Niobium

High Strength Steel

Light Weight and Weldable

Lean and Competitive Design

Environmentally Sustainable Structure

REFORMA 509 – *A TALL BUILDING CASE STUDY*

DR JITENDRA PATEL EngD MBA CEng IMechE

CONSULTANT, CBMM TECHNOLOGY SUISSE S.A.

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jp@imetallurgy.co.uk

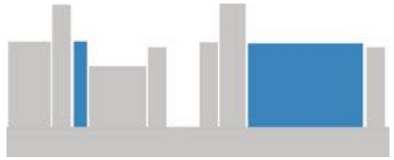
Presentation content

1. Definition of tall buildings
2. Tall buildings in the South East Asia region
3. Steel framing structures
4. The roll of steel in tall buildings
5. Case study: REFORMA 509

What is a tall building ?

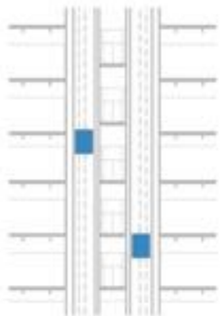
There is no absolute definition of what a "tall building" is.
The following elements are taken into consideration:

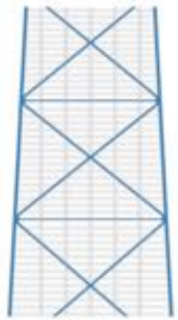
1. **Height relative to context**
2. **Proportion**
3. **Tall building technologies**



Although number of floors is a poor indicator of defining a tall building due to the changing floor to floor height between differing buildings and functions.

A building of 14 or more stories, or over 50 meters (165 feet) in height, could be used as a threshold for considering it a "tall building."





Source: CTBUH website

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Super tall buildings in South East Asia

The CTBUH defines “supertall” as a building over 300 meters (984 feet) in height, and a “megatall” as a building over 600 meters (1,968 feet) in height.

Although great heights are now being achieved with built tall buildings - **in excess of 800 meters (2,600 feet) - as of 2014 there are only < 80 supertall and 2 megatall buildings completed and occupied globally.** Thus the completion of a supertall building is still a significant milestone.

3/100	Taipei 101 - Taiwan - 508m - 101 floors - 2004
6/100	Petronas 1 - Kuala Lumpur - 451.9m - 88 floors - 1998
6/100	Petronas 2 - Kuala Lumpur - 451.9m - 88 floors - 1998
32/100	Tuntex Skytower - Taiwan - 347.5m - 54 floors - 1997
59/100	Menara Telekon Tower - Kuala Lumpur - 310m - 55 floors - 2001
70/100	North East Asia Trade Tower - Incheon Korea - 305m - 68 floors - 2011
71/100	Baiyoke Tower II - Bangkok - 304m - 85 floors - 1997
79/100	Doosan Haeundae Tower - Busan Korea - 300m - 80 floors - 2011
94/100	Haeundae I Park Marina - Busan Korea - 292.1m - 72 fllors - 2011
98/100	Busan International Finance Centre - Busan Korea - 289m - 63 floors - 2014

Composite

Concrete

Source:http://www.taiwanmag.net/2012/03/26/la-tour-taipei-101-demonstration-de-la-vigueur-et-de-la-reussite-taiwanaise

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Under construction !

Rank	Building
6/100	KL118 Tower - Kula Lumpur (ML) - 610m - 118 floors - 2019
8/100	Lotte World Tower - Seoul (KR) - 554.5m - 123 floors - 2016
29/100	LCT Landmark Tower - Busan (KR) - 411.6m - 101 floors - 2018
45/100	Vietinbank Business Centre - Hanoi (VN) - 363.1m - 68 floors - 2017
52/100	Four Seasons Palace - Kula Lumpur (ML) - 342.5m - 65 floors - 2017
57/100	LCT Residential Tower A - Busan (KR) - 339.1m - 85 floors - 2018
65/100	LCT Residential Tower B - Busan (KR) - 333.1m - 85 floors - 2018
96/100	MahaNakhon - Bangkok (TH) - 313.4m - 77 floors - 2016
97/100	The Stratford Residences - Makati (PH) - 312m - ? floors - 2016

Composite

Concrete

Unclassified

Source:http://www.taiwanmag.net/2012/03/26/la-tour-taipei-101-demonstration-de-la-vigueur-et-de-la-reussite-taiwanaise

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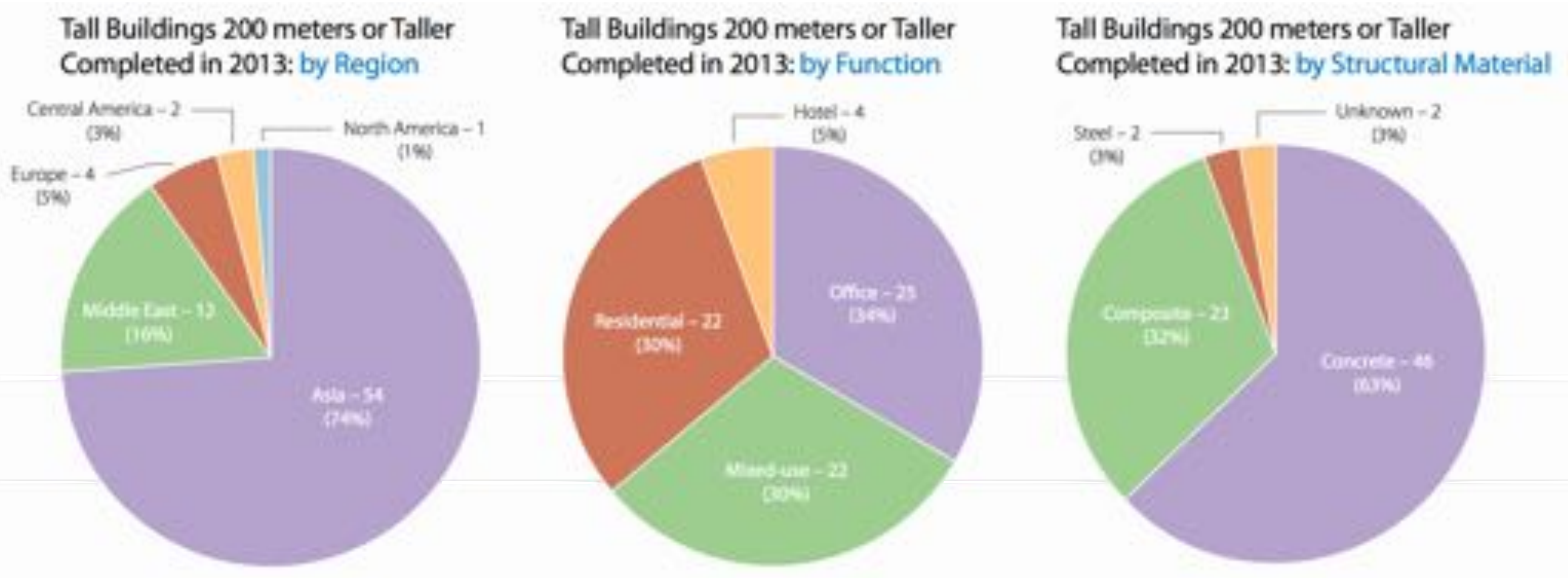
Tall Buildings in Asia

- Asia region accounted for 74% of tall buildings completed ≥200m in 2013.
- The vast majority of this was in China.



The use of composite buildings is growing

http://www.ctbuh.org/LinkClick.aspx?fileticket=Bj14RQcNyis%3d&tabid=1108&language=en-US

How do you construct tall buildings ?

For any building there is no right or wrong way for its structure to carry gravity loads to the foundation or resist lateral loads. However, there are structurally efficient, economic, architectural and other challenging solutions.

So how do you select a structural system for a building?

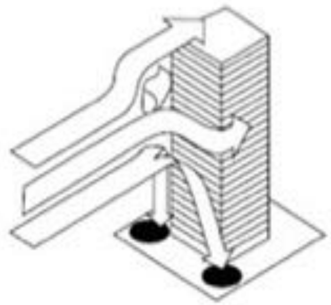
There are generally six areas that need to be considered:

1. Economics
2. Local conditions
3. Architectural aspirations and structural needs
4. Mechanical and structural needs
5. Construction time
6. Project / construction risk

Structural steel frame options

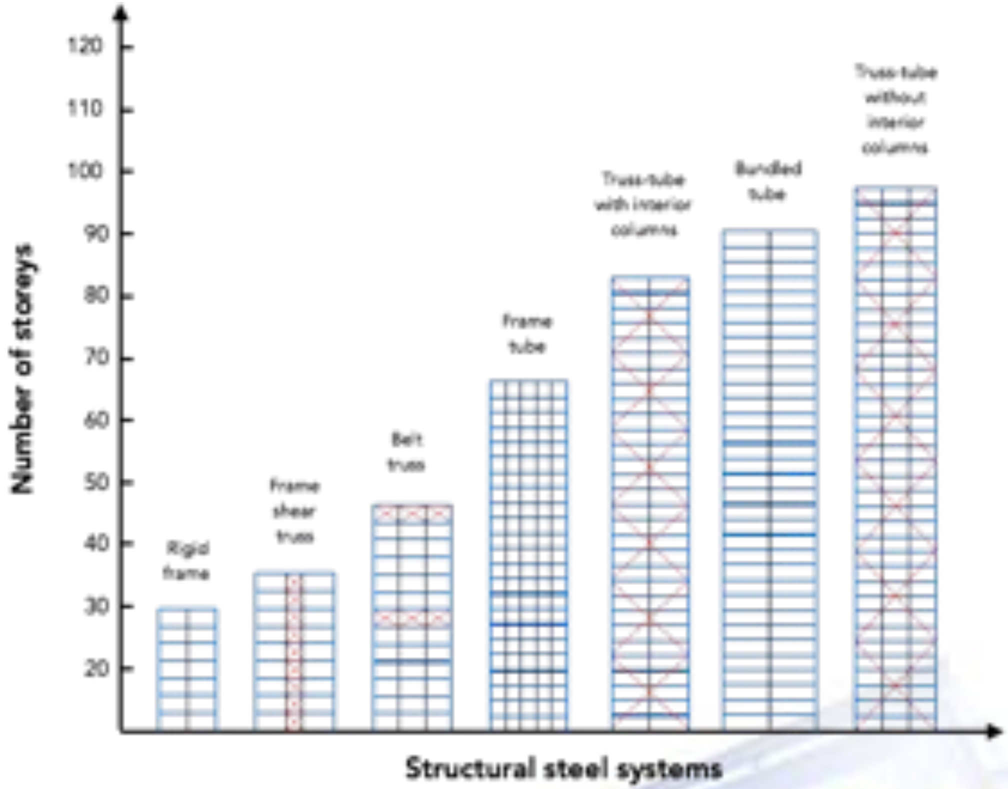
1. **Rigid frames**
2. **Semi-rigid frames**
3. **Braced frames**
4. **Rigid frames and braced frame interaction**
5. **Belt and outrigger truss systems**
6. **Tube structures**

All have a **theoretical** maximum height at which they become inefficient at transferring lateral loads.



High rise buildings must resist both gravity and lateral loads; i.e. wind and earthquakes. These lateral loads predominate the structural design as buildings get taller.

The diagram on the right is credited to Fazlur Kahn (1975) - engineer for John Hancock Centre & Sears Tower.



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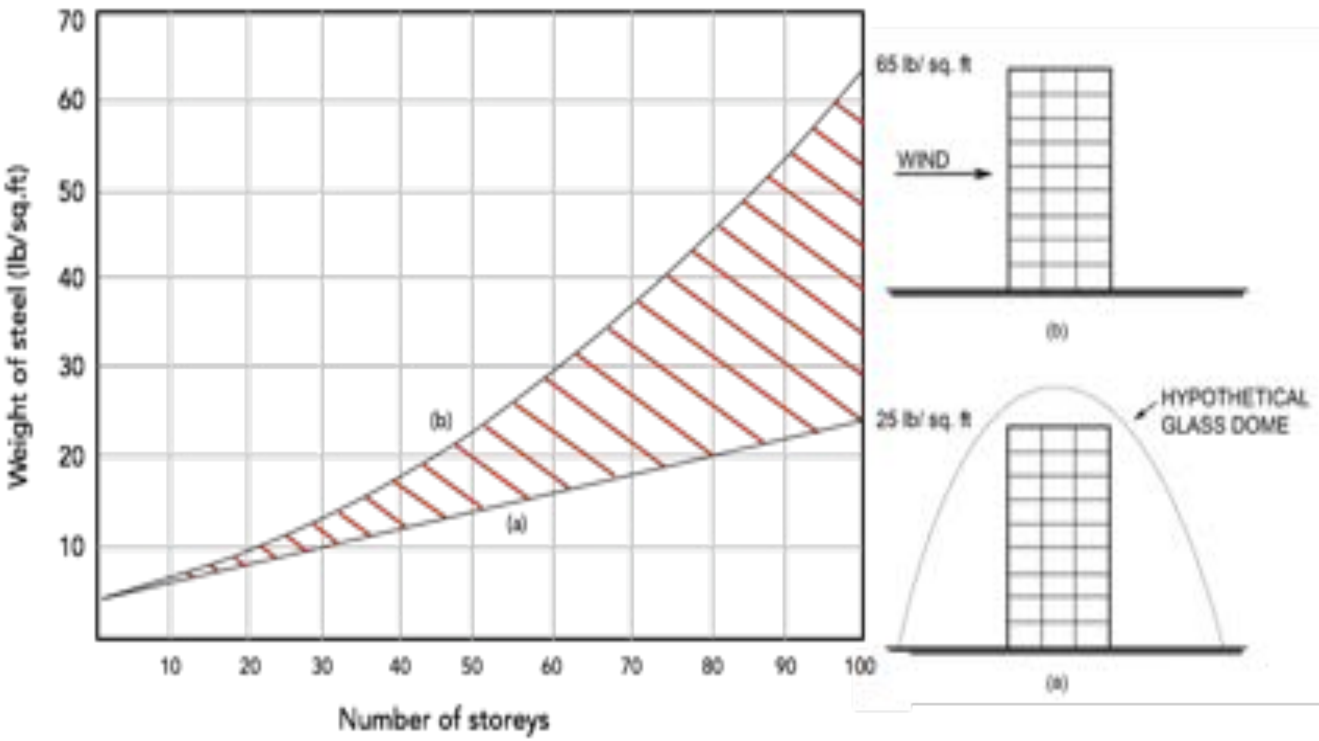
The concept of premium for heights

If there are no lateral forces on the building such as wind or earthquake, any high-rise building could be designed just for gravity loads. Girders along the column lines need to be progressively heavier towards the base of the building to carry increasing lateral forces and to augment the building's stiffness. Further to this, the columns need to be even heavier towards the base to resist lateral loads.



The net result is that as buildings becomes taller, the sway due to lateral forces becomes critical, there is a greater demand on girders and columns that make up the rigid-frame system to carry lateral forces.

Source:http://khan.princeton.edu/khanHancock.html

Structural steel framing options for high rise buildings

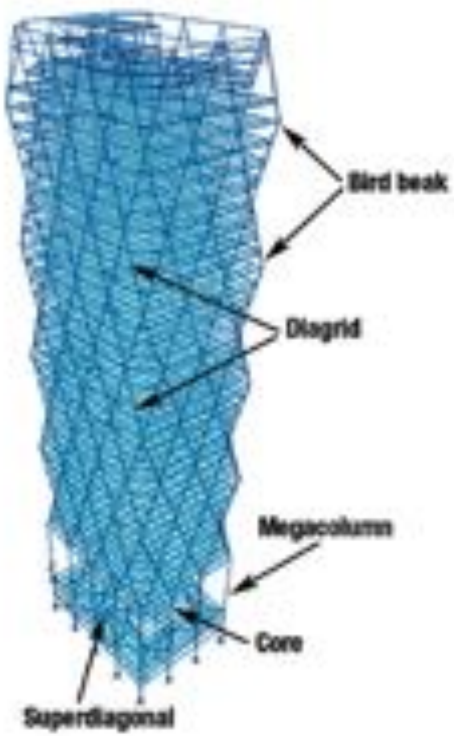
1. **Frame tube (system of rigid frames)**
2. **Bundled tube (combination of framed tubes)**
3. **Tube in tube (central and peripheral framed tubes)**
4. **Diagonalized (trussed tubes, diagrids or braced frames)**
5. **Core plus outrigger**
6. **Hybrid (combination of any two or more system)**

Belt and truss systems

Structural steel framing options for high rise buildings

Diagrid system

The diagrid system often uses an exclusive exterior frame comprised entirely of diagonal members, thereby eliminating the need for vertical columns. Vertical columns are capable only of withstanding gravity loads and the diagrid is useful for both gravity and lateral loads.



http://www.skyscrapercity.com/showthread.php?t=29266&page=10

Hearst Corporation Building - USA

http://www.worldsbiggests.com/2010/06/world-furthest-leaning-man-made-tower.html

Capital Gate - Dubai

The Leadenhall Building - London

Source: ARUP

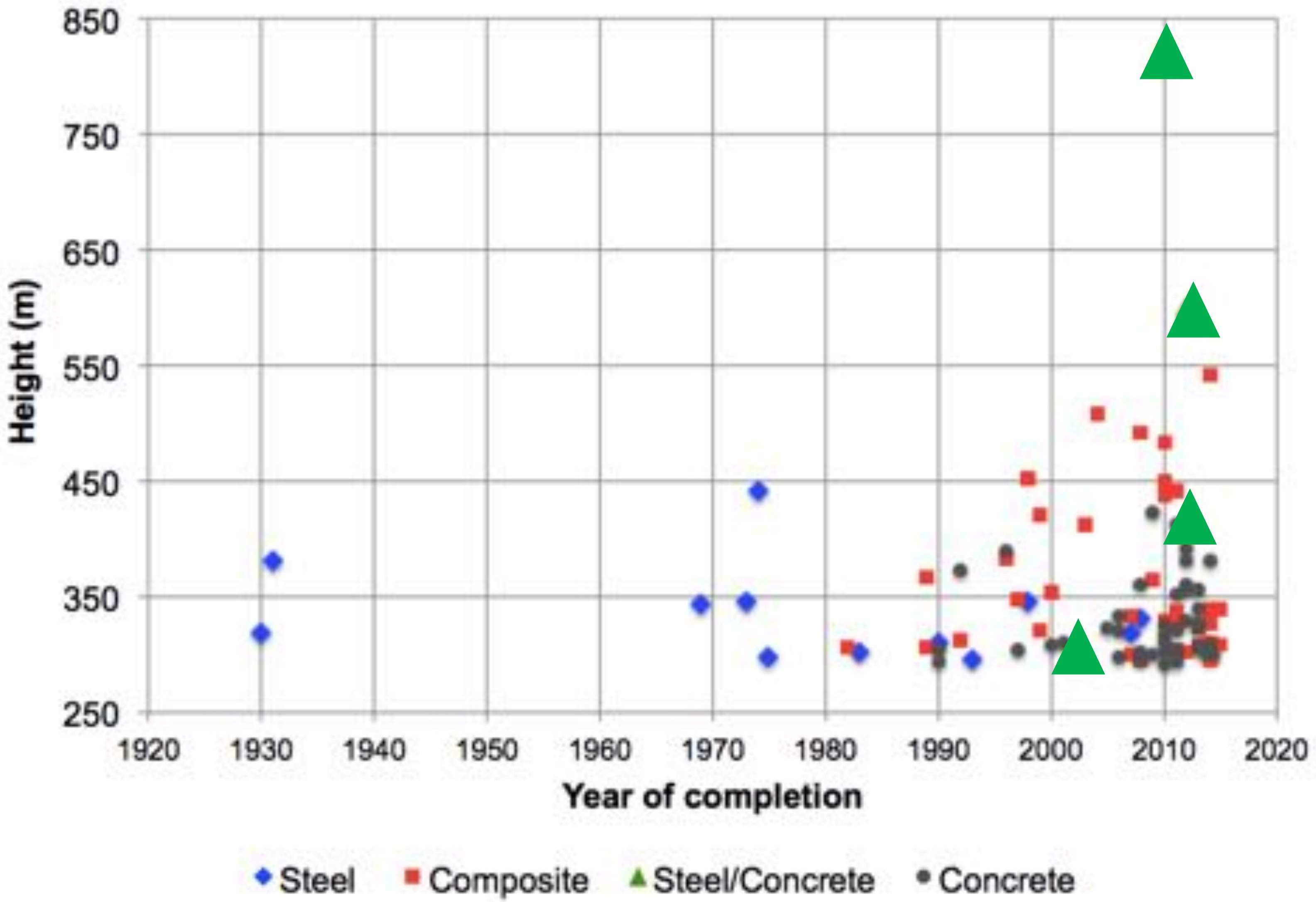
225m tall office tower
56,000m² prime office space over 42 floors
£340m, completed 2014

18,100 tonnes of steel used of which 17,000 was coated with 90 minutes fire protection. Features raked columns 27m long - 70 tonnes each.

First diagrid building without bearing an inner core. The megaframe structure is a braced diagram, surrounding all four sides. Each megaframe story sits 28m above the previous one. Diagrid nodes weigh 20 tonnes each and took up to 800 hours to fabricate.

http://www.tekla.com/uk/model-comp-2011/leadenhall.html

Tall buildings material trend



Case study: REFORMA 509

Puna Chapultapec (Reforma 509)

Client :	T69
Architect :	Taller-G
Local engineering partner :	DITEC S.A. de C.V.
Use :	Office, hotel, residential
Superstructure height :	238m
Above/below ground levels :	58 / 12
Total floor area :	70,000m^2 above ground
Primary structural system :	Concentric braced steel frame No concrete core. Composite (SRC) columns
Expected completion date :	2018

The original steel grade for all the main elements was:
Grade 50 (355MPa YS)

REFORMA 509 structure overview

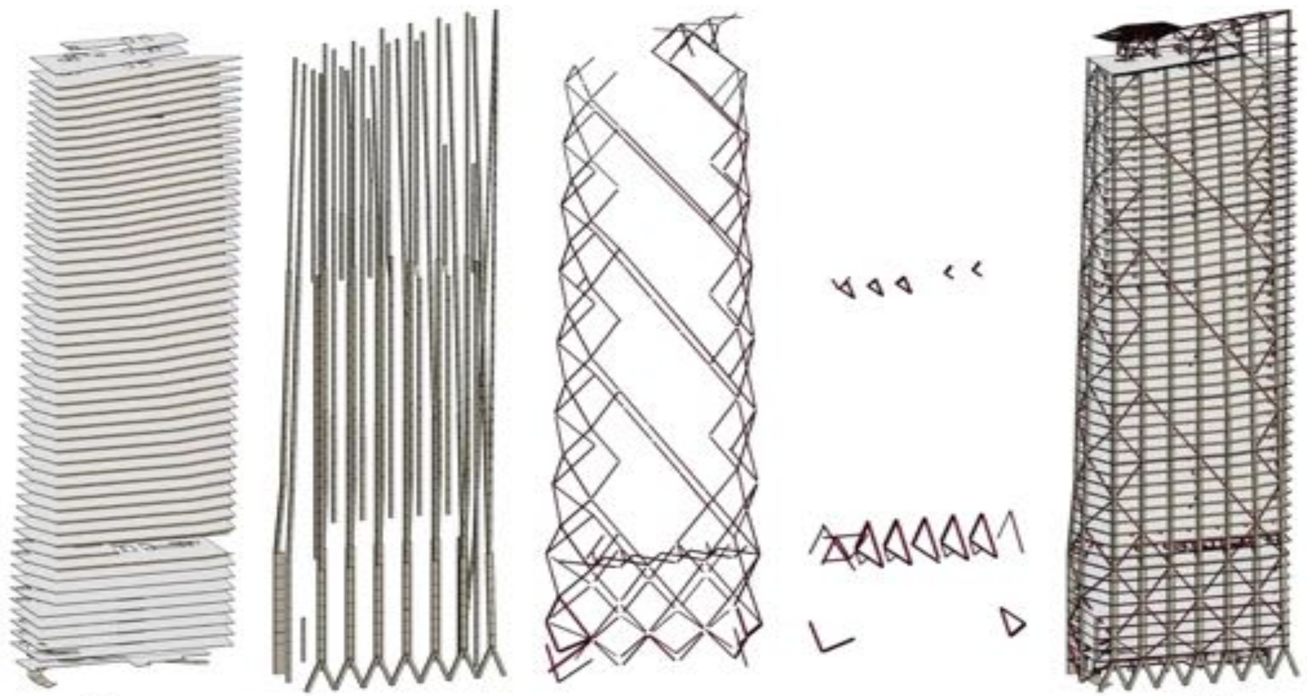
- Tower is founded on a 64m deep basement box.
- From ground level the tower comprises of conventional composite steel floors spanning onto internal columns or outer perimeter frame columns.
- Perimeter columns are braced together.
- Designed in accordance with PEER TBI Guidelines, local Mexican Codes and AISC, ASTM and ASCE standards.
- **Original total steel requirement = 11,865 t.**

Element group	Maximum permissible grade*
SRC Columns	520 MPa (75 ksi)
Megaframe edge beams	690 MPa (100 ksi)
Bracing	350 MPa (50 ksi)
Floor beams	690 MPa (100 ksi)
Transfer structure	690 MPa (100 ksi)
Hanging columns	690 MPa (100 ksi)
Helipad	690 MPa (100 ksi)
Ramp support	690 MPa (100 ksi)
Core	350 MPa (50 ksi)

* Yield strength values

Tower primary structure

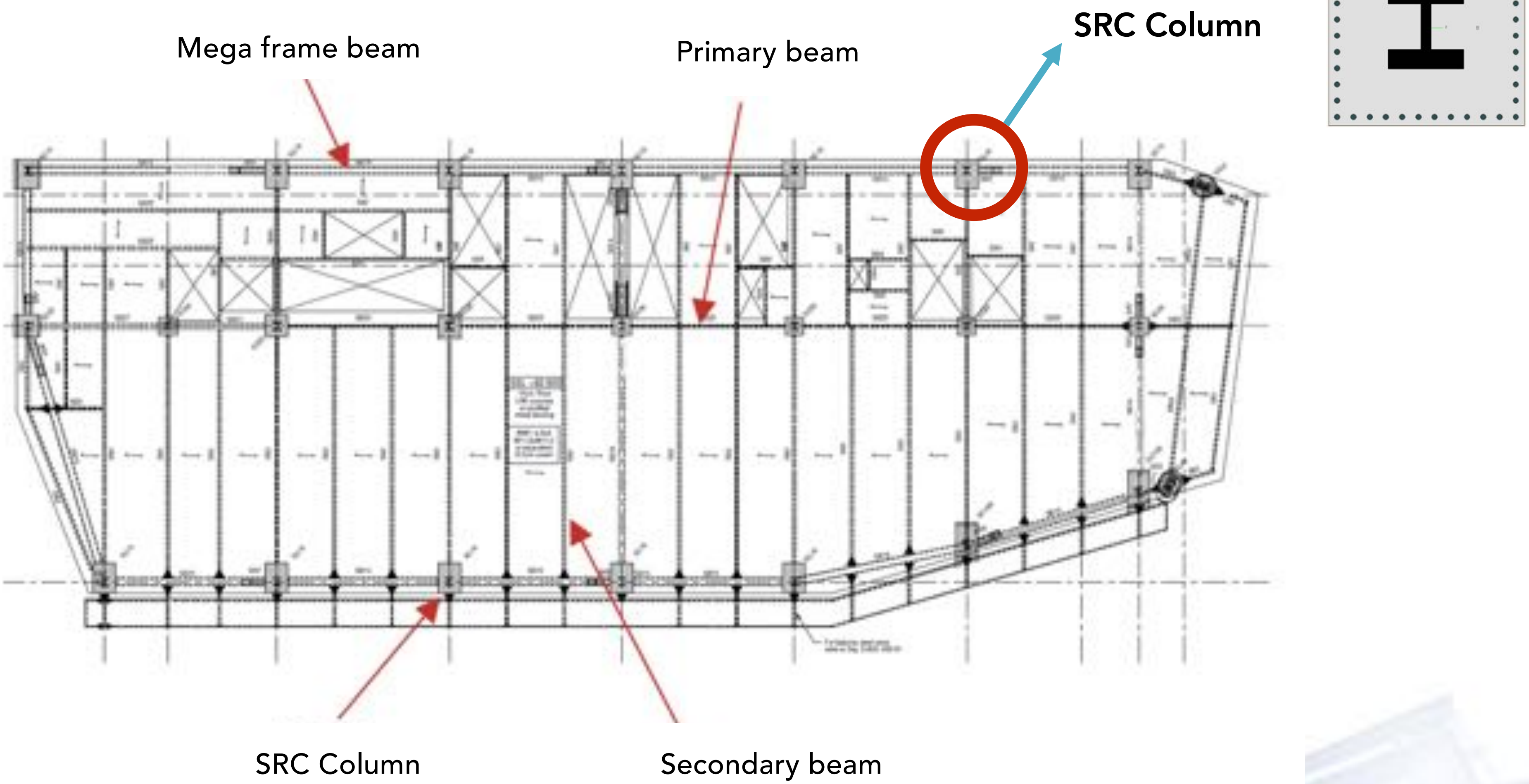
- Conventional composite floor structure spanning between internal columns & the perimeter frame.
- Transfer trusses spread the loads imposed on the internal columns to the perimeter frame.
- Perimeter columns carry all the gravity loads and over-turning forces to ground.
- The current design assumes that columns are restrained at nodes floors (typically every third floor).
- Internal & perimeter bracing that provides a shear load path for all the lateral forces imposed on the structure.



Floors | Columns | Braces | Transfer structures | Full structure

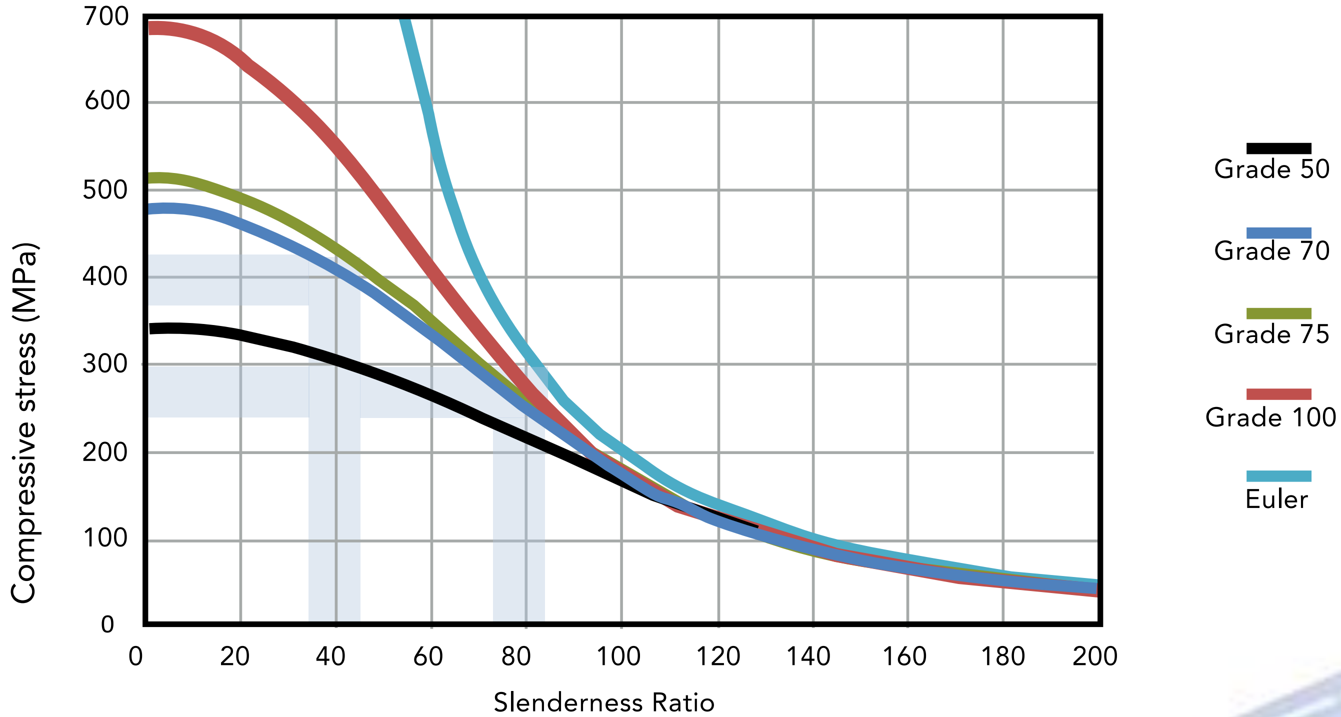
Tower primary structure

- Steel Reinforced Concrete (SRC) Columns constitute nearly 30% of the structures primary steel usage.



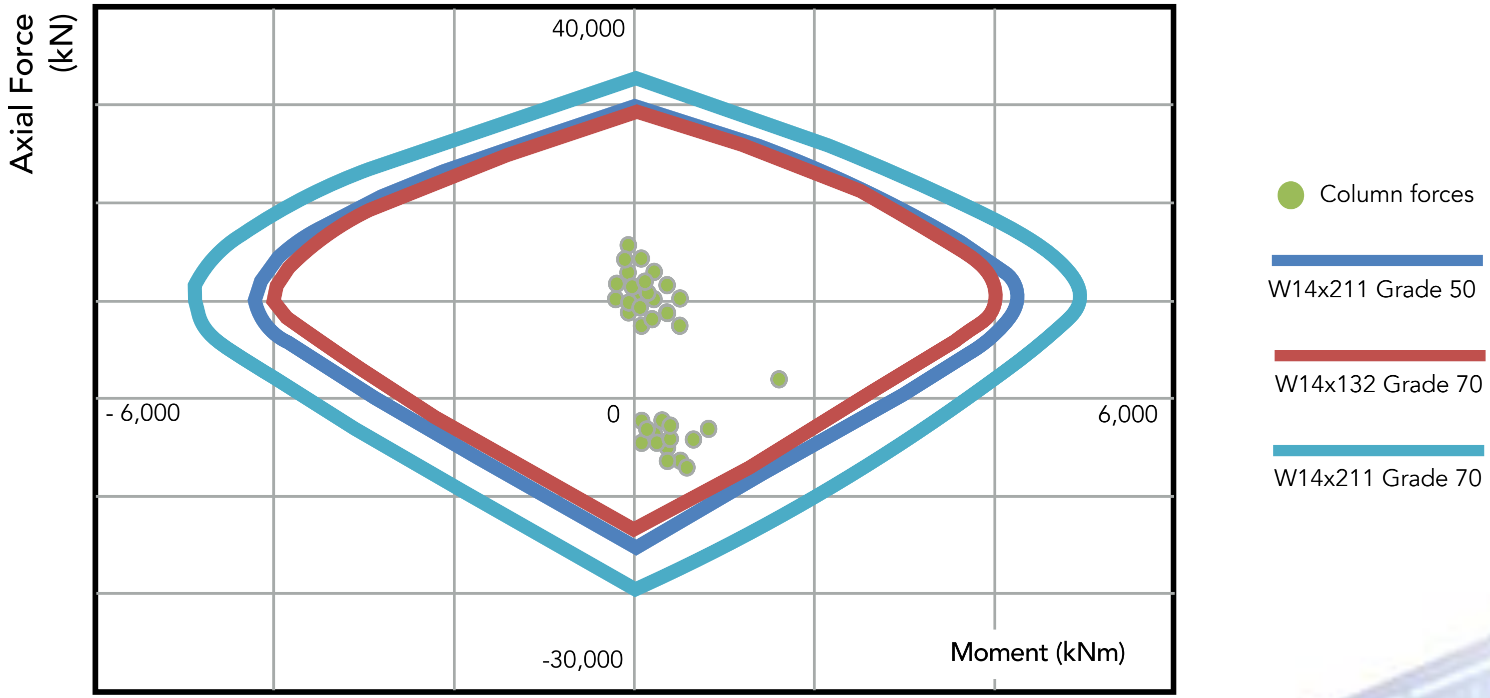
Material strength curves

- For a predominately compression structure it is informative to consider the strut buckling curves for different steel grades.
- As the main steel usage is for the SRC Columns they were examined at different strengths and the impact on the slenderness ratios.
- Typical slenderness ratio: 80 near top and 40 at base.
- The uses of HSS allows a theoretical increase in capacity of 17% and 33% at Grade 70.
- At Grade 100 this increases capacity by 29% and 83%.
- If columns are restrained at every floor this increases to 37% and 38% respectively.



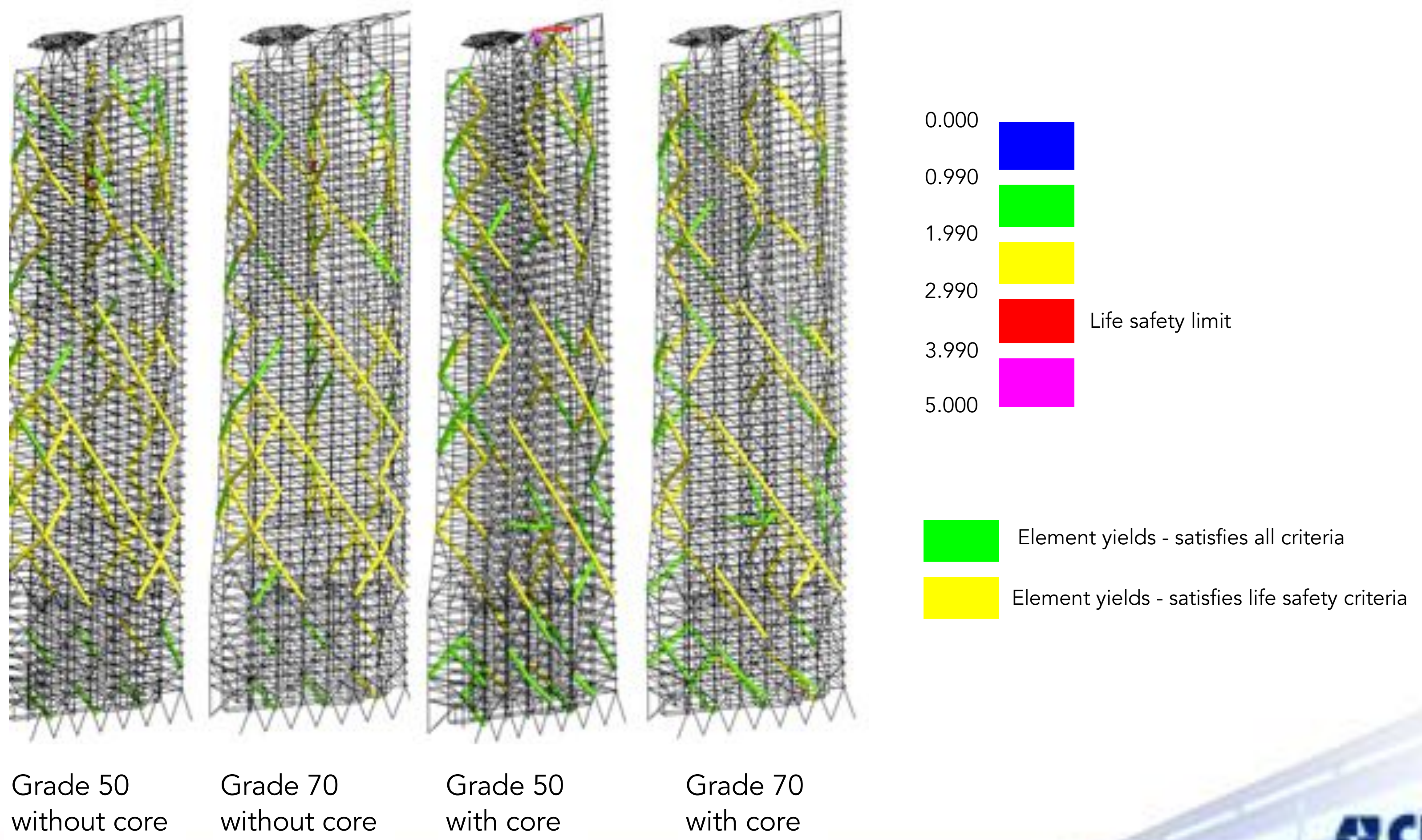
Interaction diagram N-M for columns

- As columns will also be subjected to some degree of bending moment the capacity for the SRC columns must also be analysed.
- Both slender (top) and stocky (base) columns were analysed.
- The envelope is for 80% utilisation in accordance with section I of AISC360-10.
- Analysis shows that it is possible to contain all the design forces with a W14 x 132 section Grade 70 (480MPa) steel column.
- If columns are restrained at every floor the section size reduced further to a W14 x 68 section - which is another 50% !

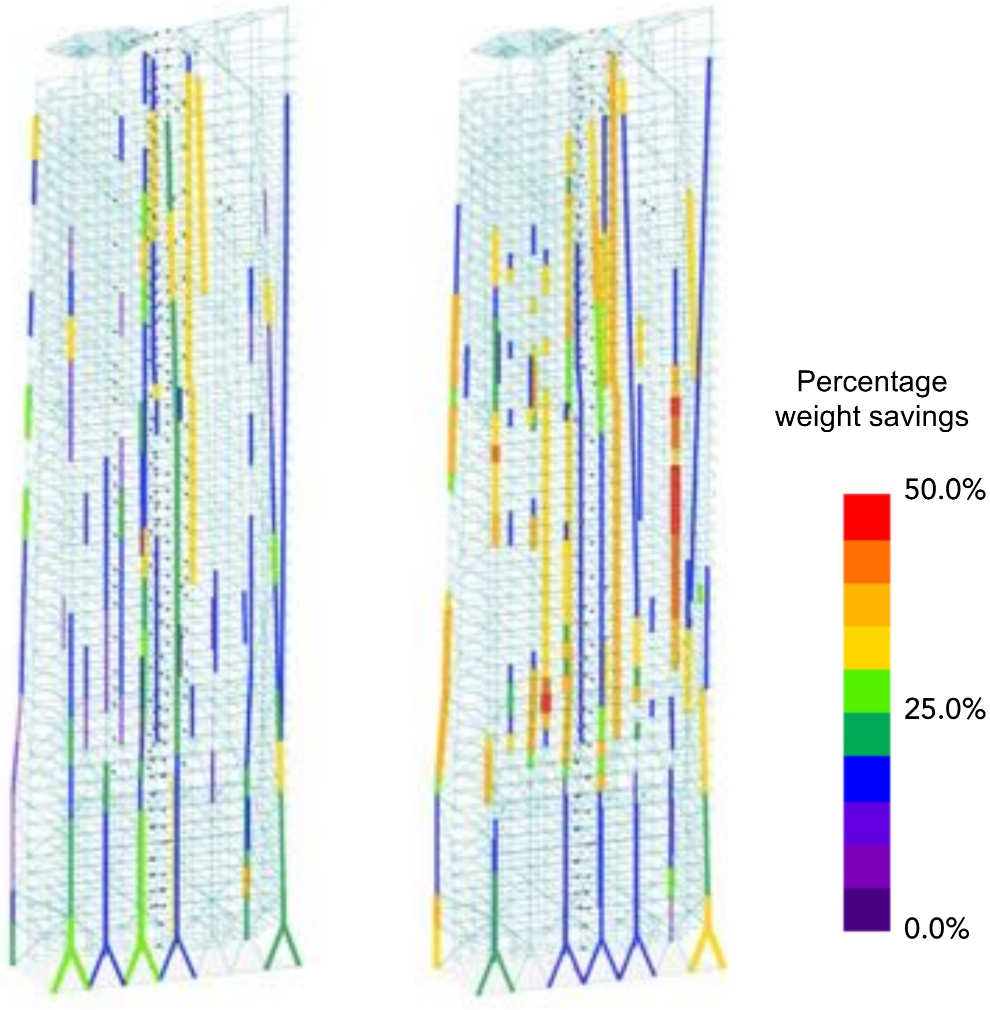


Structure – degree of ductility within bracing elements

- Seismic response - testing with one of the 7 earthquake ground motions from time-history analysis it is possible to see which elements yield.
- Criteria set by ASCE 41-06.
- There is largely no difference between a Grade 50 (355MPa) and Grade 70 (480MPa) Nb-microallyed steels.



Weight savings using Grade 70 (480MPs) Nb-HSS



Original design

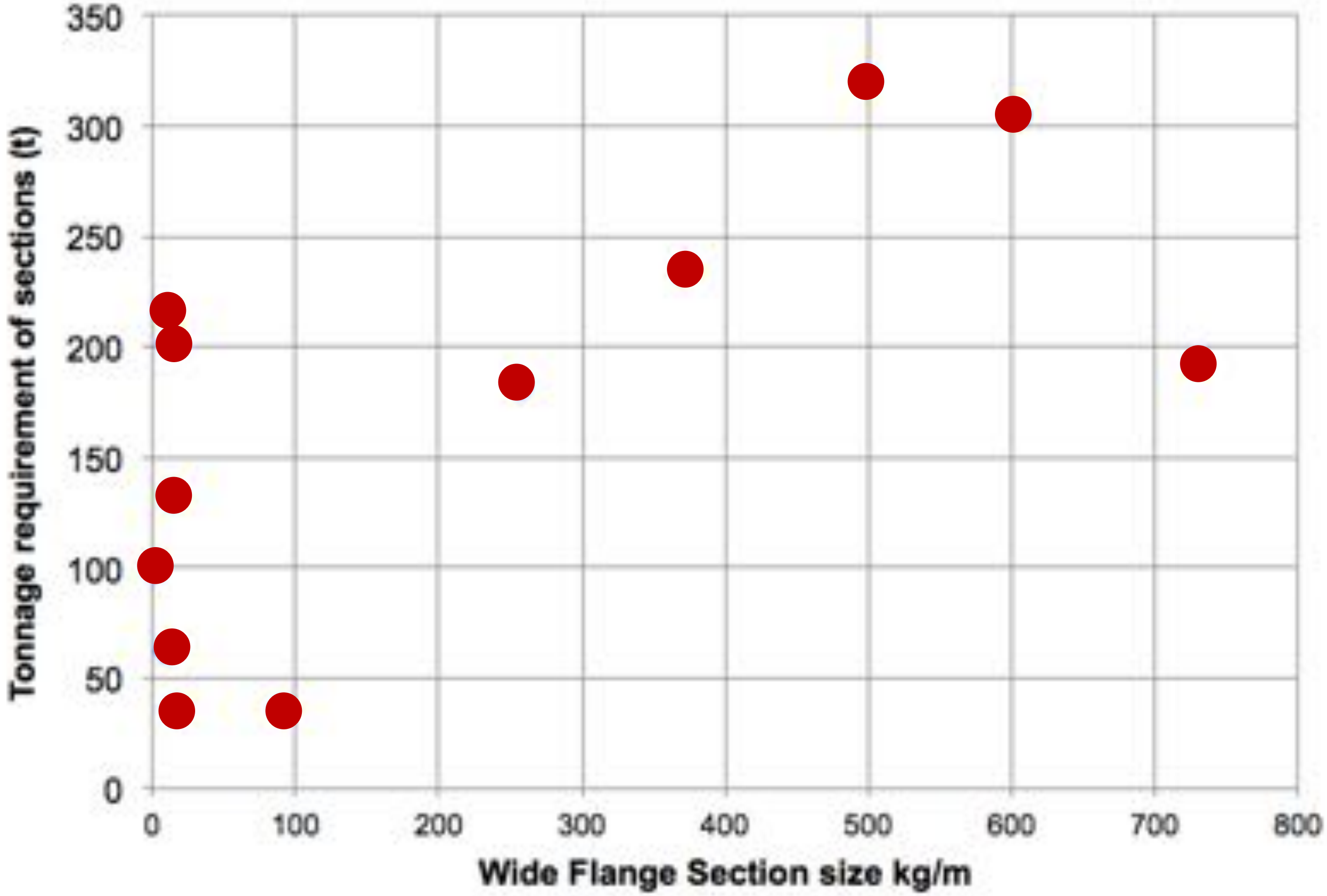
Reduced effective length

- Use of Grade 70 Nb-microalloyed HSS with a single and triple story effective length design approach has allowed a reduction in mass of up to 45% and 35% respectively.
- Columns near the base gave the most savings (less susceptible to buckling).
- Further savings were minimised due to limits imposed by code and rationalisation of columns to suit architectural and buildability criteria.

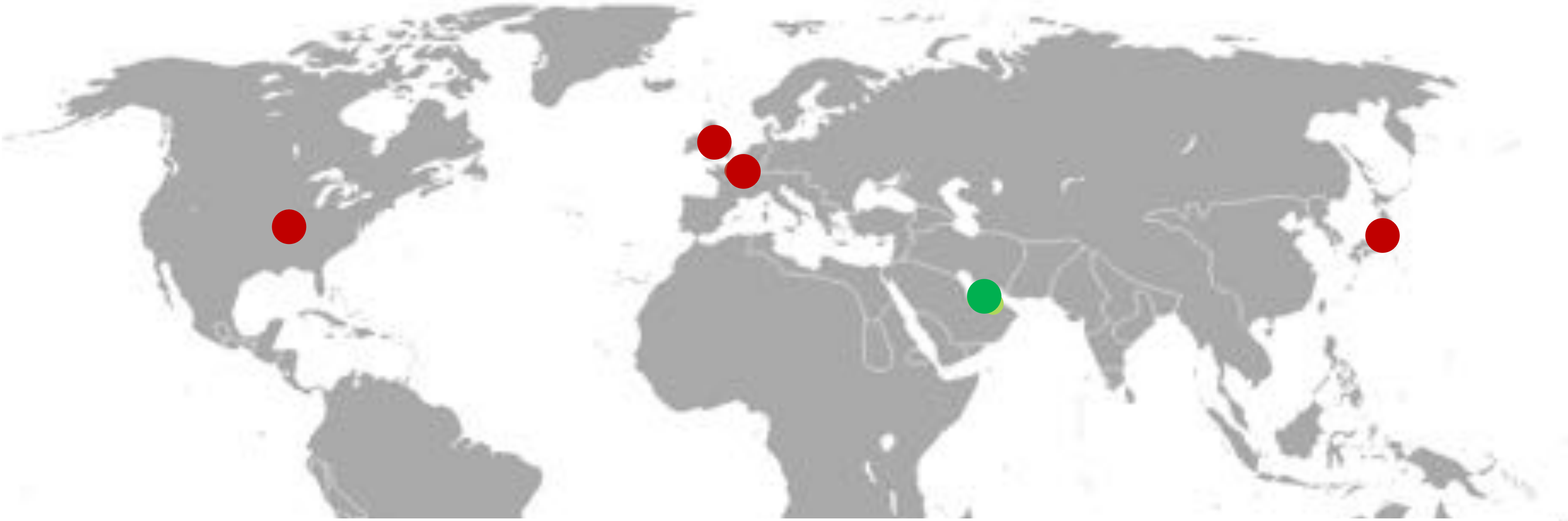
Weight savings by element type

Element Group	Restraint at node floors				Restraint at every floor		
	Original design (t)	High strength steel design (t)	Tonnage savings (t)	Percentage savings (%)	High strength steel design (t)	Tonnage savings (t)	Percentage savings (%)
SRC Columns	2,633	2,264	**369**	**14%**	1,503	**370**	**20%**
Mega-frame edge beams	1,620	1,616	4	0%	1,600	0	0%
Bracing	1,367	1,361	6	0%	1,322	0	0%
Floor beams	2,146	2,146	0	0%	2,146	0	0%
Transfer structures	448	402	46	10%	400	36	8%
Hanging columns	253	195	**58**	**23%**	184	**59**	**24%**
Helipad	85	85	0	0%	85	0	0%
Ramp support	247	247	0	0%	226	-8	-4%
Core	68	55	13	19%	247	0	0%
TOTAL	**8,867**	**8,371**	**496**	**5.6%**	**7,713**	**457**	**5.9%**

SRC column steel library



Global availability of W14 heavy sections (not comprehensive)



	EN10025:4 S355	EN10025:4 S460	ASTM A572 (Gr50)	ASTM A992 (Gr.50)	ASTM A572 (Gr.60, Gr.65)	ASTM A572 (Gr.70)	ASTM A913 (Gr.50, Gr65, Gr.70)
Europe	Yes	Yes – only to W14x257	Yes – not below W14x61		Yes – only to W14x257	no (tbc)	no
Europe	Yes	Yes	Yes		Yes	no	Yes - not below W14x90
USA	Yes	no	Yes	Yes	inquire	no	no
Japan	Yes	no	Yes - not below W14x90		no	no	no

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Creating value through use of HSS

Adopting high strength steels will require less tonnages to be used.

Reduce the project's carbon footprint:

(1) reduction in the amount of raw-material usage required and thus for transportation to the steelmaker.

(2) reduction in the amount of water and energy usage required in making the steel at the steelmaker (and corresponding lower CO_2 emissions).

(3) reduction in the energy and CO_2 emissions in transporting the steel to the project site or fabricator.

(4) less risk at site handling heavier sections.

(5) reduced construction time due to less welding or bolting by virtue of a "lighter" section.

(6) reduced surface area for fire-protection coating for exposed beams.

(7) where applied in SRCs less concrete is required (and thus similar reduced CO_2 foot print).

CO_2 savings for the SRC beams would amount to 730t of CO_2 (which equates to the annual emissions of 180 passenger vehicles).

Furthermore, when considering all the other transportation issues from shipping through to road transportation to site etc, and coupled with other reduced tonnages expected by using higher strength steels in other identified elements total CO_2 savings for Reforma 509 would easily amount to 1,000t.

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Creating value through use of HSS

- Moving from a Grade 50 (355MPa) to a Grade 70 (480MPa) steel gives significant savings in strength governed elements.
- Savings of 450-500t of steel is possible.
- **Save the client USD 600-650k.**
- Rationalisation use of higher strength reinforcement bar (80-100ksi) can allow a greater Floor Space Index (FSI) or GIA - making the project more financially attractive.
- Large sustainability benefits.
- Use of high strengths seen best in SRC and Hanging Columns.
- Higher residual steel recycle value of H-beams.

- Stiffness implications such as buckling, deflection, vibration and fatigue reduce the full benefits.
- Not suitable for elements subjected to significant inelastic deformation.
- Limited availability of heavier sections in the market at higher strengths (market opportunity for steelmakers !).
- Some codes restrict how (little) steel can be used in SRC Columns (steel/concrete ratios).
- Supply base of higher strength H-beams needs to increase !

Photos of the demolition

https://commons.wikimedia.org/wiki/File:Torre_Reforma_509_Previo_a_Demolición.jpg

Photos of the foundation

Photos of built-up sections

Photos of the build to date

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Acknowledgements

ARUP

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