MIDDLE EAST TECHNICAL UNIVERSITY
DEPARTMENT OF ARCHITECTURE / BUILDING SCIENCE PROGRAM

BS 536
STUDIES ON TALL BUILDINGS: DESIGN CONSIDERATIONS
Spring 2013-2014

Case Study: **Wuhan Greenland Center**
by
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Submitted to: Assoc.Prof.Dr. Mehmet Halis Günel

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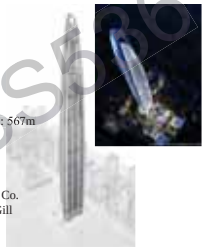
Wuhan Greenland Center



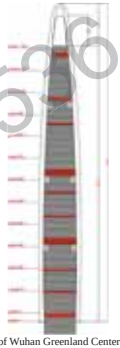
General Information [3]

Name: Wuhan Greenland Center
Location: China, Wuhan
Usage: Hotel/ Residential/ Office
Height (to tip): Architectural:636m/Occupied: 567m
Floors: 125 floors above ground
Construction End: 2017
Structural Material: Composite
Structural System: Outrigger frame system
Client: Wuhan Greenland Bin Jiang Property Co.
Architect: Design: Adrian Smith & Gordon Gill
Architecture/ Architect of Record: ECADI
Structural Engineer: Thornton Tomasetti

(http://www.skyscrapercenter.com)

Plan and Section of Wuhan Greenland Center

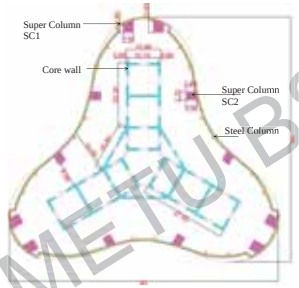
Wuhan Greenland Center, Hotel plan (http://www.google.com)



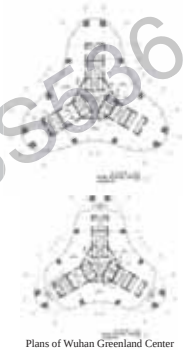
Prospective of Wuhan Greenland Center (Drawn by Nastaran Deljavan [4])

Section of Wuhan Greenland Center (Drawn by Nastaran Deljavan [5])

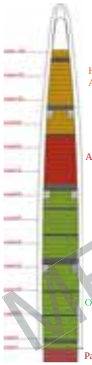
Plans of Wuhan Greenland Center



Plan of Wuhan Greenland Center (Drawn by Nastaran Deljavan [5])



Plans of Wuhan Greenland Center (http://www.google.com)



(Drawn by Nastaran Deljavan [1])

Building Usage [1]

A mixed-use skyscraper including:
- Offices up to the 69th floor
- Apartments at the 70th to 89th floors
- Hotel from the 91th to the top floor
- Outrigger trusses and belt are used for mechanical spaces[4]

Total Gross Floor Area (GFA): 393,259 m² [4]

323308 m² Above Ground[4]
70171 m² 5-story Basement[4]

Entrance of Wuhan Greenland Center[1]

While some mixed-use towers separate users by levels, the triangular floor plan of this building allows for the tenants or visitors to have separate entrances all at Ground Level. [1]

Entrance plan (Drawn by Nastaran Deljavan)

Wind Load and Earthquake Load [4]&[5]

OTM: Overturning Moment
Wind load information is provided by RWDI and dated on February 3, 2012

Lateral loads, wind and seismic, play the important role in design of Wuhan Greenland Center. Therefore, for the structural design of the tower, wind load, seismic load, and seismic load under frequent earthquake, were combined with gravity load.

For Wuhan Greenland Center, the base shear and overturning moment under wind load is much larger than the values under the frequent earthquake load.

To optimize both the structural and programmatic performance of building, four primary design solutions were implemented. [1]
- A tapered profile
- A dome top
- Triangular floor plans with rounded soft corners
- Vent slots

Architectural Building Massing Concept [1][6][5]

Wind Tunnel Test by RWDI to Study 3 Option [1]&[4]

Tower Wind Load Comparison for Different Massing Options. Based on wind load data from RWDI, February 2011 [1] & [6]

According to the table:

Option 1 did not show a reduction [1]

Option 2 reduced the overall wind load by 15% and 6.6% along "X" and "Y" respectively [1]

Option 3 did not show a significant wind load reduction [1]

Therefore, second and third option is used for design of Wuhan Greenland Center.

Option 1: tapered tower, solid surface [4]

Option 2: tapered tower, opening between the dome and crown, slotted floor at multiple elevations [4]

Option 3: wing walls and vertical slots [4]

A Tapered Profile [1]

- Reduce overall tower lateral load
- Resolve different floor plate size requirements for varied program elements without using a traditional step profile

Triangular floor plans with rounded soft corners [1]

- create unique public spaces that attract visitors to the building
- reduce the tower wind load
- Separated entrances at ground level distinguish each type of user and control access

alternation of floor plans in wuhan Greenland Center

alternation of slotted floor plans in Wuhan Greenland Center

(Drawn by Nastaran Deljavan)

Opening Between the Dome and Crown [3]

- An opening at the tower top would separate the whole tower top into an upper crown and a lower dome
- Reducing the wind load
- Top opening is a unique architectural feature
- It is as a building maintenance unit in which window cleaning machine is concealed in the crown to clean the dome surface. [1]

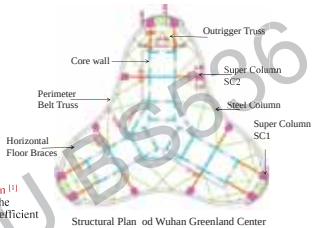
Opening Between the Dome and Crown slotted floor *(http://www.skyscrapercenter.com)*

Structure System

Outrigger frame system

Structural Elements:[4]

- **Outrigger**
- **Core**
- **Super Column**
- **Belt Truss**
- **Horizantal Braced Frame**



Structural Plan od Wuhan Greenland Center (Drawn by Nastaran Deljavan [1] & [4])

Features of Core and Super Column [1]

- "Y" shape plan make maximize the structural stiffness and it is more efficient than rectangle core
- At the tip of each tower wing a pair of massive super columns (SC1) are located
- Two additional super columns (SC2) are spaced at approximately one-third points along each face and serve to reduce the spans of perimeter structural members.
- The super columns are Steel Reinforced Concrete (SRC)
- SC1 columns are up to 3.3x4.6m in first levels

The core was organized to provide multiple benefits across different disciplines: separating office, hotel and apartment operational functions, providing significant structural stiffness and strength for the tower to resist lateral and gravity loads, and accommodating the mechanical system floor and riser space requirements.

Outrigger Truss and Belt Truss Location [4]

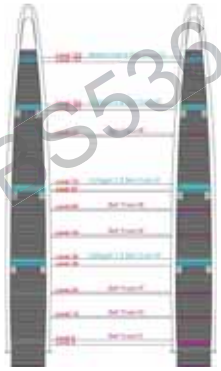
Outrigger Truss Location:[4]

3 Outrigger Truss Floors
Level 36 to 39
Level 67 to 70
Level 101 to 103

1 Header Truss Floor
Level 121 to 123

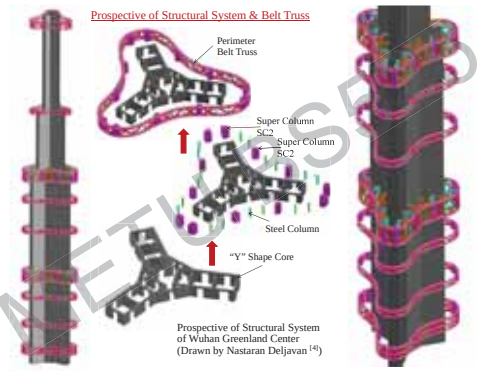
Belt Truss Location:[4]

10 Belt Truss Floor
Level 3 to 5
Level 14 to 15
Level 24 to 25
Level 48 to 49
Level 59 to 60
Level 90 to 91



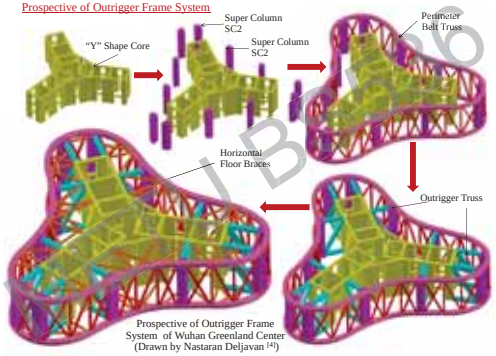
Outrigger Truss and Belt Truss Location (Drawn by Nastaran Deljavan [4])

Prospective of Structural System & Belt Truss



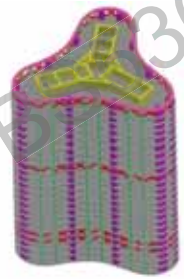
Prospective of Structural System of Wuhan Greenland Center (Drawn by Nastaran Deljavan [4])

Prospective of Outrigger Frame System



Prospective of Outrigger Frame System of Wuhan Greenland Center (Drawn by Nastaran Deljavan [4])

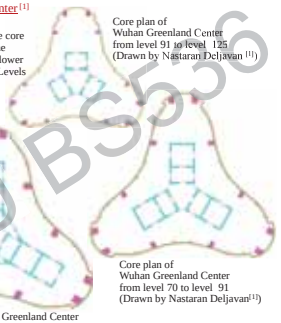
Prospective of Structural System & Belt Truss



Prospective of Structural System of Wuhan Greenland Center in first 39 levels (Drawn by Nastaran Deljavan [4])

Set Back of Core in Wuhan Greenland Center [1]

The central "Y" plan, concrete core extends 31.3m in plan from the tower center to its far ends at lower zones, and sets back twice at Levels 70 and 91. [1]



Core plan of Wuhan Greenland Center from level 1 to level 70 (Drawn by Nastaran Deljavan [1])

Core plan of Wuhan Greenland Center from level 70 to level 91 (Drawn by Nastaran Deljavan[1])

Core plan of Wuhan Greenland Center from level 91 to level 125 (Drawn by Nastaran Deljavan [1])

Slotted Floor in Wuhan Greenland Center [1]

Plan of Slotted Floor in 3 levels (Drawn by Nastaran Deljavan) Source: google

Slots are located at mechanical levels, and are carefully coordinated to avoid causing structural discontinuities. A Vierendeel truss system could be used at slotted floors, since the lack of diagonals would allow the most air flow. However, Vierendeel truss systems' structural efficiency is much less than for traditional truss systems with diagonal members; additionally, as they serve as transfer trusses supporting perimeter columns in one zone bounded by adjacent belt truss levels, the trusses are critical to prevent progressive collapse by carrying additional load from columns above in the event of failure of a perimeter column below. [1]

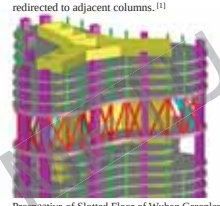
Wuhan Greenland Center Main Tower's unique architectural shape evolved from a classic tapered tower with "Y" plan shape into an elegant curvilinear figure. By locally omitting portions of floors and perimeter framing at different elevations, "slots" are created in the building envelope to provide a distinctive architectural personality while reducing wind loads on the structure from vortex shedding. [1]

Slotted Floor (http://www.skyscrapercenter.com)

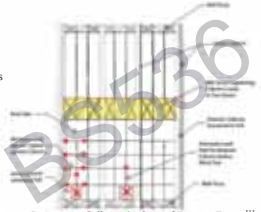
Section of Slotted Floor of Wuhan Greenland Center (Drawn by Nastaran Deljavan [4])

Slotted Floor in Wuhan Greenland Center [1]

After discussions between the architect and structural engineer, the slotted floors were located below the belt truss floors; and the continuous perimeter belt trusses are of conventional design, reducing construction costs compared to Vierendeels. In the progressive collapse analysis, floor beams can span loads normally carried by those columns if the discontinuous perimeter steel column below the floor slots fails. Those loads would then be redirected to adjacent columns. [1]



Prospective of Slotted Floor of Wuhan Greenland Center (Drawn by Nastaran Deljavan [4])



Progressive Collapse Analysis of Exterior Frame [1]

Slotted Floor (http://www.skyscrapercenter.com)

Integrating the Architecture and Structure [1]

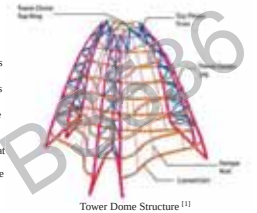
The top of the Wuhan Greenland Center Main Tower is an expression of the project design philosophy. As the tower reaches into the sky, the cladding splits at the line between two architectural components known as the body and the shield. This separation was created to help alleviate tower top wind forces and thus significantly improve building behavior. This simple but powerful statement about the effectiveness of coordinating architecture and structure in super tall building design has become the building's most iconic feature and is certain to create a landmark on the city skyline.
Rising from gently tapering tower wing tips, the taper steadily and continuously increases to the point that the tips converge on the tower centerline to form a unique 61m tall crown. Tapering of other building surfaces defines a 35m tall dome.

Prospective and Section of Dome and Crown (http://www. google.com)

Prospective of Dome and Crown (http://www.skyscrapercenter.com)

Dome Structure [1]

- Dome cladding is transparent but substantial cladding support framing is required at long spans and high wind pressures.
- Dome structural framing will be visible to visitors so a dramatic sculptural appearance is desired.
- Multiple structural schemes were proposed by the structural engineer for consideration by the architect. Systems included support framing distributed along all faces, framing concentrated at discrete locations, horizontal spanning schemes and vertically spanning schemes. For each scheme the relative hierarchy of framing sizes and functions was considered for aesthetic intent, structural efficiency and constructability.
- The selected system has horizontal curved pipe girts to support the tower skin. To minimize girt pipe diameter, gravity load pans are reduced by suspending the girts from steel hangar rods.



Tower Dome Structure [1]

Interior prospective of Dome [4]

Tower Crown Structure [1]

- Cladding of the outer crown is supported by a special tripod structural system. Because crown tripod leg framing is concealed within opaque cladding, support structural design was based on material efficiency and constructability.
- Each crown tripod leg, a half-arch in profile, is trapezoidal in cross-section or plan. The four faces of each leg are trusses following simple surfaces.
- Pipes up to 500 mm diameter are used for truss chords and smaller diameter pipes are used for web members and braces.
- The side trusses taper nearly to a point at the crown base, landing on the super columns at wing tips and connecting directly to the embedded steel columns in the super column for secure load transfer.
- The legs stop before the peak, and plane trusses are added at leg truss top panels to tie the three Tripod legs together.
- Cleaning of the dome glass will be performed by equipment suspended from the crown above.

Tower Crown Structure [1]

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