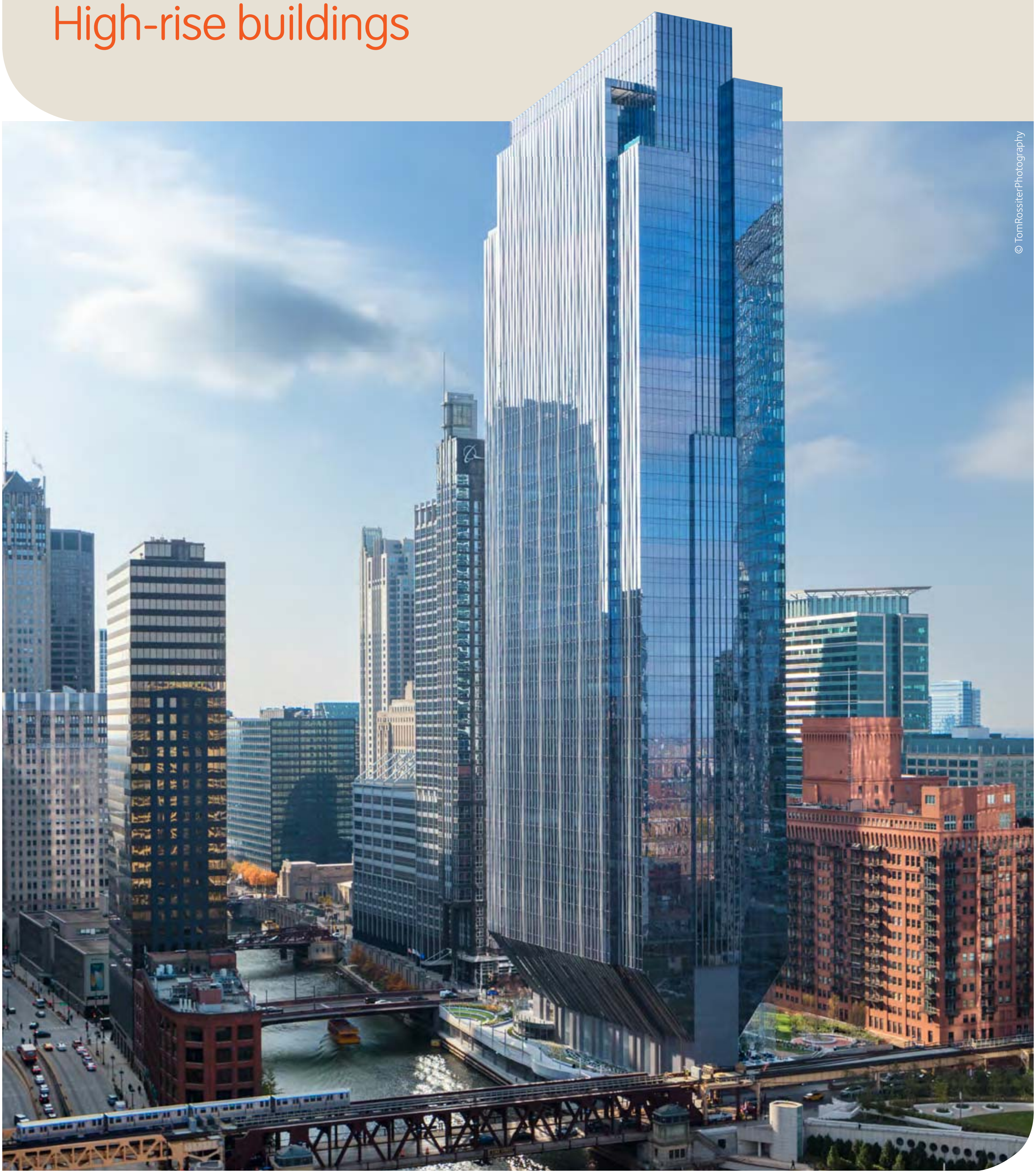
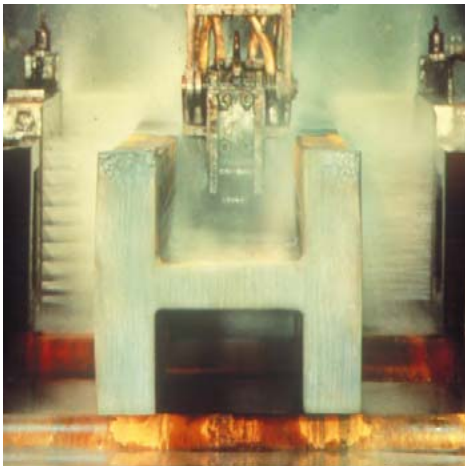
ArcelorMittal Europe - Long Products
Sections and Merchant Bars

# High-rise buildings



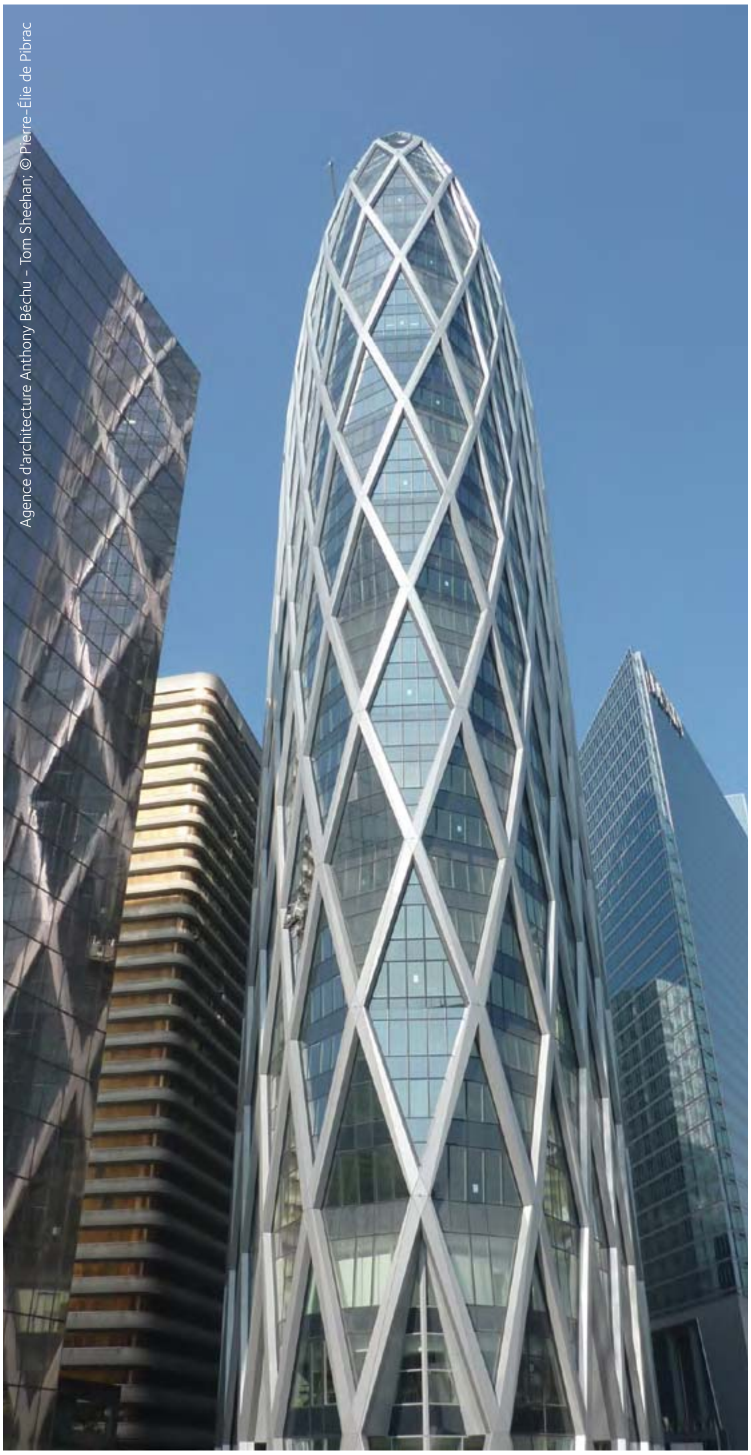
Electric arc furnace

Rolling process



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


Shanghai World Financial Center, Shanghai, China




D2 Tower, Paris, France

Dear Reader,

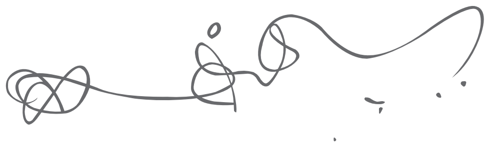
We are delighted to present to you the high-rise buildings brochure. It features suggestions and advice about the optimal use of hot-rolled shapes in tall buildings.

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.sales@arcelormittal.com.

Kind regards,



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,

Antony Wood

CTBUH Executive Director

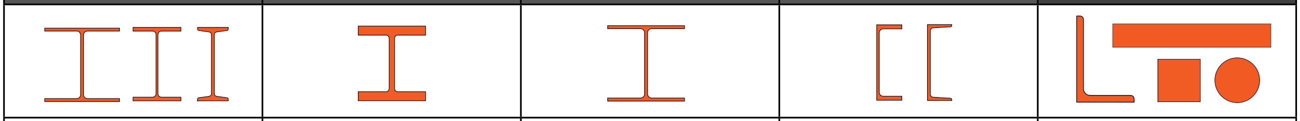
# Table of contents



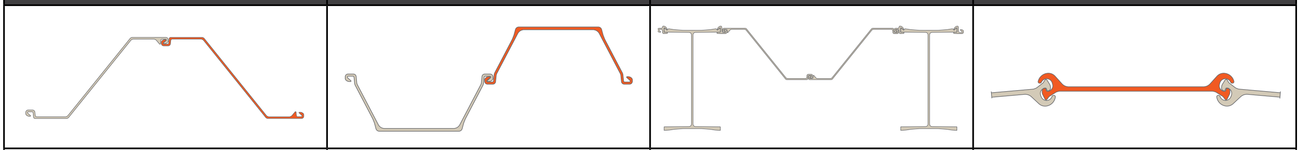
The term "high-rise building" refers in this brochure to buildings with a minimum height (height understood as height to tip) of about 150m including super tall buildings (300 metres high) and mega tall buildings (600 metres high). The number of floors is understood as the number of floors above ground.

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

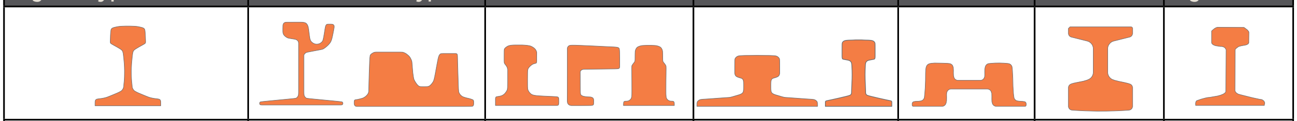
## Sections and Merchant Bars

| Sections | | | | Merchant Bars |
|---|---|---|---|---|
| Beams | Columns | Bearing Piles | Channels | Web Tailor-Made Shapes |
|  | | | | |
| HE 100 - 1000<br>HL 920 - 1100 / HLZ<br>IPE 80 - 750<br>UB 127 x 76 - 1100 x 400<br>W 6 x 4 - 44 x 16<br>GOST 10B1 -50B3<br>IPN 80 - 600<br>J 76 - 152<br>S 3 - 24 | HD 260 - 400<br>UC 152 x 152 - 356 x 406<br>W 4 x 4 .. 14 x 16<br>GOST 20K1 - 40K5 | HP 200 - 400<br>UBP 203 x 203-356 x 368<br>HP 8 - 14 | UPE 80 - 400<br>PFC 100 - 430<br>UPN 50 - 400<br>C 8 - 12<br>MC 6 - 18<br>GOST 8Y - 30Y | L 45 x 45 - 300 x 300<br>L 100 x 65 - 250 x 90<br>L 2 - 12<br>SQ 90 x 90 - 160 x 160<br>R 90 - 150<br>HTM 610 - 1016<br>WTM 24 - 40 |

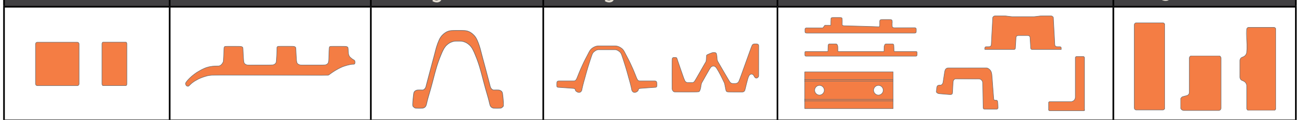
## Sheet Piles

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

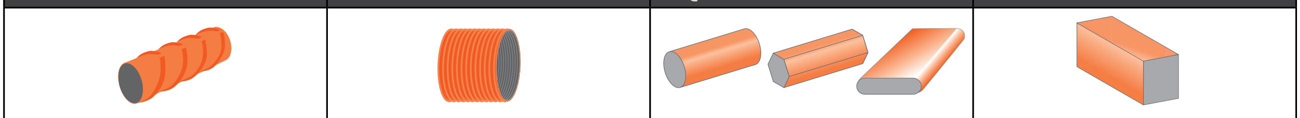
## Rails

| 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

| | | Mining | | Other special sections | |
|---|---|---|---|---|---|
| Cathode bars | Track Shoes | Mining sections | Mining Accessories | Rail Accessories | Flanges |
|  | | | | | |
| Square<br>Rectangular | Single grouser<br>Double grousers<br>Triple grousers | TH40 - TH44<br>V25 - V36 | GTHN 29<br>J21 - J36<br>A36 CLAMP<br>E74VS | Ribbed baseplates,<br>Tie plates standard,<br>Tie plates Type Pandrol,<br>Guiding bar for Metro<br>Cross hearts<br>Fishplates | Rectangular<br>L shape<br>T shape |

## Bars and Rods

| Rebars | Wire Rod | SBQ | Semis |
|---|---|---|---|
|  | | | |
| Bars : ø 8 - 40 mm<br>Coils : ø 6 - 25 mm | Round : ø 5 - 52 mm<br>Hexagon : ø 14,3 - 42,5 mm<br><br>Mesh, Low and High carbon steels,<br>Cold heading, Welding,<br>Free-cutting, Spring,<br>Steel cord, Bearing | Round : ø 15 - 170 mm<br>Hexagon : ø 14,3 - 70,4 mm<br>Round corner square : □ 63 - 200 mm² | Round billets: Ø 180 - 310 mm<br>Square billets : □ 120² - 320² mm<br>Rectangular billets: ▭ 155 x 270<br>190 x 220; 240 x 270; 265 x 385;<br>280 x 300; 280 x 310; 280 x 400 |

Visit us on:

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Partitions: **ds.arcelormittal.com/construction**
Sheet piles and Bearing piles: **sheetpiling.arcelormittal.com**
All products for construction: **constructalia.arcelormittal.com**
The intelligent construction choice: **steligence.arcelormittal.com**

# 1. About ArcelorMittal

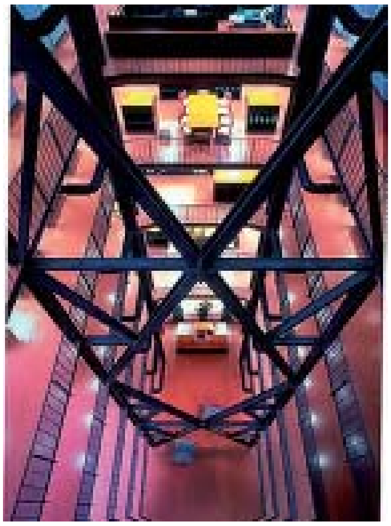
## ArcelorMittal

ArcelorMittal is the world's leading steel and mining company, with a presence in 60 countries and an industrial footprint in 18 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.

Electric arc furnace, Luxembourg

## ArcelorMittal Europe – Long Products

Long Products operates at 29 production 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

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 Steligence® Fabrication Centre 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.sales@arcelormittal.com**

*"The competition for material selection between steel, concrete, timber and other materials is as fierce as ever. Key criteria in the choice of material include element size, fire rating / the need for supplementary material, sustainability, vibration characteristics, availability, shape opportunity, as well as cost, including predictability of costs. We have found that the innovations brought to market by ArcelorMittal and steel's inherent characteristics enable the material to remain competitive and most often the material of choice. In particular, the increase in available strength and reduction in preheat requirements developed by ArcelorMittal and embodied in the A913 / HISTAR® specifications has made the selection of steel an even easier decision."*

**Barry Charnish, P.Eng.**
Principal
ENTUITIVE
Toronto, Canada

# 2. Advantages of steel

The main advantages of steel are:
- **stiffness, ductility and resistance**
- **prefabrication and speed of construction**
- **flexibility**
- **sustainability (reusability & indefinitely recyclable)**
- **reliability**


**Figure 2.1: Tour D2, half of the weight is carried by exterior steel diagrid, Courbevoie, France**

- **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
- 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 (≈ 25 floors), Buckling length = 4m

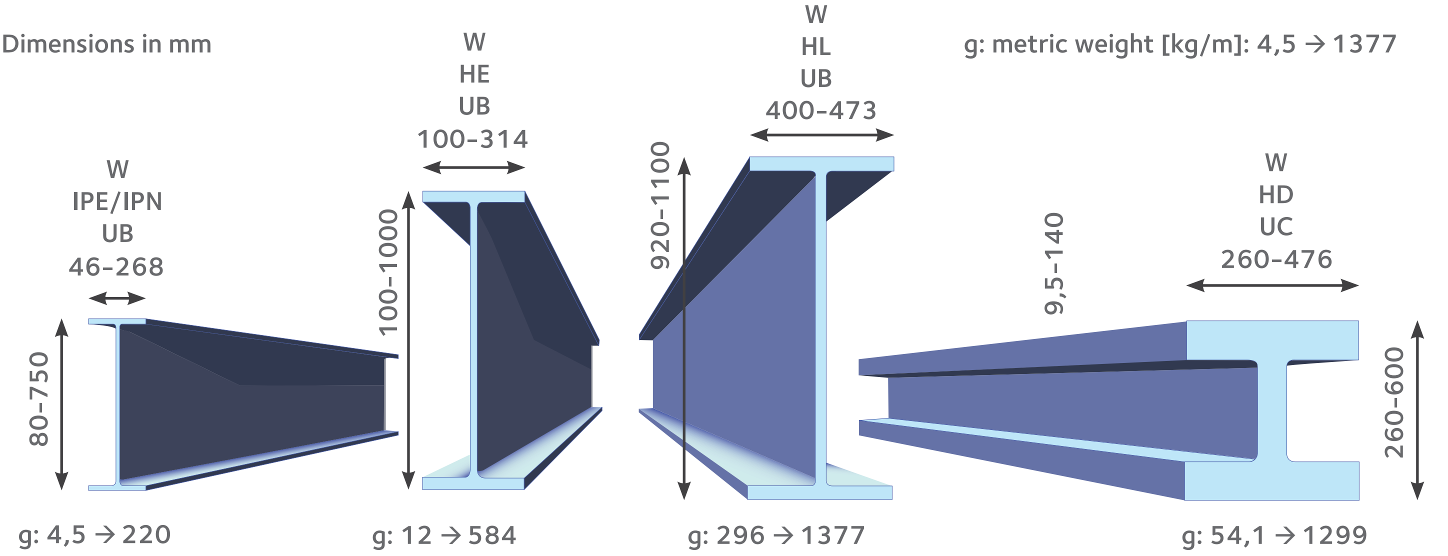
| Class / Grade | Concrete C60 | HISTAR® 460 |
|---|---|---|
| Dimensions / Section | 650 x 650mm | HD 400 x 314 |
| Weight | 1060kg/m | 314kg/m |
| Column area | 0,42m$^2$ | 0,04m$^2$ |

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


**Figure 2.2: 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




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 2.3: 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 1 500 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 $CO_2$ emissions during construction phase by as much as 30%.

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

Figure 2.4: 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.

Figure 3.1 HISTAR® in Shanghai World Financial Center

# 3. HISTAR® grades for high-rise buildings

- **Conventional steel**

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

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 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, Grade 70 steels and grade, 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 structured steels with excellent weldability and good toughness values.

An outstanding feature of these high strength steels is their low-carbon equivalent, 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 3.2: HISTAR® advantages

## 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 |
| 550 | | | | Grade 80* | | | |

*Sept. 2019: expected in A913

## Dimensions standards for HISTAR® grades

| Class / Grade | European Standards | British Standards | American Standards |
|---|---|---|---|
| Parallel flange beams | IPE 550*, IPE 600 - IPE 750 | UB 610 x 229 – UB 838 x 292 | W 24 - W 36 |
| Wide flange beams | HE 260* - HE 280*, 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 368 | HP 10 - HP 14 |

*on request

### — Benefits of HISTAR®

The yield strengths of HISTAR® grades are superior across the entire range of material thickness compared to standard structural steels (Table 3.3). 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 3.1). 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 result is 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 $CO_2$ 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.

HISTAR® steel always enables economical solutions.

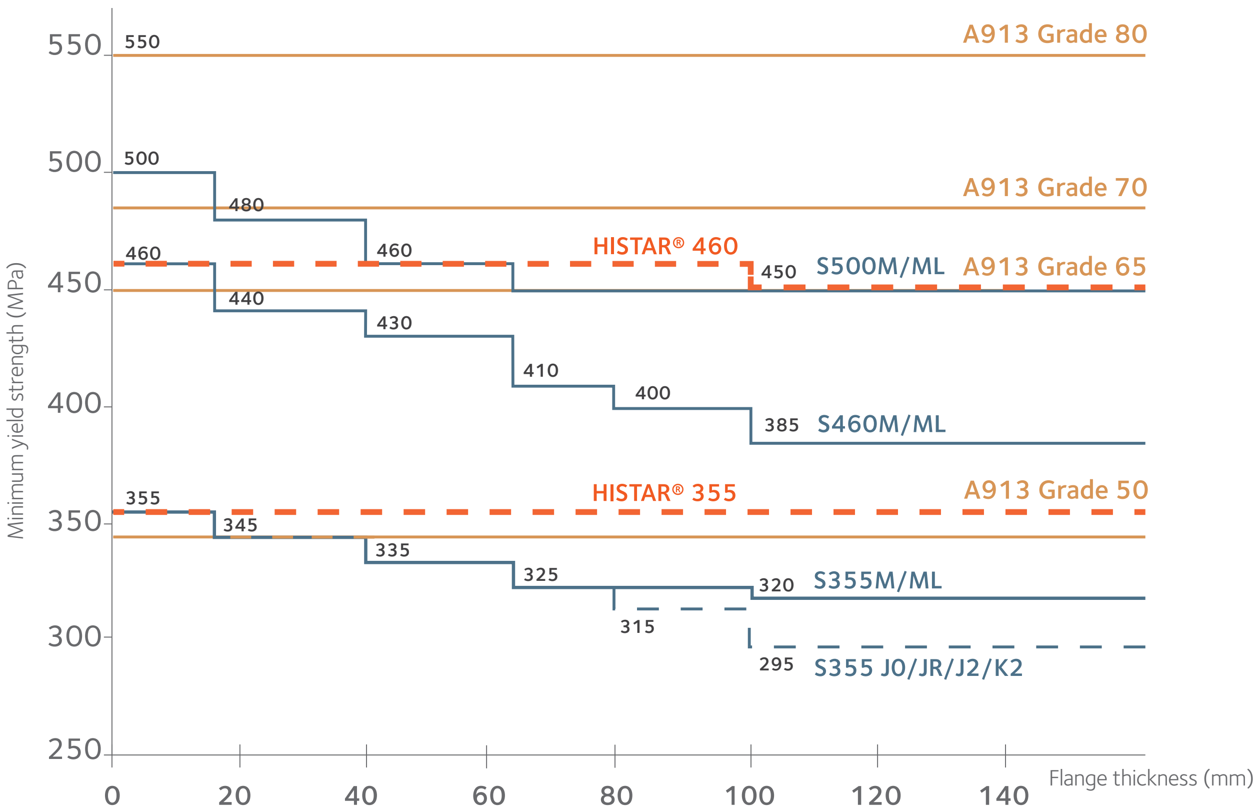



Figure 3.3: Minimum yield strength according to material thickness

*"LeJeune Steel Company has been using A913 Grade 65 for W-shapes since the late 1990s. This steel brings value to projects in the form of improved fabrication and erection efficiencies, as well as reduced material and cost."*

**Victor Shneur, P.E.**

Chief Engineer

LEJEUNE STEEL COMPANY

Minneapolis, USA

## — 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:

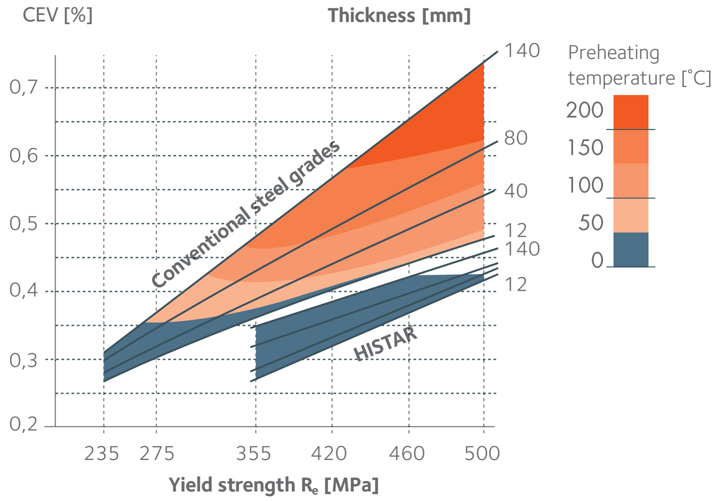
- Heat input Q ranges 10-60kJ/cm
- Temperature of the product is > 5°C
- Electrodes with low carbon equivalent and low hydrogen content, typically with a diffusible hydrogen content ≤ H10 for HISTAR® 355 and ≤H5 for HISTAR® 460, are used. The welding of a Jumbo beam of 140mm flange thickness in HISTAR® 460 was welded without (see photo below) 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.

For the American steel grades ASTM A913 Gr 50, 65 and 70, minimum preheat temperature to use it as prequalified steel grades are given in Table 3.3 of AWS D1.1:2015. Preheating can be avoided for Grade 50 and 65 when maximum H8 filler metals are used. For Grade 70, a minimum preheat temperature as defined in the table 3.3 shall be applied according to the material thickness.

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

- ambient T° < 5°C
- high hydrogen content
- high restraint conditions (leading, for example, to high tri-axial shrinkage stresses)
- low heat input
- special applications.




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

**Figure 3.4: Preheating temperatures for conventional structural steel grades and HISTAR® grades.**

No preheat conditions* for HISTAR® grades:

- For $R_e$ < 460: $H_2$ ≤ 10ml /100g
- For $R_e$ ≥ 460: $H_2$ ≤ 5ml /100g
- Q > 10 kJ/cm

**Figure 3.5: Welding of HISTAR® structural steel grades without preheating* (CJP_Complete Joint Penetration_ splice of HD400 x 1299 in HISTAR® 460)**

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

# 4. 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 4.1 shows how a typical 185m high office building of 50 storeys, with a reinforced concrete core, can use HISTAR® columns for most 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 here.

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 4.2).

- **Jumbos and SuperJumbos**

To accommodate additional loads, Jumbo and Super Jumbo sections can be used. Jumbos (G > 500 kg/m) and Super Jumbos (G > 1000kg/m) are very heavy rolled wide flange sections, due to a significant increase in flange thickness. The illustration here 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). ArcelorMittal has the record of the heaviest and the thickest rolled shape in the world (see page 9). When loads are too heavy for the strongest single Super Jumbo such as in the first three floors of the example (Figure 4.2), optimised section such as **HD Box** can be used (Figure 4.3).

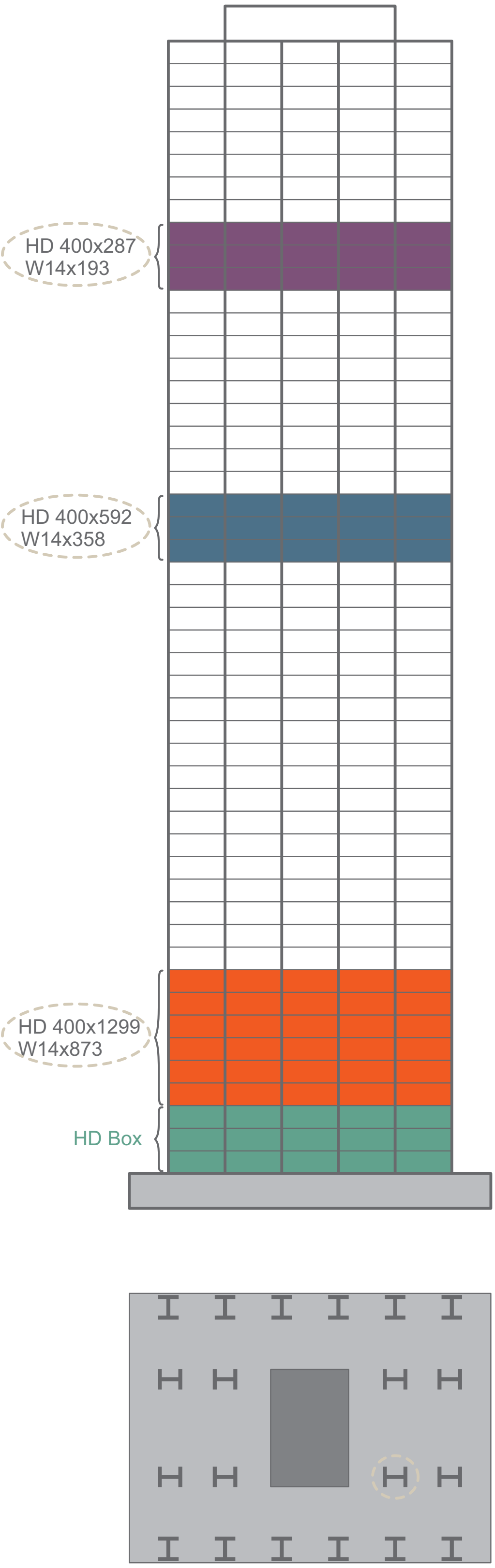



Figure 4.1: 185m high office building

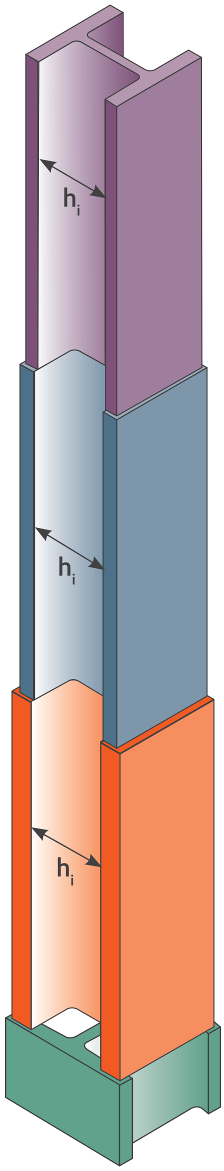



Figure 4.2: Stacking up HD 400 columns.

$h_i$ is constant within a family of sections

- **Optimised built-up sections**

Optimised sections can provide more design flexibility. ArcelorMittal supplies numerous varieties of these welded sections, such as HD Box, cruciform section, sections with cover plates and several different welded sections. 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.

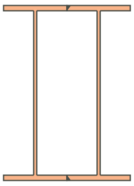
Figure 4.3: HD Box, made from 2 HD

Figure 4.4: Cruciform section

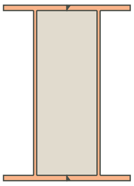
Figure 4.5: Rolled section with coverplates

Figure 4.6:  Two heavy sections welded together

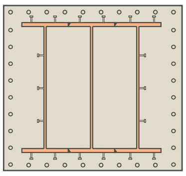
## Optimised Sections Solutions



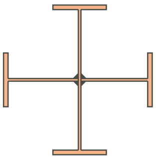
Box section welded from two sections



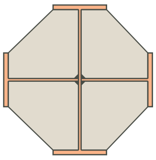
Composite column: box section welded from two sections section with concrete filling



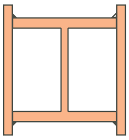
Composite column: box section welded from three sections encased in concrete



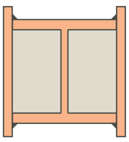
Cruciform section made out of one rolled section and two T-sections



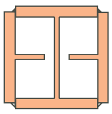
Composite column: cruciform beam with concrete filling



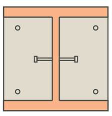
Wide flange beam boxed with two plates



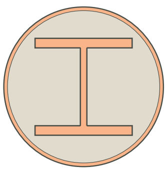
Composite column: wide flange beam boxed with two plates filled with concrete



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

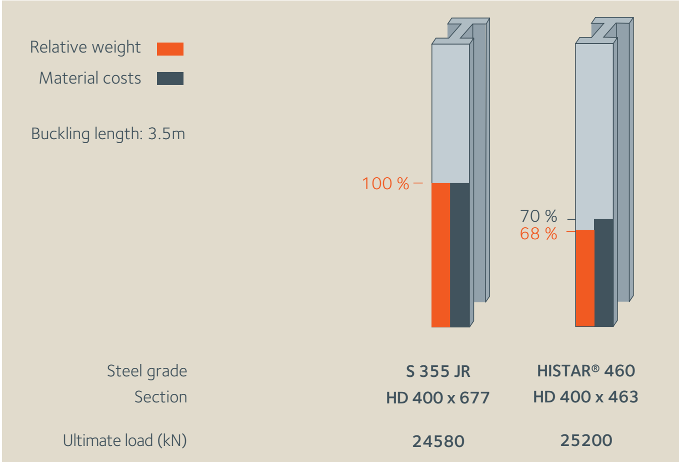



**Figure 4.7: Economical use of HISTAR®: heavy columns**

**Heavy columns:**
Gains, when using HISTAR® 460 instead of S355 JR steel:
- 32% weight savings
- 30% costs savings

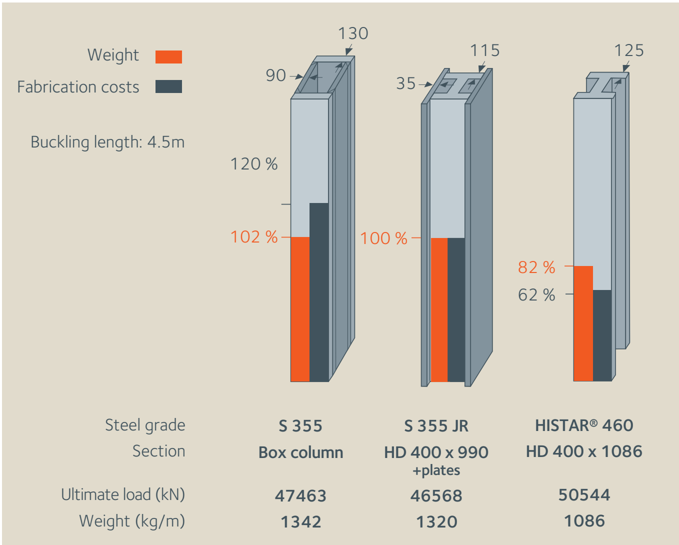



**Figure 4.8: Economical use of HISTAR®: built-up sections**

**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

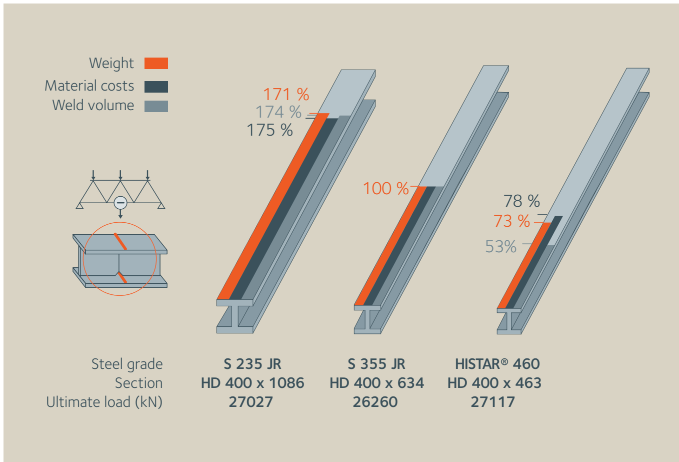
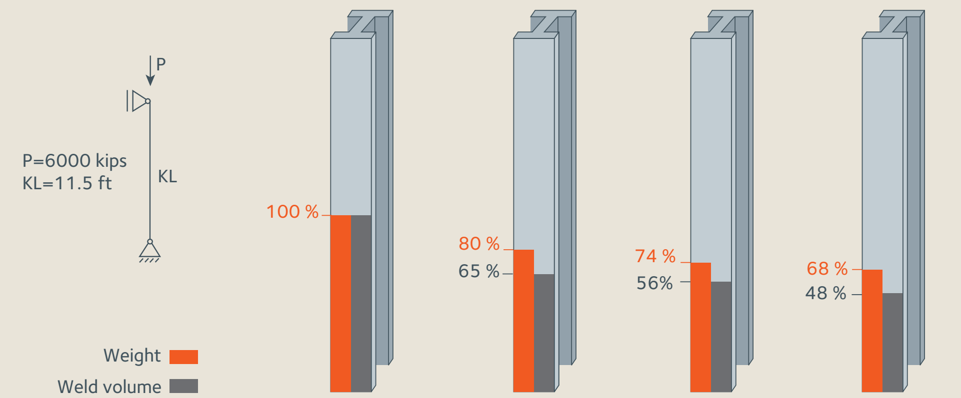


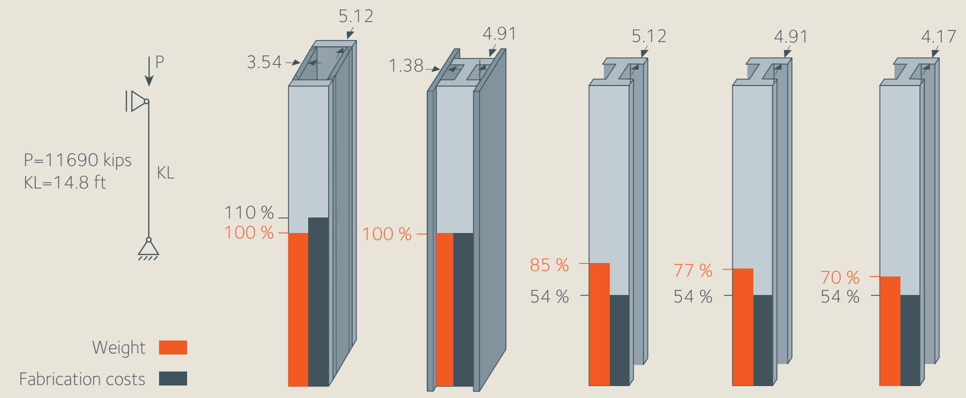

**Figure 4.9: Economical use of HISTAR®: beams in truss applications**




| | | | | |
|---|---|---|---|---|
| | S355 | HISTAR® 460 | | |
| Steel grade | A992 Grade 50 | A913 Grade 65 | A913 Grade 70 | A913 Grade 80 |
| Section | W14x16x500 | W14x16x398 | W14x16x370 | W14x16x342 |
| LRFD Ultimate load (kips) | 6165 | 6232 | 6184 | 6424 |
| Weight (lbs/ft) | 500 | 398 | 370 | 342 |

## Using HISTAR® sections to reduce column weight

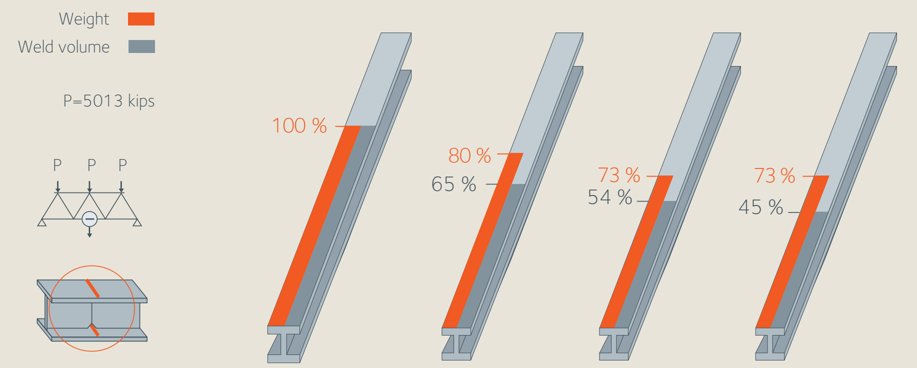
When compared to other structural steels, high-strength HISTAR® steel results in reduced weight and material costs of structures. HISTAR® also contributes to cost savings in welding, fabrication and erection.




| | | | | | |
|---|---|---|---|---|---|
| | S355 | S355 | HISTAR® 460 | | |
| Steel grade | A572 Grade 50 | A992 Grade 50 | A913 Grade 65 | A913 Grade 70 | A913 Grade 80 |
| Section | Box column | W14x16x730 +plates | W14x16x808 | W14x16x730 | W14x16x665 |
| LRFD Ultimate load (kips) | 11828 | 11825 | 12241 | 11740 | 11870 |
| Weight (lbs/ft) | 950 | 949 | 808 | 730 | 665 |

## Using HISTAR® sections to replace built-up columns

Chosing high-strength HISTAR® steel enables designers to substitute complicated and expensive built-up sections with economical hot-rolled profiles.




| | | | | |
|---|---|---|---|---|
| | S355 | HISTAR® 460 | | |
| Steel grade | A992 Grade 50 | A913 Grade 65 | A913 Grade 70 | A913 Grade 80 |
| Section | W14x16x426 | W14x16x342 | W14x16x311 | W14x16x283 |
| LRFD Ultimate load (kips) | 5014 | 5252 | 5142 | 5331 |
| Weight (lbs/ft) | 426 | 342 | 311 | 283 |

## Using HISTAR® sections to reduce weight of truss chord members

HISTAR® steel brings great benefit to the design of tension members in trusses. When used in these applications, the high-strength steel can not only lead to material cost savings but also reduction of the dead load of the system. The weight savings result in the ability to use thinner, more efficient sections and ultimately reduced fabrication and erection costs.

## HTM / WTM Web Tailor-Made Shape

To offer architects and engineers a solution for increasingly tall and slim buildings, with optimal net floor area, we now produce Web Tailor-Made (WTM / HTM) shapes to complement HISTAR® shapes.

This new product has maximum dimensions of 40” width (1 016 mm) by 4” thick (101,6 mm), and it allows something particularly unique like HISTAR®/ASTM A913 shapes, WTM/HTM products are hot-rolled with the same thermo-mechanical controlled process with in-line quenching and self-tempering (TMCP-QST), thereby enabling the elements to be welded without preheat like HISTAR/ASTM A913 shapes.

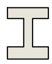
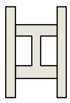
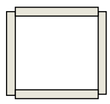
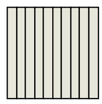
Figure 4.10: New development: Web Tailor-Made

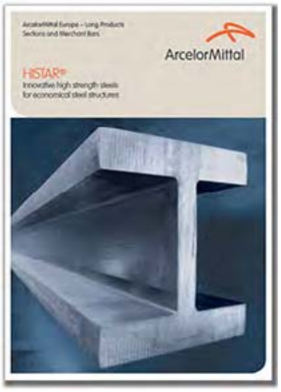
### 25 WTM/HTM sizes available
### Product designation of WTM/HTM is width x unit weight (lbs/ft respectively kg/m)

| Épaisseur/Thickness/Stärke (pouce/inch/zoll) | Largeur/Width/Breite (pouce/inch/zoll) | | | | |
|---|---|---|---|---|---|
| | 24 | 28 | 32 | 36 | 40 |
| 4 | WTM 24 x 327 | WTM 28 x 381 | WTM 32 x 436 | WTM 36 x 490 | WTM 40 x 544 |
| 3,5 | WTM 24 x 286 | WTM 28 x 333 | WTM 32 x 381 | WTM 36 x 429 | WTM 40 x 476 |
| 3 | WTM 24 x 245 | WTM 28 x 286 | WTM 32 x 327 | WTM 36 x 368 | WTM 40 x 408 |
| 2,75 | WTM 24 x 225 | WTM 28 x 262 | WTM 32 x 299 | WTM 36 x 337 | WTM 40 x 374 |
| 2,5 | WTM 24 x 204 | WTM 28 x 238 | WTM 32 x 272 | WTM 36 x 306 | WTM 40 x 340 |

| Épaisseur/Thickness/Stärke (mm) | Largeur/Width/Breite (mm) | | | | |
|---|---|---|---|---|---|
| | 609,6 | 711,2 | 812,8 | 914,4 | 1 016 |
| 101,6 | HTM 610 x 486 | HTM 710 x 567 | HTM 810 x 648 | HTM 915 x 729 | HTM 1 016 x 810 |
| 88,9 | HTM 610 x 425 | HTM 710 x 496 | HTM 810 x 567 | HTM 915 x 638 | HTM 1 016 x 709 |
| 76,2 | HTM 610 x 365 | HTM 710 x 425 | HTM 810 x 486 | HTM 915 x 547 | HTM 1 016 x 608 |
| 69,8 | HTM 610 x 334 | HTM 710 x 390 | HTM 810 x 446 | HTM 915 x 501 | HTM 1 016 x 557 |
| 63,5 | HTM 610 x 304 | HTM 710 x 355 | HTM 810 x 405 | HTM 915 x 456 | HTM 1 016 x 506 |

### Comparison between solutions

| Axial compression | |  reference |  |  |  |
|---|---|---|---|---|---|
| Buckling Length = 31 ft (9.5 m) | | W 14 x 873 (W 360 x 1 299) | W 14 x 873 + 2 x WTM 40 x 544 (HD 400 x 1 299 + 2 x WTM 1 016 x 810) | Box of 4 x WTM 40 x 544 (WTM 1 016 x 810) | Stack of 10 x WTM 40 x 544 (WTM 1 016 x 810) |
| Weight | lbs/ft | 873 | 1 961 | 2 181 | 5 440 |
| | (kg/m) | (1 299) | (2 919) | (3 240) | (8 100) |
| | % | 100 | 225 | 250 | 623 |
| Max. Axial Load | kips (kN) | 8 604 (38 273) | 28 835 (128 646) | 35 642 (159 080) | 84 260 (378 239) |
| | % | 100 | 335 | 414 | 979 |
| | % weight | 100 | 149 | 166 | 157 |
| Inertia, weak axis | $in.^4$ ($cm^4$) | 6 111 (254 372) | 48 184 (1 994 075) | 171 095 (7 121 545) | 200 210 (8 879 604) |
| | % | 100 | 788 | 2 800 | 3 276 |
| | % weight | 100 | 351 | 1 121 | 526 |
| Inertia, strong axis | $in.^4$ ($cm^4$) | 18 129 (754 600) | 60 866 (2 530 521) | 197 975 (8 240 377) | 200 210 (8 333 333) |
| | % | 100 | 336 | 1 092 | 1 104 |
| | % weight | 100 | 149 | 437 | 177 |

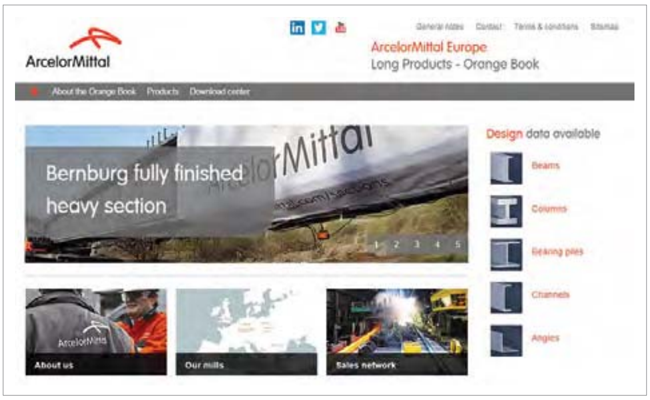



- **Predesign tools, design tables:**
  Different design tables exist according to different standards (European, British, American etc.). Here are some examples.

| | 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 4.1: **Eurocode (EN 1993-1-1: 2005)** design buckling resistance [kN] of strong and weak axis of HD columns sections in HISTAR® 460.

http://orangebook.arcelormittal.com/




| | 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 |

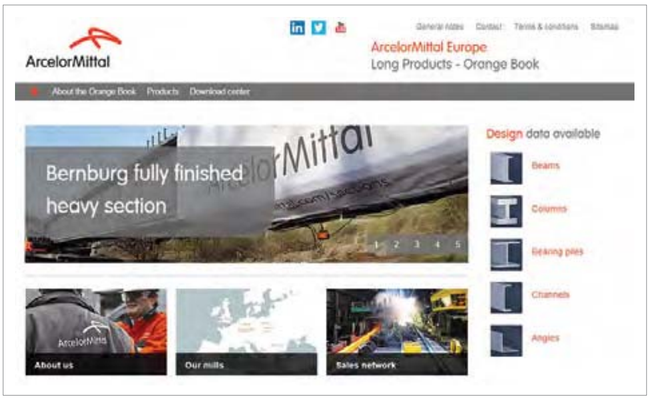
Table 4.1 (continued): **Eurocode (EN 1993-1-1: 2005)** design buckling resistance [kN] of strong and weak axis of HD columns sections in HISTAR® 460.

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

http://**orangebook.arcelormittal.com/**




| | 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 4.2 (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 4.3: **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 4.3 (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 4.4: **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 4.5: **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 4.6: **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 4.7: **American Standard (ANSI/AISC 360-16)** design buckling resistance [kN] of cruciform columns in Grade 65.


## • Megacolumns

Megacolumns are composed of more than one structural steel wide flange shape with longitudinal rebar and ties embedded in concrete. These are 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.

High-rise buildings have been built in recent years all around the world and most of their structures are made 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.

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

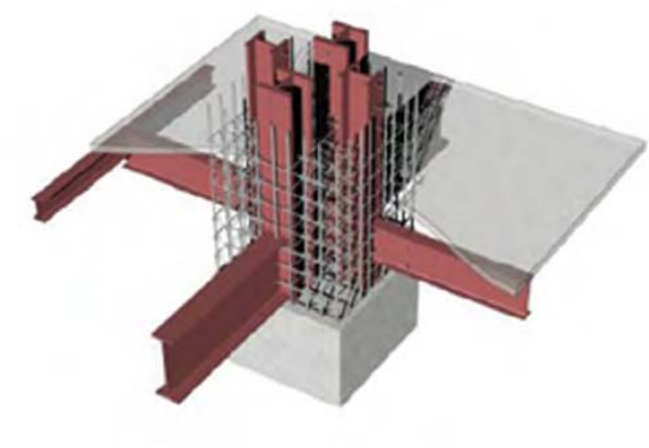
Experimental performance tests on composite megacolumns with encased hot rolled steel sections supported and founded by ArcelorMittal, were carried out between February and September 2015 at the China Academy of Building Research Technologies (CABR) Laboratories and the Laboratories of Tsinghua University,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


**Figure 4.11 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.

© Magnusson Klemencic Associates



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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 mega-columns, 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 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 4.13: 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 4.11). 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 4.13).

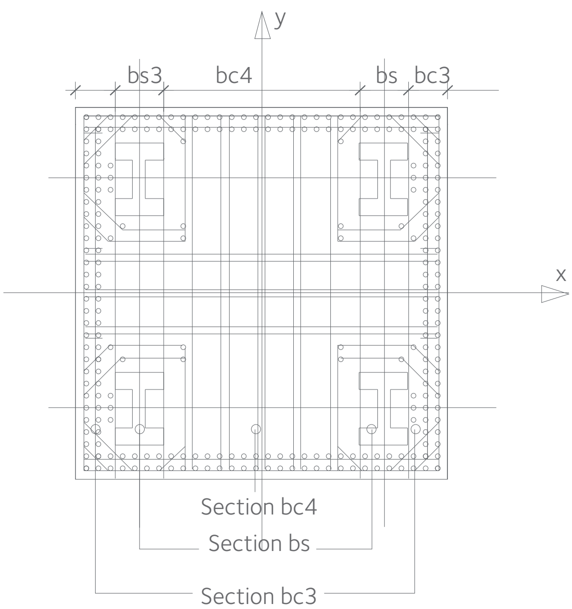



**Figure 4.12: Section layout of reinforcement Example of the Eurocode 4 Design Method**

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 Safir software. FEM models also allow for a deeper insight on steel-concrete interaction forces and stress distribution.

- **Design rules**

Subsequently, simplified design methods based on European, Chinese and US codes were suggested, and the results compared to numerical and experimental values.
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/Research Reports**.

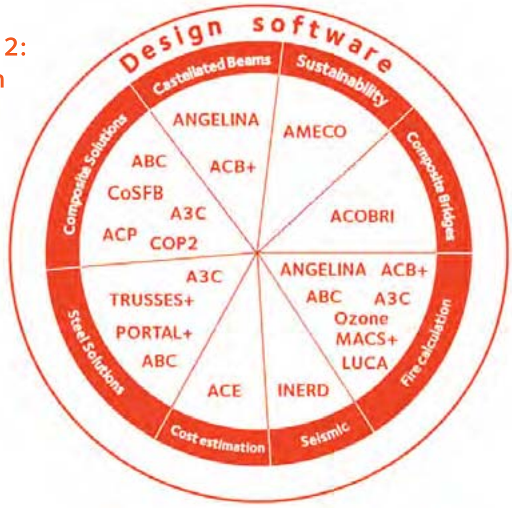
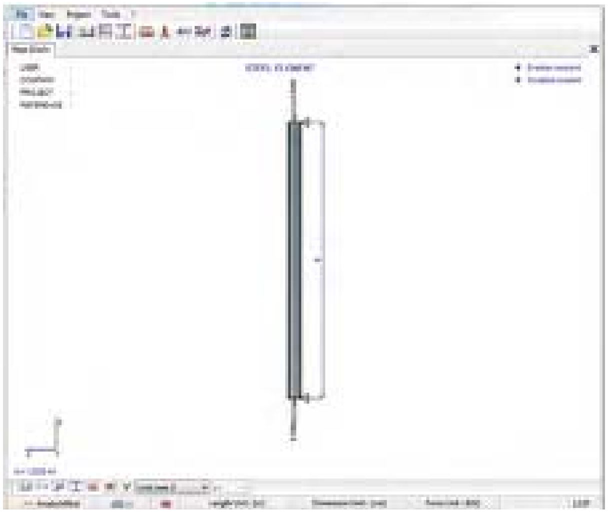
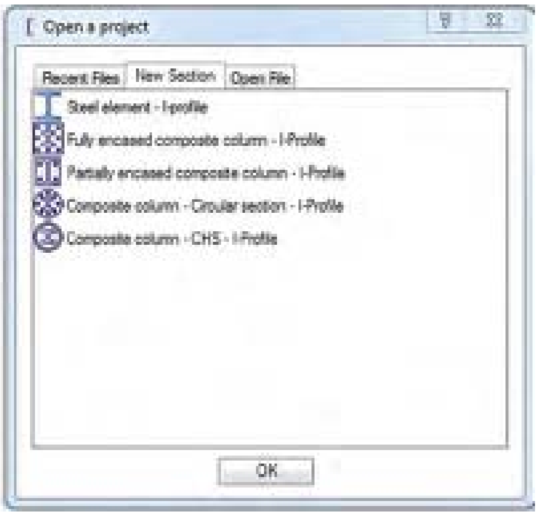



Figure 4.12: pre-design softwares available on sections.arcelormittal.com

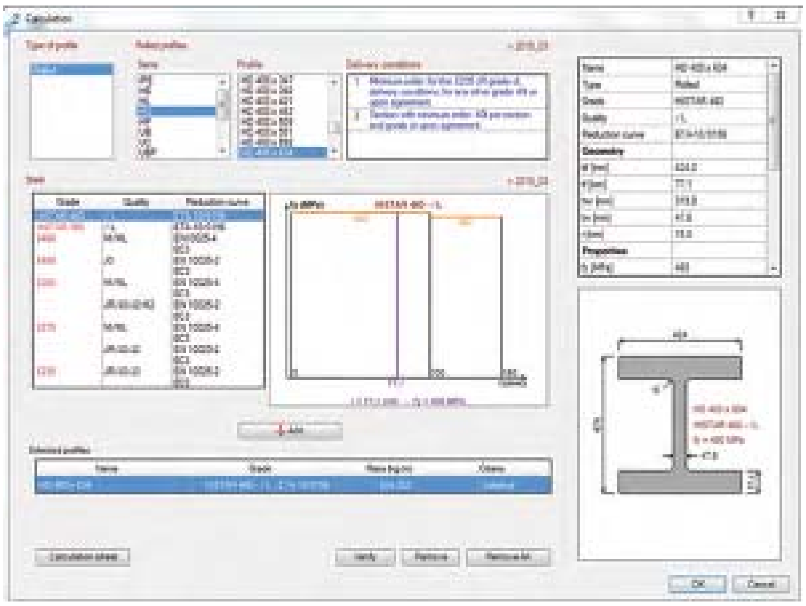
- **Predesign tools, software**
A3C – Verification of steel and composite (partially or totally encased) columns in cold and fire conditions

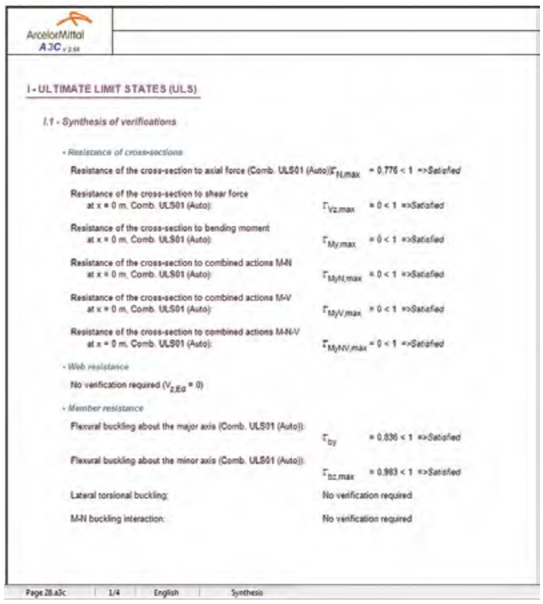
A3C: This software is available for free at **sections.arcelormittal.com** in the "Design aid" menu: Design Software. The A3C software allows the designer to perform a detailed verification of a single steel member or a composite steel-concrete column (partially encased, fully encased in concrete or 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. HISTAR® 460). With a single click, a resistance check can be performed (see below), additionally the fire protection thickness can also be provided.





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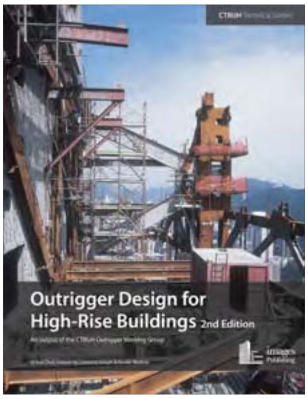
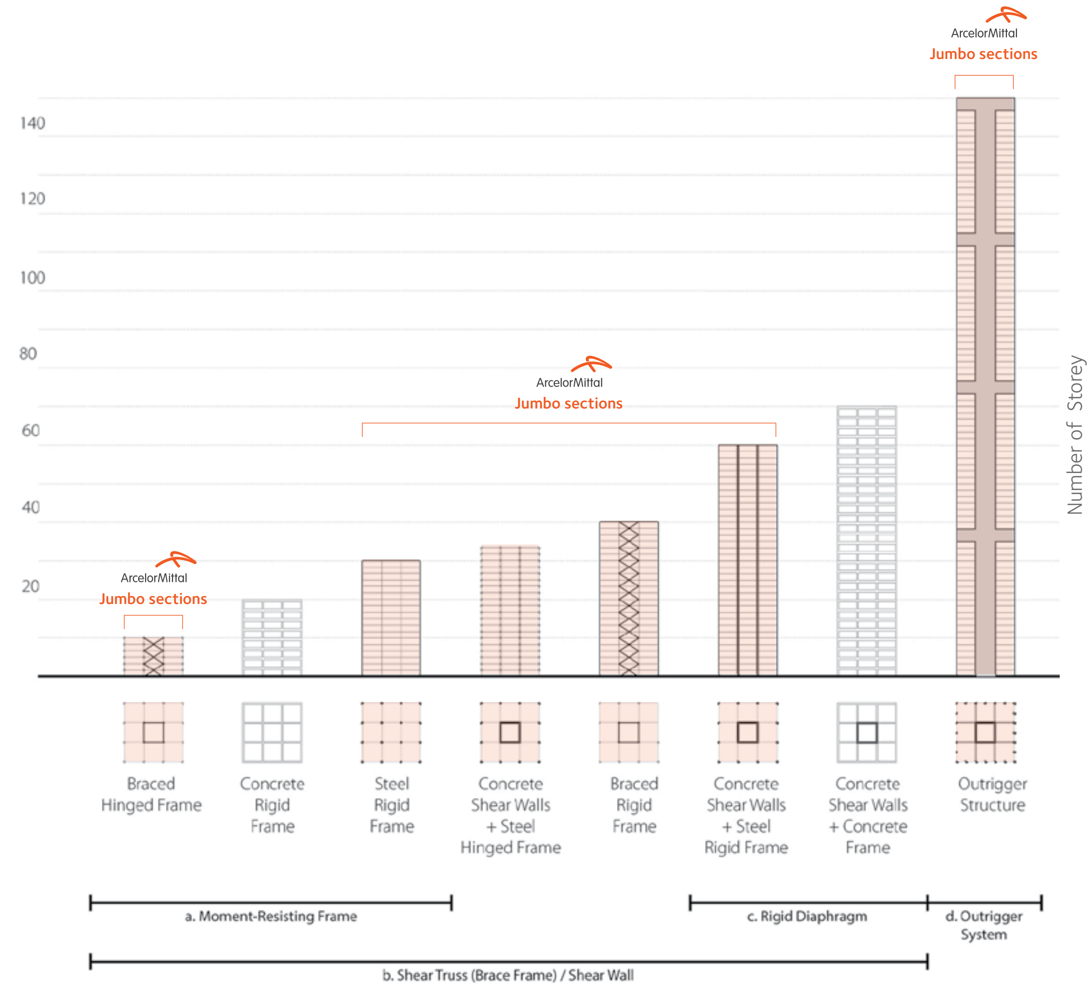



# 5. Bracing systems




*Source: M. M. Ali & K. S. Moon (2007); Redrawn by CTBUH*

Structures that can utilise Jumbo beams

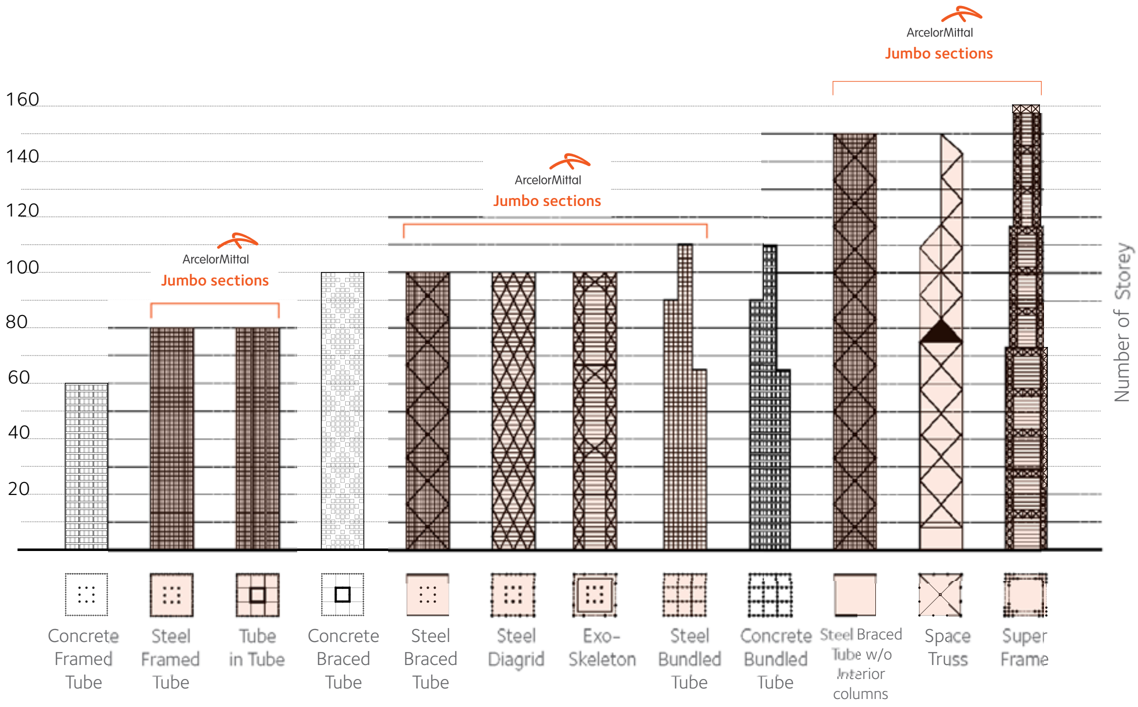
Other structures

**Figure 5.1: Interior Structural Systems for Tall Buildings including (a) moment-resisting frames, (b) shear truss (brace frame)/shear walls, (c) rigid diaphragms,and (d) outrigger 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




*Source: M. M. Ali & K. S. Moon (2007); Redrawn by CTBUH*

**Figure 5.2: Exterior Structural Systems for Tall Buildings**

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 5.1) and exterior (Figure 5.2) (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 5.1) are composed of two main systems: moment-resisting frames (Figure 5.1a) and shear truss (braced frame)/shear wall (Figure 5.1b). 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 5.1c) 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 5.3).

*Source: M. M. Ali & K. S. Moon (2007), redrawn by CTBUH*

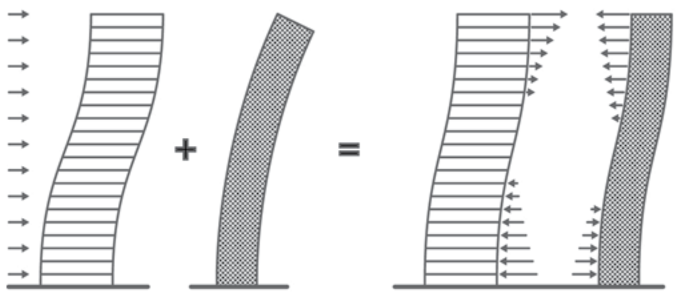


**Figure 5.3: Shear Wall-Rigid Frame Interaction**

Another alternative solution, becoming popular today for super tall buildings, is the so-called outrigger system (Figure 5.1d) 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 5.4). 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

*Source: Taranath (1998) Redrawn by CTBUH*

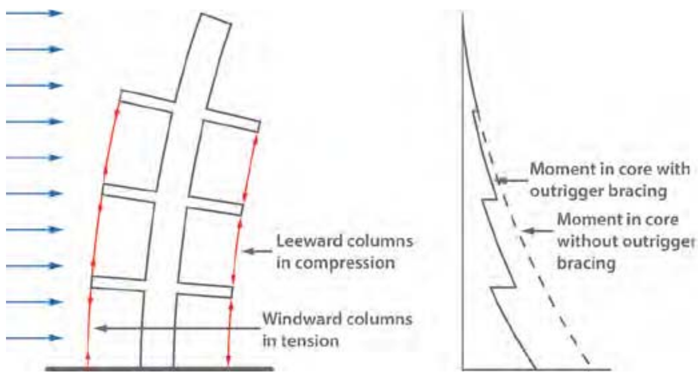



**Figure 5.4: Outrigger structural system principles**



*Ali, M.M., and Moon, K.S., 2007. Structural Developments in Tall Buildings: Current Trends and Future Prospects. Architectural Science Review, 50(3), 205-233.


Figure 5.5: New York Times Tower, New York City, USA

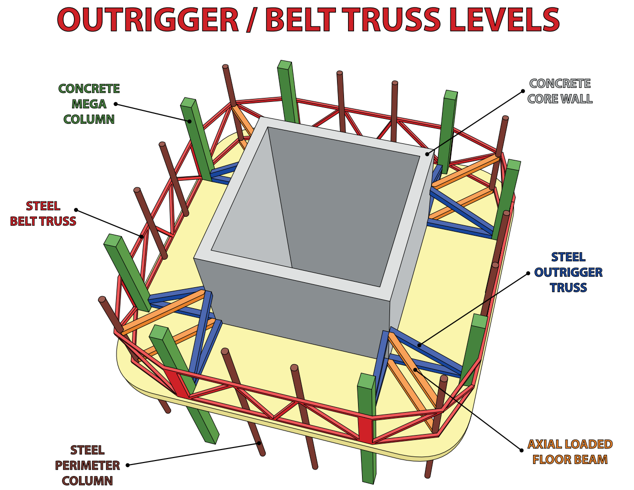



Figure 5.7: Outriggers trusses and belt trusses

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 5.2) 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 5.6), 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.

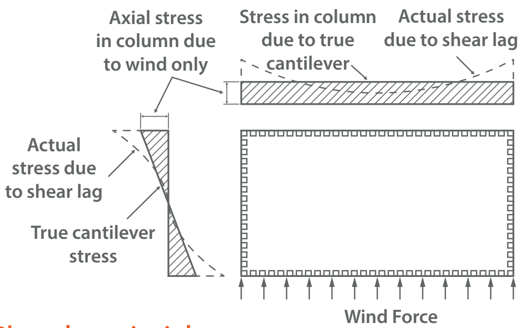



Figure 5.6: Shear lag principles

- 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 5.7)

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 5.8). 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*

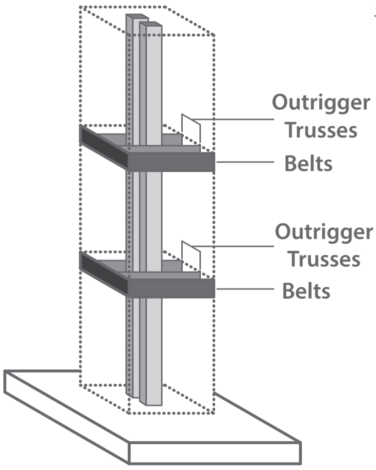



Figure 5.8 Outrigger and belt trusses location scheme in a tall building

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 5.9). Additional information can be found in the CTBUH Technical Guide "Outrigger Design for High-Rise Buildings" (see p.29).

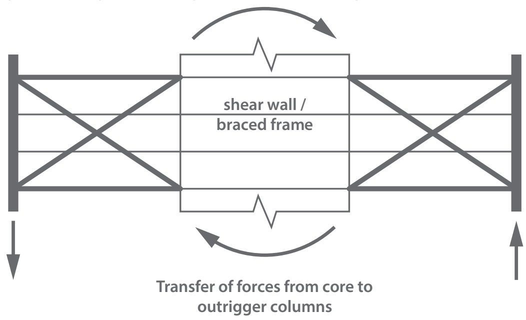



Figure 5.9: Force transfer using an outrigger system


Figure 5.10: 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 5.11) [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 5.11).
- 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.

- **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 therefore increase building robustness.

- **Connections**

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*

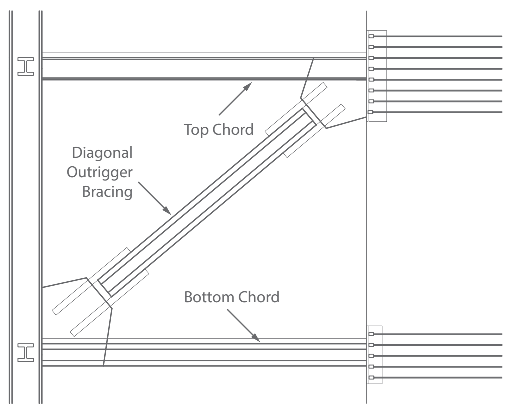
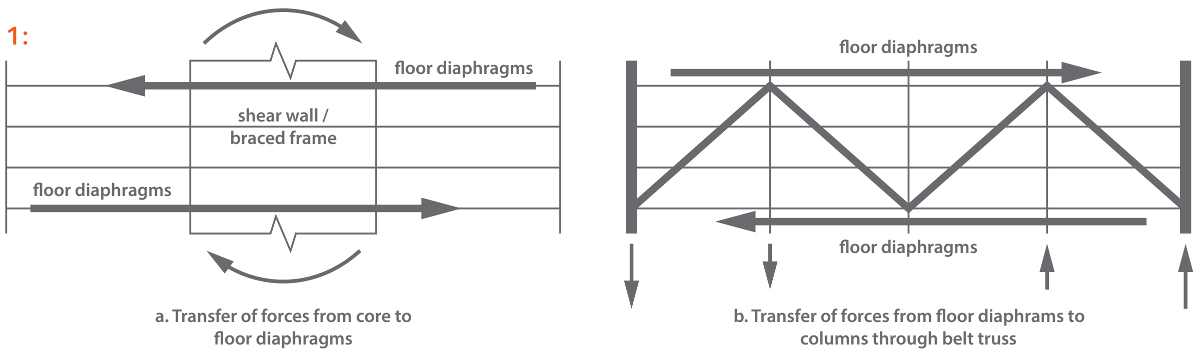



Figure 5.12: Outrigger connection with embedded plates and bar anchors [Choi, 2012] **

Figure 5.11: Force transfer using a belt truss and a virtual outrigger




*Nair, R., 1998. Belt Trusses and Basement as ‘Virtual’ Outriggers for Tall Buildings. Engineering Journal, Fourth Quarter, 140-146.

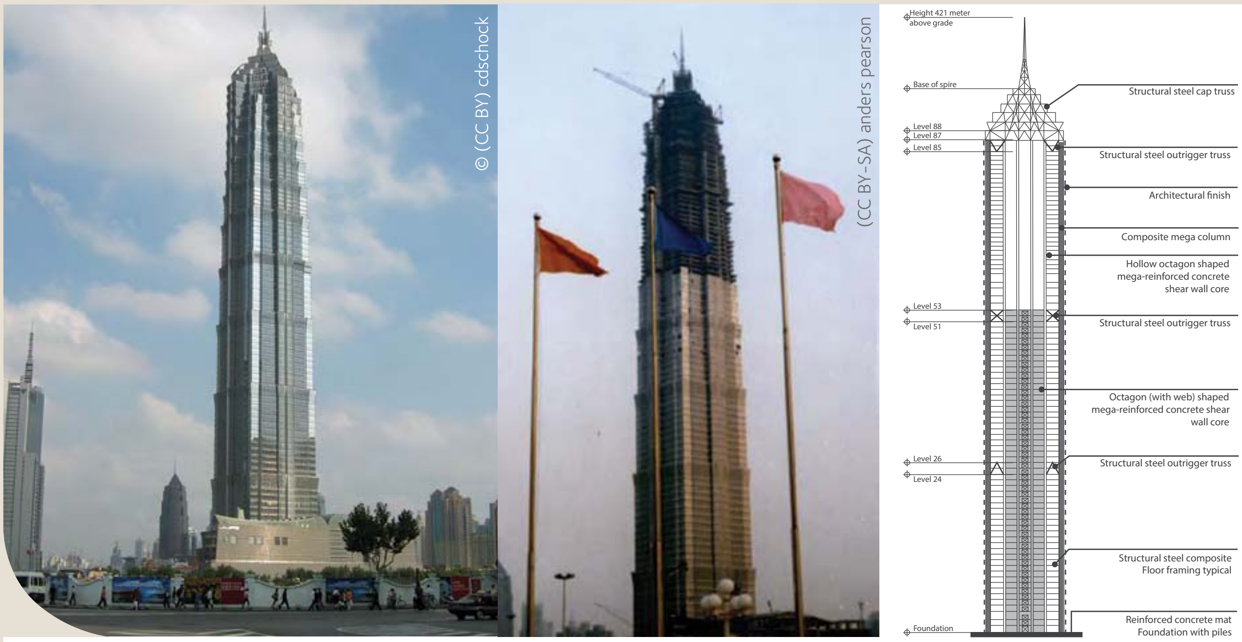



**Figure 5.13: Jin Mao Tower, Shanghai, China**

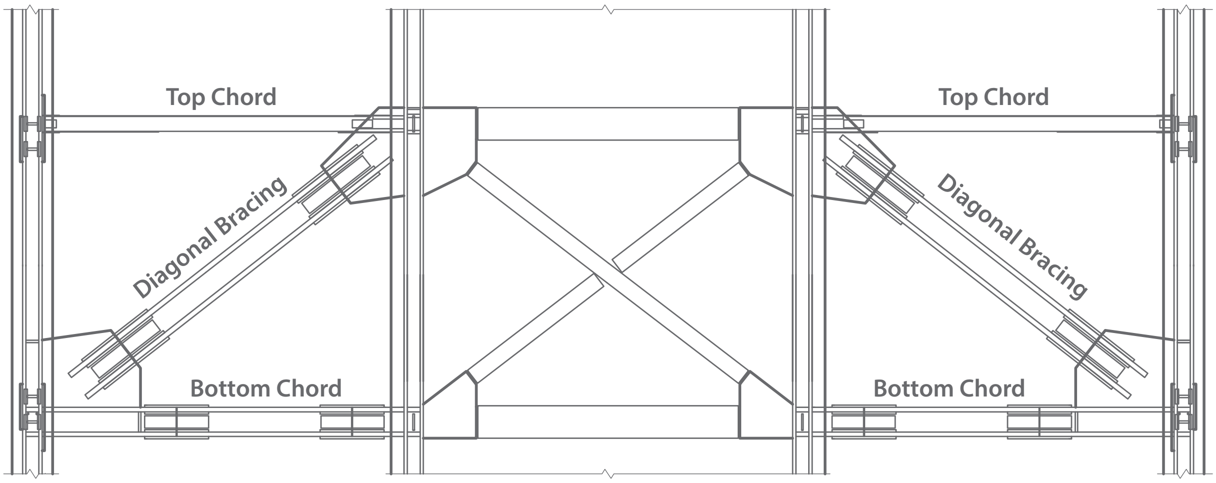



**Figure 5.14: Outrigger connections with continuous steel members [Choi, 2012]****

possible connections: continuous steel members (Figure 5.14) and steel to concrete with embedded plates and anchors (Figure 5.12).

- 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 locations throughout the building height. Therefore, ArcelorMittal Jumbo profiles are ideal for such applications. 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 5.15).

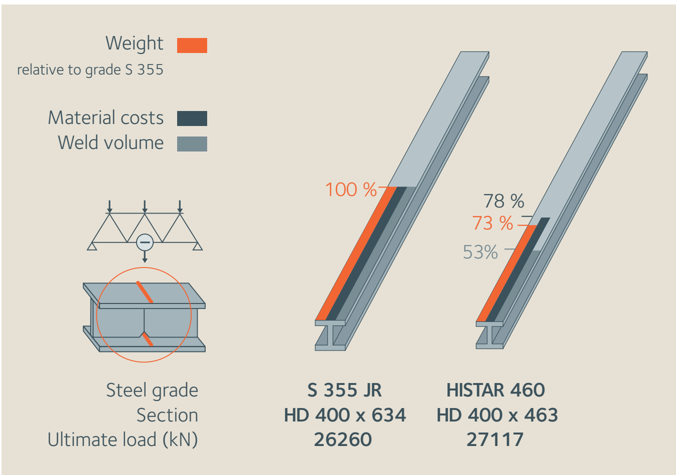



**Figure 5.15: HISTAR® in trusses**

- 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 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.

**Choi, H.S., Ho, G., Joseph, L., and Mathias, N., 2012. Outrigger Design for High-Rise Buildings: Am Output of the CTBUH Outrigger Working Group. Council of Tall Buildings and Urban Habitat: Chicago.



Figure 5.16: Shanghai tower, Shanghai, China

The effect of wind on a building can be described as two mechanisms: buffeting and vortex-shedding. The bufetting component acts in the along-wind direction and it is can be easily estimated from code approaches. The vortex-shedding component acts mainly in perpendicular direction to the downstream flow and it 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 considered, 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 11.

## • Applications

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

- Shanghai Tower, Shanghai, China (Figure 5.16)
- New York Times Tower, New York City, USA (Figure 5.5)
- 300 North LaSalle, Chicago, USA (Figure 5.10)
- Jin Mao Tower, Shanghai, China (Figure 5.13)
- Ref. projects detailed in chap.13 and summarised in Fig. 5.17.

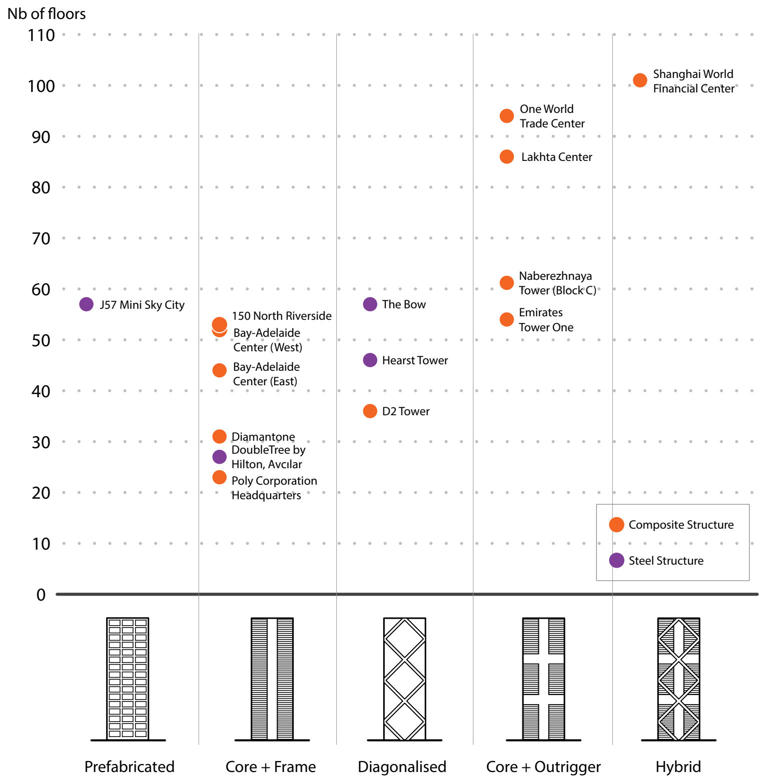



Figure 5.17: Bracing systems of the reference projects

*ASCE, 2015. Wind-Induced Motion of Tall Buildings: Design for Habitability. American Society of Civil Engineers.

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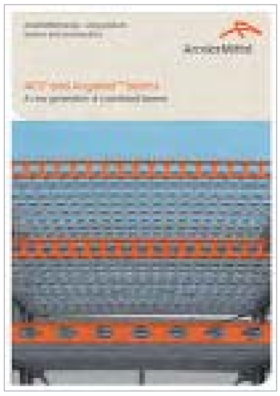


# 6. Beams and floor systems

## • 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 6.1). 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 6.2).

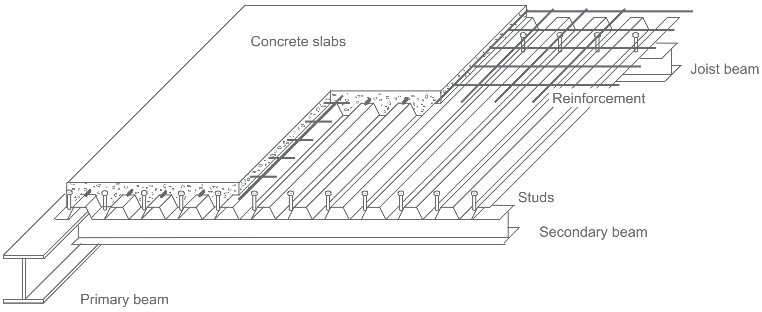
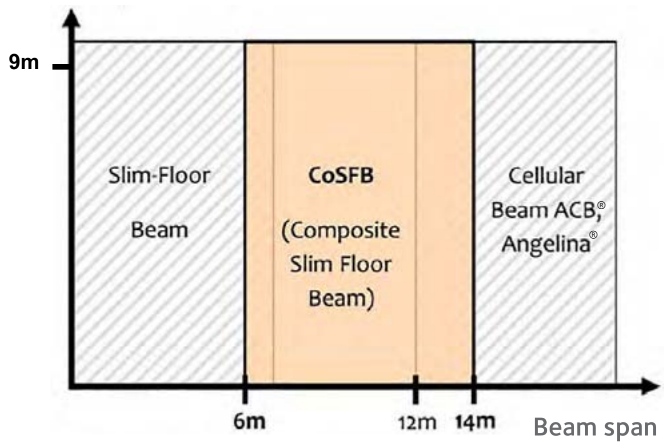



**Figure 6.1: Composite floor system**

| | 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 6.2: Slab depending on the span**




## • Floor systems specific for high-rise buildings

In high-rise buildings, floor systems must be light and slim 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 6.3). Once divided, the beam can be reassembled with a longer web, taking advantage of the cutting pattern. These cutting patterns can produce several different castellated beams, including sinusoidal cut (Figure 6.4), 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.

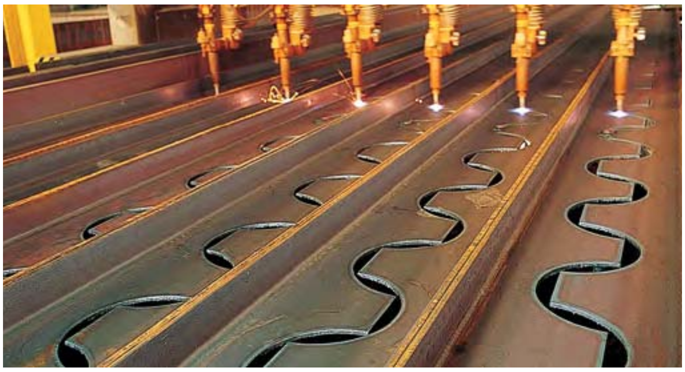


Figure 6.3: Flame cutting table for hot rolled sections

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.

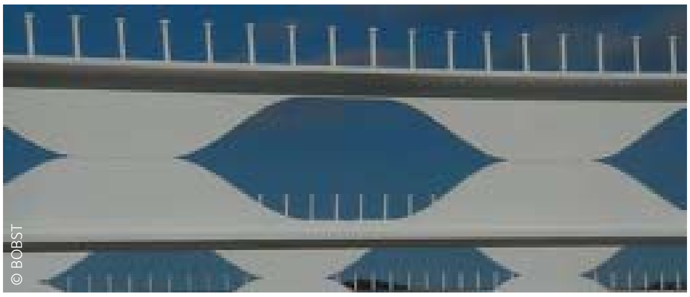



Figure 6.4: Angelina® beams

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 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 6.5.

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/m$^2$ plus 1kN/m$^2$ for partitions
Slab depth = 130mm; Beam spacing = 3m

Figure 6.5: 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 6.6 and 6.7).

Figure 6.6: Slim-Floor for parking in IFB (Nantes, France)

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 6.8).

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

Figure 6.7: Slim-Floor (Eich Clinic, Luxembourg)

The Integrated Floor Beam (IFB) replaces the lower flange with a wider plate (Figure 6.8), while the Slim-Floor Beam (SFB) attaches a plate wider than the lower flange directly to the bottom of a beam element (Figure 6.9).

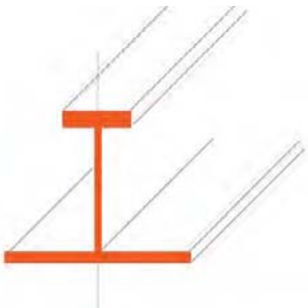


Figure 6.8: IFB system

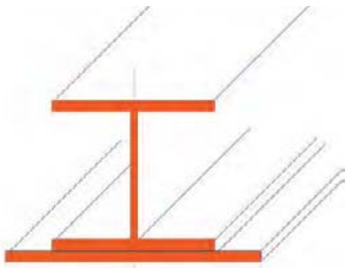
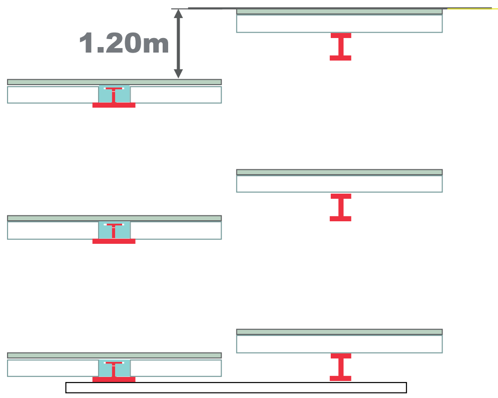


Figure 6.9: SFB system

**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.

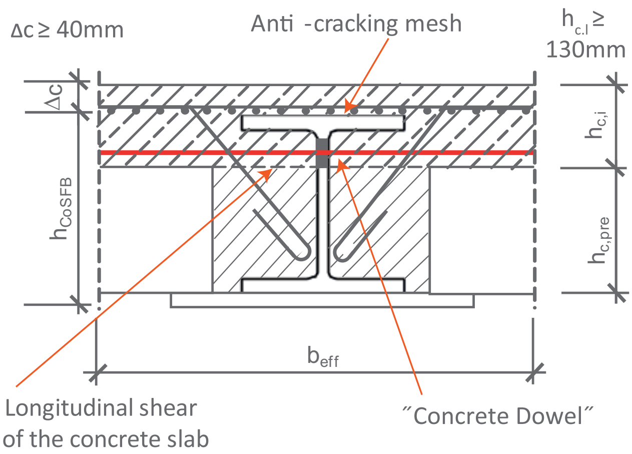


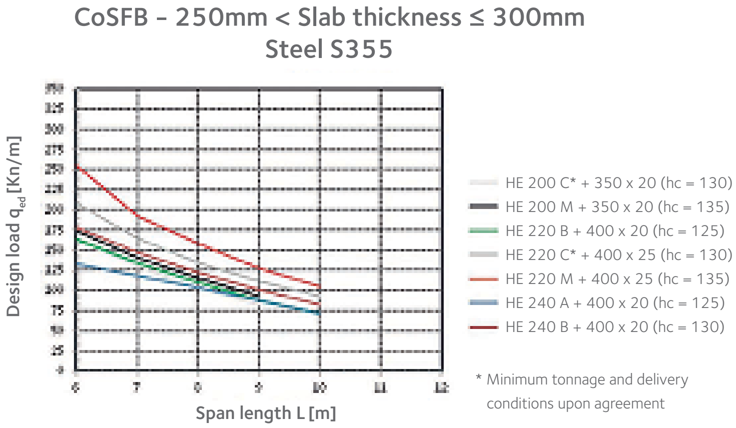

**Height advantage with Slim-Floor**

| 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 6.10: Design tables: - S355 - for office buildings; A welded plate - 20mm thick and 150mm wider than the section is used in all cases.**




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 6.11 to Figure 6.13). 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.

Figure 6.11: CoSFB and Cofraplus 220

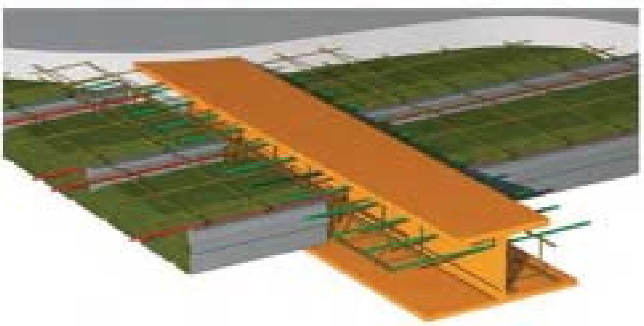


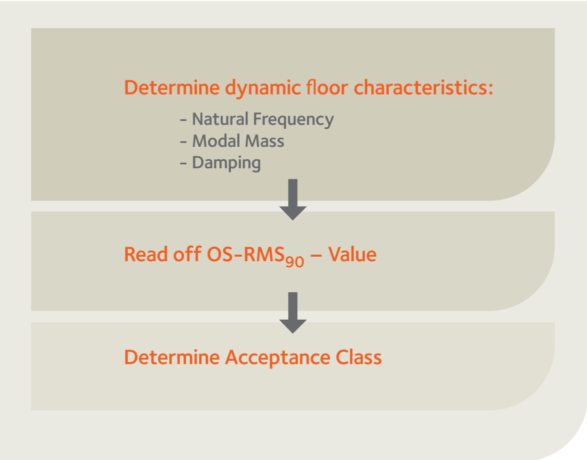
Figure 6.12: CoSFB and Cofradal 260

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 spacing from 5m to 10m

Figure 6.13: CoSFB




**Design procedure for vibrations**

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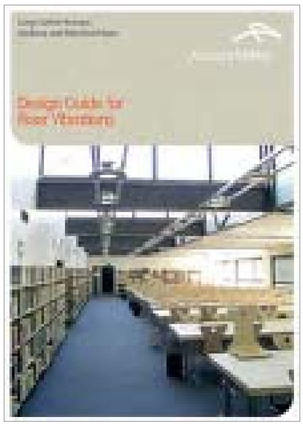



## • Vibration

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

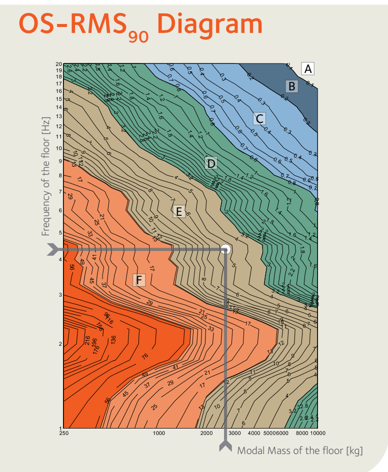
- ultimate limit states are those related to strength and stability;
- serviceability limit states are mainly related to vibrations and hence are governed by stiffness, masses, damping and the excitation mechanisms.

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 considered. 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$_{90}$ Lower Limit | OS-RMS$_{90}$ Upper Limit | Critical Workspace | Health | Education | Residential | Office | Meeting | Retail | Hotel | Industrial | Sport |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.0 | 0.1 | | | | | | | | | | |
| B | 0.1 | 0.2 | | | | | | | | | | |
| C | 0.2 | 0.8 | | | | | | | | | | |
| D | 0.8 | 3.2 | | | | | | | | | | |
| E | 3.2 | 12.8 | | | | | | | | | | |
| F | 12.8 | 51.2 | | | | | | | | | | |

(Function of Floor)

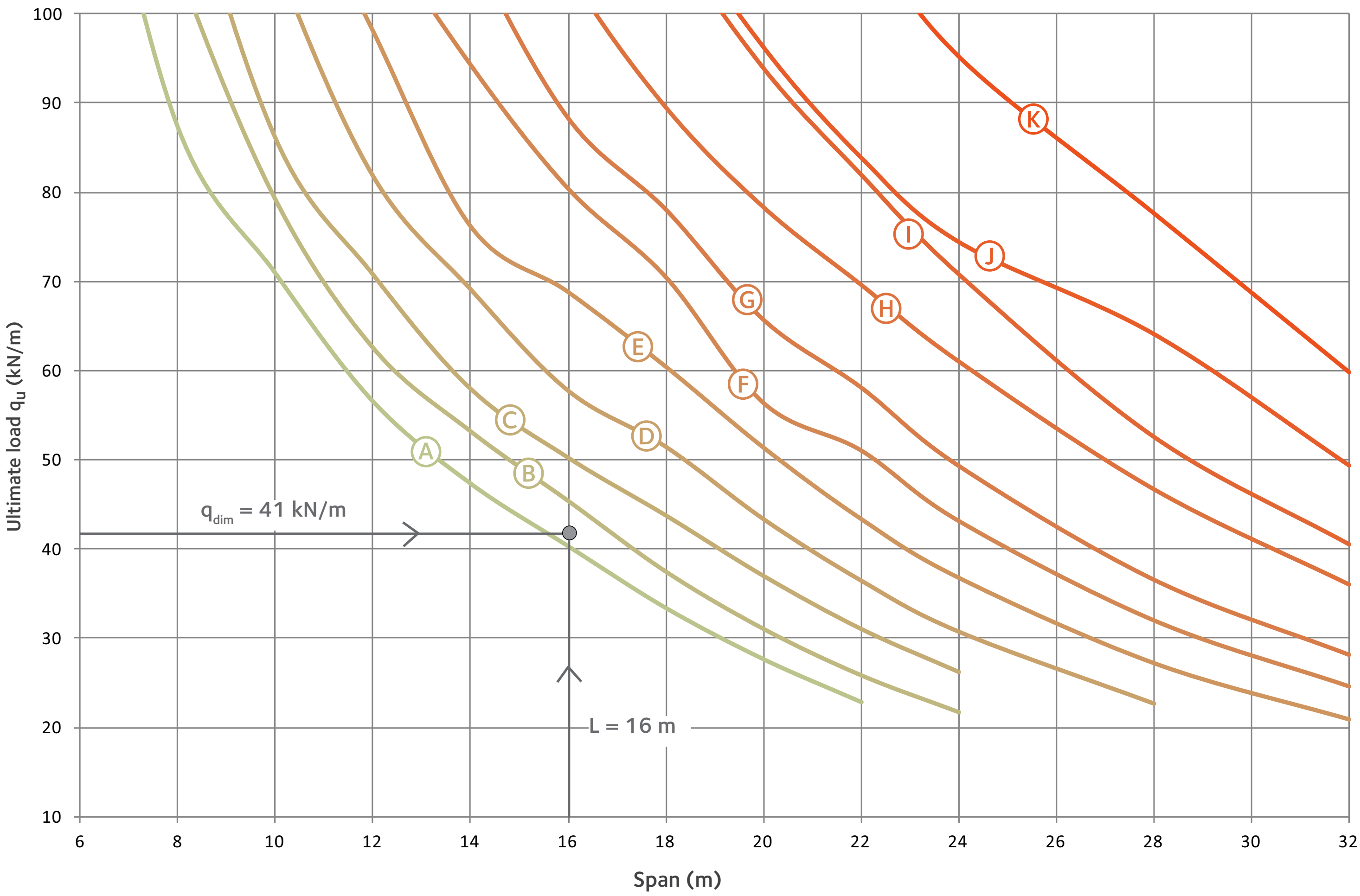
Recommended
Critical
Not recommended

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 Square$_{90}$) 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 |

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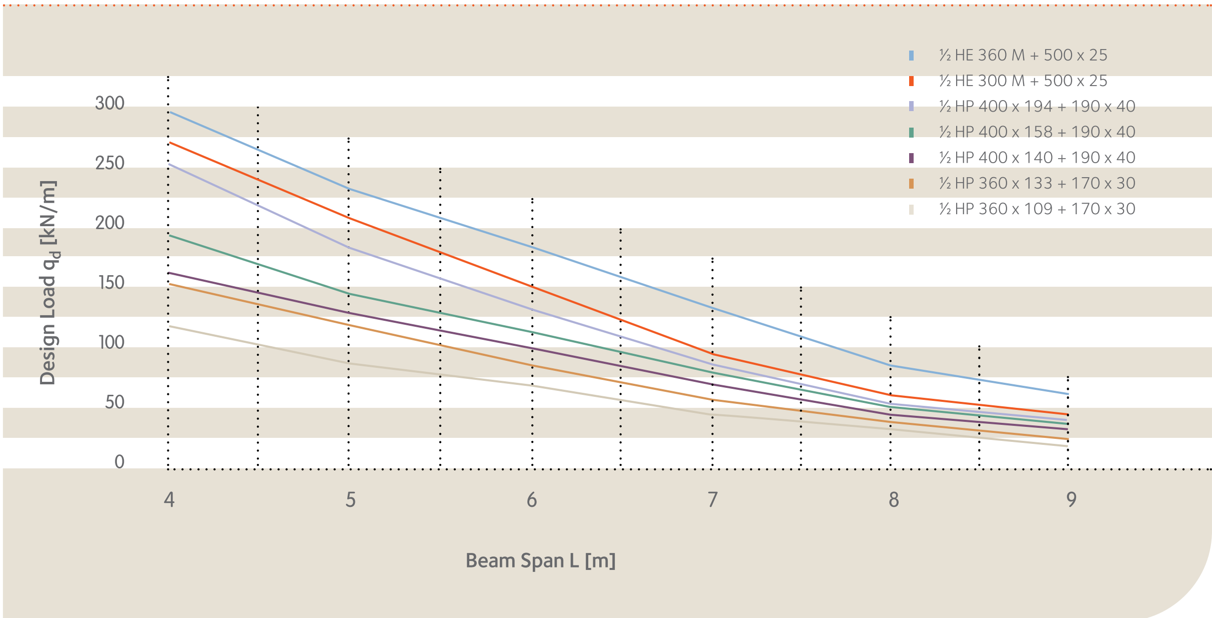
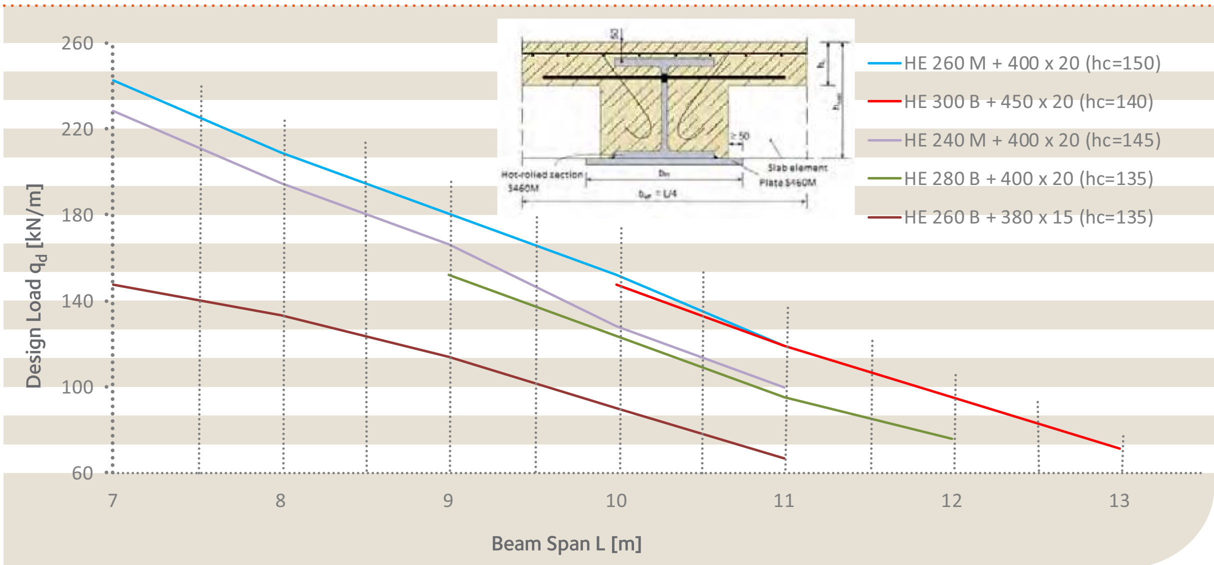
## Slim-Floor IFB – Slab thickness < 200 mm




## CoSFB – 300mm ≤ Slab thickness ≤ 350mm – Steel S460



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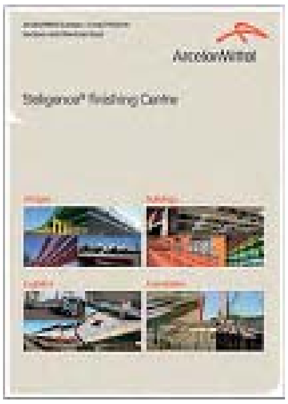


# 7. Connections

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 to be economically and structurally efficient, and ArcelorMittal sections offers several 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 7.1) 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.

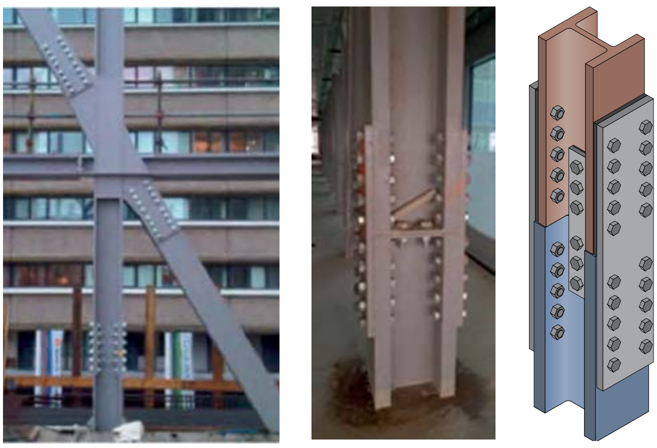


**Figure 7.1: Bolted connection of two HD/UC/W columns**

– Welded Connections:
Jumbo and Super Jumbo columns can be connected by welding (Figure 7.2). 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 several advantages:

- smaller connection footprint
- no additional connection elements such as bolts, nuts, washes, etc.
- no reduced cross section resistance due to holes
- continuity of the structural element at the joint ensuring higher stiffness and clear load path transmission
- high reliability through adequate quality control procedure (procedure for beveling, welding, control during and after welding)

**Figure 7.2: Column joint before welding**

Figure 7.3: CJP butt weld preparation for Jumbo column

Figure 7.5: 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 7.3) 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 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:

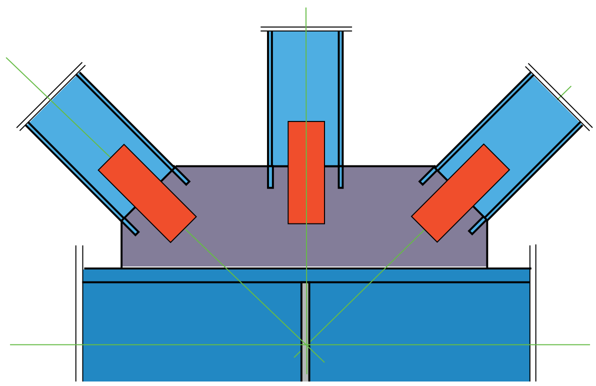


Figure 7.4: Gusset plates connection

- Bolted Connections:

Unlike columns, bracing systems use a web-based connection, and using gusset plates and stiffeners, forces from trusses can be adequately transmitted to beams and columns. This can be seen in Figure 7.4 to 7.7, with the I-sections oriented in such a way, using 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.

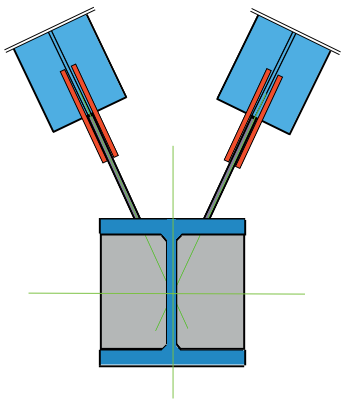


Figure 7.6: Gusset plates connection (cross-sectional view)

- 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 if they have the same chamber* size (See Figure 7.8 to 7.11). 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 7.7: Mariner Stadium close up on gusset plates connection in S355 (Gr. 50) with S460 (Gr. 65) beams

Figure 7.9: 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 0 300 | 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 7.8: Selection of shape according to the rolling programme

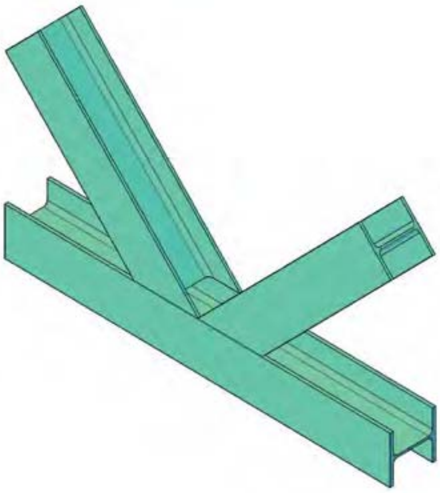


Figure 7.10: Various shapes with equal chamber* size

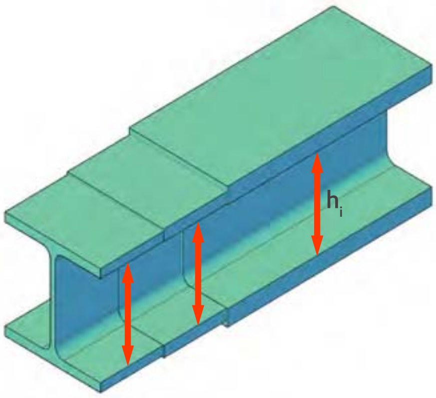



Figure 7.11: Equal chamber* size

*inner distance between flanges

Figure 7.12: Bevel preparation on Jumbo

Figure 7.14: Mistral Residential Tower, Izmir, Turkey

- Steligence® Fabrication Centre

The Steligence® Fabrication Centre manufactures customs joints for steel sections. It 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 to produce 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.

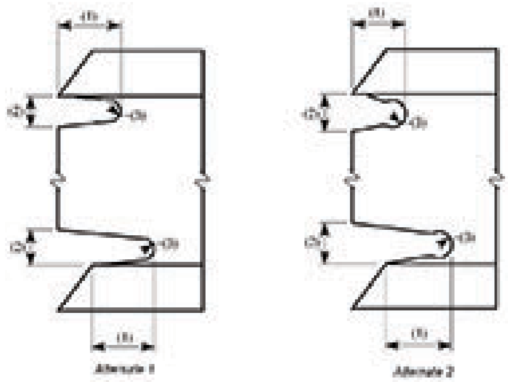


Figure 7.13: Weld access hole geometry

(1) Length: Greater of 1.5 x $t_w$ or 11/2 in. (38 mm). Tolerance is ± 1/4 in. (6 mm).
(2) Height: Greater of 1.5 x $t_w$ 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 heavvy shapes.

The height (h) of the access hole (Figure 7.13) 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 7.14), 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 Steligence® Fabrication 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
  - 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

Structural members with long uninterrupted spanning and large loading capacity are needed in the design of tall buildings, convention centres, sport arenas and airport concourses. The latest product developments made by ArcelorMittal permits the use of large jumbo steel profiles. When such profiles are used in areas of high seismicity, the welded connection design requires a careful development from welding performance specifications (WPS) point to ensure that the required rotational capacities to reach interstudy drifts can be developed. One technique used to control the flexural demand from the beam is to utilise

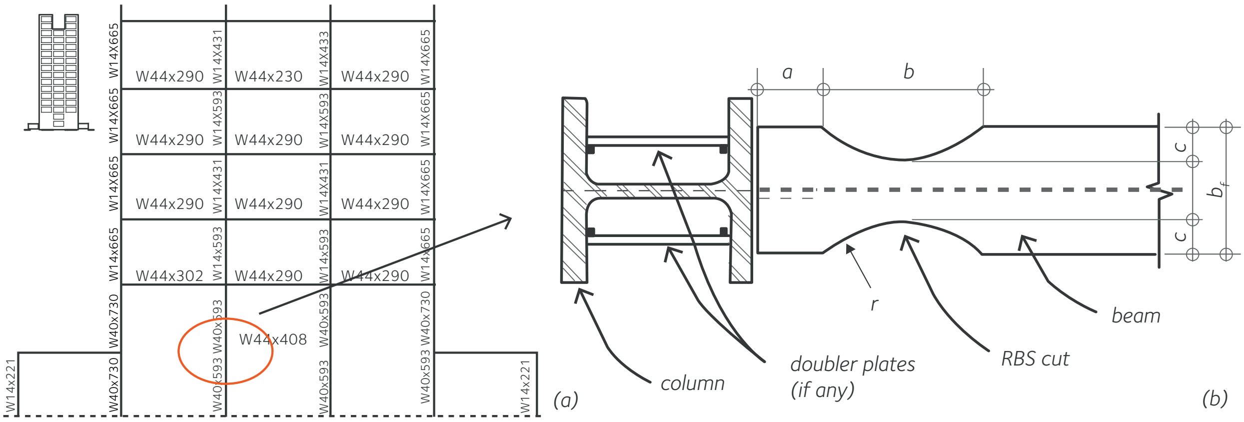



**Figure 7.15: a) Sections at the lower storeys of the Case study building, b) Plan detail of the examined beam-column connections with doubler plates.**

reduced beam sections (RBS), which effectively limit the demands at the beam-column interface (Figure 7.15,b). The RBS concept was proposed initially in the late 1990s to alleviate problems encountered in the 1994 Northridge Earthquake with conventional welded connections. Following, different shapes of RBS have been studied along the time. The current AISC Provisions for Steel Buildings (AISC 360-16), Seismic Provisions (AISC 341-16) and the Provisions for Prequalified Connections for Special and Interme-diate Steel Moment Frames (AISC 358-16) allow the use of these connections but only for sections up to 900 mm in depth and 450 kg/m in weight. To extend the coverage of these specifications to much larger sections, a joint experimental and analytical program was undertaken by Virginia Tech and ArcelorMittal. Another main objective of the experimental programme was to determine an acceptable balance between the deformation obtained from flexural yielding of the RBS and shear yielding of the column web PZ.
The experimental campaign is based on a trial design to determine the realistic member size in buildings with high seismicity area. The study consisted of a square office building tower with fifteen stories and a large open atrium at the 1st floor. Special Moment Frames with RBS connections were considered exclusively for the seismic-load-resisting system. These frames are located at the perimeter and are typically three bays wide, except at the lower levels as shown in Figure 7.15a. From these typical frames, sample connections were extracted as possible test specimens. Figure 7.15b depicts the schematic of a specimen. Each specimen exceeds the size limitation outlined in the AISC 358-16 in at least one regard.

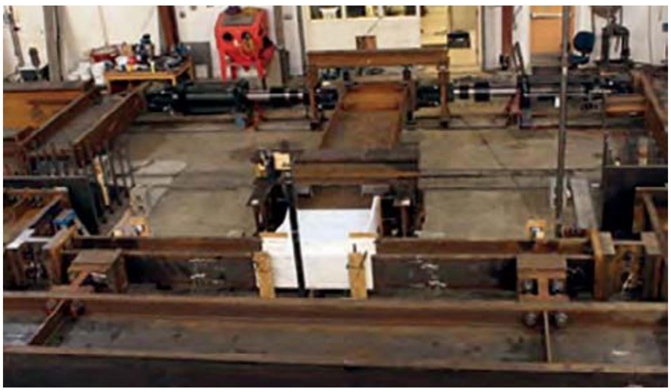


**Figure 7.16: Specimen in testing orientation with two actuators.**

The specimens were secured within a rigid frame that is affixed to the strong floor laboratory as illustrated in Figure 7.16 and the schematic representation in Figure 7.17. The pieces in red indicates where the frame was being fixed to the strong floor. The specimens were tested in the horizontal orientation in displacement control with the actuators reacting to the testing frame. The specimens were subjected to the loading protocol described in AISC 341-16.

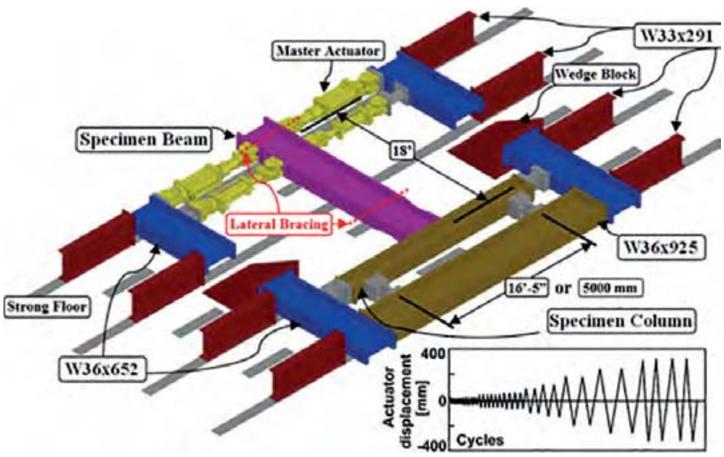



**Figure 7.17: Test setup with four actuators and loading protocol (ANSI/AISC 341-16).**

The test results, especially the M-θ response indicates typical flexural yielding and post-buckling softening after the maximum capacity was reached. Figure 7.18 shows the yielding patterns of SP2 at the end of the test.

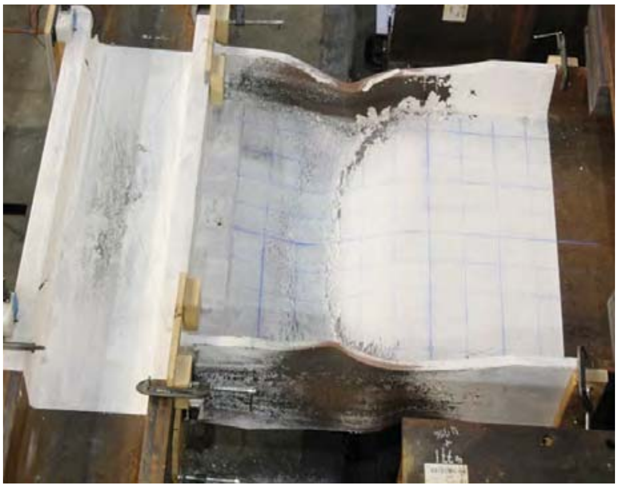


Figure 7.18 Images of the SP2 test specimen in the plastic regim

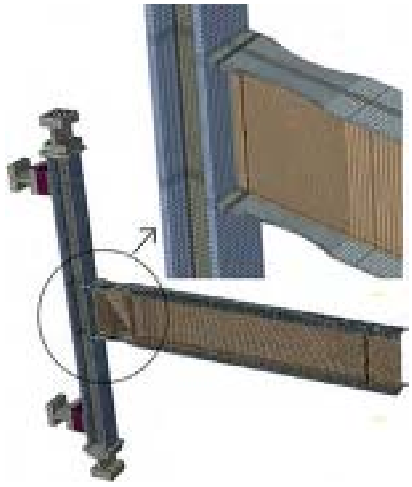


Figure 7.19. Abaqus Numerical model of SP2.

To obtain a more detailed insight into the behaviour, three-dimensional (3D) models of beam-column assemblages with RBS connection were constructed and analysed using the non-linear finite element (FE) program ABAQUS (DSS, 2014). Eight-node brick elements (C3D8R) were used in all models. Extruded solid elements from heavy W sections representing the column were connected to the beams using tie constraints. Special attention was given to the characteristics of the RBS region and the column PZ by considering the exact measured dimensions from the experimental specimens. The specimens, including the four stub elements made of W sections used as boundary conditions, were modelled together (Figure 7.19).

The non-linear numerical simulations of the all four tests are illustrated, in terms of M-θ curves, in Figure 7.20. Comparison with the test results indicate that the analysis provides an accurate representation in terms of stiffness and yield strength as well as overall hysteretic response.

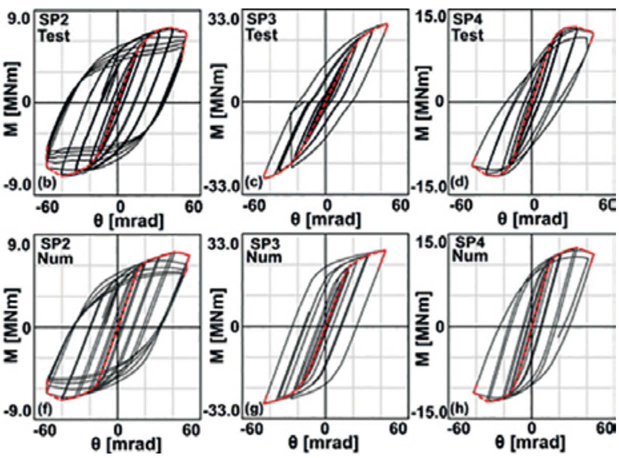



Figure 7.20 Comparative assessment of M-θ curves between the experimental tests and numerical simulations.

Importantly, the models can capture closely the initiation of local flange buckling as well as development and distribution of plasticity in the RBS and PZ regions. The experimental and numerical results showed that the strength, stiffness, ductility, hysteretic response and failure mode of such connections are largely dependent on the beam and column section sizes. The results indicated that RBS beam sections with relatively high depth-to-web thickness slenderness ratios develop reliable failure modes characterised by extensive yielding at the RBS, followed by yielding at the panel zone (PZ) and ultimately, flange buckling at RBS. Also, for relatively deep columns, force induction from beam flanges, combined with RBS flange buckling, could produce out-of-plane column rotation. These connections developed responses characterised by stable hysteretic response, a relatively strong PZ and reliable ductility levels. In contrast, compact sections with relatively low depth-to-web thickness ratios may develop unreliable response with yielding developing almost concomitantly and at RBS and PZ, having a relatively equal contribution to the total connection deformation. Numerical simulations showed that for connections with relatively compact sections, a higher concentration of stresses may occur at the PZ and at the beam, web with lower stress levels developing at the RBS flanges. These observations indicate the need for an alternative design procedure of RBS for connections incorporating large compact sections. More importantly, the connections investigated in this paper reached reliable rotational capacities, that correspond to a minimum inter-story drift required by North American prequalification standards.

Corresponding code changes based on the results of this research are expected in the next publication of AISC 358.

# 8. 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 can 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 finished product, the quality can be tested in advance.

**Figure 8.1: Driven piles with reinforcement at the base to increase the cone friction resistance and thus provide support for high loads**

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.

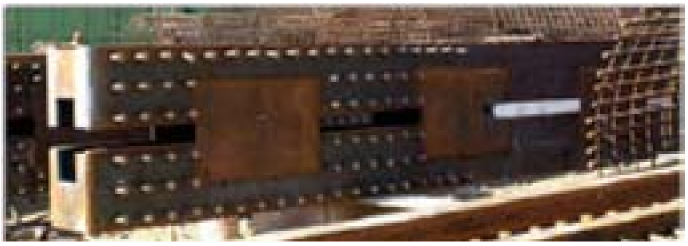
Steel piles generally obtain their bearing capacity through skin friction. In suitable soils, the point bearing pressure can also be considered in addition to the skin friction capacity. There are various ways to further increase the skin friction and point-bearing pressure, including, but not limited 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 8.1).

Rolled sections can be supplied within lengths up to 40 meters, as seen in the Wilhelmshaven Power Plant, which uses HE 800 B sections between 33,8 and 38,8m (Figure 8.2). 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.

## King Post Piles with Jumbos



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.

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 8.3). 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 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.

**Figure 8.2: Use of HE 800 B with lengths ranging from 33,80 to 38,80m for foundations (Wilhelmshaven power plant).**

**Figure 8.3: 26-metre long foundations for the top down construction method with no splicing required.**

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.

# 9. 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 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.


**Figure 9.1: Intumescent coating layer**

It is a reactive paint coating that expands under high temperature to provide adequate insulation to the steel member (Figure 9.1). As a paint coating, it offers several 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 9.2: 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 9.2). 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 9.3, 9.4)
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 9.3: Partially encased

Figure 9.4: Fully encased

**Fire safety engineering studies**
Adequate fire protection can be achieved for a reduced cost by applying several advanced fire engineering methods, which can optimise or, in some cases, completely avoid passive fire protection. One of the options available is the FRACOF (Fire Resistance Assessment of Partially Protected Composite Floors)/membrane effect. This method avoids any passive fire protection measures on secondary beams. Only beams linked to columns require protections (Figure 9.5).
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 9.5: Fire test on unprotected cellular beams (FRACOF)

Progressive collapse resisted through tensile forces in adjacent beams

Belt truss redistribute induced forced due to column loss

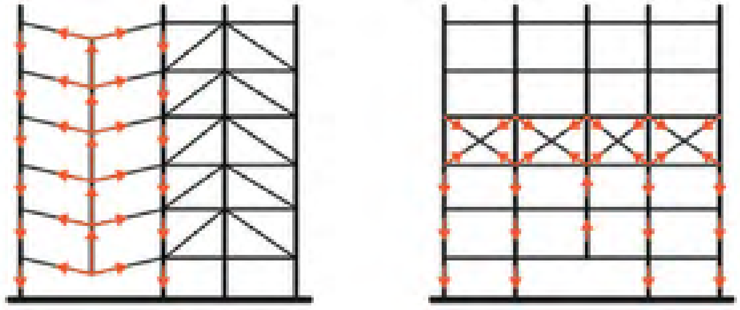


**Figure 10.1 Column loss scenarios with and without belt truss systems [Eltobgy, 2013][(1)] redrawn by CTBUH.**

# 10. 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 because 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. However, this a probabilistic value since the properties and the environmental conditions are not deterministic. 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 must be bigger that 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 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 the structure in the case there is a partial collapse of an element. The connection between the core and the columns is critical 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 10.1.

* 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 Internations, 16(2), 108-112.
*** ASCE, 2010. ASCE 7-10: Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers.
(1) Eltbology, 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.

*"HISTAR®/ASTM A913 material has enabled Walter P Moore to extend our reach in providing high-strength seismic systems in the most challenging locations. Grade 65 material, which is permitted for columns in ductile seismic systems, has enabled us to be more efficient and more effective in designing structures to withstand the most intense seismic motions."*

**Rafael Sabelli, S.E.**

Principal, Director of Seismic Design

WALTER P MOORE

San Francisco, USA

# 11. Earthquake design

Earthquake refers to the earth shaking with a sudden release of energy that creates seismic waves. These events are mainly cause 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 11.1). 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 reduces with the distance from the epicenter. Therefore, there are regions of the world with 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 11.2). The vertical component of the earthquake is usually about 50% of the horizontal component, except near 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 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 11.3). 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

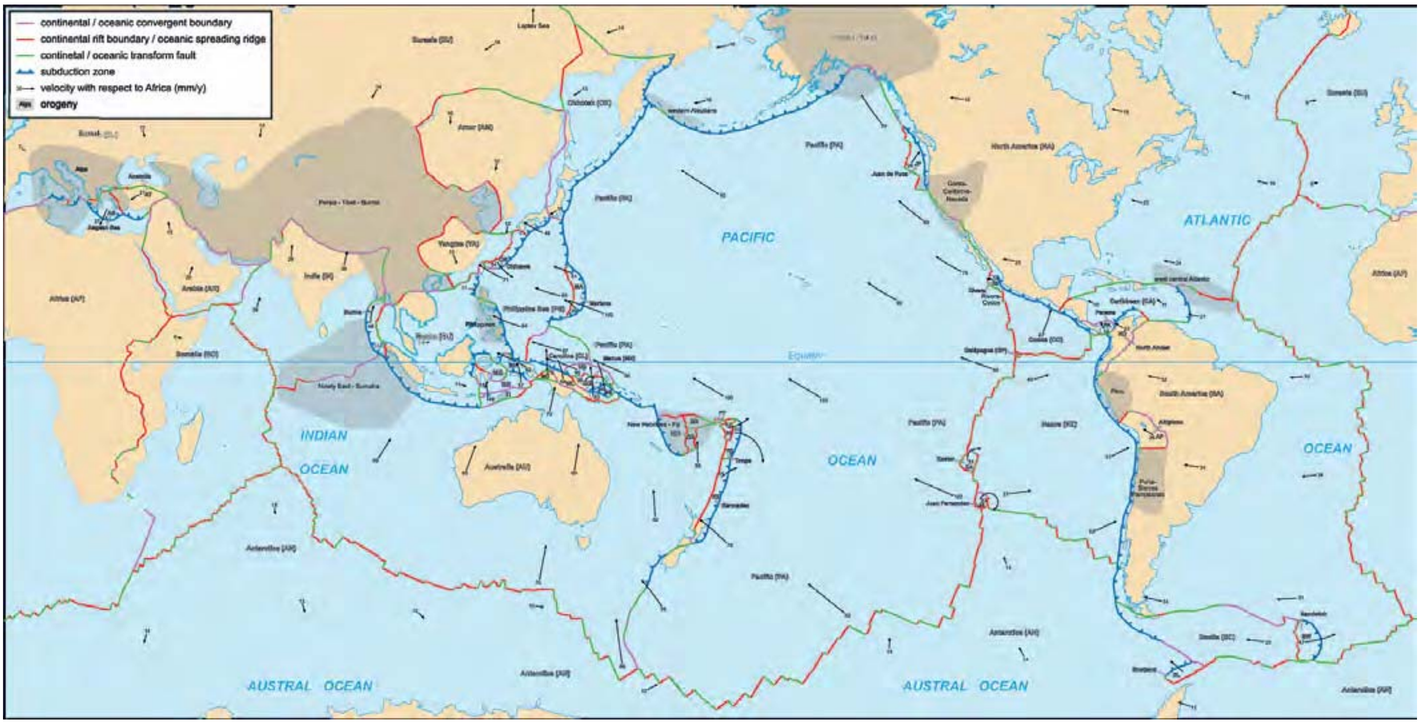
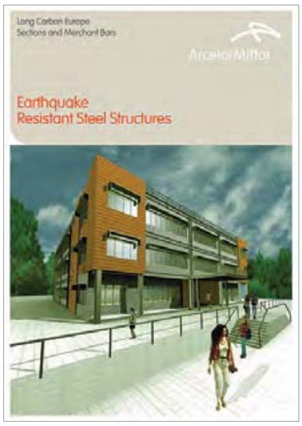



**Figure 11.1: World map showing the main tectonic plates. From Bristol University website: www.ideers.bris.ac.uk**

download from **sections.arcelormittal.com**:



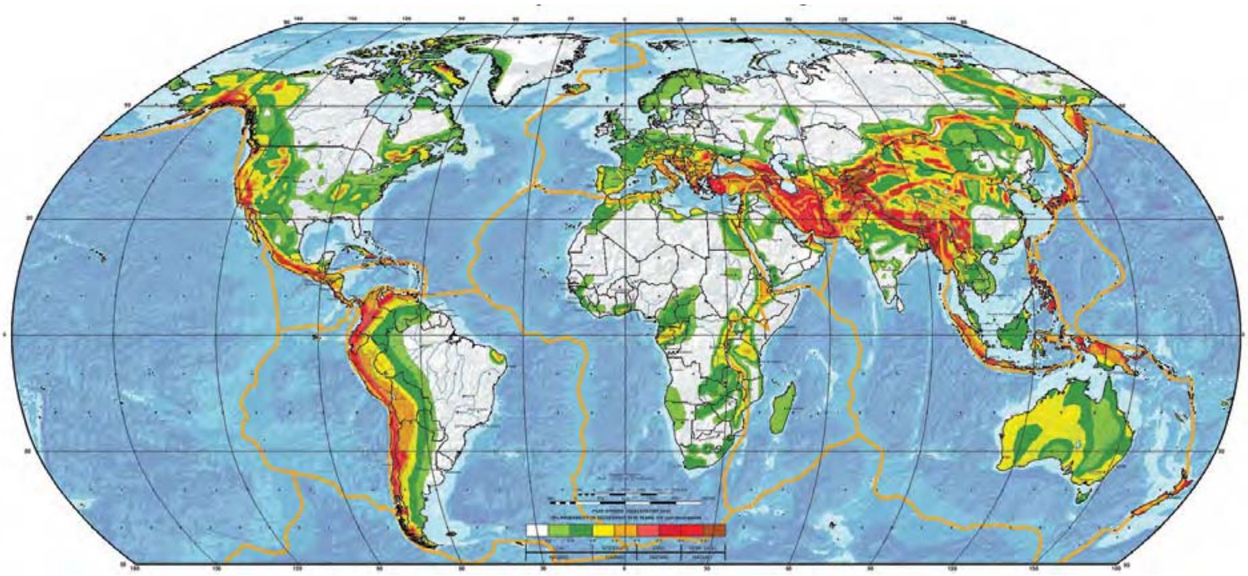



**Figure 11.2: Global seismic hazard map, 1999**

**[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 11.4.

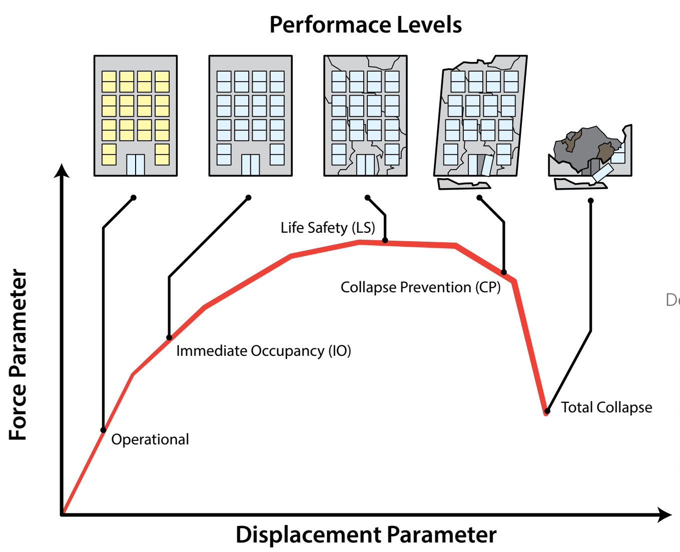



**Figure 11.3 Structural Performance Objectives**

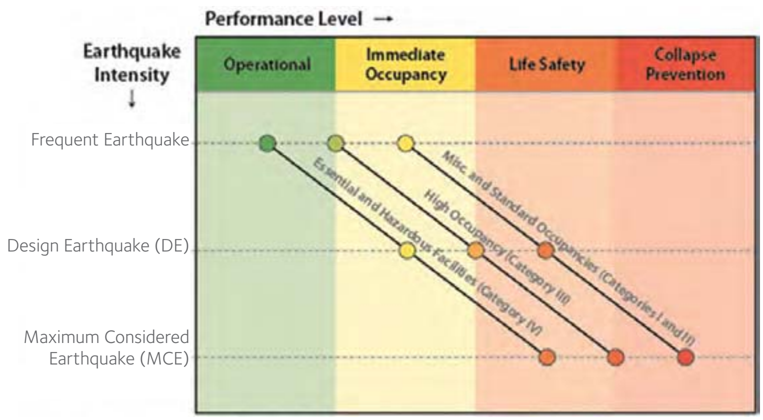



**Figure 11.4. Performance Levels of Code-Based Buildings at Various Risk Category Levels**

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 11.5. 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 is designed such that only those selected zones (plastic hinges) will be plastically deformed (as shown in Figure 11.6). 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 11.5). 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 11.6 to 11.8). This connection can be

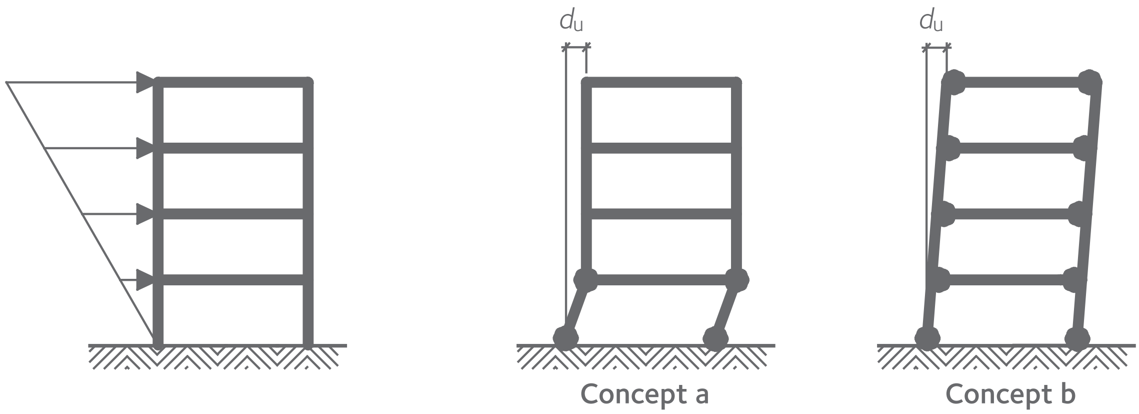



**Figure 11.5: Examples of 'Dissipative' and 'Non-Dissipative' global behaviours of structures. "Non-dissipative" structure fails in a soft single storey mechanism**

Figure 11.6: RBS: Reduced Beam Section Plasticisation

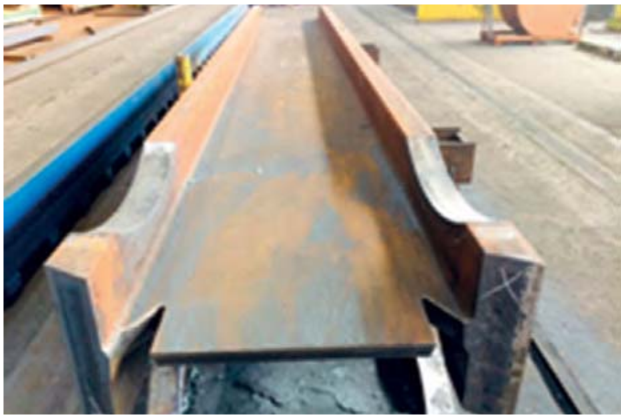


Figure 11.7: Reduced beam

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. Several steel moment frame buildings experienced brittle fractures of beam-to-column connections because of the earthquake. The SAC Joint Venture, under contract by FEMA, studied the "strong column – weak beam" design concept (Figure 11.8). 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.

Because 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 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 11.8). Prequalified joints for earthquake resistance as defined in the American code cover almost the whole range of ArcelorMittal sections (see chapter 7, page 46).


Figure 11.8: Reduced beam

download **Environmental Product Declaration** from **sections.arcelormittal.com**:

*HISTAR® steel: only ~600 kg $CO_2$ /tonne*

according to the Environmental Product Declaration


# 12. Sustainability of Steel

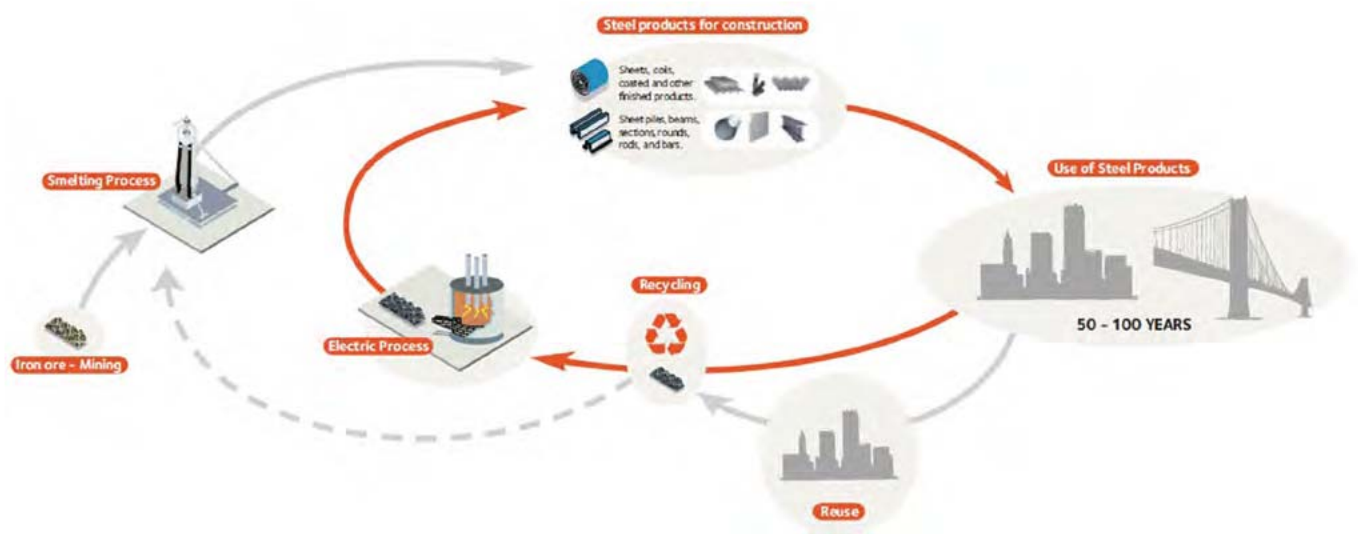



**Figure 12.1: 1,2 tonnes of steel recycled by ArcelorMittal each second**

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 most of the steel material used in new high-rise structures (Figure 12.1). 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's ferrous resource in the world. With 33 million tonnes of $CO_2$ 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 $CO_2$ 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.

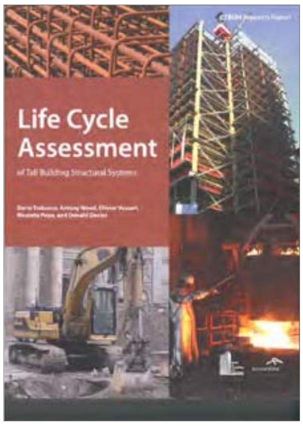


* see at the top of the page: Environmental Product Declaration

**www.eurofer.org (EUROFER Sustainability Vision Paper)

*"Sustainability has clearly become a major driver of change in tall building development..."*

according to "Life Cycle Assessment of Tall Building Structural Systems"




• 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. A complete description of the research programme, including detailed information on the individual studies that were performed, can be found at **https://store.ctbuh.org/research-reports/48-life-cycle-assessment-2015.html**.

• Global Warming Potential and Embodied Energy

Due to climate changes that have occurred in recent years because 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 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 $CO_2$ 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.

• Steel structure performances

To verify the sustainability of steel as a structural product, 60-storey tower scenarios were developed for different structural arrangements.
In this analysis, all-concrete solutions performed worse (on average) than the other scenarios that used steel, in terms of GWP (Figure 12.2).

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. Most 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

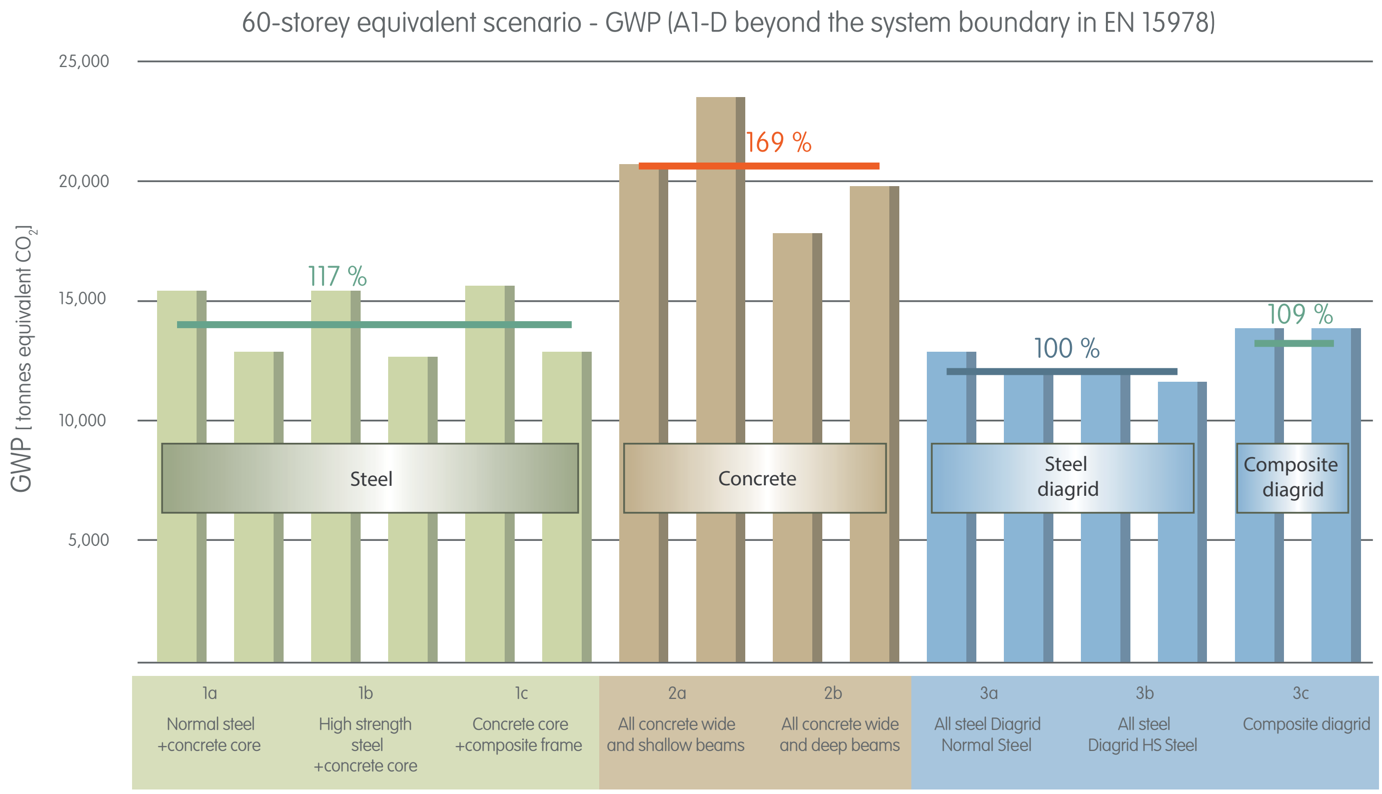



**Figure 12.2: LCA of the 60-storey Scenarios Global Warming Potential ($CO_2$)**

versus


avg1.7% in terms of GWP
avg1.9% in terms of EE

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

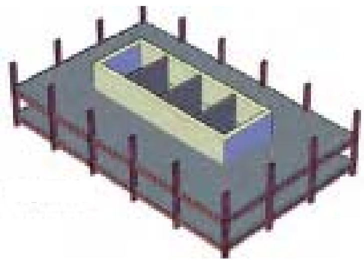
**Figure 12.3: Environmental effect of transport**

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 12.3).

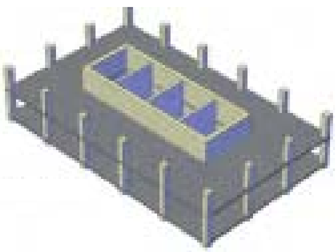
Furthermore, transportation of both construction materials to the site and transportation of demolition material and waste off sites does not account for a significant amount of the total GWP (between 1 and 2,5%) or the total EE (between 0,9 and 3,2%). This means that, in some cases, it is more important 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 58: **Environmental Product Declaration**).

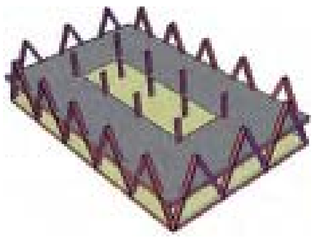
Also, the structures designed with these materials have a significantly lower GWP and EE than structures designed with the average environmental values published by WorldSteel (WorldSteel Association 2011)* (Hammond & Jones 2011)**.



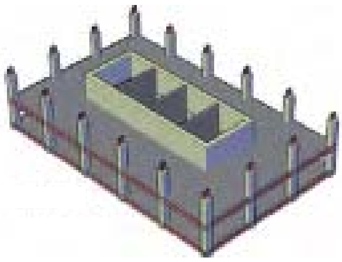
*Steel Frame with Concrete Core*



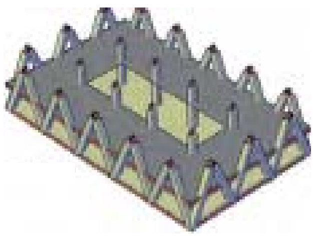
*Concrete Structure*



*Steel Diagrid Structure*



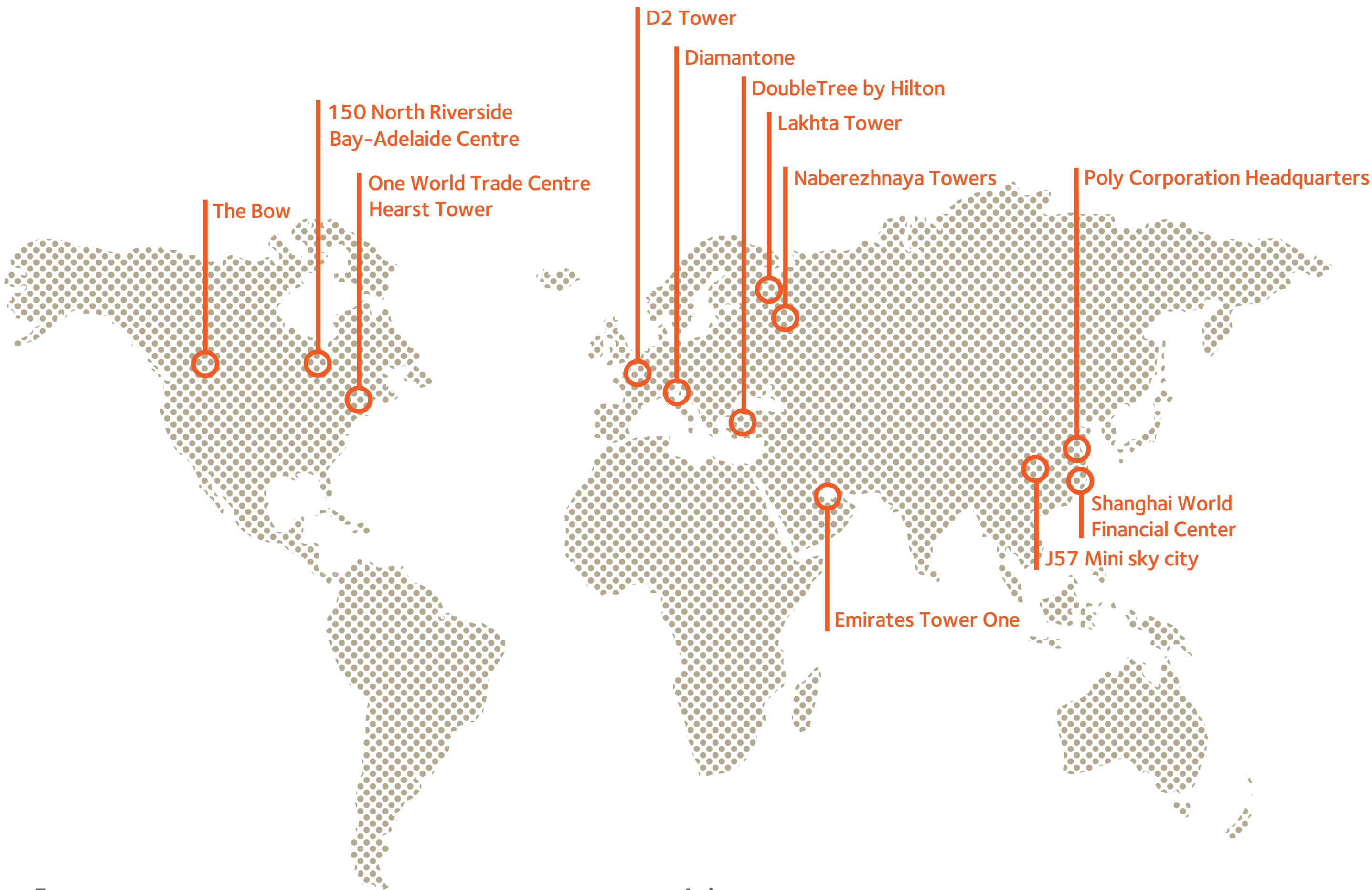
*Composite Structure*



*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.

# 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

**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

**Asia**

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

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


**ArcelorMittal on the Skyscraper Center:**
**http://www.skyscrapercenter.com/company/7007**

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

| Projects 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 |
| TORRE REFORMA 509 | MEXICO, ME |
| 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 AVNEUE* | 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 |
| PHELPS DODGE TOWER | PHOENIX, AZ |
| 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 |

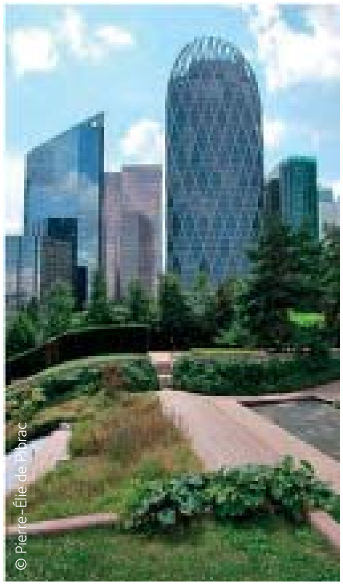
| Projects Europe | Location |
|---|---|
| REMBRANDT TOWER | AMSTERDAM, NL |
| TORRE MAPFRE | BARCELONA, ES |
| THE PINNACLE | LONDON, UK |
| 25 CHURCHILL PLACE | LONDON, UK |
| DIAMOND OF ISTANBUL | ISTANBUL, TR |
| HILTON DOUBLETREE HOTEL | ISTANBUL, TR |
| PUERTA DE EUROPA | MADRID, ES |
| TORRE REPSOL | MADRID, ES |
| TORRE DE CRISTAL | MADRID, ES |
| TORRE BANKIA | MADRID, ES |
| DIAMANTONE | MILANO, IT |
| DESIO TOWER | MILANO, IT |
| NABEREZHNAYA 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 |

| Projects 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 |

*using ASTM A913 Grade 70

Europe

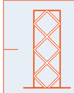
Height: 171m (561ft)
Number of Floors: 36
Gross floor area: 54 500m²
Building Function: Office
Structural material: Steel columns and beams with composite floors and a reinforced concrete core
Completion: 2014
Architect: Agence d'architecture Anthony Béchu – Tom Sheehan
Structural Engineer: DVVD; Setec TPI
General Contractor: GTM Bâtiment (Vinci group)
ArcelorMittal Steel: 3 000 tonnes of HD 400 sections in HISTAR® 460 and 1 200 tonnes of ACB® beams
Fabricator: Iemants



© Pierre-Élie de Pibrac

# D2 Tower (Paris, France)

Project Overview: To answer the specific needs for the construction of the D2 Tower, ArcelorMittal supplied 50,000 m² of steel for the composite floor deck and 4 200 tonnes of structural steel and beams. Designed in the large urban renewal project of La Défense, the D2 Tower, inaugurated in January 2016, is the first high rise building in France with an external steel grid structure.

| 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 |

- Steel Structure

The perimeter diagrid consists of large and heavy, hot rolled steel sections, mainly HD 400, in HISTAR® 460 steel grade, allowing interesting 30% weight reduction and about 25% cost decrease for the steel needed for the building structure. Mainly 12m long sections were assembled on site in a V-shape, each weighing about 14 tonnes. Each V covers the height of 3 floors and is integrated into the curtain wall of different sized and shaped glazed elements. The ACB® beams' circular openings in the web simplified the layout of the technical installations and an increased usable floor height.

- HISTAR® 460 & ACB® beams

ArcelorMittal Europe – Long Products provided 4,000 tonnes of structural steel, thereof 3 000 tonnes of HISTAR® 460 sections for the diagrid and 1 200 tonnes of ACB® beams.
To note that hot rolled sections in high strength steel grades are produced by few mills on the market and ArcelorMittal Differdange is the only one capable to offer HISTAR® grades.

ArcelorMittal Construction France also contributed to this project, providing 50 000 m² of Cofraplus® 60, composite steel decking for the floors. Chosen for its light weight and high strength, it combines the performance of a galvanized steel profile with that of reinforced concrete. The ACB® beams between the external structure and the concrete core support the Cofraplus® 60 floor deck.

- Shortening construction time

Thanks to the steel structure the weight of the tower was significantly reduced compared to a concrete structure. The steel structure reduced the overall costs, shortened the construction time, allowed a faster occupancy and return on the investment.
Overall, the use of a composite flooring system and cellular floor beams increased the total usable floor area and allowed the construction to be time efficient: according to time schedule and budget, the construction could be carried out at a steady rate of 3 floors in 3 weeks.

Europe

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
Fabricator: ENKA



# Naberezhnaya Towers (Moscow, Russia)

Project Overview: 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.

| 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 |

## • 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.

## • HISTAR® 460

The Naberezhnaya Towers are the first projects to use a special high strength steel produced by ArcelorMittal (HISTAR® 460 for Russian weather conditions). 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

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
ArcelorMittal Steel: 3 800 tonnes
Fabricator: StahlBau Pichler in Bozen/Bolzano

© Lorenzo de Simone

# Diamantone (Milan, Italy)

Project Overview: 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.

| 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 |

## • Steel Structure

Designed with steel columns, composite flooring, and a reinforced concrete core, the building is lighter than a conventional reinforced concrete structure. 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 just 10-15 % higher than S235 grade material, 30-40% of the savings could be achieved exclusively in the material costs.

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 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 Sections

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.

## • Avoiding traffic impact

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.

Europe

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: 2000 tonnes
Fabricator: Gülermak


# DoubleTree by Hilton (Istanbul, Turkey)

Project Overview: 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.

| Building systems / Steel Solutions | ArcelorMittal Solutions | | | Fire resistance |
|---|---|---|---|---|
| | Heavies | High strength steel | Finished beams | |
| Bracing | steel frame | HISTAR® 460 | | Intumescent coating |
| Columns | perimeter columns | HISTAR® 460 | | Intumescent coating |
| Floor solutions | | S355 primary beams | composite beams | Intumescent coating |

## • 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 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.

## • HISTAR® 460 Jumbo columns

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

Height: 462m (1 516ft)
Number of Floors: 87
Gross floor area: 163 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
Fabricator: CIMOLAI, NTZMK, BELENERGOMASH, CZMK, ZZMK, Kurganstalmost


# Lakhta Center (St. Petersburg, Russia)

Project Overview: 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. The tower will be the headquarter of Gazprom, the world's largest gas company.

| Building systems / Steel Solutions | ArcelorMittal Solutions | | | Fire resistance |
|---|---|---|---|---|
| | Heavies | High strength steel | Finished beams | |
| 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 |

## • HISTAR® 460

The structural frame of the tower's star shaped cross-sectional footprint, slightly different on every floor, features at its centre a circular core in concrete housing mainly the elevators. The tower's 73 000 m² facade is formed from 16 500 pieces of glass. At its perimeter, the structure rests on steel-composite-columns made of structural sections in quality steel HISTAR® 460 Russia. This high-performance steel grade allowed relevant cost savings in the programme, by optimising the weight and time to process and install.

The heavy H-sections were processed by cutting into T-sections to make cruciform shaped column profiles, which were subsequently encased in concrete. For the construction of the tower and the two multi-functional buildings, ArcelorMittal Europe – Long Products' mill in Differdange (Luxembourg) delivered 21 254 tonnes of steel sections, that includes processing. Differdange mill is the only plant offering HISTAR® 460 that combines extremely demanding mechanical requirements with an excellent ease of processing at welding. The Differdange mill is known for an excellent track record of delivering tall buildings of this nature and is a proud supplier in helping to shape the skylines of cities across the world.

## • 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. 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.

## • ArcelorMittal technical support

At ArcelorMittal, the detection and following of this project already began in 2008. Over the years, at each phase of the project's development, the teams convinced the structural engineers and the general contractor of the job to select a solution with heavy sections. Our research center in Esch (Luxembourg) was right from the start on board to support the mill in fine-tuning the quality of the steel and to achieve its homologation as HISTAR® 460 Russia with the relevant official institute and authority in Russia.

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America

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 super columns, 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
Fabricator: Cives Northern


# Hearst Tower (New York, USA)

Project Overview: 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 in 1928. Envisioned as the base of a skyscraper, the height was stunted due to the Great Depression. More than 70 years later, the Hearst Tower gave nod to Mr. Hearst's vision by incorporating his original building's façade into its final design. The tower presents a distinctive method to create dialogue between old architecture and new by using a completely glass facade that appears to be floating above the base. Upon entering the building, occupants are greeted with a spacious lobby, which occupies the entire space of the original building and provides access to the main elevator lobby, cafeteria, auditorium and meeting areas.

| Building systems / Steel Solutions | ArcelorMittal Solutions | | | Fire resistance |
|---|---|---|---|---|
| | Heavies | High strength steel | Finished beams | |
| Bracing | diagrid | | | sprayed |
| Columns | perimeter column: W14 x 16 | A913 - Grade 65 | | sprayed/Intumescent coating |
| Floor solutions | | A913 - Grade 50 | composite beams | sprayed |

## • Structural System

The four sides of Hearst Tower are formed by a diagonal steel structure wrapping around the perimeter of the building and braced by a steel core. This series of 16,5-meter-tall triangulated structural elements form a steel "diagrid" – an efficient structural form that results in a 20-percent reduction in the volume of steel required to support the building, when compared to a conventional moment frame structure. Bolstered by ten-storey-tall concrete-reinforced steel super columns, the diagrid system contributes to the building's overall structural stability and in conjunction with the tower's composite steel and concrete floors, enables 12-meter-long column-free spans throughout the building's interior.

## • ArcelorMittal Steel Sections

Contributing more than 10 000 tonnes of structural steel to this project, ArcelorMittal's HISTAR Grade 460 (ASTM A913 Grade 65) sections make up the visually striking diagrid system, visible on the facade of the building, and serving as the wind bracing and gravity load system. The external cladding of the diagrid is covered with stainless steel to give the tower its clean and modern finish.

## • Sustainability

Considered one of the most environmentally friendly buildings ever constructed, Hearst Tower was the first New York City commercial office building to achieve LEED Gold Certification from the US Green Building Council and bettered itself in 2012 with a LEED Platinum rating. Built using 85-percent recycled steel and designed to consume 26-percent less energy than conventional buildings, the building's sustainable features include: a 64-cubic-meter reclamation tank that collects rainwater runoff from its roof; a high-performance, low-emission glass facade that enables internal spaces to be flooded with natural light, while limiting solar radiation from overheating interior spaces; light sensors that control the amount of artificial light used on each floor based on the available natural light; motion sensors that allow lights and computers to be automatically turned off in vacant rooms; and high-efficiency heating and air-conditioning equipment, which utilise outside air for cooling and ventilation for 75 percent of the year.

America

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
Fabricator: Supreme / Walters Joint Venture


# The Bow (Calgary, Canada)

Project Overview: Calgary's second tallest building, The Bow features a unique curved design that is articulated by its external structural steel diagrid. Derived from an in-depth climate analysis, the south-facing tower's bold form curves toward the sun to maximize occupants' exposure to natural light and heat, and by turning the convex facade into the prevailing wind, the structural loads are minimised. The building features three spacious, six-storey-tall sky gardens and a series of atria, which gives occupants a working environment that promotes sociability and interaction.

| 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 |

## • Structural System

To achieve the building's aesthetic, sustainability, geometry, and space planning goals, steel was a natural choice for The Bow's structure. The building's distinct perimeter diagrid frame contributes to its hybrid lateral force resisting system (LFRS) – the remainder of which is composed of three braced frames on the curved south elevation, two on the north elevation, and steel moment resisting frames throughout.

Due to its location south of the Bow River, it was required that the top of the building be low enough to avoid casting shadows on the river in the September equinox. To achieve this demand, a network of interior columns was added to cut down floor spans and maintain a depth of floor framing less than 485mm.

## • ArcelorMittal Steel

As Canada's largest steel-framed building, The Bow is comprised of 39 000 tonnes of steel, of which 3 320 tonnes are ArcelorMittal's HISTAR Grade 460 (ASTM A913 Grade 65) wide-flange shapes. The use of high strength structural steel enabled benefits that include: smaller vertical load carrying members; lightweight, long-span floors; large column free areas for more open spaces and increased flexibility to meet tenant needs; as well as more economic foundations, when compared to a concrete building, due to reduced weight of the overall structural system.

America

Height: 541,3m (1776ft)
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:15 000 tonnes of steel, primarily W14 x 16 in A913 - Grade 65
Fabricator: Banker and ADF


# One World Trade Center (New York, USA)

Project Overview: Representing renewal and hope, One World Trade Center stands at a symbolic 1 776 feet (541m) in height – including its spire – and features a slender, tapering triangular form that shimmers in the light and acknowledges the National September 11 Memorial that exists adjacent to it. The tower's design is an innovative mix of architecture, safety and sustainability sets a high standard of social responsibility in urban design by incorporating new architectural and environmental standards. With a total usable floor area of over 325 000m², the tower is composed of 71 levels of office space, a grand public lobby, an observation deck, parking, 5 100m² of below-grade retail space, as well as broadcast and antennae facilities.

| 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: W14 x 16 | A913 - Grade 65 | | sprayed |
| Floor solutions | | | cellular beams | sprayed |

### • Structural System

One World Trade Center's structure employs a ductile perimeter steel moment frame that surrounds a reinforced concrete core wall system, which work together to provide resistance to gravity, wind and seismic forces. The combined structure lends substantial rigidity and redundancy to the overall building, while providing column-free interior spans for maximum office flexibility. The building's chamfered corners form an aerodynamic and structurally efficient shape, which reduces exposure to wind loads and therefore reduces the amount of building materials necessary due to lower demands on the tower's lateral system.

### • ArcelorMittal Steel Sections

While 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 HISTAR® Grade 460 (ASTM A913 Grade 65) sections as large as W14x730 serving as columns at the perimeter of the tower's base.

### • Safety and Fire Design

Following a new generation of life-safety standards, which incorporate redundant measures, the structure features enhanced fireproofing for the structural steel, an egress route (core) that is enclosed by up to three feet of reinforced concrete, dual interconnected fire standpipes, and extra water storage to allow for high capacity sprinkler heads. In addition to its 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, these features were all integrated into the design without negatively affecting the efficiency or constructability, and they are considered highly advanced state-of-the-art life-safety systems that will lead the way for new high-rise building standards.

America

Height: 221m (724ft); Number of Floors: 54
Gross floor area: 136 010m² (1,463,999 ft²)
Building Function: Office; Completion: 2017
Structural material: Steel columns, composite beams and concrete core
Developer: Riverside Investment & Development
Architect: Goettsch Partners
Structural Engineer: Magnusson Klemencic Associates
General Contractor: Clark Construction Group, LLC
ArcelorMittal Steel: 3534 t incl. 1 365 t of W14 x 16 in A913 Grade 65 and 109 t of W14x16 and W14 x 16 in A913 - Grade 70
Fabricator: Zalk Josephs

# 150 North Riverside (Chicago, USA)


Project Overview: Located just meters away from the Chicago River to its east and a century-old railway to its west, 150 North Riverside is a 54-storey office building that features 136 010m² of leasable space. A signature component of the building is the core-supported structure, which was required in response to the constraints of the site. This innovative solution resulted in the tower's dramatic form and enabled its footprint to have an area 70-percent smaller than the typical floors above.

| 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 |

- Structural System

Designed as a typical office building from level 8 through level 54, the core-supported plan employs an efficient, yet complex, transfer truss system to shift the load from its exterior columns to be supported on its concrete core. The core rests on a 3m-deep concrete mat supported on a collection of 16 rock-socketed caissons below, each with a 3m diameter.

- ArcelorMittal Steel

Constructed using 2 530 tonnes of ASTM A913 Grades 65 and 70 wide-flange shapes, these products not only enabled the design of a more efficient structure, but they also contributed to simplification in the fabrication and erection of the complex elements in this system. Benefits include:

  - Reduction of 18% (550 tonnes) in the weight of wide-flange column elements, a benefit that limits the building's carbon footprint, lowers material transportation costs and decreases the demand on crane lifts
  - Substitution of single W36x925 (A913 Grade 65) rolled sections to replace the built-up, concrete-filled box sections originally considered for the sloping transfers to the concrete core
  - Utilisation of toe-to-toe W36x925 (A913 Grade 65) rolled sections in lieu of built-up box sections at the mega-columns at the building's north and south faces
  - Elimination of the need for preheat at A913 Grade 65 columns where heavy cantilevered floor framing elements connected across the section

- ArcelorMittal Technical Support

Working closely with the structural engineer and fabricator, ArcelorMittal's technical support team consulted on value engineering propositions that enabled a 6% total savings in the weight of the structural frame and resulted in this tower being first in the world to employ the world's largest structural shapes: W36x925 and W14x873 sections.

America

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: 1 915 tonnes A913 - Grade 65, 1 330 tonnes in A913 - Grade 70
Fabricator: Walters

# Bay-Adelaide Centre (Toronto, Canada)

Project Overview: Located in Toronto's financial district, and comprised of the presently completed East Tower (22 Adelaide Street West) and West Tower (333 Bay Street), as well as the planned North Tower, Bay-Adelaide Centre will – upon completion – house more than 300 000 sq m of "AAA" class commercial office space, a city park and an open-air plaza. Originally conceived in 1987, the development has a storied history, having passed through numerous proposed configurations, a selection of construction starts and stops, and most important in the storybook of structural steel – it has twice served as the pilot project for ArcelorMittal's HISTAR® (ASTM A913) steel.

| 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 |

## • ArcelorMittal Steel Sections

Bay-Adelaide Centre's East and West Towers are both composite buildings that feature structural steel gravity systems with a central concrete core that resists lateral loading. Combined, ArcelorMittal has contributed more than 5 285 tonnes of material to these buildings, including 1915 tonnes of ASTM A913 Grade 485 and 1330 tonnes of ASTM A913 Grade 70. For Bay-Adelaide Centre's East Tower, the structural system realised an overall weight savings of more than nine percent when the high-strength steel was used in columns and short-span transfer girders – a benefit that not only reduced the cost of the building, but also contributed to limits in the loss of useable floor area due to reduced sizes of vertical columns.

## • ArcelorMittal Technical Support

Bay-Adelaide Centre's lead structural engineer has stated that working on the design of an office complex for more than 25 years enabled ample opportunity for innovation. Embracing that notion, the engineer continuously engaged with ArcelorMittal's technical support team, to access literature on new products, understand material composition, and obtain material test results – intel that was necessary to evaluate value engineering options and to present new products for approval by building code officials. The successful collaboration between this engineer and ArcelorMittal's technical support team resulted in Bay-Adelaide Centre holding titles of being first development in the world to use HISTAR® Grade 460 (ASTM A913 Grade 65) – for design of the 1989 version of the project's first tower* - and being first in the world to use HISTAR® Grade 485 (ASTM A913 Grade 70) – for the construction of the East Tower.

* Bay-Adelaide Centre's first tower – namely, South Tower – was the first high-rise in the world to incorporate HISTAR® (ASTM A913) steel into its design. Material for the first several levels of the building was produced, delivered, and fabricated, but due to an economic recession in Toronto, the building ceased construction in 1991 and its HISTAR® (ASTM A913) steel was not erected.

Asia

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
Fabricator: Eversandai


# Emirates Tower One (Dubai, UAE)

Project Overview: The Jumeirah Emirates Towers are one of the most distinctive skyscraper duos in the world and were some of the first high-rises 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.

| 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 |

## • Structural System

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 provides for maximum stability. A steel and concrete hybrid solution throughout the tower allows for an abundance of column-free office space.

## • HISTAR® 460

Building stability is 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

Height: 207,8m (682ft)
Number of Floors: 57
Gross floor area: 179 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
Fabricator: Yuanda Keijian

# J57 Mini Sky City (Changsha, China)

Project Overview: 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.

| 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 |

## 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.

## HISTAR® 460 prefabricated sections

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 $CO_2$ emissions compared to conventional buildings with a similar function. Furthermore, another reason for which ArcelorMittal was specifically selected was the fact that the majority of the steel from Differdange was derived from recycled scrap steel elements.

## Speed of construction

The structure of J57 is entirely made of steel and has no concrete core. As it was 90% prefabricated in the factory it was possible to erect 3 floors per day.
In total, less than 19 days were necessary to erect the building, hosting 4 000 offices and 800 apartments.

Asia

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
Fabricator: Jinggong Gang-Gou


# Poly Corporation Headquarters (Beijing, China)

Project Overview: 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.

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

## • ArcelorMittal Steel Sections

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.

Asia

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
Fabricator: 'Grand Tower' Steel Structure

# Shanghai World Financial Center (Shanghai, China)


Project Overview: 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.

| 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 |

- Steel Structure

High-strength steel was 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.

- HISTAR® 355

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 several structural elements. For example, at any level the small perimeter columns can 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.

Regarding 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.

*"ArcelorMittal's technical support is thoughtful, forward-looking and robust. MKA continues to benefit from the collaborative and supportive relationship ArcelorMittal provides."*

**Ron Klemencic, P.E., S.E., Hon. AIA**

Chairman & CEO

MAGNUSSON KLEMENCIC ASSOCIATES
Structural + Civil Engineers

Seattle, USA

# 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.sales@arcelormittal.com**

• Steligence® Fabrication 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 1 500 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 11 research centers located in Europe and North America.

In 2018 we invested $290 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
24-26, Boulevard d'Avranches
LU-1660 Luxembourg
T : +352 4792 4800

**Sales agencies**

**AFRICA**
ArcelorMittal International Africa
Casanearshore park
Shore 18- N° 302-2
1100, Bd Al Qods - Sidi Maarouf
MA- Casablanca
T : +212 522 74 96 00

**BRAZIL**
ArcelorMittal International Brasil
Alameda Santos 700, 12° andar, Cerqueira Cesar
CEP 01418-100 SP - São Paulo
T : +55 11 36 38 69 04

**CHILE**
ArcelorMittal International Chile
Av. Providencia, 1208 - Oficina 1805
Ed. Pamplona/Providencia/Santiago
T : +56 2 2248 3391

**CHINA (People's Republic of )**
ArcelorMittal International Shanghai
Unit A2-13F Time Square, 500 Zhangyang Road
Pudong, CN- Shanghai 200122
T : +86-21 58 36 82 00

ArcelorMittal International Beijing
Beijing Vantone Center, Tower A, Room 1702 No. 6
Chaowai Street, Chaoyang District 100020 Beijing
CN- 100020 Beijing
T : +86-10 59 07 05 03

ArcelorMittal International Hong Kong
Room 2301, 88 Hing Fat Street,
Causeway Bay, Hong Kong
T : +852 2522 4123

**COLOMBIA**
ArcelorMittal International Colombia
Calle 90 N° 12 # 45 Of. 605 - Bogotá
T : +57 1 623 40 22

**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

**EGYPT**
ArcelorMittal International Fze Representative Office
Unit No F19, Floor No 1,
Katameya Heights Business Center,
5th Settlment, New Cairo 11835 – Egypt
T : +20 2 20200084

**INDIA**
ArcelorMittal International India
Unit 202 A, Dosti Pinnacle,
Wagle Industrial Estate,
IN-400604 Thane (West)
T +91 22 4248 9518

ArcelorMittal International India
6th Floor, M6 , Uppal Plaza (Near Apollo Hospital)
Jasola Community Center, Jasola
IN- 110044 New-Delhi
T : +91 11 46759492

**KOREA**
ArcelorMittal International Korea
6F Jinnex Lakeview, 99 Ogeum-Ro
Songpa-Gu, Seoul, Korea
Postal code 05548
T : 82-2-6200-6571

**MEXICO**
ArcelorMittal International Mexico
Calle Privada de los Industriales 110 A
Desp. 802
Col. Industrial Benito Juarez
Queretaro, Qro.
MX-76100 MEXICO
T : +52 442 218 6872

**NIGERIA**
ArcelorMittal Projects Nigeria
22B Olori Muyibatu Oyefusi Street
Off Omorinre Johnson
Lekki Phase 1, Lagos, Nigeria
T : +234 1 277 0802

**PERU**
ArcelorMittal International Peru
Calle Tomas Ramsey N° 930
Oficina 1105 - Magdalena del Mar - Lima 17
T : +51 1 26 13 131

**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

**SENEGAL**
ArcelorMittal International Africa
Immeuble Lot 43
Ambassade du Luxembourg
Cité des jeunes cadres Lébous
Route de l'Aéroport Léopold
Sédar Senghor – Yoff BP 11750 Dakar, Senegal
M +221 775 696 354/ +221 785 897 232

**SINGAPORE**
ArcelorMittal International Singapore
08-01/05 Anson House - 72, Anson Road
SG-079911 Singapore
T : +65 67339033

**SOUTH AFRICA**
ArcelorMittal South Africa
PO Box 2 PP 10109
Vanderbiljpark 1900
REPUBLIC OF SOUTH AFRICA
T : +27 (0)16 889 4440
T: +27 ( 0) 889 3661

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

**TURKEY**
ArcelorMittal CL Çelik Deş Ticaret A.Ş.
Esentepe Mah. Büyükdere Cad.
Metrocity A Blok 171/A Kat:23 Şişli
TR-34394 Istanbul
T : +90 212 317 49 24

**UNITED ARAB EMIRATES**
ArcelorMittal International FZE
Plot S40703 - South Zone 4
AE-PO Box 262098 - Dubai
T : +971 4 803 5900

**UNITED STATES OF AMERICA**
ArcelorMittal International North America
1 South Dearborn, 18th floor
US-Chicago, IL, 60603
T : +1 312 899 3500

**UKRAINE**
ArcelorMittal International Ukraine
20 Velyka Zhytomyrska str.
01025 Kyiv, Ukraine 01601
T : +38 044 321 0 321

**VIETNAM**
ArcelorMittal International Vietnam
D35, 40 Ba Huyen Thanh Quan, Ward 6
Dist. 3, Ho Chi Minh City, VN
T : + 84 28 39307248

sections.sales@arcelormittal.com

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# ArcelorMittal Commercial Sections

## Headquarters

**LUXEMBOURG**
ArcelorMittal Commercial Sections
66, rue de Luxembourg
LU-4221 Esch sur Alzette
T : +352 5313 3010

**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

**BELGIUM + THE NETHERLANDS**
ArcelorMittal Commercial Netherlands B.V.
Eemhavenweg 70
NL-3089 KH Rotterdam
T : +31 (0)10 487 09 22

**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

**CZECH REPUBLIC**
ArcelorMittal Europe CZ s.r.o.
Francouzská 6167
CZ-708 00 Ostrava Poruba
T : +420 553 401 005

**DENMARK**
ArcelorMittal Commercial Long Denmark A/S
Artillerivej 90, stuen
DK-2300 Copenhagen S
T : +45 33 74 17 11

**ESTONIA**
ArcelorMittal Commercial Baltics OÜ
Roosikrantsi 2
EE-10119 Tallinn, Estonia
T : +372 51979170

**FINLAND**
ArcelorMittal Commercial Long Finland OY
Topeliuksenkatu 15
FI-00250 Helsinki
T : +358 9 74 222 460

**FRANCE**
ArcelorMittal Commercial Long France S.A.S.
Domaine de Pelus
16, Avenue de Pythagore
FR-33700 Merignac
T : +33 5 57 92 09 10

**GERMANY**
ArcelorMittal Commercial Long Deutschland GmbH
Gereonstraße 58
50670 Köln
T : +49 221 572 90

Augustenstraße 7
DE-70178 Stuttgart
T: +49 711 489 80 0

**GREECE AND CYPRUS**
ArcelorMittal Europe - Long Products
9, Karagiorga Saki Str
GR-16675 Glyfada Athens
T : +30 210 960 42 79

**ICELAND**
Gudmundur Arason EHF
Skútuvogur 4
IS-104 Reykjavik
T : +354 568 6844

**ITALY**
ArcelorMittal Commercial Italy
Strada Torino 43
IT -10043 Orbassano (Torino)
T : +39 011 906 3931

**NORWAY**
ArcelorMittal Commercial Long Norway A/S
Holmenveien 20,
NO-0374 Oslo
T : +47 22 83 78 20

**POLAND**
ArcelorMittal Commercial Long Poland
Al. Pilsudskiego 92
PL-41 308 Dabrowa Gornicza
T : +48 32 776 92 45

**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

**SWEDEN**
ArcelorMittal Commercial Sweden AB
Västmannagatan 6
S-11124 Stockholm
T : +46 8 534 80 94 0

**SWITZERLAND**
ArcelorMittal Commercial Schweiz AG
Industriestrasse 19
CH-8112 Otelfingen
T : +41 56 437 16 70

**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

**UNITED KINGDOM**
ArcelorMittal Commercial UK Ltd
3rd Floor, Fore 2
Huskisson Way, Shirley
Solihull B90 4SS - Great Britain
T : +44 121 713 6600

## Services

**Steligence® Fabrication Centre**
Z.I. Gadderscheier
L-4984 Sanem
Tel.: +352 5313 3057
cs.eurostructures@arcelormittal.com

Find also your local agency at
**sections.arcelormittal.com**/About us.

sections.sales@arcelormittal.com