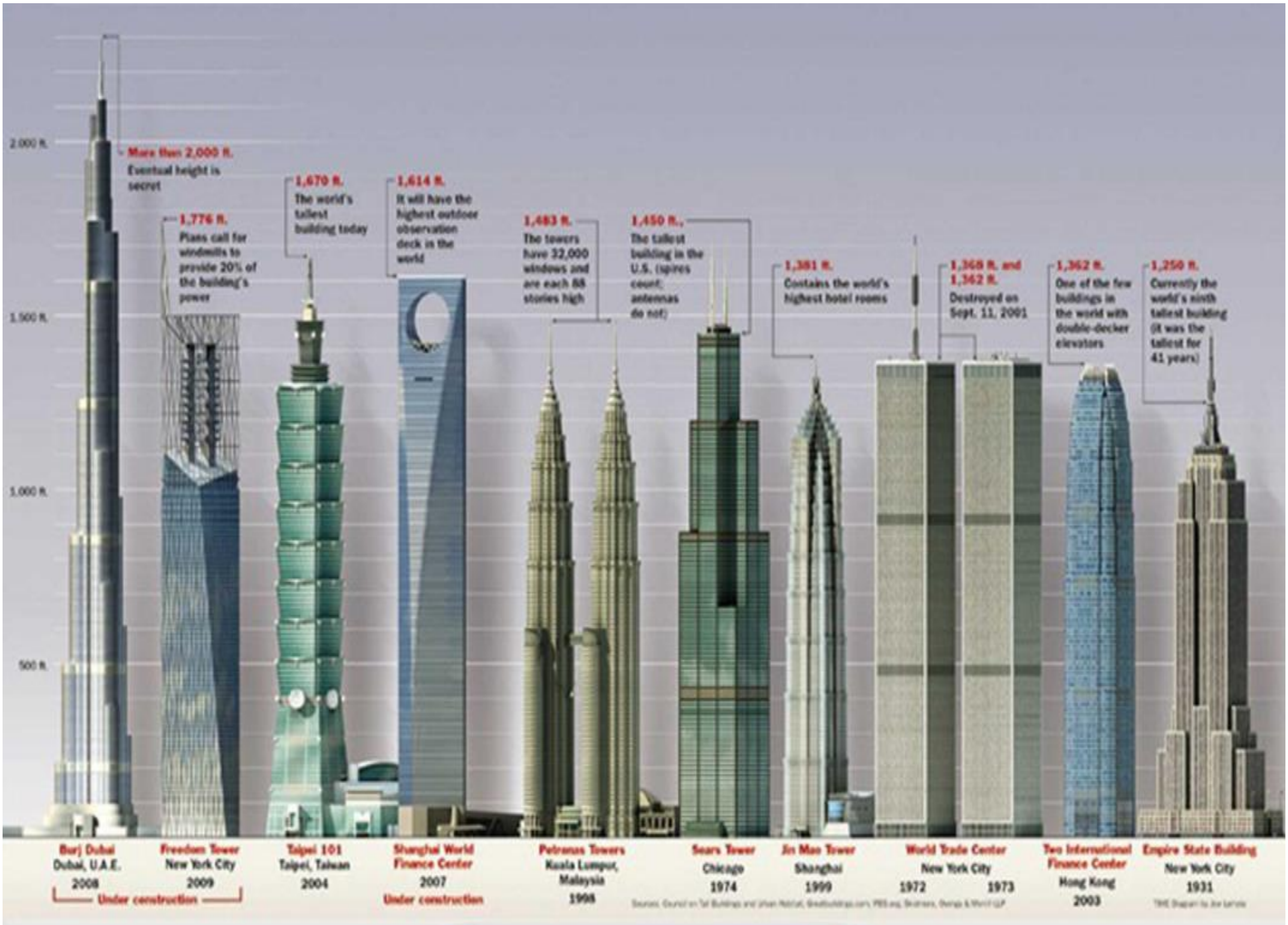
Tall Building



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مراجع:

- سازه های بلند، استاد طاحونی.
-آنالیز و طراحی سازه های بلند، ترجمه دکتر حاجی کاظمی.

- **Tall Building Structures - Analysis and Design, Smith, Bryan Stafford; Coull, Alex.**
- **Tall Buildings, Performance-based guidelines and regulations, Joe Maffei, Jack Moehle**
- **Structural Analysis and Design of Tall Buildings, Steel and composite Construction, Bungale S. Taranath.**
- **Tall Buildings: structural systems and aerodynamic form, Mehmet Halis Günel and Hüseyin Emre Ilgin.**
- **Structural Analysis of Regular Multi-Storey Buildings, Karolya ZalKa.**
- **The Tall Buildings Reference Book, Dave Parker and Antony Wood.**
- **WIND and EARTHQUAKE RESISTANT BUILDINGS STRUCTURAL ANALYSIS AND DESIGN, John A. Martin**
- **Super Tall Building Design Approach, Hi Sun Choi, P.E. Principal, Vice President**
- **Model Making Workshop — Structure of Tall Buildings and Towers,**
- **HIGH RISE STRUCTURAL SYSTEMS, AKSHAY REVEKAR, DURGESH PIPPAL**
- **Wind loading and structural response, Dr. J.D. Holmes**

Class Activity:
Numerical Model Making And Correct Submitting It’s Article

Class Activity - Numerical Model Making

Step 1- Divide the class into groups of two to five.

Step 2- Find the research title for each group.

Step 3- Each group is required to build a Numerical Model that should have at least 18 stories.

- Consider:

- Structurally stable
- Resistant to wind & earthquake
- Using linear static, nonlinear static and nonlinear dynamic analysis.
- Definition the hinges in structural elements
- Finding seismic responses of every story under the influence of earthquakes records.

Step 3- Write the draft of research report almost in 10-15 pages.

Class Activity- Submitting The Article

Step 1- Write one standard paper according to the research as a Final report

Step 2- Each group should consider a journal for sending the paper.

Step 3- Finally, response to revise, acceptance, or sometimes changing the journal…..

- In the early 20th century, cities became bigger. **Urban populations were growing** but **land supply was limited**. High-rise buildings became an essential solution to the problem.

- **New technologies and building materials**, such as industrial reinforced concrete, steel and elevators, made high-rise structures feasible.

Types of Occupancy

- CONDO
- HOTEL
- $ RETAIL
- PARKING


amc 18
$

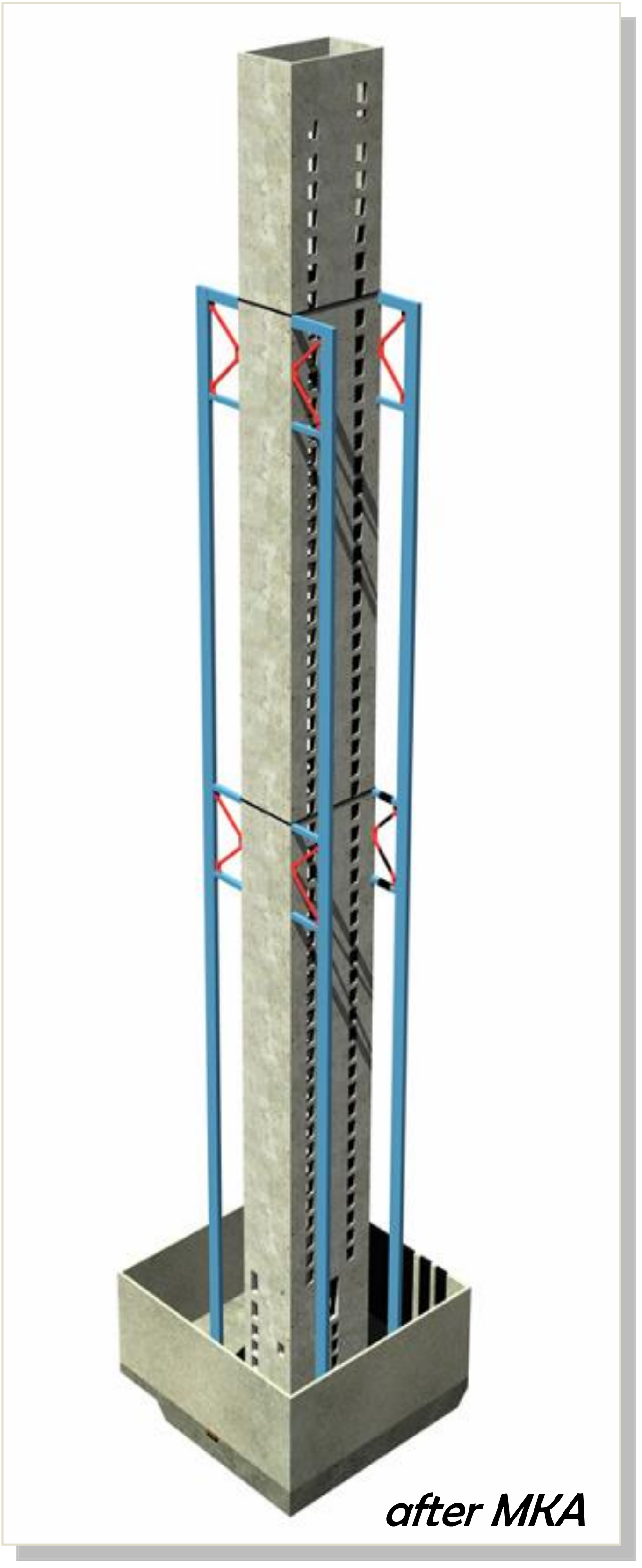
What's different about these buildings?

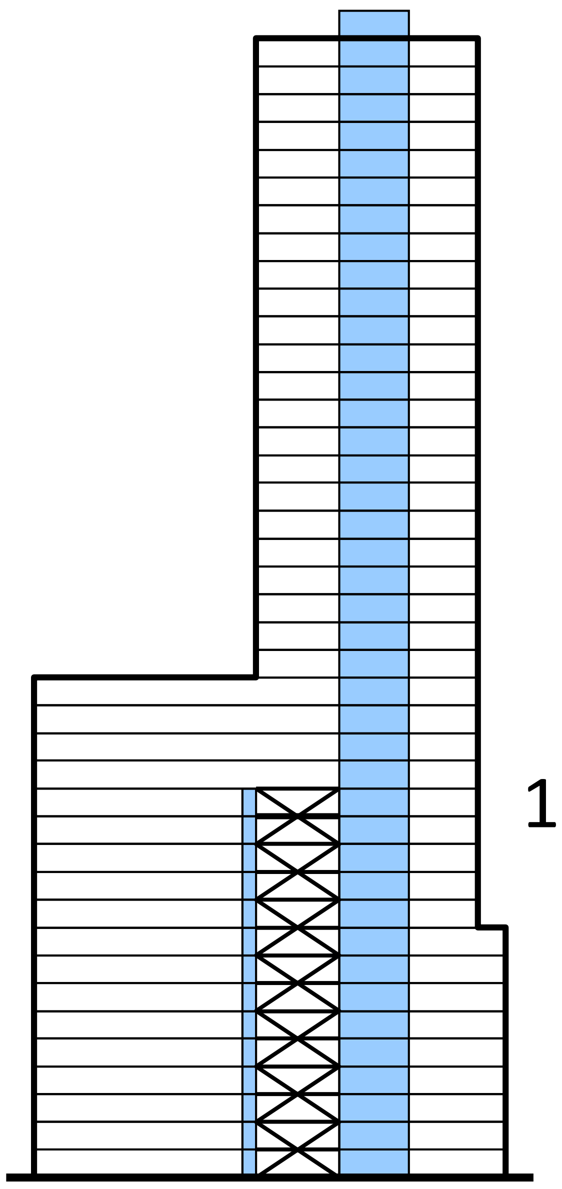
- High-performance materials

- Framing systems not satisfying code prescriptive limits

- Non-prescriptive designs are accepted in the code by demonstrating at least equivalent seismic performance.

UBC 1629.10.1, 1605.2, 104.2.8

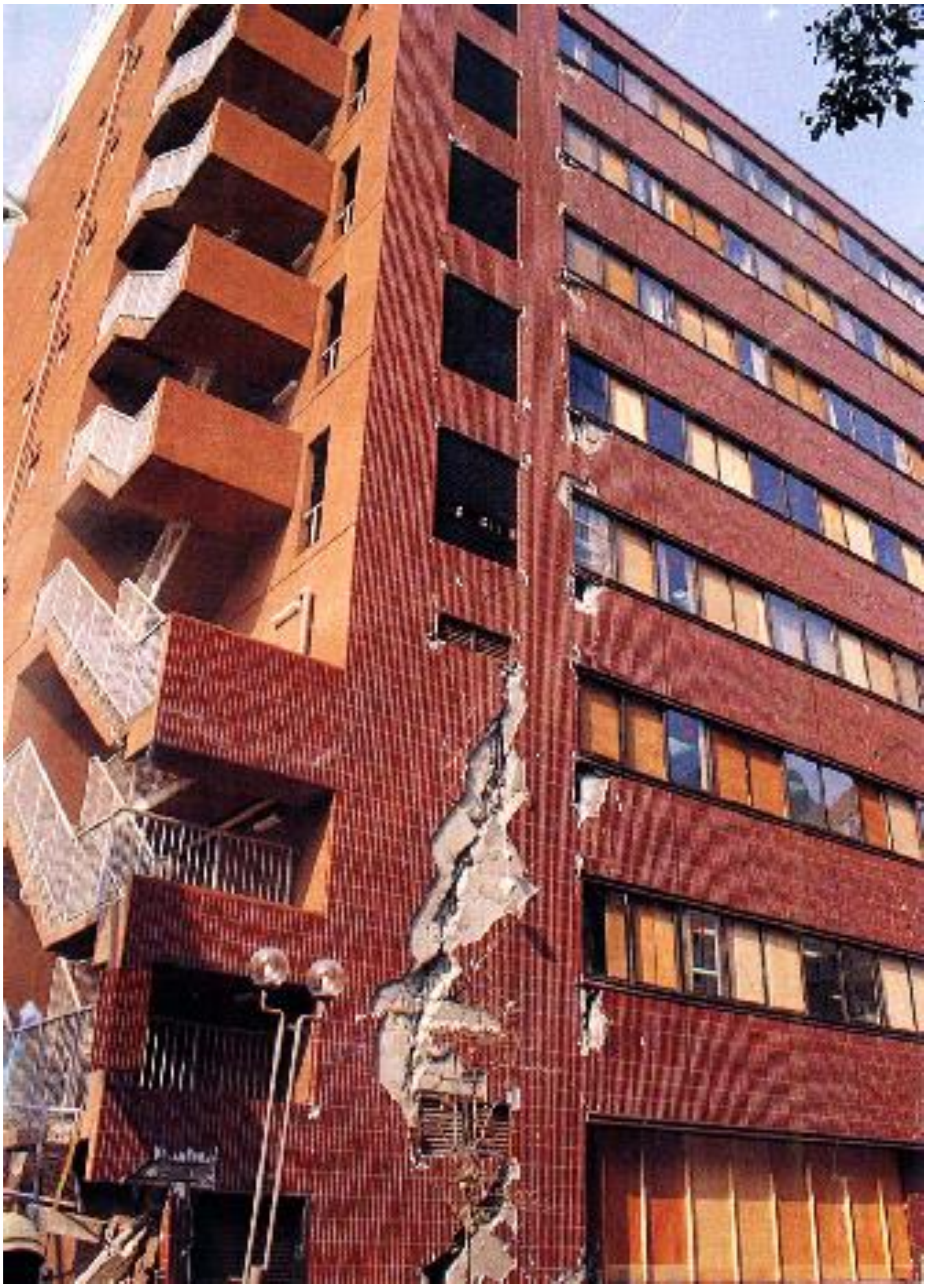




(a) Building elevation

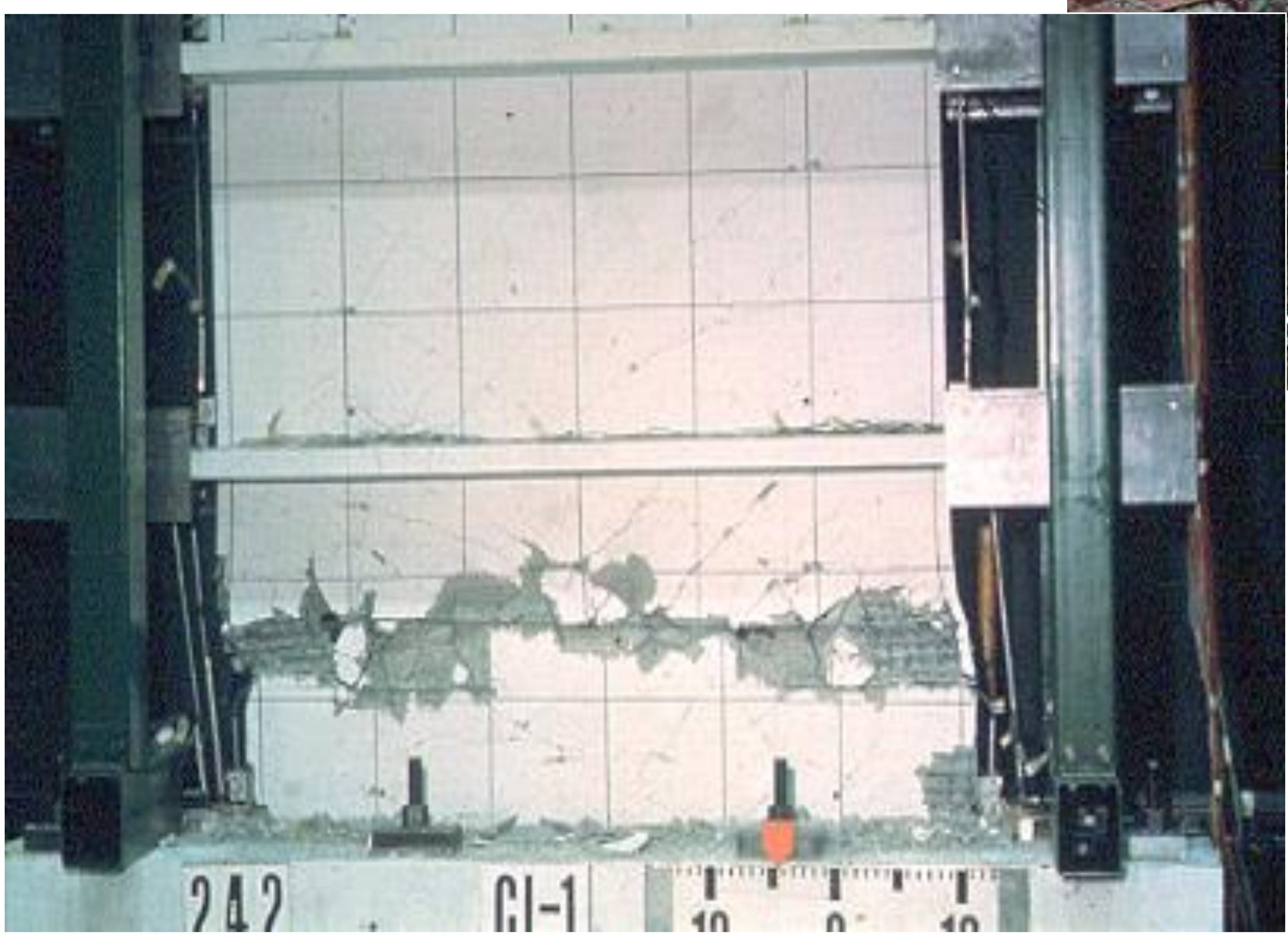
	Roof drift, ft	Wall base shear, k	Wall moment at 13th floor, 1000 x k-ft
Minimum Maximum Mean (m) m + σ c.o.v.	2.1 6.7 4.2 5.4 0.23	7600 29700 15500 22200 0.43	513 1080 900 1090 0.21
Nonlinear static		5500	760

(b) Summary of results



Protection against shear failure

Protection against sliding shear



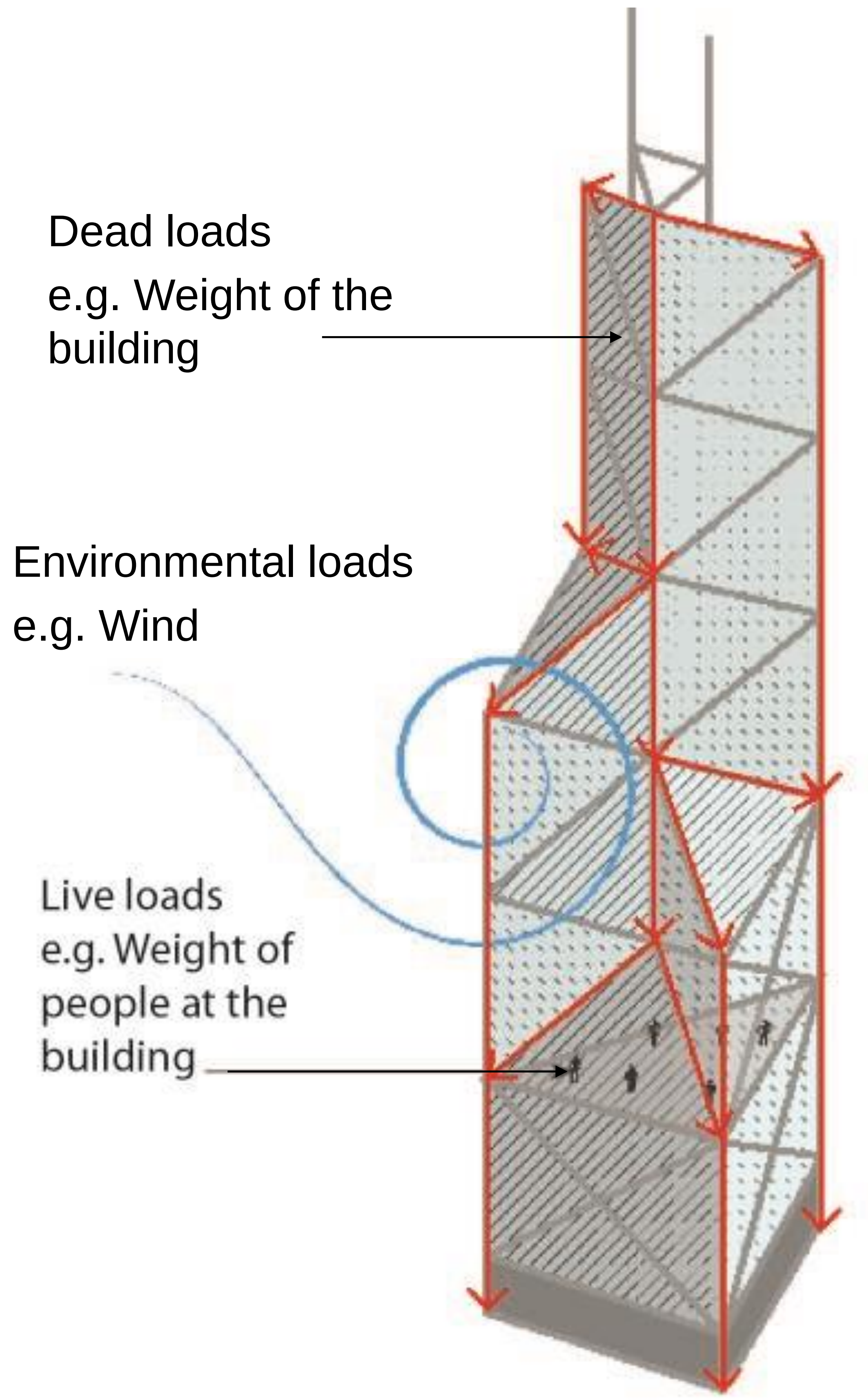
Loads and Forces on Buildings

There are three types of loads generally:

- **Dead Load**
  - Dead loads are the **loads of the structure and fixed components**.
  - It is a **permanent force** that is relatively constant for a extended period of time.
  - The force is **gravitational**.
- **Live Load**
  - Live load is a **changing force** generated by **mobile objects** inside the building, such as people within the building or stock in a warehouse.
  - The force is **gravitational**.
- **Environmental Load**
  - Environmental loads are forces acting on the building from its environment and may include **wind, rain, earthquakes and temperature changes**.
  - The forces created can be either horizontal or vertical, positive or negative.

Vertical Forces

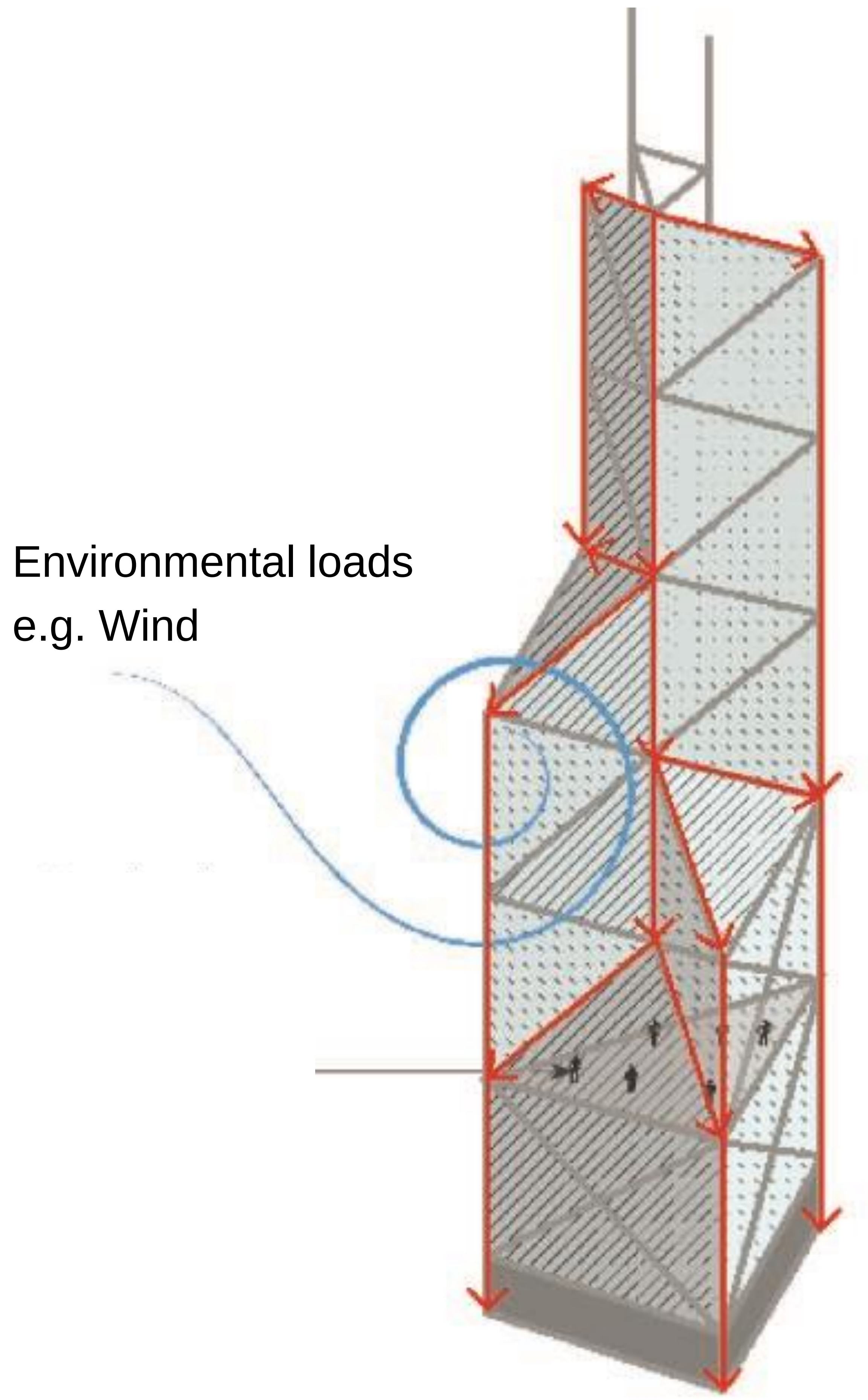
- Dead loads and live loads contribute to the vertical forces on the structure of buildings.
- Vertical loads are transferred from the floors to the columns and walls, and eventually to the soil or bedrock.
- At times, environmental loads also act vertically.



Horizontal Forces

- **Environmental loads** contribute most of the horizontal forces acting on the structure of a building, with loads from wind being the most common.

- Adding **cross bracing or shear walls** can improve structural resistance to shear forces.



Internal Forces

- The internal strength of the entire structure must be **=** or **>** the total forces applied on the building

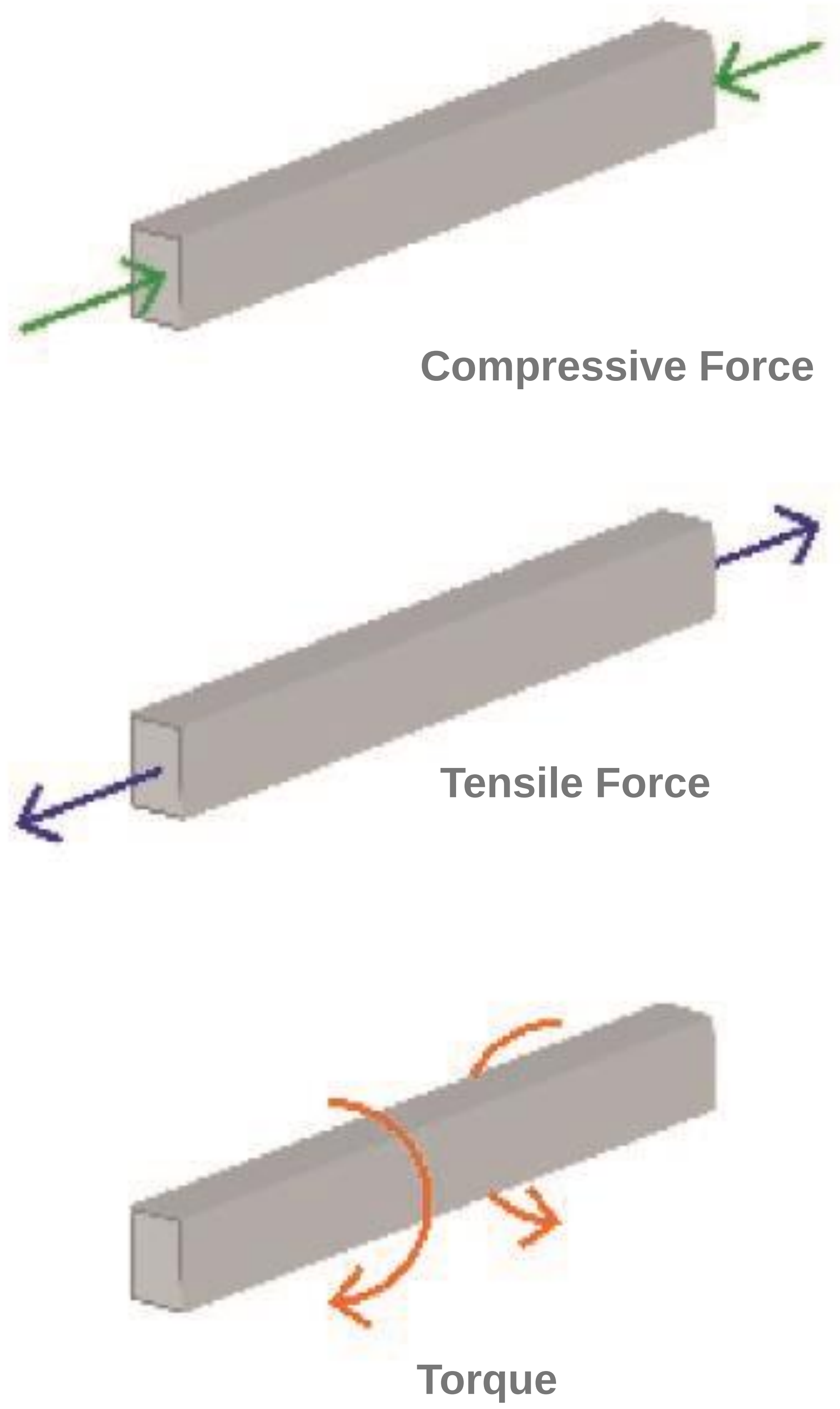
- The ability to withstand all forces depends on the **structural component's dimensions** and the **solidity** and **elasticity of the material**.

- **Internal forces :**
  - **Compressive and Tensile Forces**

According to Newton's Third Law, forces act in pairs

  - **Torque**

If **opposing forces are applied at different points**, a structural element may become twisted.



Internal forces in a structural element

History of Structures

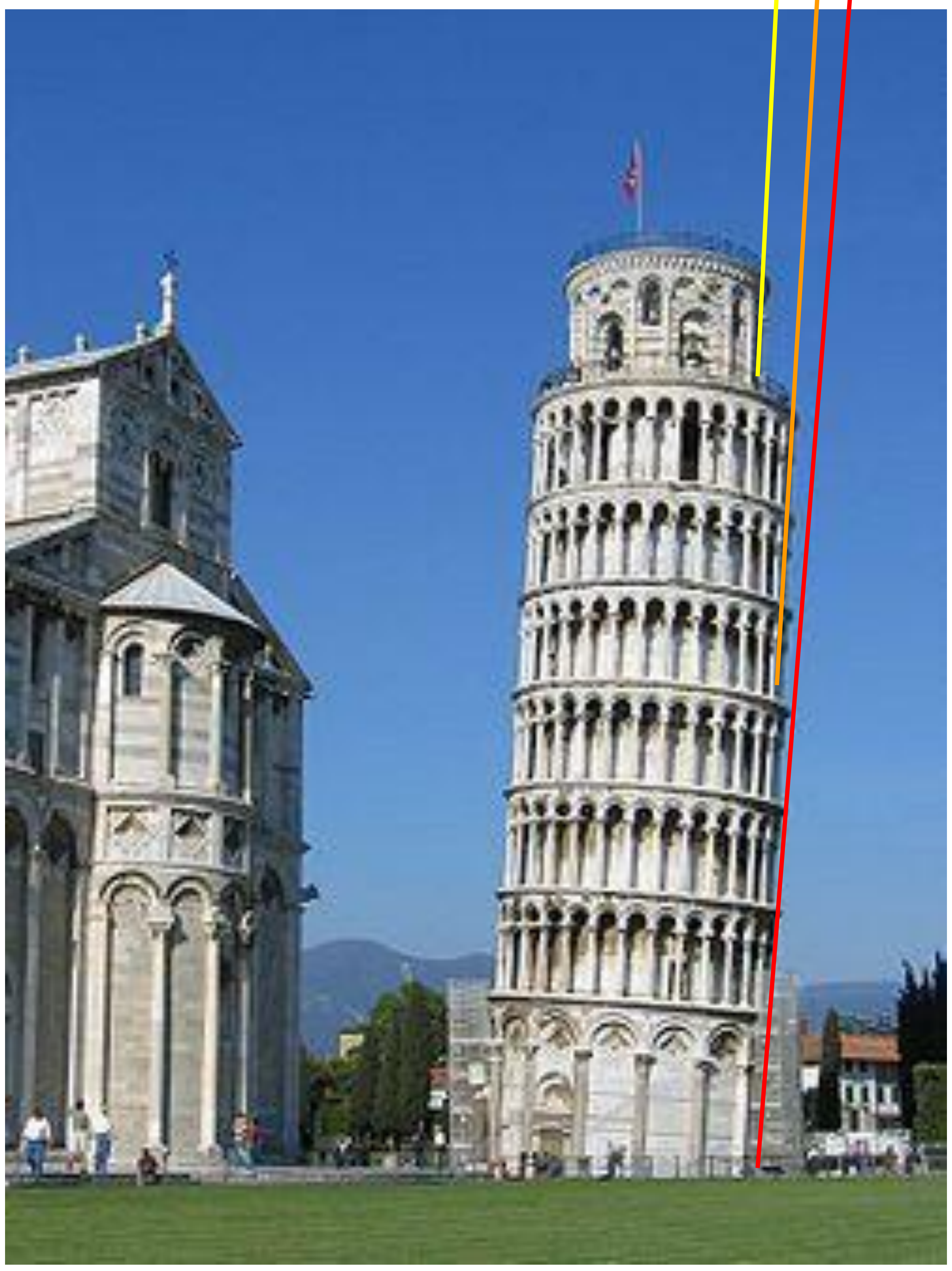
- **Stonehenge**
  2500 BC ?
  76 feet (23m) tall

- **Egyptian Pyramids**
  2500 BC ?
  480 feet (146m) tall

History of Structures

- Tower of Pisa
    - 1350 AD
    - 183 feet (56m) tall

Lessons



- Foundation settlement
  - Respect the geotech
- High aspect ratio = sensitive to small base movement
- Verticality during and after construction
- Correction attempted as they built

History of Structures

- **Empire State Building**
  - **1931**
  - **102 stories**
    - **1453 feet (443m) tall**
    - **Steel frame**
    - **Fast construction**

History of Structures

- **Burj Dubai**
  - **2008**
  - **162 stories (850M ?)**

Tallest 20 in 2020


Taipei 101


KLCC Petronas


Chicago Spire


Incheon 151 Tower


Shanghai Center


Doha Convention Center


Pentominium

How Tall? Or How Many Floors?

Floor to Floor Height Estimates

Typical Office:

11' ~ 14'	(8' ~ 9.5' clear)
3.35m ~ 4.25m	(2.5m ~2.9m clear)

Typical Residential:

8' ~ 11'	(7.5' ~ 9' clear)
2.45m ~ 3.35m	(2.3m ~ 2.75m clear)

What is “Aspect Ratio”?

- **Building height vs. footprint**
- **Aspect ratio (height/structural lateral system footprint width or depth)**
  - **Preferably <6**
  - **Could be < 10 if special features to improve wind comfort are included**

Evolution of Building Design Approach

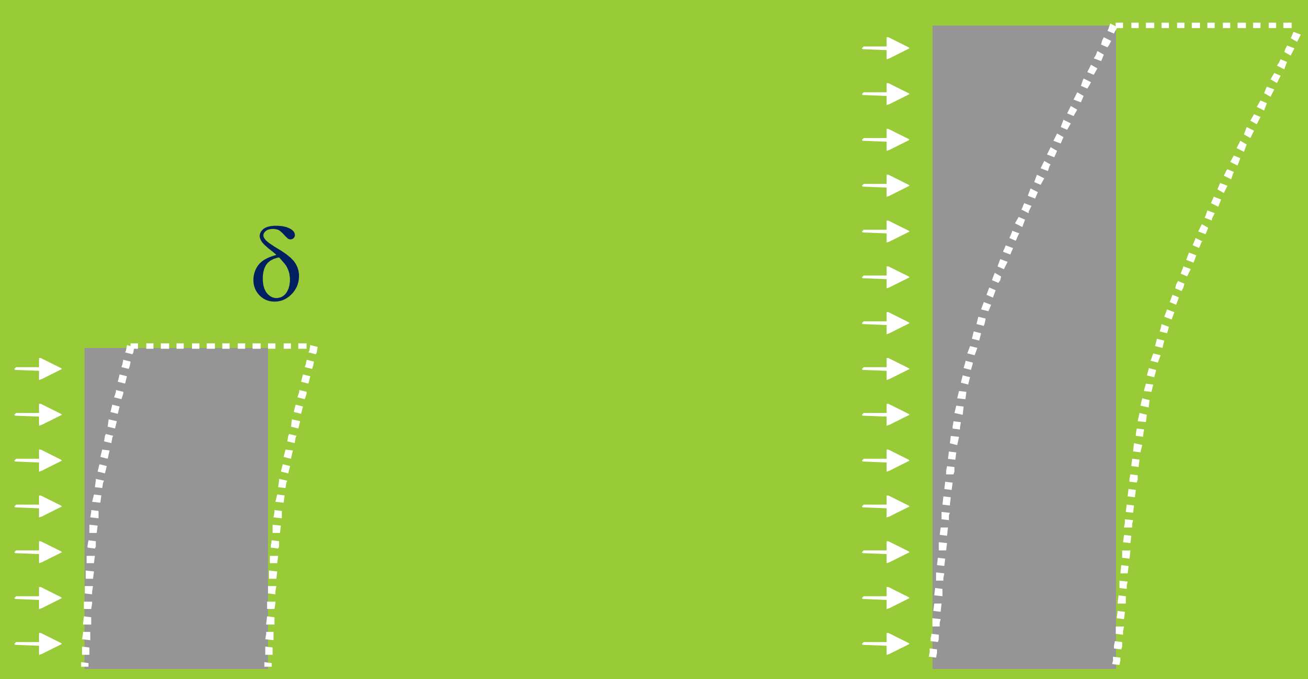
Gravity Control (~h) – Strength Design (~h²)

Evolution of Building Design Approach

- **Intermediate Size Building: Deflection**

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

16 δ = h^4

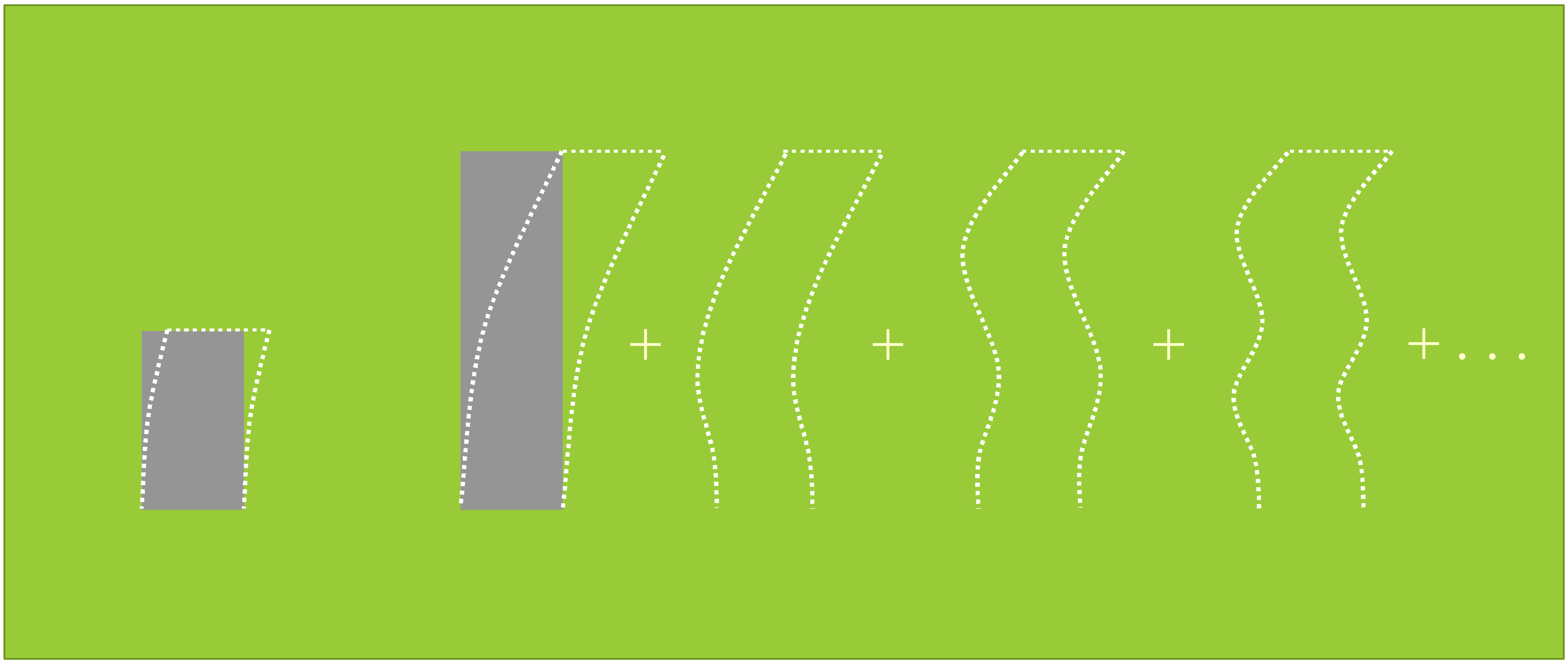


- **Drift limit based on h;** **h^4 / h ~h^3**

Evolution of Building Design Approach

- **Tall Building:**

  Wind Induced Bldg Motion (acceleration) Control – Dynamic Stiffness Design (~h^3)



Evolution of Building Design Approach

- Force Based Design
  - Displacement Based Design
    - Performance Based Design

Building Drift or Lateral Deflection

- **Overall Building : no PDelta**
  US/Dubai (1020 year wind) H / 400 – H / 500
  Korea (50100 year wind) H / 500

- **Interstory Wind Drift: no PDelta**

US/Dubai	**(1020 year)**	**h / 350**
Korea	**(50100 year)**	**h / 350**
China	**(100 year)**	**h / 500 – h / 800 depends on H**

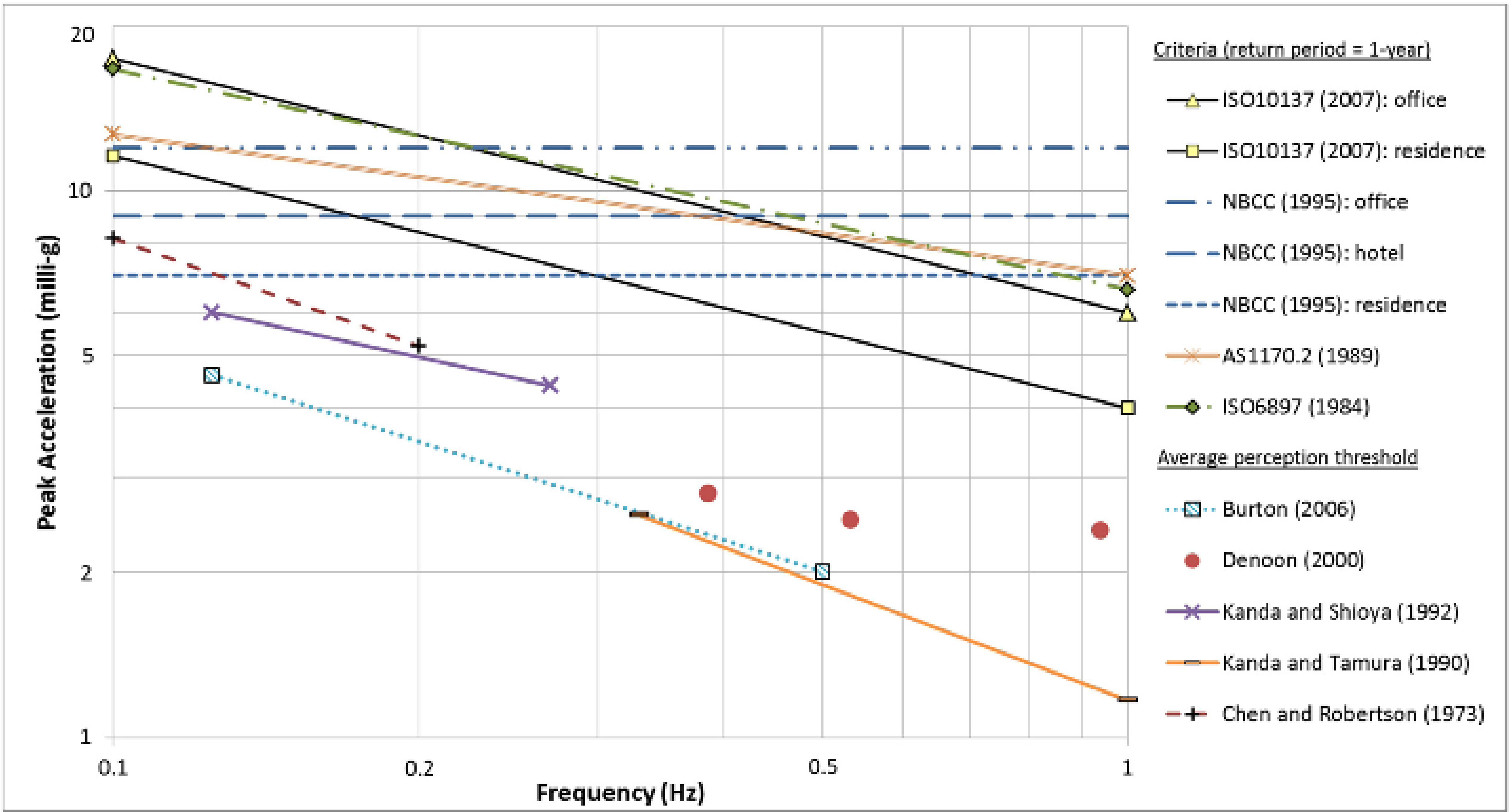
- **Interstory Seismic Drift : with PDelta**
  Inelastic Drift < 0.01h – 0.02h (h / 100 – h / 50)

Human Comfort Criteria under Wind Induced Building Motions

- **USPractice:**
  Building Acceleration Limit (10 year wind)
  Residential = 10 – 15 millig
  Hotel = 15 20 millig
  Office = 20 25 millig
  Retail = 25 + millig

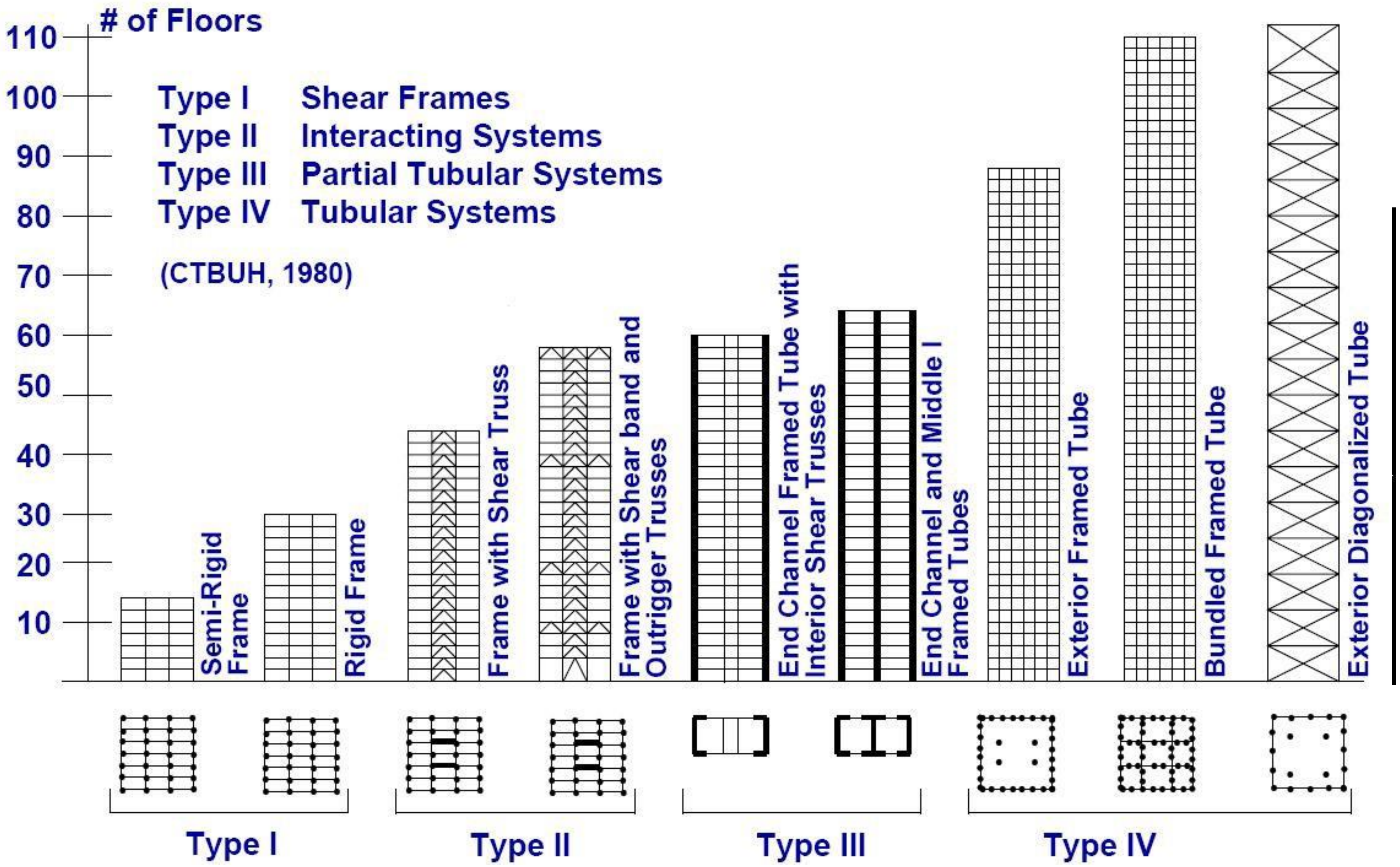
- **ISO based on 1 year**

- **JapaneseCode(AIJ) based on 1 year seasonal**



Peak Acceleration (milli-g)
20
10
5
2
1
0.1
0.2
0.5
1
Frequency (Hz)
Criteria (return period = 1-year)
ISO10137 (2007): office
ISO10137 (2007): residence
NBCC (1995): office
NBCC (1995): hotel
NBCC (1995): residence
AS1170.2 (1989)
ISO6897 (1984)
Average perception threshold
Burton (2006)
Denoon (2000)
Kanda and Shioya (1992)
Kanda and Tamura (1990)
Chen and Robertson (1973)

Lateral Load Resisting Systems



Ideal Structural Systems for Super Tall Buildings

- Flared
- Bundled
- MegaFrame
- Linked
- Tripod

Structural System #1

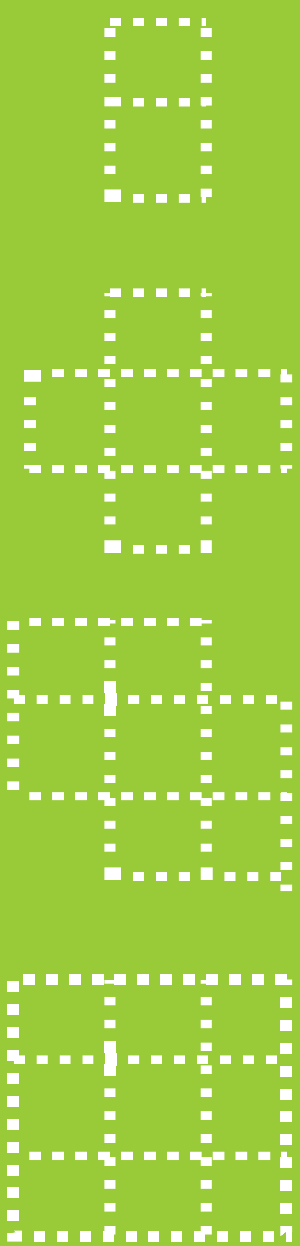
- Flared

Eiffel Tower

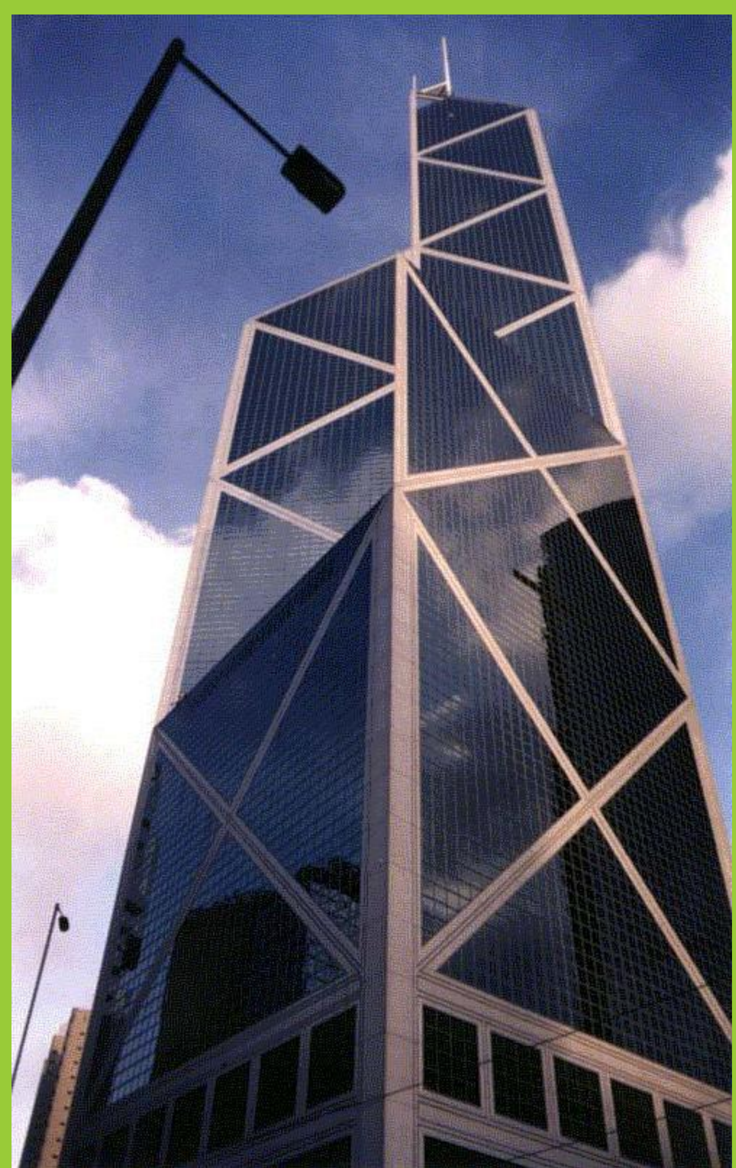
Burj Dubai

Structural System #2

Bundled



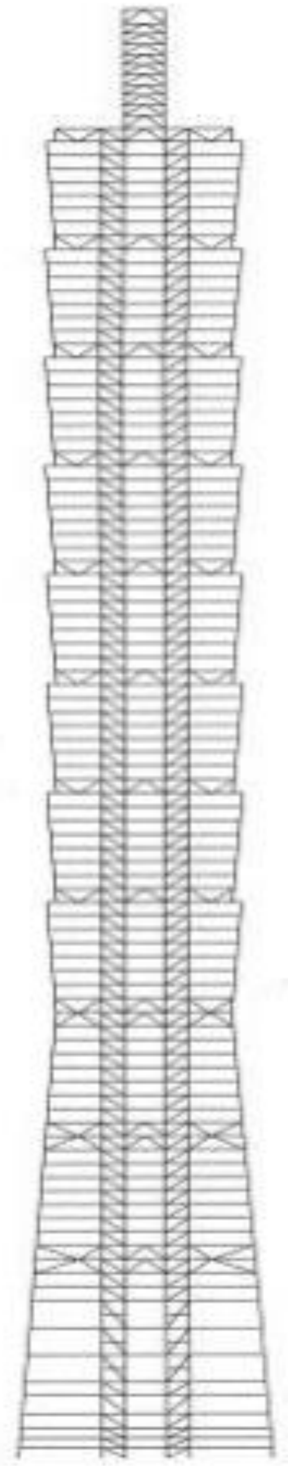
Sears Tower

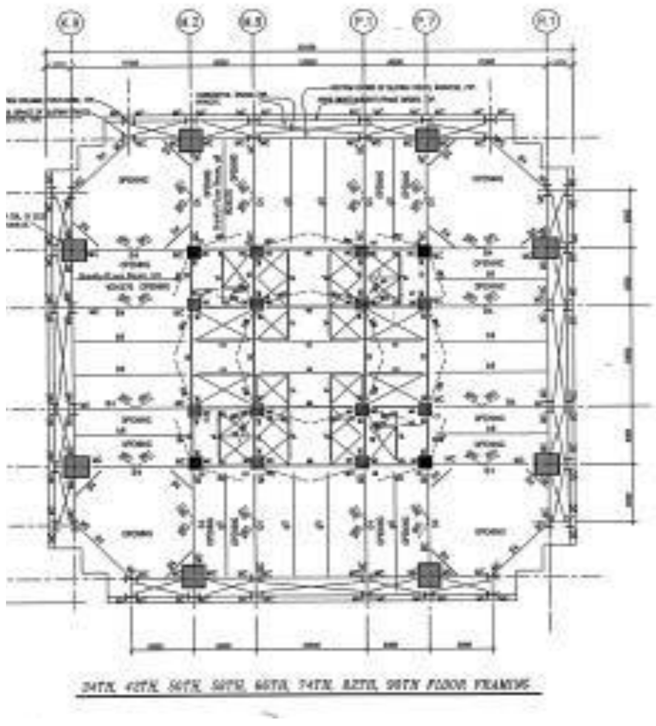


Bank of China, HK

Structural System #3

MegaFrame (Outriggers)





Structural System #4

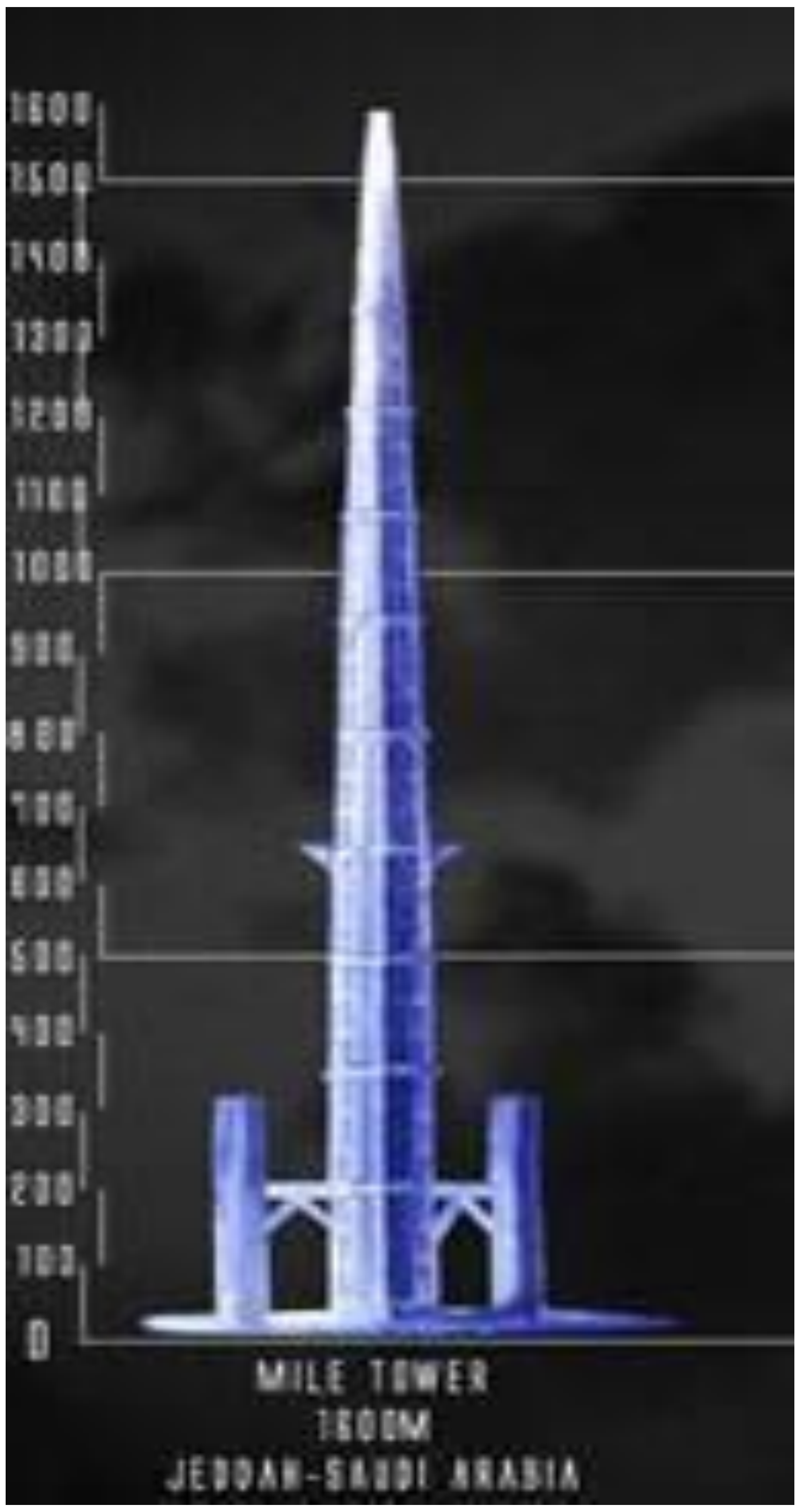
Linked

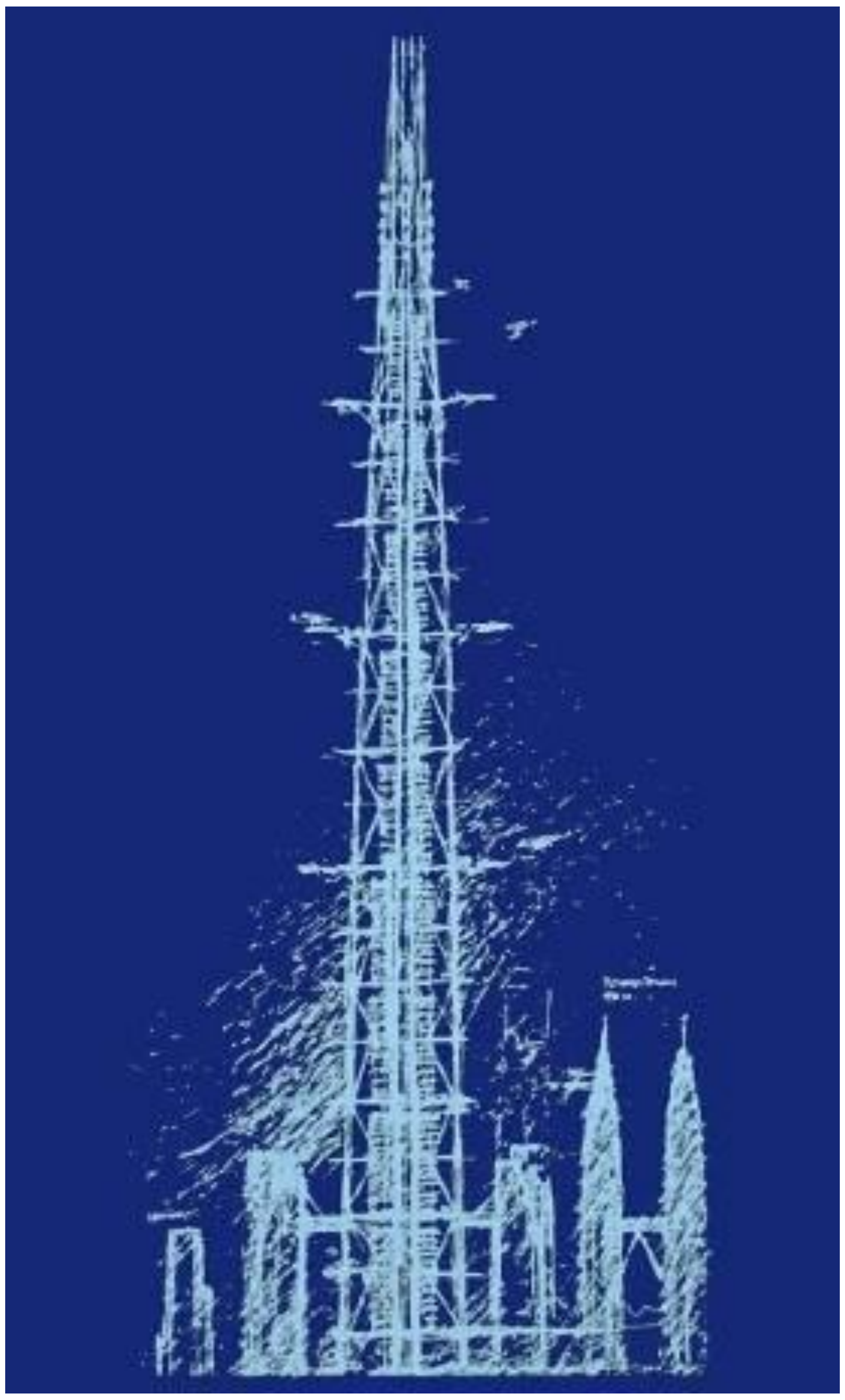
151 Incheon Tower

Nakheel Tower

Structural System #5

Tripod Solution





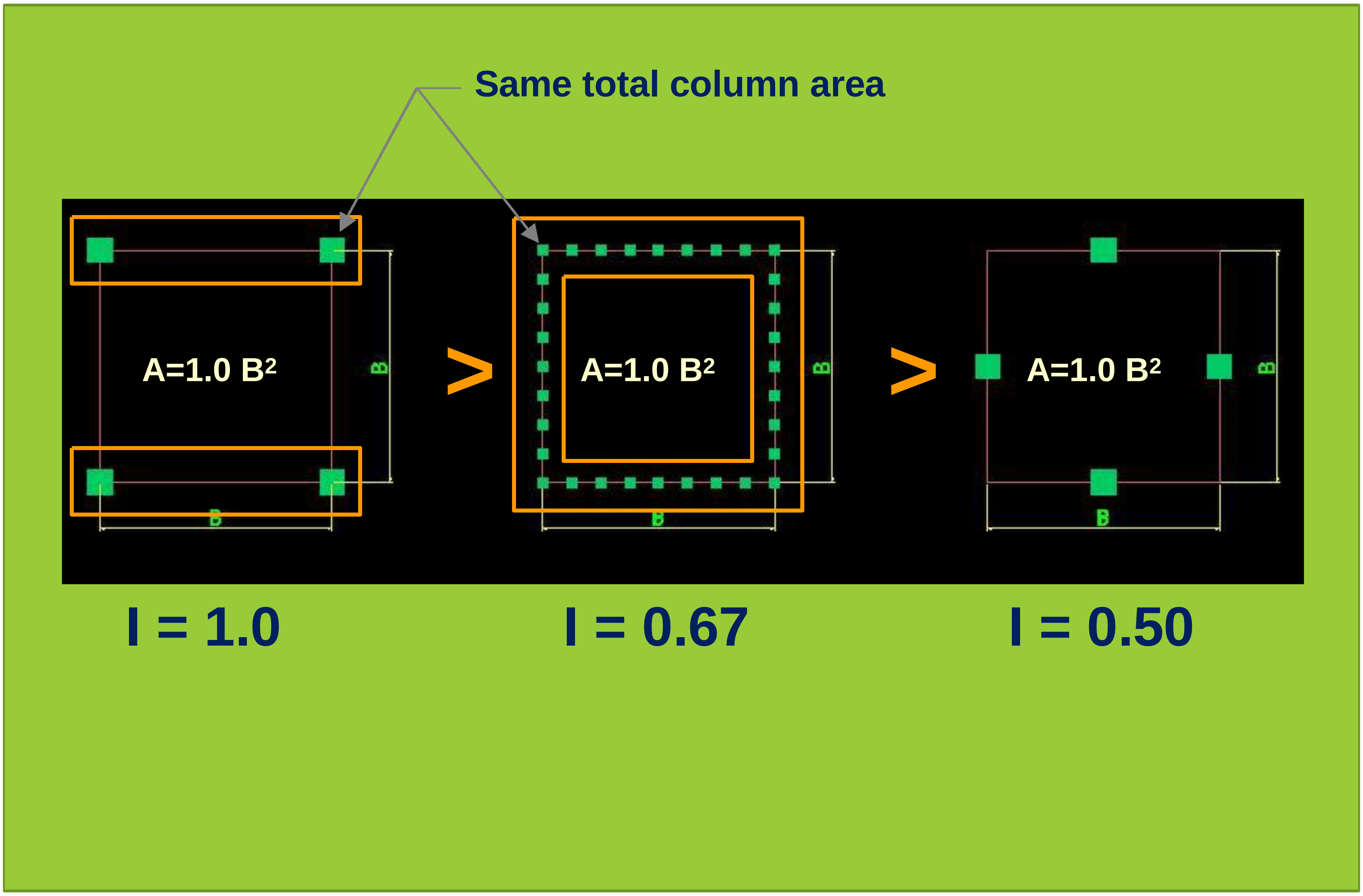
Mile High Tower

Ideal Structural Shape Efficiencies

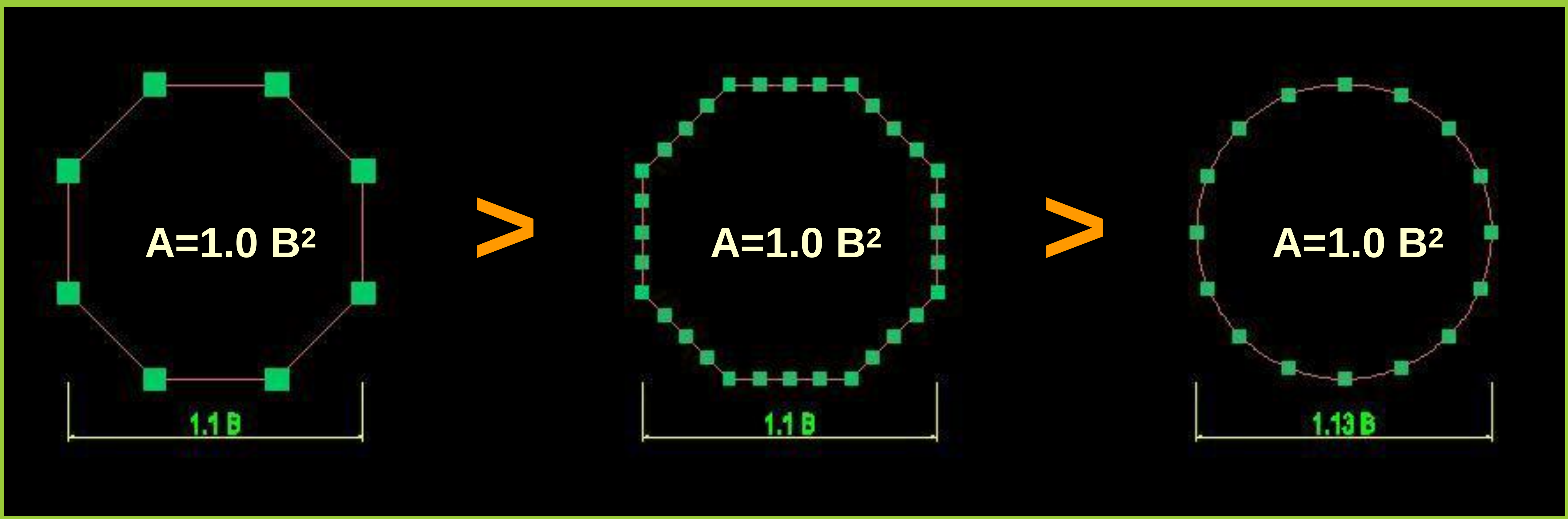
(Based on Building Stiffness for the Same Floor Area)

- Rectangular
- Circular (Polygon)
- Triangular

Rectangular Shape Efficiency



Polygon/Circular Shape Efficiency

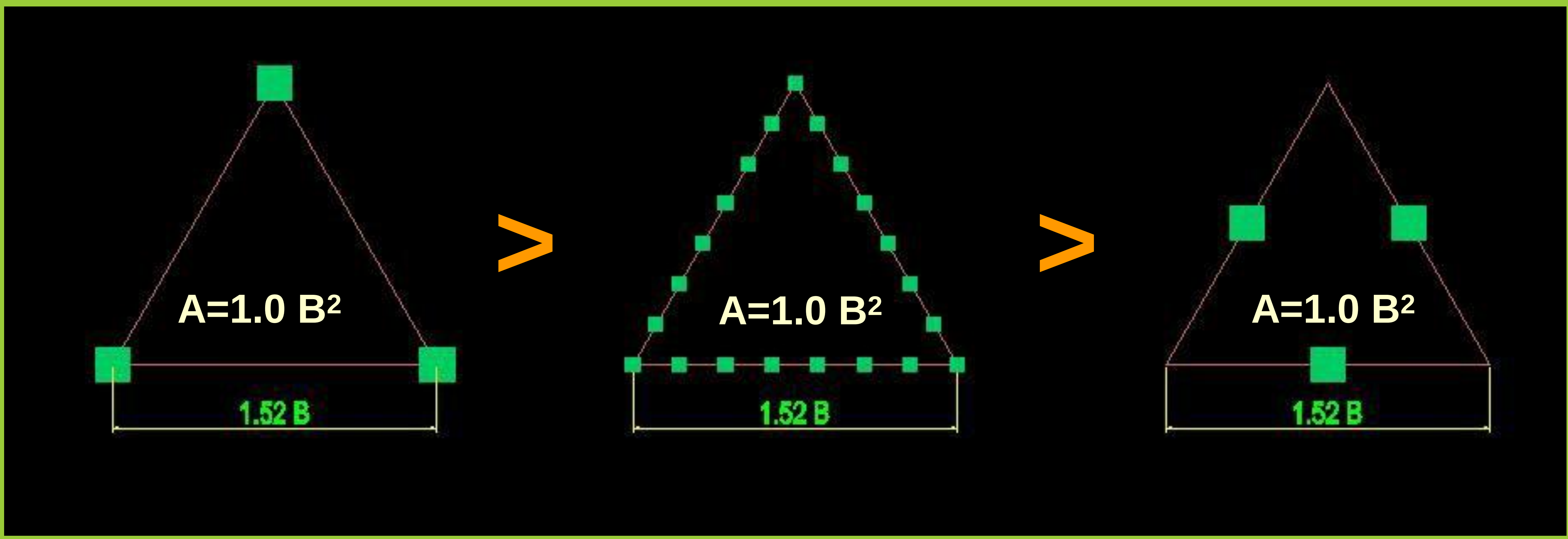


I = 0.71

I = 0.65

I = 0.64

Triangular Shape Efficiency



I = 1.54 | I = 0.77 | I = 0.38

Ideal Structural Shape Efficiencies

(Based on Building Stiffness for the Same Floor Area)

- **Triangular > Rectangular > Circular (Polygon)**

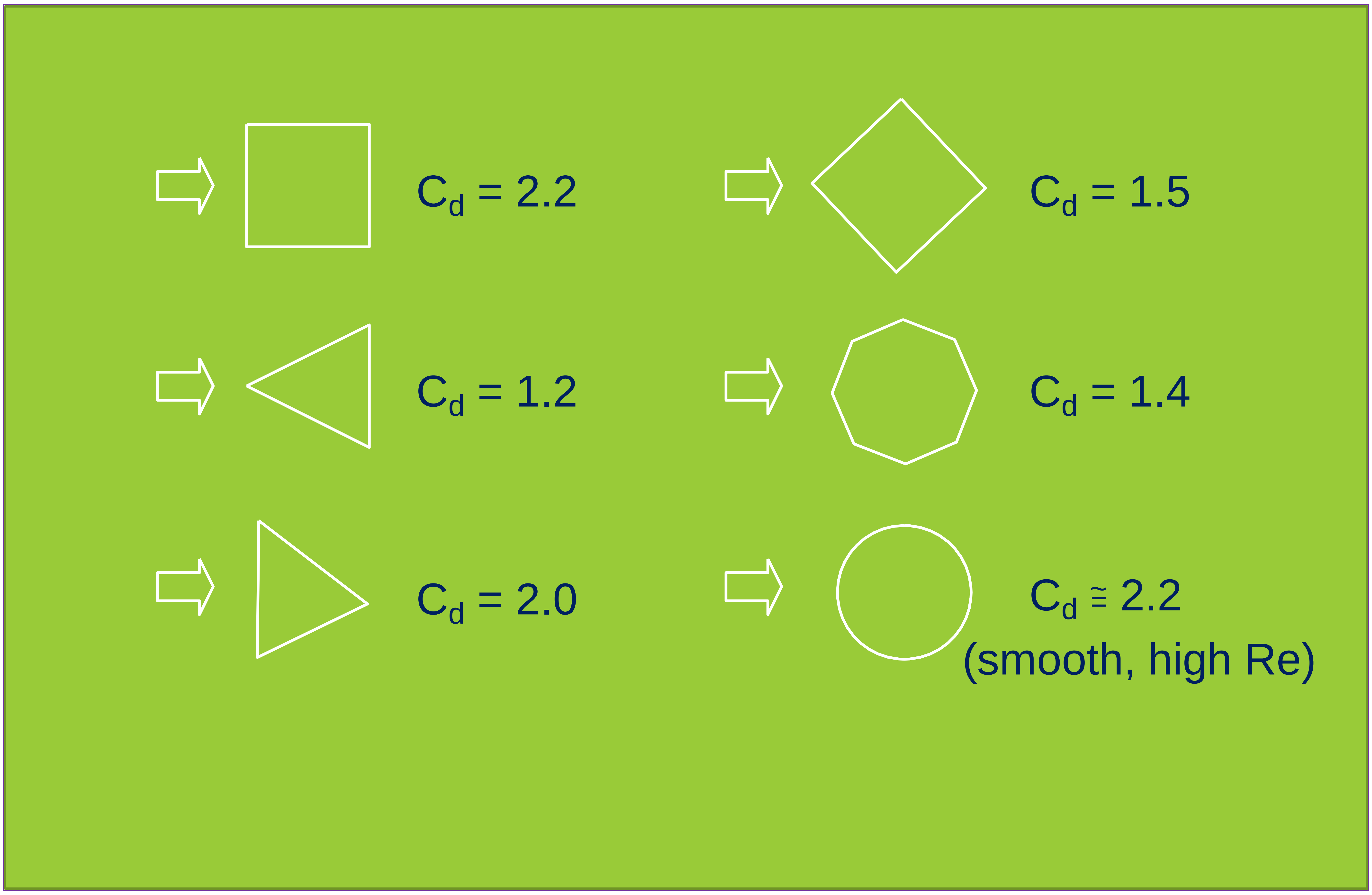
Triangular	Rectangular	Circular (Polygon)
I = 0.77-1.54	I = 0.67-1.00	I = 0.64 - 0.71
B = 1.52	B = 1.00	B = 1.1 1.3

- **Lumped Corner Columns > Distributed Columns**

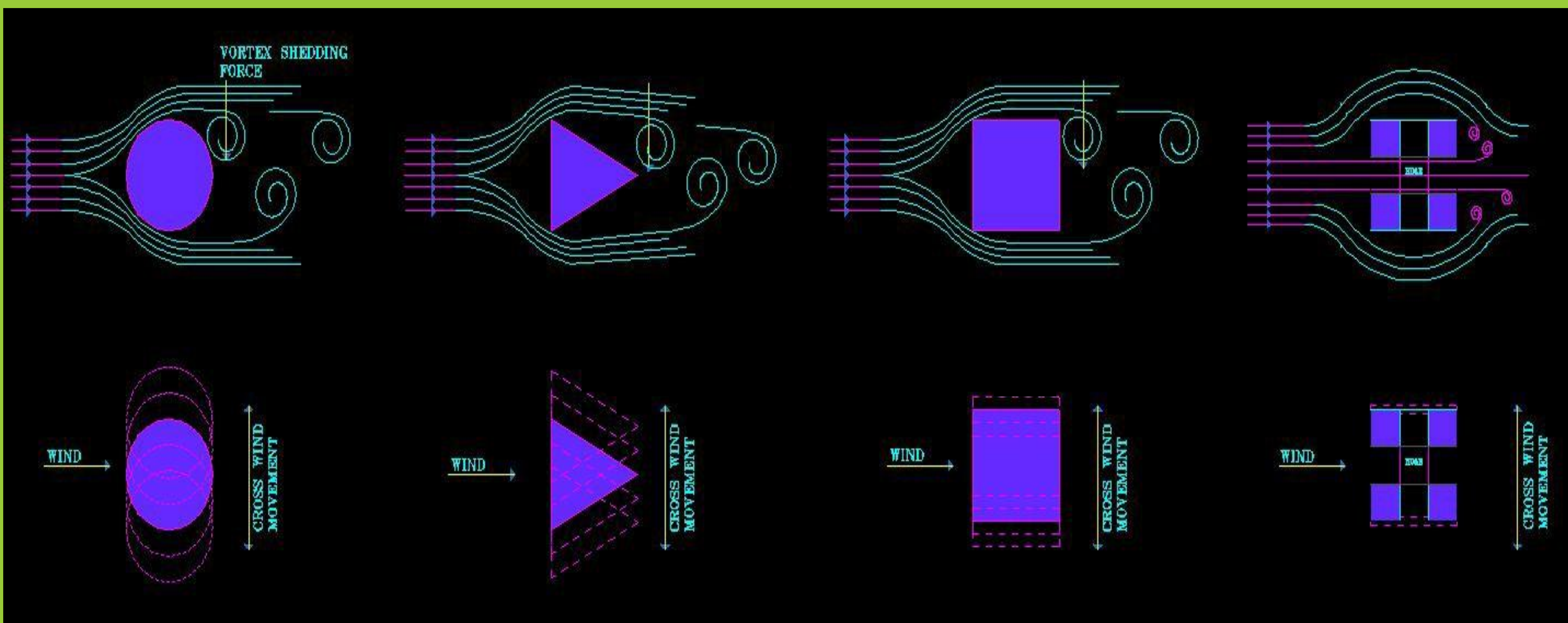
Wind Design:
Building Shapes and Aerodynamics

- Rectangular
- Circular
- Triangular

Drag Coefficient – along wind



Vortex Shedding Effects <u>Cross</u>wind



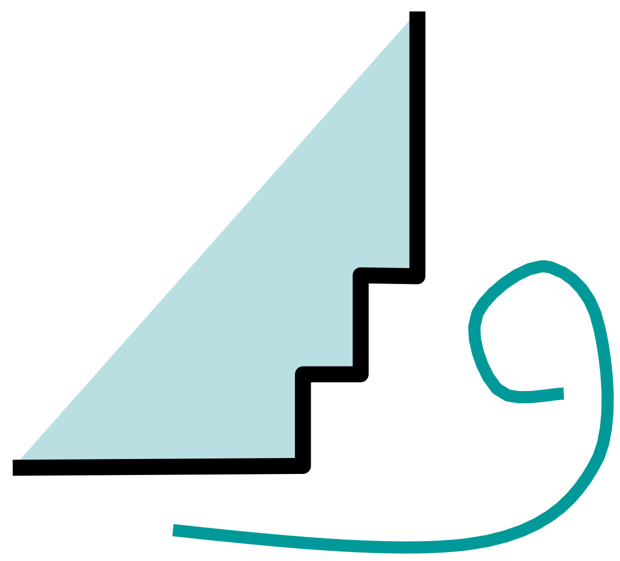
Modification to Building Shapes to reduce Wind Effect

- Stair Step Corner
- Through Building Openings
- Rotate ad Twist

'Stair Step' Corners

- Rough corner can reduce Vortex Shedding effects.

plan



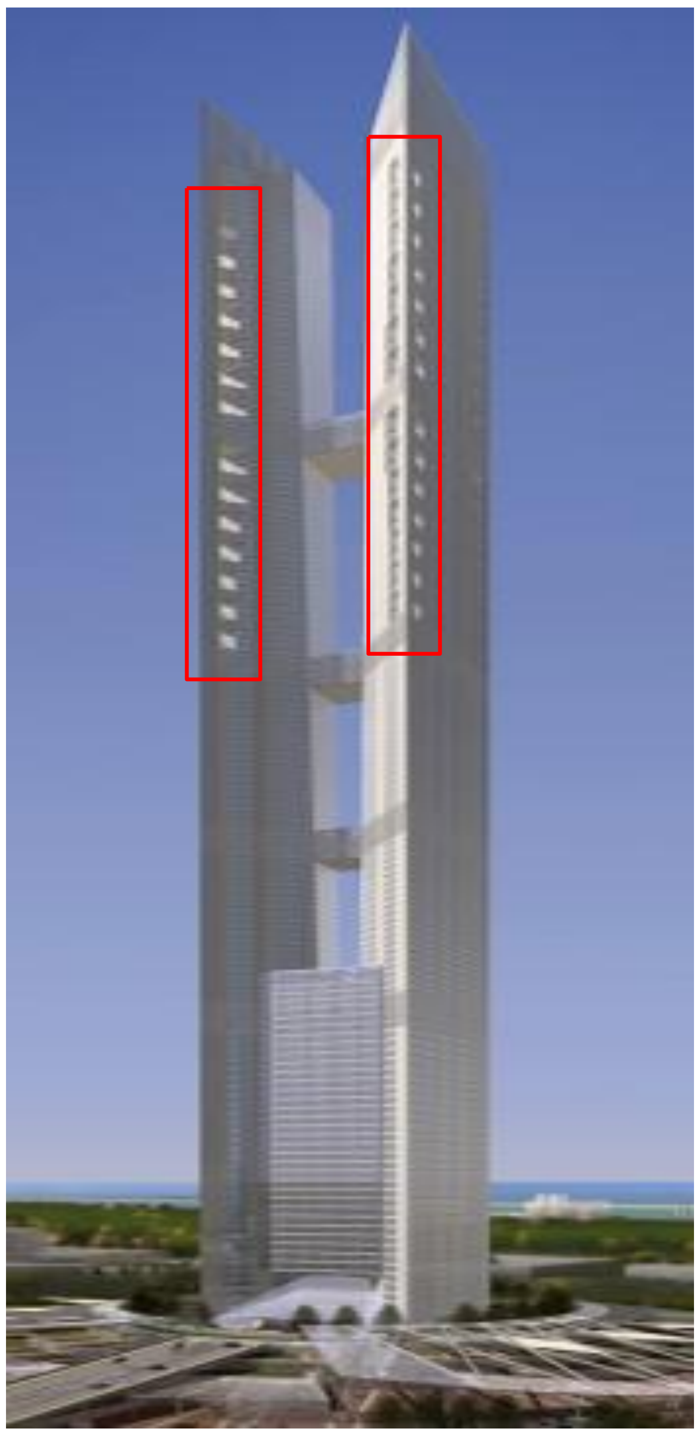
Taipei 101

ThroughBuilding Openings

Shanghai Financial Center

- Openings reduce wind forces (Reduced 'Sail Area')

ThroughBuilding Openings



151 Incheon Tower

- **Slots reduce wind forces and sway from vortex shedding**

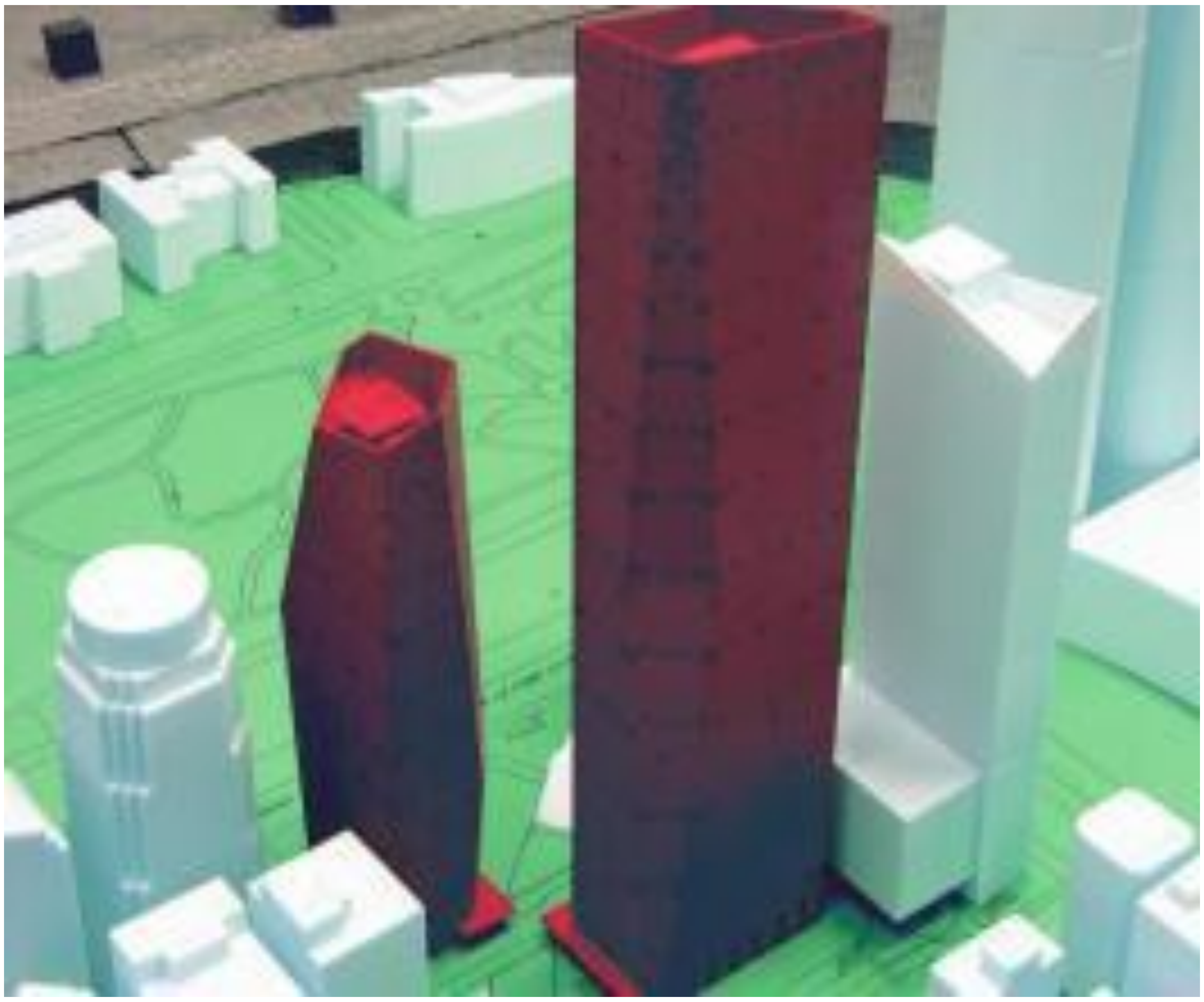
Rotate/Twist

Shanghai Center

- Rotate to minimize load from prevailing direction
- Twist avoids simultaneous vortex shedding along height

Wind Tunnel Test

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

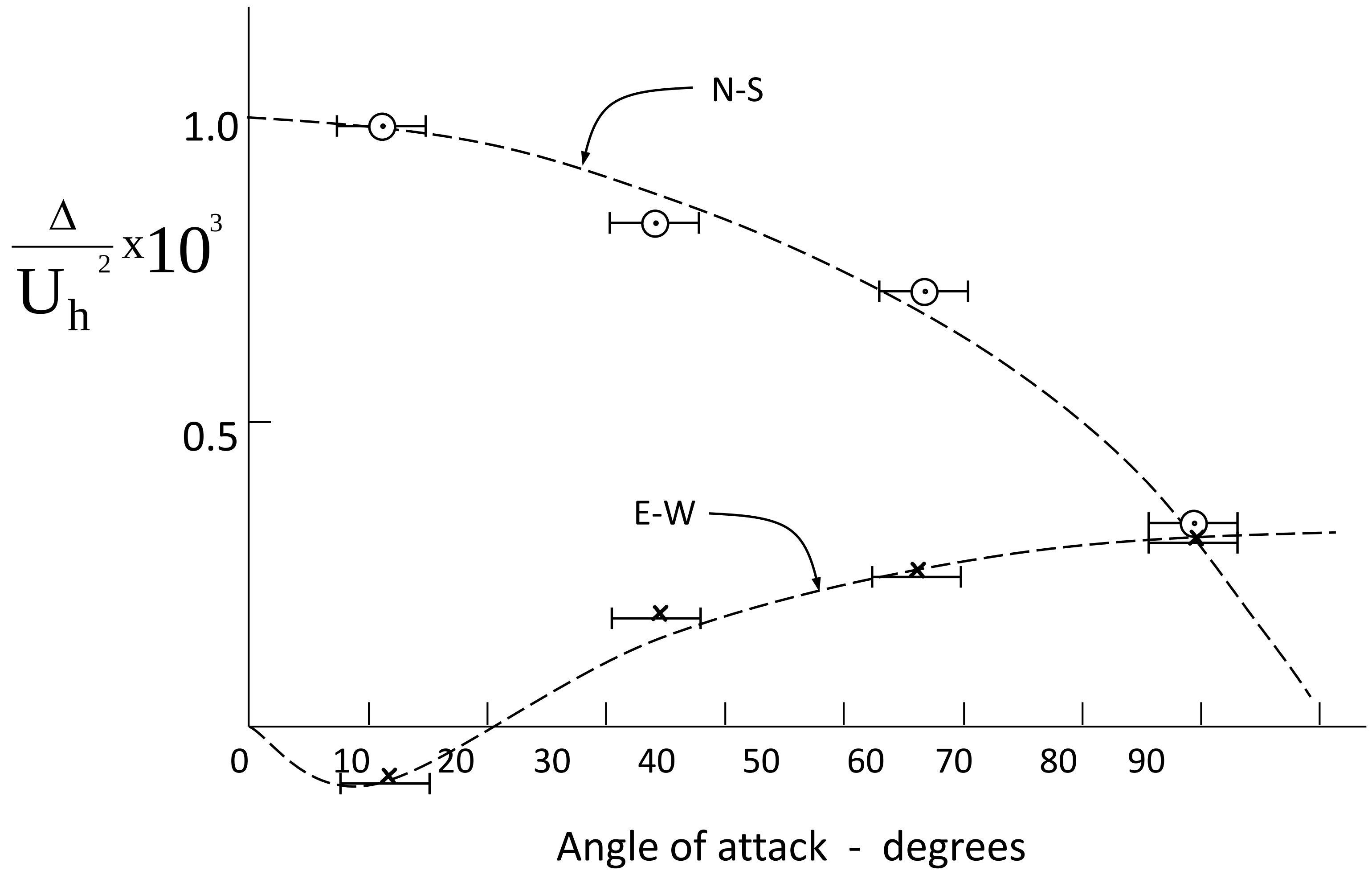


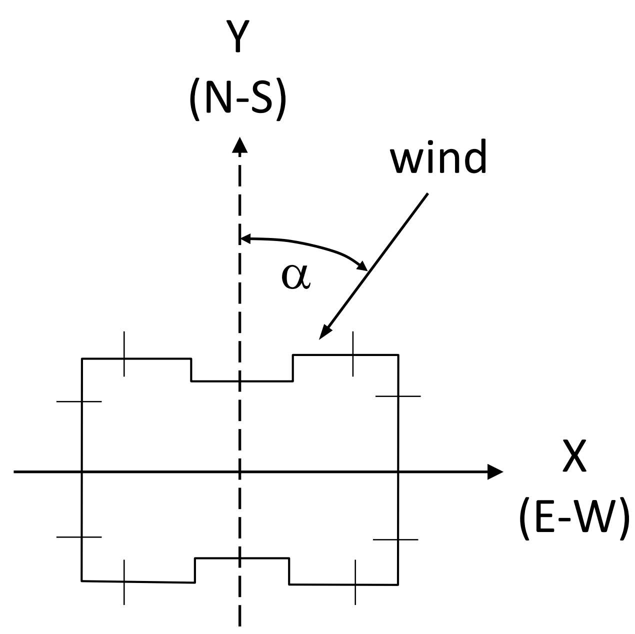
Tall buildings

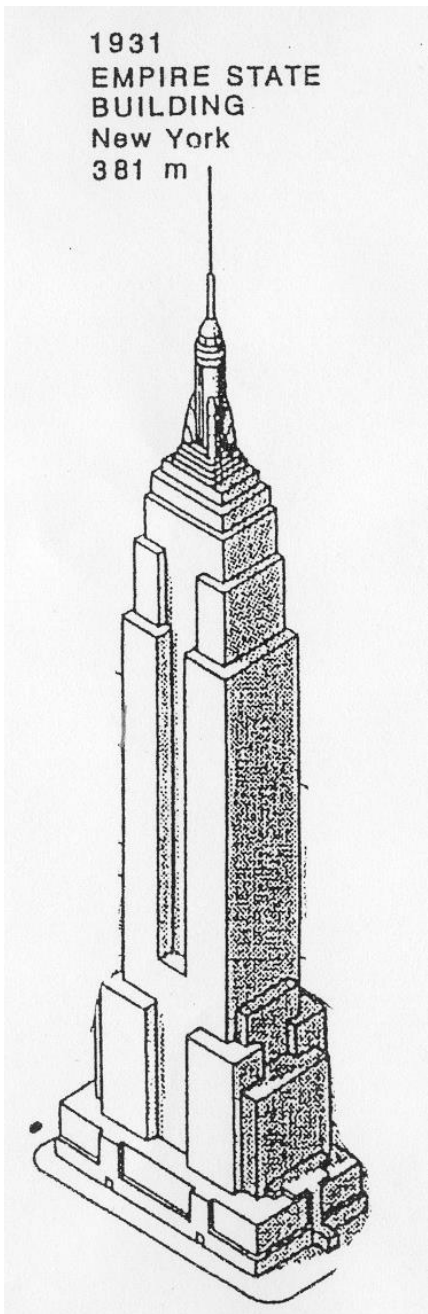
- ‘Rule-of-thumb’ first mode frequency : 46/h Hertz (h in metres)
- Sometimes torsional response is significant depending on geometry and structural system
- serviceability response (peak accelerations and deflections in top floors)

Tall buildings

- Empire State Building - full-scale and wind-tunnel studies in 1930’s







Δ - Mean deflection (inches)

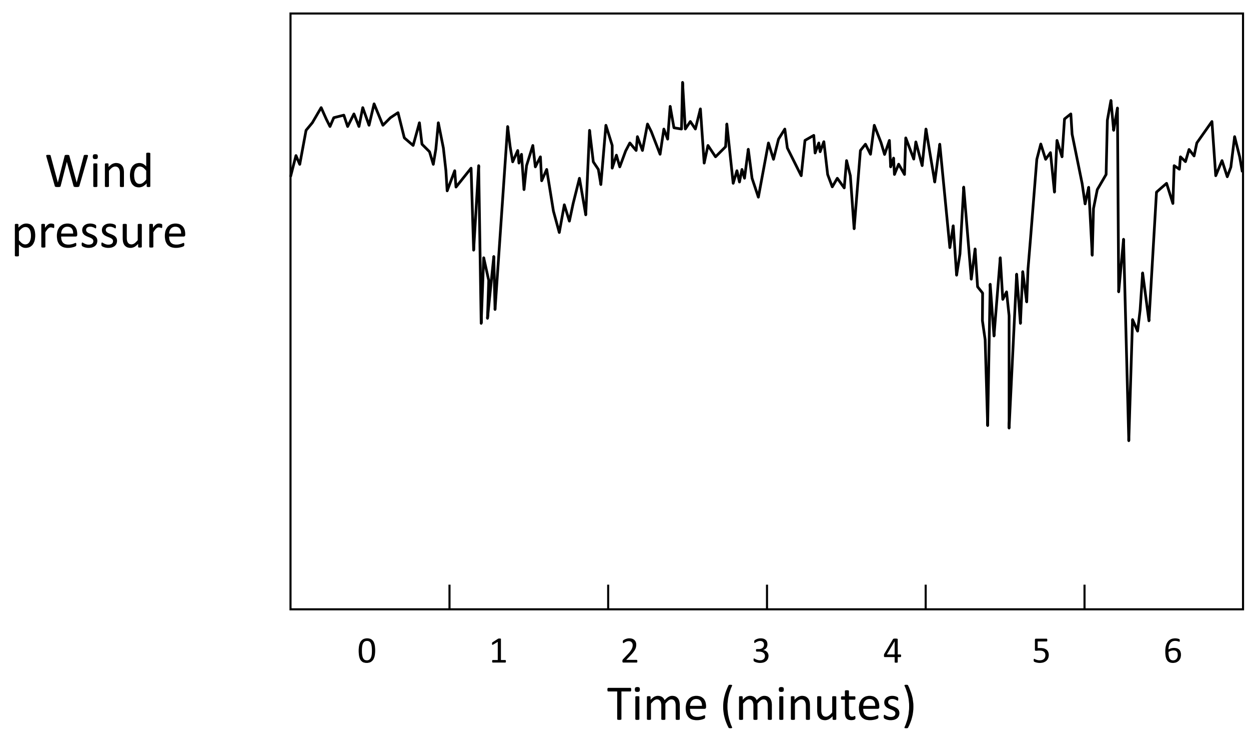
U_h - Mean wind speed at 1250 feet in MPH (uncorrected)

Much stiffer in east-west direction

Tall buildings

- Commerce Court building, Toronto, Canada - 1970’s

Studies of local pressure peaks and implications for **glass design** :

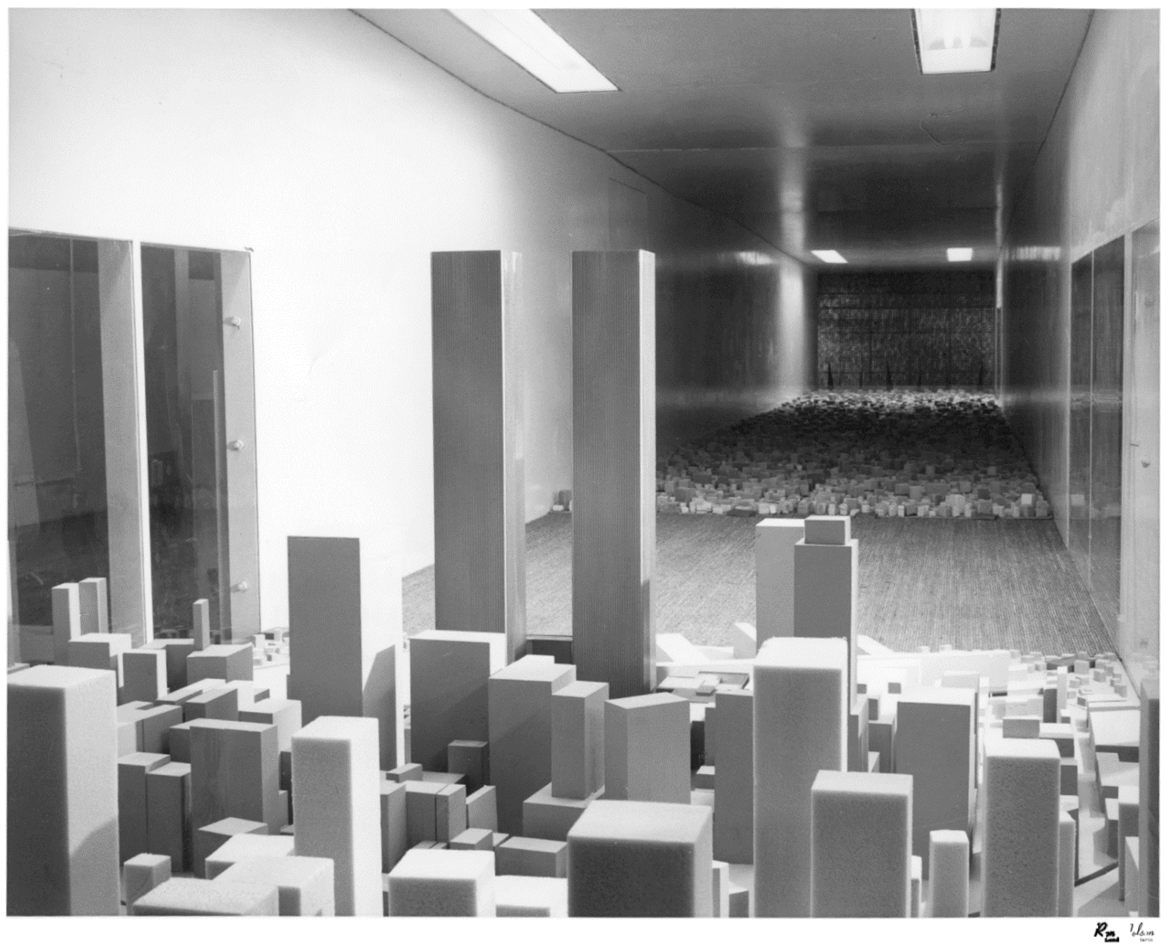


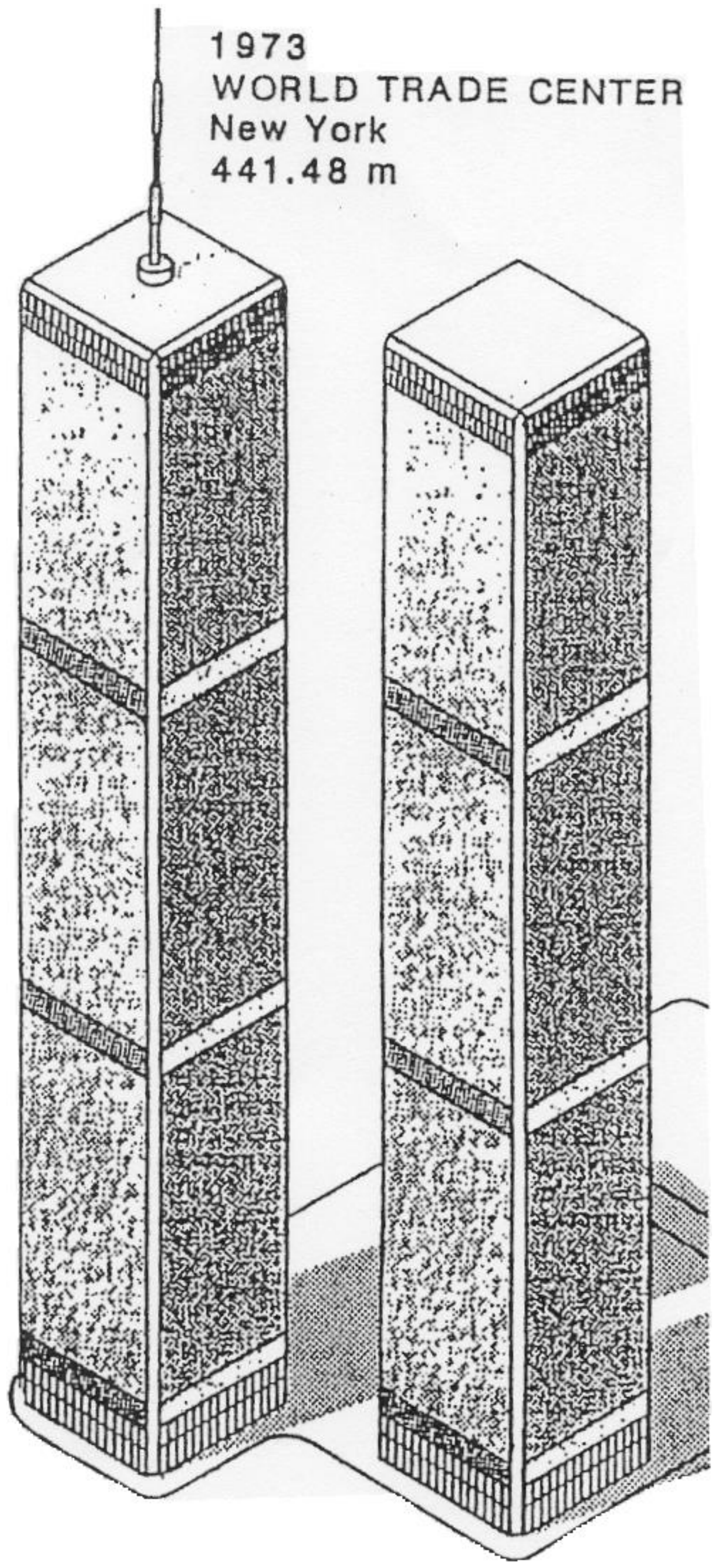
Acceleration measurements showed significance of torsional component (twist)

1/200 scale aeroelastic model showed good agreement with full scale

Tall buildings

- World Trade Center – New York 1973-2001

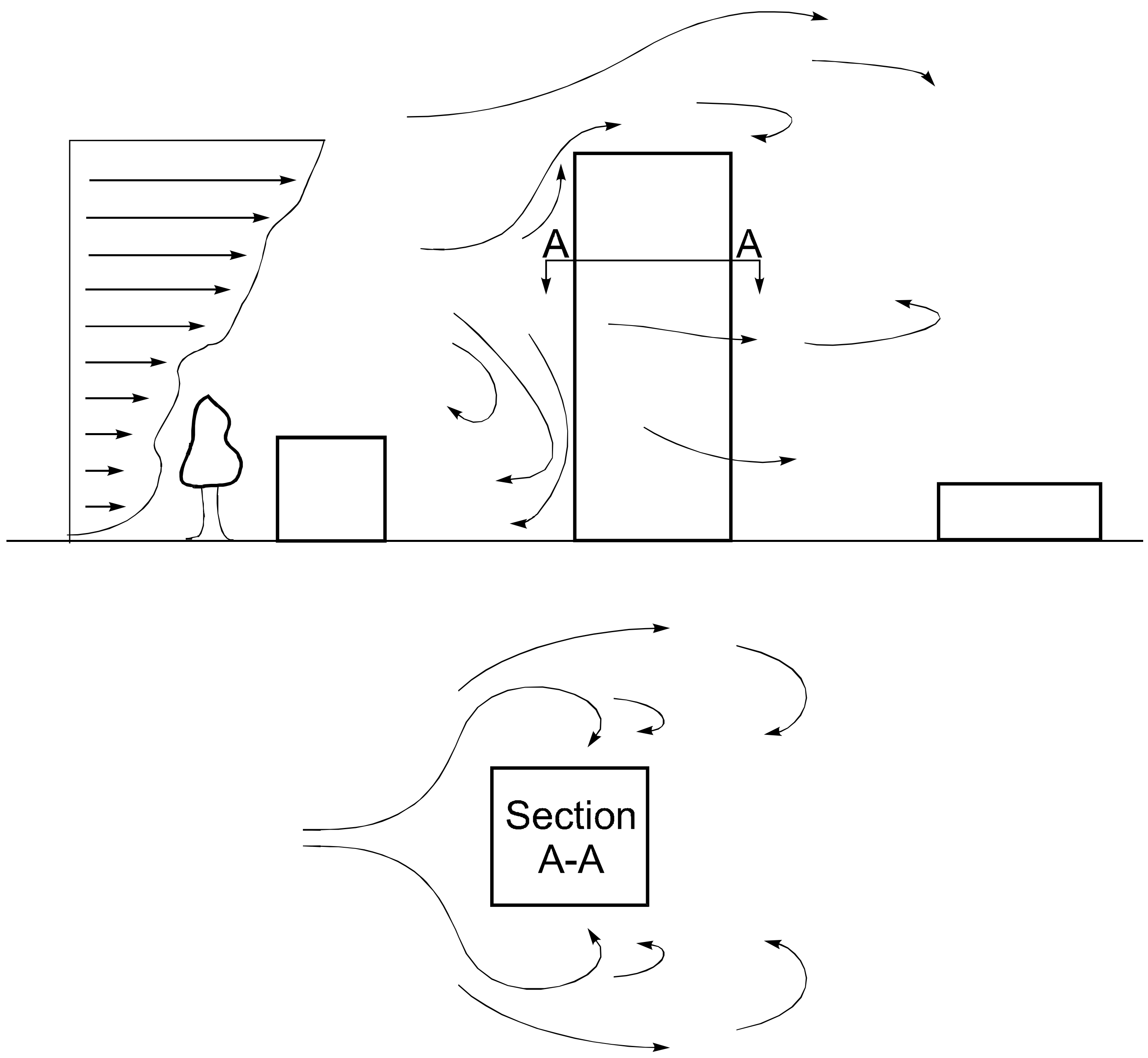




- First buildings to be tested in a turbulent boundary-layer flow wind tunnel (mid 1960's)

Tall buildings

• Flow around a tall building :



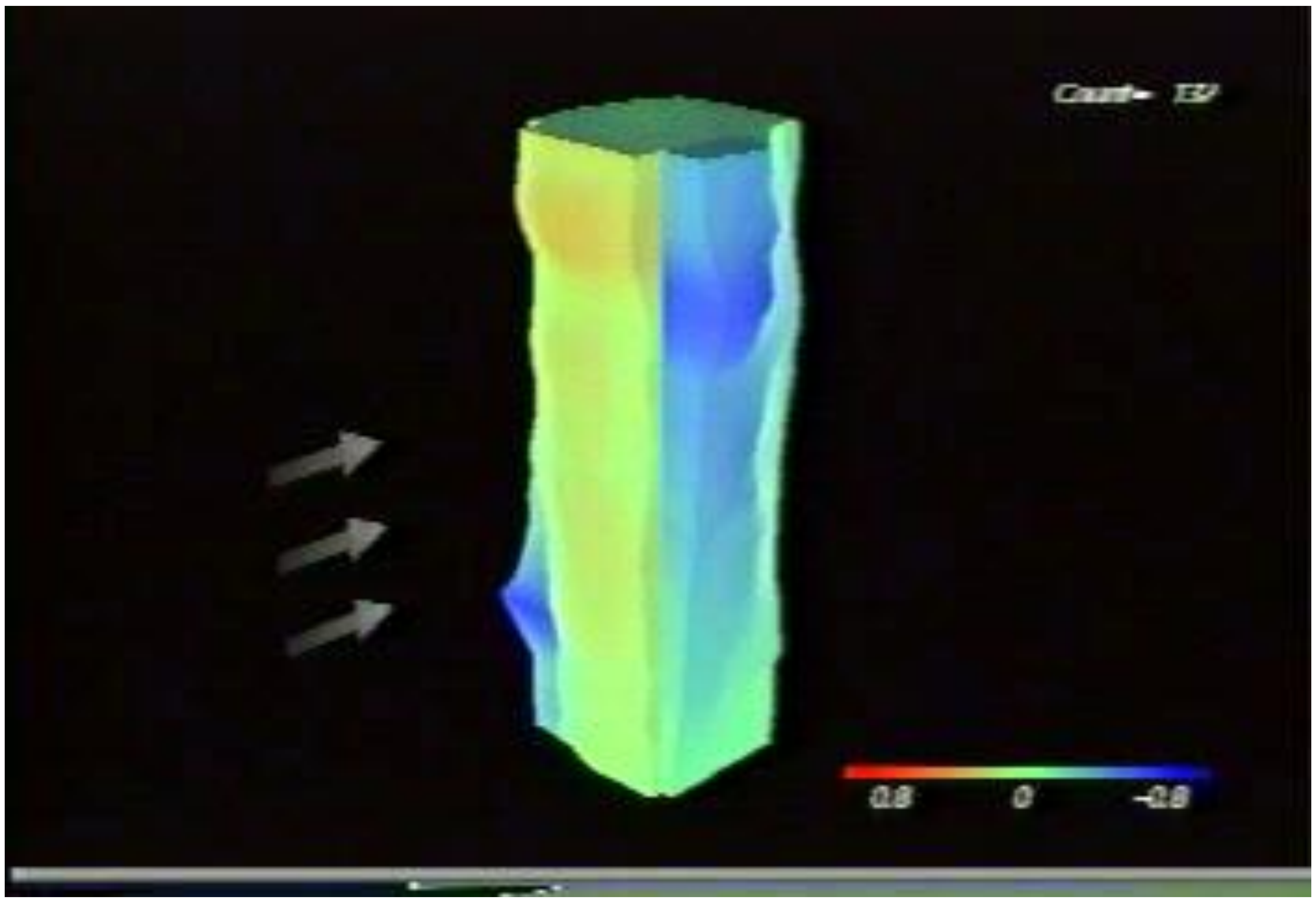
Tall buildings

- Pressure fluctuations on a tall building :

(movie by Shimizu Corporation, Tokyo, Japan)

Tall buildings

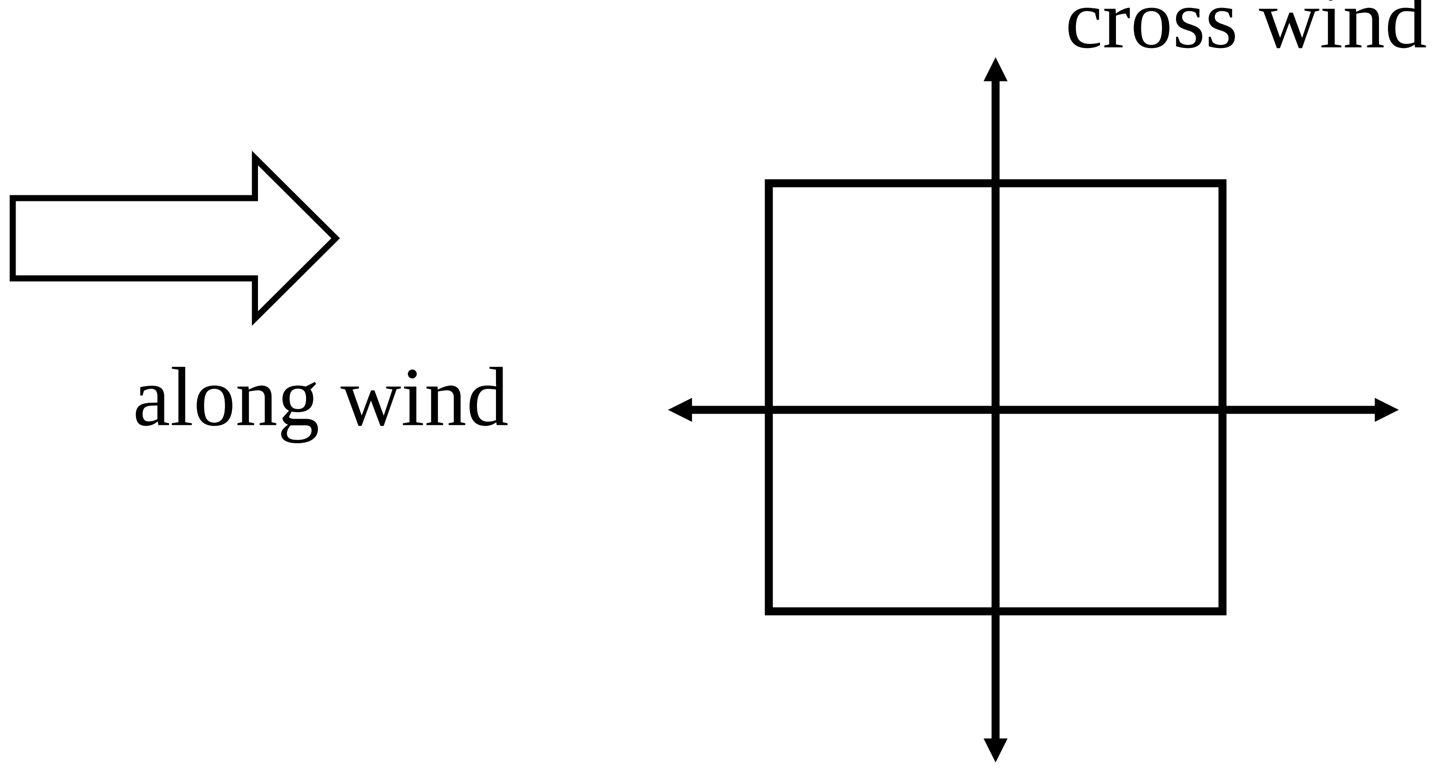
- Pressure fluctuations on a tall building :



(movie by Shimizu Corporation, Tokyo, Japan)

Tall buildings

- Overall loading and dynamic response



Cross-wind vibrations are usually greater than

along-wind vibrations for buildings of heights greater than 100m (330 feet)

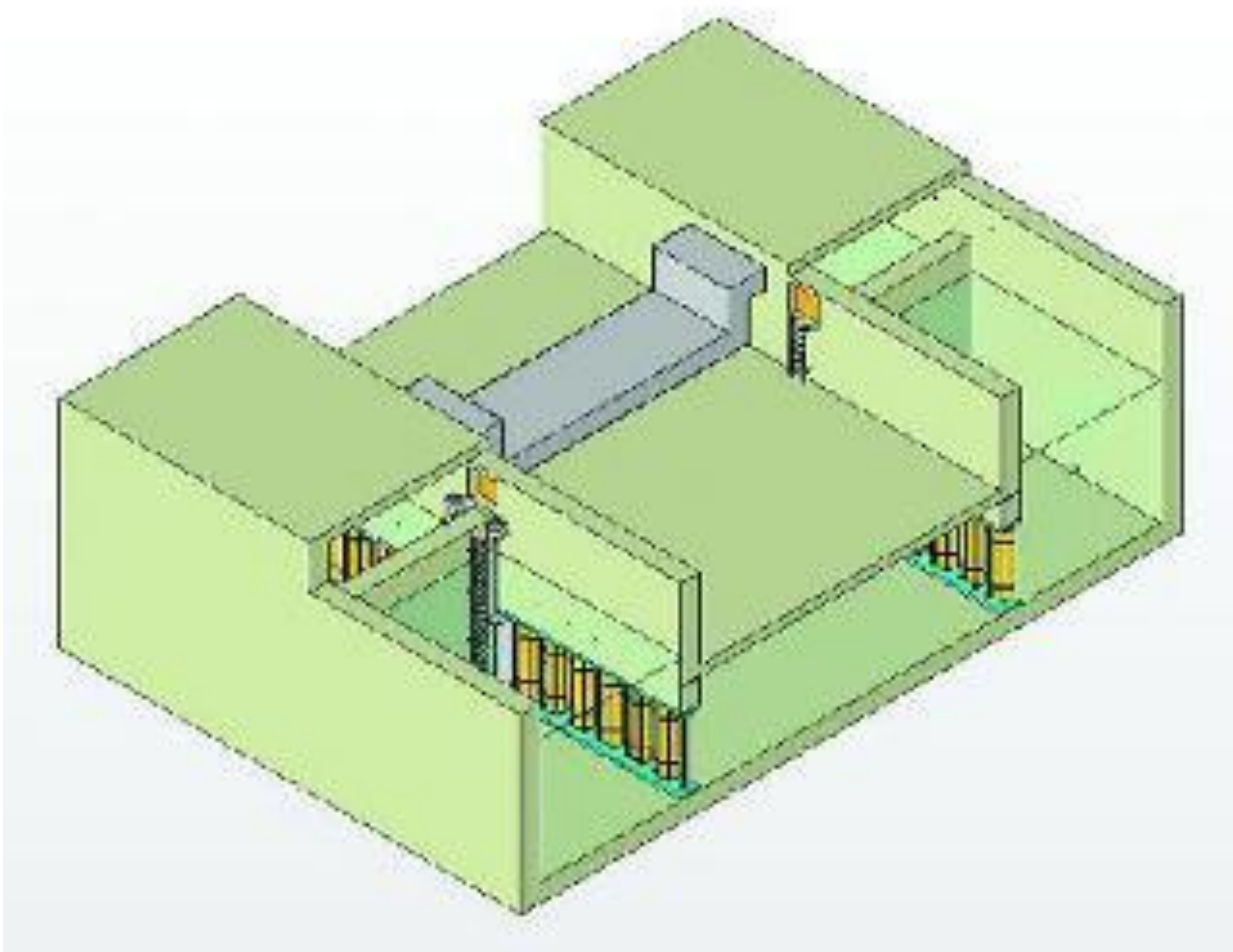
Damping and Dynamics

- 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

Tuned Mass Damper

Tuned Liquid Column/Slush Damper



Seismic Design Issues

- Minimum base shear may govern seismic Less critical than wind for tall building with long natural period
- Interstory drift max at upper floors
- Ductile detailing still important!
- Geometric compatibility
- Performance Based Design

Structural Material Selection (1)

- Availability of local material
- Reliability of material quality control
- Reliability of local labor and training
- Constructability (ability to erect large, heavy steel members)
- Relative cost
- Construction speed
- Architectural layout Impact
- Cultural attitudes

Structural Material Selection (2)

- Building weight
  - Foundation load
  - Net uplift
  - Seismic mass
- Dynamic behavior
  - Stiffness
  - Period (~ mass / stiffness)
  - Damping

Foundation Design

- Intensive soil investigation and analysis
- Construction sequences
- Model deep basement "anchor" against overturning vs. baseline at top of mat
- Pile depths – verticality
- Dewatering for deep basements

Building Heightrelated Issues (1)

- Differential column shortening and column cambering
  - Steel = elastic
  - Concrete = creep, shrinkage
  - Mixed (concrete core, steel perimeter) = severe differential

- Construction sequence for outriggers
  - Load redistribution
  - Delayed connections

Building Heightrelated Issues (2)

- Verticality during and after construction
- Effects on nonstructural components (cladding area, riser lengths, elevators, stairs, etc.)
- Experience in design and construction
- Capability to interpret codes
  - Apply international standards?

Building Heightrelated Issues (3)

- Concrete rate of strength gain
  - Slow loading of columns, foundations
  - Fast floor cycles
- Consistent specifications
  - Structure
  - Equipment (elevators)
- Appropriate Value Engineering

Other Consideration
Think Green

EDDIT Tower Singapore

O14, Dubai

Structural Sustainable Design

- Recycled materials
- Local manufacturers
  - Less travel distance = less pollution
- No waste of materials
- Fly ash or slag in concrete mixes

Design Team Requirement Highlights

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

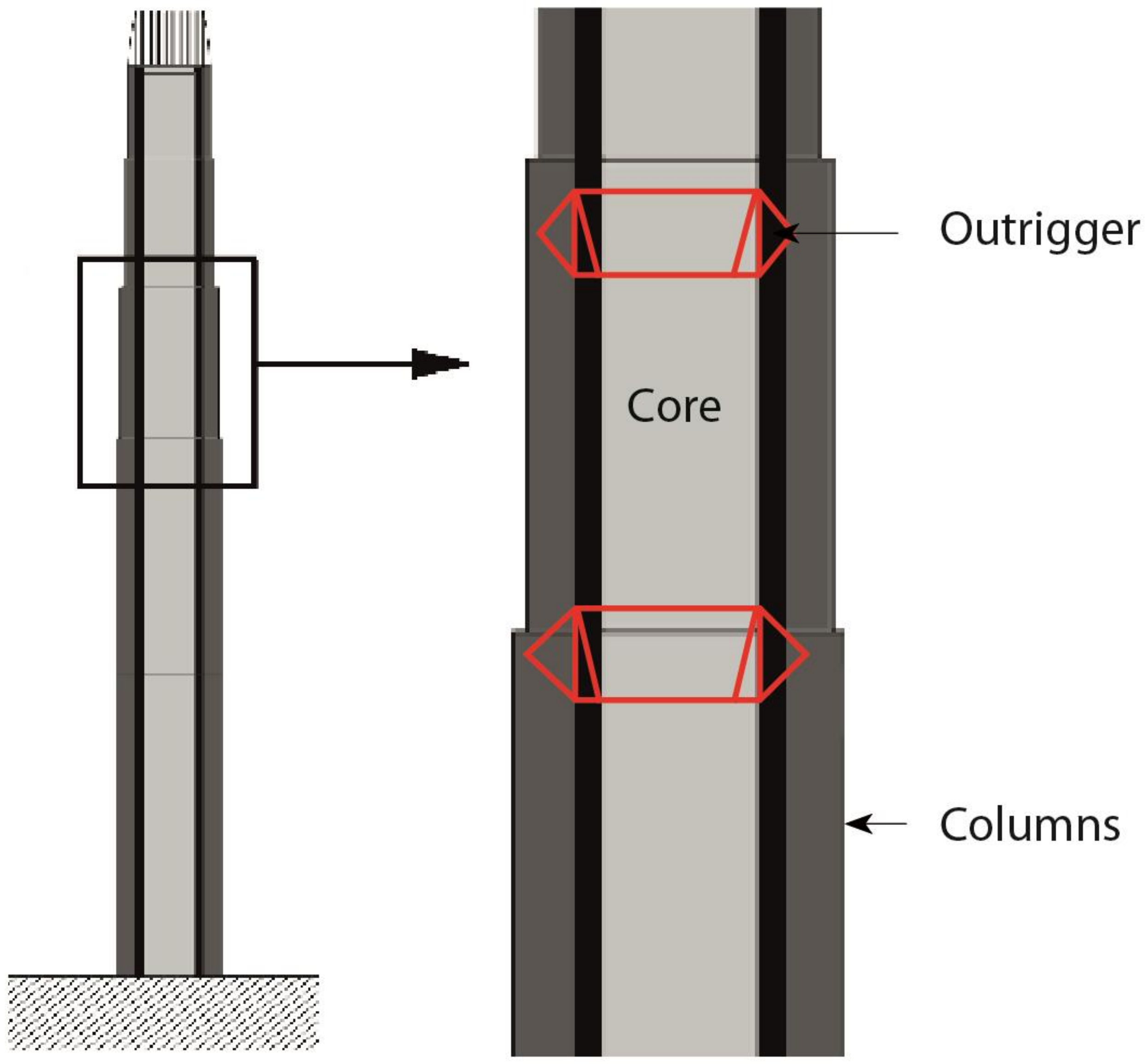
Typical Structural Systems in Tall Buildings

Installation of outriggers at the International Commerce Centre

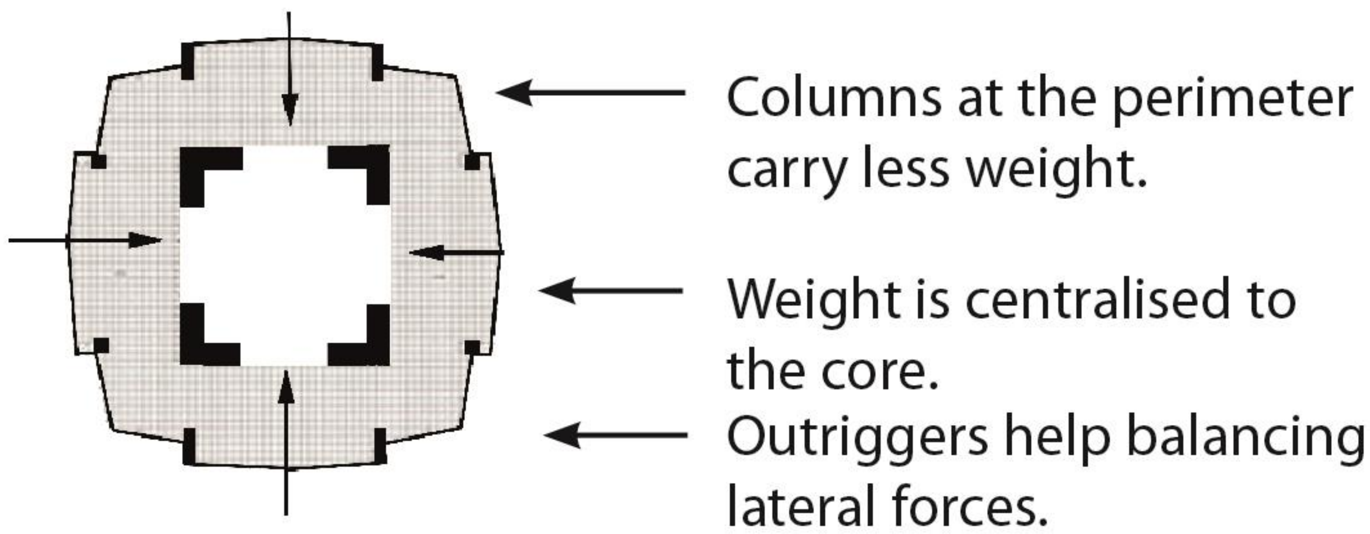
© Raymond Wong

Core and Outrigger structure

- The International Commerce Centre is built using a ‘**Core and Outrigger**’ concept.
- The core at the centre of the building bears most of the vertical load,
- while columns at the perimeter carry less weight and are thus smaller in dimension.
- Loads are transferred to the core through steel outriggers that balance the lateral forces on the whole building.



Outrigger connecting the core and the columns



Plan of International Commerce Centre

The **International Commerce Centre** (abbreviated **ICC**) is a 108-storey (see below), 484 m (1,588 ft) commercial skyscraper completed in 2010 in West Kowloon, Hong Kong.

Steel

- It is a common construction material for tall buildings
- **good** performance in withstanding **compressive and** tensile forces, as opposed to concrete's low tensile strength in compression.
- Relatively **weak in fire-resistance**.

The Bank of China Tower is a steel trussed-tube structure. The whole building acts as a single tubular truss, with the diagonals wrapping the building to transfer loads.

Bank of China Tower

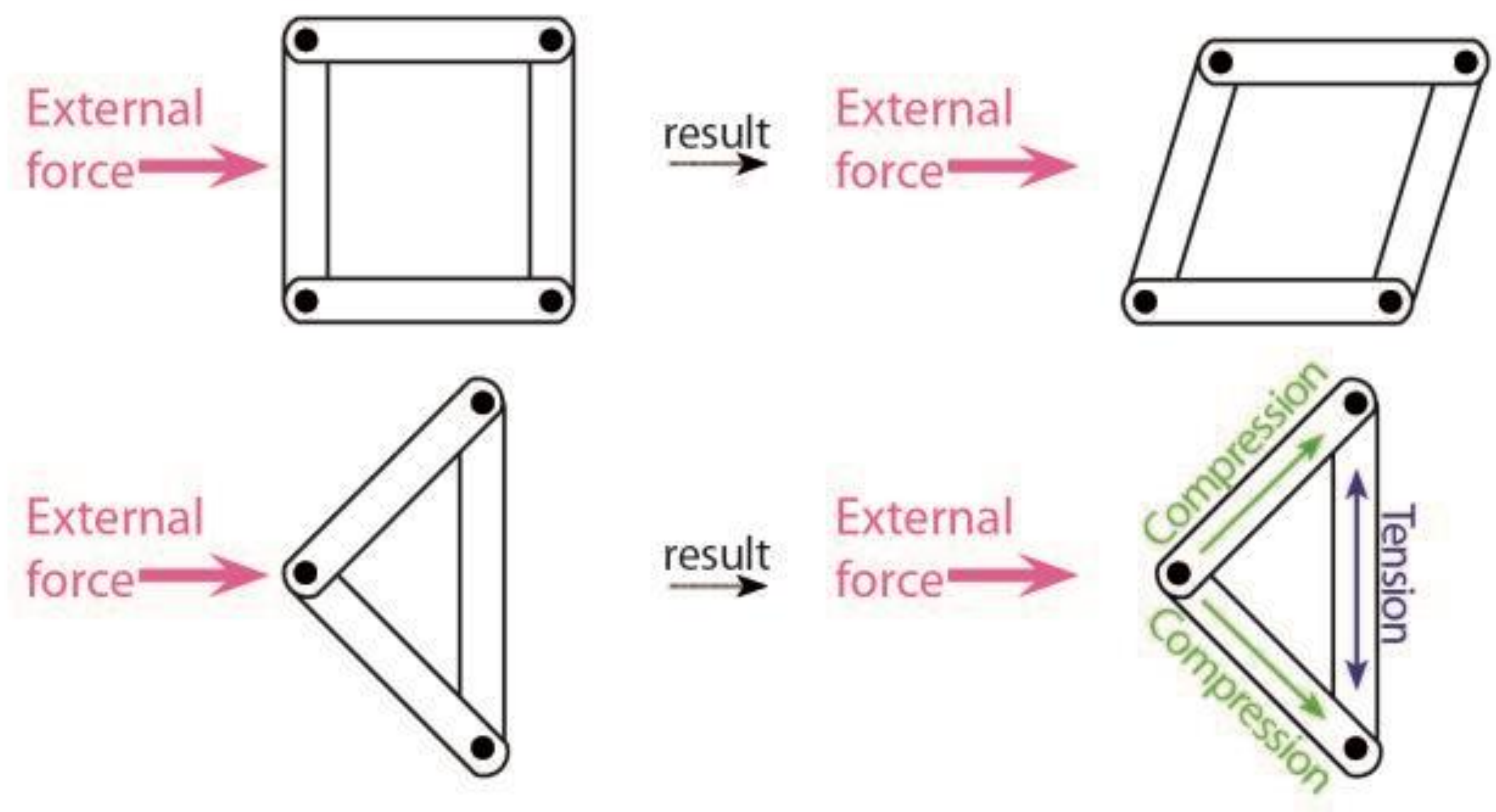
The Bank of China Tower (abbreviated BOC Tower) is one of the most recognisable skyscrapers in Central, Hong Kong. It houses the headquarters for the Bank of China (Hong Kong) Limited. The building is located at 1 Garden Road, in Central and Western District on Hong Kong Island.

Truss

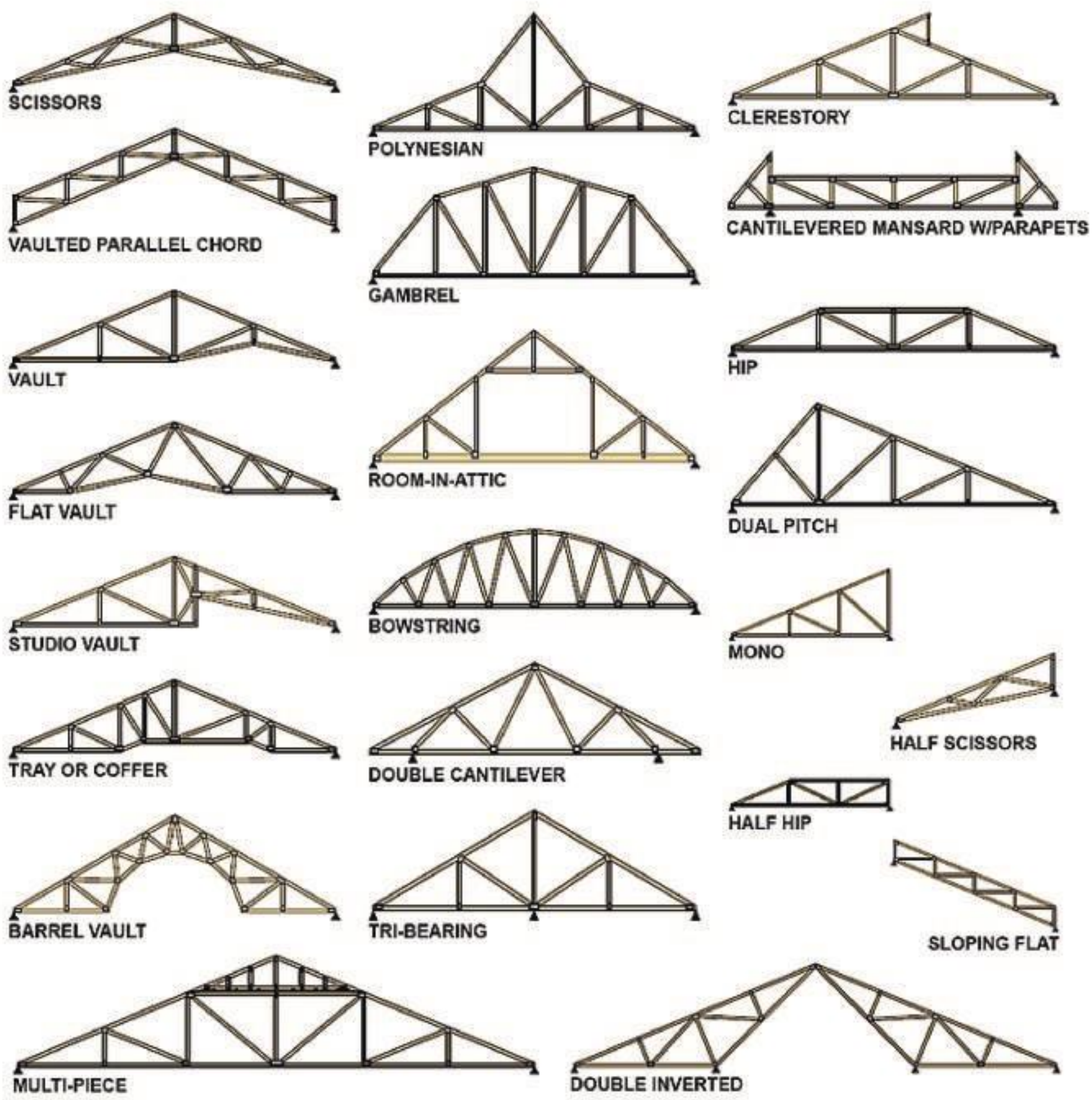
Common structural element in architecture.

Steel members are joined together into **triangular shapes**, which are able to **resist external forces**.

When joined together, these triangles can form large truss systems that can **span long distances**.



Truss



Common types of truss

Summary

Although humans have long attempted to build tall structures, skyscrapers began to appear in our cities in the late 19th century as a result of technological breakthroughs in building materials and methods, including reinforced concrete, steel, and elevators.

Typical structural systems used in tall buildings include core and outrigger structures, steel frames and trusses.

HIGH RISE
STRUCTURAL SYSTEMS


Demand for High-Rise Buildings
• Scarcity of land in urban areas
• Increasing demand for business and residential space
• Economic growth
• Technological advancements
• Innovations in Structural Systems
• Desire for aesthetics in urban settings
• Concept of city skyline
• Cultural significance and prestige
• Human aspiration to build higher

INTRODUCTION AND DEFINITION

High rise is defined differently by different bodies.

standards

“A multi-story structure between 35-100 meters tall, or a building of unknown height from 12-39 floors is termed as high rise.

The International Conference on Fire Safety –

"any structure where the height can have a serious impact on evacuation“

Building code of Hyderabad, India-

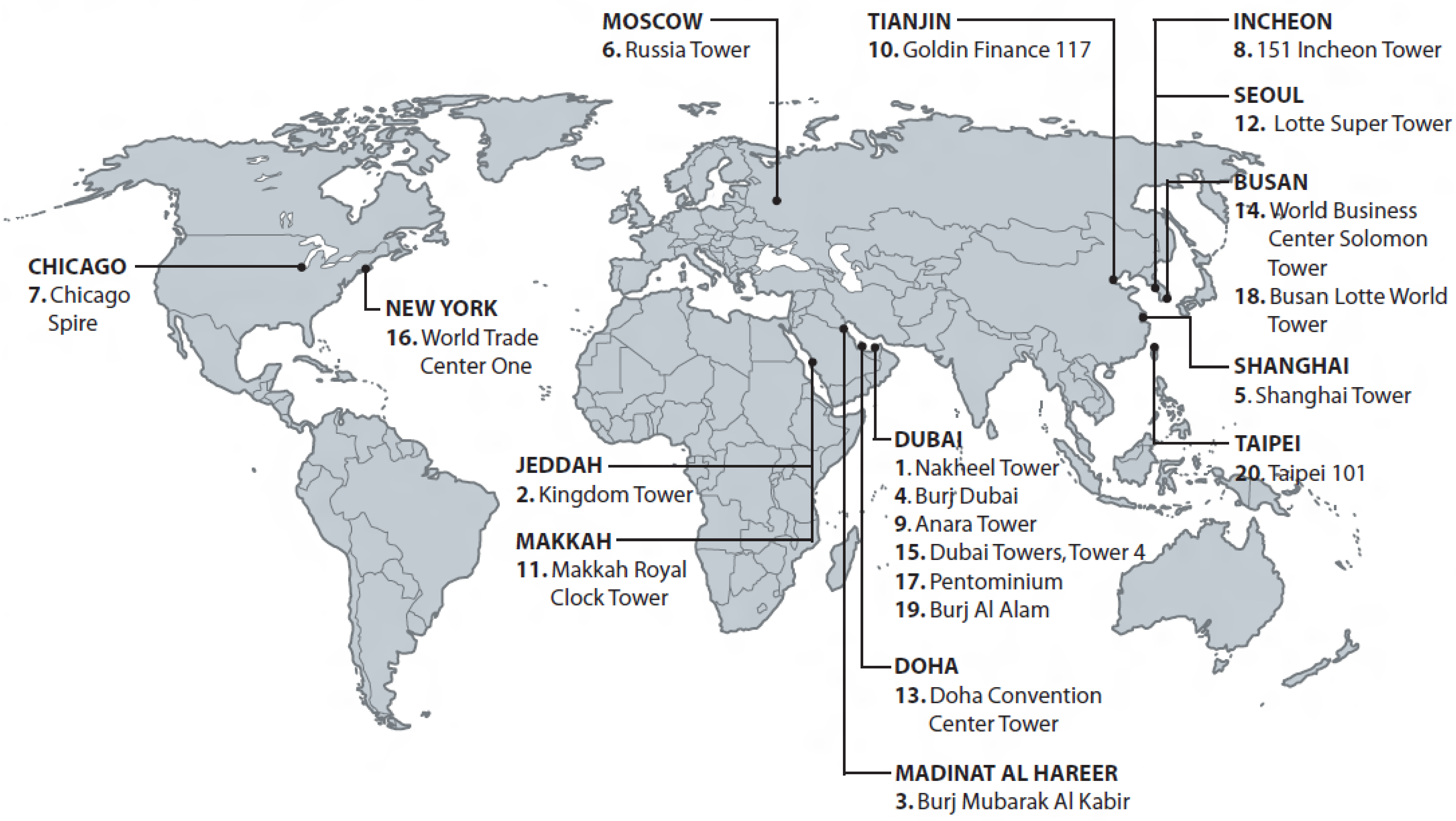
A high-rise building is one with four floors or more, or one 15 meters or more in height.

Massachusetts, United States General Laws –

A high-rise is being higher than 70 feet (21 m).

GEOGRAICAL DISTRIBUTION OF HIGHRISE

Locations: The Tallest 20 in 2020



Criteria: The Tallest 20 in 2020

GEOGRAICAL DISTRIBUTION OF HIGHRISE

Skyscrapers in Regions

#	Continent	Buildings	Percent
1	Asia	24,302	33.16 %
2	North America	22,863	31.20 %
3	Europe	13,114	17.89 %
4	South America	9,903	13.51 %
5	Oceania	2,244	3.06 %
6	Africa	859	1.17 %

(Tables source: Emporis Corporation April 2004)

Most Skyscrapers

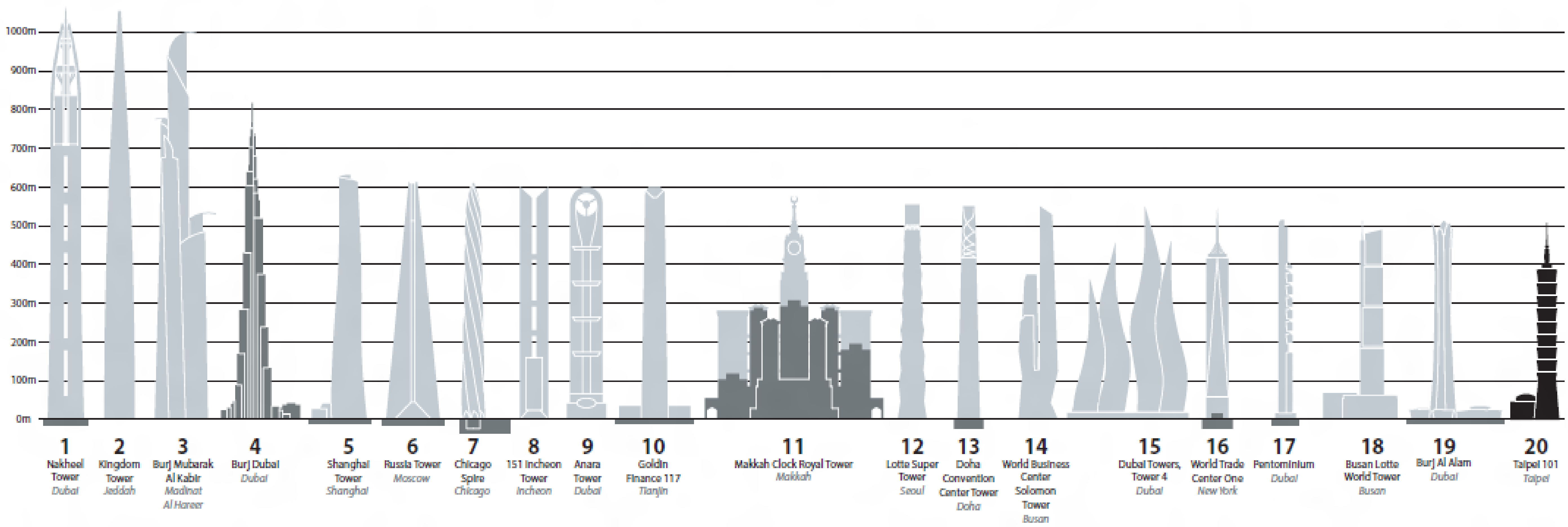
#	City	Buildings
1.	Hong Kong	7,254
2.	New York City	5,317
3.	Singapore	3,489
4.	Istanbul	2,090
5.	São Paulo	2,043
6.	Rio de Janeiro	1,854
7.	Toronto	1,582
8.	Tokyo	1,466
9.	Buenos Aires	1,410
10.	London	1,277
11.	Chicago	1,024
12.	Bangkok	706
13.	Osaka	685
14.	Sydney	652
15.	Caracas	650
16.	Milan	625
17.	Seoul	589
18.	Shanghai	523
19.	Kuala Lumpur	515
20.	Vancouver	501
21.	Madrid	500
22.	Curitiba	495
23.	Mumbai	476
24.	Honolulu	431
25.	Los Angeles	416

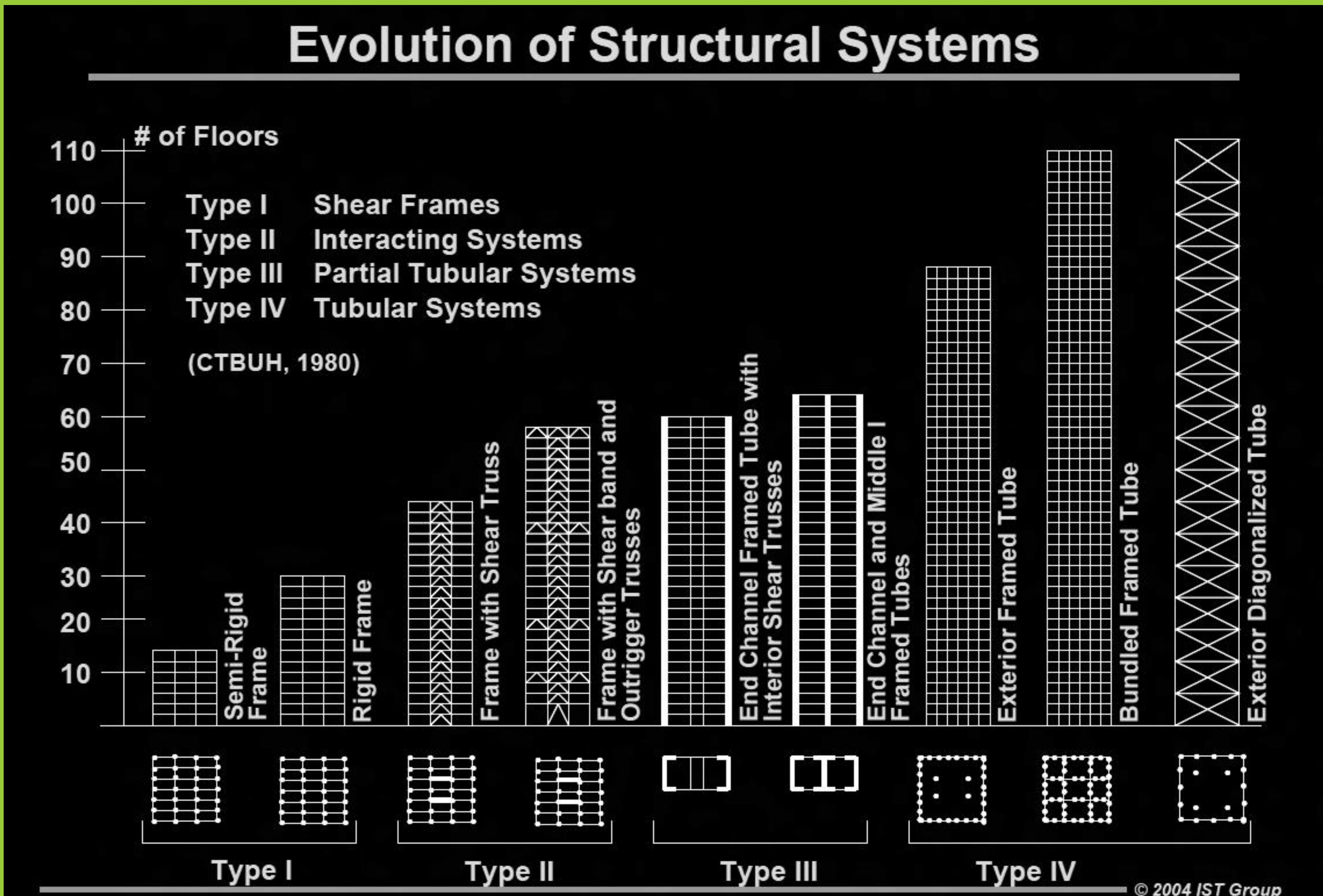
Council
on
Tall Buildings
and
Urban Habitat

The Tallest 20 in 2020

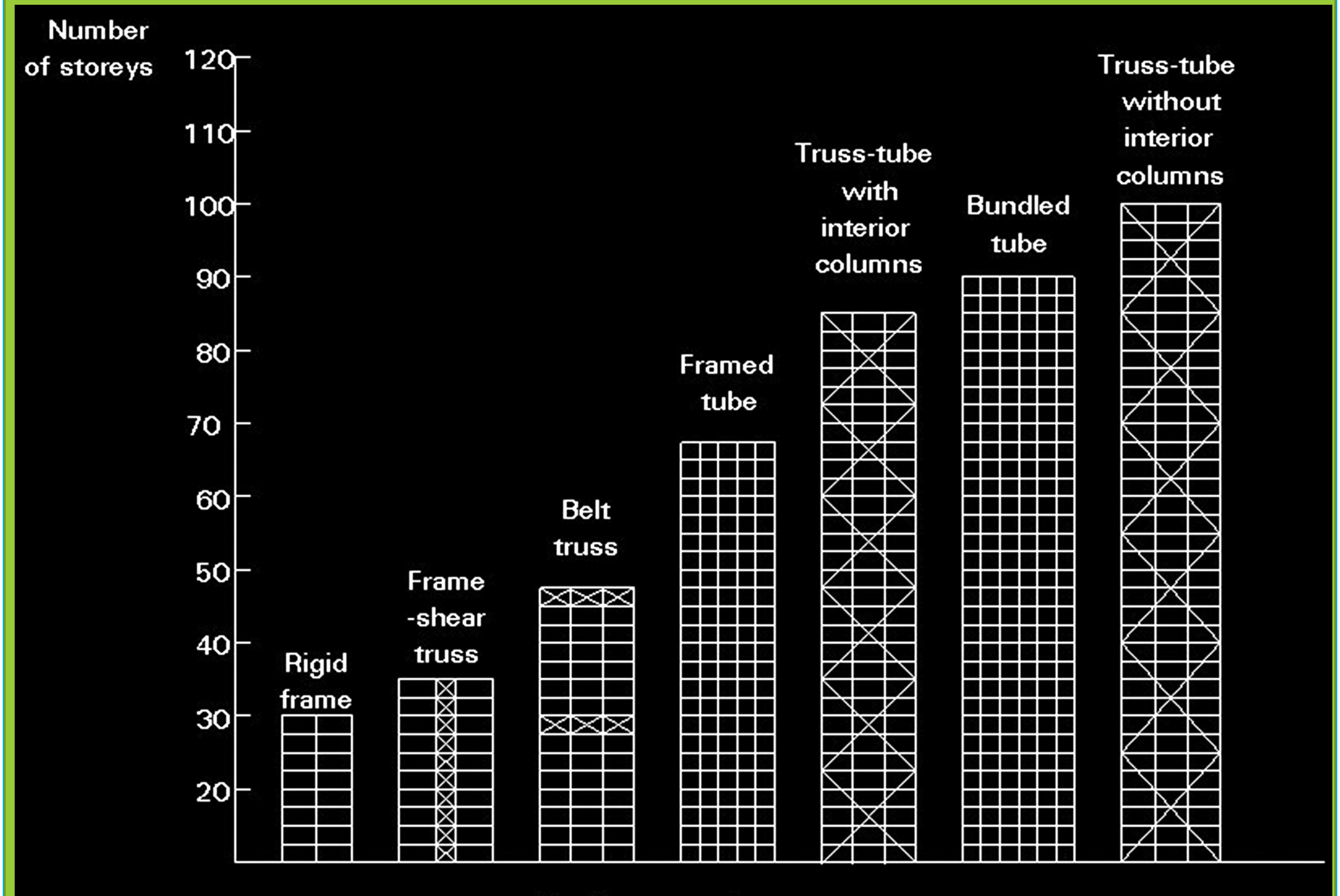
CTBUH Projection, Second Edition, January 2009

Due to the current economic climate, some buildings on this list may have slowed construction / development pace or have been put 'on hold' recently. The current intention, however, is that all projects on the list will be completed, though that may change in the coming months / years. Only buildings that are fully in the public domain and fulfill all the criteria listed at the end of this document are included in the CTBUH Tallest 20 in 2020 – there may well be other proposed buildings that would make the list, but are for client / project confidentiality reasons not yet publicized. Also, due to the changing nature of early stage designs and client information restrictions, some height data for 'proposed' tall buildings that appears on this list is unconfirmed.

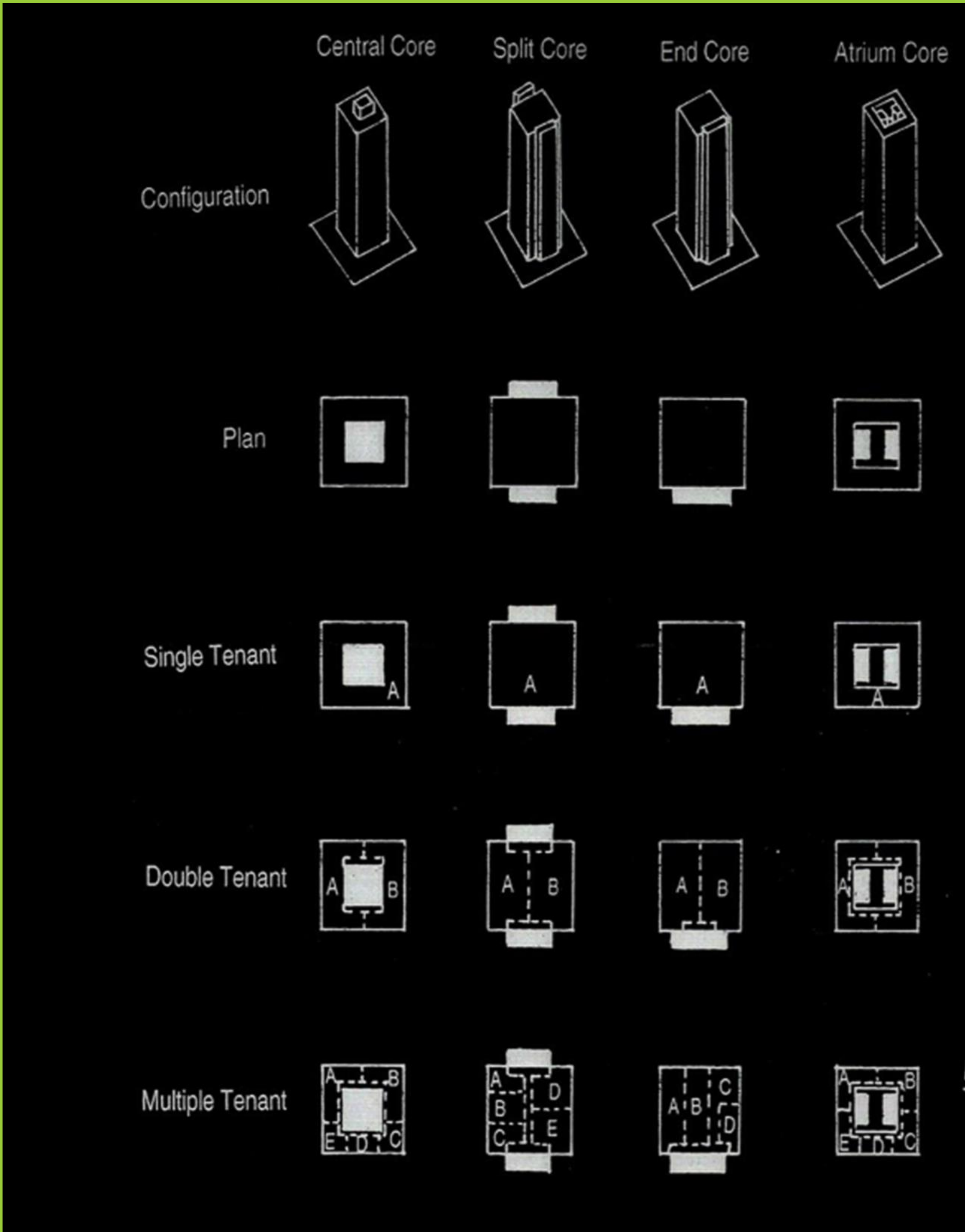



Evolution of Structural Systems
# of Floors
110
100
90
80
70
60
50
40
30
20
10
Type I Shear Frames
Type II Interacting Systems
Type III Partial Tubular Systems
Type IV Tubular Systems
(CTBUH, 1980)
Semi-Rigid Frame
Rigid Frame
Frame with Shear Truss
Frame with Shear band and Outrigger Trusses
End Channel Framed Tube with Interior Shear Trusses
End Channel and Middle I Framed Tubes
Exterior Framed Tube
Bundled Framed Tube
Exterior Diagonalized Tube
Type I
Type II
Type III
Type IV
© 2004 IST Group

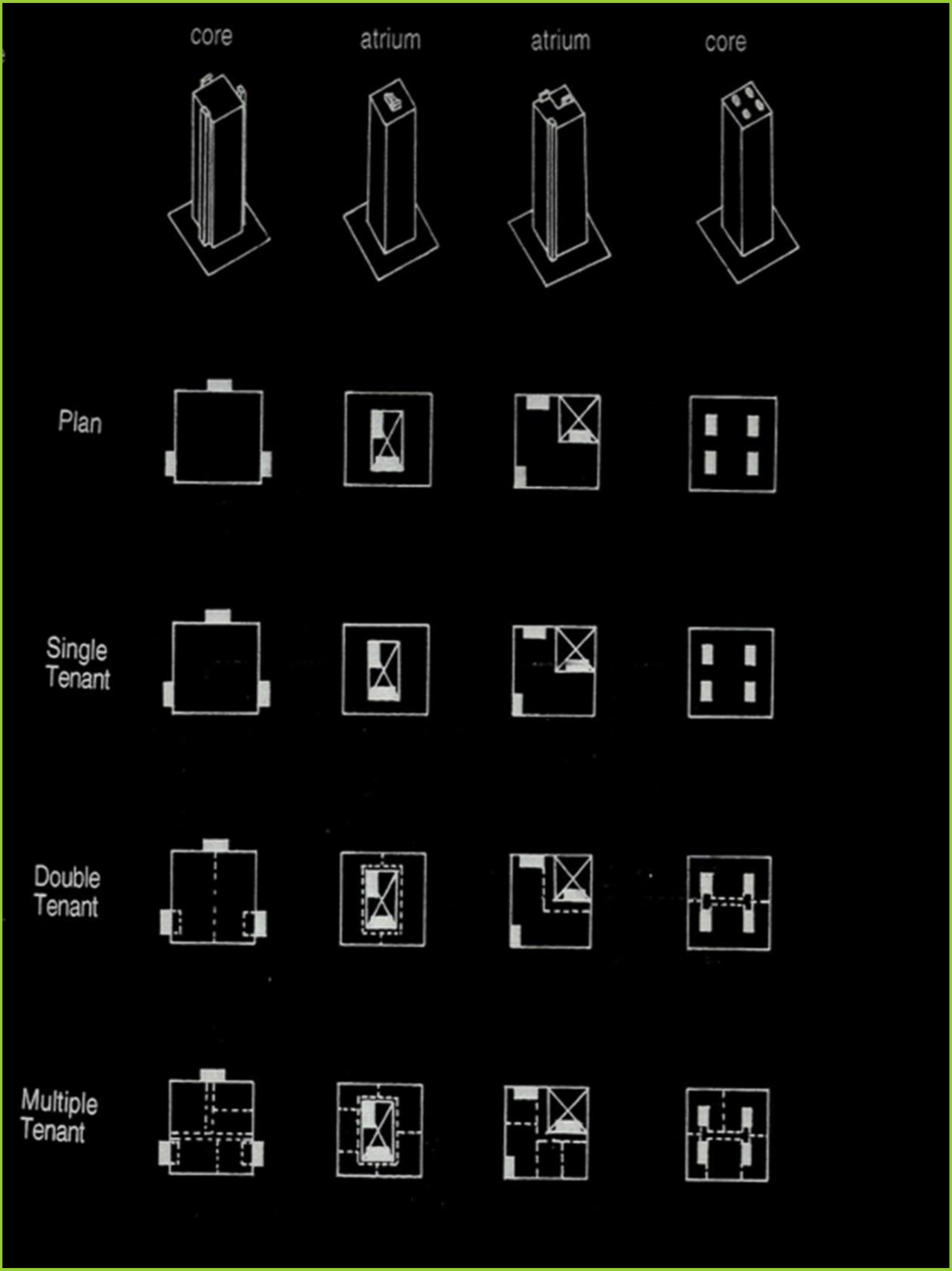
STEEL STRUCTURAL SYSTEMS AND THE NO. OF STOREYS



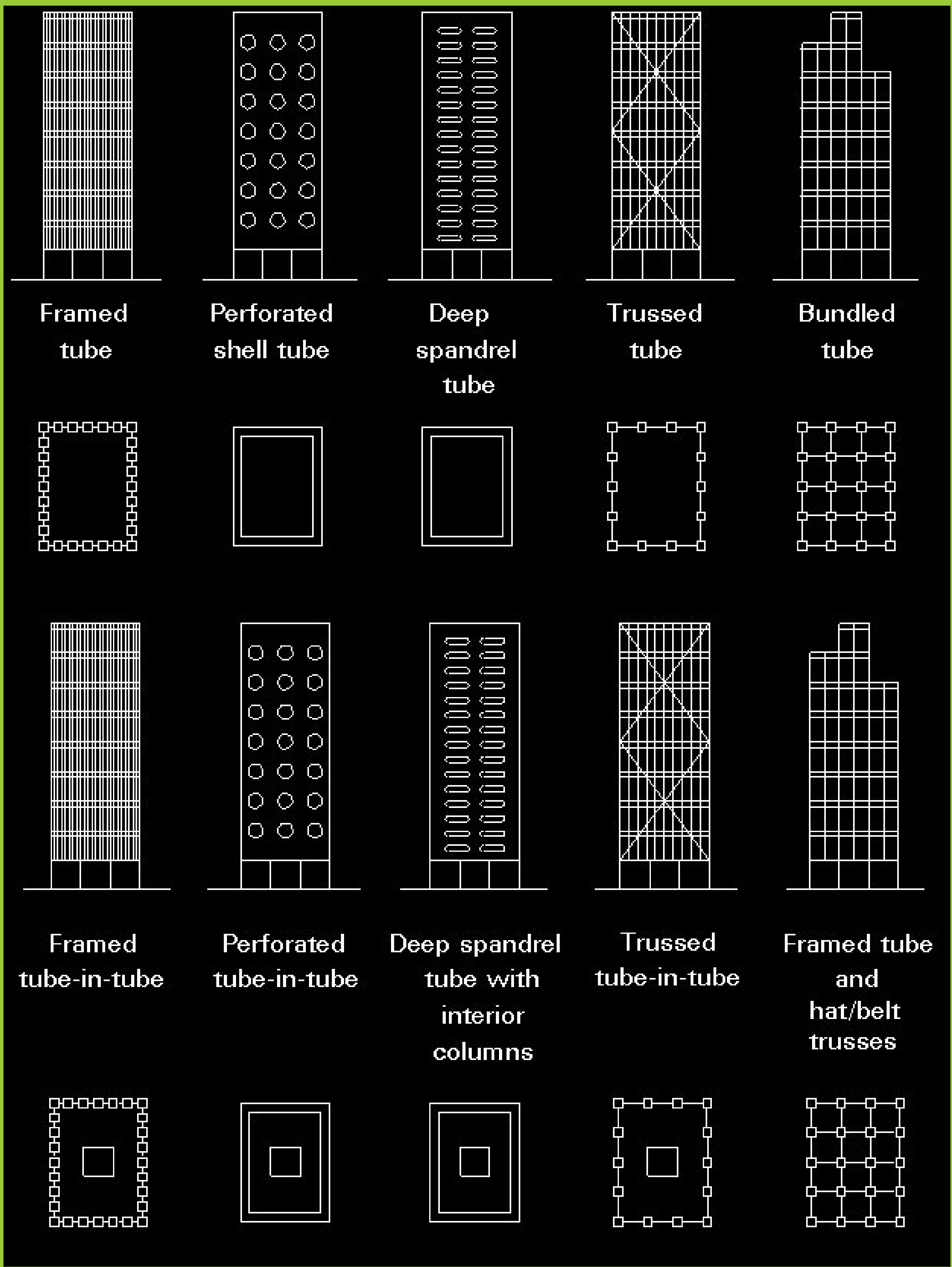
TYPES OF CORE SYSTEMS

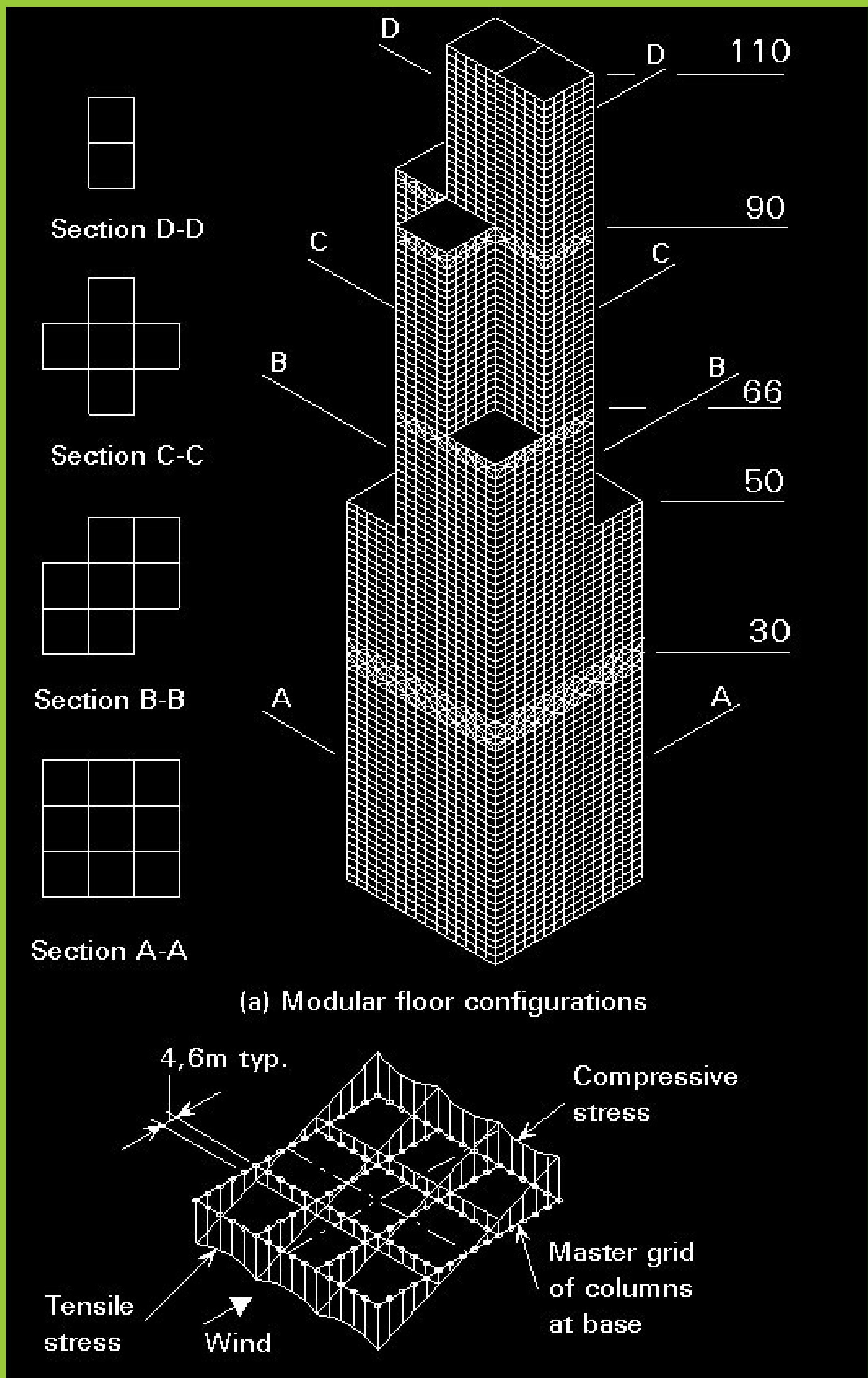


TYPES OF CORE SYSTEMS

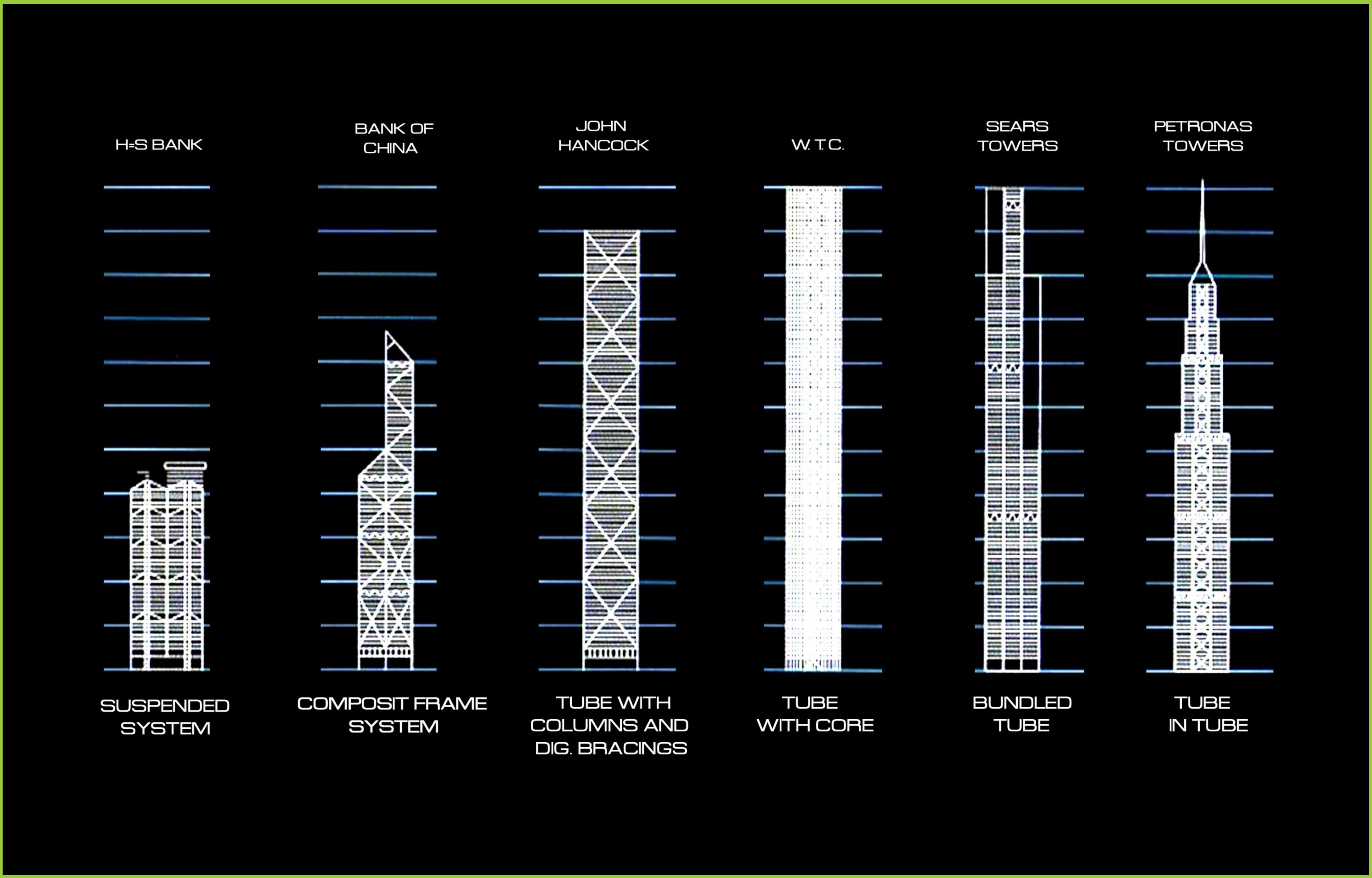


TYPES OF TUBULAR SYSTEMS



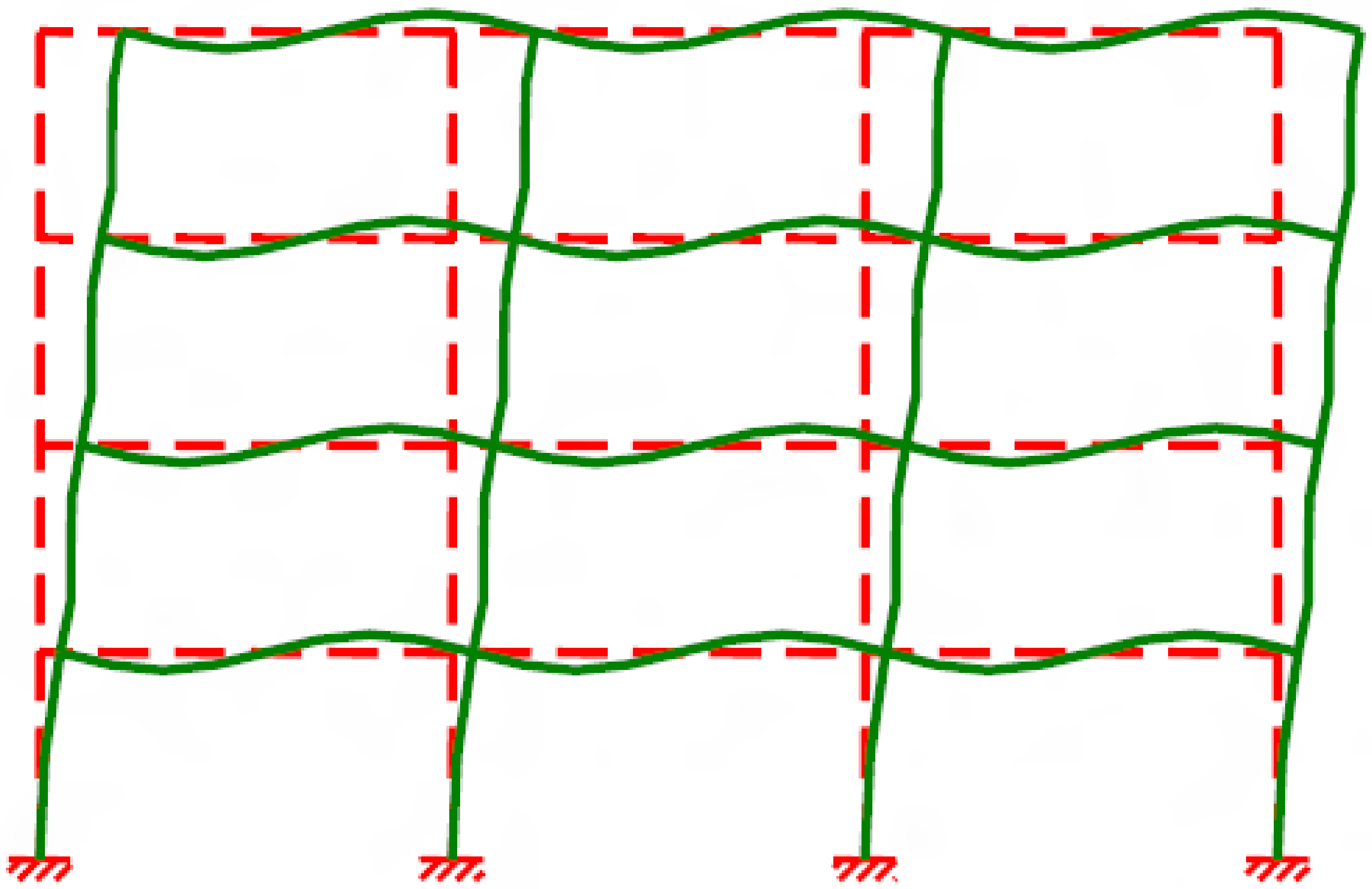


EXAMPLES OF STEEL STRUCTURAL SYSTEMS



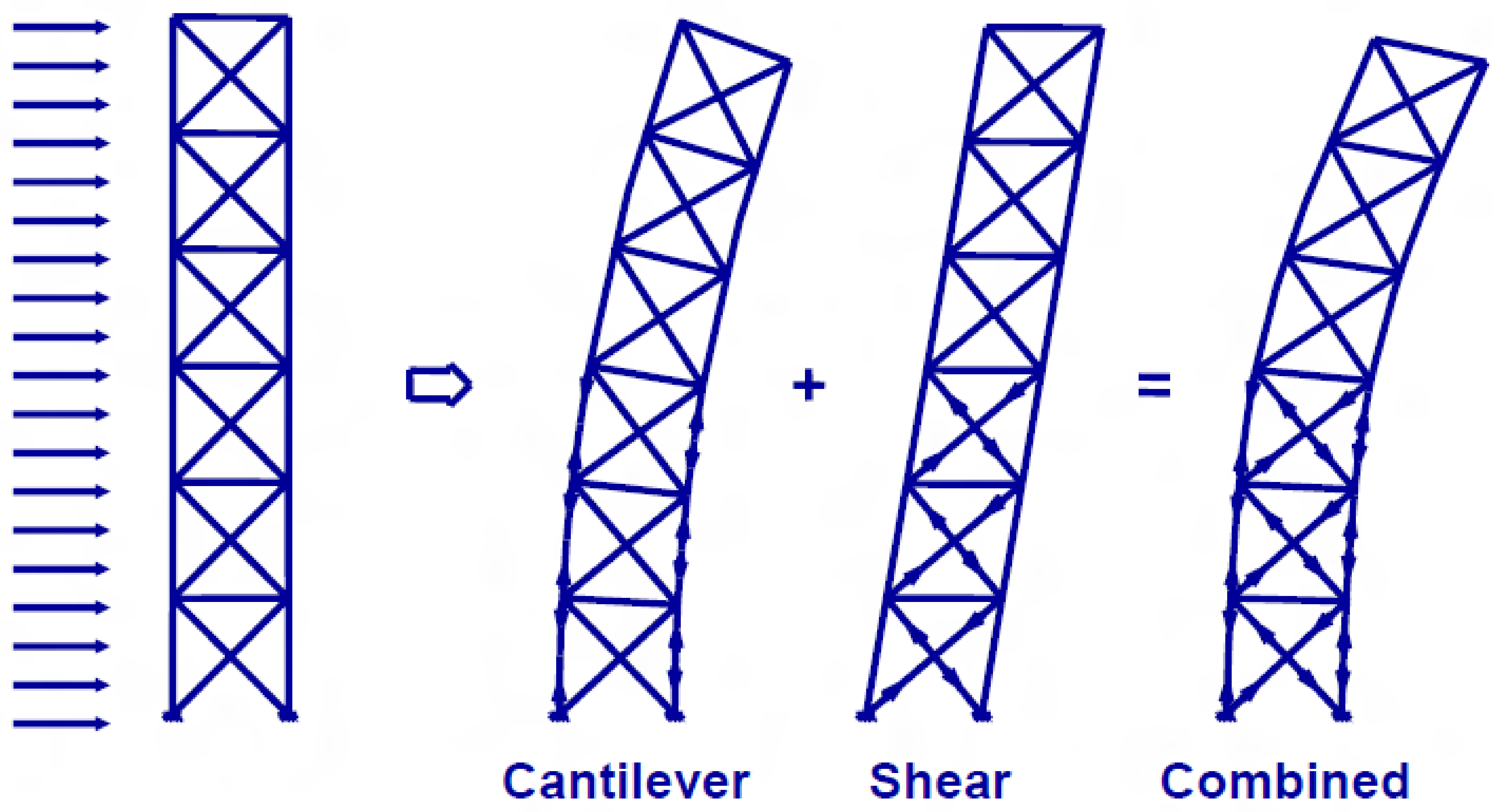
Shear Frame System

- Resists lateral deformation by joint rotation
- Requires high bending stiffness of columns and beams
- Rigid joints are essential for stability
- Not effective for heights over 30 stories



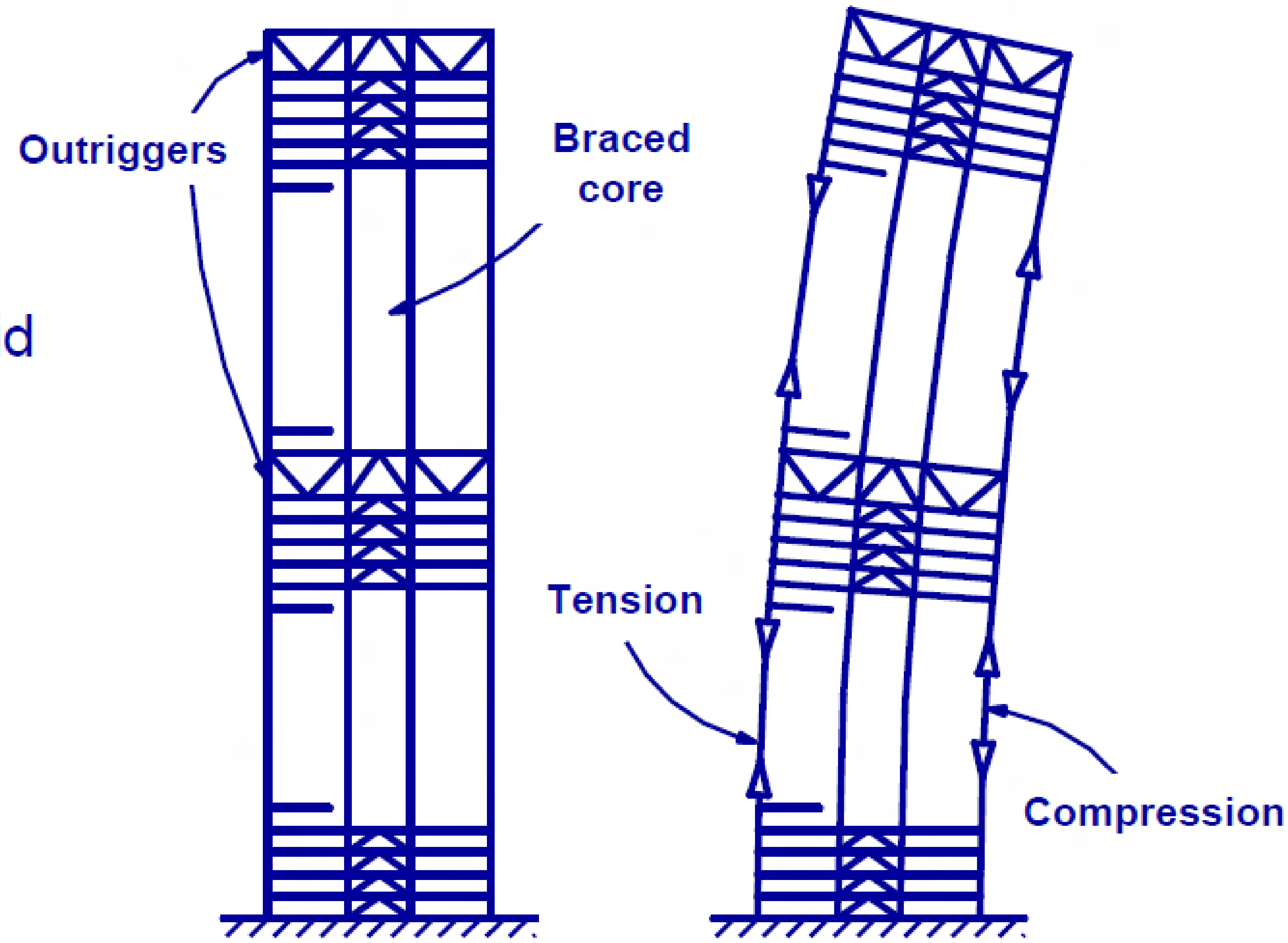
Braced Frame System

- Lateral forces are resisted by axial actions of bracing and columns
- Steel bracing members or filled-in bays
- More efficient than a rigid frame



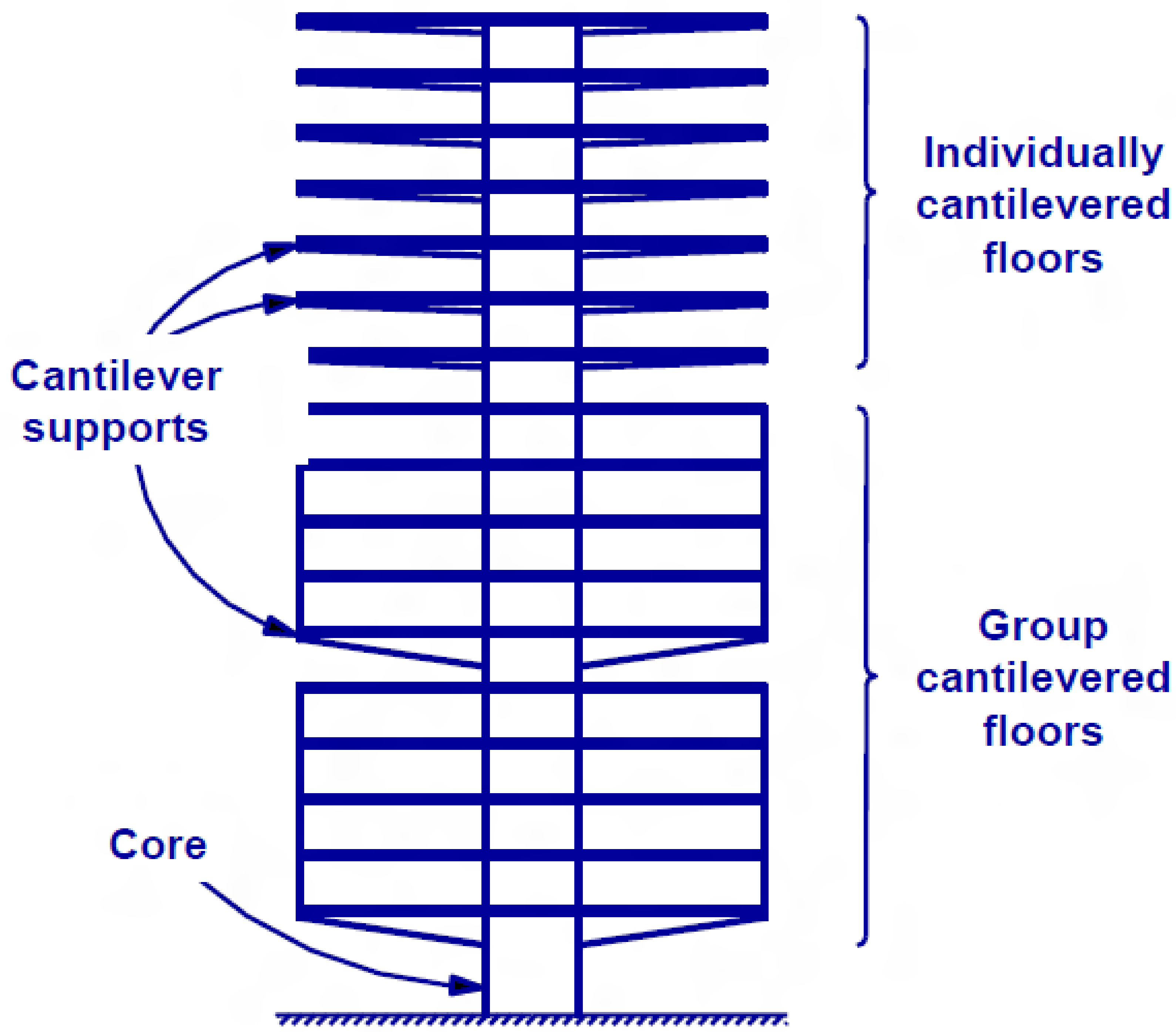
Outrigger Braced Structure System

- 1- or 2-story deep truss connects core to perimeter columns
- Increases the bending rigidity
- Dependent of rigid core for shear resistance



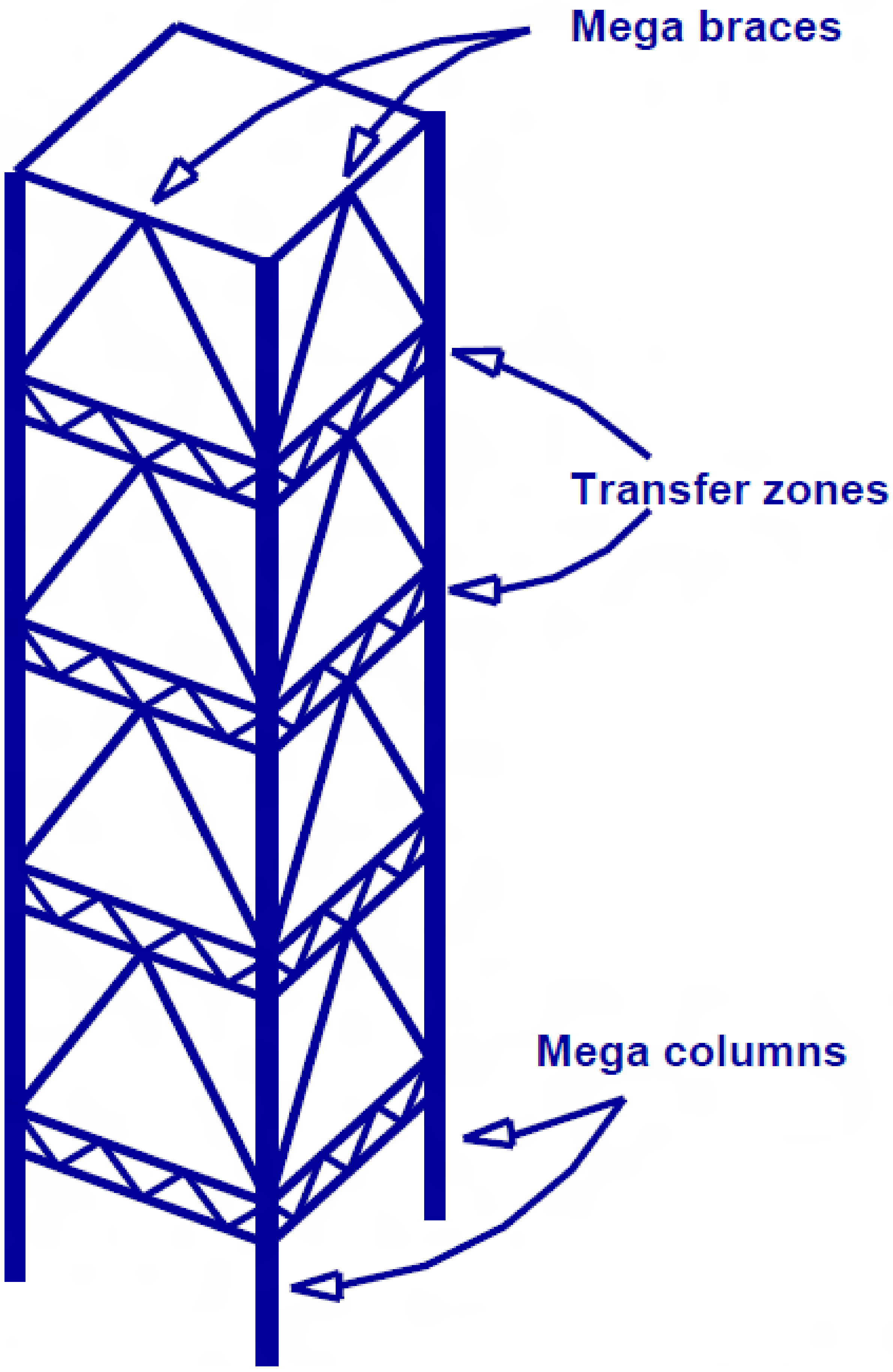
Core Structure System

- Lateral and gravity loads supported by central core
- Eliminates columns and bracing elements
- Core is inefficient because it is not deep in respect to bending
- Moment supported floors are inefficient



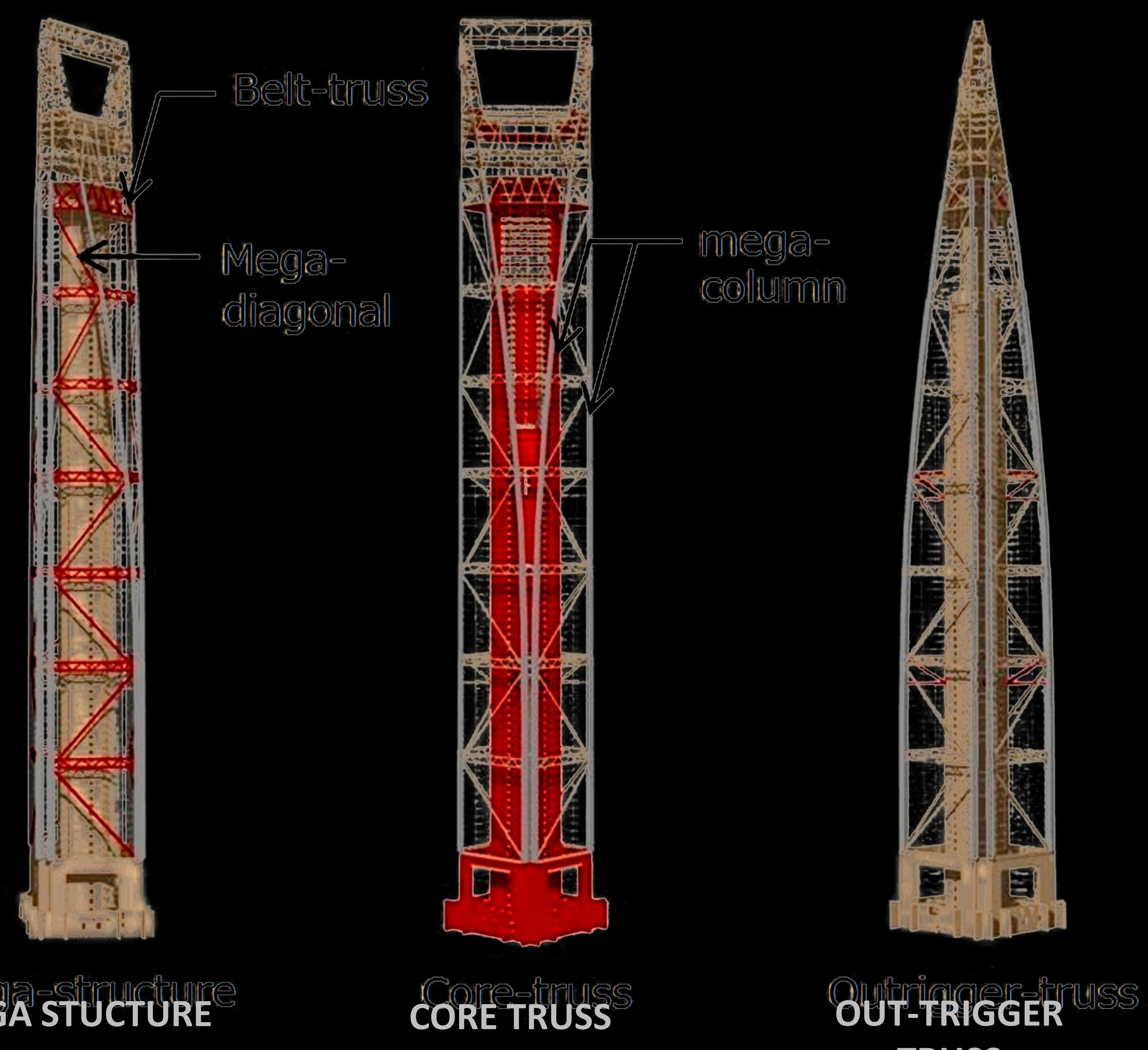
High-Efficiency Mega-Braced Frame System

- Very large columns and bracing
- Small number of columns
- Bracing extends over multiple floors
- Stiff transfer floors allow for internal flexiblity



BELT TRUSS SYSTEM

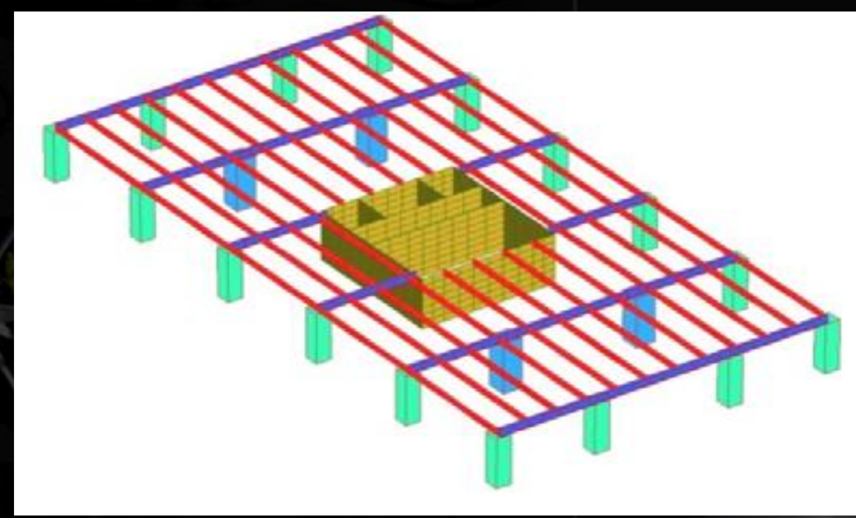
SHANGHAI TOWER

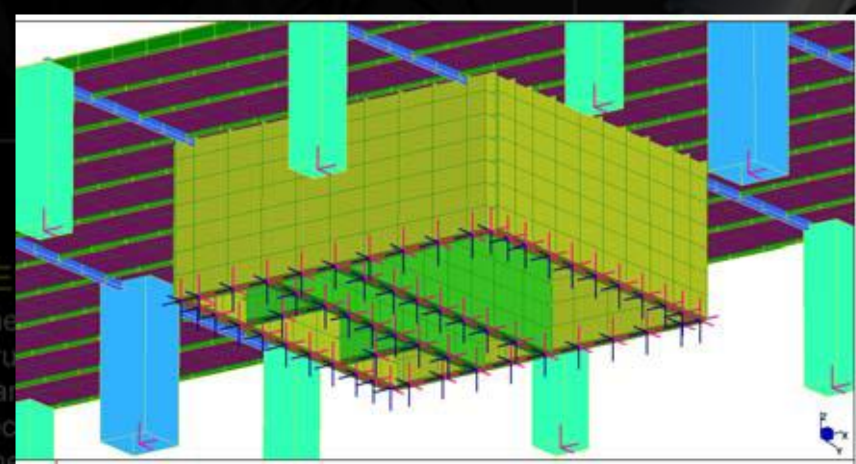


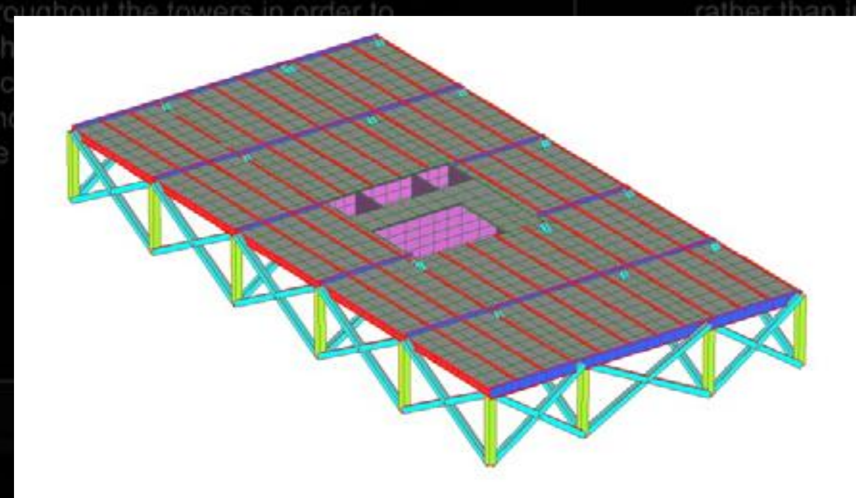
MEGA STUCTURE

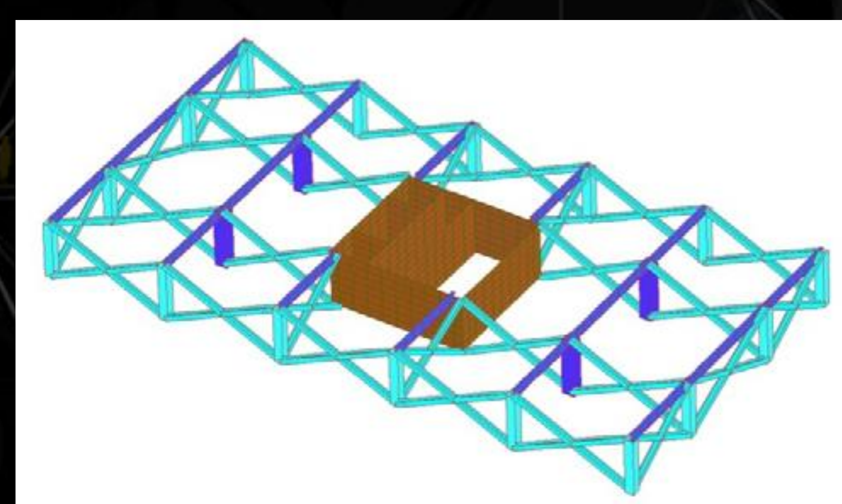
CORE TRUSS

OUT-TRIGGER TRUSS



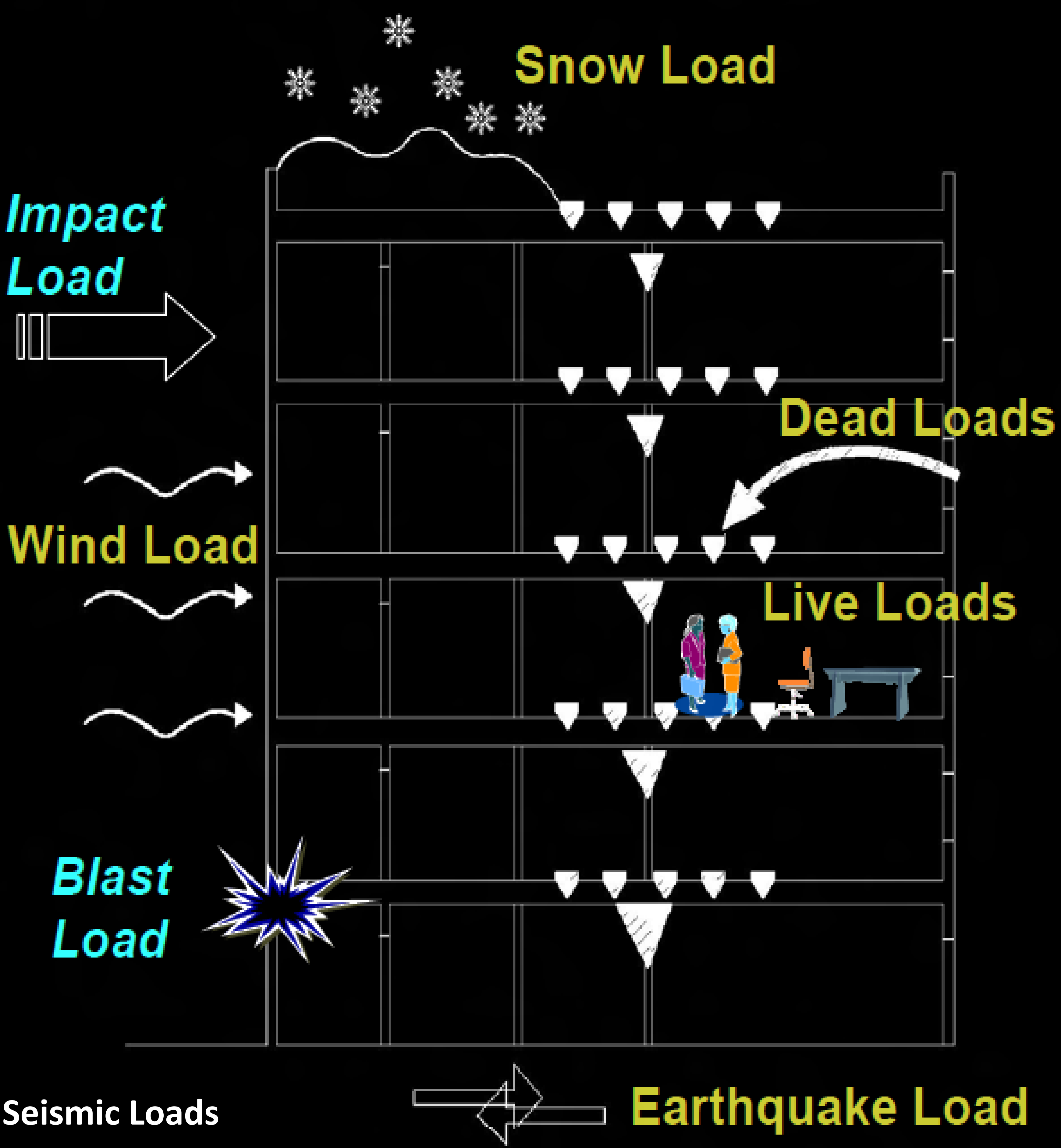




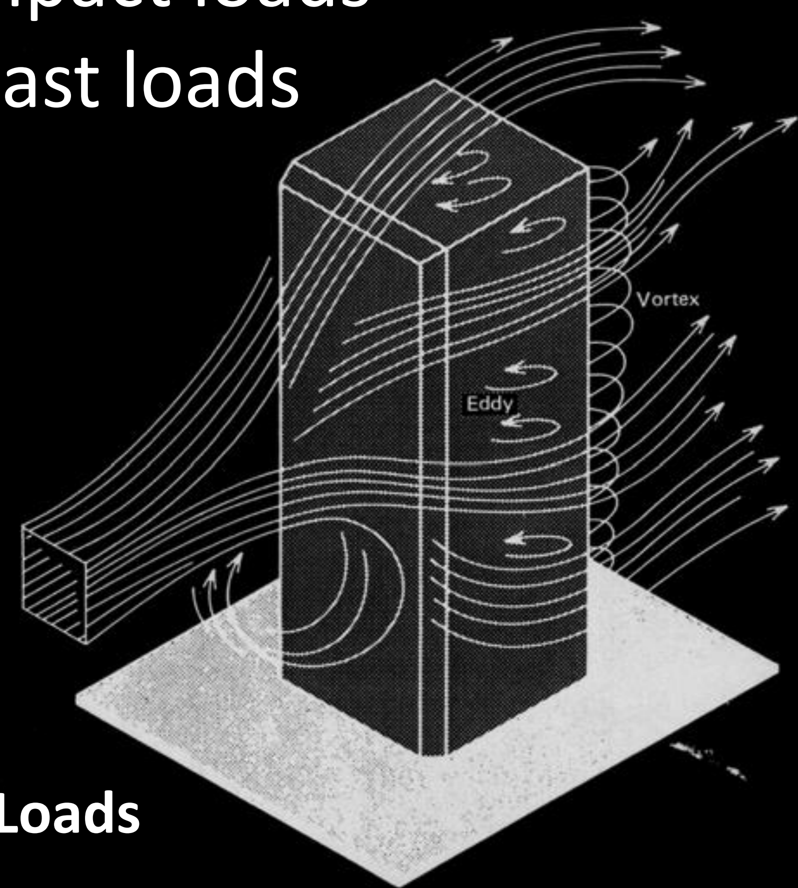


Structural Loads

- Gravity loads
  - Dead loads
  - Live loads
  - Snow loads
- Lateral loads
  - Wind loads
  - Seismic loads
- Special load cases
  - Impact loads
  - Blast loads



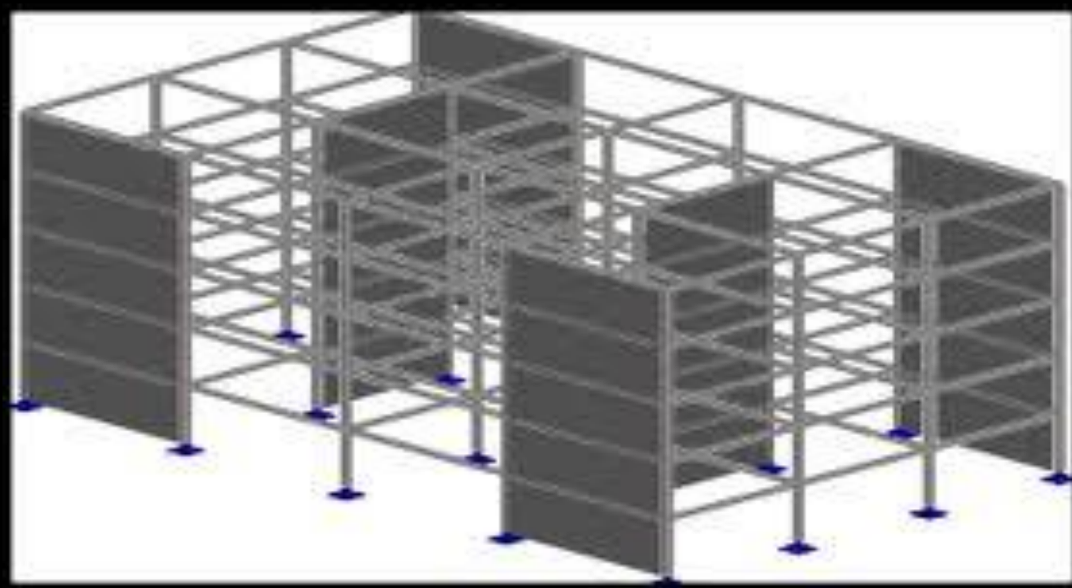
Seismic Loads

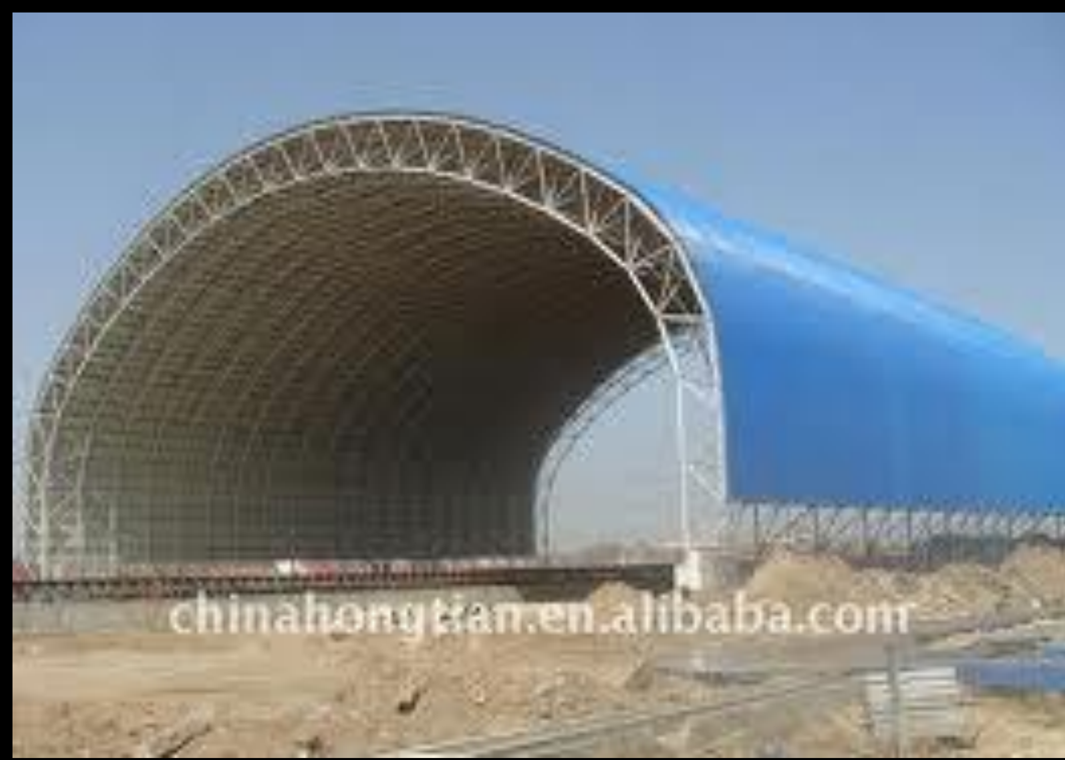


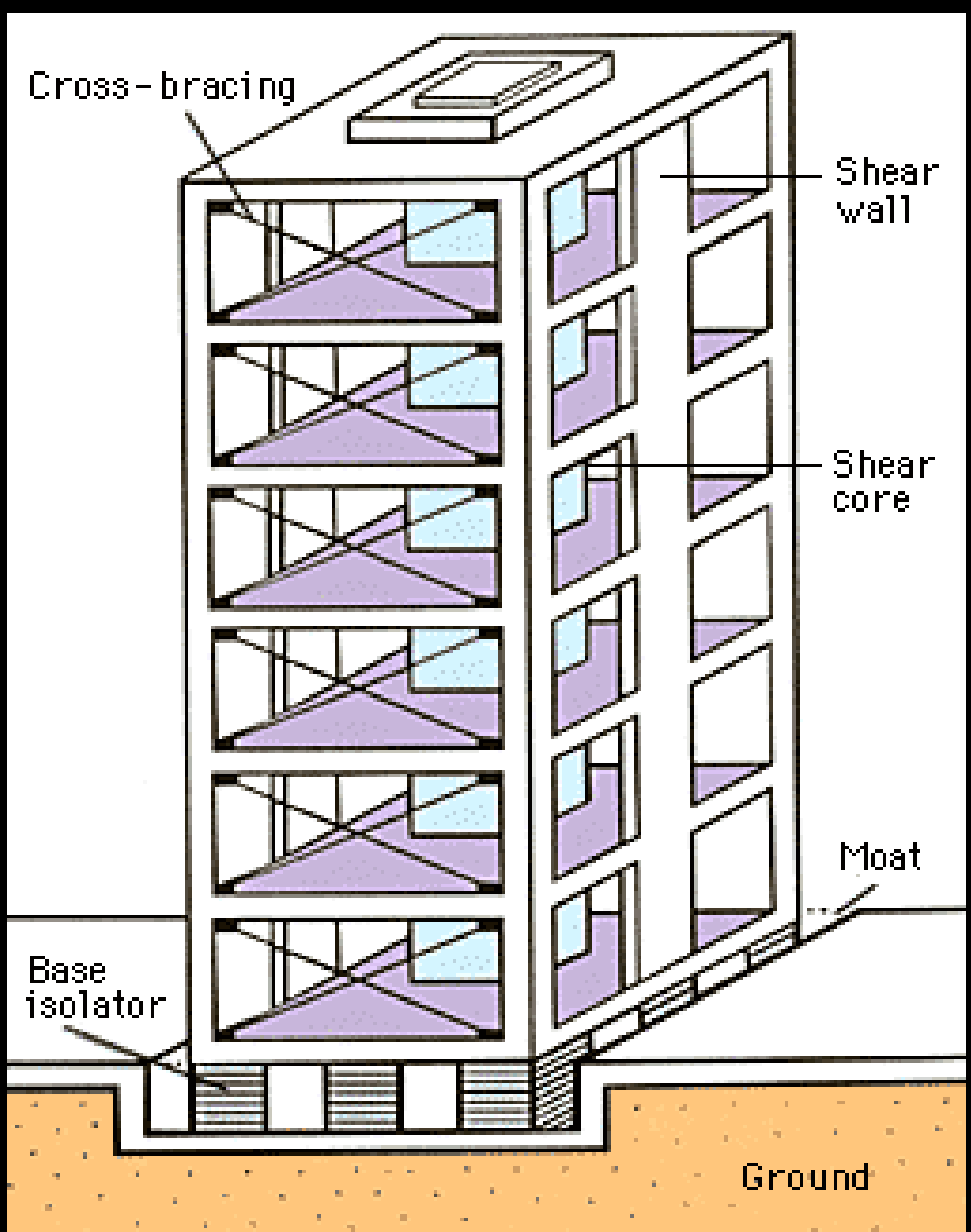
Wind Loads

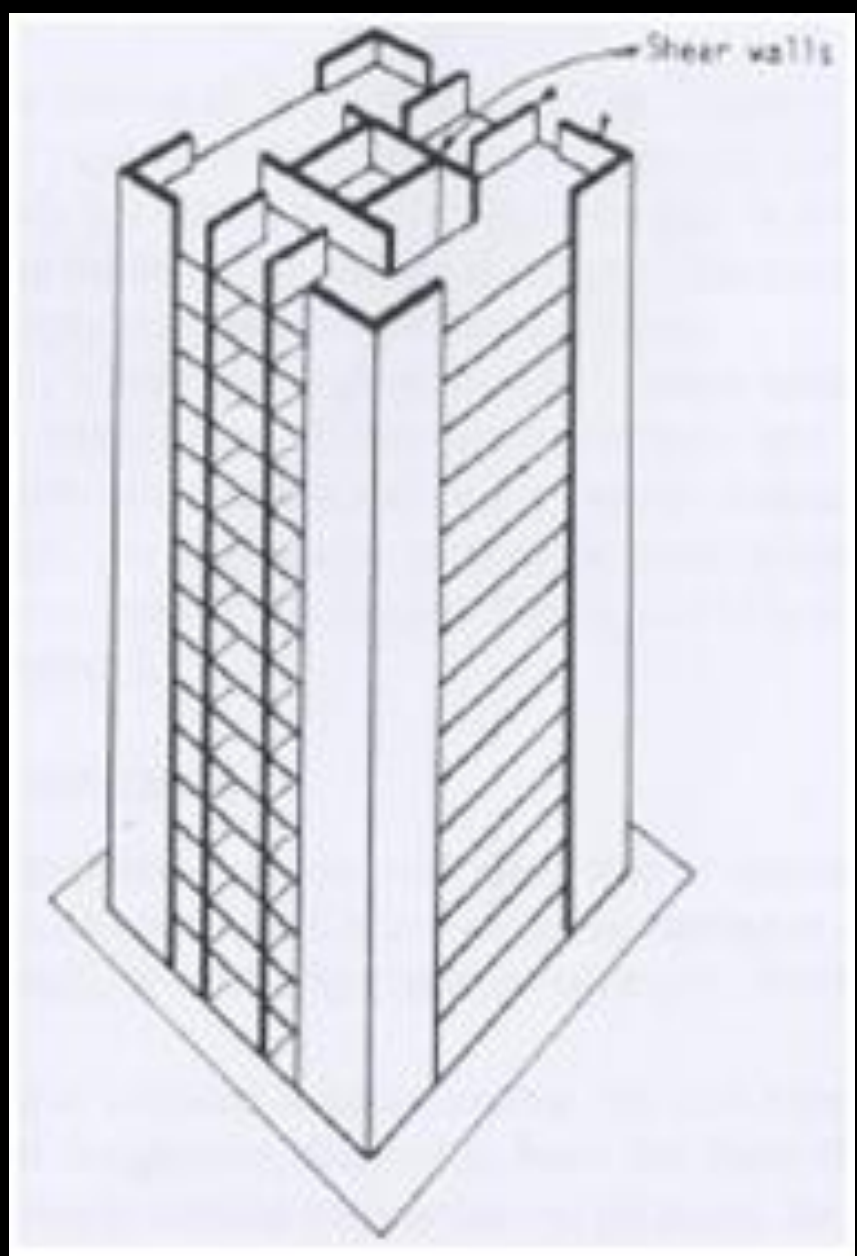
Shear wall system

- A type of rigid frame construction.
- The shear wall is in steel or concrete to provide greater lateral rigidity. It is a wall where the entire material of the wall is employed in the resistance of both horizontal and vertical loads.
- Is composed of braced panels (or shear panels) to counter the effects of lateral load acting on a structure. Wind & earthquake loads are the most common among the loads.
- For skyscrapers, as the size of the structure increases, so does the size of the supporting wall. Shear walls tend to be used only in conjunction with other support systems.









FRAMED-TUBE STRUCTURES]

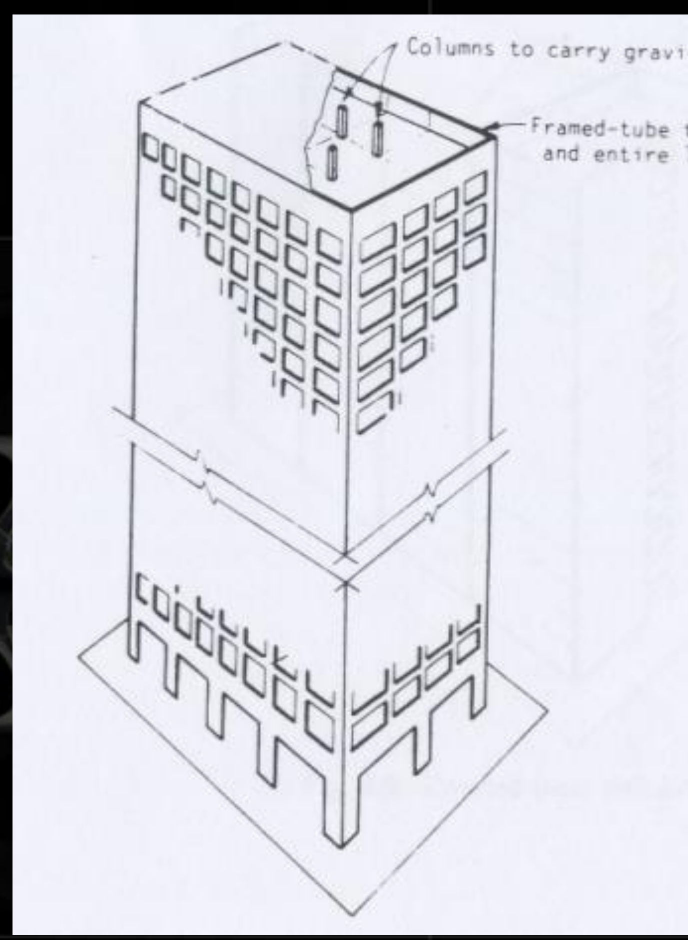
The lateral resistant of the framed-tube structures is provided by very stiff moment-resistant frames that form a "tube" around the perimeter of the building.

Gravity loading is shared between the tube and interior column or walls.

When lateral loading acts, the perimeter frame aligned in the direction of loading acts as the "webs" of the massive tube of the cantilever, and those normal to the direction of the loading act as the "flanges".

The tube form was developed originally for building of rectangular plan, and probably it's most efficient use in that shape.

Dewitt chestnut



THE TRUSSED TUBE

The trussed tube system represents a classic solution for a tube uniquely suited to the qualities and character of structural steel.

Interconnect all exterior columns to form a rigid box, which can resist lateral shears by axial in its members rather than through flexure.

The system is tubular in that the fascia diagonals not only form a truss in the plane, but also interact with the trusses on the perpendicular faces to affect the tubular behavior. This creates the x form between corner columns on each façade.

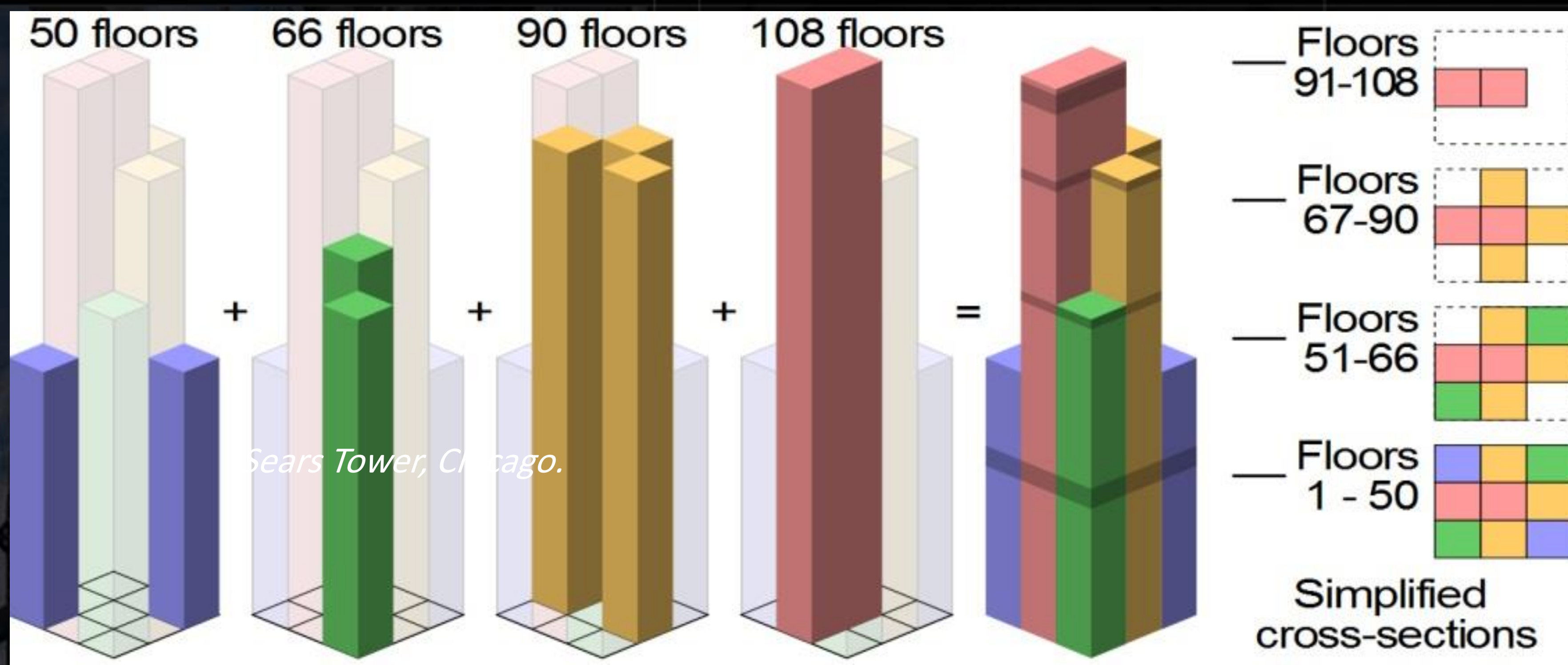
Relatively broad column spacing can resulted large clear spaces for windows, a particular characteristic of steel buildings.

BUNDLED TUBE SYSTEM

The concept allows for wider column spacing in the tubular walls than would be possible with only the exterior frame tube form.

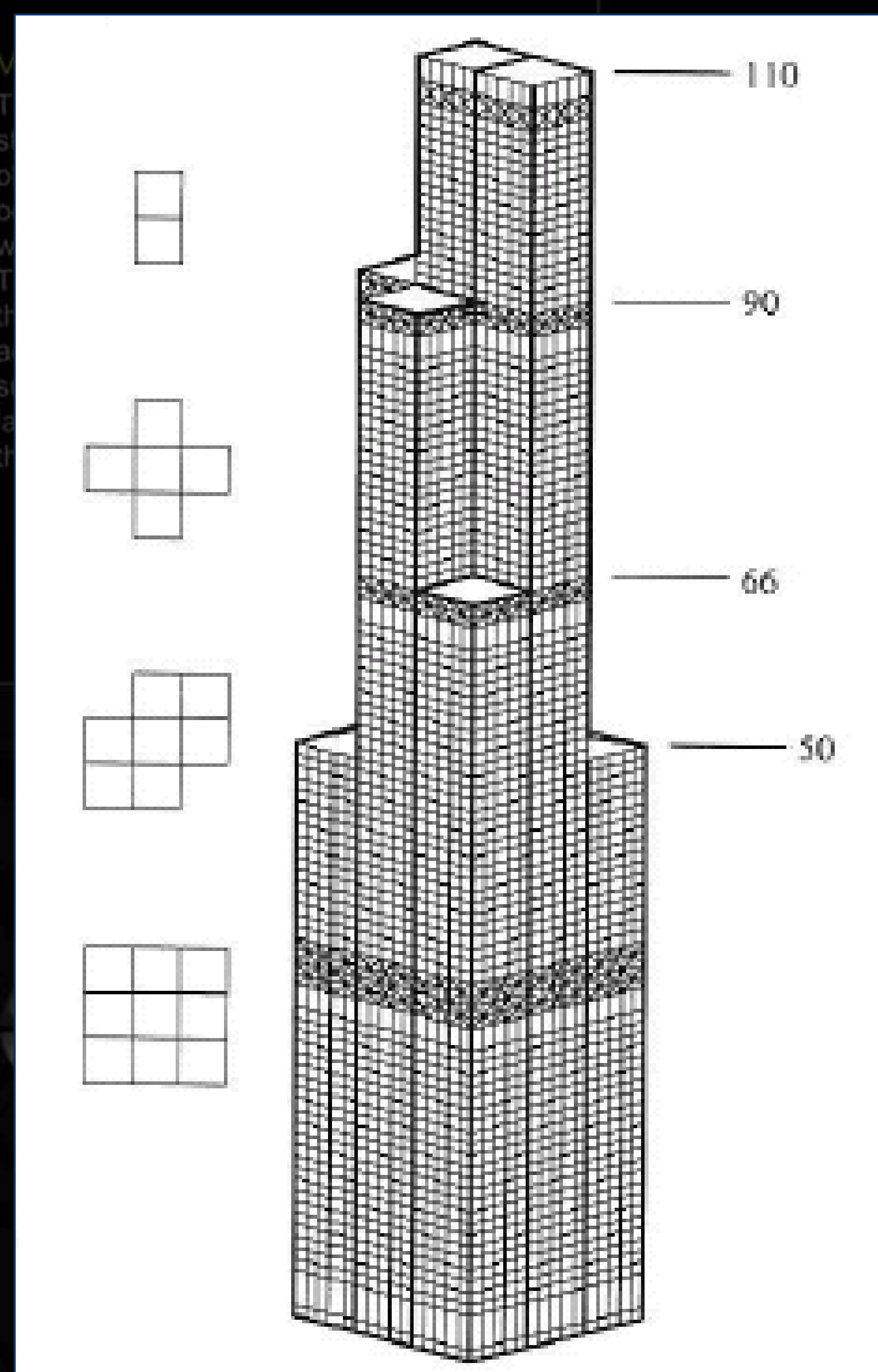
The spacing which make it possible to place interior frame lines without seriously compromising interior space planning.

The ability to modulate the cells vertically can create a powerful vocabulary for a variety of dynamic shapes therefore offers great latitude in architectural planning of at all building.



Sears Tower, Chicago.

Burj Khalifa, Dubai.



TUBE-IN-TUBE SYSTEM

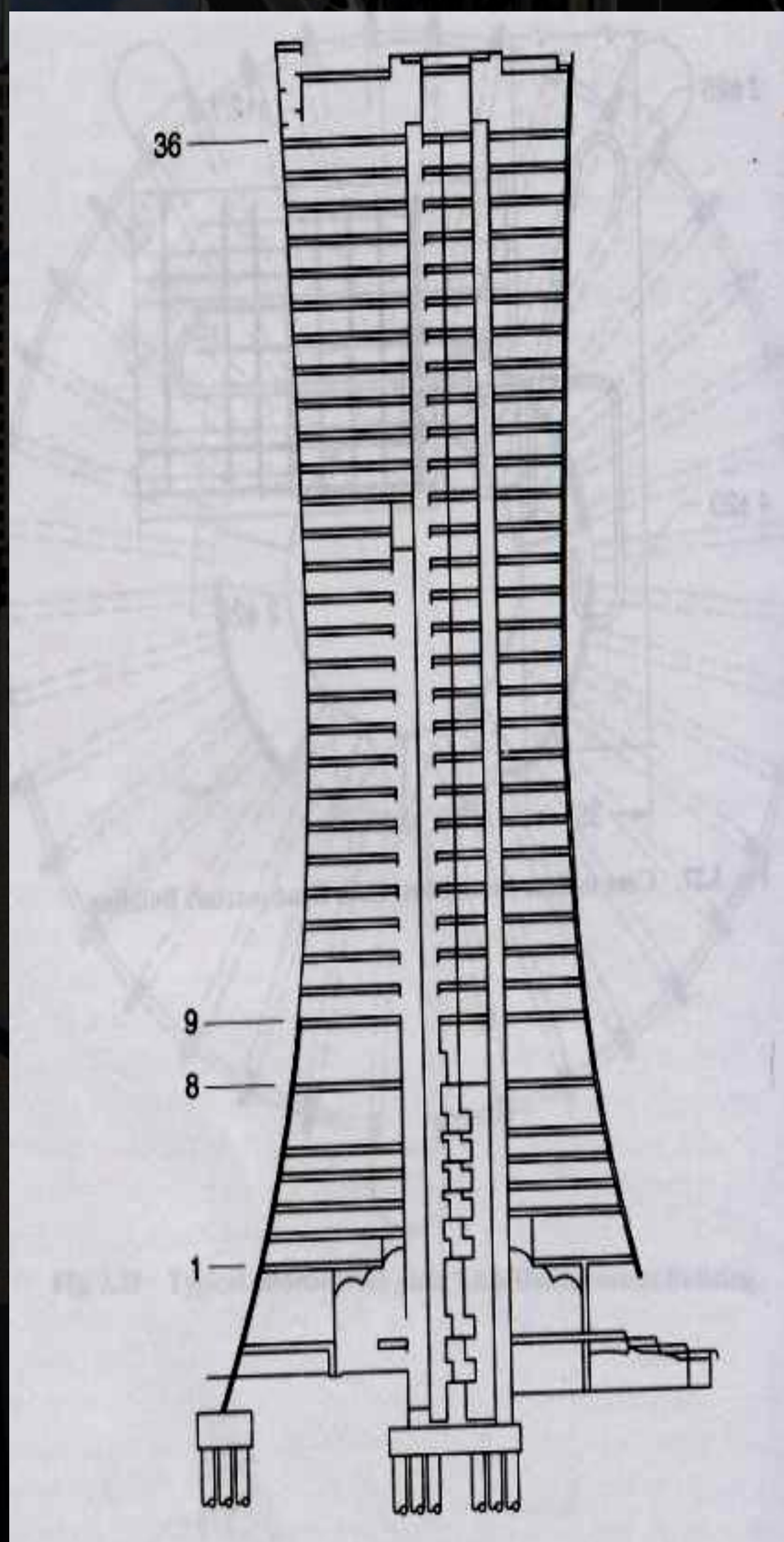
This variation of the framed tube consists of an outer frame tube, the "Hull," together with an internal elevator and service core.

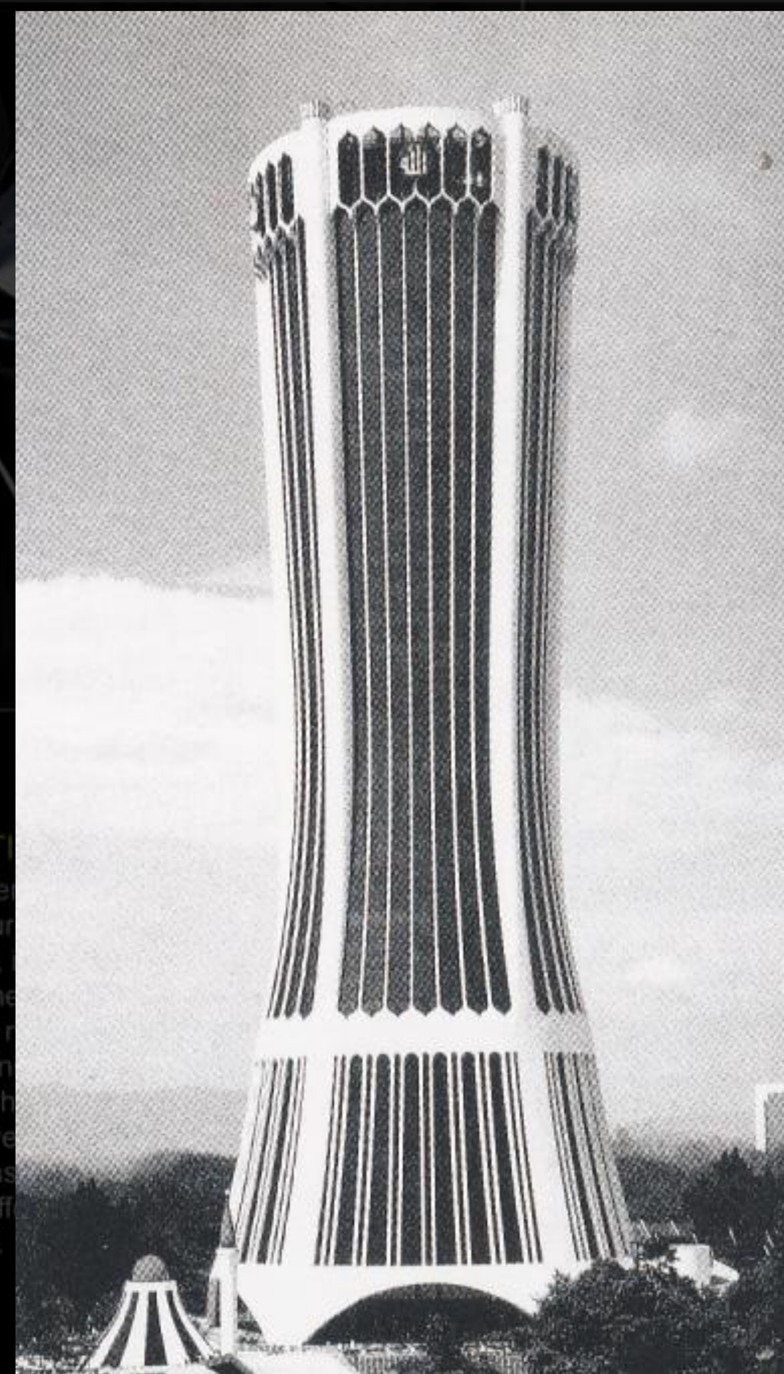
The Hull and core act jointly in resisting both gravity and lateral loading.

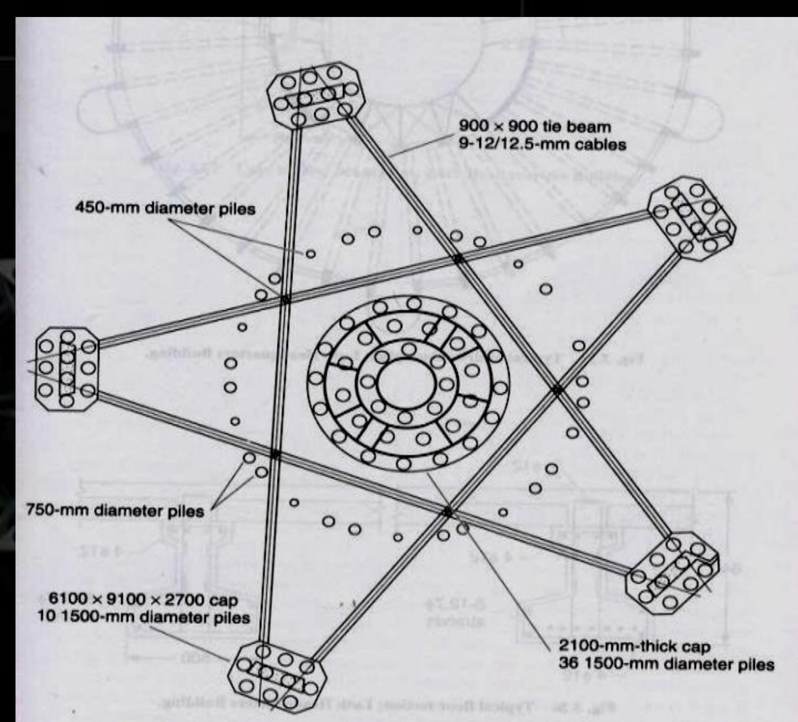
The outer framed tube and the inner core interact horizontally as the shear and flexural components of a wall-frame structure, with the benefit of increased lateral stiffness.

The structural tube usually adopts a highly dominant role because of its much greater structural depth.

Lumbago Tatung Haji Building, Kuala Lumpur

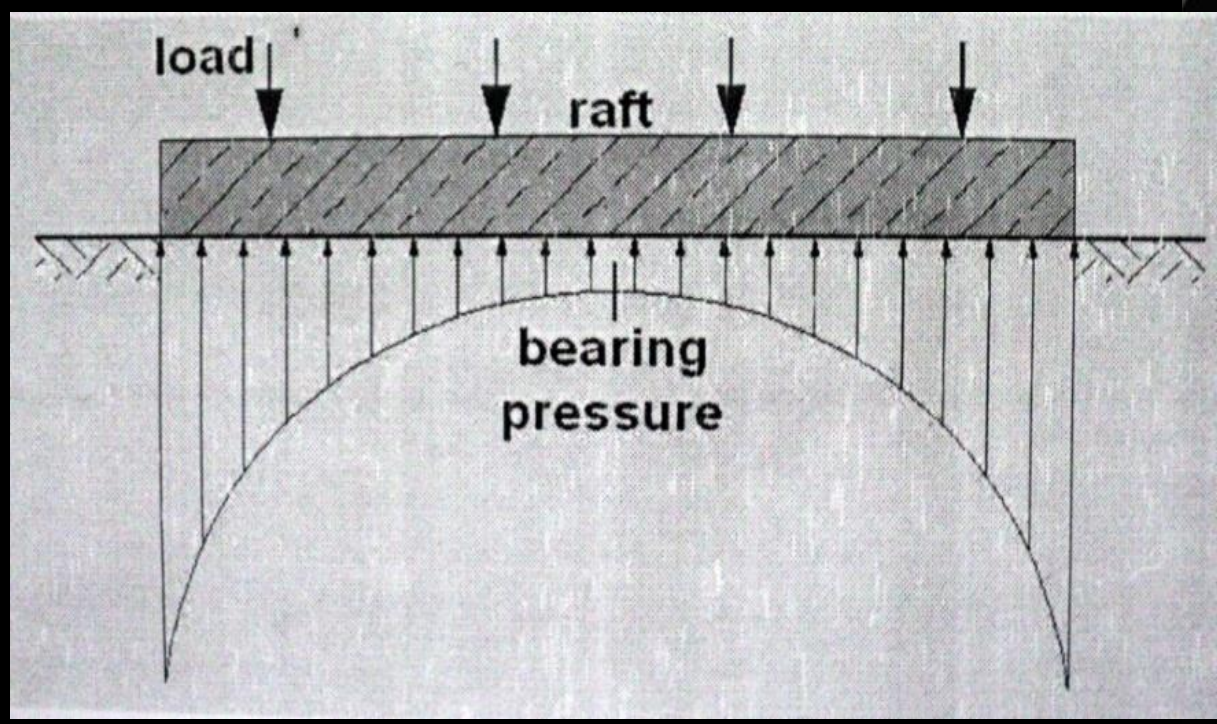


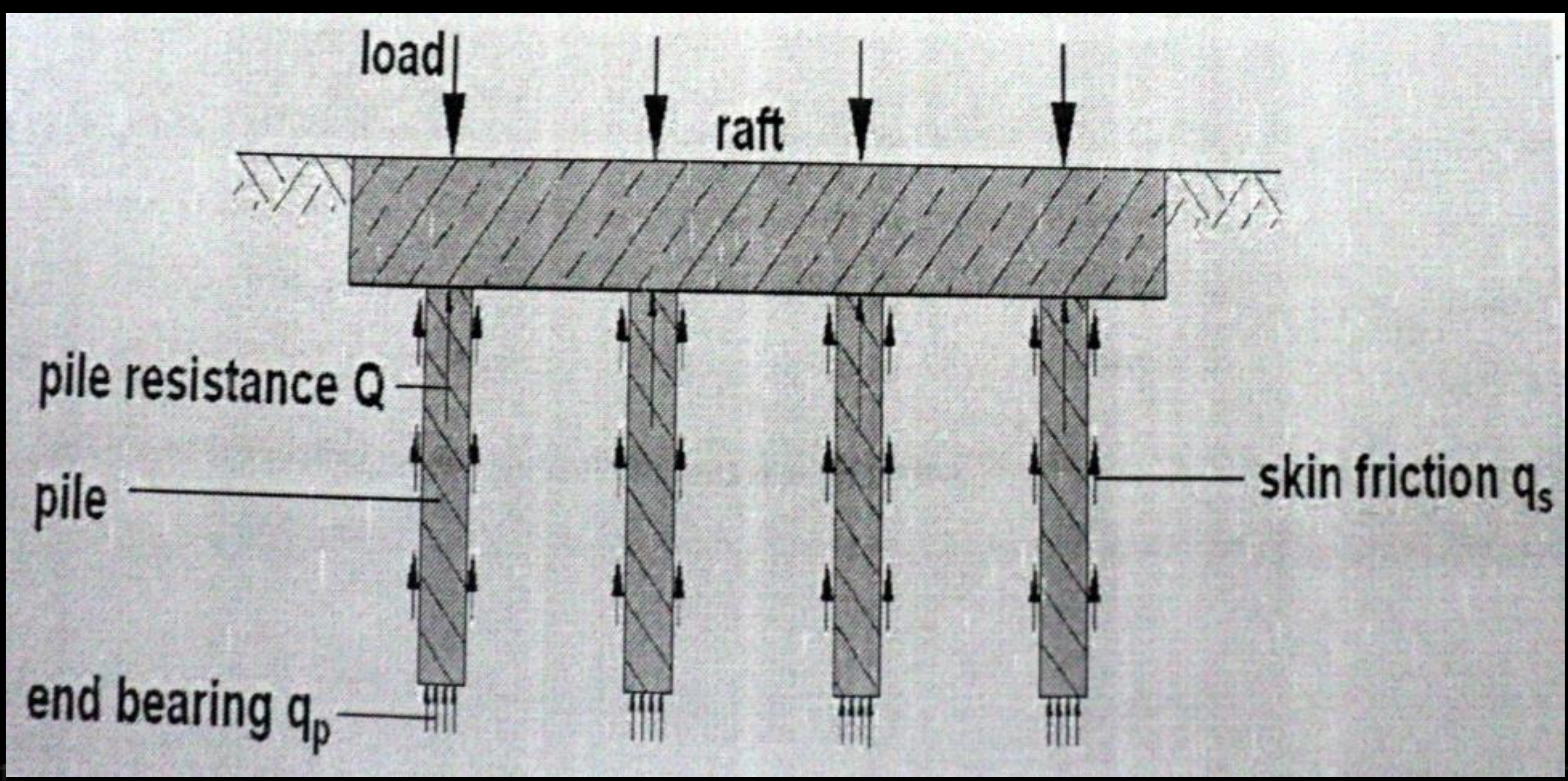


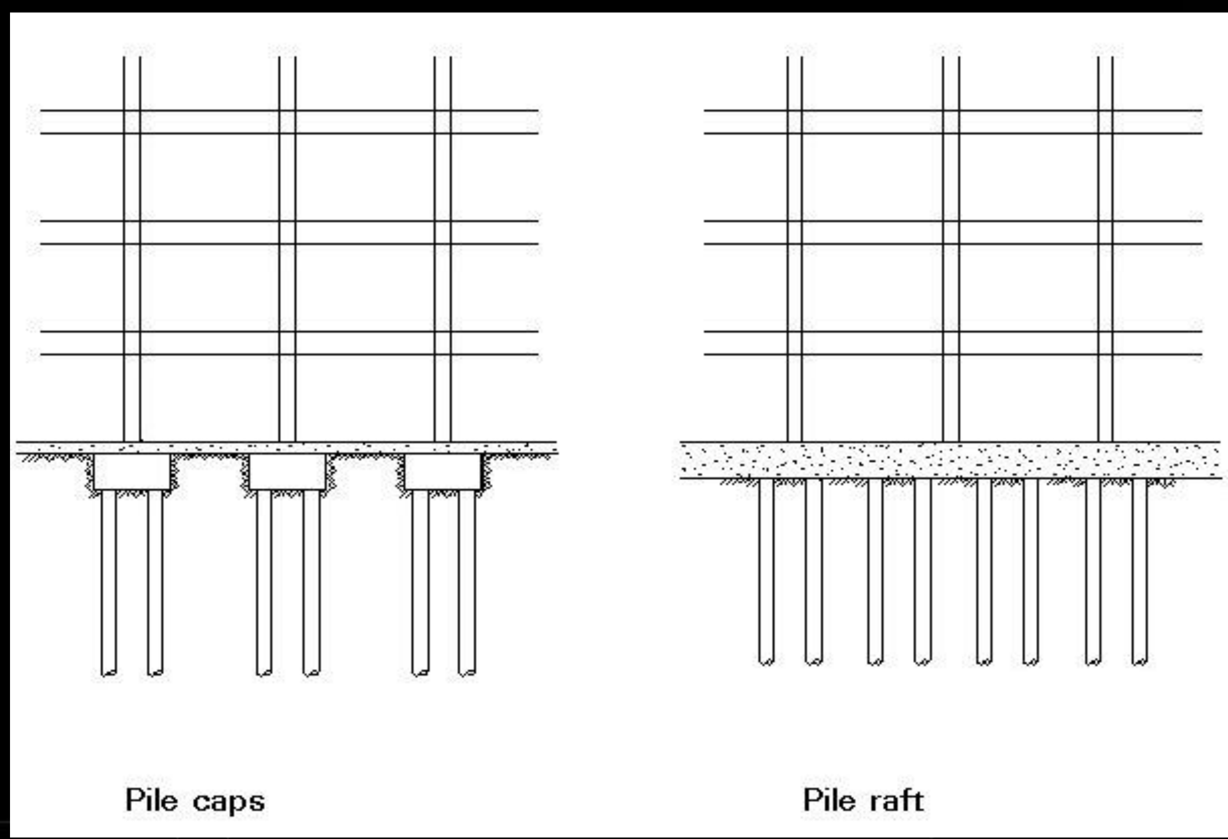


Foundation Types

- Raft foundation: one of the most common foundation. It is known for its load distributing capability. With the usage of this type of foundation the enormous load of the building gets distributed & helps the building stay upright and sturdy. Loads are transferred by raft into the ground.
- Pile foundation: used for high rise construction. load of building is distributed to the ground with the help of piles. Transfer the loads into the ground with an Adequate factor of safety.
- Combined raft-pile: is the hybrid of 2 foundation. It Consists of both the pile and raft foundation. Useful in marshy sandy soil that has low bearing capacity.







CONSTUCTION METHODS AND TECHNIQUES

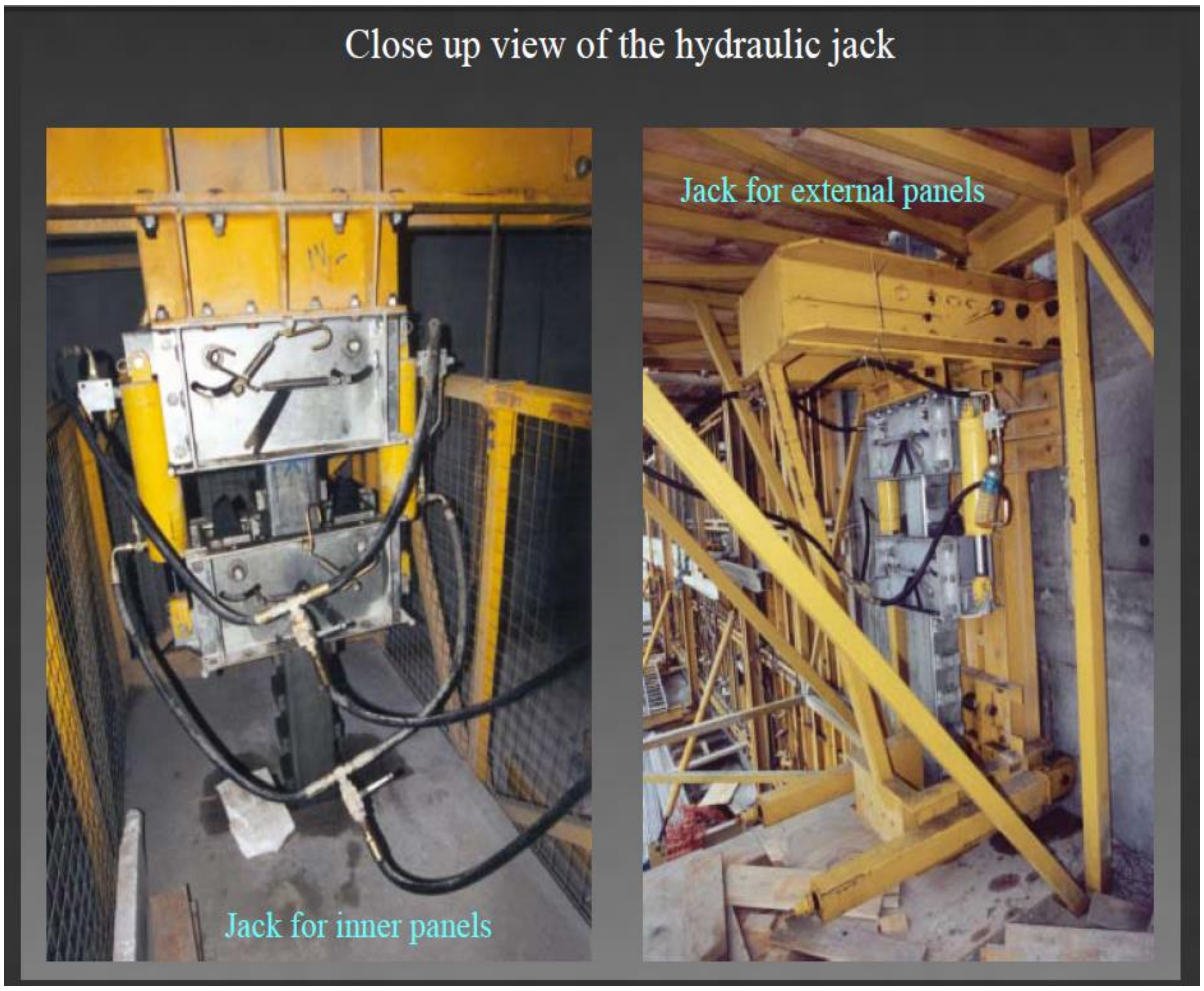
Slip forming, **continuous poured**, **continuously formed**, or **slip form construction** is a construction method in which concrete is poured into a continuously moving form. Slip forming is used for tall structures (such as bridges, towers, buildings, and dams), as well as horizontal structures, such as roadways. Slip forming enables continuous, non-interrupted, cast-in-place "flawless" (i.e. no joints) concrete structures which have superior performance characteristics to piecewise construction using discrete form elements. Slip forming relies on the quick-setting properties of concrete, and requires a balance between quick-setting capacity and workability. Concrete needs to be workable enough to be placed into the form and consolidated (via vibration), yet quick-setting enough to emerge from the form with strength. This strength is needed because the freshly set concrete must not only permit the form to "slip" upwards but also support the freshly poured concrete above it.

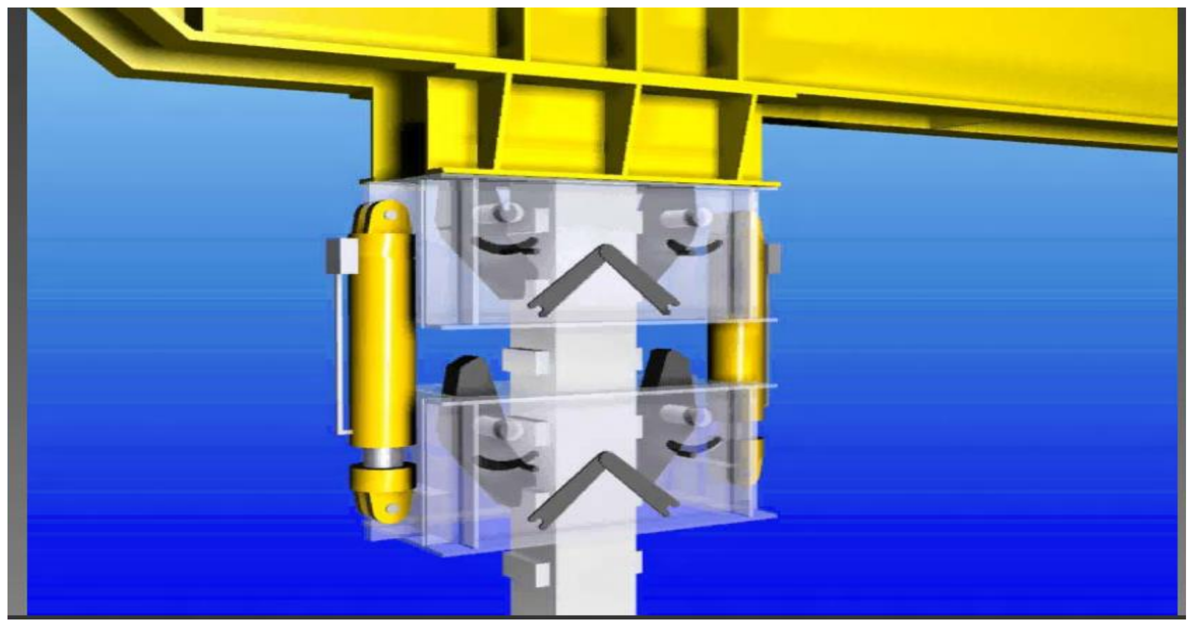
In **vertical slip forming** the concrete form may be surrounded by a platform on which workers stand, placing steel reinforcing rods into the concrete and ensuring a smooth pour. Together, the concrete form and working platform are raised by means of hydraulic jacks. Generally, the slipform rises at a rate which permits the concrete to harden by the time it emerges from the bottom of the form

SLIP FORM CONSTRUCTION

Slipforming is an economical, rapid and accurate method of constructing reinforced concrete. At its most basic level, slipforming is a type of movable formwork which is slowly raised, allowing the continuous extrusion of concrete.

CLIMB FORM CONSTRUCTION





CLIMB FORM CONSTRUCTION
is an economical, rapid and accurate method of constructing reinforced concrete, or post-tensioned concrete structures. At its most basic level, slipforming is a type of movable formwork which is slowly raised, allowing the continuous extrusion of concrete.

TABLE FORM/FLYING FORM

A table form/flying form is a large pre-assembled formwork and falsework unit, often forming a complete bay of suspended floor slab. It offers mobility and quick installation for construction projects with regular plan layouts or long repetitive structures, so is highly suitable for flat slab, and beam and slab layouts. It is routinely used for residential flats, hotels, hostels, offices and commercial buildings.

SYSTEM COLUMN FORMWORK

The column formwork systems now available are normally modular in nature and allow quick assembly and erection on-site while minimising labour and crane time. They are available in steel, aluminium and even cardboard (not reusable but recycled) and have a variety of internal face surfaces depending on the concrete finish required. Innovations have led to adjustable, reusable column forms which can be clamped on-site to give different column sizes.

VERTICAL PANEL SYSTEMS

Crane-lifted panel systems are commonly used on building sites to form vertical elements and usually consist of a steel frame with plywood, steel, plastic or composite facing material.

The systems are normally modular in nature, assembly times and labour costs are considerably lower than traditional formwork methods with far fewer components required. They offer greater opportunities for reuse for different applications on site.

Panel systems are extremely flexible and the larger crane-lifted versions can be used for constructing standard concrete walls, perimeter basement walls, columns and in conjunction with jump form climbing systems.

JUMP FORM SYSTEMS

Generally, jump form systems comprise the formwork and working platforms for cleaning/fixing of the formwork, steel
fixing and concreting. The formwork supports itself on the concrete cast earlier so does not rely on support or access from other parts of the building or permanent works.
Jump form, here taken to include systems often described as climbing form, is suitable for construction of multi-storey vertical concrete elements in high-rise structures, such as shear walls, core walls, lift shafts, stair shafts and bridge pylons. These are constructed in a staged process. It is a highly productive system designed to increase speed and efficiency while minimising labour and crane time.
Systems are normally modular and can be joined to form long lengths to suit varying construction geometries.
Three types of jump form are in general use:

TYPES OF JUMP FORM

Normal jump/climbing form
units are individually
lifted off the structure and relocated at the next construction level using a crane.

Guided-climbing jump form
also uses a crane but
offers greater safety and control during lifting as units remain anchored/guided by the structure.

Self-climbing jump form
does not require a crane as
it climbs on rails up the building by means of hydraulic
jacks, or by jacking the platforms off internal recesses
in the structure. It is possible to link the hydraulic jacks and lift multiple units in a single operation.

TUNNEL FORM

Tunnel form is used to form repetitive cellular structures, and is widely recognised as a modern innovation that enables the construction of horizontal and vertical elements (walls and floors) together.

Significant productivity benefits have been achieved by using tunnel form to construct cellular buildings such as hotels, low- and high-rise housing, hostels, student accommodation, prison and barracks accommodation.

BUILDING CONSTRUCTION

Introduction

This ***Part One*** will address;

Type 1 – Fire Resistive and

Type 2 – Noncombustible buildings.

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Codes

In New York State, building construction, heating plants, HVAC, etc., are regulated by the following;

The Building Code

The Existing Building Code

The Fire Code

The Fuel and Gas Code

The Mechanical Code

The Plumbing Code

The Residential Code and

The Energy Conservation Code

also Reference Standards (NFPA, ANSI, ASME, etc..)

Additionally, we also have to comply with;

NYS approved "more resistive" local codes (i.e., county, town, city, village)

These codes provide *minimum* requirements.

As with all codes, there are exceptions, such as, the NYS Building Code does not apply to detached one-and two-family dwellings and multiple single-family dwelling (townhouses) not more than three stories in height with separate means of egress. These buildings fall under the *Residential Code of New York State*.

Why Know Building Construction

WHY KNOW BUILDING CONSTRUCTION?

To alert you to potential construction hazards,

To enable a safe and effective fire attack,

By knowing basic building construction types, we can approximate how fire will spread and allow us to extinguish it quickly.

"The building is your enemy… know your enemy"
Francis L. Brannigan.

Construction Types

Buildings are constructed by one of ***five*** construction categories;

Type “1” - Fire Resistive – *Least* Combustible

Type “2” - Non-Combustible

Type “3” - Ordinary

Type “4” - Heavy Timber

Type “5” - Wood Frame – *Most* Combustible

Simply put, “It either burns (combustible) or it does not burn (noncombustible)”

Four of the five types have subgroups “A” or “B”

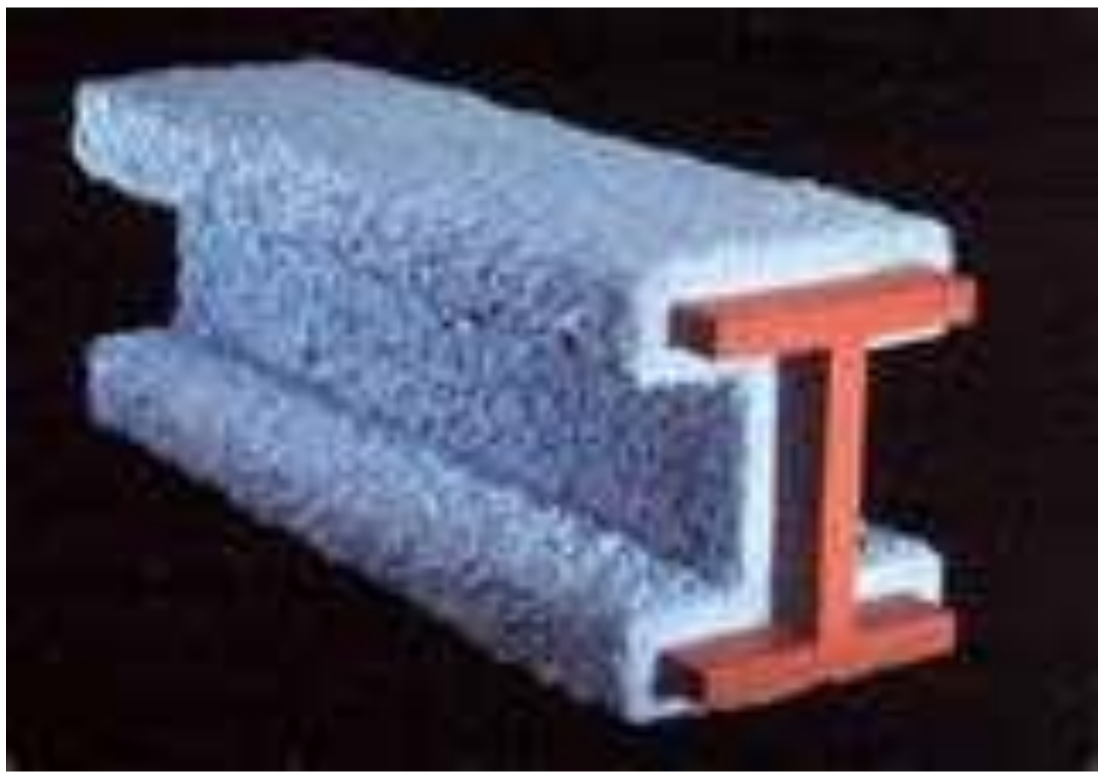
Subgroups

Subgroup “A”

Means <u>Protected</u>;

all structural members have an additional fire rated coating or cover by means of sheetrock, spray on, or other approved method,

the additional fire rated coating or cover extends the fire resistance of the structural members by at least 1 hour.

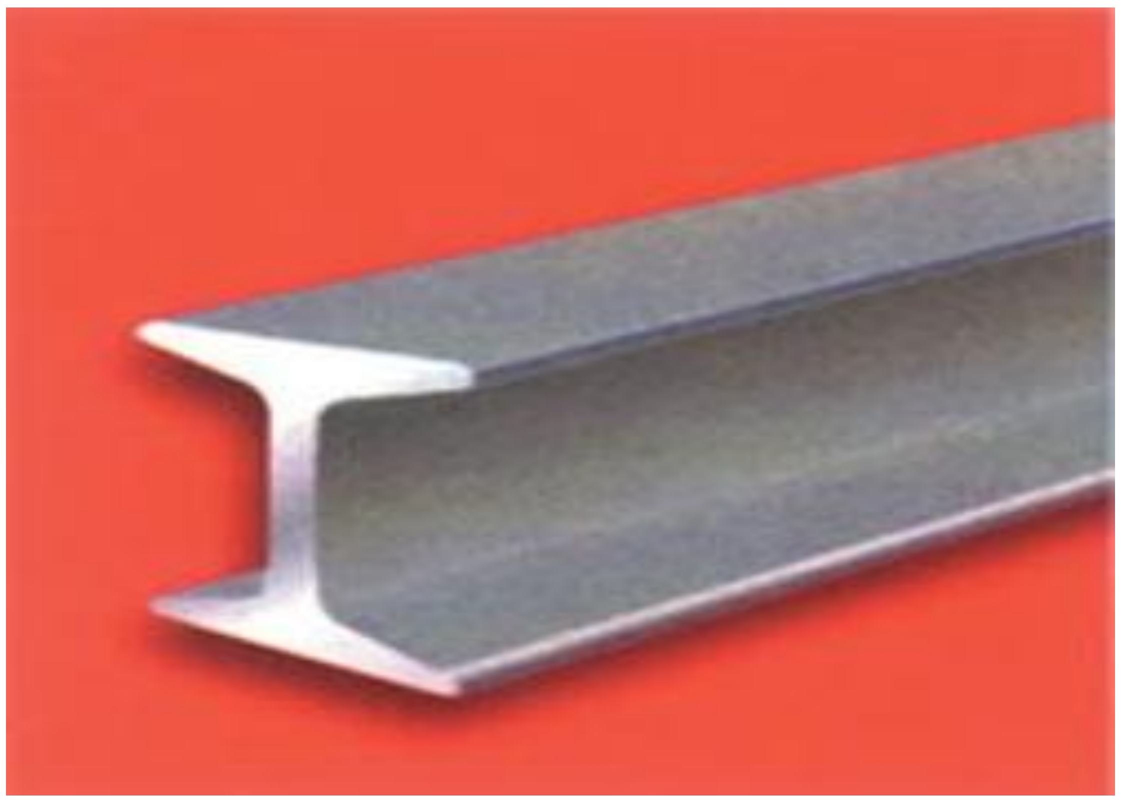


Subgroup "B"

Means Unprotected;

all structural members have no additional fire rated coating or cover,

exposed members are only fire resistant according to their natural ability, characteristics, and fire rating.



–STRUCTURAL CHARACTERISTICS AND HAZARDS

TYPE “1” – Fire Resistive

STRUCTURAL CHARACTERISTICS AND HAZARDS

Type "1"- (A) (protected) - Fire Resistive

(ISO Class 6)
(#332, NFPA 5000 "Building & Safety Code")

Fire Resistive Rating

structural frame, columns, etc. - 3 hour rating
bearing walls (Exterior & Interior) – 3 hour rated
floor construction, beams and joists – 2 hour rated
roof construction, beams and joists – 1 ½ hour rated

2010 New York State Building Code

Type "1"- (B) (unprotected) - Fire Resistive

(ISO Class 5)

(#222, NFPA 5000 "Building & Safety Code")

Fire Resistive Rating

structural frame, columns, etc. - 2 hour rating

bearing walls (Exterior & Interior) – 2 hour rated

floor construction, beams and joists – 2 hour rated

roof construction, beams and joists – 1 hour rated

2010 New York State Building Code

TYPE "1" - Fire Resistive

Characteristics;

structural members noncombustible or limited combustible,

protected steel and reinforced concrete are the most common material,

1"A" - reinforced concrete walls ≤ 4" thick,

1"A" - hollow masonry ≤ 12" thick,

1"A" - reinforced concrete floor ≤ 4" thick,

1"A" - horizontal & vertical load bearing metal supports, ≤ 2 hour rating.

1"B" – walls, floors less thick than 1"A".

TYPE "1" - Fire Resistive

Characteristics;

- the most fire resistive form of construction,
- used for most "high-rise" buildings,
- used for buildings with a high life-safety hazard,
- primary hazard- contents, unprotected openings and auto exposure,
- intended to confine any fire to its location,
- can have unlimited height.

Type 1"A" construction has less restrictions on height and area per story. As an example:

An office building (a Business Occupancy) if built by one the following construction types;

Type 1a = unlimited height and area per story.[1]

1 This does not apply to an "High Hazard" occupancy

Type 3a = 5 stories and 28, 500 ft area per story.[2]

Type 5a = 3 stories and 18,000 ft area per story.[2]

2 A fire sprinkler installation would allow an increase in height and fire area. 2010 NYS

NOTE: Local Zoning Codes can place height restrictions.

Design Factors

Design Factors

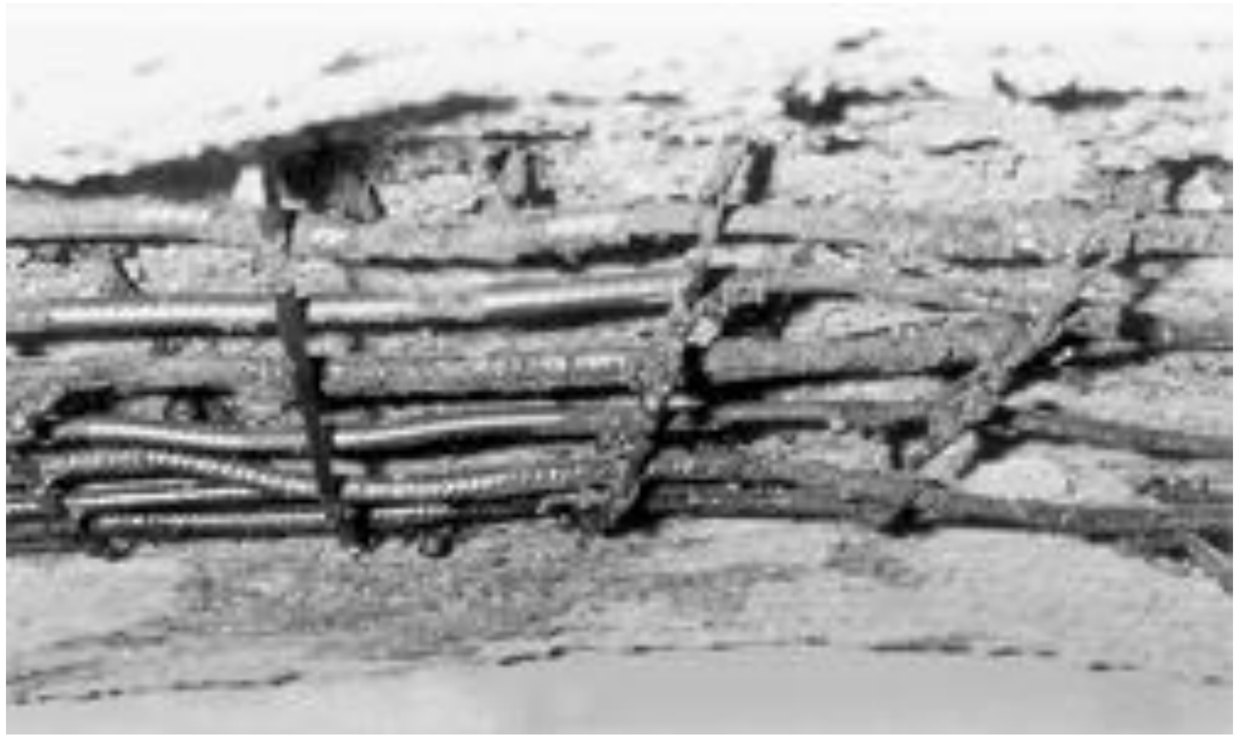
Fire resistive buildings can have substantial wooden interior finishes,

Plywood or wood paneling is common in executive offices, dining rooms, and conference rooms,

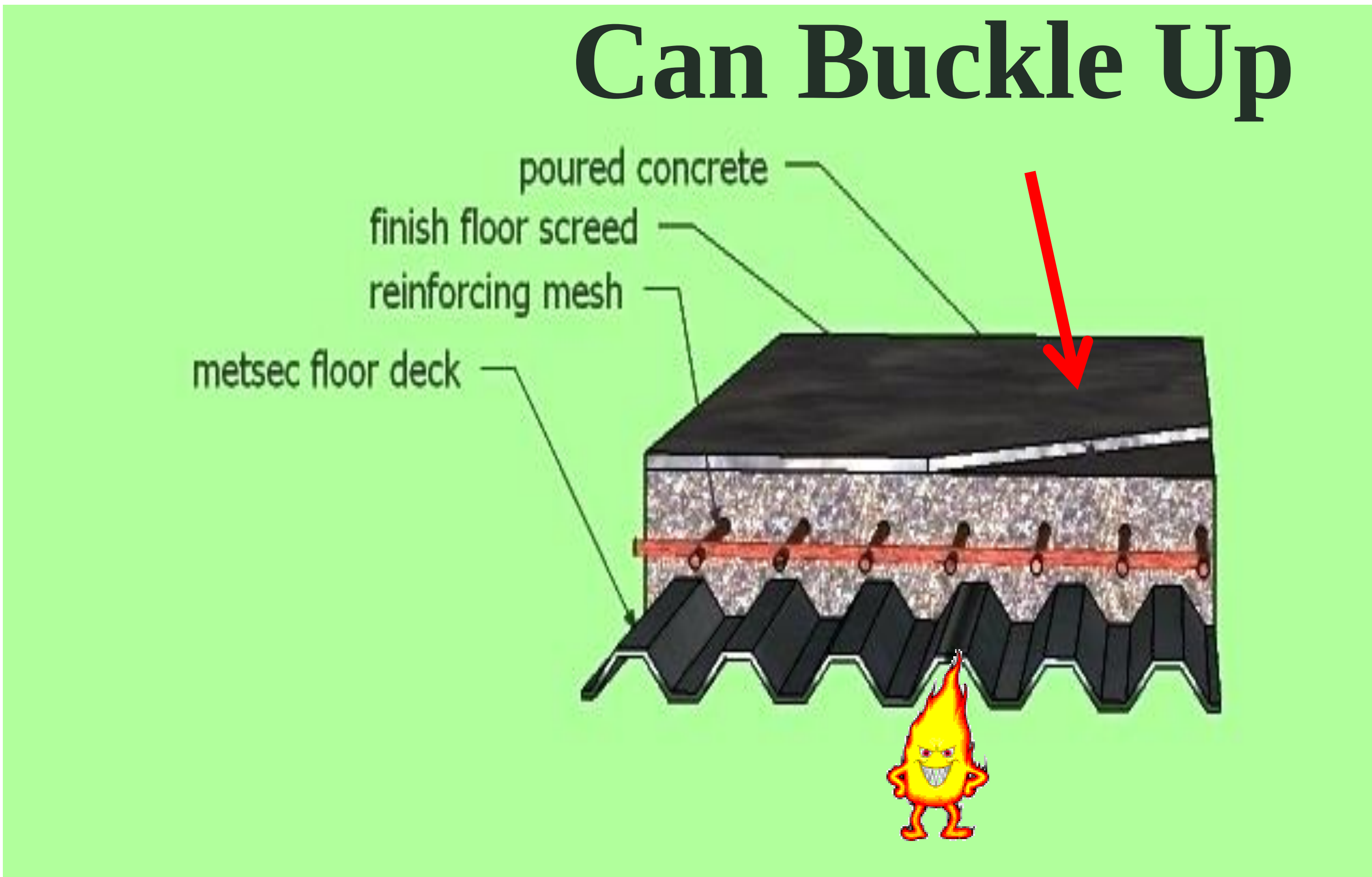
Fire resistive buildings, to some degree, resist fire caused collapse,

In reinforced concrete buildings, heated concrete ceilings can "spall" and collapse,

Heated concrete floors can buckle upward.



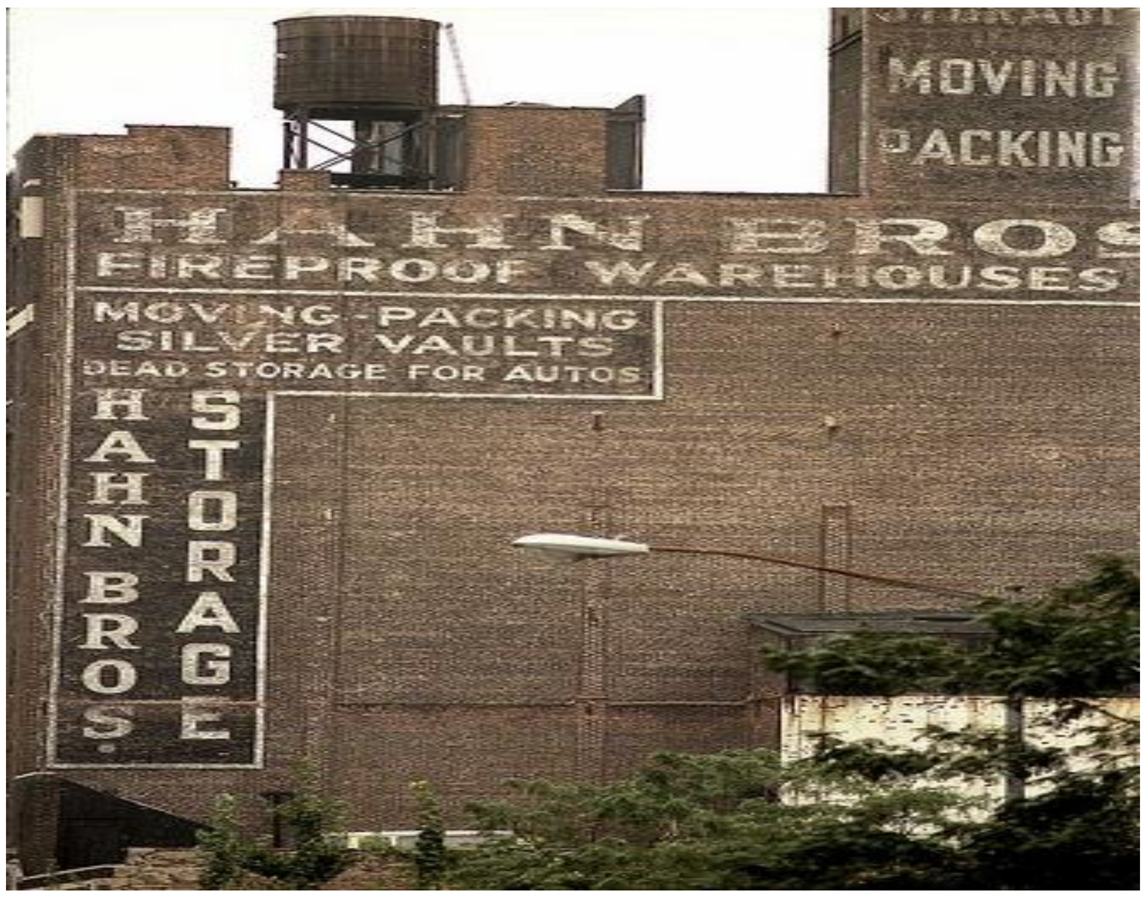
Fire spalled concrete



Buildings

Fire resistive buildings have been around since the early 1900's,

In the "old days", they were called "fireproof" buildings.



Fire Resistive buildings were built during three distinct time periods, 1900-1920, 1920-1940 and post WWII.

Fire Resistive Buildings 1900 - 1920

Fire Resistive Buildings 1900 - 1920;

steel frame, with no standards for protection,

cast iron columns were often unprotected,

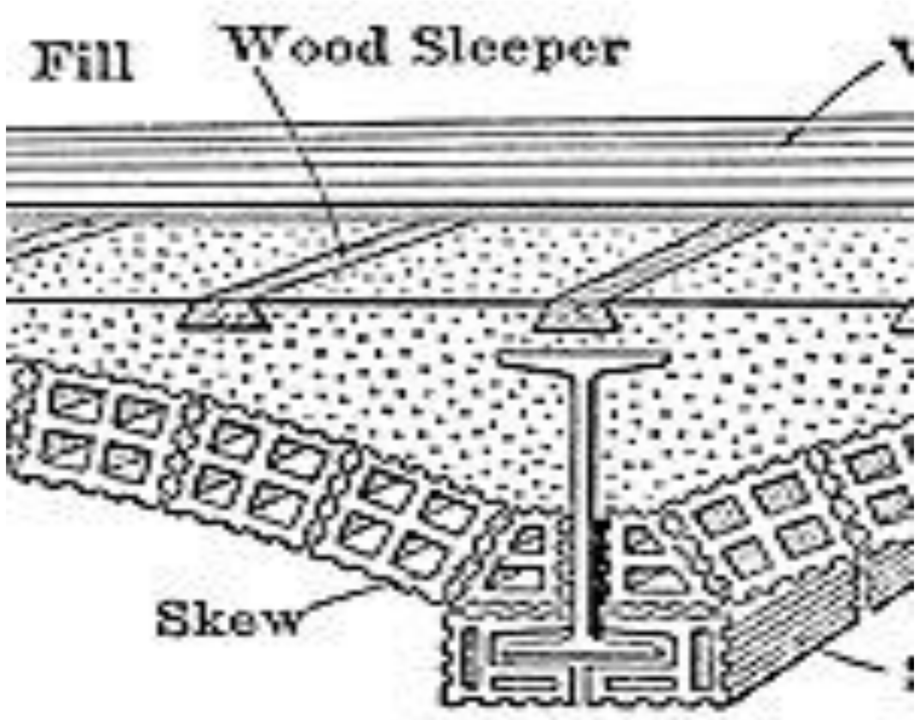
ornate open stairways were common,

open elevator shafts,

outside fire escapes,

tile arch floors,

standpipes may be inadequate in size.


Fill
Wood Sleeper
Skew

Fire Resistive Buildings 1920 - 1940

Fire Resistive Buildings 1920-1940;

fireproofing of steel were often of concrete or tile,

the construction was considered “Heavy”, the Empire State Buildings weighs about 23 lbs/cubic. ft.,

wet masonry walls provide a seal at the floor line,

shafts are enclosed,

adequate standpipe systems,

fire tower stairways,

floor area was limited,

windows could be opened,

windows leaked which limited “stack effect”.

Fire Resistive Buildings - Post World War II

Post WWII Fire Resistive Buildings;

steel or concrete frame,

typical modern high-rise weighs about 8 lbs/cu. ft.,

concrete forced lighter “fireproofing” of steel,

“Spray On” fireproofing is ineffective and a health hazard,

fluorescent lights and air conditioning permit infinite floor areas,

“stack effect” is possible,

utility shafts and telephone conduits provide smoke and fire ducts,

Fire Resistive Buildings - Post World War II

prefabricated panels or glass walls make the seal at the floor edge doubtful,

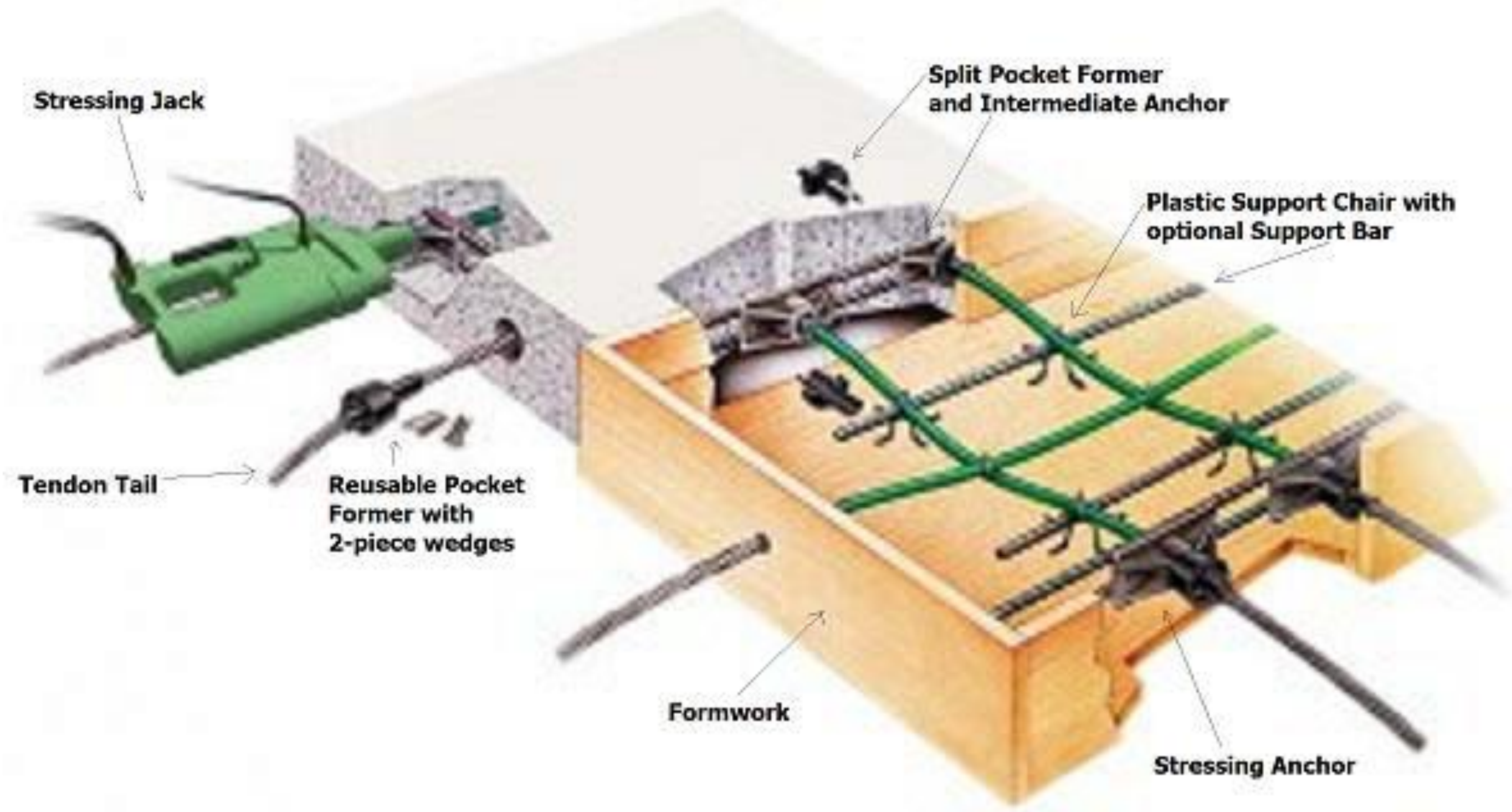
"Core" construction;

increases exit distances,

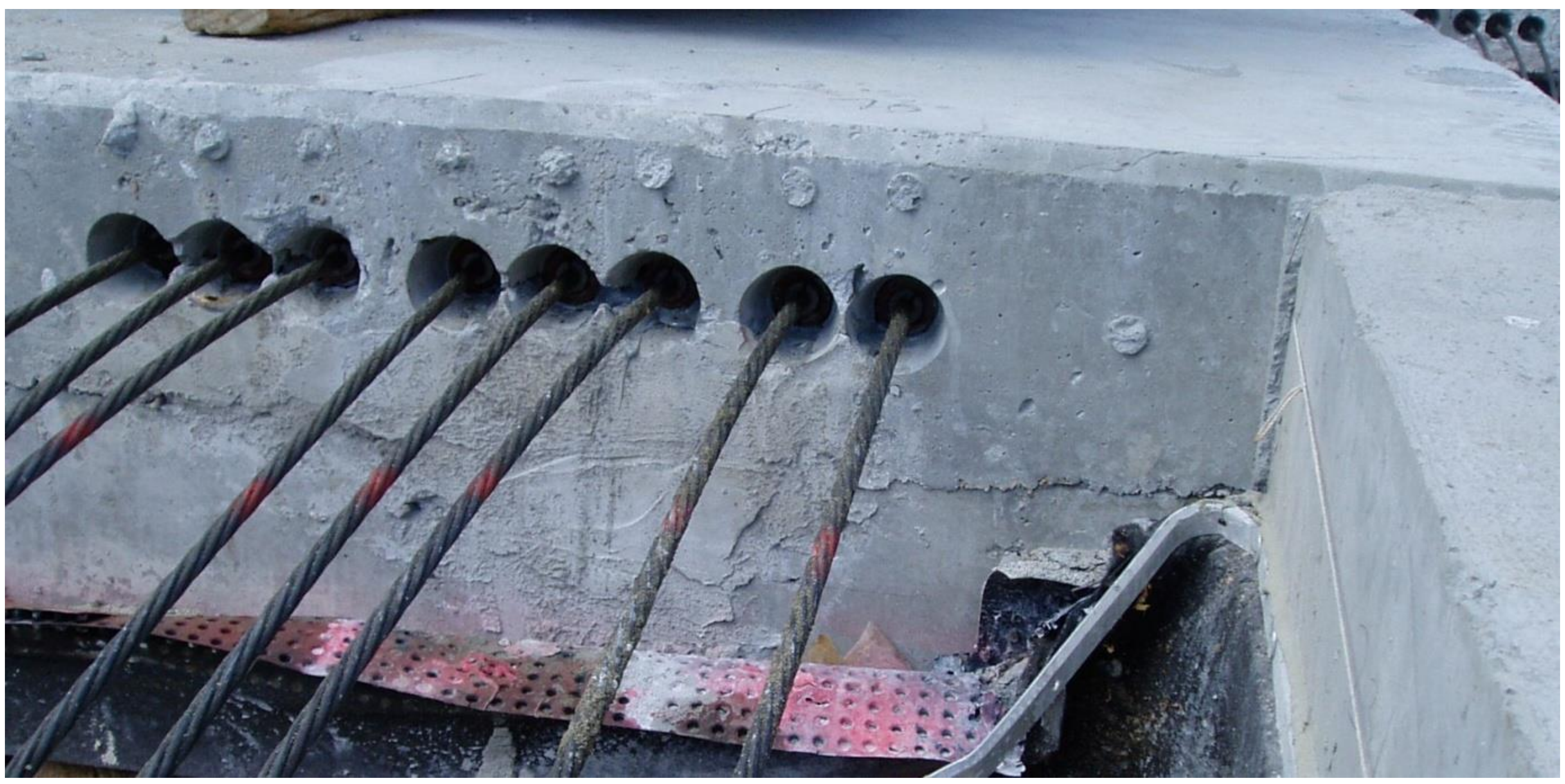
scissor stairs are used,

shafts may be enclosed with gypsum, if displaced, leaving shafts unprotected,

"Post-tensioned" concrete floors, dangerous when cutting.



Post-tensioned concrete



Methods of Fire Resistance

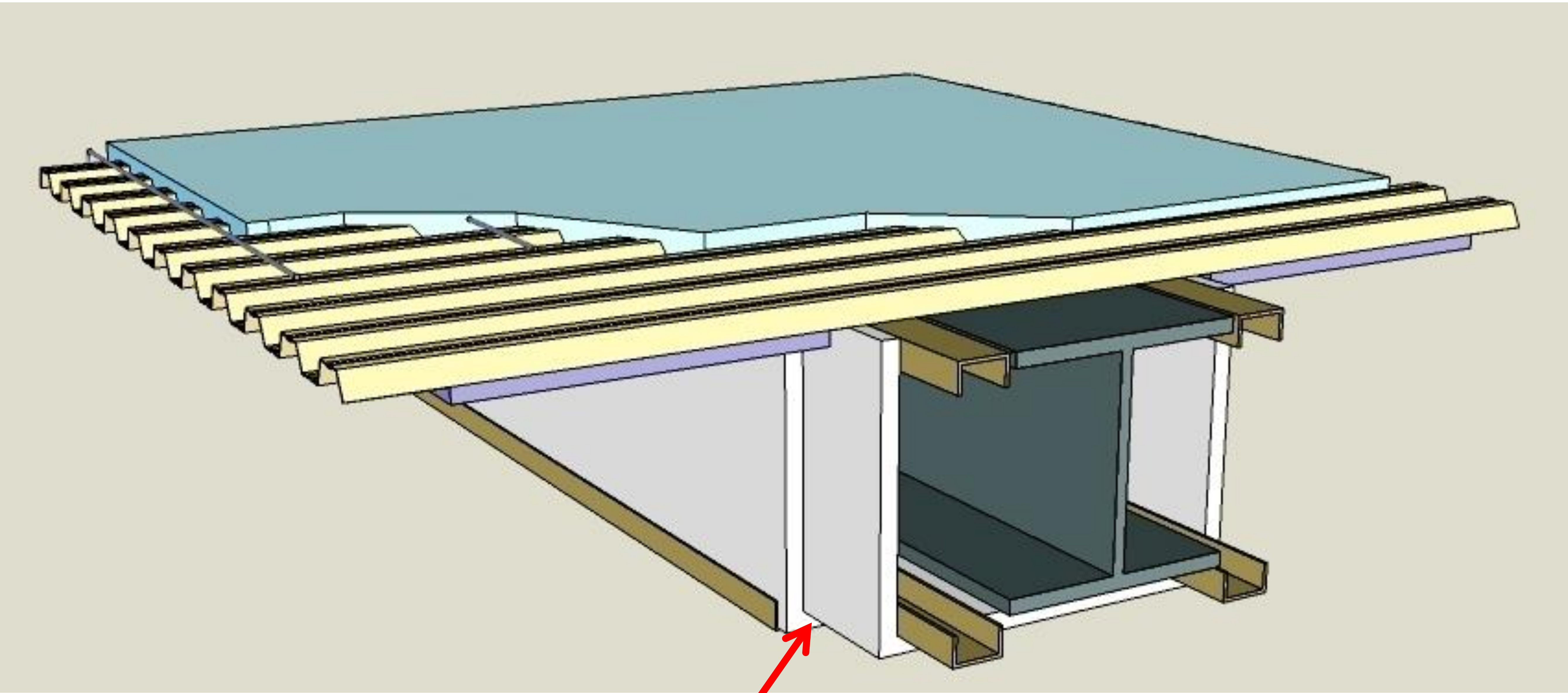
Methods of Fire Resistance

Material is
<u>INHERENTLY</u>
fire resistive

Methods of Fire Resistance

Protection is <u>DIRECTLY</u> applied

Methods of Fire Resistance



Protection by <u>Membrane</u>

Fire Spread

Fire Spread;

when built at the turn of the 1900's, fire resistive buildings were supposed to confine a fire by its construction,

unfortunately this is no true anymore in the modern fire resistive building,

There are several means by which fire and smoke can spread in modern fire resistive buildings;

Central Air Conditioning (HVAC) ducts,

Auto Exposure and

Unprotected openings.

HVAC Systems;

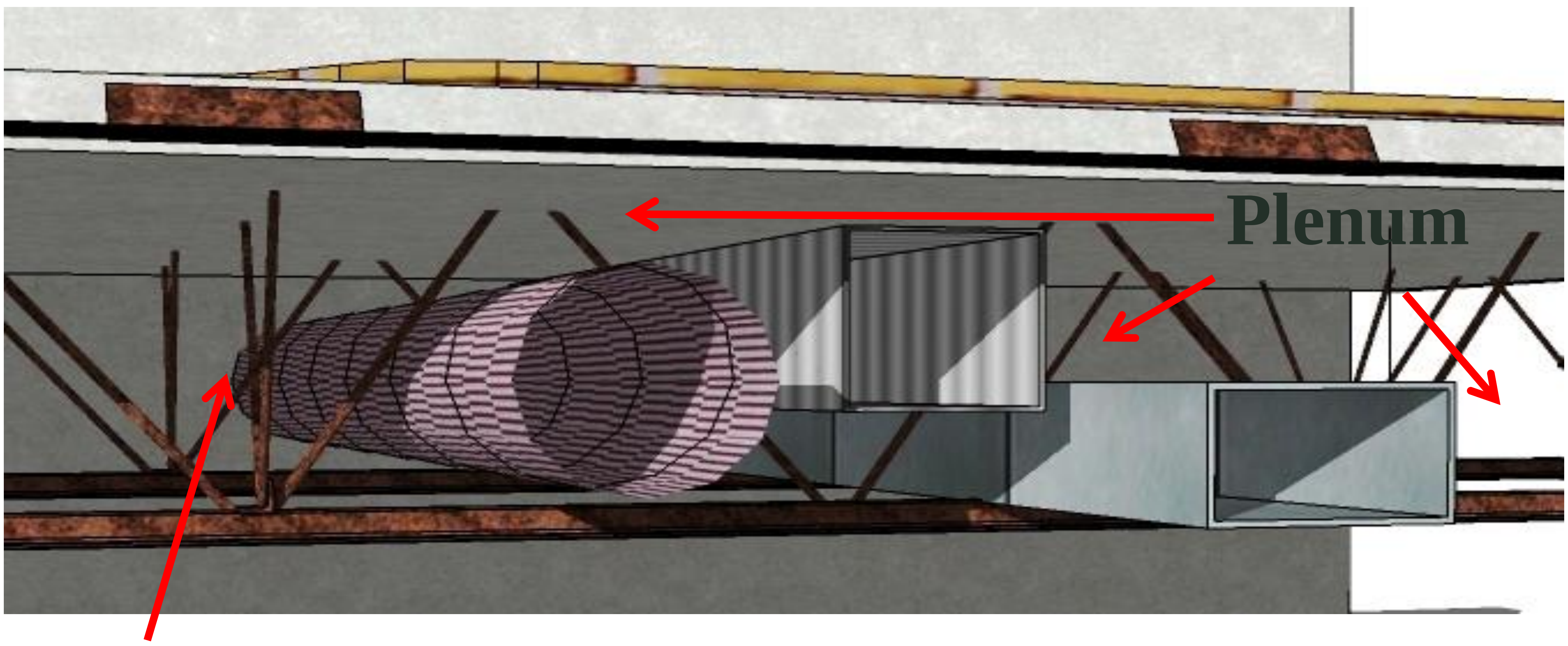
serve the entire building with cool and warm air,

ducts supply conditioned air,

these ducts can allow fire & smoke to spread,

the ducts penetrate every fire barrier,

pierce walls, floors, partitions and ceilings.



Unprotected openings

Auto Exposure

vertical spread from windows below to windows above,

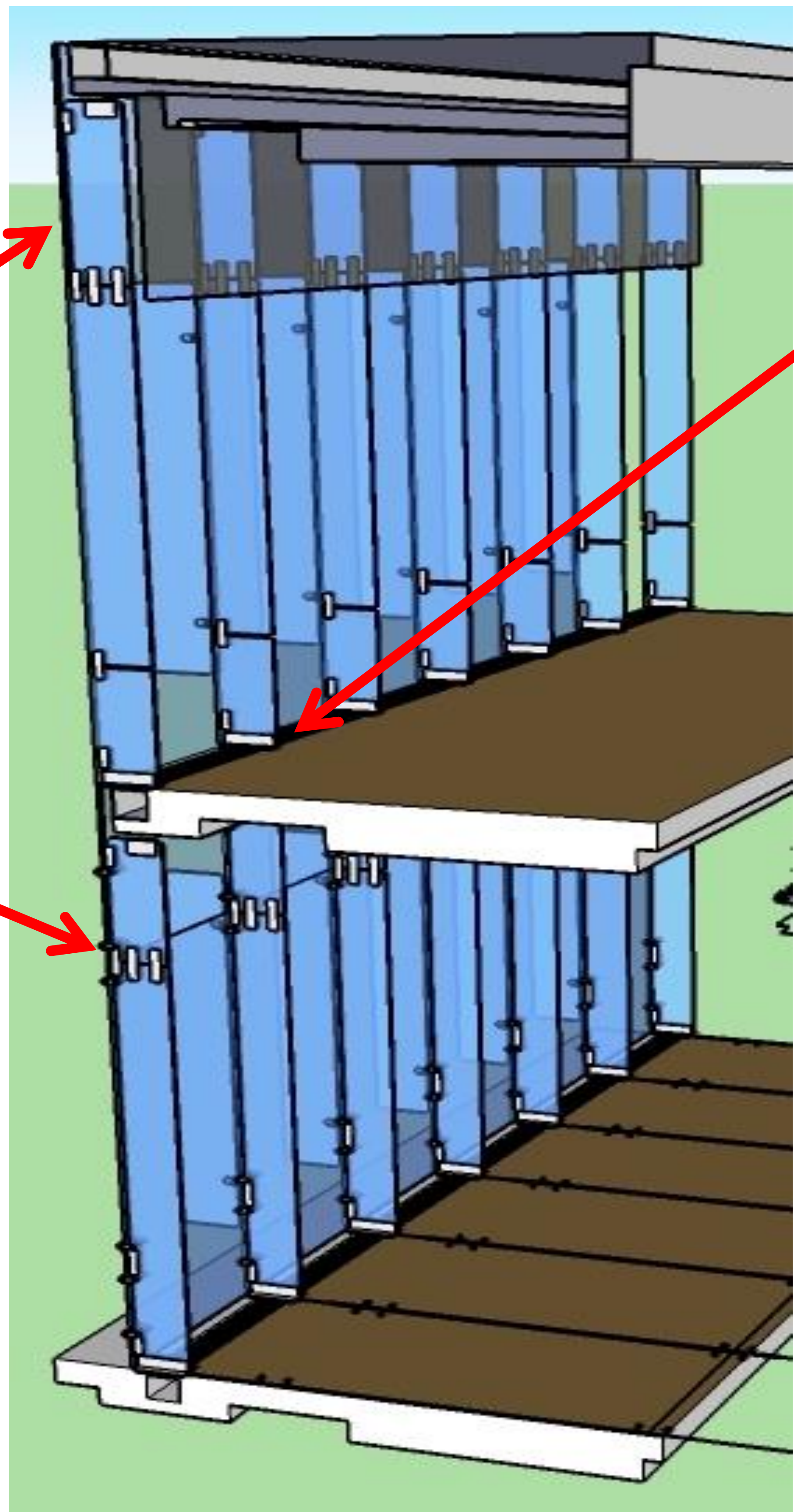
a heat shattered window can melt and break the window directly above,

even if windows don't break or melt, a small concealed space between the exterior wall and the floor can allow vertical spread of fire.

Note: The 2010 NYS Building Code requires vertical separation of openings by a "Spandrel Girder" to prevent this auto exposure. This does not apply if the building is sprinklered or 3 stories or less.

Unprotected Openings

Prefabricated panel or glass outer wall. Also called a "Curtain Wall"



Concealed space that is supposed to be sealed to prohibit smoke and fire spread between floors, often is not properly done or missing.

Historic Fire Resistive Fires

One Meridian Plaza, Philadelphia, PA

Fire started on 22nd floor

Stopped at 30th floor by automatic sprinkler

Unprotected penetrations - no HVAC fire dampers

Auto Exposure

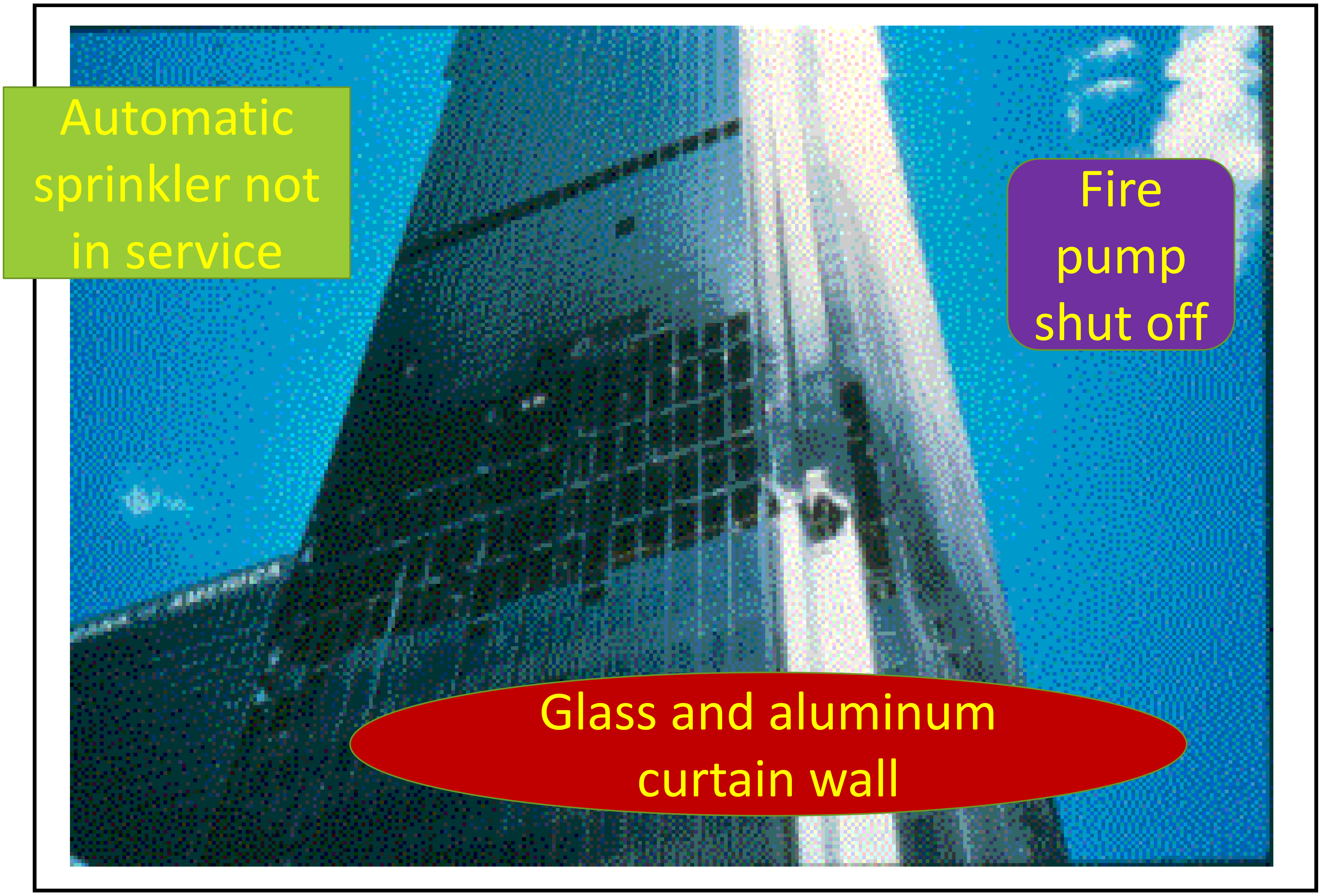
First Interstate Bank Fire, Los Angeles, CA

Fire started 12th floor, burned to the 16th floor

Extension via space between floor and glass curtain wall & auto exposure

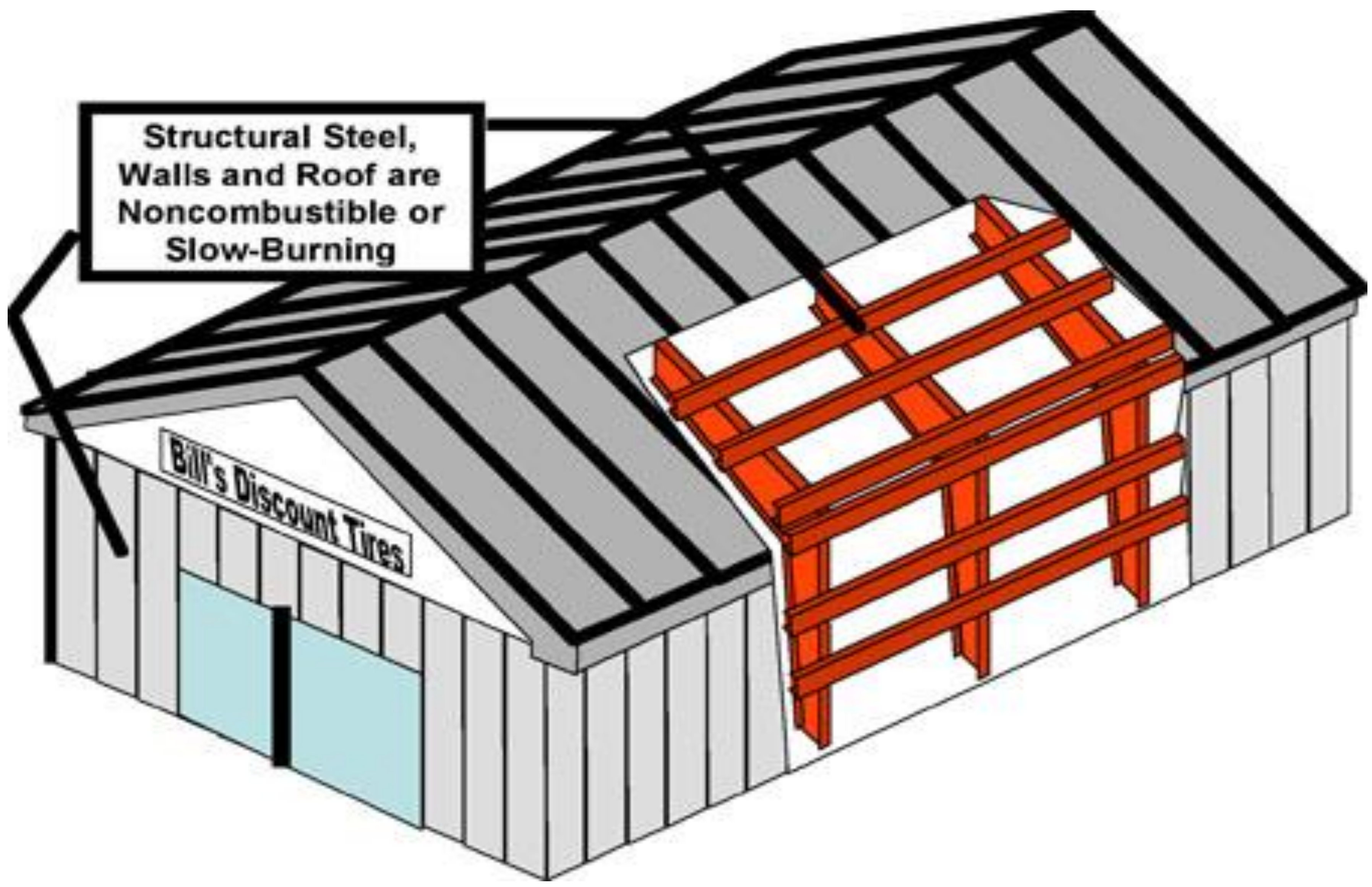
Minor fire extension via penetrations, (electric, communications) & HVAC

First Interstate Bank Fire, Los Angeles, Ca., the morning after



STRUCTURAL CHARACTERISTICS AND HAZARDS

TYPE "2" – Noncombustible



STRUCTURAL CHARACTERISTICS AND HAZARDS

Type "2"- (A) (protected) - Noncombustible

(ISO Class 4)

(#111, NFPA 5000 "Building & Safety Code")

structural frame, columns, etc. - 1 hour rating

bearing walls (Exterior & Interior) – 1 hour rated

floor construction, beams and joists – 1 hour rated

roof construction, beams and joists – 1 hour rated

2010 New York State Building Code

STRUCTURAL CHARACTERISTICS AND HAZARDS

Type "2"- (B) (unprotected) - Noncombustible

(ISO Class 3)

(#000, NFPA 5000 "Building & Safety Code")

structural frame, columns, etc. - 0 hour rating

bearing walls (Exterior & Interior) – 0 hour rated

floor construction, beams and joists – 0 hour rated

roof construction, beams and joists – 0 hour rated

2010 New York State Building Code

TYPE “2” - Noncombustible

Characteristics;

structural members are noncombustible but have less fire resistance,

unprotected steel generally the defining characteristic,

non-combustible materials besides concrete and steel also common. Such as concrete block exterior walls with unprotected steel beams, or trusses for roof support is common.

TYPE "2" - Noncombustible

Characteristics;

similar to Type 1, only degree of fire resistance is less,

in some cases, materials with no fire resistance is used,

primary hazards- contents and steel deformation,

heat build up during fire may cause structural supports to fail,

insulated roof materials may contribute to fire spread.

Design Factors

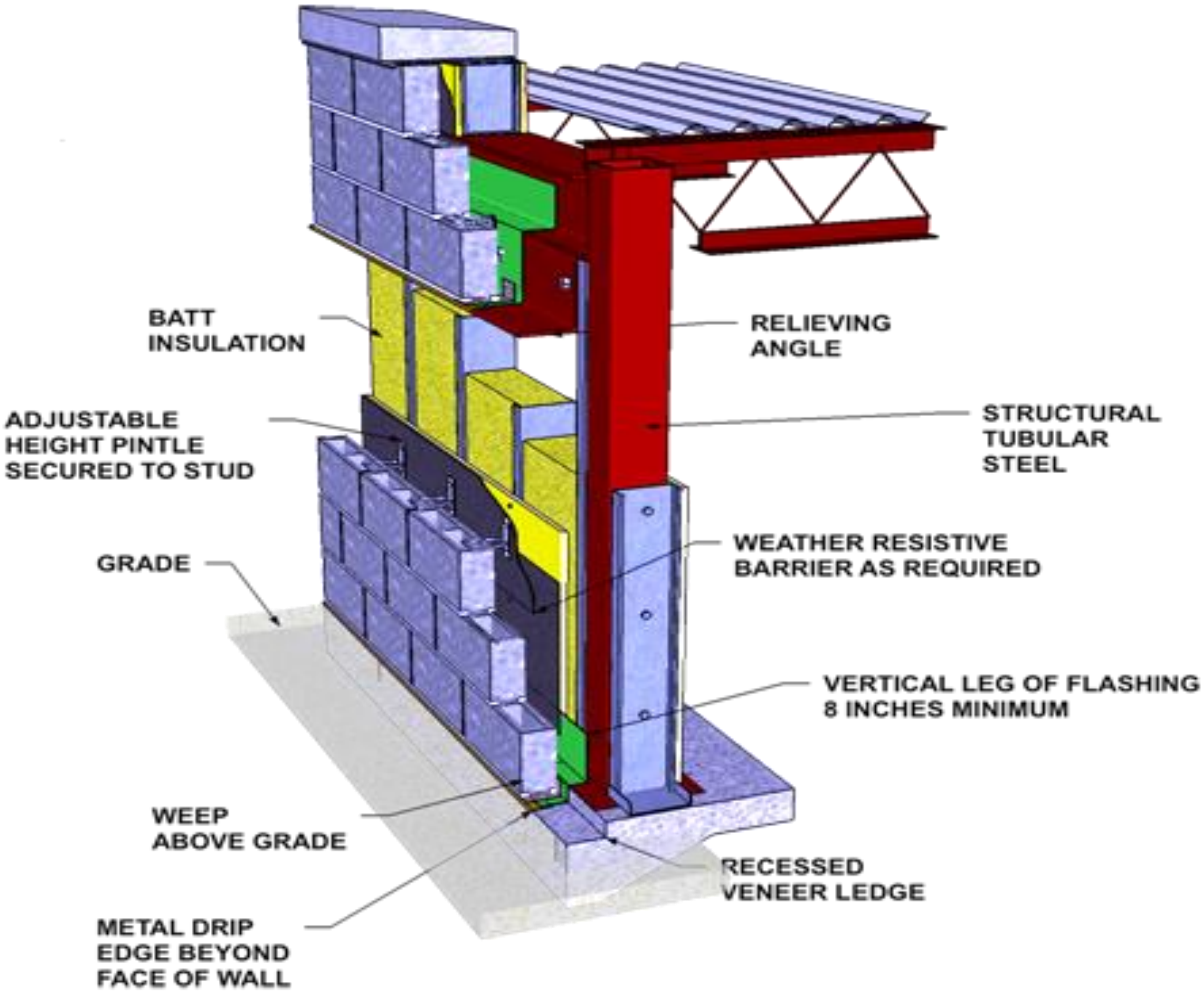
Three basic types of noncombustible buildings;

metal frame structure covered by metal exterior walls,

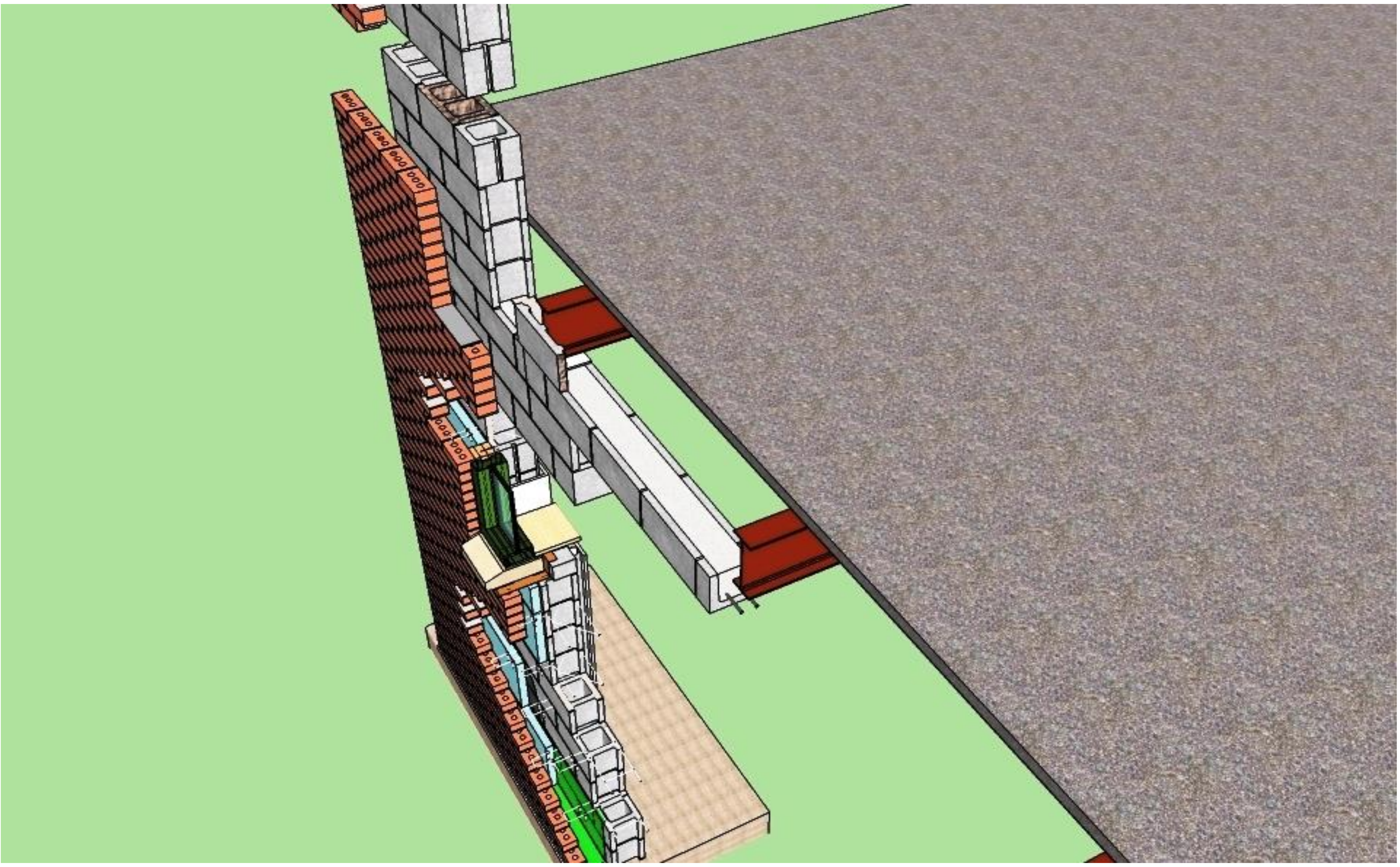
metal frame structure enclosed by concrete block, non-bearing walls,

concrete block bearing walls supporting metal roof structure.

Steel frame with metal exterior walls



Cavity wall concrete block veneer



Block wall supporting steel decking

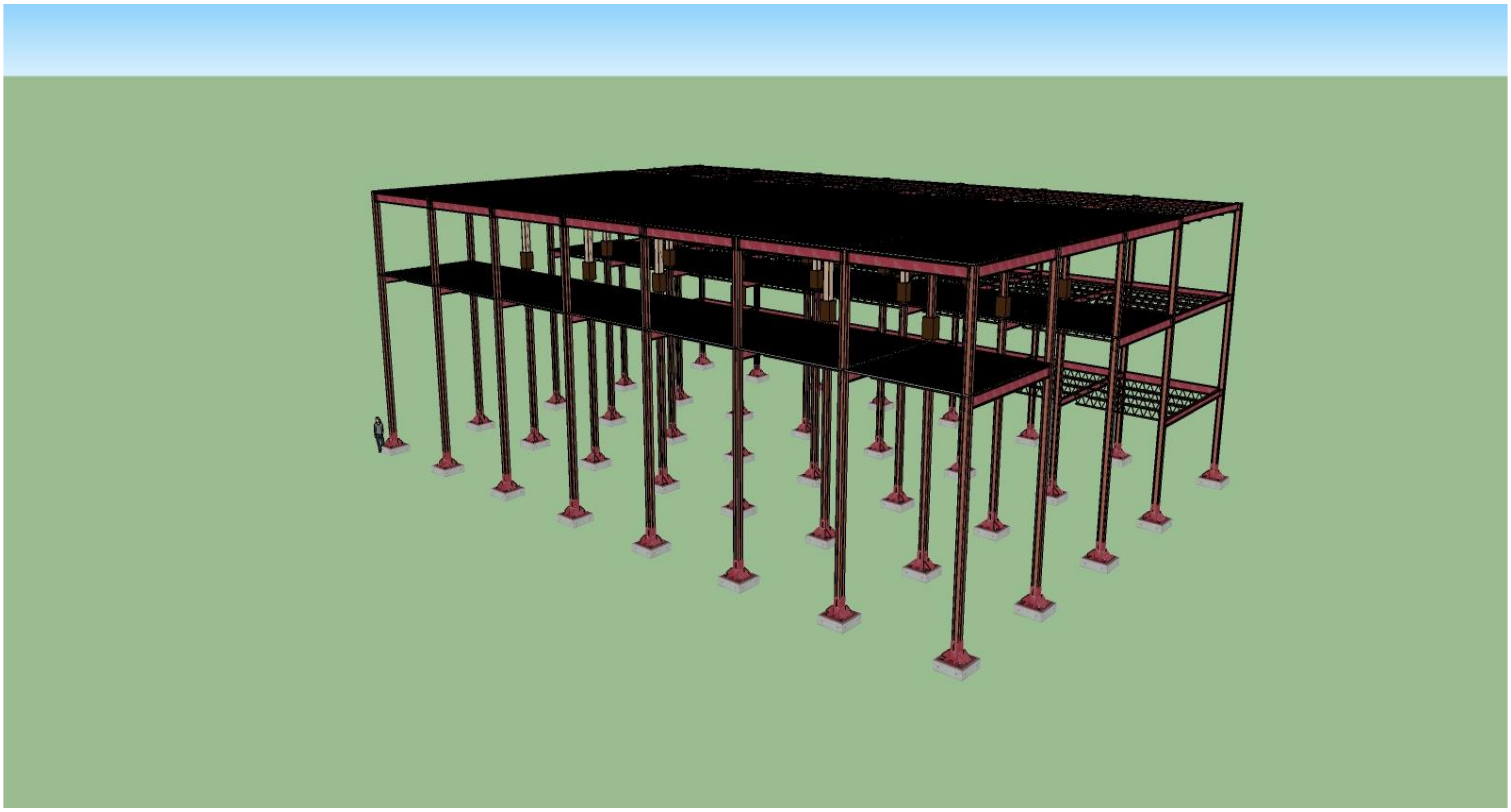
Steel Roof

Steel roof support systems may be either;

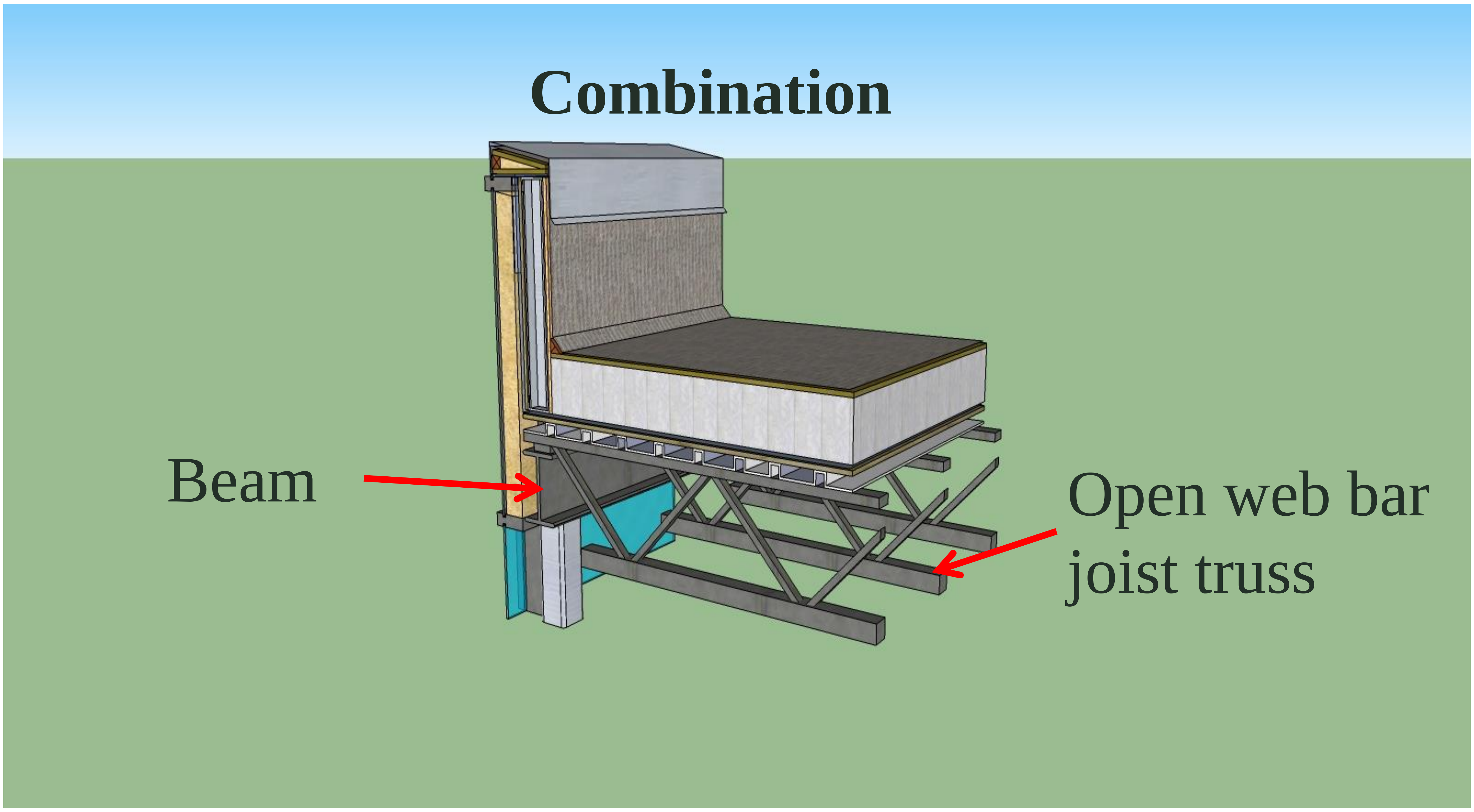
- solid steel girders and beams,
- lightweight open web bar joist, or
- a combination of both.

The open web bar joist is the MAIN structural hazard of non-combustible construction.

There is collapse danger from a roof cave-in.



Solid steel girders and beams



Open web bar joist truss and beam

Historic Fire

GM transmission plant fire, 1953 Livonia, MI

Class 2 construction,

Insulated metal deck roof fire –

Was the principle factor to destruction of the plant.

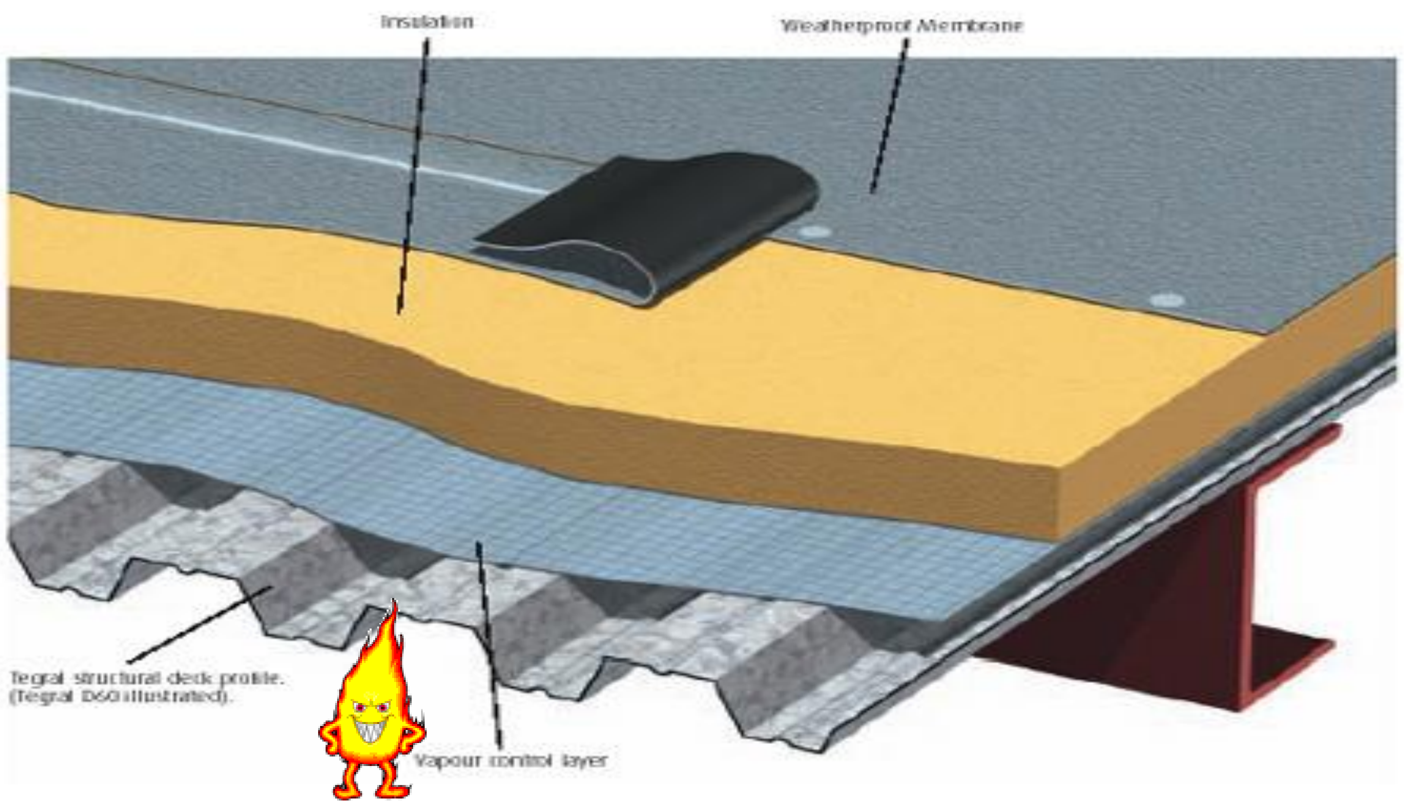
when fire occurs below metal deck roof, the metal heats up,

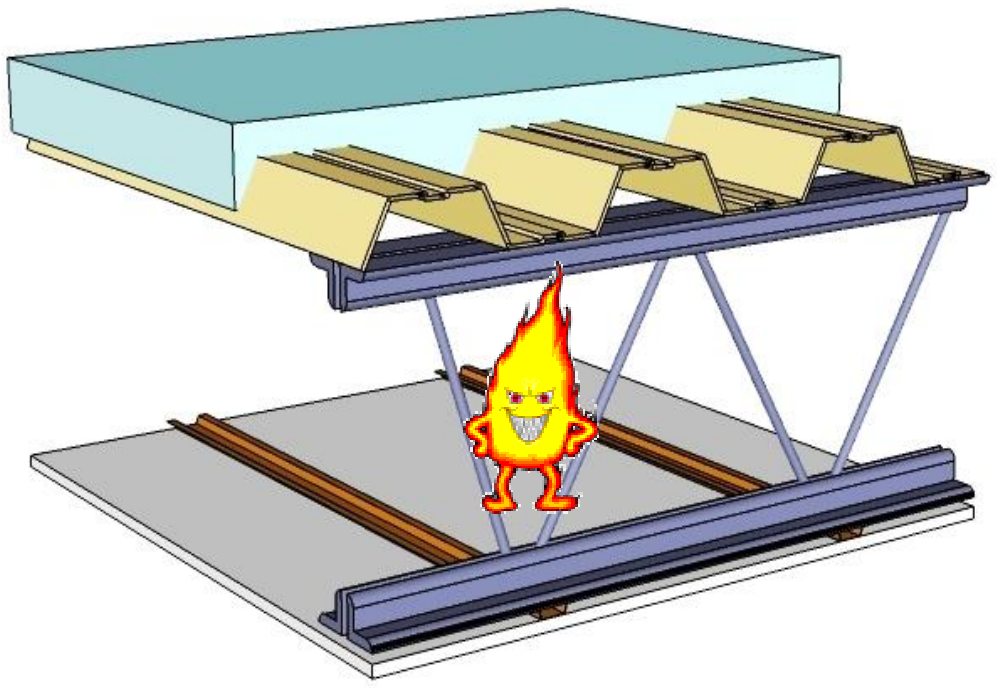
heat is conducted through the deck to the bituminous adhesive holding the insulation down,

the adhesive liquefies and the vaporizes,

the gas can not escape through the roof material, so it is forced down through the deck joints,

mixes with air and fire below and ignites.





Hazards Related to Type 1 & 2 Construction

Hazards Typical of Type 2 &1 Construction

- Heavy content fire load
- Combustible finishes and furnishings
- Large open spaces

Hazards Related to Type 2 &1 Construction

Heavy content loading;

- ✓ combustibles stored in high piles next to each other,
- ✓ usually found in commercial and storage facilities,
- ✓ this may override sprinkler system and provide access problems,
- ✓ proper inspection and enforcement effective in these types of facilities.

Hazards Related to Type 1 & 2 Construction

Combustible furnishings/finishes;
contribute to fire spread and smoke production.

Large open spaces;
contributes to spread,
warehouses, churches, large atriums, common attics, and theaters.

SUMMARY

Summary

Types 1 and 2 buildings:

Non-combustible Elements.

Steel conducts heat, elongates and fails.

Unprotected steel structures can be extremely hazardous because of the potential for early collapse.

Open web bar joists have no fire resistive rating and can fail after 5 to 10 minutes of elevated temperatures.

Heavy fire loads can be found in conference rooms, restaurants, storerooms and communication rooms.

Fire does spread in modern fire resistive buildings.

Fire problems with insulated metal deck roofs.

Prepared by Thomas Bartsch

Chief Fire Inspector (ret)

Seismic Design Guidelines for Tall Buildings

RONALD O. HAMBURGER

SENIOR PRINCIPAL

SIMPSON GUMPERTZ & HEGER INC.

PEER

Quake Summit 2010

October 8, 2010

Purpose

Recommended alternative to the prescriptive procedures for seismic design of buildings contained in *ASCE 7* and the *International Building Code (IBC)*.

Intended for use by structural engineers and building officials engaged in the seismic design and review of individual tall buildings.

The new breed of tall buildings

Designed without dual moment-resisting frames

Justified using nonlinear analyses and “performance-based” procedures adapted from ASCE 41

The Source

ASCE STANDARD
Seismic Rehabilitation of Existing Buildings
AN ALTERNATIVE PROCEDURE FOR SEISMIC ANALYSIS AND DESIGN OF TALL BUILDINGS LOCATED IN THE LOS ANGELES REGION
A CONSENSUS DOCUMENT
2008 EDITION
Council on Tall Buildings and Urban Habitat
Recommendations for the Seismic Design of High-rise Buildings
Draft for Comment - 1
21 February 2008
Principal Authors
Michael Willford
Andrew Whittaker
Ron Klemencic
DEPARTMENT OF BUILDING INSPECTION

The Approach

Design per the building code with
- a few exceptions
  - Exceed height limits for structural systems
  - Use different R values
  - Neglect redundancy requirements

Develop nonlinear analytical model
- MCE (2%-50 year) shaking
- Conservative values on acceptable parameters

Rigorous Peer Review

Purpose

Suggest improved design criteria that will ensure safe and useable tall buildings following future earthquakes
based on:

- Recent design experience
- State-of-art research

Development Team

RESEARCH

Jack P. Moehle

Yousef Bozorgnia

Jonathan Stewart

Helmut Krawinkler

PRACTICE

Ronald Hamburger

James Malley

C.B. Crouse

Farzad Naeim

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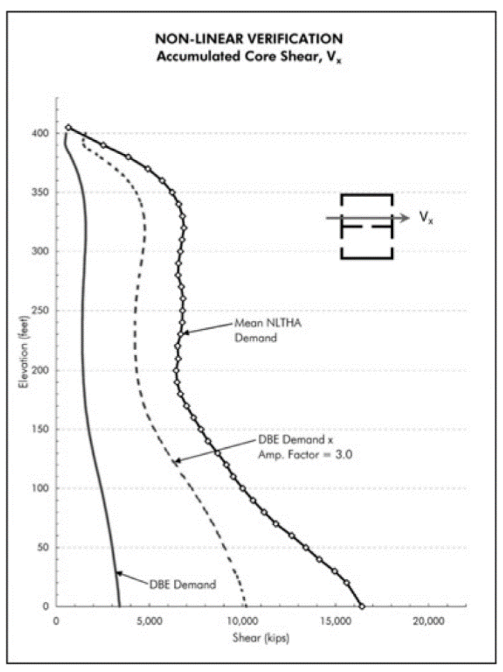
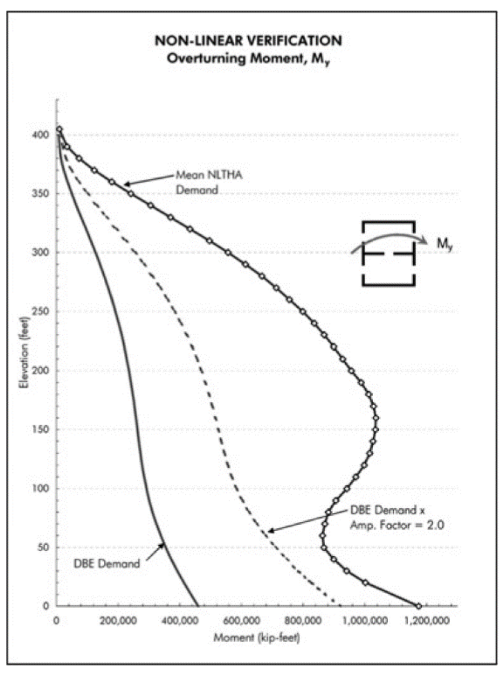
Table of Contents

Scope -

Design of tall buildings:

- Fundamental periods >> 1 second
- Significant mass participation and response in higher modes
- Slender aspect ratio
  - Large portion of drift due to flexural behavior as opposed to shear behavior





Performance Intent

Similar to that historically contained in SEAOC Blue Book & ASCE-7 for Ordinary Occupancies

- Small risk of collapse (perhaps 10%) in MCE shaking
- Limited risk (50%) of loss of cladding in MCE shaking
- Negligible risk to life for design shaking
- Negligible risk of occupancy loss for Service level shaking

Other Objectives

- Possible
- Need to modify these criteria on project-specific basis

Design Criteria

Formal written criteria required

- Building description
- Codes and standards
- Performance Objectives
- Gravity Loading
- Seismic Hazards
- Wind Loading
- Load Combinations
- Materials
- Analysis Procedures
- Acceptance Criteria

Seismic Input

Two Event Levels

- Service level
  - Elastic response spectrum - required
  - Response history analysis - alternate

- Maximum Considered level
  - Nonlinear response history

Preliminary Design

Configuration Issues

Structural Performance Heirarchy (capacity-design)

Wind

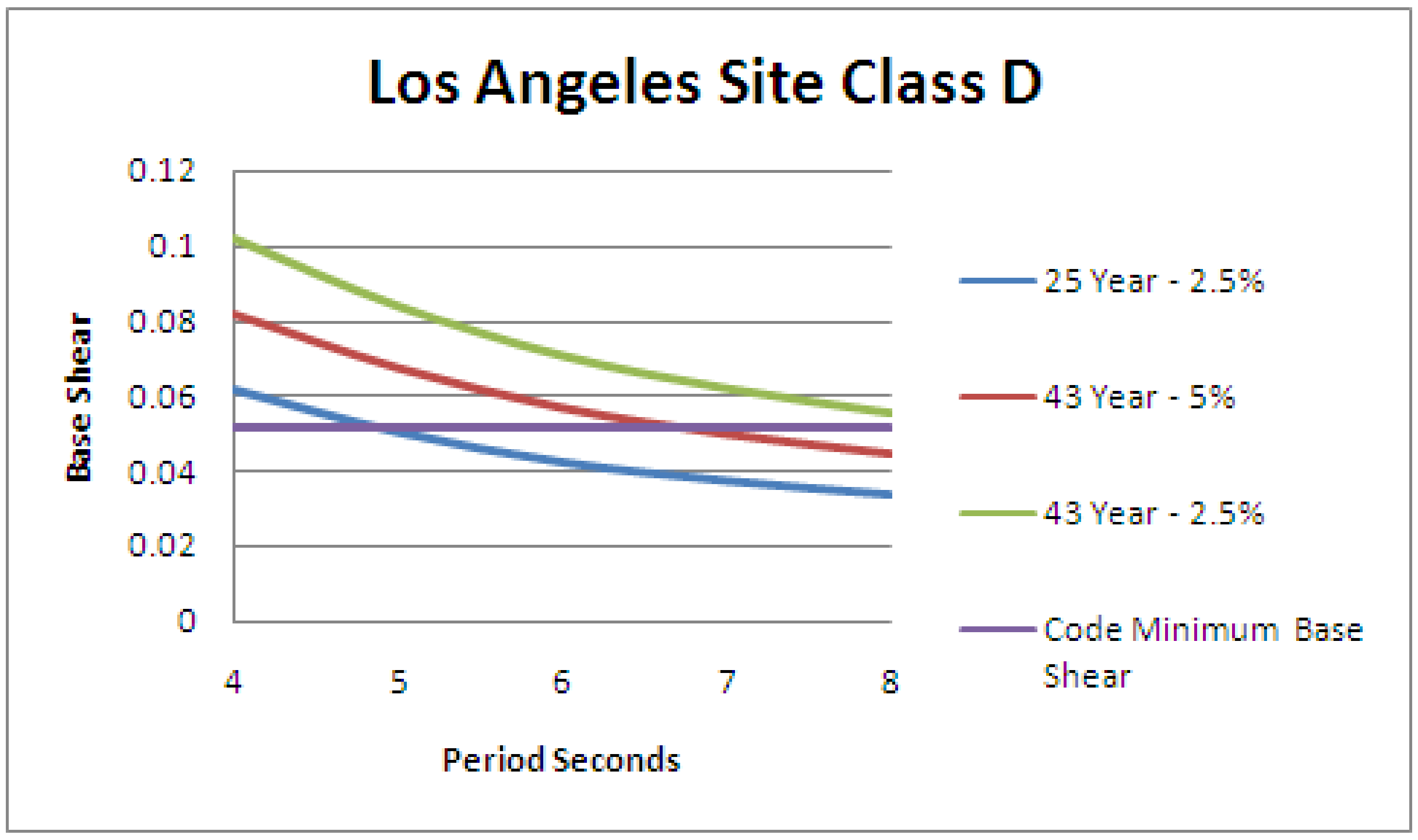
Higher Mode Effects

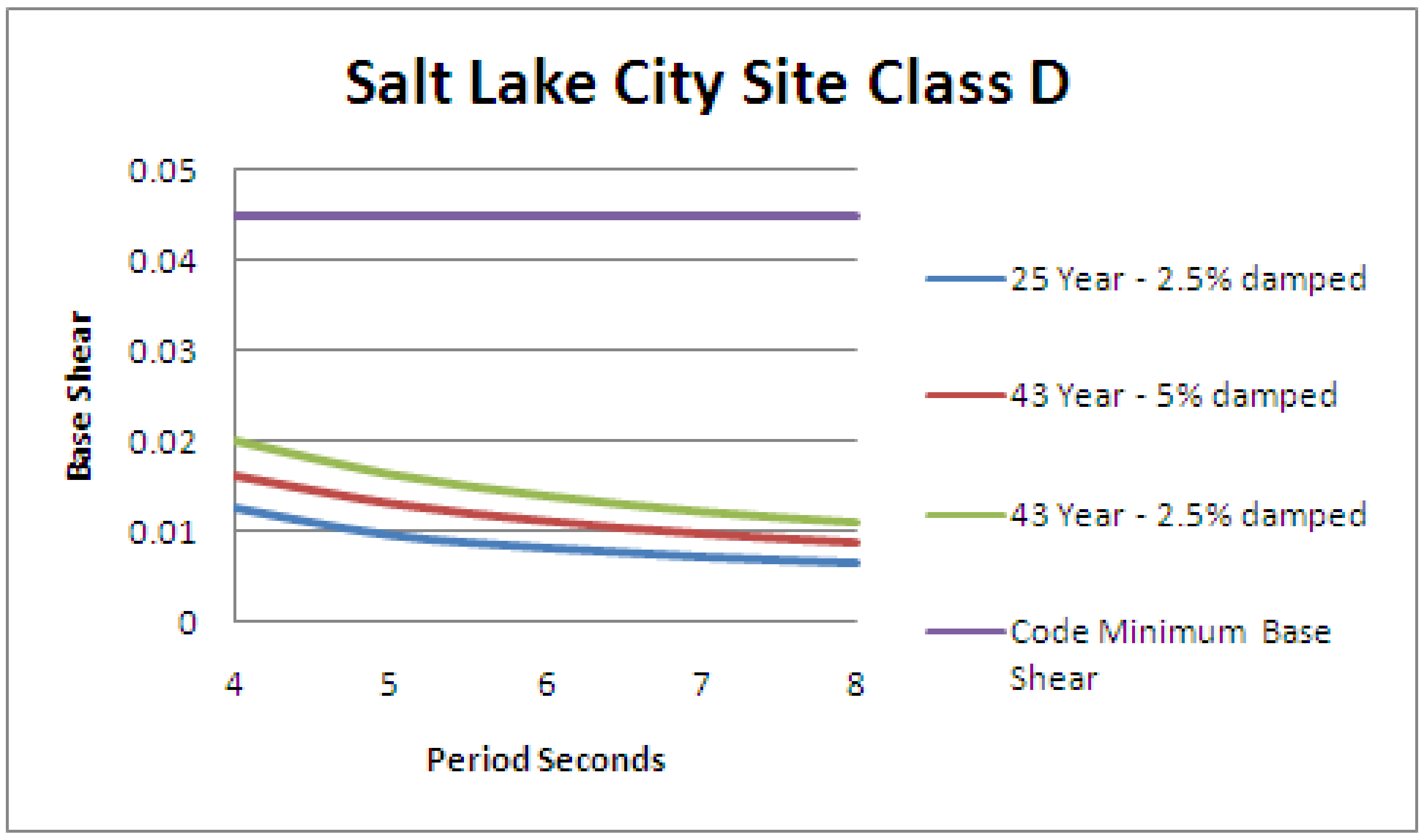
Diaphragms

Nonparticipating elements

Foundations

Service Level Design





50% - 30 years (43 year return)

Elastic analysis – 2.5% damping

Maximum DCRs 150% of expected strength

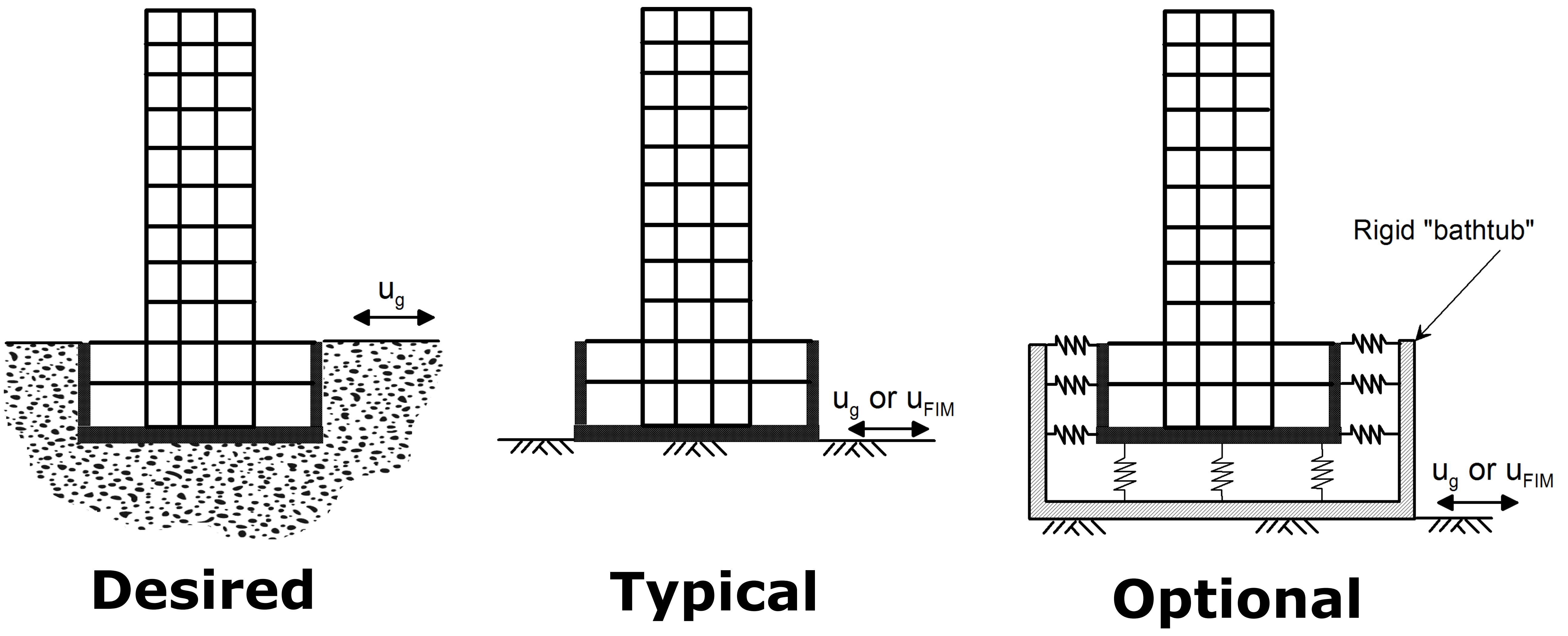
Story drift limited to 0.005

Maximum Considered Level

3-D nonlinear response history analysis

Ground motion input at structure base

SSI Permitted

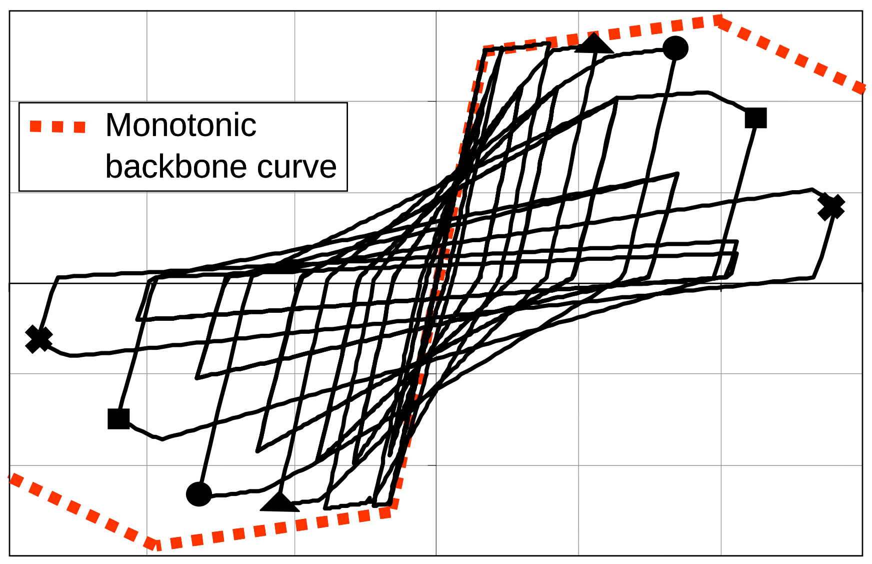


Maximum Considered Level

Modeling must consider degradation effects

Global acceptance criteria

- Transient drift
  - <3 % mean
  - <4.5% any run
- Residual drift
  - <0.01 mean
  - <0.015 any run

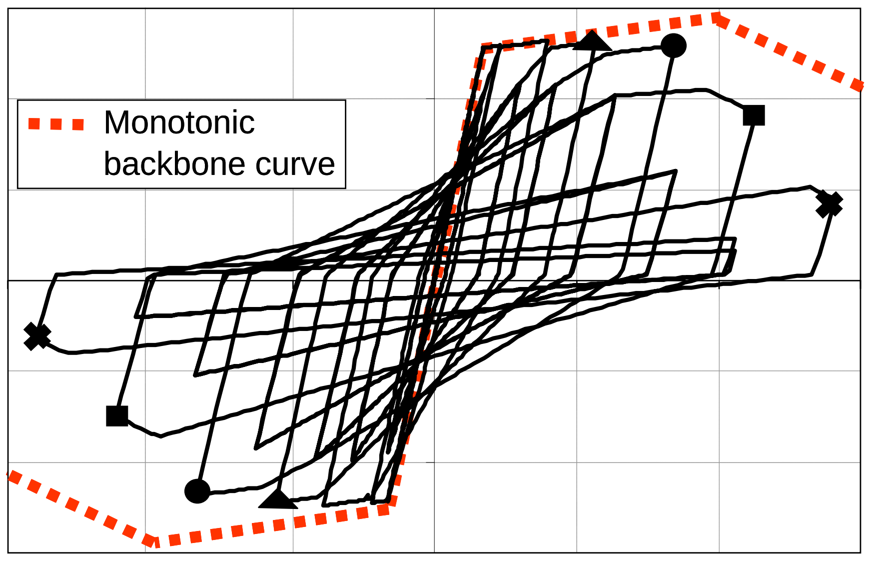


Maximum Considered Level

Component Acceptance

Ductile actions

- Response within validity limits of hysteretic model



Brittle actions

- Inconsequential failure

- Significant consequence

$$\overline{Q} \le Q_{n,e}$$

$$Q_u \le \phi Q_{n,e}$$

$$Q_u = 1.5\overline{Q}; \quad \overline{Q} + 1.3\sigma \ge 1.2\overline{Q}$$

Peer Review

Qualifications

Responsibilities

Documents to be reviewed

Stages of Review

Resolution of concerns

Summary

Successful multi-disciplinary effort

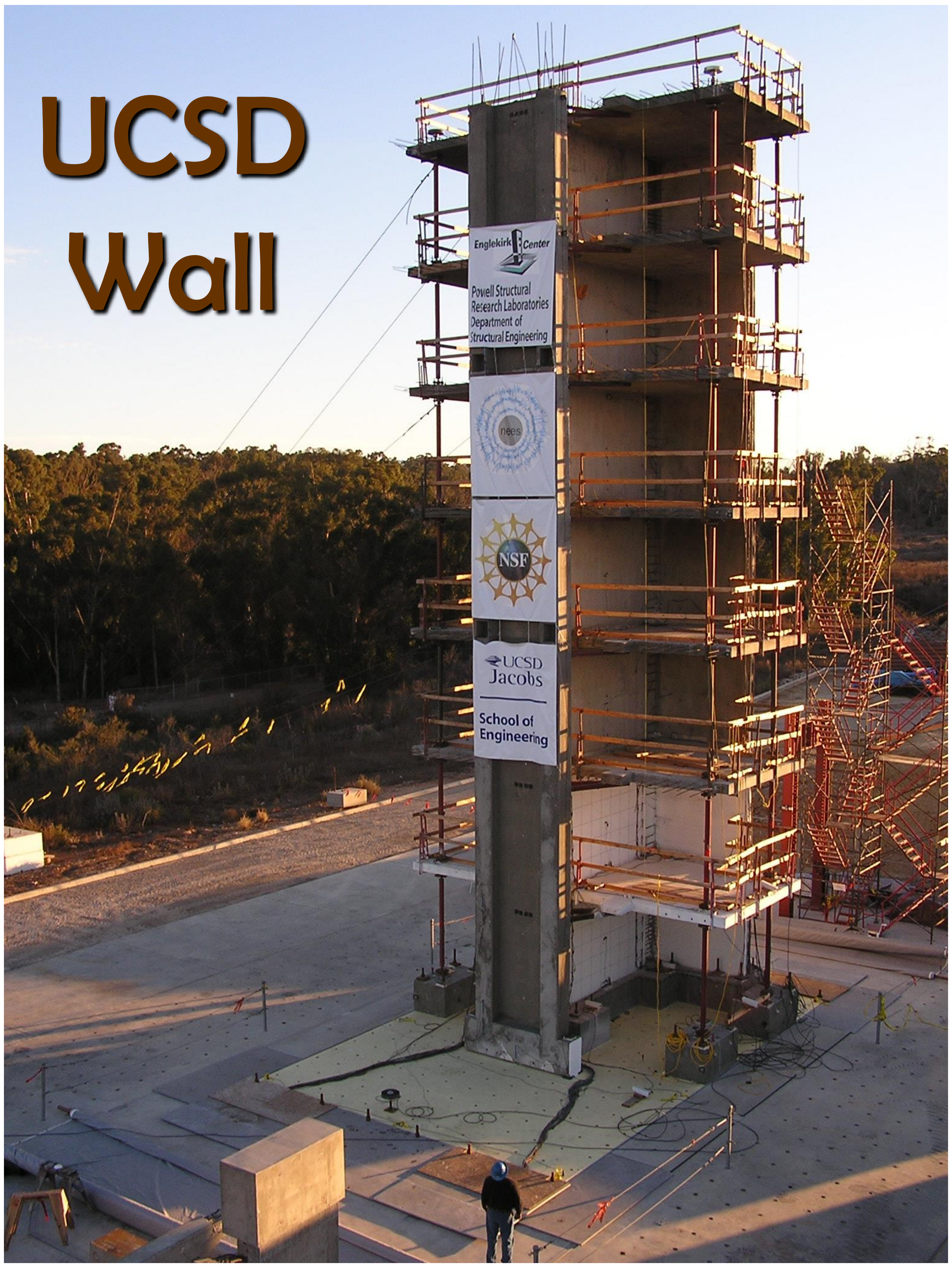
- Geotechnical engineers & Seismologists
- Structural engineers
- Building Officials

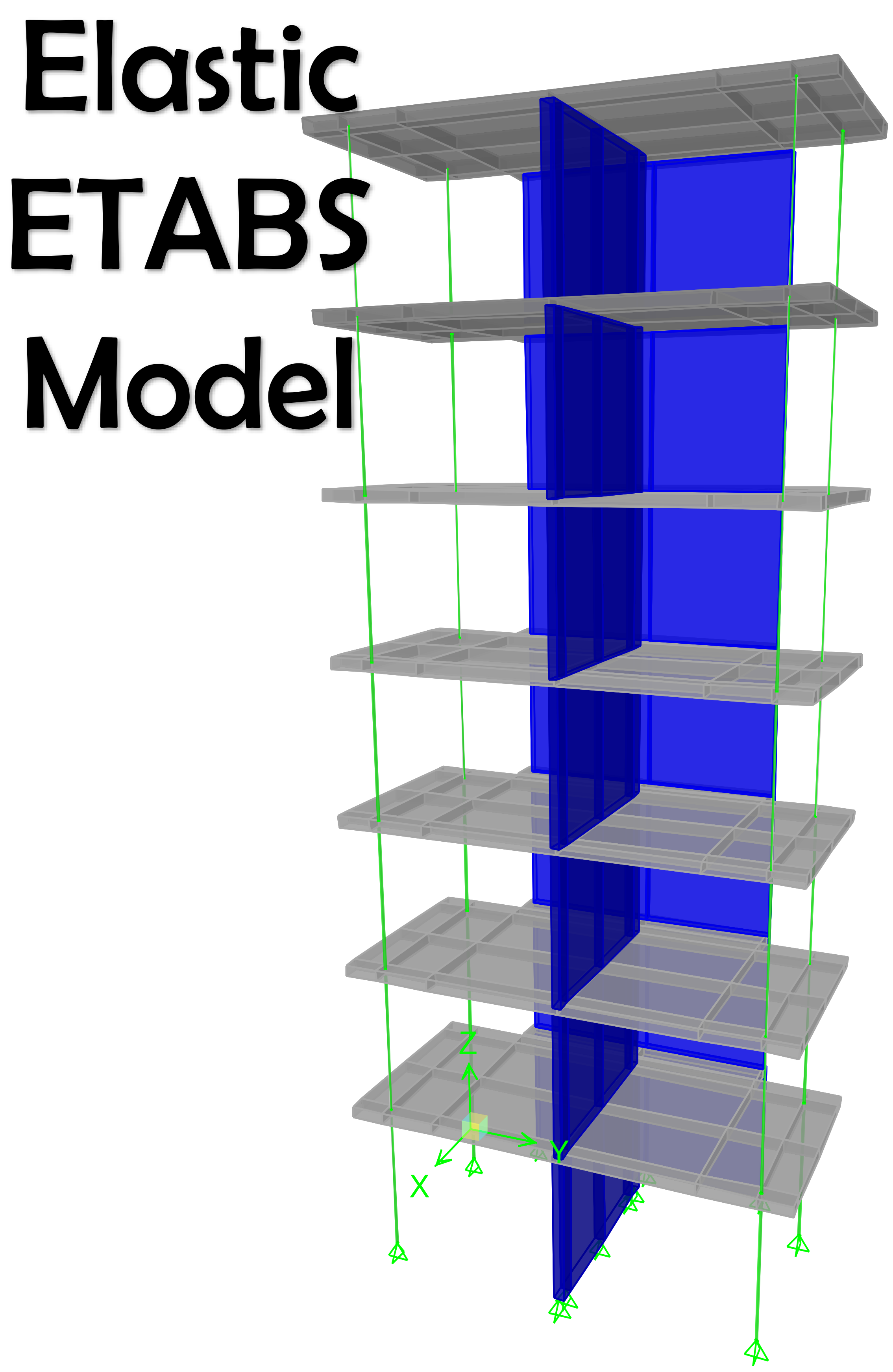
Project has had positive impact on the design of real structures

Has also affected design practice internationally

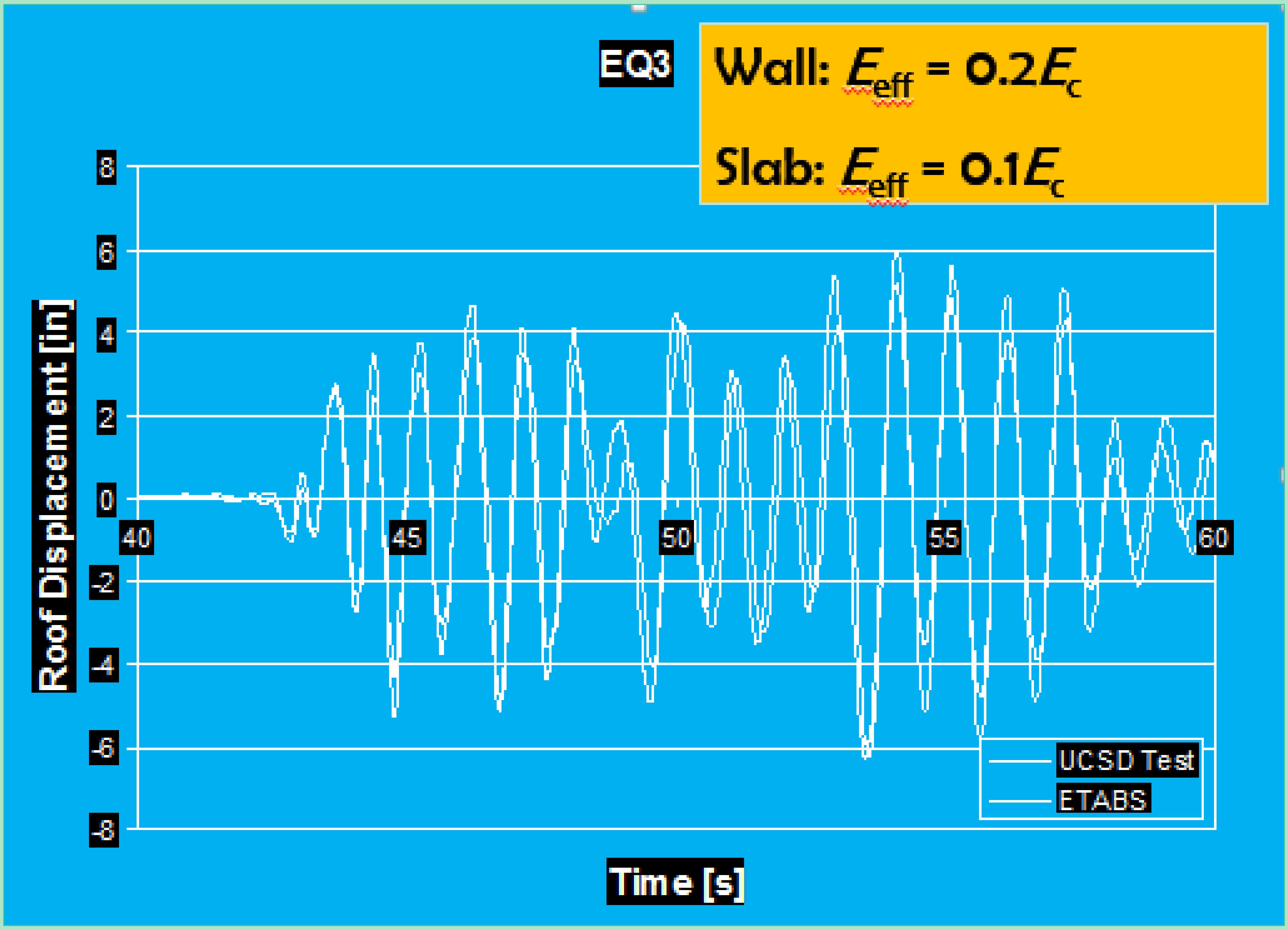
Thank You

Linear and nonlinear modeling assumptions





RUTHERFORD & CHEKENE



RUTHERFORD & CHEKENE