon completion, One World Trade Center became North America's highest building and the third tallest in the world.

With a total usable floor area of over 325 000 m², the new tower is composed of offices, a grand public lobby, an observation deck, parking, and, broadcast and antennae facilities. Below ground level, the building also includes approximately 5 100m² of retail space and connects to an extensive transportation network.

• Steel Structure

The tower's structure is designed around a strong, redundant steel frame made of beams and columns, using both weld and bolt connections. This structural frame is built around a reinforced concrete core wall system at the centre of the tower, which acts as the main spine and provides support for gravitational loads as well as resistance to wind and seismic forces. Together, the structure lends substantial rigidity and redundancy to the overall building, while providing column-free interior spans for maximum office flexibility. The ductile perimeter moment frame twines around all vertical and sloped perimeters, forming a tube system.

Also, in New York City, skyscraper design is governed by wind loads; the chamfered corners of the floors form an aerodynamic and structurally efficient shape, which reduces exposure to wind loads and reduces the amount of structural steel needed.

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
 Bracing		concrete core + steel frame	A913 - Grade 65		sprayed
 Columns		internal columns	A913 - Grade 65		sprayed
Floor solutions				cellular beams	sprayed

Thus, the demand on the lateral system of the tower is also reduced.

- ArcelorMittal Steel

ArcelorMittal supplied both structural steel sections and plates for the tower's steel frame. The project features more than 12 500 tonnes of structural shapes, including Jumbo and Super Jumbo columns for the perimeter of the tower's base. These sections were produced by the company's mill at Differdange, Luxembourg and supplied to the project through efforts led by ArcelorMittal International North America. These beams and columns, mostly in the W14 x 16 family, are primarily made of HISTAR® Grade 65 (ASTM A913/913M).

- Safety and Fire Design

The new generation of life-safety standards, that incorporate redundant measures, was integrated subtly into the infrastructure. The structure incorporates enhanced fireproofing for the structural steel that exceeds current codes. Furthermore, the core is enclosed by up to three feet of reinforced concrete surrounded by a steel moment frame. There are dual interconnected fire standpipes and extra water storage to allow for high capacity sprinkler heads. If a standpipe is cut or broken, the interconnecting valve automatically cuts off water supply to that standpipe and redirects it to the other standpipe, ensuring that every other floor has sprinkler protection. In addition to a concrete-enclosed core, the tower includes a protected tenant-collection point on each floor and a separate stairwell for first responders. From an architectural perspective, all of these features are integrated into the design without negatively affecting the efficiency or constructability. The building incorporates highly advanced state-of-the-art life-safety systems that exceed the requirements of the New York City Building Code and that will lead the way for new high-rise building standards.

While the building does incorporate unprecedented security, it also promotes openness and accessibility for the five million annual visitors.





America

Facts:

Height: 221,1m (725ft)

Number of Floors: 53

Gross floor area: 111 000m²

Building Function: Office

Structural material: Steel columns and composite beams, supported by a steel-framed concrete core

Completion: 2017

Architect: Goettsch Partners

Structural Engineer: Magnusson Klemencic Associates

General Contractor: Clark Construction Group, LLC

ArcelorMittal Steel: 1 365 tonnes of W14 x 16 in A913 Grade 65 and 109 tonnes of W14x16 and W14 x 16 in A913 - Grade 70

150 North Riverside (Chicago, USA)

150 North Riverside, a building commissioned by Riverside Investment & Development, is a 53-storey office building with approximately 111 000m² of rentable space.

The building is designed by the architectural firm Goettsch Partners, with Magnusson Klemencic Associates serving as

Structural Engineer. It is located on one of the most prominent sites in the city: the south branch of the Chicago River.

The signature component of 150 North Riverside is the way the building appears to stand on one foot. With its vertical exterior columns seemingly terminating at level 8, the building has a significantly smaller base, when compared to the typical floors above. This special layout was required to accommodate the complexities of the building site. The project is located just meters away from the Chicago River on its east side and a rail yard that has been active for more than a century on its west side. The constraint of the railway, which made it impossible for the building's exterior columns to extend to solid ground, pushed the design team to develop what is known as a core-supported framing plan.

- Steel structure

In the core-supported plan, the building was essentially designed as a typical office building from level 8 through level 54 with an efficient, yet complex, transfer truss system that enables the weight of the building to be supported on its concrete core below level 8. The core is then supported on a 3m deep concrete mat that transfers the load to a collection of 16 rock-socketed caissons below (each with a 3-meter diameter).

Overall, the total savings in the weight of the structural frame for 150 North Riverside was 6%. When comparing the savings to the columns, where the high-yield A913 steels were most commonly employed, the weight savings was 18%.

In addition to the weight savings, the fabricator noted distinct benefits due to avoiding preheat requirements when welding A913 Grade 65 material. In particular, the building features cantilevered framing elements composed of thick sections for which it was necessary to connect by welding completely across their cross sections (this is known as a Complete Joint Penetration or CJP weld). ASTM A913 Grade 65 steel is approved by the American Welding Society to be



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Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
 Bracing		concrete core <i>with steel frame</i>	A913 - Grade 65/70		sprayed
 Columns		<i>internal columns</i>	A913 - Grade 65		sprayed
Floor solutions				composite beams	sprayed

connected via welding without having to heat the section before commencing the process. This characteristic is unique to this grade, and the major benefit of it is that the fabricators can save a lot of time and energy in its processes.

Lastly, the use of the high strength steel and larger section sizes eliminated virtually all cover plating requirements for the columns. Again, a major benefit to the fabrication of the project, removing the need to cover plate columns saves a significant amount of labour hours and cost on projects. Erection of steel at 150 North Riverside started in May 2015 and the project is already receiving a lot of attention. Completed in 2017, 150 North Riverside is a case study for state-of-the-art structural steel systems used in tall buildings.

• ArcelorMittal Steel

150 North Riverside is the first U.S. building built (and 3rd in North America) with A913 Grade 70 sections from Luxembourg. The building will be constructed using 2 530 tonnes of ASTM A913 Grades 65 and 70 column sections. ArcelorMittal is the only producer of the ASTM A913 specification, a material that is manufactured by ArcelorMittal Europe - Long Products' Differdange mill in Luxembourg.

The structural engineer, in cooperation with Zalk Josephs, the project's fabricator, determined that incorporating 70ksi steel sections into the design would lead to considerable savings in fabrication hours and cost. Prior to the material being specified on this project, A913 Grade 70 rolled shapes had been used on only two projects (both in Canada). ArcelorMittal International's North America sales team worked closely with ArcelorMittal Europe - Long Products to provide the fabricator with the A913 Grades 65 and 70 sections. The project not only incorporates these unique specifications, but its design also uses some of the world's largest structural shapes: W36 x 925 and W14 x 873 sections. Like the ASTM A913 specification, these are uniquely produced by ArcelorMittal Europe - Long Products' Differdange mill. Thanks to ArcelorMittal steel, there have been large savings in cost and weight of structural steel.

Overall, ArcelorMittal's products offered the most cost-effective approach to designing the structural system for this distinctive building. Their large sections and high strength material provided the only "off-the-shelf" solutions that could resist the building's heavy loads. A list of specific benefits - identified by the customer - that ArcelorMittal's steel brought to this project includes incorporating A913 Grade 70 material into the perimeter columns which enabled the use of 65 ksi rolled shapes at the base of the structure. This resulted in significant savings of fabrication and erection costs and a reduction in the structural weight of 550 tonnes.



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America

Facts:

Height: West Tower – 214,7m (704ft); East Tower – 196m (643ft)

Number of Floors: West Tower – 52; East Tower – 44

Gross floor area: West Tower – 128 113m²; East Tower – 112 477m²

Building Function: West Tower – Office; East Tower – Residential and, Office

Structural material: Steel frames, with concrete cores and composite floors

Completion: West Tower – 2010; East Tower – 2016

Architect: KPMB Architects; Adamson Associates; WZMH Architects (West Tower Only); ERA Architects (West Tower Only)

Structural Engineer: West Tower – Halcrow Yolles; East Tower – Entuitive

General Contractor: EllisDon Construction Services Inc.

ArcelorMittal Steel: 1 348 tonnes in A913 – Grade 70

Bay-Adelaide Centre (Toronto, Canada)

The Bay-Adelaide Centre is an office complex in the financial district of Toronto. Upon completion, the complex will consist of 3 towers, two of which are currently complete (East and West tower) and the final tower is planned (North tower). These three towers will eventually house 3,2 million square feet in commercial office space.

Conceived in 1987, the Bay-Adelaide Centre was originally intended as a two-tower complex, with public space. This concept consisted of a 275-meter South Tower, with 57 office floors and 4 penthouse levels and a smaller, 12-storey North Tower.

Over the next 20 years there were multiple unsuccessful attempts to revive the project. Finally the construction kicked off again in 2006 and in 2010 the 52-storey West Tower became Bay-Adelaide Centre's first completed tower. In 2013, the design of the 44-storey East Tower was restarted and it was completed in 2016. Following the final design and construction of the last phase (North Tower), the entire development is expected to be finished by 2020.

As with any multi-phase development, collaboration between the various teams involved (i.e. Structural Engineer, Architects, Developer, Contractors, Suppliers, etc.) and the use of the most innovative structural materials was crucial to arrive at this milestone, which required over 25 years of design and construction. As a result, this development features the world's first high-rise constructed using 485MPa (70ksi) steel.

- Steel Structure

Working on the design of an office complex for more than 25 years represents a unique challenge. The passage of time leads to the creation of multiple designs, implementation of multiple building codes, and exploration of multiple design and material standards. More importantly, the passing of time provides opportunities to incorporate new innovative materials and designs into the project.

Throughout the development of the design, the developers



challenged the design team to not only reduce the cost of the building, but to also reduce the loss in useable floor area due to the size of vertical elements such as columns and structural walls. Rising to the challenge, the structural engineers initiated discussions with material suppliers to understand the market and what constraints existed with respect to the strength and stiffness values of basic materials (i.e. steel and concrete).

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
 Bracing		concrete core with steel frame	A913 - Grade 65/70		sprayed
 Columns		internal columns	A913 - Grade 65		sprayed
Floor solutions				composite beams	sprayed

In the initial development, the structural design team looked at three potential options for the structural floor system, which required spans of 14,5 meters (47,5ft):

- 1) conventional reinforced concrete beam and slab construction,
- 2) post-tensioned concrete beam with reinforced concrete slab construction, or
- 3) structural steel with composite concrete on steel deck framing.

Initially, the post-tensioned concrete design, with 350mm by 1,350mm (14in. by 52in.) reinforced concrete columns, was selected. After nearly completing the working drawings and sub-grade construction based on the post-tensioned concrete design, the client decided to switch to structural steel with composite concrete and steel deck to achieve a quicker completion date. The steel scheme had to be developed so as to maintain the floor to floor heights, which had previously received municipal approval (maximum shadowing of Toronto City Hall).

This led the structural engineers to develop a composite truss scheme with composite concrete on steel deck (with studs). The new truss system required the mechanical system to be converted from conventional rectangular ducts to a pair of round ducts, concrete corbels to be constructed in the reinforced concrete shear wall core, and the perimeter columns to be adjusted from reinforced concrete to steel columns.

The final structural design selected in 2006 for the West Tower included the steel-framed composite floors systems, with steel columns and a concrete core. Through the success of the West Tower, structural steel framing system was chosen at the first step when the design of the East Tower began.



● ArcelorMittal Steel

Originally, a steel box section of 350 by 900mm (14in. by 36in.) was selected for the columns, as they had a smaller overall size compared to the reinforced concrete, and thus, had a minimum impact on the floor area. That being said, the structural engineers recognised that at more than 2 455 kilogrammes per meter (1 650 pounds per foot), this may not be the most economical solution. This was especially apparent given the new alternative in steel materials that had recently come onto the market, namely HISTAR® steel.

By 2006, when the West Tower was fully underway, HISTAR® steel was a common building material and Grade 50 and 65MPa were readily available. Ultimately, A913, Grade 65 steel was selected for the perimeter frame of the West Tower. Following the completion of the West Tower, the East Tower was designed from the beginning using HISTAR® material, as the Structural Engineer was now familiar with the product. Now available up to 485MPa (70ksi), using this alternative led to a saving of more than nine percent for the overall weight of structural steel in the building. Once construction began in 2013, Bay-Adelaide Centre East Tower became the first high-rise building in the world designed and constructed with ASTM A913 Grade 70 material.



Asia

Facts:

Height: 354,6m (1 163ft)
 Number of Floors: 54
 Gross floor area: 68 500m²
 Building Function: Office
 Structural material: Steel columns, outriggers and belt trusses, with a concrete core
 Completion: 2000
 Architect: NORR Limited
 Structural Engineer: Hyder Consulting; Leslie E. Robertson Associates
 General Contractor: Brookfield Multiplex
 ArcelorMittal Steel: 5 000 tonnes in HISTAR® 460

Emirates Tower One (Dubai, UAE)

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
 Bracing		concrete core + outriggers + belt trusses	HISTAR® 460		sprayed
 Columns					sprayed
Floor solutions				composite beams	sprayed

The Jumeirah Emirates Towers are one of the most distinctive skyscraper duos in the world, and were some of the first skyscrapers to be located along Sheikh Zayed Road in the financial centre of Dubai. Their completion in 2000 began a trend that has since seen the thoroughfare boom with construction activity and some of the tallest towers in the world.

On the periphery of the complex, a beautifully landscaped environment with lush vegetation and meandering pathways imparts the feeling of an oasis in an otherwise rigid urban landscape. The towers rise from a three-storey terraced podium, which houses a boutique retail mall, restaurants and cafés. At the base, intersecting planes of curvilinear and vertical elements frame grand staircases that lead to the podium levels. Clad in silver aluminium panels with both silver and copper reflective glass, the slim towers capture shifting sunlight throughout the day and enhance the bright city lights at nightfall.

Both towers feature equilateral cross sections with a triangular footprint that affords the structure more stability from the lateral forces of wind and earthquakes. In Emirate Tower One, steel transfers at level nine distribute loads from concrete-filled steel tubular columns into three triangular legs at the perimeter. Three additional transfer floors and a tuned mass damper at the peak provide for maximum stability. A steel and concrete hybrid solution throughout the tower allows for an abundance of column-free office space.

• Steel Structure and ArcelorMittal Steel

Building stability was provided by coupling the central reinforced concrete core to the perimeter columns using outrigger and belt trusses at plant room levels. The outrigger and belt trusses run



around the perimeter of the building and connect back to the core and are made with ArcelorMittal's high-strength HISTAR® 460 steel sections.



Asia

Facts:

Height: 207,8m (682ft)
 Number of Floors: 57
 Gross floor area: 1 79 600m²
 Building Function: Residential; Office
 Structural material: Steel
 Completion: 2015
 Architect: Broad Sustainable Building Co., Ltd
 Structural Engineer: Sky City Investment Co., LTD
 General Contractor: Sky City Investment Co., LTD
 ArcelorMittal Steel: 10 345 tonnes of prefabricated sections in HISTAR® 460

J57 Mini Sky City (Changsha, China)

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
	Bracing	pre-fabricated steel frames	HISTAR® 460		sprayed
	Columns				sprayed
Floor solutions				modular construction	sprayed



J57 Mini Sky City was built in a combined construction time of only 19 days, which is almost at a pace of 3 completed floors per day. The tower was developed by Broad Sustainable Building (BSB), which is a construction company specialising in prefabricated buildings. The tower was built with energy-efficient, factory-produced elements, using the BSB prefabricated construction method, which won the 2013 Council on Tall Buildings and Urban Habitat (CTBUH) Innovation Award. Using this construction method reduced the use of up to 15 000 concrete trucks, and avoided the release of dust associated with conventional Chinese construction processes. J57 includes 19 ten-meter tall atriums, 800 apartments and

office space for 4 000 people, which highlights the flexibility of the building use, even if it uses this construction method.

• Steel Structure

90% of the tower is made of manufactured block that are developed offsite. The block can simply be locked together and secured with high strength ribs and bolts. This provides adequate structure, increases the rate of construction, and simplifies the construction process. The flexibility of the spaces, strength of the structure, rate of construction, and the accuracy and precision of each module can only be achieved by using steel elements.

• ArcelorMittal Steel

ArcelorMittal provided 10 345 tonnes of HISTAR® steel sections from Differdange to build the frame of J57 Tower. The team of ArcelorMittal Europe – Long Products supplied was selected by BSB, due to the accuracy of the size and strength of their steel sections; this is the most crucial element to ensure that prefabricated buildings are built according to the construction schedule.

• Sustainability

According to the Architect of J57, Xian Min, in addition to significantly reducing the amount of concrete required and eliminating the dust on the construction site, this construction method is so energy efficient that it will save 12 000 metric tonnes of CO₂ emissions compared to conventional buildings with a similar function. Furthermore, another reason that ArcelorMittal was specifically selected was the fact that the majority of the steel from Differdange has derived from recycled scrap steel elements.



Asia

Facts:

Height: 106m (348ft)
 Number of Floors: 23
 Gross floor area: 103 308m²
 Building Function: Office
 Structural material: Composite columns, with steel mega trusses
 Completion: 2006
 Architect: Skidmore, Owings & Merrill LLP
 Structural Engineer: Skidmore, Owings & Merrill LLP
 General Contractor: China State Construction Engineering Corporation
 ArcelorMittal Steel: 4 500 tonnes in HISTAR® 420/355

Poly Corporation Headquarters (Beijing, China)

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
 Bracing Columns		columns + mega truss	HISTAR® 420/355		sprayed
					sprayed
Floor solutions				composite beams	sprayed

Poly Corporation Headquarters, located in Beijing, houses the various subsidiaries of the China Poly Group Corporation. The building consists of 24 unique, L-shaped office floors, which are built around a 90-meter tall atrium. The atrium is enclosed by the world's largest cable-net supported glass wall.

Upon completion in 2006, this interior atrium became the tallest lobby in the world, completely free of any columns.

• Steel Structure and ArcelorMittal Steel

The distinctive atrium of the Poly Corporation Headquarters is made possible by the unique façade support system, developed by Skidmore, Owings and Merrill LLP, known as the Rocker. The "Rocker" allows the cable-stayed system, which uses two large, parallel-strand bridge cables in diagonal fold lines, to accommodate any effects of earthquakes and heavy winds and assist in the suspension of the 8-storey museum structure within the atrium. This entire system is supported by the mega truss at the top of the tower.

Furthermore, the building was the first building designed and erected with ASTM A913 (HISTAR®) grades in China; before completion of this tower, the highest grade of steel specified in building applications in China was 345MPa. ASTM A913/Gr. 450 (65ksi) was a too big jump from 345MPa steel for the committee of experts. They approved ASTM A913 up to 420MPa (60ksi) after welding tests without preheating at room temperature and mechanical tests on Jumbo sections were performed at the Welding Research Institute in Beijing (CRIBC) to convince the committee of experts of the excellent behaviour of HISTAR® steel. Thus, all the columns of the building as well as the mega truss on top, which supports the façade of glass, were designed in 420MPa.

• Fire resistance

Composite columns were used in the structure, which provides acceptable fire resistance.



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Asia

Facts:

Height: 494,3m (1 622ft)

Number of Floors: 101

Gross floor area: 381 600m²

Building Function: Hotel; Office

Structural material: Steel outriggers and belt trusses, with composite megacolumns and a concrete core

Completion: 2008

Architect: Kohn Pedersen Fox Associates; Mori Building; Irie Miyake Architects and Engineers

Structural Engineer: Leslie E. Robertson Associates

General Contractor: China State Construction Engineering Corporation; Shanghai Construction Group

ArcelorMittal Steel: 17 000 tonnes in HISTAR® 355

Shanghai World Financial Center (Shanghai, China)

The Shanghai World Financial Center, located in Shanghai's Pudong District, is a symbol of commerce and culture that speaks to the city's emergence as a global capital. This landmark is comprised of 101 storeys and reaches almost 500 meters above the city skyline. Its appearance combines two intersecting arcs and a square prism – forms representing the ancient Chinese symbols for earth and sky.

Upon completion in 2008, it became the tallest building in China and second tallest in Asia (second only to TAIPEI 101). It also received the CTBUH 2008 Best Tall Building Asia & Australasia and Best Tall Building Worldwide award.

The tower is a virtual city within a city; it houses a mix of office and retail functions, as well as a hotel on the 79th to 93rd floors. Occupying the tower's uppermost floors the Shanghai World Financial Center Sky Arena offers visitors aerial views of downtown Shanghai and the winding river below as well as access to the Sky Walk on the 100th-floor sky bridge. Sky lobbies are located at the first two levels where outriggers are applied (28th and 29th, 52nd and 53rd). Furthermore, a museum and sophisticated urban retail spaces are located at the base of the tower. The Shanghai World Financial Center combines functionality and smart construction.

• Steel Structure

Originally conceived in 1993, the project had to be put on hold during the conception of the foundation, due to the Asian financial crisis. Afterwards, it was requested to redesign the structure to be lighter and resistant to higher wind loads while keeping the existing foundations. High-strength steel was seen as the obvious choice for the main structure of the building to reduce its weight. The entire structure consists of three parallel and interacting systems:

1. the mega-structure consisting of the major structural columns, the major diagonals, and the belt trusses to form a braced frame;
2. the concrete walls of the services core; and
3. the outrigger trusses which interact between the concrete walls and the megacolumns.



The diagonals of the mega-structure are formed from welded structural steel boxes. These steel boxes are filled with concrete, providing increased stiffness, non-linear structural behaviour, and structural damping. The columns of the mega-structure are of composite structural steel and reinforced concrete, one at each of the four corners of the rectilinear base and six as the floor plan morphs into a six-sided form at higher levels.

Building systems	Steel Solutions	ArcelorMittal Solutions			Fire resistance
		Heavies	High strength steel	Finished beams	
	Bracing	mega-composite columns	HISTAR® 355		sprayed
	Columns	concrete core + outriggers + belt trusses			sprayed
Floor solutions				composite beams	sprayed



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• ArcelorMittal Steel

ArcelorMittal supplied 17 000 tonnes of high-strength steel HISTAR® 355 sections, which were used in the outriggers trusses, belt trusses and megacolumns.

• Robustness, Redundancy and Safety

The structural system is designed to accept the simultaneous loss of a number of structural elements. For example, at any level the small perimeter columns are able to be accidentally removed without the disproportionate collapse of the surrounding structure. Additionally, members of the perimeter belt trusses can be removed without disproportionate collapse. Similarly, accidental removal can be accepted for the steelwork within the services core.

In regard to fire safety, the exits, fire and smoke propagation were studied using a service approach (which guaranteed a level of safety in excess of legal requirements) with computer simulations that led to some modifications in design (i.e. width of stairs, location of exits) to improve building evacuation times.

Being a mixed steel and concrete structure, it was possible to ensure optimal fire protection and impact resistance for the entire steel structure of Shanghai World Financial Center.



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14. ArcelorMittal services

- Technical Advisory

ArcelorMittal provides you with technical advice to optimise the use of our products and solutions in your projects for free. The technical advice covers basic and elaborated concepts, counterproposals, predesigned of structural elements, construction details, assistance in value engineering, surface protection advisory, metallurgy, welding procedure and fire protection. Our specialists are ready to support your initiatives all over the world.

To facilitate the design of your projects, we also offer software and technical documentation that you can consult and download for free from our website:

sections.arcelormittal.com

Contact us at: **sections.tecom@arcelormittal.com**

- Beam Finishing Centre

As a complement to the technical capacities of its partners, ArcelorMittal is equipped with high-performance finishing tools and can provide a wide range of fabrication services, including the following:

- drilling of materials up to 140mm in thickness
- flame cutting
- T cut-outs
- notching
- cambering
- curving
- straightening
- cold sawing to exact length
- welding and fitting of studs
- shot blasting
- surface treatment

Contact us at: **cs.eurostructures@arcelormittal.com**

- Sales Network

Our sales network works closely with all ArcelorMittal mills. We provide you with a seamless interface with mills offering world-class products and services throughout the globe. You can find the complete list of our agencies on the next two pages and on our website.

- R&D

With 1 400 full-time researchers employed across the globe, our research centers are at the heart of developing new steel products and solutions. To keep us at the forefront of innovation in steelmaking and mining technology, ArcelorMittal has 12 research centers located in Europe and North America.

In 2016 we invested \$239 million in R&D, with ≈40% of that money targeted on processes, ≈55% on products and solutions and 5% on exploratory research.

- ArcelorMittal in Construction

ArcelorMittal has also a website dedicated to a full range of products for the construction market (structures, façades, roofing, etc.): **constructalia.arcelormittal.com**

ArcelorMittal International

Headquarters

LUXEMBOURG

ArcelorMittal International Luxembourg
24, Boulevard d'Avranches
LU-1660 Luxembourg
T : +352 4792 1
international@arcelormittal.com

Sales agencies

AFRICA

ArcelorMittal International Africa
Casaneashore park
Shore 14- RDC - Plateau N° 2
1100, Bd Al Qods - Sidi Maarouf
MA- Casablanca
T : +212 522 74 96 00
ami-africa@arcelormittal.com

AZERBAIJAN

Azerbaijan Representative Office
AGA Center 13th floor Office # 13/5
Khojali Avn. 55 Baku
AZ-1025
T : +99 412 464 4144
ami-azerbaijan@arcelormittal.com

BRAZIL

ArcelorMittal International Brasil
Alameda Santos 700, 12° andar, Ceiqueira Cesar
CEP 01418-100 SP - São Paulo
T : +55 11 36 38 69 04
ana.hofman@arcelormittal.com.br

CHILE

ArcelorMittal International Chile
Av. Providencia, 1208 - Oficina 1805
Ed. Pamplona/Providencia/Santiago
T : +56 2 2248 3391
ami-chile@arcelormittal.com

CHINA (People's Republic of)

ArcelorMittal International Shanghai
Unit A2 13F Time Square, 500 Zhangyang Road
Pudong, CN-Shanghai 200122
T : +86 21 58368200
ami-china@arcelormittal.com

ArcelorMittal International Beijing
Rm.1702, Tower A, Beijing Vantone
Center, No. 6 Chaowai Street
Chaoyang District, CN-Beijing 100020
T : +8610 5907 0503
ami-beijing@arcelormittal.com

ArcelorMittal International Urumqi
8F China Development Bank tower
Fountain Plaza, No 333 Zhang Shang Road
CN-Urumqi, XinJiang
T : +86 991 23396 02
ami-china@arcelorm.com

COLOMBIA

ArcelorMittal International Colombia
Calle 90 N° 12 # 45 Of. 605 - Bogotá
T : +57 1 623 40 22
ami-colombia@arcelormittal.com

ECUADOR

ArcelorMittal International Ecuador
Calle del Establo y Av. De los Conquistadores
Edif. Cemacol, Ofic. F - Cumbayá
CP 170902 - Quito
T : +593 2 289 2161 / 2162
ami-ecuador@arcelormittal.com

EGYPT

ArcelorMittal International Egypt Representative Office
Unit No 96, Floor No 9, 2 Aly Rashed Street
Star Capital Tower 2, Heliopolis West, Cairo 11771
T : +20 2 24800868
ami-egypt@arcelormittal.com

INDIA

ArcelorMittal International Mumbai
Unit 202 A, Dosti Pinnacle
Plot E-7, Road No.: 22 - Wagle Estate
IN-Thane (West) 400604 - Maharsahtra
T : +91 22 424 895 00
ami-india@arcelormittal.com
vivek.Sinha@arcelormittal.com

ArcelorMittal International New Delhi
Plaza M-6, 6th Floor,
Jasola District Centre
IN-New Delhi - 110 025
T : +91 11 46759409
ami-delhi@arcelormittal.com

KOREA

ArcelorMittal International Korea
6F Jinnex Lakeview, 65-2
Bangi-Dong, Songpa-Gu - Seoul
Postal code 138-828
T : 82-2-6200-6571
ami-korea@arcelormittal.com

MEXICO

ArcelorMittal International Mexico
Calle Privada de los Industriales 110 A
8° Piso Desp. 801 802
Col. Industrial Benito Juarez
Queretaro, Qro.
MX-76100 MEXICO
T : +52 442 218 6872
ami-mexico@arcelormittal.com

NIGERIA

ArcelorMittal Projects Nigeria
1B Adebayo Doherty Street
Off Admiralty Way, Lekki Ph1, Lagos
T : +234 1 277 0802
ami-nigeria@arcelormittal.com

PERU

ArcelorMittal International Peru
Calle Tomas Ramsey N°930
Oficina 1105 - Magdalena del Mar - Lima 17
T : +51 1 421 43 64
ami-peru@arcelormittal.com

RUSSIA

ArcelorMittal International Moscow
Bolshaya Ordynka Street 44, building 4
RU-119 017 Moscow
T : +7 495 721 15 51
F : +7 495 721 15 55
ami-moscow@arcelormittal.com

SENEGAL

ArcelorMittal International Senegal
AMDSI Sénégal SARL
Dakar, Stèle Mermoz - Imm. SAPHIR
SN-B.P.25377 Dakar Fann
T : +221 33 859 76 30
ami-senegal@arcelormittal.com

SINGAPORE

ArcelorMittal International Singapore
08-00 Anson House - 72, Anson Road
SG-079911 Singapore
T : +65 67339033
ami-singapore@arcelormittal.com

SOUTH AFRICA

ArcelorMittal International South Africa
Block C, Stoneridge Office Park
8 Greenstone Place - Greenstone 1609
REPUBLIC OF SOUTH AFRICA
T : +27 (0)11 201 2045 (direct)

TAIWAN

ArcelorMittal International Taiwan
8F A3; n°502 Jiou Ru 1st Rd.
San Min Dist., Kaohsiung - TAIWAN ROC
T : +886 7 390 04 25
ami-taiwan@arcelormittal.com

TURKEY

ArcelorMittal International Celik Dis Ticaret A.S.
Esentepe Mah. Büyükdere Cad.
Metrocity A Blok 171/A Kat:16 - Şişli
TR-34394 Istanbul
T : +90 212 317 49 00
ami-turkey@arcelormittal.com

UNITED ARAB EMIRATES

ArcelorMittal International FZE
Plot S40703
South Zone 4
AE-PO Box 262098 - Dubai
T : +971 4 803 5900
ami-dubai@arcelormittal.com

UNITED STATES OF AMERICA

ArcelorMittal International North America
1 South Dearborn, 13th floor
US-Chicago, IL, 60603
T : +1 312 899 3500
ami-america@arcelormittal.com

UKRAINE

ArcelorMittal International Ukraine
20 Velyka Zhytomirskya Str.
UK-01025 Kiev
T : +38 044 201 4912
ami.ukraine@arcelormittal.com

VENEZUELA

ArcelorMittal International Venezuela
Edificio Keope, Avenida Vera Cruz, Piso 4, Oficina 45 A
VE-Las Mercedes/Caracas 1060 A
T : +58 212 993 46 35 / 993 81 01 / 991 41 97
ami-venezuela@arcelormittal.com

VIETNAM

ArcelorMittal International Vietnam
D35, 40 Ba Huyen Thanh Quan, Ward 6
VN-Dist. 3, Ho Chi Minh City
T : + 84 8 39307248
ami-vietnam@arcelormittal.com

ArcelorMittal Commercial Sections

Headquarters

LUXEMBOURG

ArcelorMittal Commercial Sections
66, rue de Luxembourg
LU-4221 Esch sur Alzette
T : +352 5313 3010
F : +352 5313 2799
sections.tecom@arcelormittal.com

SPAIN

ArcelorMittal Comercial Perfiles España S.L.
Ctr. Toledo. Km. 9,200
ES-28021 Madrid
T : +34 91 797 23 00

Sales agencies

AUSTRIA

ArcelorMittal Commercial Sections Austria GmbH
Vogelweiderstraße 66
AT-5020 Salzburg
T : +43 662 88 67 44
sections.austria@arcelormittal.com

BELGIUM + THE NETHERLANDS

ArcelorMittal Commercial Netherlands B.V.
Eemhavenweg 70
NL-3089 KH Rotterdam
T : +31 (0)10 487 09 22
sections.benelux@arcelormittal.com

BOSNIA HERZEGOWINA

ArcelorMittal Zenica
Bulevar kralja Tvrtka, no. 17
BA-72000 Zenica
T : +384 32 467 268

BULGARIA

ArcelorMittal Commercial Long Bulgaria
26 Antim I str, office 6
BG-1303 Sofia
T : +359 287 09 028
georgi.genov@arcelormittal.com

CZECH REPUBLIC

ArcelorMittal Commercial Long Czech s.r.o.
Vratimovska 689
CZ-70702 Ostrava Kunčice
T : +420 59 568 6040

DENMARK

ArcelorMittal Commercial Long Denmark A/S
Artillerivej 90, stuen
DK-2300 Copenhagen S
T : +45 33 74 17 11
sections.denmark@arcelormittal.com

ESTONIA

ArcelorMittal Commercial Baltics
Tatari 6
EE-10116 Tallinn
T : +372 64 14 338
erik.saar@arcelormittal.com

FINLAND

ArcelorMittal Commercial Long Finland OY
Topeliuksenkatu 15
FI-00250 Helsinki
T : +358 9 74 222 460
sections.finland@arcelormittal.com

FRANCE

ArcelorMittal Commercial Sections France S.A.
Domaine de Pelus
4, rue Graham Bell
FR-33700 Merignac
T : +33 5 57 92 09 10
sections.france@arcelormittal.com

GERMANY

ArcelorMittal Commercial Long Deutschland GmbH
Gereonstraße 58
50670 Köln
T : +49 221 572 90
sections.deutschland@arcelormittal.com

Augustenstraße 7

DE-70178 Stuttgart
T : +49 711 489 80 0
sections.deutschland@arcelormittal.com

GREECE AND CYPRUS

ArcelorMittal Commercial FCSE Greece Ltd.
Zeppou 51
GR-16675 Glyfada Athens
T : +30 210 960 42 79
sections.greece@arcelormittal.com

ICELAND

Gudmundur Arason EHF
Skútuvogur 4
IS-104 Reykjavik
T : +354 568 6844
Kari@ga.is

ITALY

ArcelorMittal Commercial Sections Italia Srl
Strada Torino 43 c/o
Europalace Center
IT -10043 Orbassano (TO)
T : +39 011 906 3931
sections.italia@arcelormittal.com

NORWAY

ArcelorMittal Commercial Long Norway A/S
Holmenveien 20,
NO-0374 Oslo
T : +47 22 83 78 20
sections.norway@arcelormittal.com

POLAND

ArcelorMittal Commercial Long Poland
Al. Pilsudskiego 92
PL-41 308 Dabrowa Gornicza
T : +48 32 776 67 27
sections.poland@arcelormittal.com

ROMANIA

ArcelorMittal Commercial Long Romania S.R.L.
7 9 Intrarea Tudor Stefan
2nd Floor, AP. 4
Sector 1, 011 655 Bucharest
T : +40 31 405 47 93
sections.romania@arcelormittal.com

SWEDEN

ArcelorMittal Commercial Sweden A.B.
Birger Jarlgatan 4 A
SE-111 45 Stockholm
T : +46 8 534 80 94 0
sections.sweden@arcelormittal.com

SWITZERLAND

ArcelorMittal Commercial Schweiz AG
Industriestrasse 19
CH-8112 Otelfingen
T : +41 56 437 16 70
sections.switzerland@arcelormittal.com

TURKEY

ArcelorMittal CL Çelik Deş Ticaret A.Ş.
Esentepe Mah. Büyükdere Cad.
Metrocity A Blok 171/A Kat:16 - Şişli
TR-34394 Istanbul
T : +90 212 317 4980
oktay.atcali@arcelormittal.com

UNITED KINGDOM

ArcelorMittal Commercial Long UK Ltd
3rd Floor, Fore 2
Huskisson Way, Shirley
Solihull B90 4SS
GREAT BRITAIN
T : +44 121 713 6600
sections.uk@arcelormittal.com

Services

ArcelorMittal Europe - Long Products

Technical Advisory
66, rue de Luxembourg
L-4221 Esch-sur-Alzette
Tel.: + 352 5313 3010
sections.tecom@arcelormittal.com

Eurostructures Beam Finishing Centre

Z.I. Gadderscheier
L-4984 Sanem
Tel.: +352 5313 3057
cs.eurostructures@arcelormittal.com

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