Thornton Tomasetti

Tall Building Design Approach

At Seoul City College

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October 01, 2015

Thornton Tomasetti - Weidlinger

Thornton Tomasetti

- Among top five structural firms globally
- Staff of 1200 in 54 offices across the U.S., Europe, Asia and Middle East
- Unique symbiosis of engineering design and forensics
- Partnership founded in 1956

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Locations

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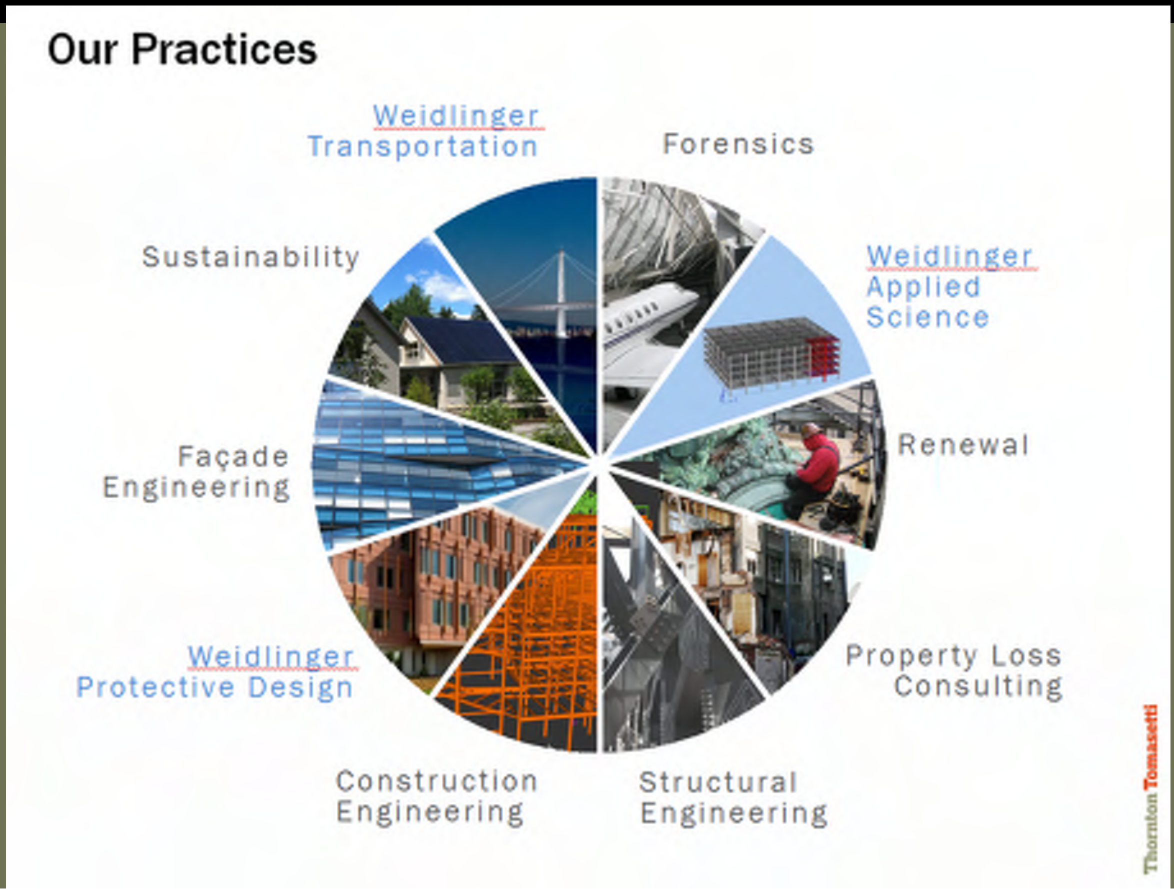
Practices



PR Outline

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- Definition of Super Tall or Mega Tall Building.
- Things to know about Height
- Structural Design: Strength, Serviceability, Dynamic Property
- Workflow of Structural Building Design
- Discuss Other Structural Considerations

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What's super tall or mega tall?

Based on CTBUH (Council on Tall Buildings and Urban Habitat)

Mega Tall Building : 600m (~ 2000 ft) tall

Super Tall Building : 300m (~ 1000 ft) tall

Note:

Height to Architectural Top

Highest Occupied Floor

Height to Tip

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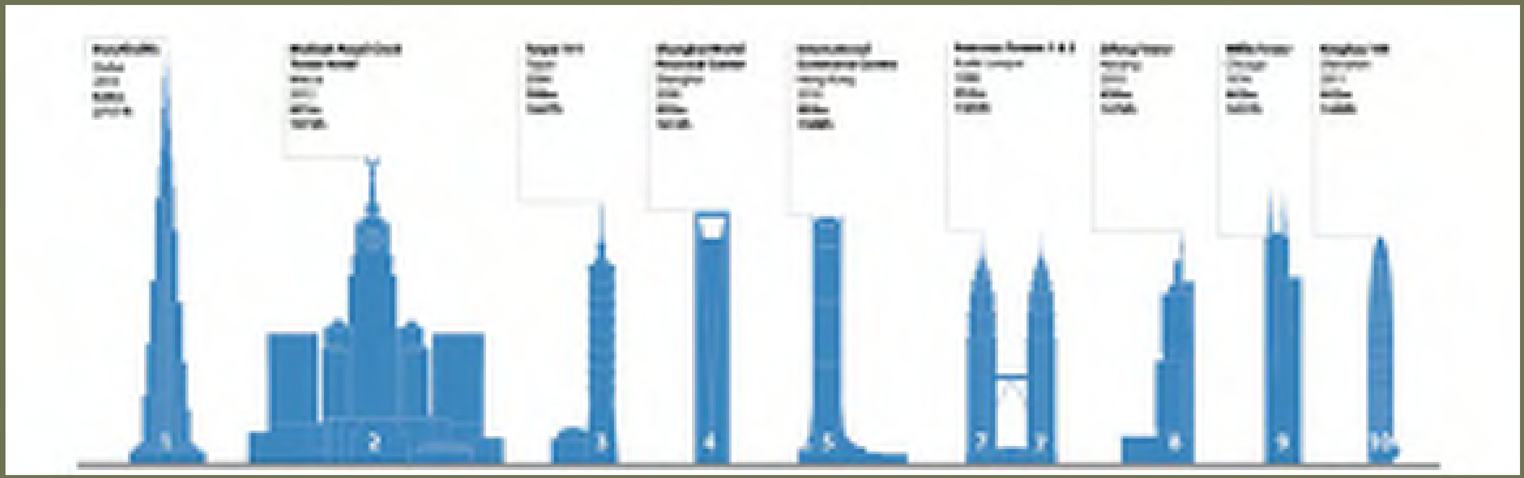
How is the Height of a Tall Building Measured?

Height to Architectural Top

Height is measured from the level[1] of the lowest, significant, open-air, pedestriaentrance to the architectural top of the building, including spires, but not including antennae, signage, flag poles or other functional-technical equipment.



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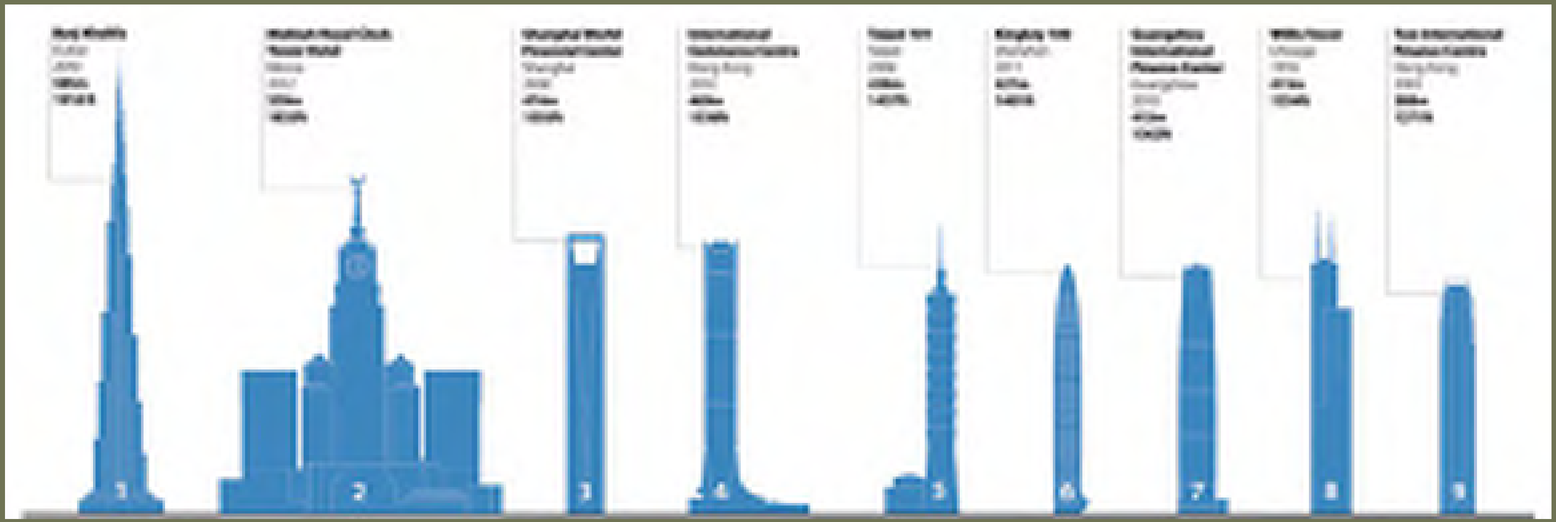
How is the Height of a Tall Building Measured?

Highest Occupied Floor

Height is measured from the level[1] of the lowest, significant, open-air, pedestrian entrance to the finished level of the highest occupied floor within the building.



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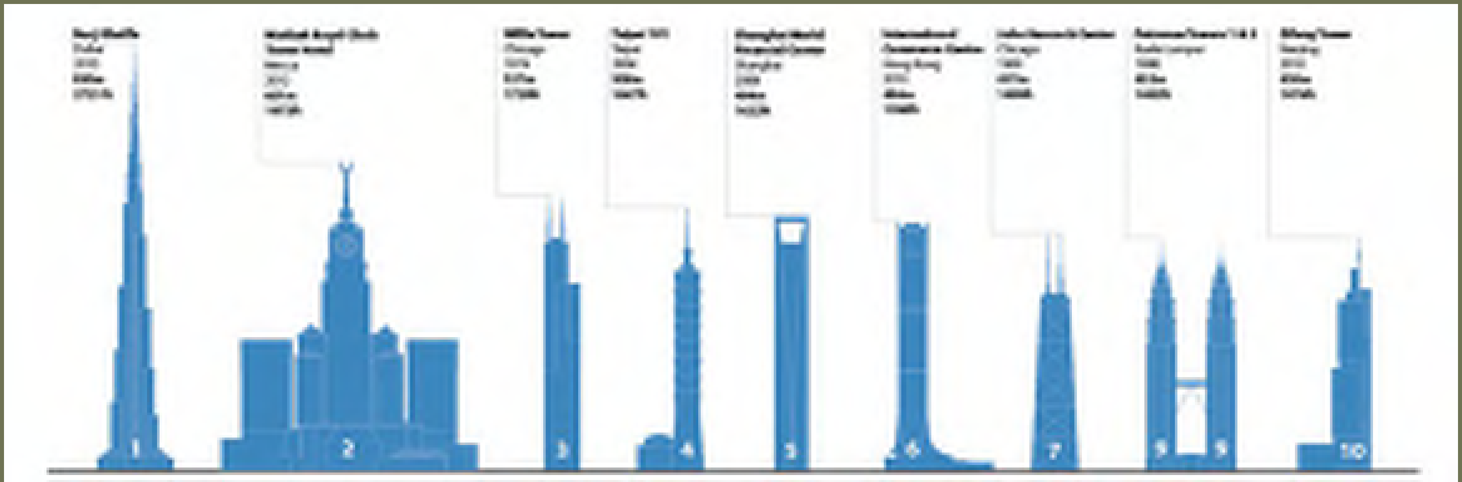
How is the Height of a Tall Building Measured?

Height to Tip

Height is measured from the level of the lowest, significant, open-air, pedestrian entrance to the highest point of the building, function of the highest element (i.e., antennae, flagpoles, signage and other functional-technical equipment).



What is “Aspect Ratio”?

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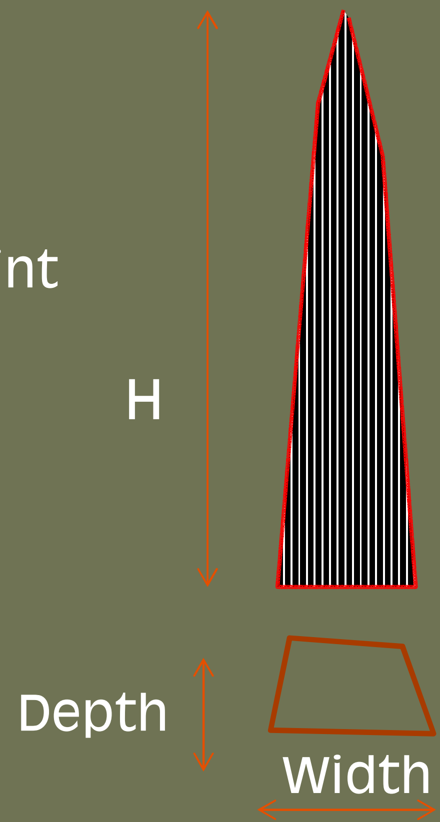
Building height (H) vs. footprint (Width or Depth)

Aspect ratio = (height / structural lateral system footprint width or depth)

Preferably < 6

Could be > 10

if special features to improve wind comfort are included (TMD)



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Floor to Floor Height (h)

Floor-to-Floor Height (h) – Clear height

Typical Office:

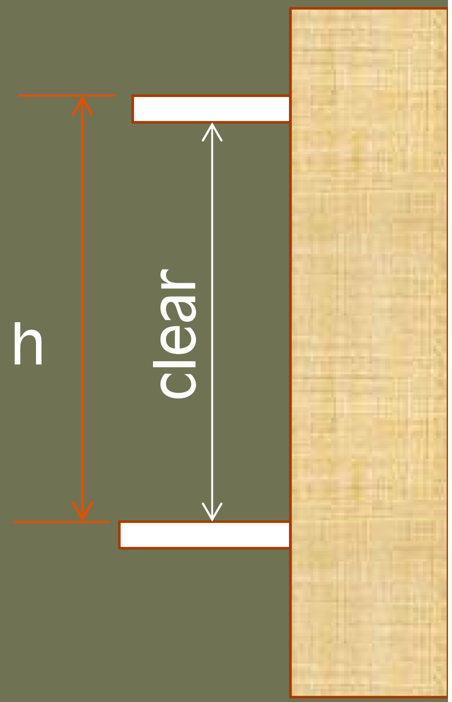
h = 11′ ~ 14′ (8′ ~ 9.5′clear)

h = 3.35m ~ 4.25m (2.5m ~ 2.9m clear)

Typical Residential:

h = 8′ ~ 11′ (7.5′ ~ 9′ clear)

h = 2.45m ~ 3.35m (2.3m ~ 2.75m clear)



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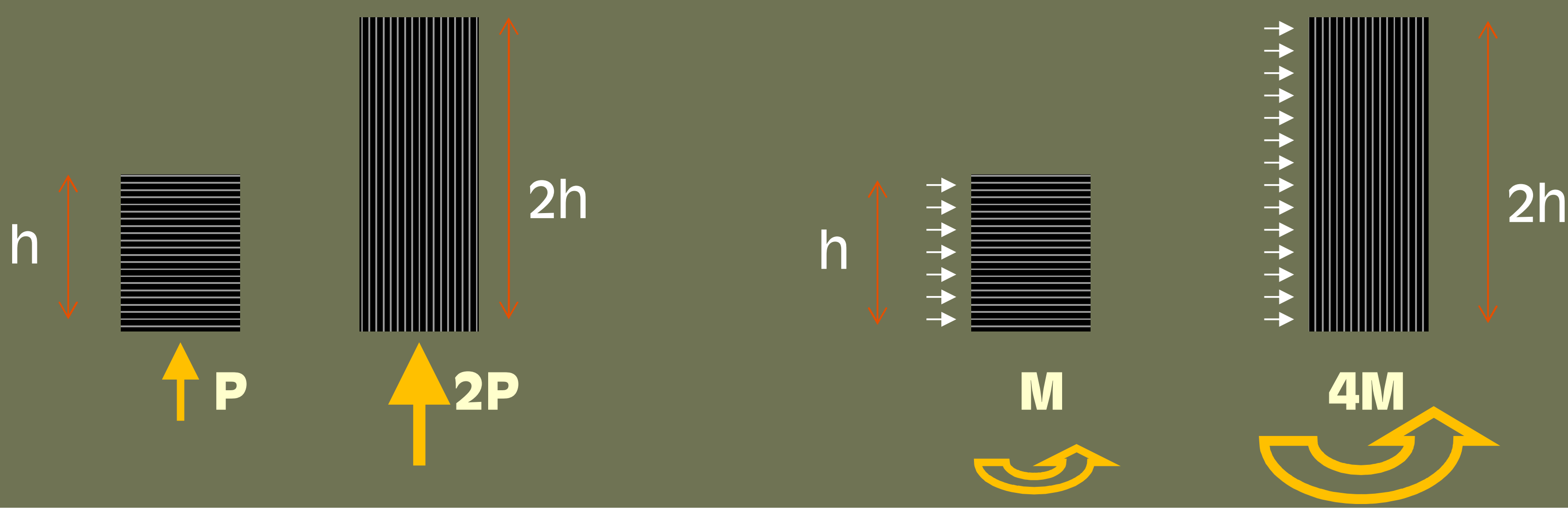
Strength Design: Small Building

Short Building : Strength Design (강도 설계)

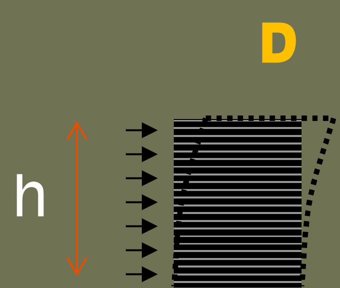
Gravity Load W = (~ h) and Strength Design M = (wh^2 /2)



Serviceability : Deflection

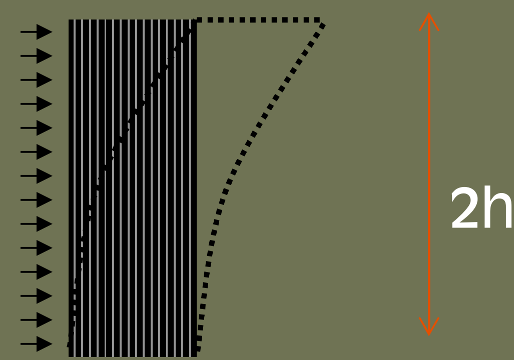
Intermediate Size Building: Deflection

Lateral Load Control – Stiffness Design (~ h^3)



Drift limit
based on h;

$16D = h^4$



$h^4 / h \sim h^3$

Dynamic Property (Period and Acceleration)

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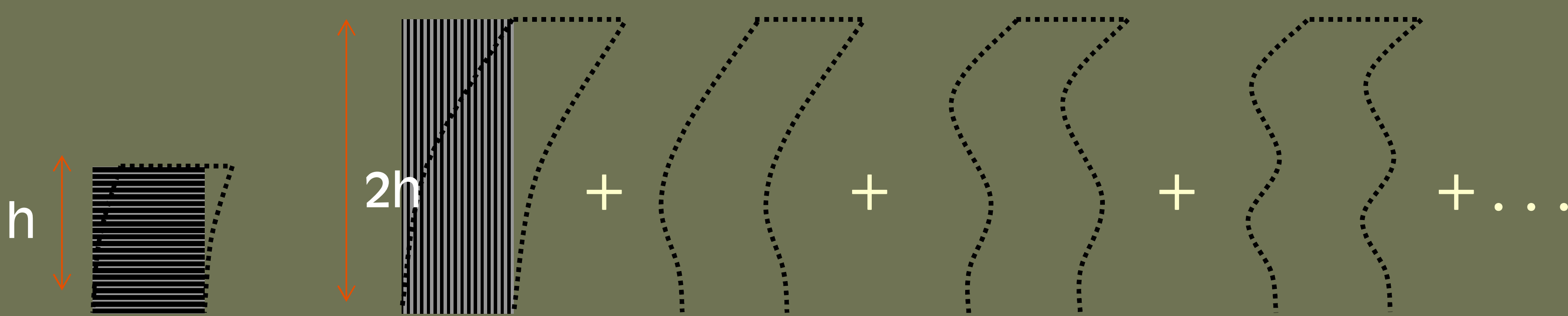
Tall Building:

Wind Induced Building Motion (acceleration) Control

– Dynamic Stiffness Design (~ h^3)



Work Workflow

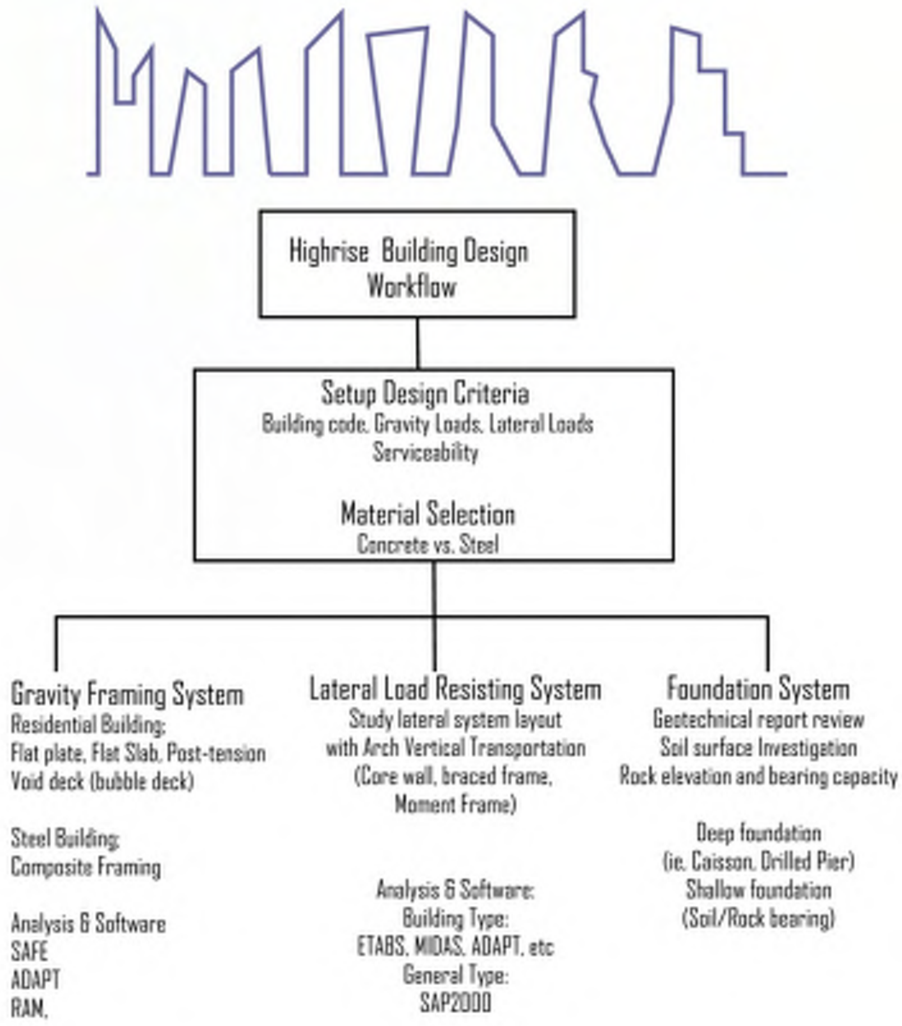
1. Setup Design Criteria:
    - Building Code
    - Gravity Load (DL, LL), Wind, EQ
    - Serviceability

2. Material Selection

 (Concrete or Steel)

3. System selection

 (Foundation, gravity, Lateral)



Building Drift or Lateral Deflection

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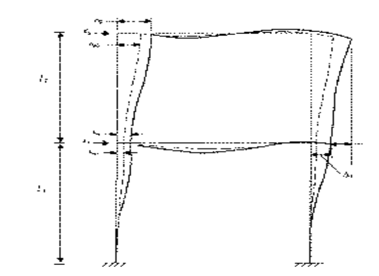
Overall Building Deflection due to Wind:

US (10-20 year wind) H / 400 – H / 500

Inter-story Wind Drift:

US (10-20 year) h / 350



Inter-story Seismic Drift : with P-Delta – code defined

Inelastic Drift < 0.01h ~ 0.02h (h / 100 ~ h / 50)

Human Comfort Criteria under Wind-Induced Building Motions

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- US Practice:

  Building Acceleration Limit (10 year wind)

Residential:	10 ~ 18 milli-g (0.1 ~ 0.18% g)
Hotel:	15 ~ 20 milli-g
Office:	20 ~ 25 milli-g

- ISO based on 1 year and 5 year
- Japanese Code (AIJ) based on 1 year seasonal

Gravity System

Load:

Dead Load = selfweight

SDL = Ceiling, MEP, Curtain wall

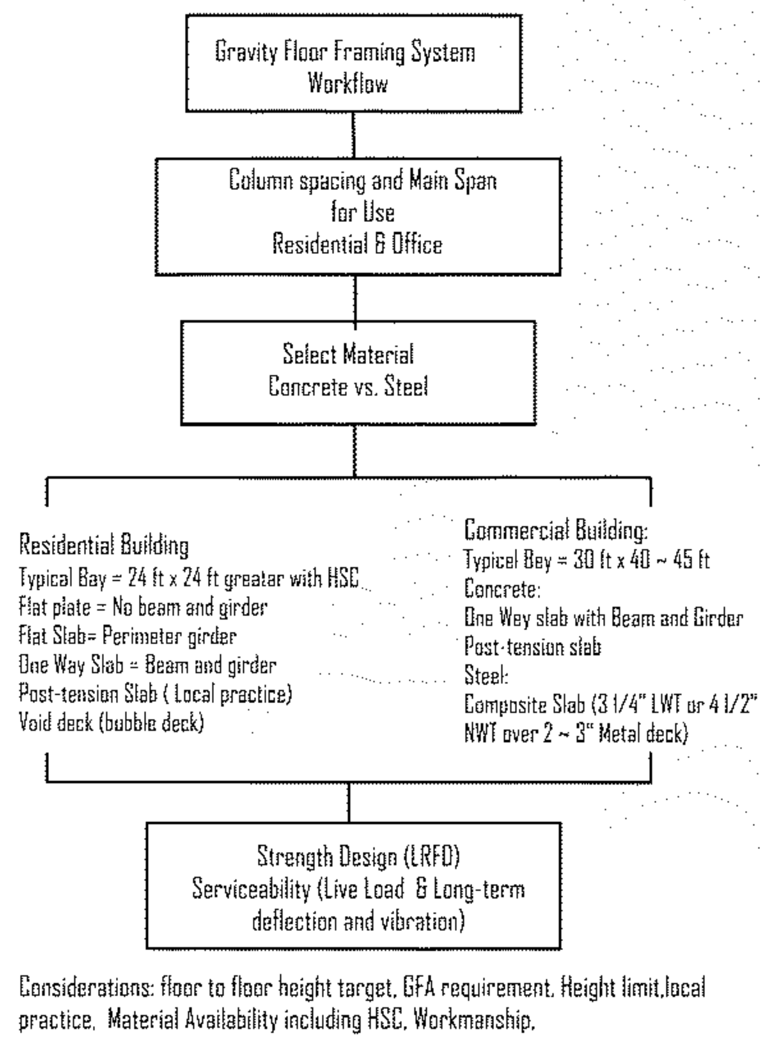
Live Load

Material Selection (Concrete or Steel)

Residential or Office

Flat plate, PT slab, One way,

Composite slab (with steel beam)



Gravity System

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Concrete

Flat plate, PT slab, One way,

Steel

Composite slab (with steel beam)

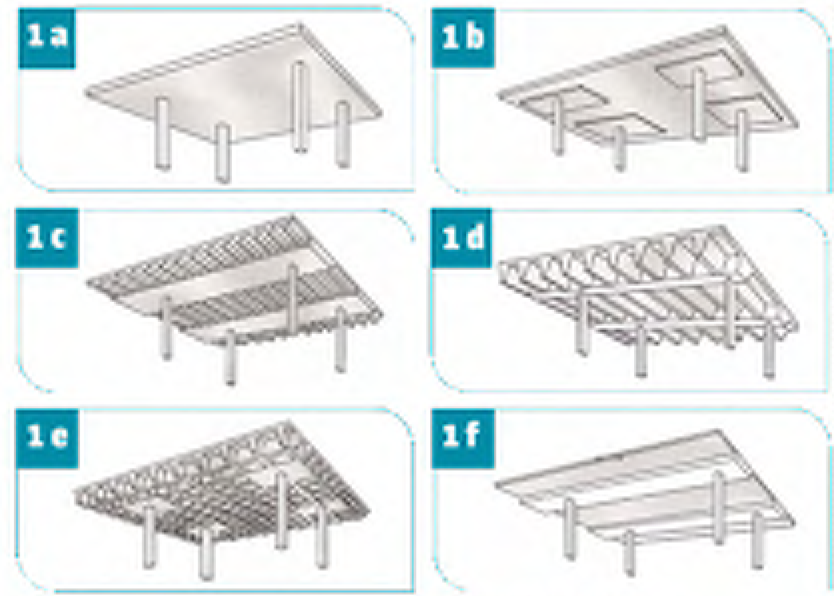


Figure 1: Cast-in-place reinforced concrete floor systems: (1a) Flat plate (1b) Flat slab (1c) One-way joist (1d) Wide-module joist (1e) Two-way joist (1f) Banded-beam.

Foundation System

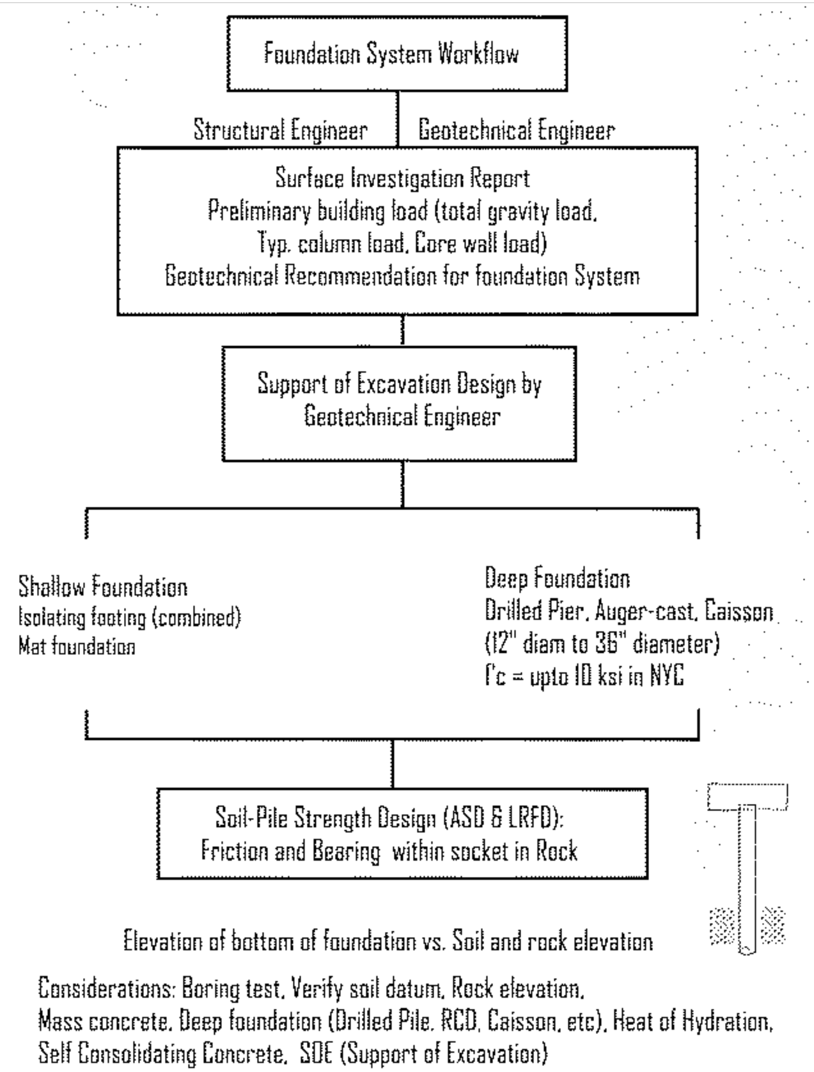
Surface Investigation Report

Support of Excavation Design

By Geotechnical engineer

Selection of foundation

Shallow foundation vs, Deep foundation



Foundation Design

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- Intensive soil investigation and analysis required
- Geotechnical Engineer recommends foundation System.
- Rock Elevation, Type
- Mat foundation location
- Soil/ Rock Bearing Capacity
- Concentrated building weight affecting strength and settlement (vertical and rotational) studies

Lateral System

Selection of Material

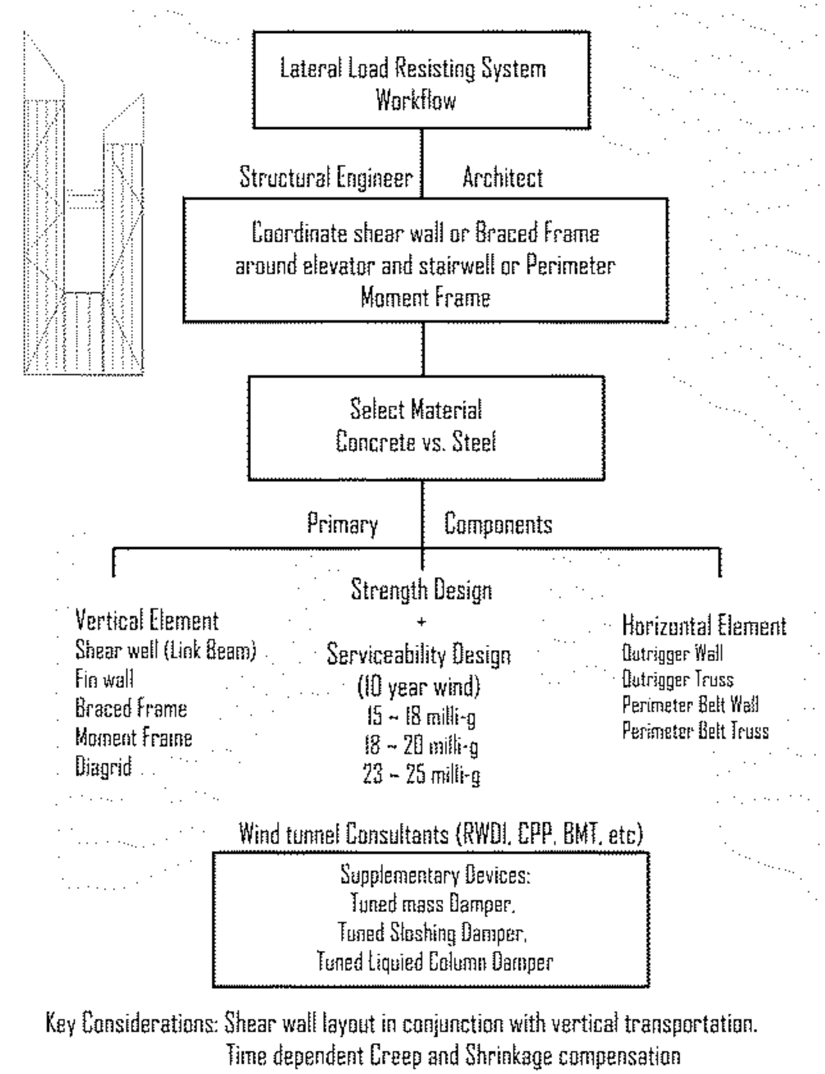
- RC Shear Wall
- Steel Braced Frame, Diagrid
- Moment Frame

Strength Design (ACI318, AISC LRFD)

Serviceability

Drift & Acceleration

Damper



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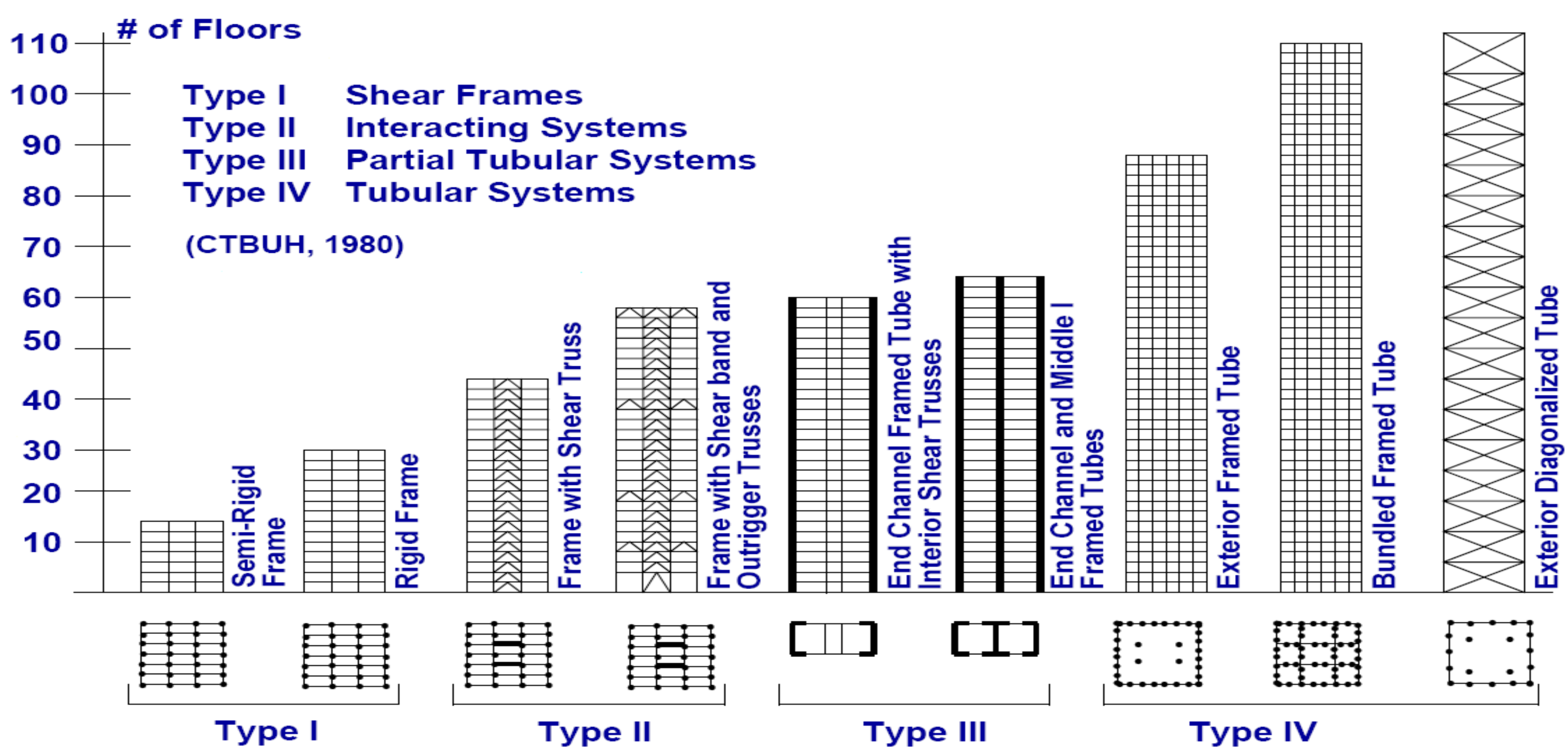
Lateral Load Resisting Systems: Steel



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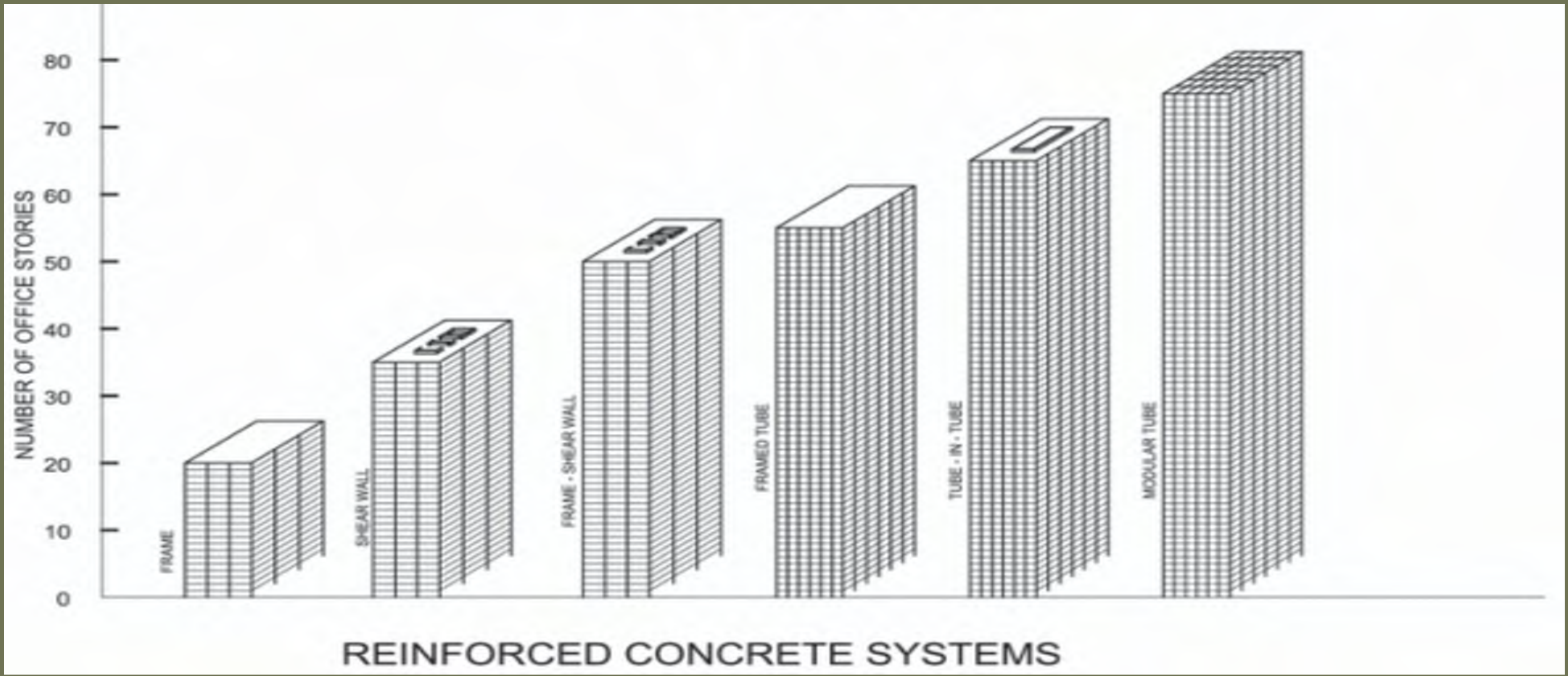
Lateral Load Resisting Systems: Concrete



Taipei 101

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Overview

- Taipei
- 1667 ft to Spire
- 101 story
- 3.85 million ft^2
- Office
- A/E: C.Y. Lee/TT
- 2004 Completion

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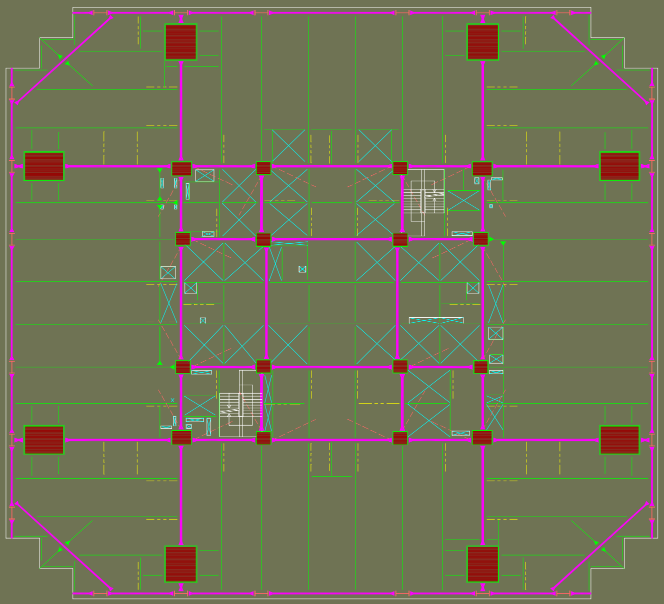
Structural System



Outrigger Trusses, Braced Core
Mega-Frame (Belt Truss + Super Column)

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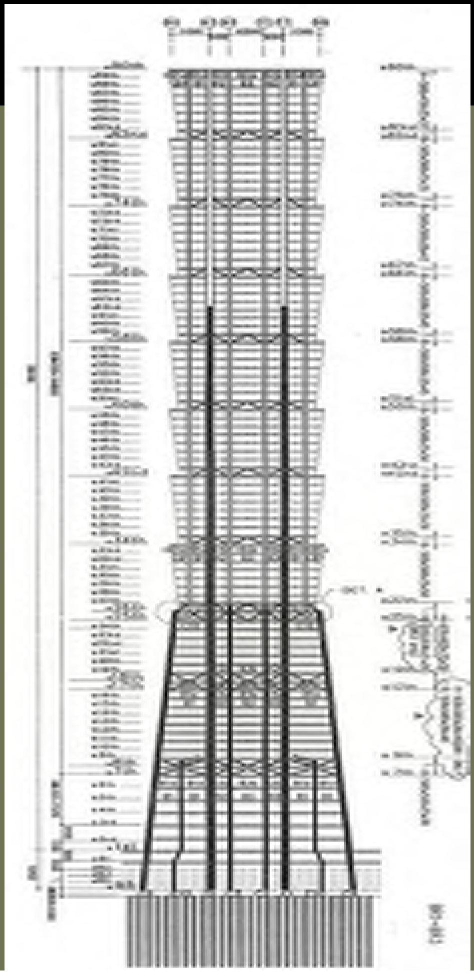
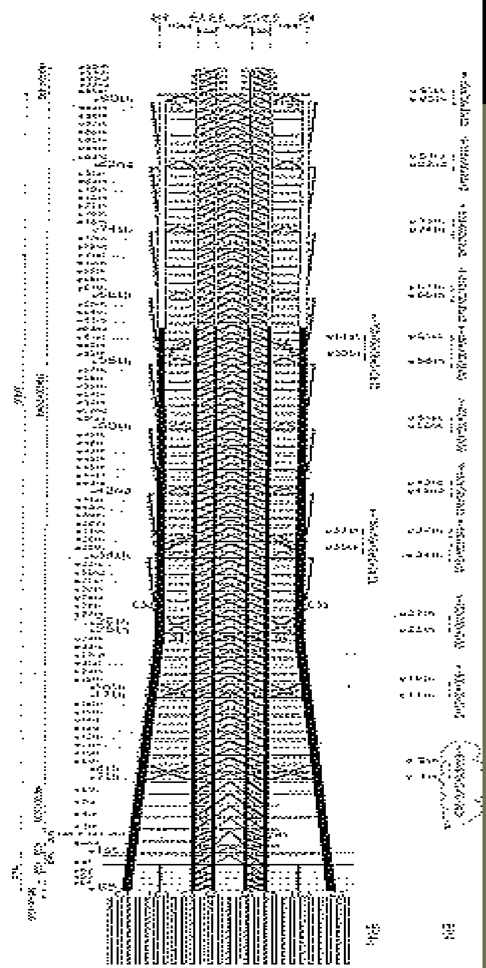
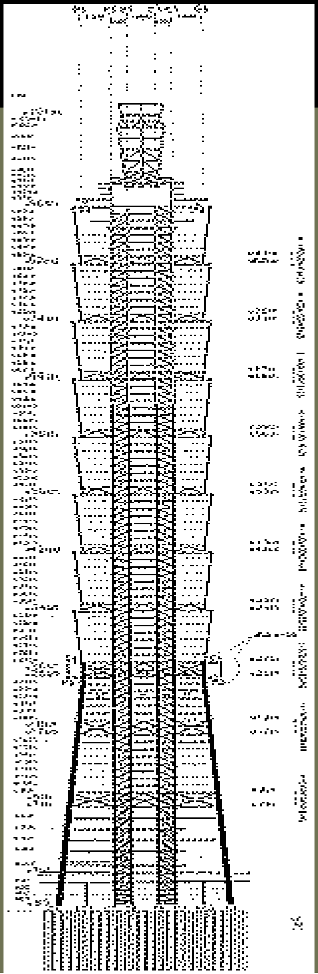
Exterior Moment Frame Elevation



MEGA Frame Elevation



Interior Braced Frame Elevation



Building TMD Simulation

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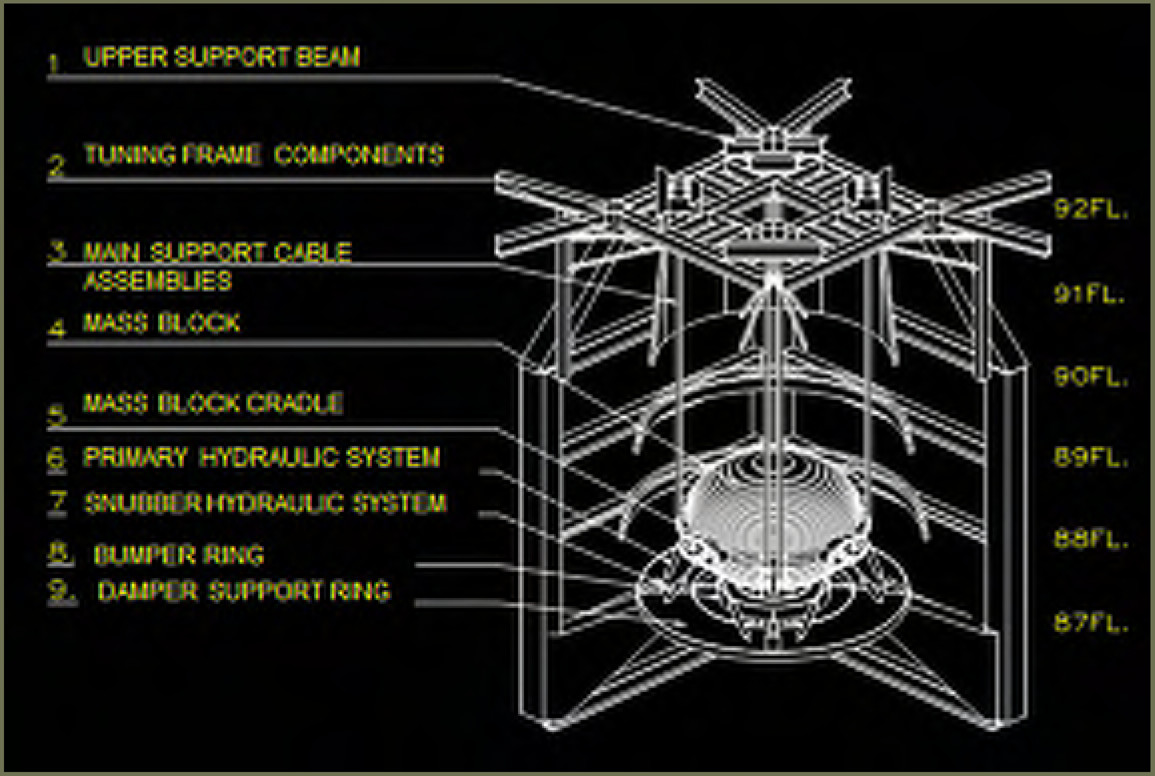

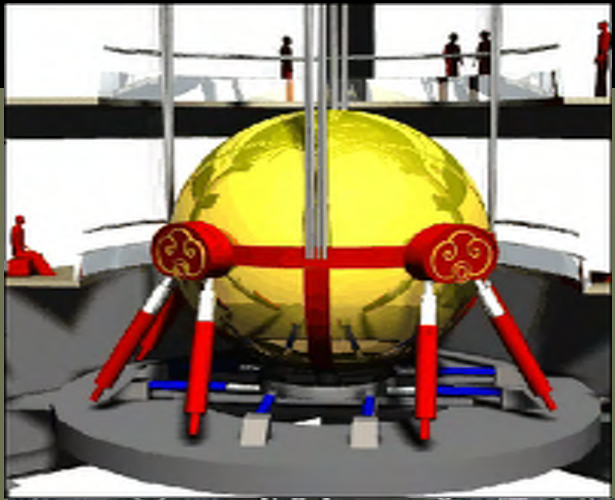

Shanghai Tower

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Overview

- Shanghai
- 2074 ft to Tip
- 128 story
- 4.09 million ft^2
- Hotel/office/ exhibition/retail
- A/E: Gensler/TT

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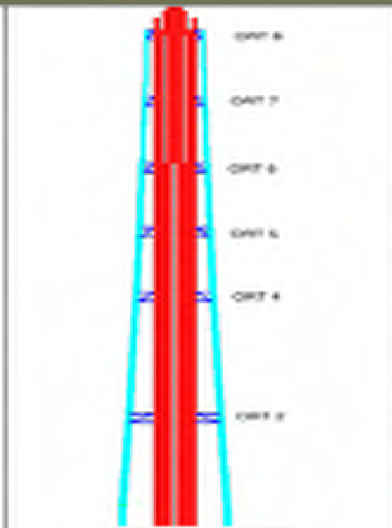
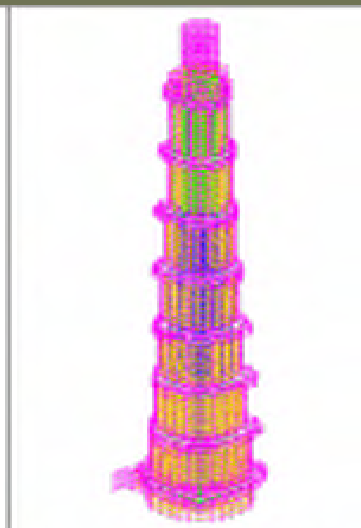
Structural System

Mega Frame



Outrigger Locations



Structural 3D Model

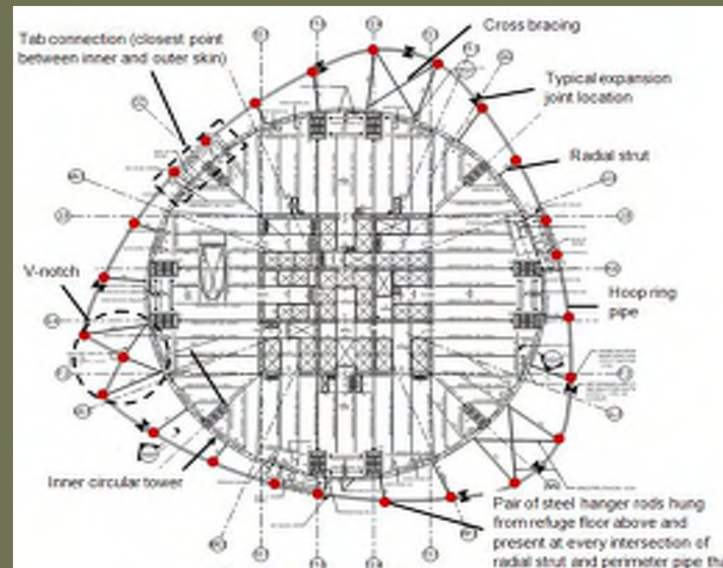


Figure 4. Typical structural floor plan

Reinforced Concrete Core, Super Composite Column, Steel Outrigger Trusses

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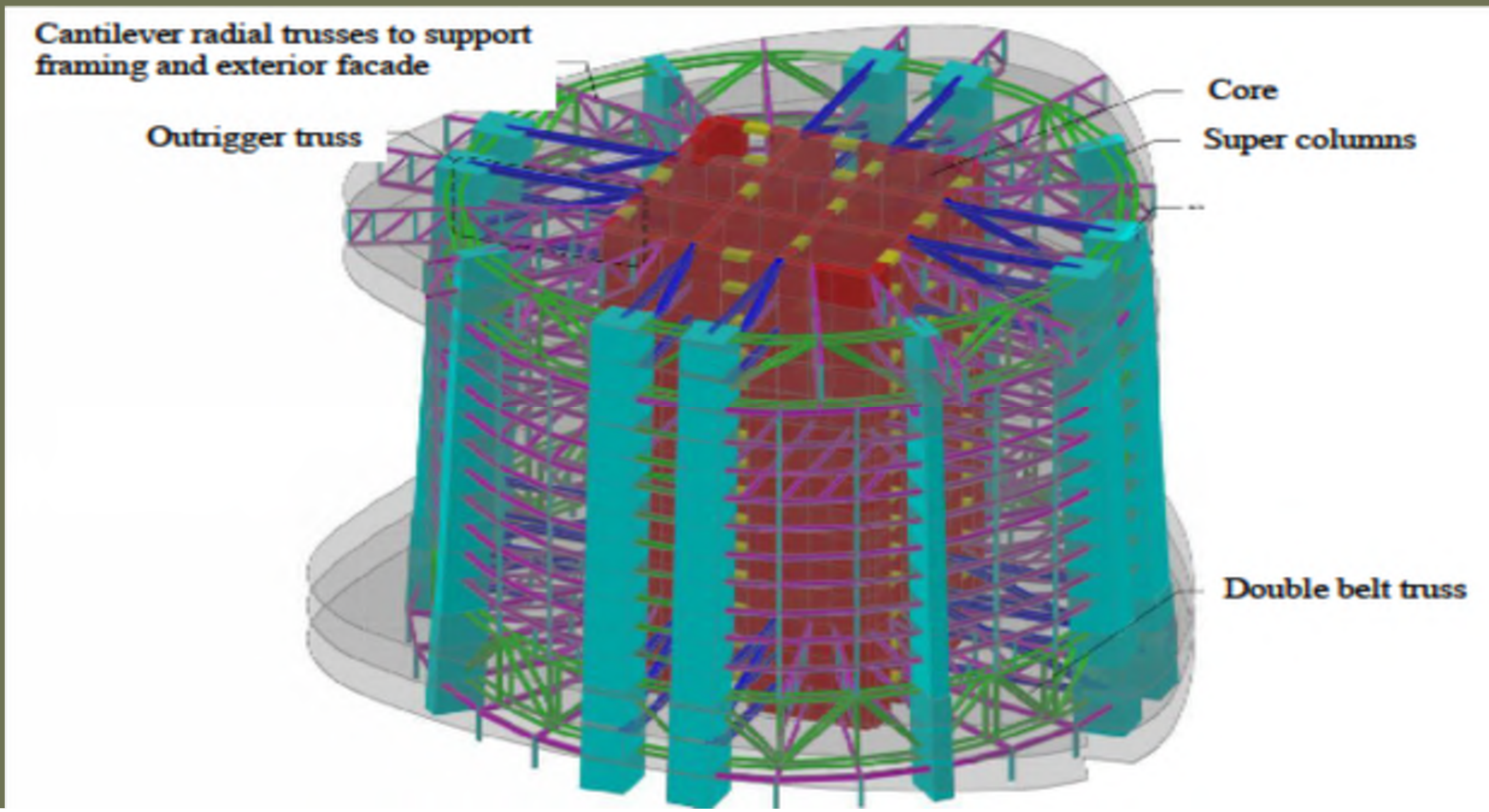
Structural System



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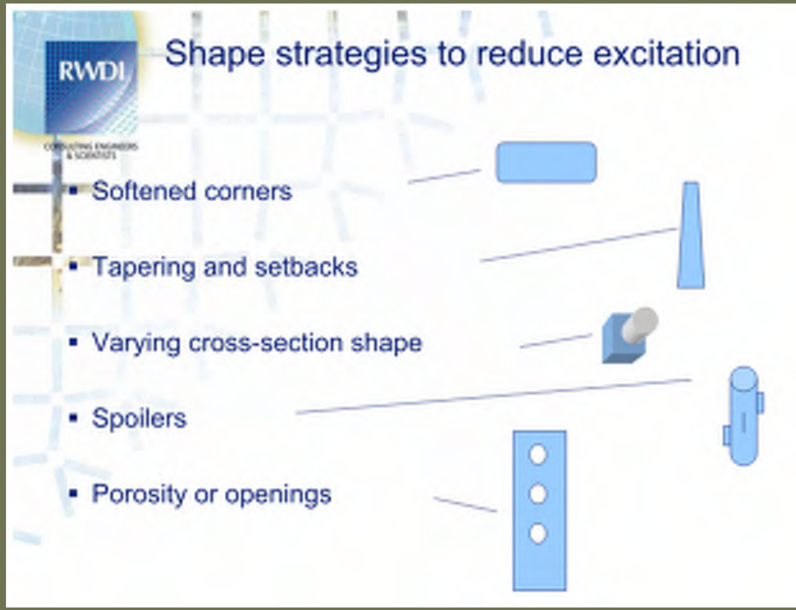
Efficient Shape Strategy for Tall Building

Shape Strategies to reduce Wind Vortex Shedding Effect

- Softened Corners
- Tapering and Setbacks
- Varying Cross-section shape
- Porosity or Openings



Softened Corners

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Rough corner can reduce Vortex Shedding effects.

Corner plan

TAIPEI 101

Tapering and Setbacks

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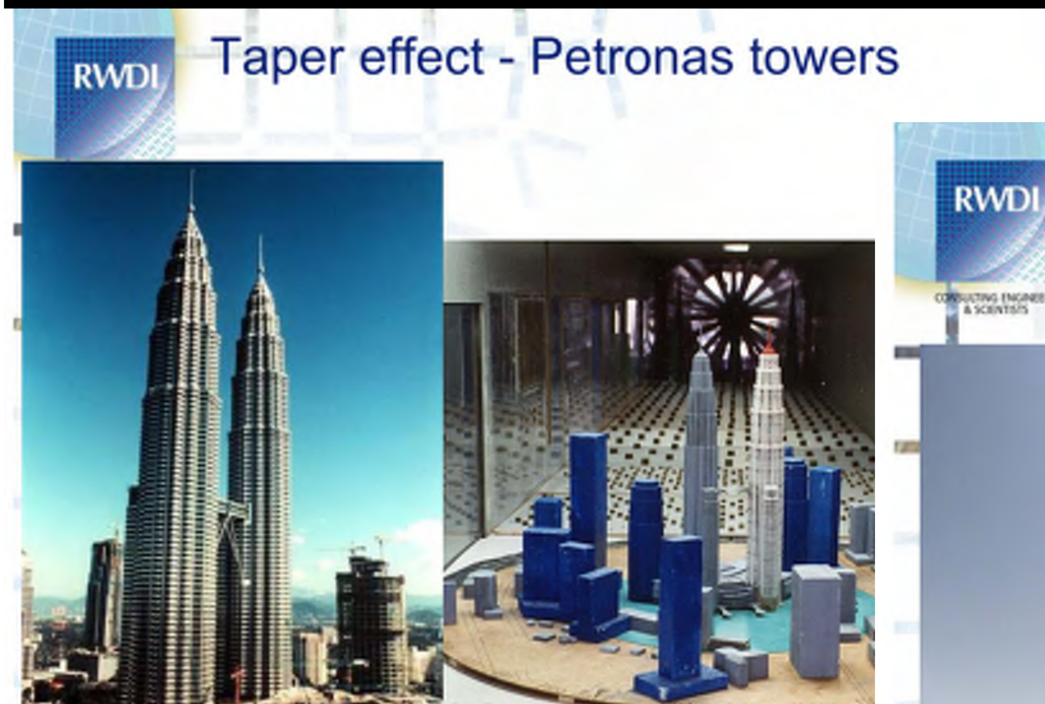

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Through-Building Openings

Openings reduce wind forces

(Reduced 'Sail Area')

SHANGHAI FINANCIAL CENTER

Through-Building Openings

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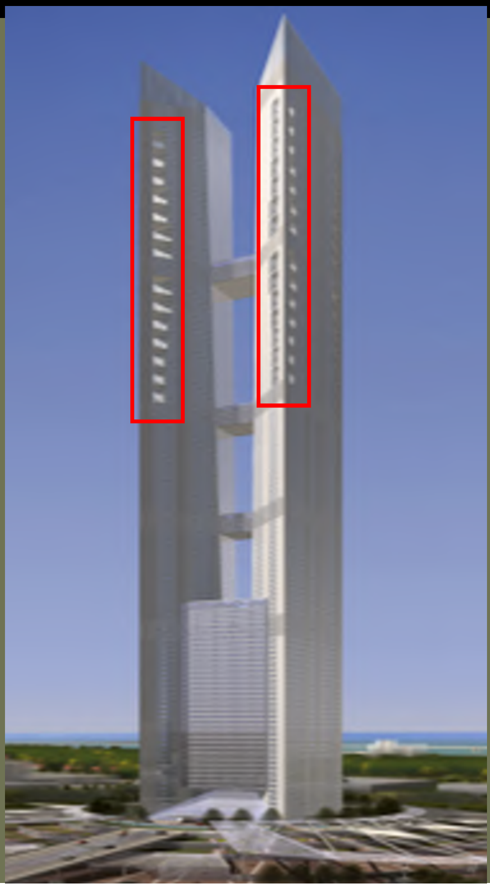
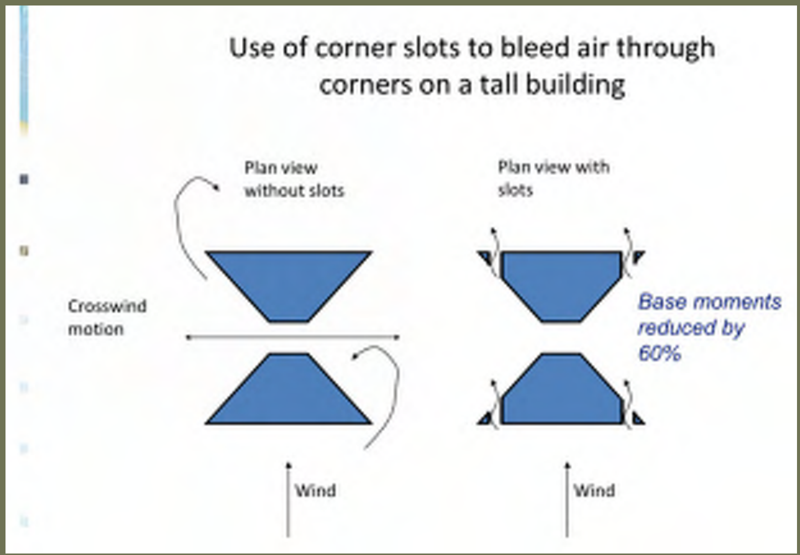


Slots reduce wind forces and sway from vortex shedding



151 INCHEON TOWER

Rotate/Twist

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Rotate to minimize load from prevailing direction

Twist avoids simultaneous vortex shedding along height

SHANGHAI TOWER

Wind Tunnel Test

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- HFFB: High Frequency Force Balance Test
- HFPI: High Frequency Pressure Integration using rigid pressure tap model
- Aerodynamic Elastic Model Testing
- Cladding Test

Wind Tunnel Test

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- HFFB: High Frequency Force Balance Test
- HFPI: High Frequency Pressure Integration using rigid pressure tap model
- Aerodynamic Elastic Model Testing
- Cladding Test

Wind Tunnel Test Types

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- WIND TUNNEL TESTS
  - STRUCTURAL LOAD TESTS
    - High-Frequency Force-Balance
    - Pressure Integration
    - Aeroelastic
      - "Stick" 2 DOF
      - MDOF
  - CLADDING PRESSURE TESTS
  - PEDESTRIAN LEVEL COMFORT TESTS
  - OTHER TESTS
    - Water Flume (Snow Load)
    - Sectional Model (Bridge)
    - Air Quality
    - CFD

Wind Tunnel Test

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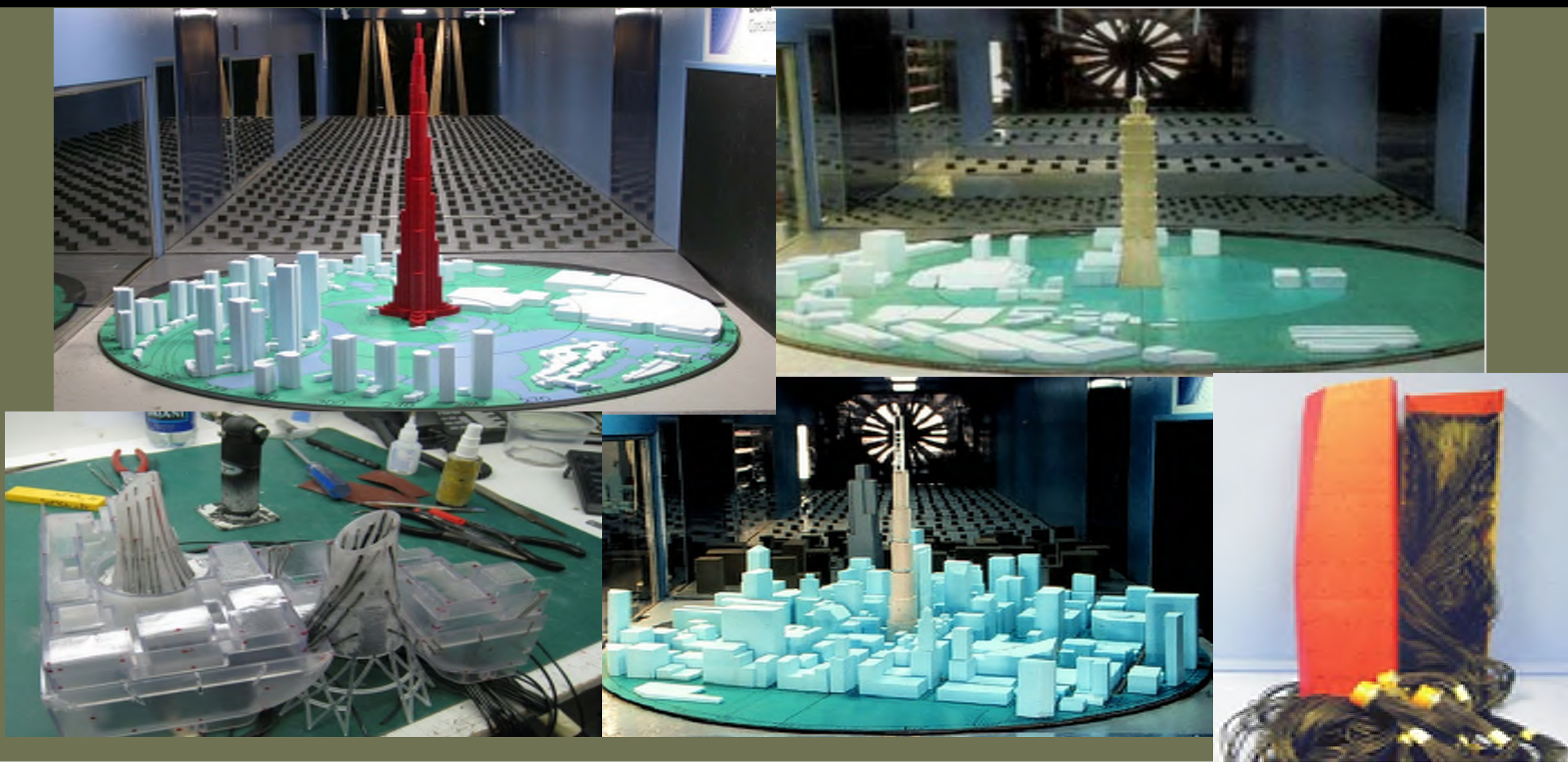

Damping and Dynamics

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- Damping directly reduces bldg accelerations
- Some damping inherent in construction
  (Concrete framing > steel framing)
- When inherent damping is not sufficient, provide supplementary damping
- Dampers occupy space : Quantity and location based on modes to be treated
- Costs include purchase, installation, tuning, maintenance, inspection

Supplementary Damping Devices

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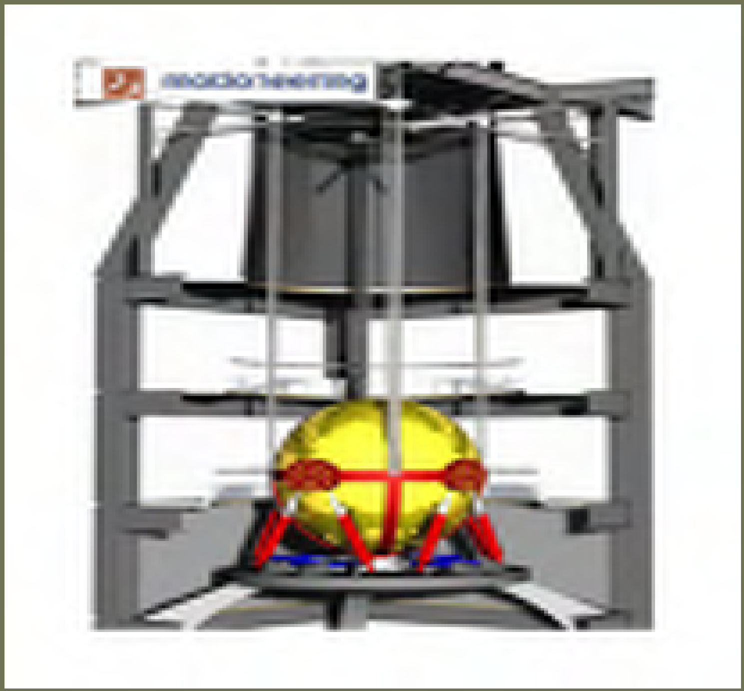
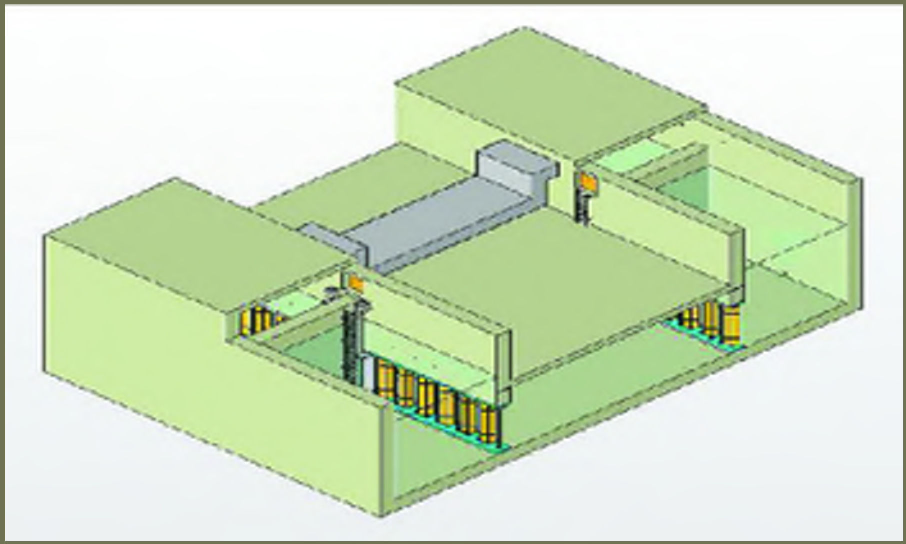
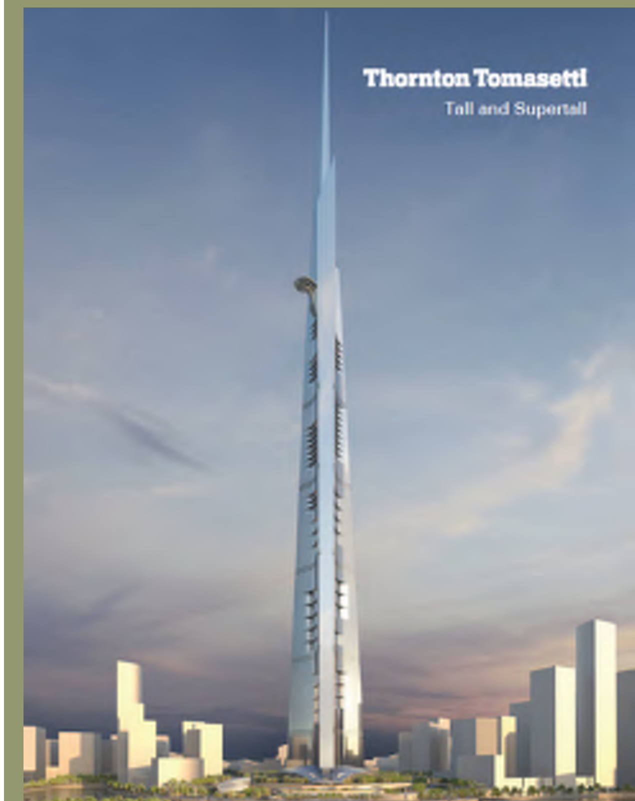
Tuned Mass Damper



Tuned Liquid Column/Slush Damper



Representative Tall Projects









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Kingdom Tower

Owner
Kingdom Holding Company

Developer
Jeddah Economic Company

Total Area
530,000 m2

Building Height
+1,000 m

Jeddah, Saudi Arabia

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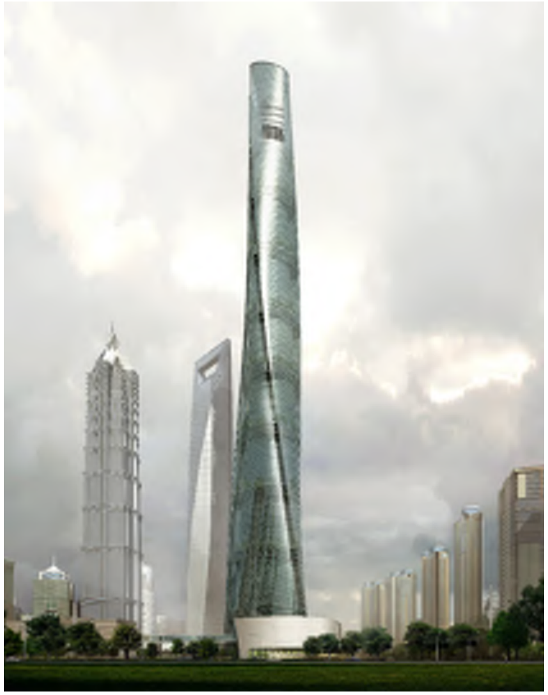
Shanghai Tower



Client
The Shanghai Tower Construction & Development Company

Architect
Gensler

Completion Date
2014

Construction Cost
$2.2 billion

Total Area
4.1 million sf

Number of Stories
124 stories

Shanghai, China

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Signature Tower

Owner
PT Grahamas Adisentosa

Architect
Smallwood, Reynolds, Stewart, Stewart & Associates

Completion Date
2017

Total Area
593,000 m²

Jakarta, Indonesia

Haeundae Doosan We've The Zenith

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Owner
Doosan Construction and Engineering Co. Ltd.

Architect
DeStefano + Partners, Ltd.

Completion Date
2012

Total Area
572,534 m^2

Busan, South Korea

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The New York Times Building

Owner/Client
The New York Times Company

Architect
Renzo Piano Building Workshop

FXFowle Architects

Gensler (interiors)

Completion Date
2007

Construction Cost

$650 million

New York, New York

Hotel Crescent
Baku

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Owner
Gilan Holding

Client/Architect
Heerim Archtiects& Planners

Completion Date
2015

Construction Cost
$0.7 billion

Total Area
178,000 m²

International Finance Centre (IFC) Seoul

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Owner
American International Group

The Seoul Metropolitan Government

Client/Architect
Arquitectonica

Completion Date
2013

Construction Cost
$1.6 billion

Total Area
509,524 m^2

Seoul, South Korea

Federation of Korean Industries, Headquarters Building

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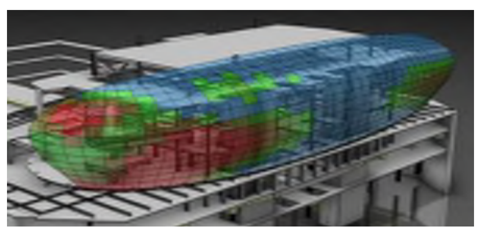

Owner
Federation of Korean Industries

Architect
Adrian Smith + Gordon Gill Architecture

Completion Date
2013

Total Area
Tower: 170,000 m^2

Conference center: 6,000 m^2

Height
245 meters (804 feet)

Seoul, South Korea

Images courtesy AS+GG

Incheon International Airport Phase III

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Owner
Incheon International Airport Corporation

Client/Architect
Heerim

Completion Date
2017

Construction Cost
$1.8 billion

Total Area
350,000 m²

Incheon, South Korea

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West 57

Owner/Client
Durst Fetner Residential

Architect

BIG-Bjarke Ingels Group (BIG)

Total Area
800,000 gsf

Number of Units
600

New York, New York

Image courtesy of BIG-Bjarke Ingels Group

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Design Team Requirement Highlights

- Collaborate with each other
- Respect professional opinions
- Try to meet all requirements
- Use all available resources
- Perform proper decision-making and value engineering
- Think green
- Work with experienced professionals!

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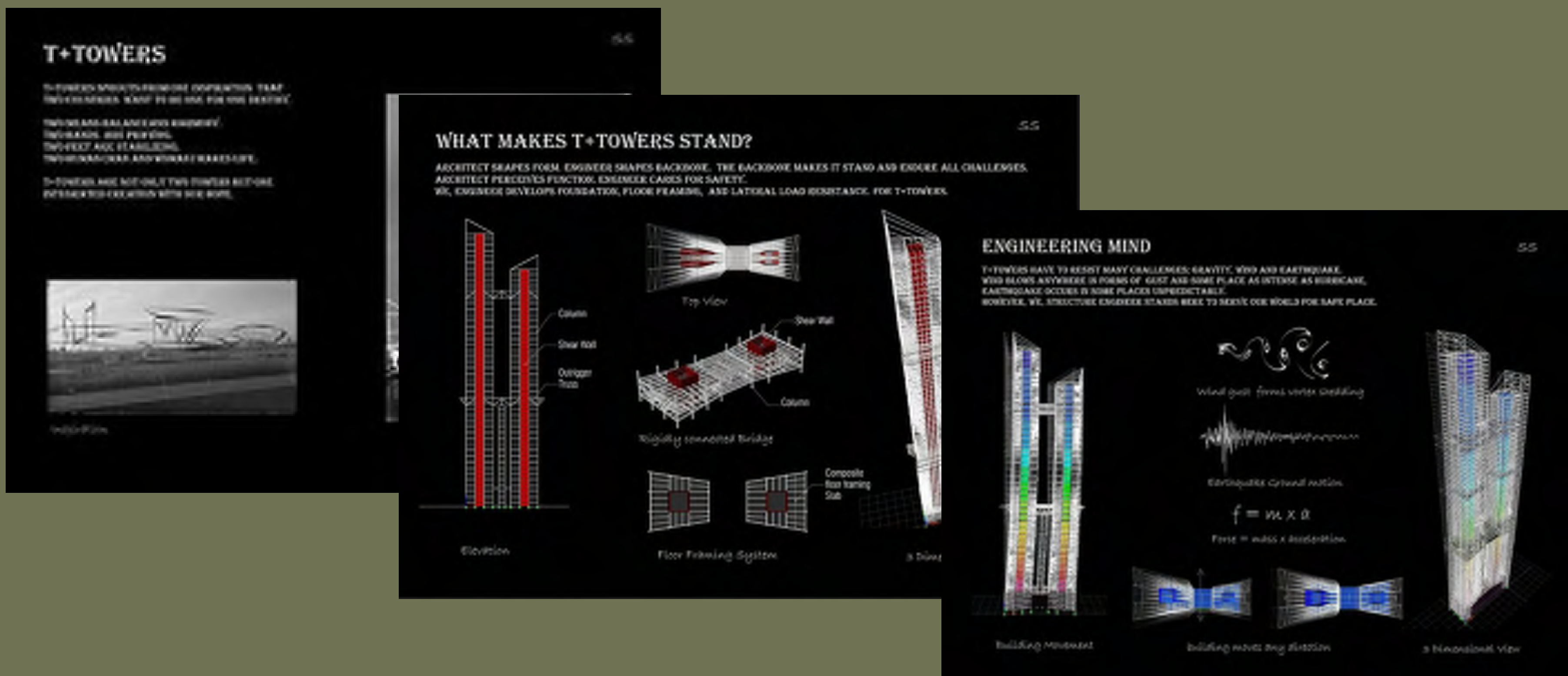
Structural Engineer / Designer



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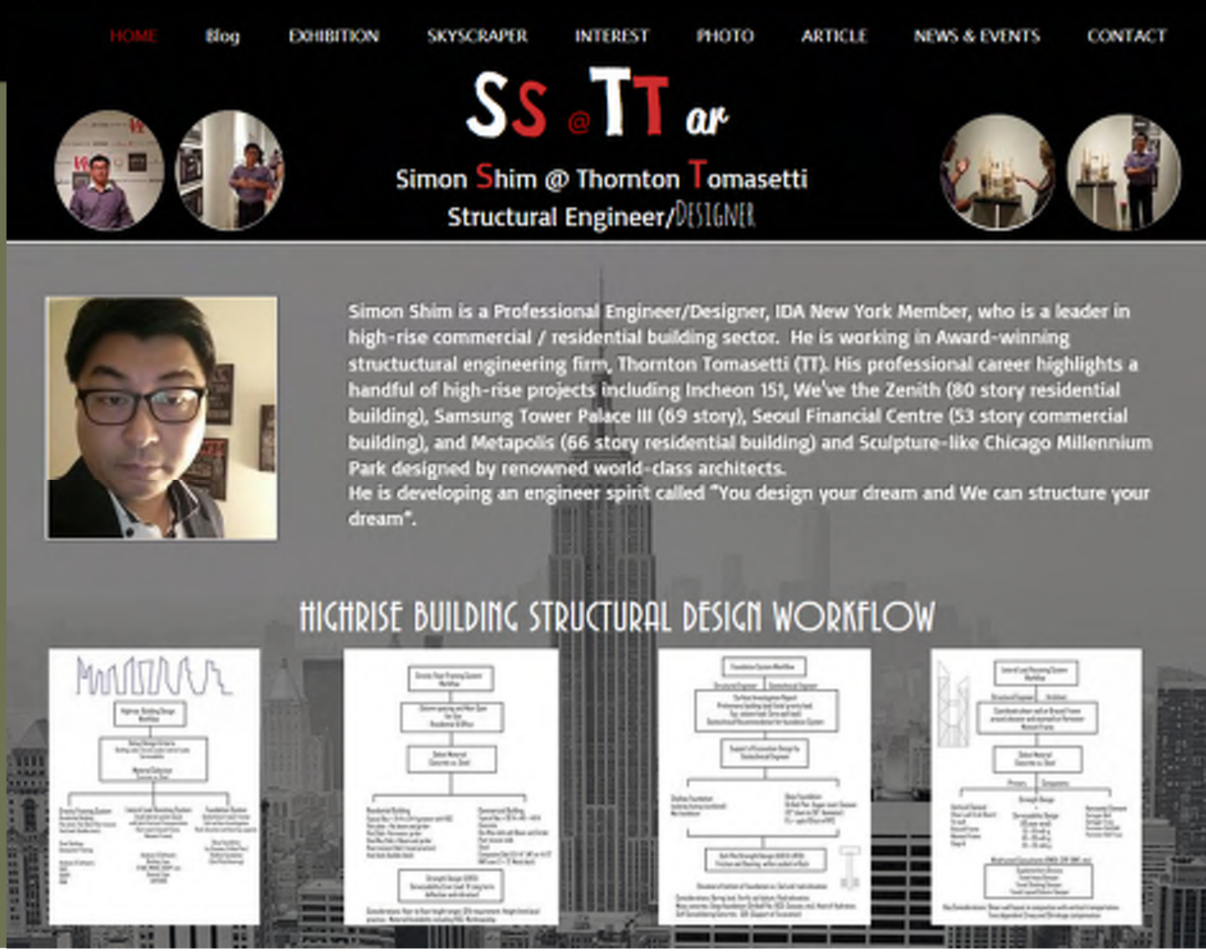

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