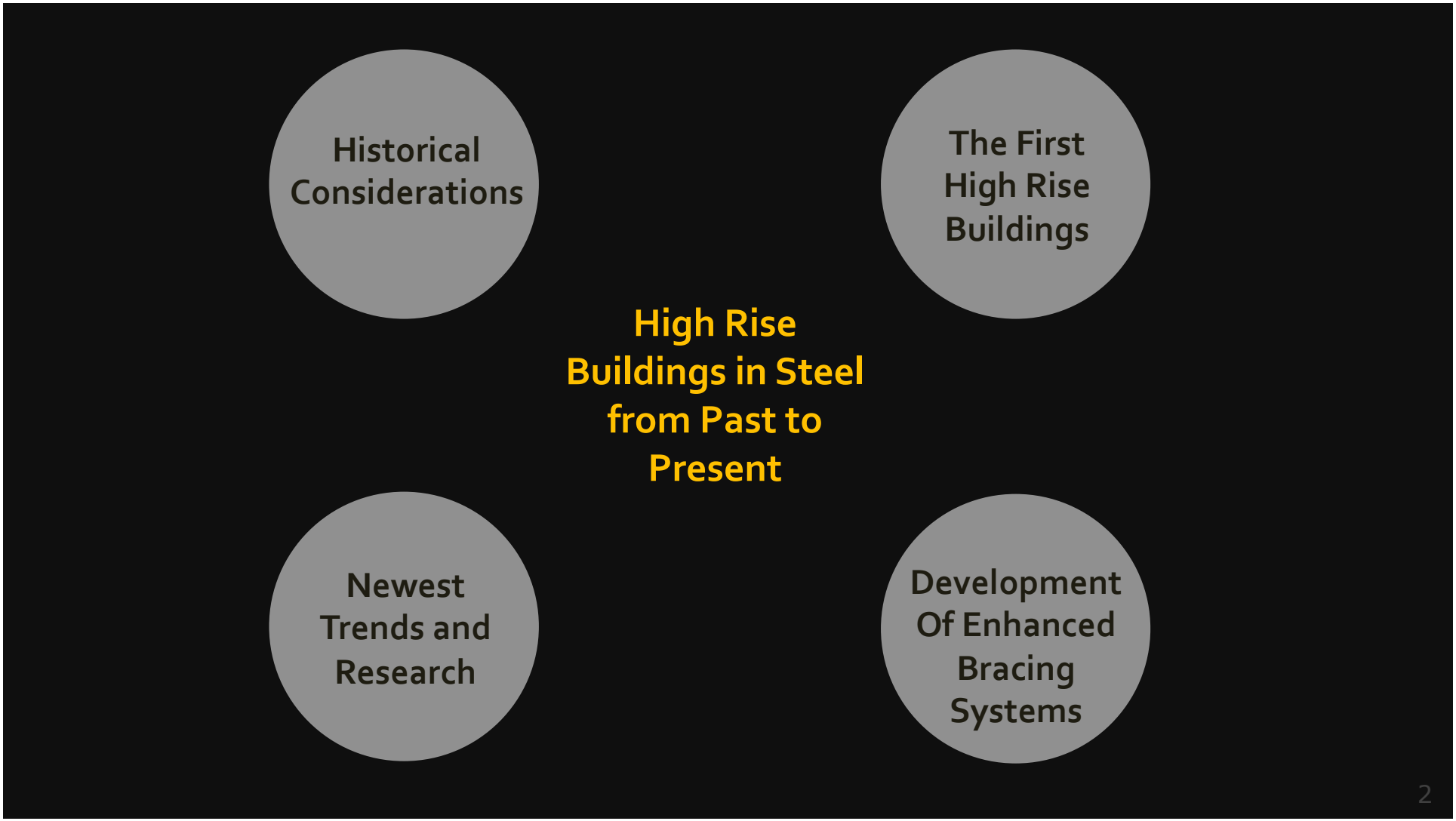
High Rise Buildings in Steel - from Past to Present

Prof. Dr. –Ing. Christoph Odenbreit

ArcelorMittal Chair of Steel and Façade Engineering
University of Luxembourg


Historical Considerations
The First High Rise Buildings
High Rise Buildings in Steel from Past to Present
Newest Trends and Research
Development Of Enhanced Bracing Systems

Historical Considerations

The First High Rise Buildings

High Rise Buildings in Steel from Past to Present

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Development Of Enhanced Bracing Systems

The Tower of Babel

ca. 700 B.C.

Drawing of
Peter Bruegel Sen.
(1525-1569)

Towers of Bologna

12th Century

Hight
ca. 97 m

The City of Shebam,
South of Jemen

ca. 1500 A.D
500 buildings

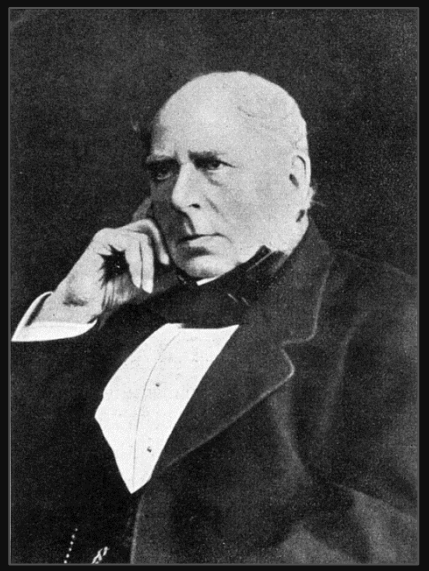
Max. 9 storeys

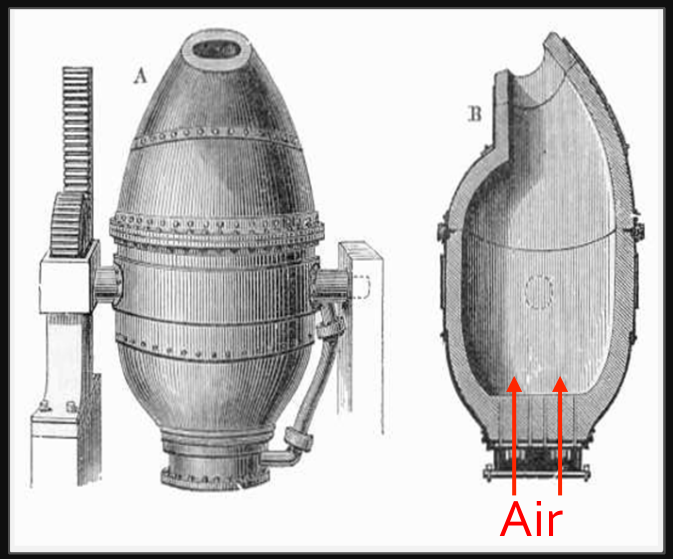
Buildings out of
Timber and Clay

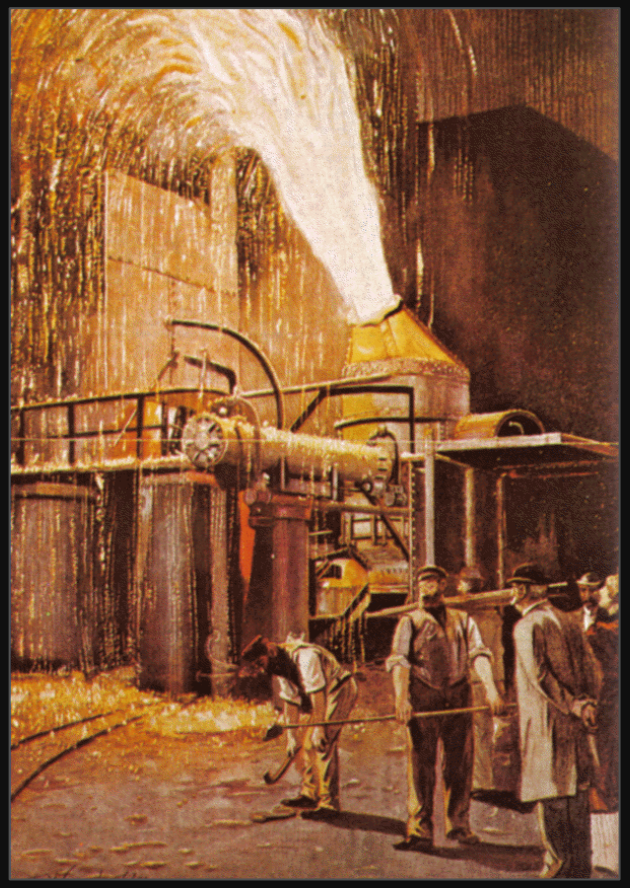
Pre-Requisitions for the Modern High Rise Building:

(1) Building Material

The Bessemer Process







Henry Bessemer
(1813 – 1898) England

Inventor of the Bessemer Converter & Process
Patent in 1885

Pre-Requisitions for the Modern High Rise Building:

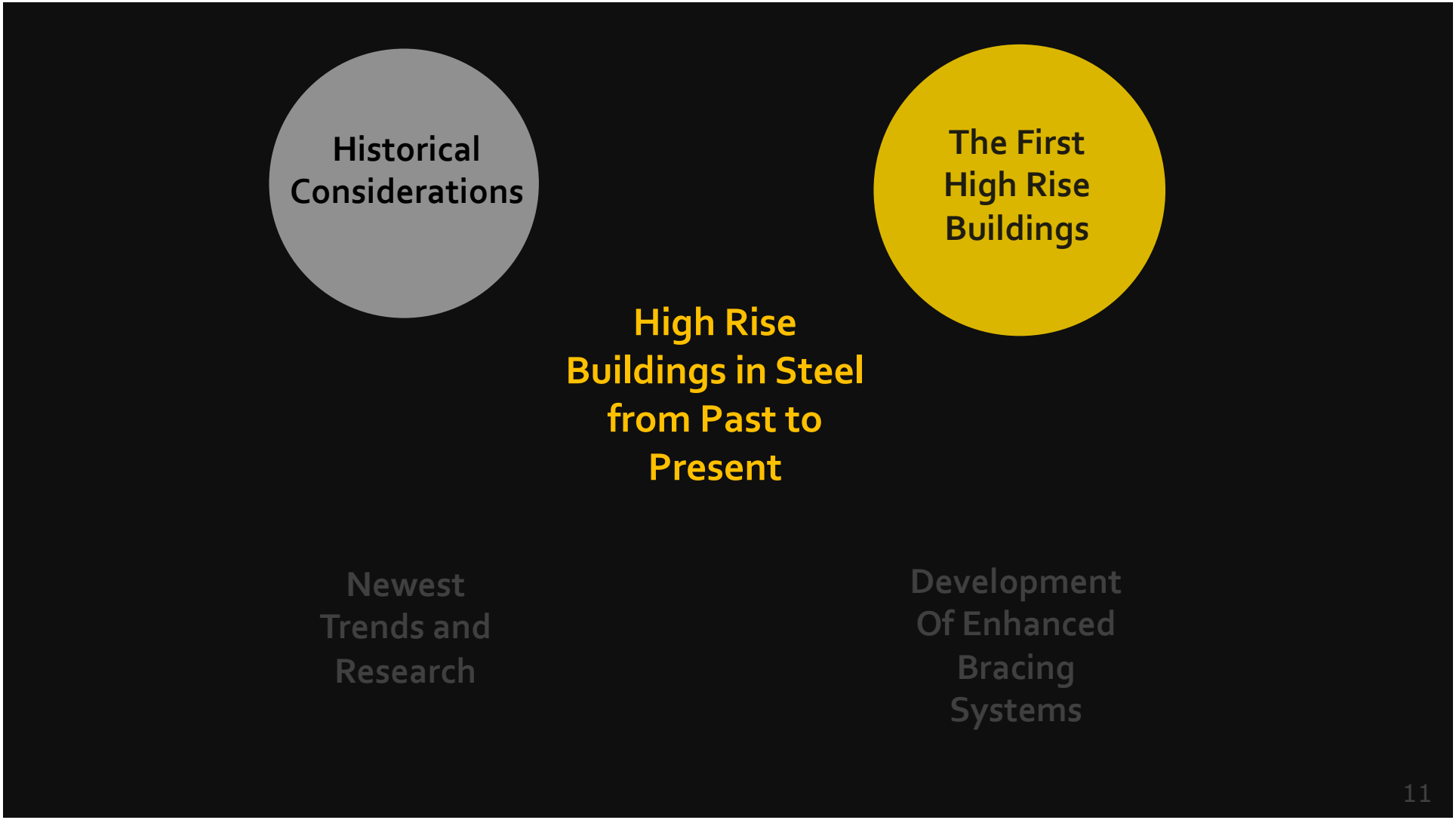
(1) Building Material
(2) Elevator

The Elevator

Elisha Grave Otis
1811-1861

Inventor of the Elevator

Otis
Elevator with
Steam-Powered Engine.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The First High Rise Building –

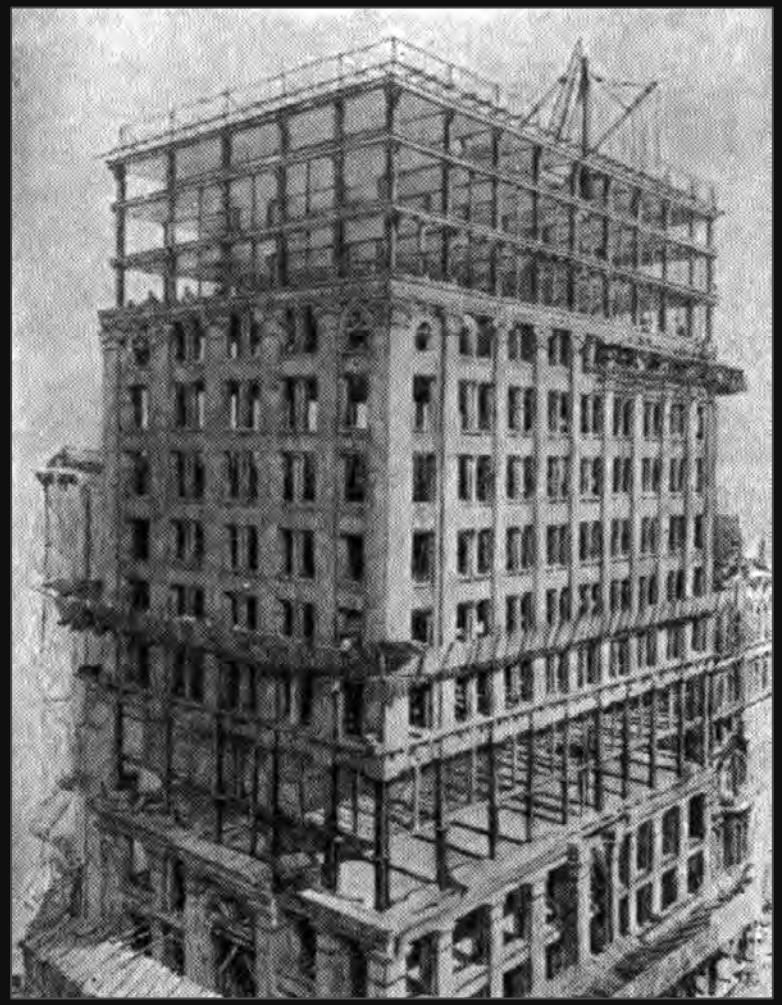
The «Home Insurance Building»

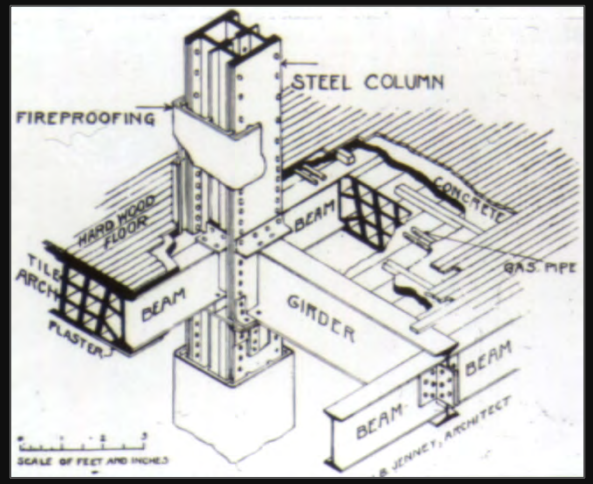
1885
Chicago

Hight 42 m

The building is seen as the first
High Rise Building

Architect: William Le Baron Jenny
Construction:
Steel frame and two reinforced
concrete walls





Steel Profiles
Rivets
No Welding

The «Empire State Building»

1930-1931
New York

Hight 443 m

(for nearly 40 years the
world's highest building)

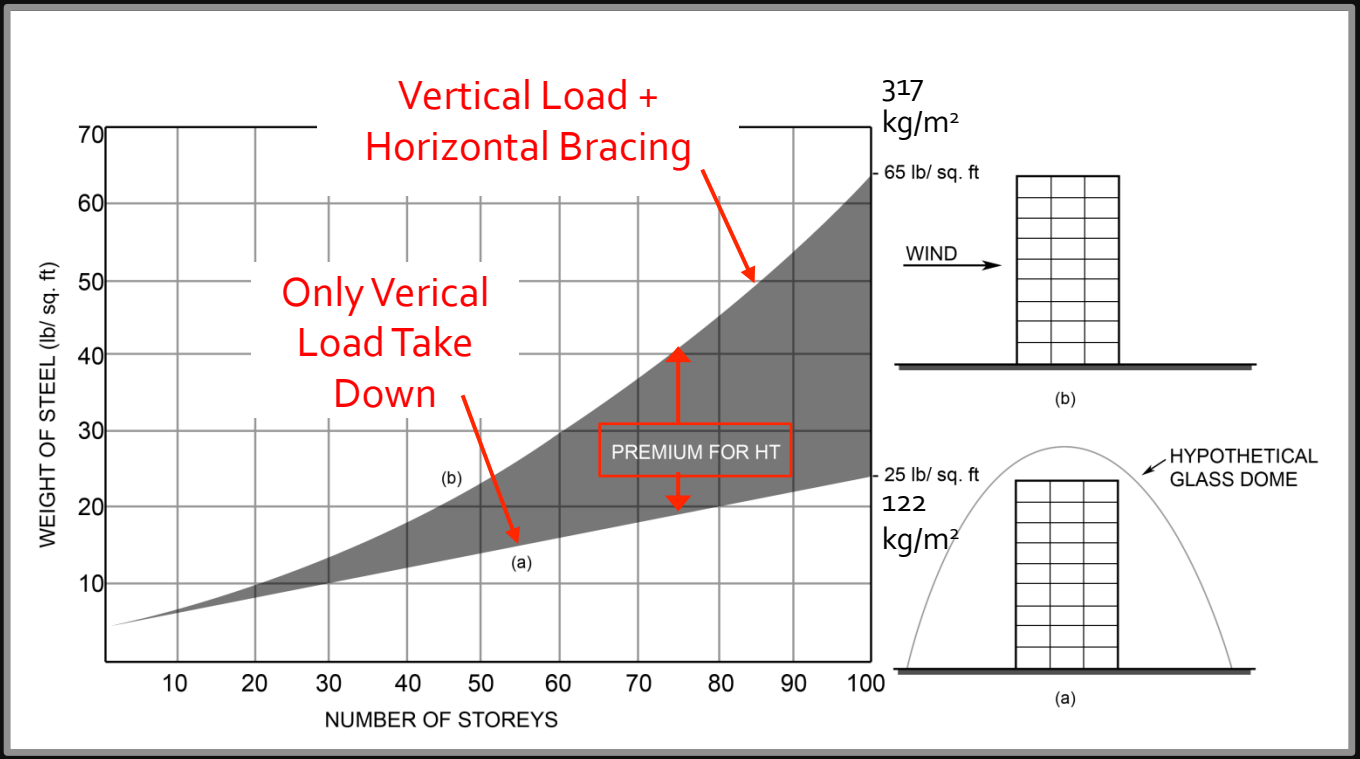
Architects : William F. Lamb of
"Shreve, Lamb and Harmon"

Steel Consumption

Khan (1959) : Premium-For-Hight

455 m										
365 m										
275 m			First National Bank,Seattle	Civic Centre	Dome Centre	Chase M. Bank	East Nat. Bank Chicago	U.S Steel	John Hancock Centre	Word Trade Centre
180 m		Equit. verscherung								
90 m	Gateway Centre									
	1	2	3	4	5	6	7	8	9	10
Building module m	1,37	1,47	1,422	1,47	1,52		1,52			0,99
Span between column centres	13,72	11,75	10,973		12,20					18,29
Plan dimensions	41,76x82,91	35,36x53,83	38,40x43,90		37,80x74,37					63,70x63,70
Plan area	3462		1655							3995
Total floor area			68183	136098			176510		260120	
No. of floors for occupants		33	36	28			49			94
No. of service floors		1	4	2	3		4		3	4
Total no. of floors		35	50	30	56		60	64	100	104
Floor - floor height				5,49				3,60		
Total height m		135,64	135,62	197,21	225,55		256,34	256,34	335,28	411,48
No. of groups of lifts	2x6	2x6,1x5			4x8					
No. of goods lifts	12	17	22	42	32					
No of goods elevators	1	1			2					
Self weight of steel kg/m ^{2}	92,76	151,35	159,65	214,82	180,65	234,35	178,88	146,47	145,00	209,94
Steel cost $/t	300.-	345		420,0	3270,3800	350,0	425,0		375,0	600,0
Steel cost $/m ^{2}	30,66	52,72		99,0	64,56/75,32	90,38	79,62		92,53	138,60
Total steel weight t			10886		29838		32668		38102	

Khan (1959) : Premium-For-Hight



Historical Considerations

The First High Rise Buildings

High Rise Buildings in Steel from Past to Present

Newest Research and Trends

Development Of Enhanced Bracing Systems

Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

Tube System with Shear Frames (Shear Walls)

Outrigger System

Tube in Tube Bracing

Space Truss Bracing

Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

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Outrigger System

Tube in Tube Bracing

Space Truss Bracing

Staggered Truss Bracing

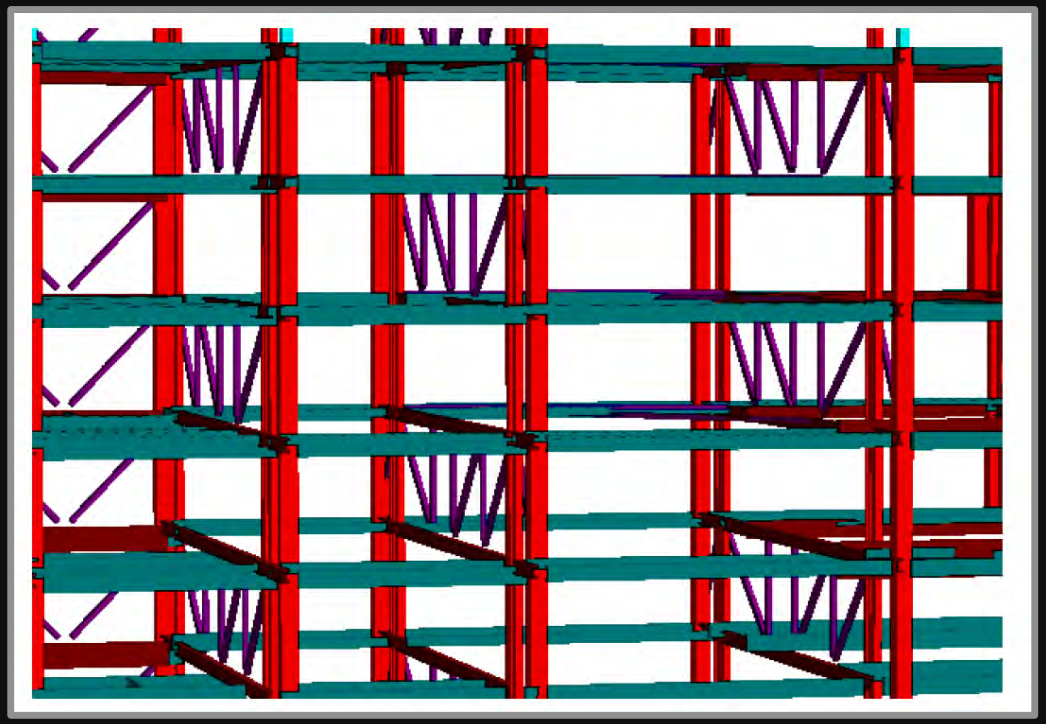
Godfrey Hotel, Chicago

2014

Hight: 16 storeys

Architect : Valerio Dewalt Train
Structural Engineer : Structural Affiliates International


THE GODFREY
GODFREY
PARKING



Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

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Tube System with Shear Frames (Shear Walls)

Outrigger System

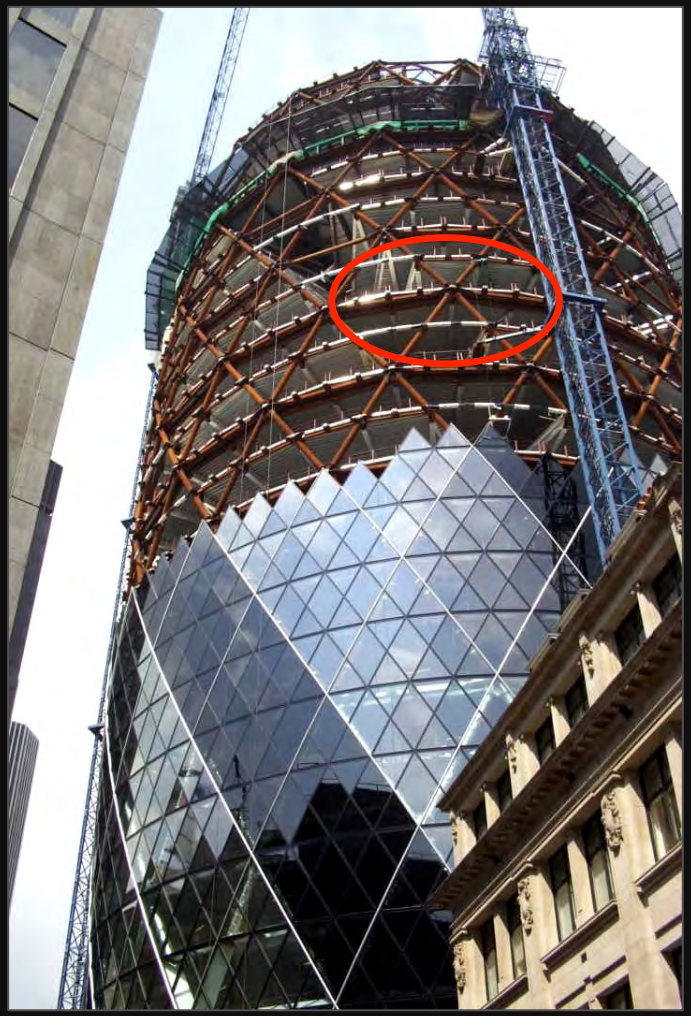
Tube in Tube Bracing

Space Truss Bracing

30 St. Mary Axe, London
2004

Hight: 180 m

Architects : Ken Shuttleworth
& Norman Foster



Tour D2

Paris, La Défense
2014

Hight: 171 m

Architects : Anthony Béchu / Tom Sheehan


HUET

Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

Tube System with Shear Frames (Shear Walls)

Outigger System

Tube in Tube Bracing

Space Truss Bracing

Tube System with External X-Bracing

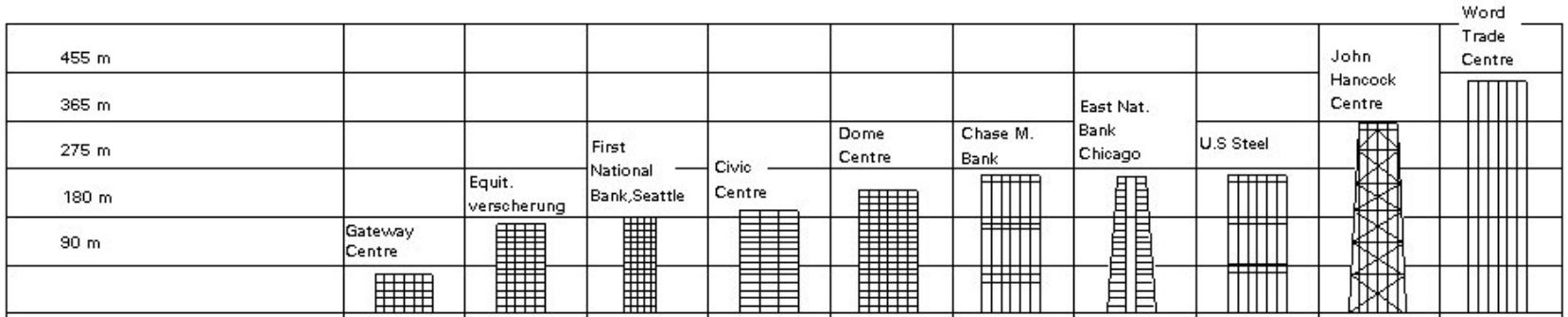
John Hancock Center

1968-1970
Chicago

Hight: 344 m (100 storeys)

Architects : & Engineers :
Skidmore, Owings & Merrill (F. Khan)

Construction: Braced Tube
(Steel frame & Megastructure X-bracing)



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Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

Tube System with Shear Frames (Shear Walls)

Outigger System

Tube in Tube Bracing

Space Truss Bracing

Bundled Tubes

Sears Tower (Willis Tower)

Chicago 1973

Architects & Engineers : SOM
(Skidmore, Owings & Merrill)
Bruce Graham, Fazlur Khan

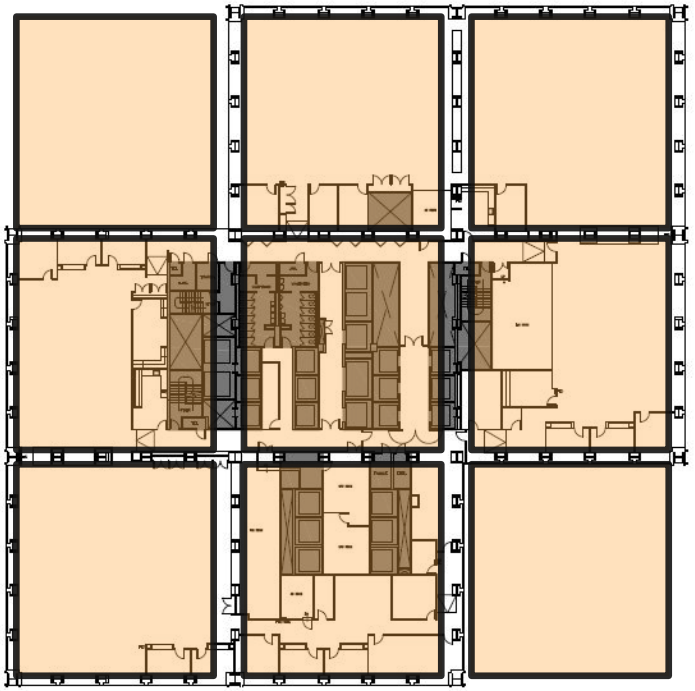
Hight: 442 m, 108 storeys

Construction:
Bundled Tube System with
Steel Frames.

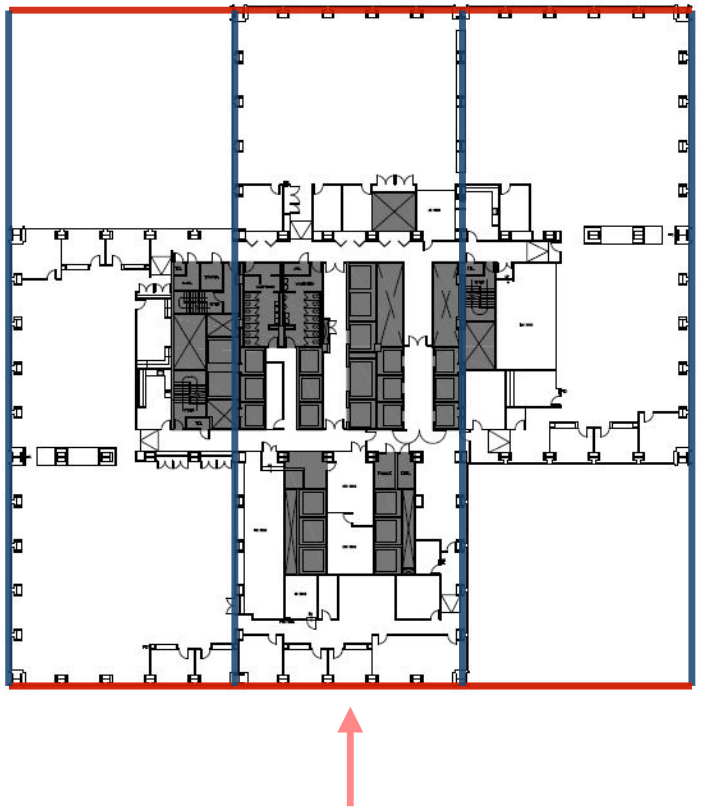
Fazlur Khan

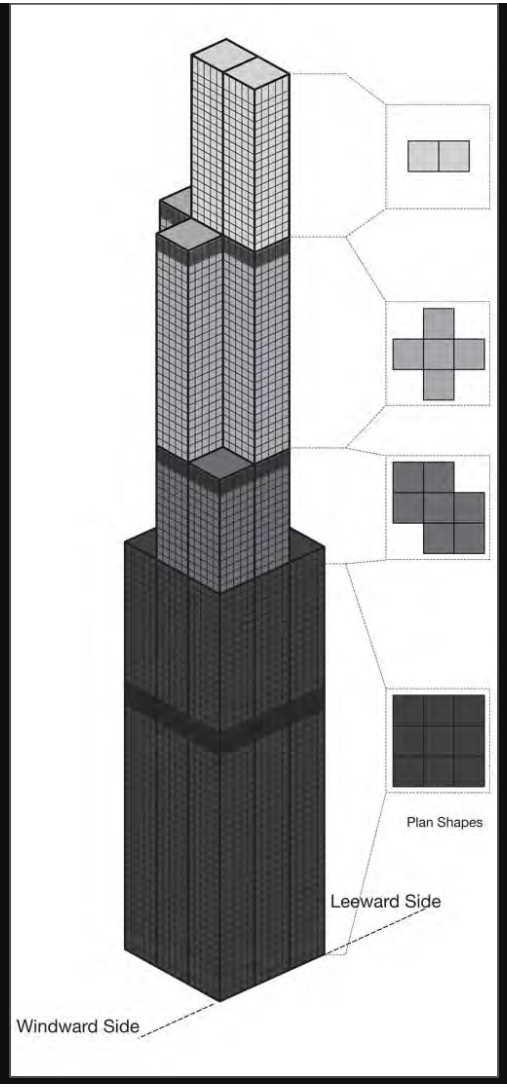
Fazlur Khan with his doughter,
Yasmin Sabina Khan

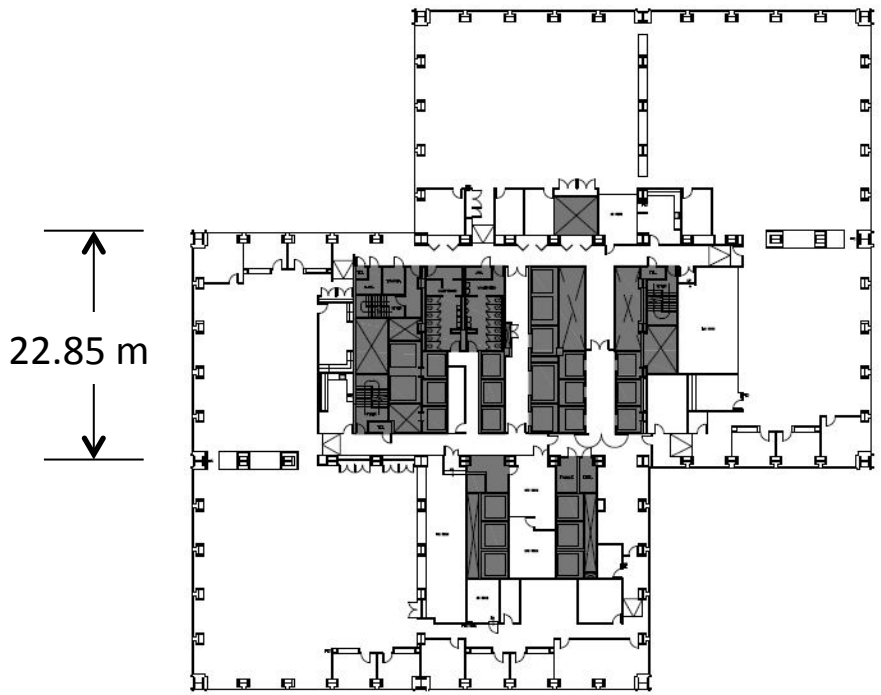
Bundled Tubes



Double
-T-Section
with
Flange
and Web




Plan Shapes
Leeward Side
Windward Side


22.85 m


SEARS TOWER
OWNER: SEARS ROEBUCK & CO
CONTRACTOR: DIESEL CONSTRUCTION CO

Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

Tube System with Shear Frames

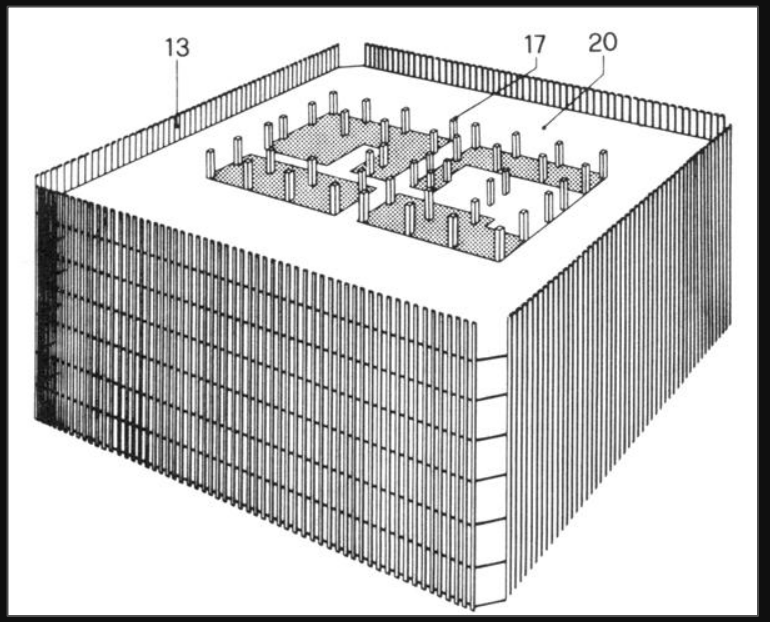
Outigger System

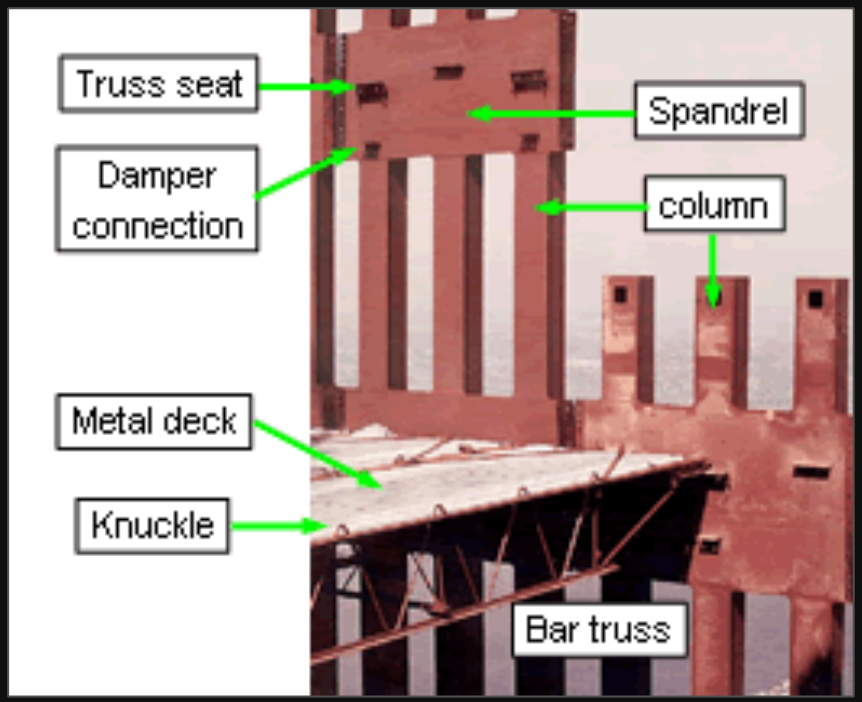
Tube in Tube Bracing

Space Truss Bracing

Tube System with Shear Frames

World Trade Center, NY
1970
Hight: 417 m




Truss seat
Damper connection
Metal deck
Knuckle
Spandrel
column
Bar truss

Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

Tube System with Shear Frames

Outrigger System

Tube in Tube Bracing

Space Truss Bracing

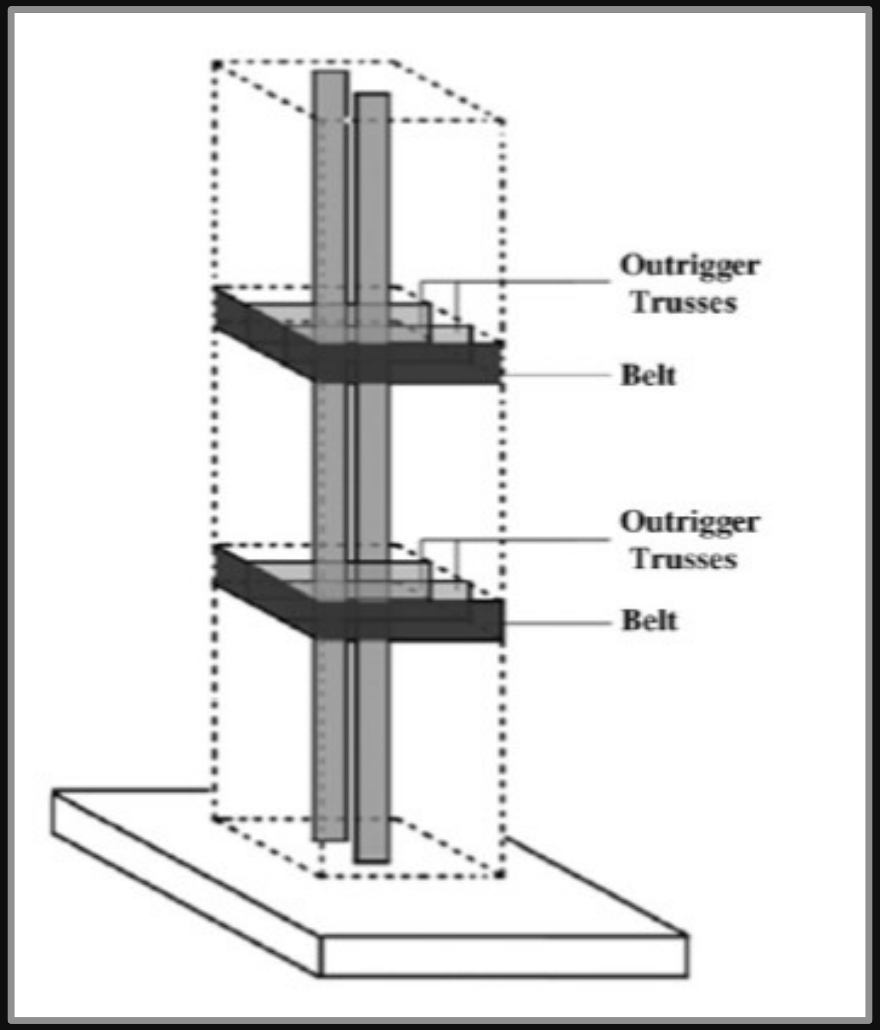
Outrigger System

First Wisconsin Center, Milwaukee, Wisconsin

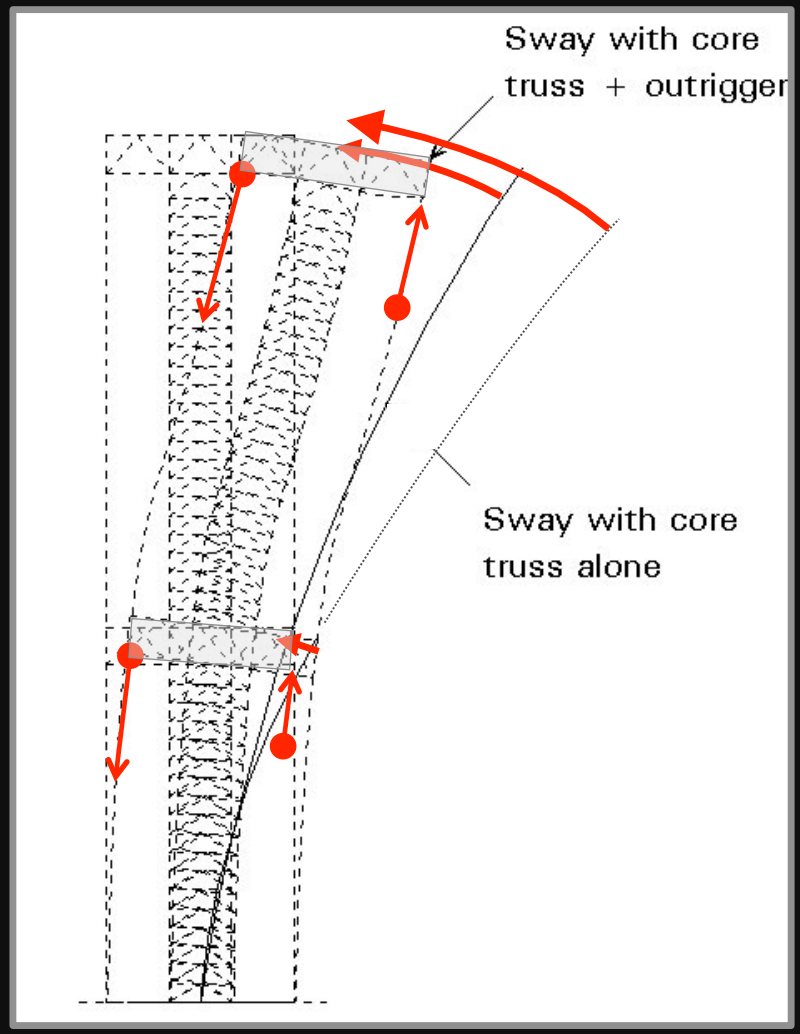
1972

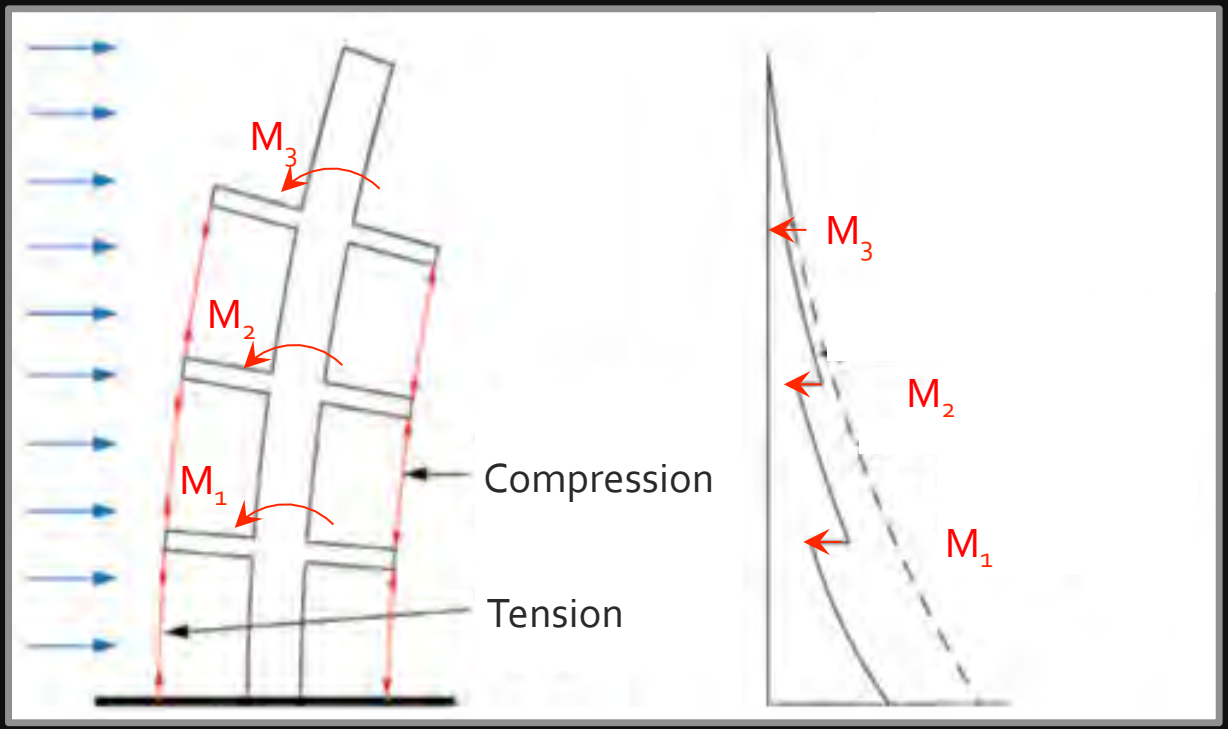
Hight: 183 m

SOM and Fitzhugh Scott Architects


Outrigger
Trusses
Belt
Outrigger
Trusses
Belt

Effect in Terms of Deflection





Effect in Terms of Bending Moments

Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

Tube System with Shear Frames (Shear Walls)

Outrigger System

Tube in Tube Bracing

Space Truss Bracing

Tube in Tube Bracing

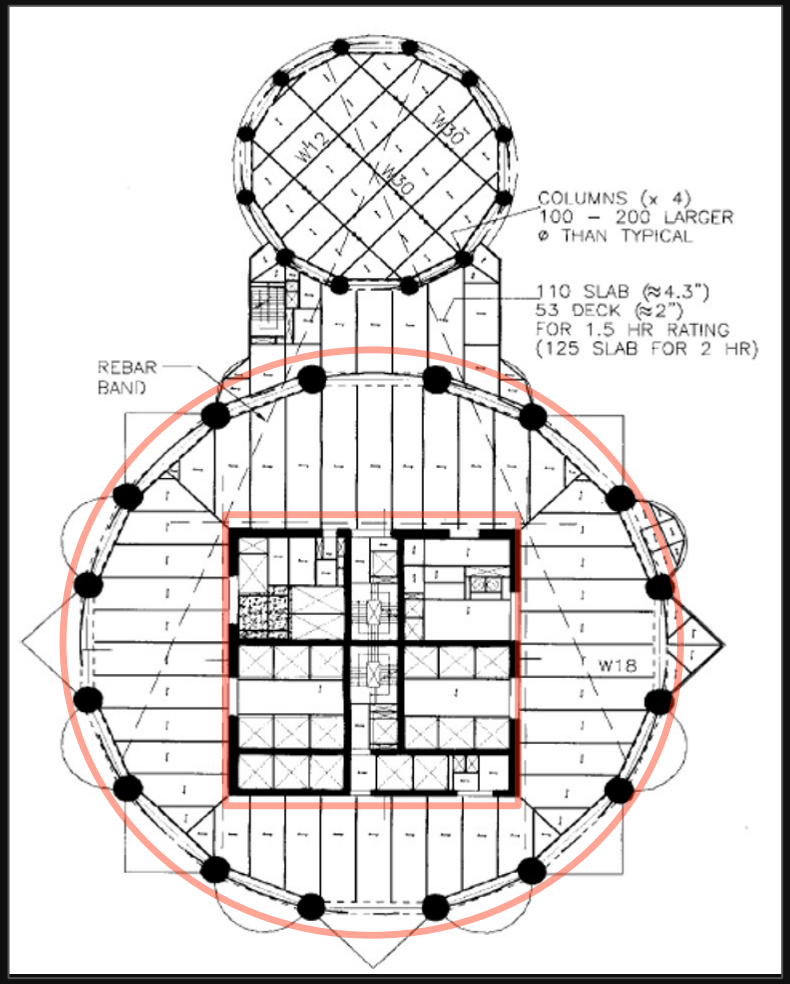
Petronas Towers

Kuala Lumpur, 1999

Hight: 452

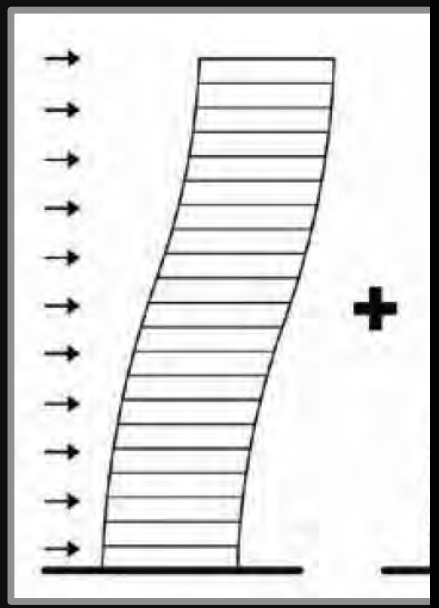
Architect: Cesar Pelli & Associates, New Haven,
Structural Engineering : Thornton Thomasetti

Construction:
Mixed Steel-Concrete Structure


W12
W30
W30
COLUMNS (x 4)
100 – 200 LARGER
ø THAN TYPICAL
110 SLAB (≈4.3")
53 DECK (≈2")
FOR 1.5 HR RATING
(125 SLAB FOR 2 HR)
REBAR
BAND
W18

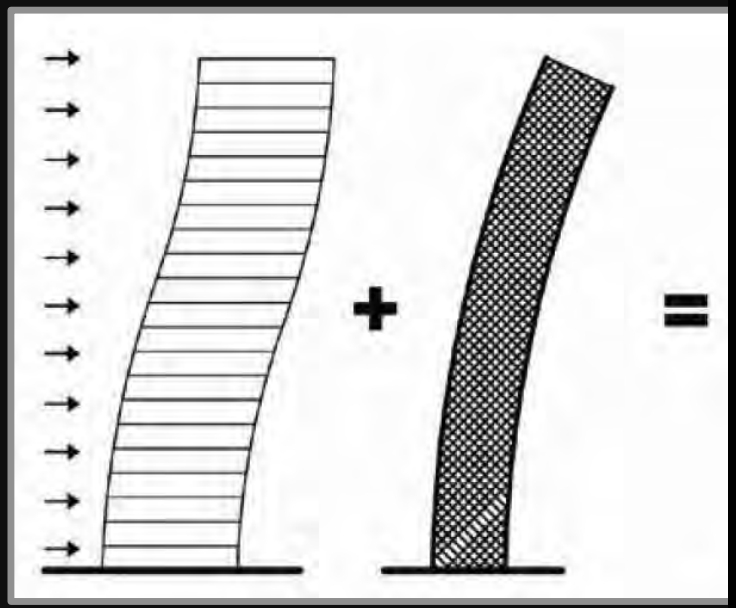
Shear Wall/Truss – Frame Interaction Forces

Fazlur Khan



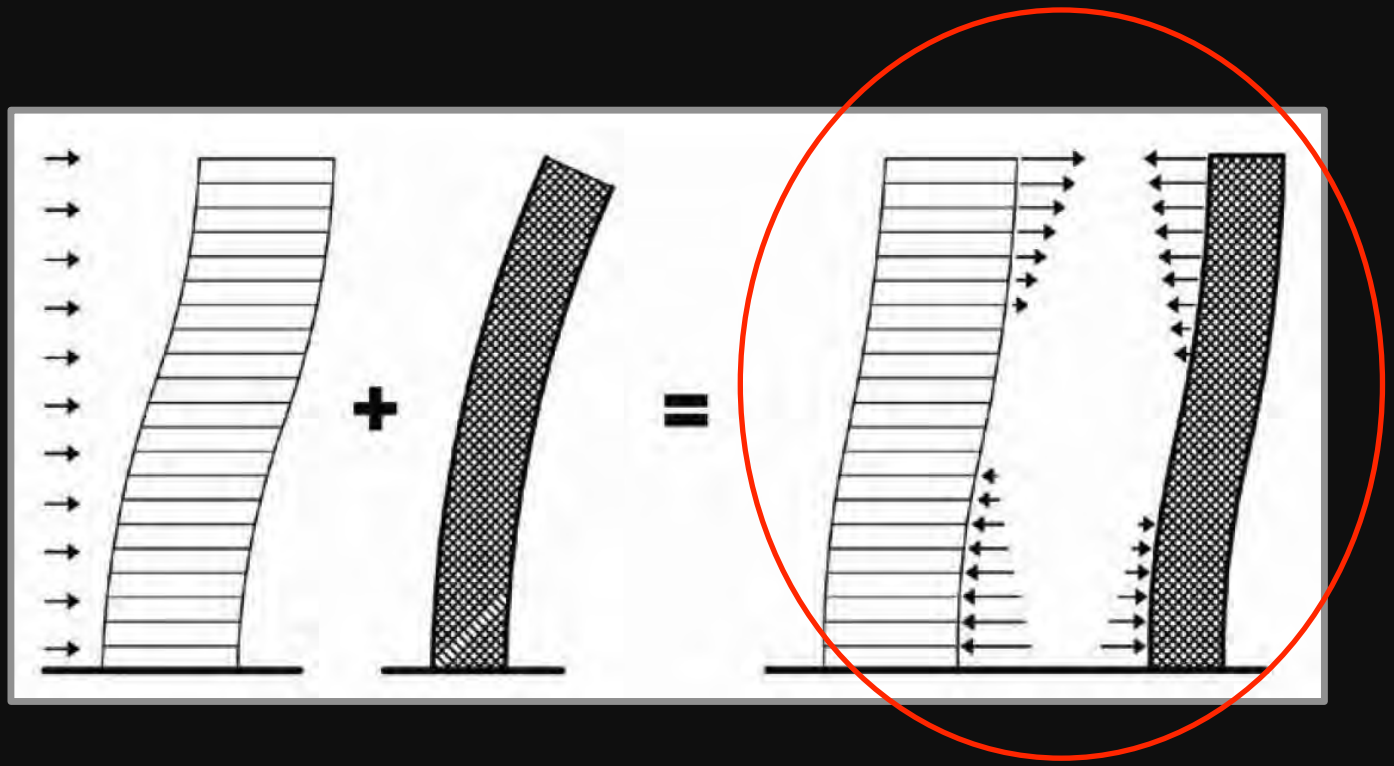
Shear Wall/Truss – Frame Interaction Forces

Fazlur Khan



Shear Wall/Truss – Frame Interaction Forces

Fazlur Khan



Staggered Truss Bracing

Diagrid Structure

Tube System with External X-Bracing

Bundled Tubes

Tube System with Shear Frames (Shear Walls)

Outrigger System

Tube in Tube Bracing

Space Truss Bracing

Space Truss Bracing

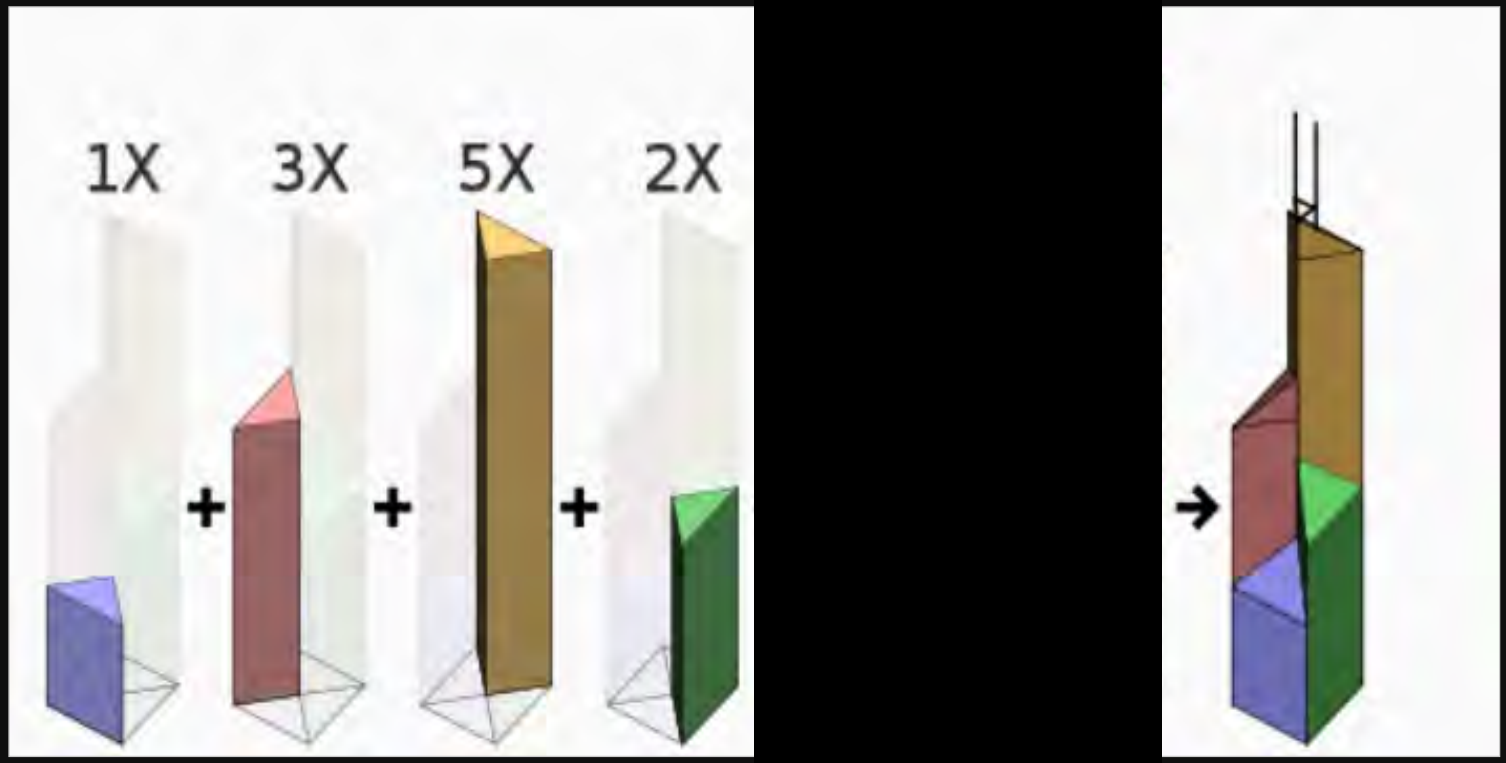
Bank of China, Hong Kong

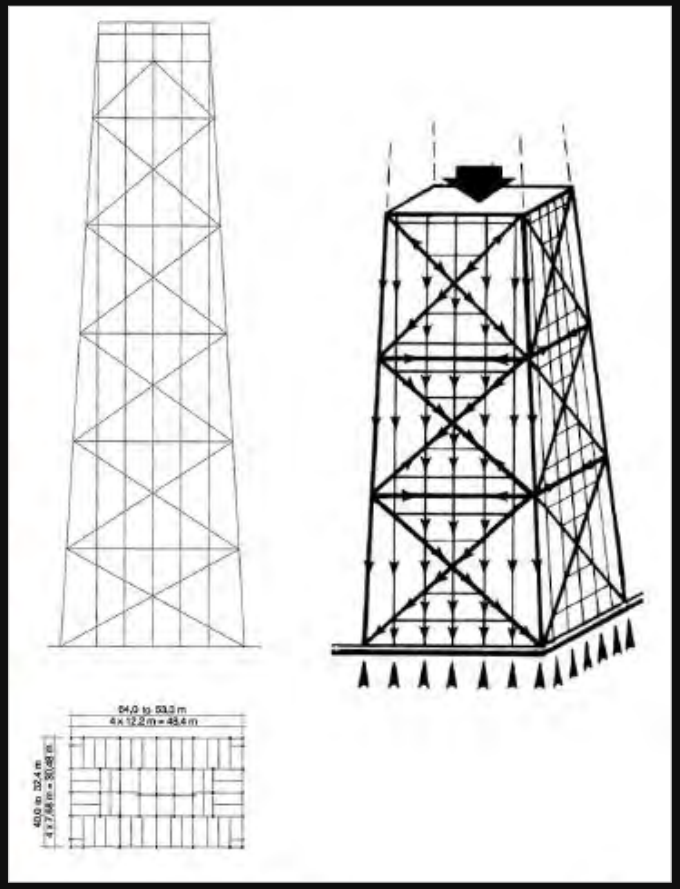
Hong Kong, 1999

Hight: 315 m

Architect: I.M Pei and Partners
Structural Engineering :
Leslie E. Robertson Associates

Structures :
Steel / Steel-Composite


1X
3X
5X
2X



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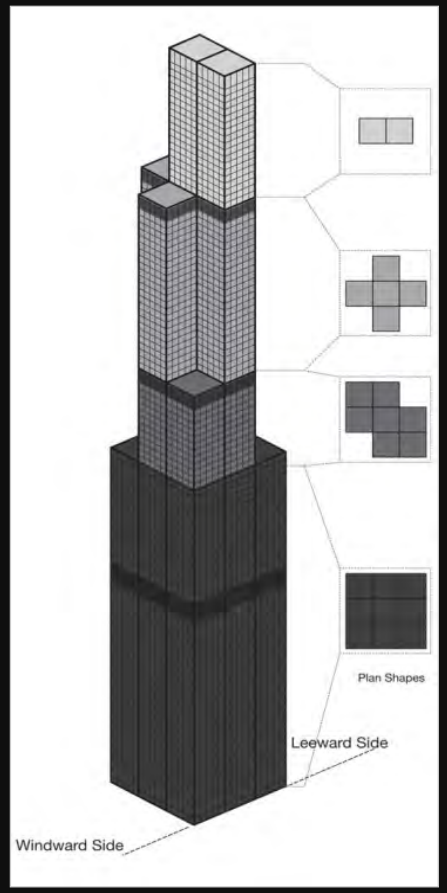
Plan Shapes
Leeward Side
Windward Side

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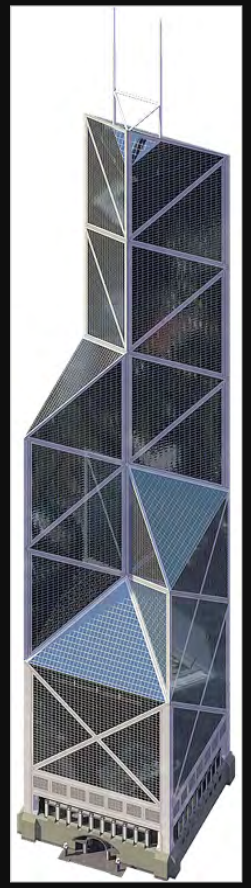

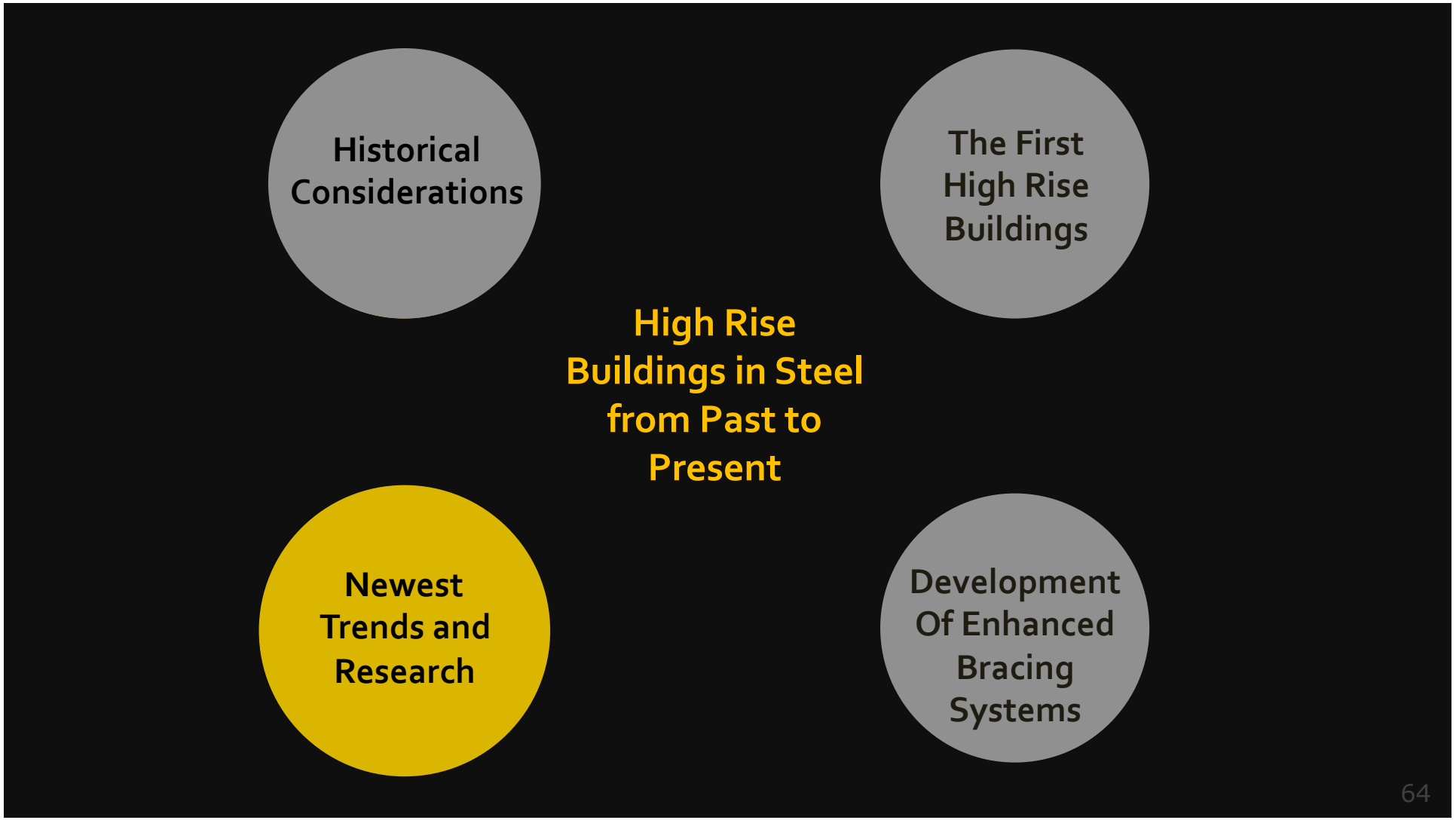
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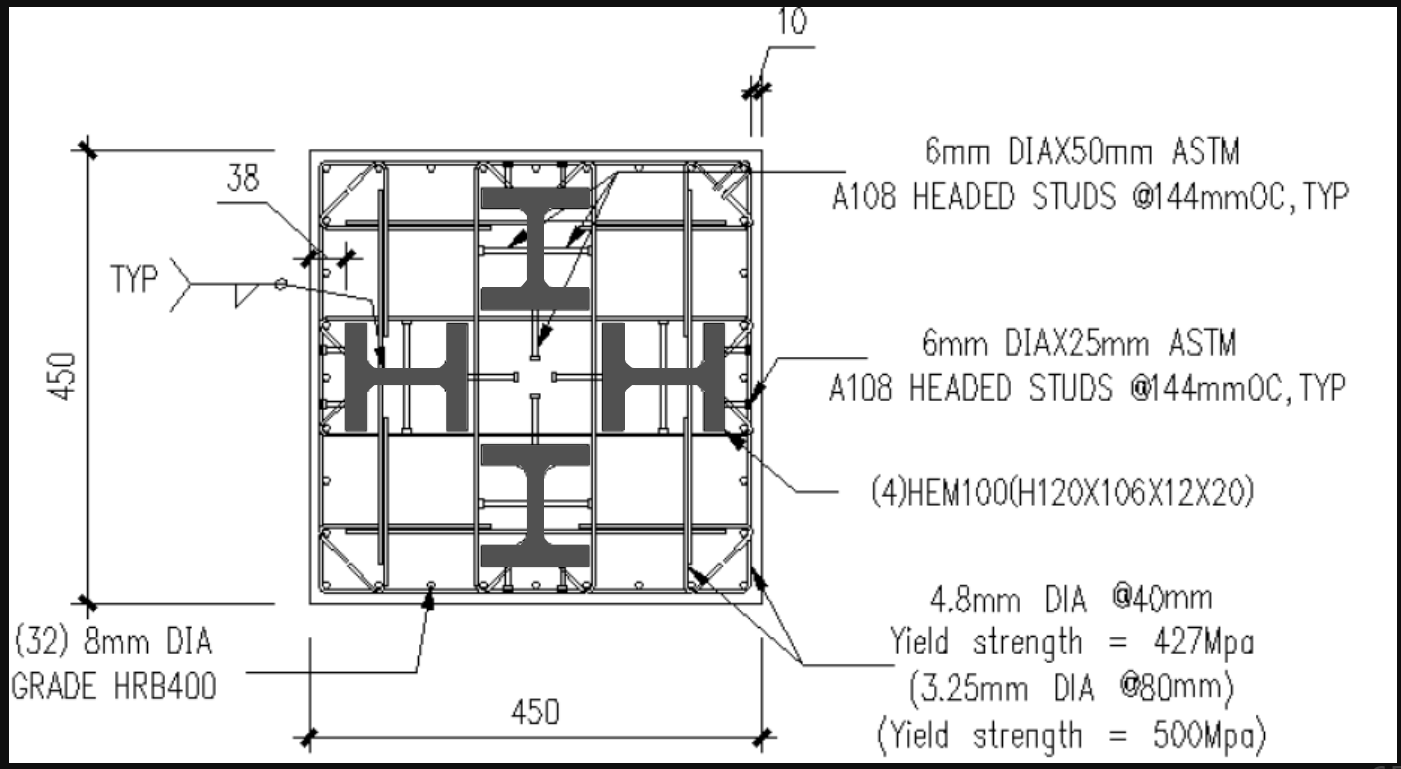
Development Of Enhanced Bracing Systems

Research on Super Columns :

ArcelorMittal

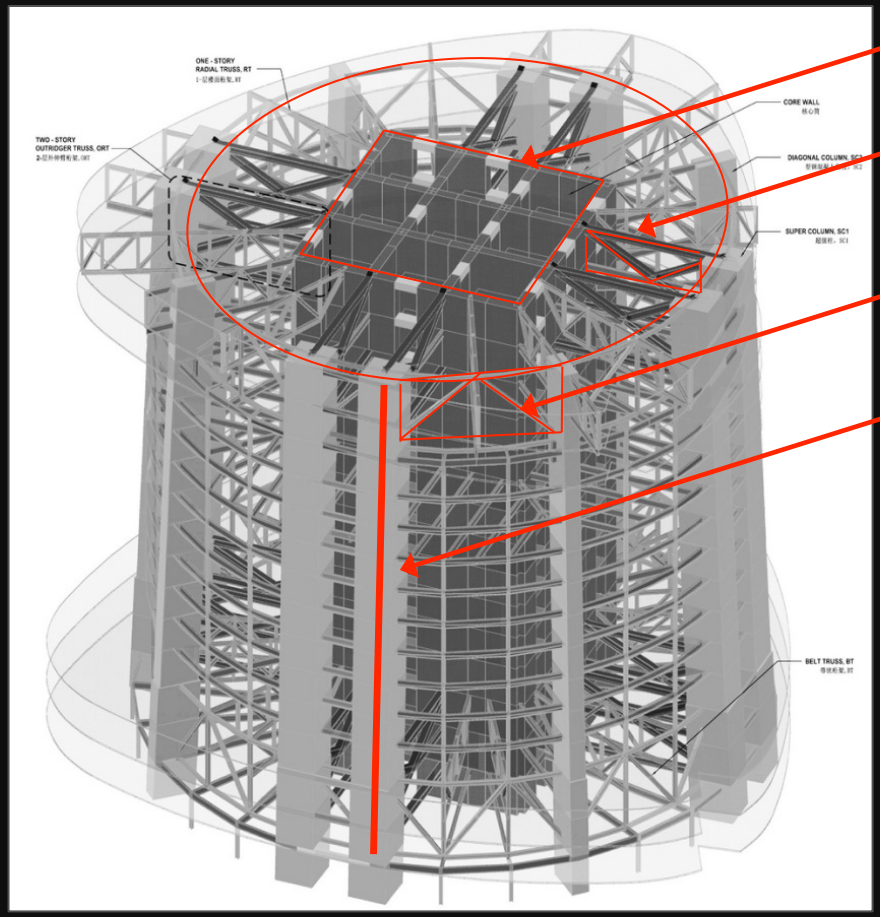
China Academy of Building Research

Tsinghua University Beijing




S5-vert e = 0

Principle



Core (Concrete/Composite)

Outrigger & Shear Trusses

Belt Truss

Super Columns

Projects

Combined
Core + Super Columns + Outrigger System

International Finance Center
Hong Kong

2003

Hight 412 m

Architect 7 Engineers:
Cesar Pelli / Ove Arup

Super Columns +
Outrigger + Super Frames

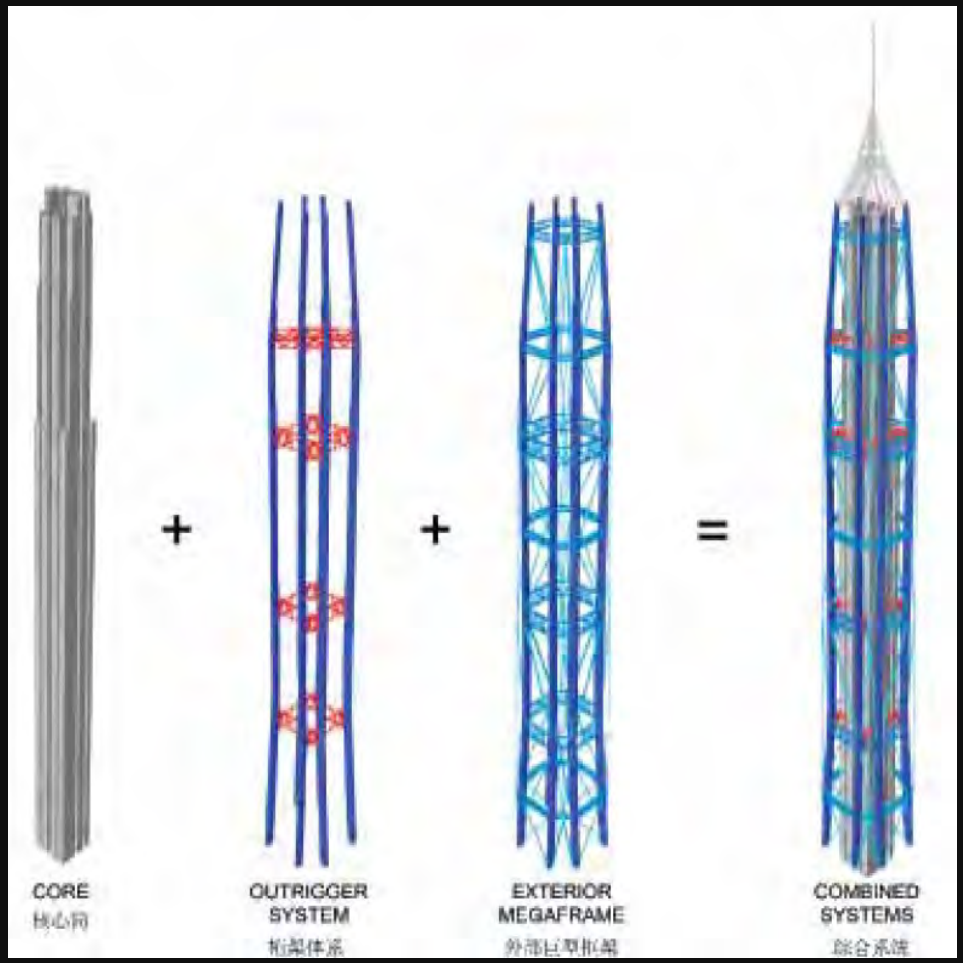
Ping Anh Finance Center
Shenzen

Under Construction

Hight 660 m

Architect & Engineers:

Kohn Pedersen Fox &
Thornton Thomasetti


CORE
核心筒
OUTRIGGER
SYSTEM
EXTERIOR
MEGAFRAME
COMBINED
SYSTEMS


品质保障
价值创造
飞火流星


品质保障
价值创造

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Thank You for Your Attention

Prof. Dr. –Ing. Christoph Odenbreit

ArcelorMittal Chair of Steel and Façade Engineering
University of Luxembourg