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# Comparing the structural system of some contemporary high rise building form

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**Abstract**

Throughout history, human beings have built tall monumental structures such as temples, pyramids and cathedrals to honour their gods.

Today's skyscrapers are monumental buildings too, and are built as symbols of power, wealth and prestige.

These buildings emerged as a response to the rapidly growing urban population.

Architects' creative approaches in their designs for tall buildings, the shortage and high cost of urban land, the desire to prevent disorderly urban expansion, have driven the increase in the height of buildings.

**The Research Problem:** The increase in the height of buildings makes them vulnerable to wind and earthquake induced lateral loads.

occupancy comfort (serviceability) are also among the foremost design inputs .

Excessive building sway due to wind can cause damage to non-structural elements, the breakage of windows.

**Therefore, It was necessary** to study the different construction systems in the design of the high towers and the study of the impact of wind and earthquakes on the building and on construction.

**The purpose of the research**: Studying the appropriate Structur systems in high rise buildings and comparing the different systems , Determining the design opportunities for different tower construction systems.

Study of vertical and horizontal expansion of buildings and development of large-scale buildings.

**Research Methodology:**

**The research methodology was based on theoretical and analytical Side:**

**Theoretically** The methodology of the study was based on a combination of different structural systems suitable for vertical expansion .

Comparison between the different construction systems and the design of the buildings in high altitude

**Analytically** Study of some examples of high buildings Identification of the elements of comparison between the spaces of the various systems of the construction of towers such as: the possibilities of internal divisions and the opening of spaces on some, , the heights of tower spaces on all roles, the formation of the tower block, internal movement, spatial needs of services.

**Key words**

**Tall Building - Definitions - Challenges - High-rise building process - structural systems.**

## Introduction

Human beings have always been struggling to push the limits of nature in their age-old quest for height, from the legendary Tower of Babel in antiquity, purportedly designed with the aim of reaching heaven, to today's tallest building.

Case studies of some of the world's most iconic buildings, illustrated in full colour, will bring to life the design challenges which they 7U presented to architects and structural engineers. The Empire State Building, the Burj Khalifa, the

Taipei 101 and the Pirelli Building are just a few examples of the buildings whose real-life specifcations are used to explain and illustrate core design principles, and their subsequent effect on the fnished structure.

**1.1 Tall Building:**

"Tall building", "high-rise building" and "skyscraper" are diffcult to defne and distinguish solely from a dimensional perspective because height is a relative matter that changes according to time and place.

While these terms all refer to the notion of very tall buildings, the term "skyscraper" is the most forceful.

The term "high-rise building" has been recognised as a building type since the late nineteenth century, while the history of the term "tall building" is very much older than that of the term "high-rise building".

As for the use of the term "skyscraper" for some tall/high-rise buildings reflecting social amazement and exaggeration(1).

Fig.1 : The longest 10 towers in the world

**1.2 Definition.**

There is no general consensus on the height or number of storeys above which buildings **should be classifed as tall buildings or skyscrapers**.

The architectural/ **structural height of a building** is measured **from the open-air pedestrian entrance to the top of the building**, ignoring antennae and flagpoles.

The **CTBUH (2)** measures the "height to architectural top" from the level of the lowest "signifcant open-air pedestrian entrance" to the architectural top of the building, including spires, but not including antennae, signage, flag poles or other functional-technical equipment.

**1.2.1 According to the CTBUH1**

According to **the CTBUH1 (Council on Tall Buildings and Urban Habitat),** buildings of 14 storeys or 50 metres' height and above could be considered as "tall buildings"; buildings of 300 metres' and 600 metres' height and above are classifed as "supertall buildings" and "megatall buildings" respectively

**1.2.2 According to the Emporis Standards**

According to the Emporis Standards, buildings of 12 storeys or 35 metres' height and above, and multi-storey buildings of more than 100 metres' height, are classifed as "high-rise buildings" and "skyscrapers" respectively (Emporis Data Standards ES 18727, ESN 24419).(3)(1995)

**1.2.3 According to Ali and Armstrong, the authors of Architecture of Tall Buildings**

the tall building can be described as a multistorey building generally constructed using a structural frame, provided with high-speed elevators, and combining extraordinary height with ordinary room spaces such as could be found in low-buildings. In aggregate, it is a physical, economic, and technological expression of the city's power base, representing its private and public investments.

**1.3 Emergence and Historical Development.**

No other symbols of the modern era are more convincing than the gravity defying, vertical shafts of steel, glass, and concrete that are called "skyscrapers."

Like the Greek temples or the Gothic cathedrals that were the foremost building types of their own ages, skyscrapers have become iconic structures of industrial societies. These structures are an architectural response to the human instincts, egos and rivalries that always create an urge to build higher, and to the economic needs brought about by intense urbanisation.

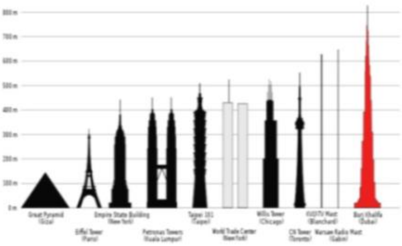


Fig.2 : Emergence and Historical Development

In the late 19th century, the first tower building would have been typically an office building of more than 10 storey's.

The concept was undoubtedly originated in the USA, in Chicago and in New York, where space was limited and where the best option was to increase the height of the buildings.

The Home Insurance Building in Chicago was perhaps the first tower building in the world.

Built in 1884-1885 its height was 42 m/10 storeys.

Monadnock Building, Chicago, USA, 1891

Fig.3: The Home Insurance Building in Chicago

## 1.4 The process of high-rise building.

| Monadnock Building | IBM Building | The John Hancock Center | Swiss Re's |
|---|---|---|---|
|  |  |  |  |

Figure 3. The process of high-rise building. Source: [14].

Tab1: The process of high-rise building .Ref: Tall Buildings Structural Systems and Aerodynamic Form Mehmet Halis Günel and Hüseyin Emre Ilgin

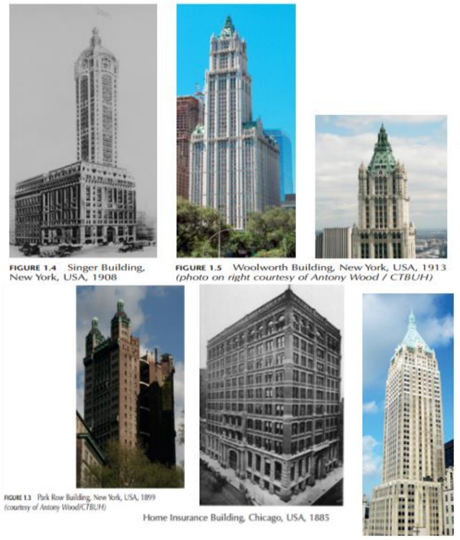



FIGURE 1.6 The Trump Building, New York, USA, 1930

## 2. The Challenges Facing in the Design of Tall Building.

## 2.1 The Effect Of Wind On Tall Building.

At frst wind loads were ignored because the weight of the construction materials and structural systems used in the frst skyscrapers made **vertical loads** more critical than **lateral loads**, but over time wind loads became important, as the strength to weight ratio of construction materials and the ratio of floor area to structural weight in structural systems increased and the total weight and rigidity

**Wind speed and pressure increase parabolically according to height, and therefore wind loads affecting tall buildings become important as the height of the building increases.**

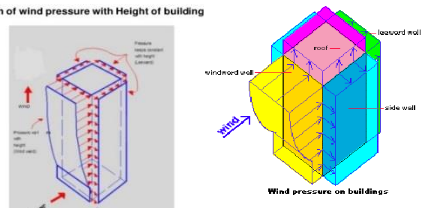



Fig.4: wind pressure on high building .

**In general**, structural design begins to be controlled by wind loads in buildings of more than 40 storeys (ACI SP-97, 1989).

**Today**, thanks to developments in structural systems and to high-strength materials, tall buildings have increased in their height to weight ratio but on the other hand reduced in stiffness compared with their precursors, and so have become greatly affected by wind.

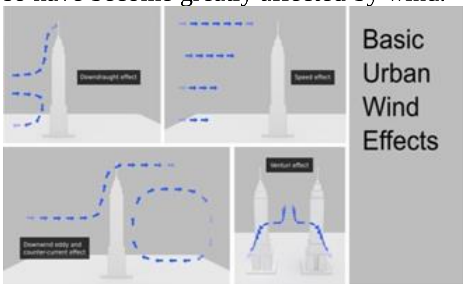


Fig.5:basic wind effects on high building .

**wind-induced building motion**

Wind-induced building motion can essentially be divided into three types:

- along-wind motion
- across-wind motion
- torsional motion

## 2.2 The Effect of earthquakes

Earthquakes are the propagation of energy released as seismic waves in the earth when the earth's crust cracks, or when sudden slippage occurs along the cracks as a result of the movement of the earth's tectonic plates relative to one another. With the cracking of the earth's crust, faults develop.

Over time, an accumulation of stress in the faults results in sudden slippage and the release of energy. The propagation of waves of energy, formed as a result of seismic movement in the earth's cru the building foundations and becomes the earthquake load of the building. In determining earthquake loads, the characteristics of the structure and records of previous earthquakes have great importance. Compared with wind loads, earthquake loads aremore intense but of shorter duration..st, acts .

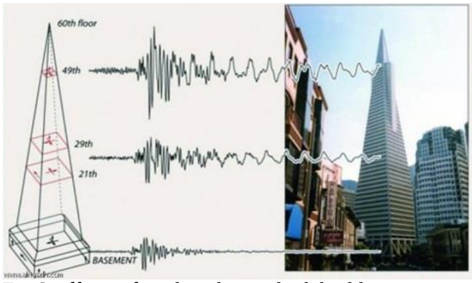


Fig.6: effects of earthquakes on high building .

**The lateral inertia forces on a structure created by an earthquake are functions of:**

1) the magnitude and duration of the earthquake.

2) the distance of the structure from the centre of the earthquake (epicentre) .

3) the mass of the structure, the structural system and the soil-structure interaction.

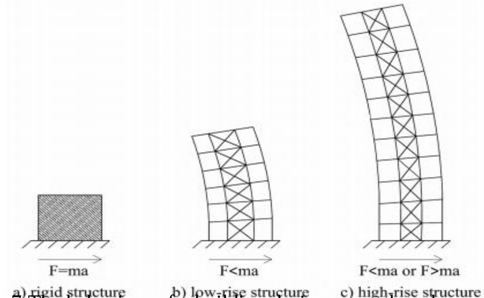


Fig7:The behaviour of a building during an earthquake

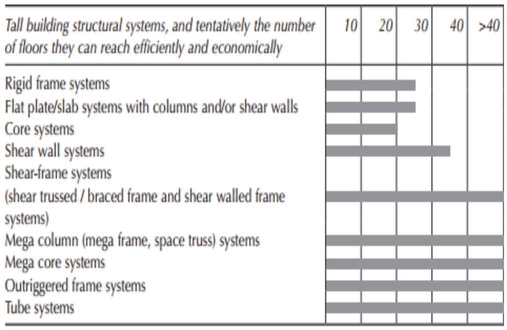
## 2.3 The Structural system of Tall Buildings.

The set of tall building structural systems has developed over time, starting with rigid frame systems, and with the addition of shear-frame, mega column (mega frame, space truss), mega core, outriggered frame, and tube systems, it has made much taller buildings possible.

**Today, many tall building structural systems and classifcations are discussed in the literature and used in practice (Khan, 1969; Khan, 1973; Schueller, 1977; Smith and Coull, 1991; Taranath, 1998). Steel, reinforced concrete and composite structural systems for tall buildings can be categorised by their structural behaviour under lateral loads**

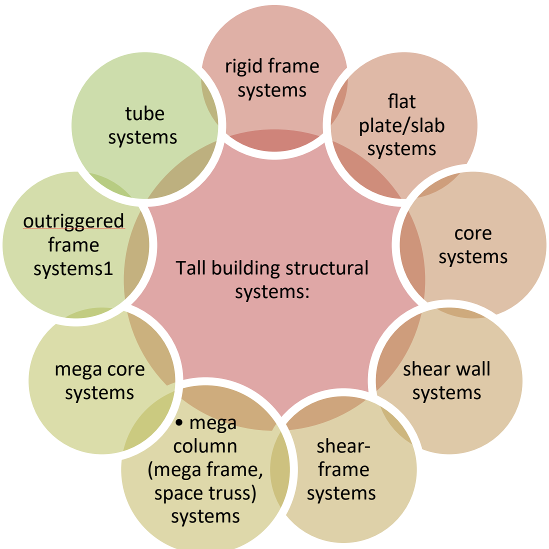
Fig.8 : The Structural system of Tall Buildings..

## Tall building structural systems and the number of floors they can reach :

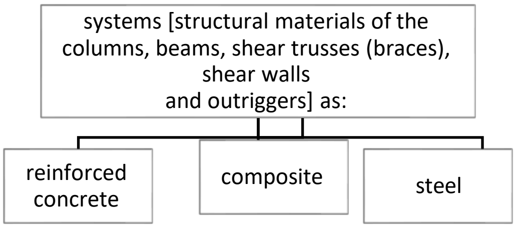



Tab.2 :no.of floors to The Structural system of Tall Buildings..
Ref: Tall Buildings Structural Systems and Aerodynamic Form Mehmet Halis Günel and Hüseyin Emre Ilgin

## Tall building structural systems




1) Rigidframe systems.
2) flat plate/slab systems.
3) core systems.
4) shear wall systems.
5) shear-frame systems .
6) mega column (mega frame, space truss) systems.
7) mega core systems.

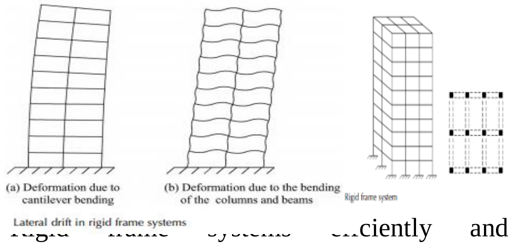



8) outriggered frame systems.
9) tube systems .

### 2.4.1 Rigid frame systems

**Rigid frame systems, also called moment frame systems, are used in steel and reinforced concrete buildings. This system consists of beams and columns.**

**A rigid frame is an unbraced frame that is capable of resisting both vertical and lateral loads by the bending of beams and columns.**




Rigid frame systems [illegible]ciently and economically provide suffcient stiffness to resist wind and earthquake induced lateral loads in buildings of up to about 25 storeys. Some examples of tall buildings .

**using the rigid frame system with steel structural material include:**

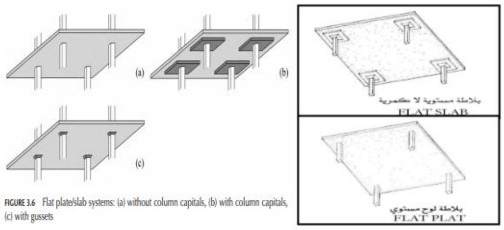
• the 12-storey, 55m high Home Insurance Building(Chicago,1885)
• the 21-storey, 94m high Lever House (New York, 1952.


Fig.9 : the 12-storey, 55m high Home Insurance Building (Chicago,1885)
• the 21-storey, 94m high Lever House (New York, 1952)

**2.4.2 Flat plate/slab system**

Flat plate/slab systems are used in reinforced concrete buildings. This system consists of beamless floor slabs of constant thickness and columns. Shear walls also can be placed in addition to or instead of the columns (a).

Column capitals (b) or gussets (c) can be placed on the upper ends of the columns in order to reduce the punching effect created by shear forces in the connections between the columns and slabs. Using a flat ceiling instead of one with beams, and thus attaining the net floor height, is a major architectural advantage of this system.



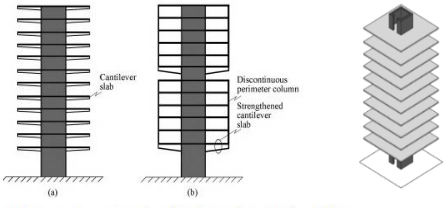

**2.4.3 Core systems**

Core systems are used in reinforced concrete buildings. This system consists of a reinforced concrete core shear wall resisting all the vertical and lateral loads.

**In general**, a core wall is an open core that is converted into a partially closed core by using floor beams and/or slabs so as to increase the lateral and torsional stiffness of the building.

Although the behaviour of closed cores is ideal against building torsion under lateral loads, a partially closed core is used to approximate this for architectural reasons.

Thus, a partially closed core is produced by supporting the open part of the core with



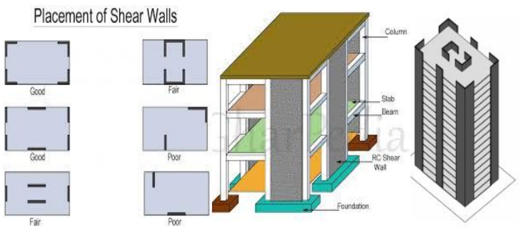

beams and/or slabs having satisfactory strength against shear and bending

**2.4.4 Shear wall systems**

Shear wall systems are used in reinforced concrete buildings. This system consists of reinforced concrete shear walls, which can be perforated (with openings) or solid.

Shear wall systems can be thought of as a vertical cantilever rigidly fxed at the base, and can resist all vertical and lateral loads on a building without columns.

Shear wall systems effciently and economically provide suffcient stiffness to resist wind and earthquake induced lateral loads in buildings of up to about 35 storeys.




**2.4.5 Shear-frame systems.**

Rigid frame systems economically do not have suffcient resistance against lateral loads in buildings over 25 storeys because of bending on columns that causes large deformations. In this case, the total stiffness and so the economical height of the building can be increased by adding vertical shear trusses (braces) and/or shear walls to the rigid frame to carry the external shear induced by lateral loads This interactive system of frames and shear trusses and/or shear walls is called the "shear-frame system", and is quite effective against lateral

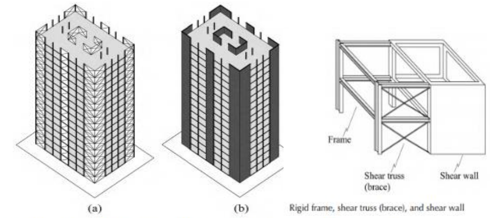



Fig.10: shear trussed frame (braced frame) system
Fig.11: shear walled frame system

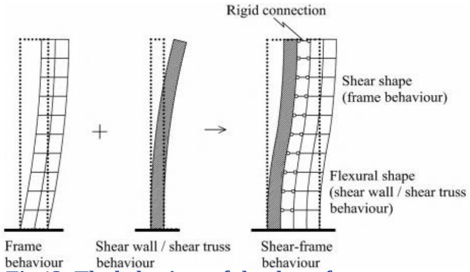



**Fig.12: The behaviour of the shear-frame system under** lateral loads

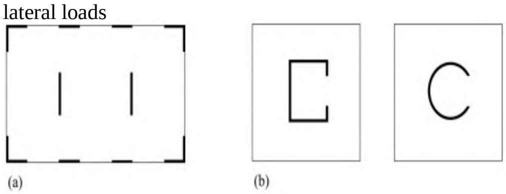



Fig.13: (a) Shear trusses / shear walls in plan, (b) partially closed cores in plan

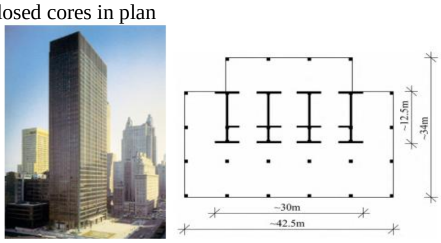
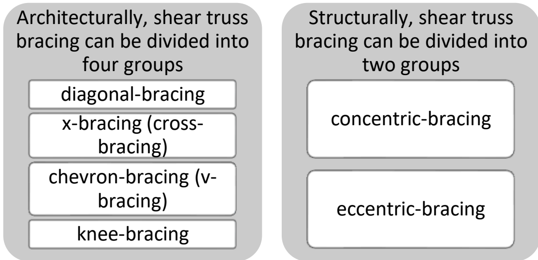



Fig.14: Seagram Building, New York, USA, 1958 (photo courtesy of Antony Wood / CTBUH)

## 2.4.5.1 Shear trussed frame (braced frame) systems.

Shear trussed frame (braced frame) systems consist of rigid frames and braces in the form of vertical trusses .

Diagonal brace elements between the columns of the rigid frame create a truss frame at that bay where those columns act as vertical continuous chords. Columns, beams and braces are generally made of steel, sometimes composite, but rarely are of reinforced concrete.



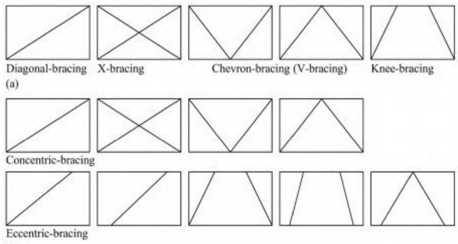




Fig.15: Types of bracing

## 2.4.5.2 Shear walled frame systems

Shear walled frame systems consist of rigid frames and reinforced concrete shear walls that are perforated or solid.

**In general**, shear walls are of reinforced concrete; occasionally of composite formed by concrete encased structural steel, or of steel plates.

Columns and beams are reinforced concrete, steel or composite. Some examples of tall buildings using the shear walled frame system with reinforced concrete structural material include:

the 32-storey, 127m high Pirelli Building (Milan, 1958) (the frst reinforced concrete building utilising the interactive system of rigid frames and shear walls)

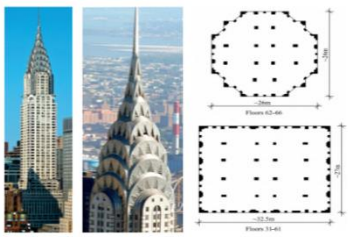


Fig.16: Chrysler Building, New York, USA, 1930(photo on Rightcourtesy of Antony Wood/CTBUH)

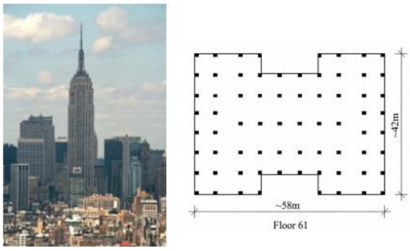



Fig.17: Empire State Building, New York, USA, 1931(photo courtesy of Antony Wood/CTBUH)

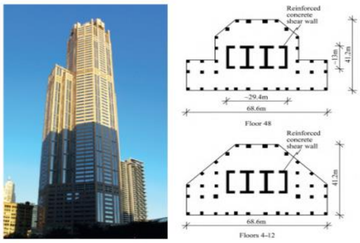
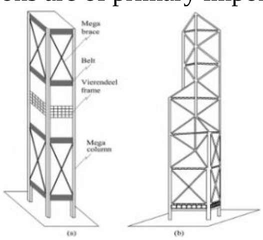



Fig.18: 311 South mWacker Drive, Chicago, USA, m1990(photo courtesy ofm Marshall Gerometta/CTBUH)

**2.4.6 Mega column (mega frame, space truss) systems.**

Mega column systems consist of reinforced concrete or composite columns and or shear walls with much larger cross-sections than normal, running continuously throughout the height of the building. In this system, mega columns and/or mega shear walls can resist all the vertical and lateral loads .

In mega column systems, horizontal connections are of primary importance.




Mega column (mega frame, space truss) system

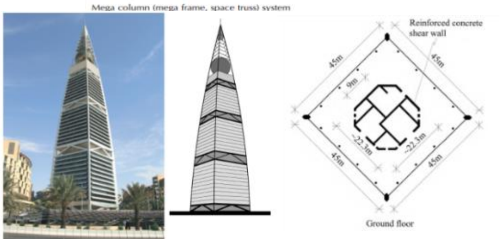



Fig.19: Al Faisaliah Center, Riyadh, Saudi Arabia, 2000

Fig.20: Commerzbank Tower, Frankfurt, Germany, 1997

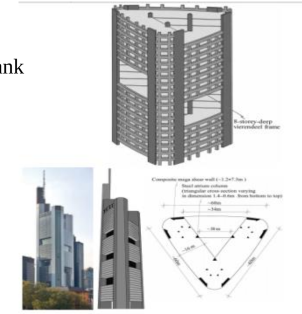
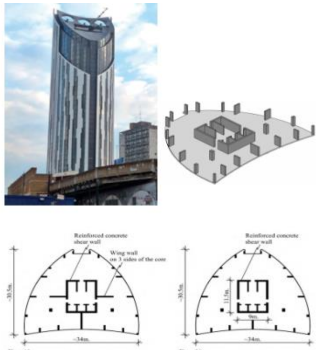


Fig.21: Strata, London, UK, 2010



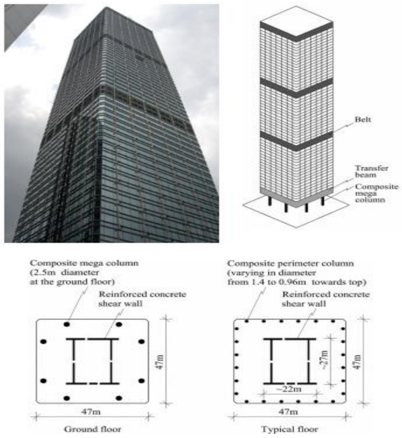
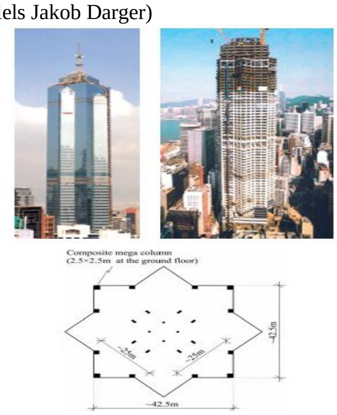




Fig.22: Cheung Kong Centre, Hong Kong, China, 1999 (photo courtesy of Niels Jakob Darger)

Fig.23: The Center, Hong Kong, China, 1998 (photos courtesy of Derek Forbes)



## 2.3.7 Mega core systems.

Mega core systems consist of reinforced concrete or composite core shear walls with much larger cross-sections than normal, running continuously throughout the height of the building.

Since the mega core can resist all vertical and lateral loads in this system, there is no need for columns or shear walls on the perimeter of the building. In mega core systems, floor slabs are cantilevered from the core shear wall (a).

Mega core systems can also be used with strengthened cantilever slabs (b).

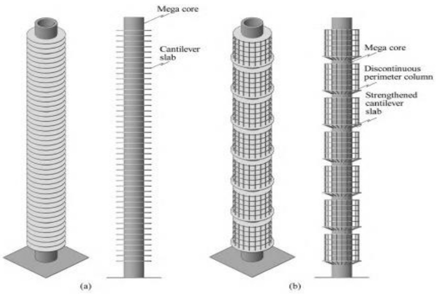
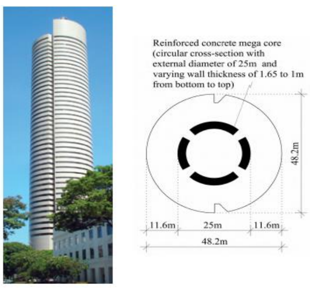



Fig.24: Slabs in the mega core system: (a) cantilever slab, (b) supported cantilever slab


Fig.25: Aspire Tower, Doha, Qatar, 2006 (credit for Photo: CTBUH)

Fig.26;
8 Shenton Way,
Singapore,
Singapore, 1986



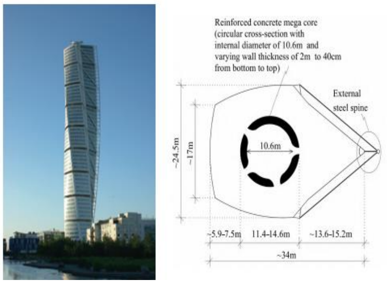




Fig.27 : HSB TurningTorso, Malmö, Sweden, 2005(photo courtesy of Santiago Calatrava/SamarkArchitecture & Design)

## 2.4.8 Outriggered frame systems.

Outriggered frame systems have been developed by adding outriggers to shear-frame systems with core (core-frame systems) so as to couple the core with the perimeter (exterior) columns. The outriggers are structural elements connecting the core to the perimeter columns at one or more levels throughout the height of the building so as to stiffen the structure .

An outrigger consists of a horizontal shear truss or shear wall (or deep beam).

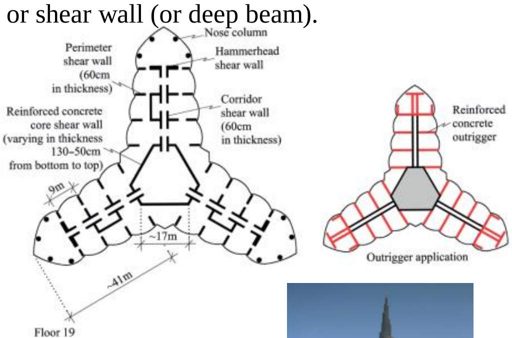



Fig.28:
Burj Khalifa, Dubai,
U.A.E, 2010

## 2.4.9 Tube systems.

The tube system was innovated in the early 1960s by the famous structural engineer Fazlur Rahman Khan who is considered the "father of tubular design" (Weingardt, 2011).

The tube system can be likened to a system in which a hollow box column is cantilevering from the ground, and so the building exterior exhibits a tubular behaviour against lateral loads.

This system is evolved from the rigid frame system and can be defned as a three dimensional rigid frame having the capability of resisting all lateral loads with the facade structure.

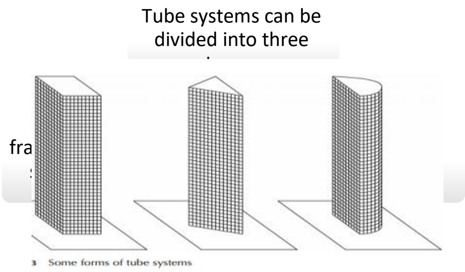



Fig.29;The Plaza on Dewitt, Chicago, USA, 1966 (photocourtesy of Marshall Gerometta/CTBUH)

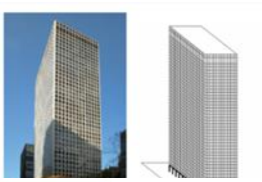


Fig.30 : The First Canadian Centre, Calgary, Canada, 1982 (photo courtesy of Fiona Spalding -Smith)

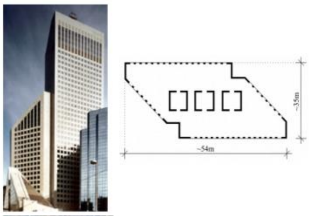



Fig.31 World Trade Center Twin Towers, New York, USA, 1972

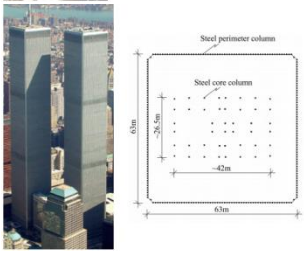
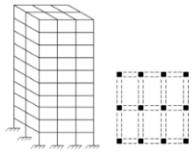
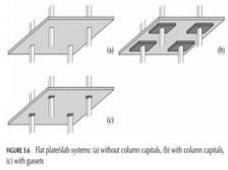
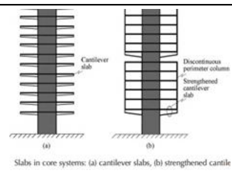
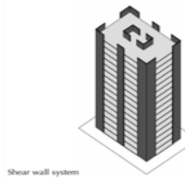
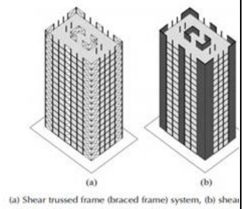
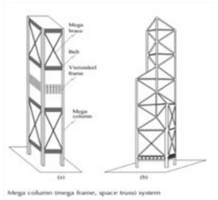
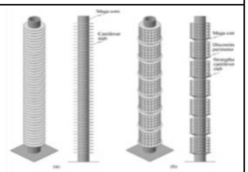
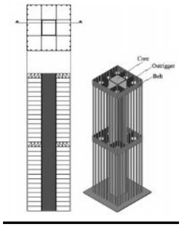
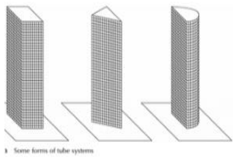



Fig.32: CCTV Headquarters, Beijing, China, 2011 (courtesy of M.Bunyamin Bilir)

**<u>Comparison of high buildings structur system: number of storeys and Picture of each system</u>**

| **<u>structur system</u>** | **<u>Picture</u>** |
|---|---|
| **<u>Rigid frame systems</u>**<br>up to about 25 storeys |  |
| **<u>Flat plate/slab systems</u>**<br>(a) without column capitals,<br>(b) with column capitals,<br>(c) with gussets<br>up to about 25 storeys |  |
| **<u>Core systems</u>**<br>(a) cantilever slabs. (b) strengthened cantilever slabs.<br>up to about 35storeys. | <br> |
| **<u>Shear wall systems</u>**<br>up to about 35 storeys. | <br> |
| **<u>Shear-frame systems</u>**<br>(a) Shear trussed frame (braced frame) system.<br>(b) shear walled frame system.<br>Up to 38-storey | <br> |
| **<u>Mega column (mega frame, space truss) systems</u>**<br><br>Up to 73-storey |  |
| **<u>Mega core systems</u>**<br>(a) cantilever slab.<br>(b) supported cantilever slab.<br>Up to 57-storey. |  |

| | |
|---|---|
| **Outriggered frame systems**<br>Up to 163-storey |  |
| **Tube systems**<br>a)framed-tube systems<br>b)trussed-tube systems<br>c) bundled-tube systems<br>Up to 40 storeys |  |

Moreover, it was the winner of "Global Icon Award 2010" by CTBUH; "Best Tall Building 2010, Middle East and Africa" by CTBUH; and "Distinguished Building Award" in 2011 by AIA (American Institute of Architects).

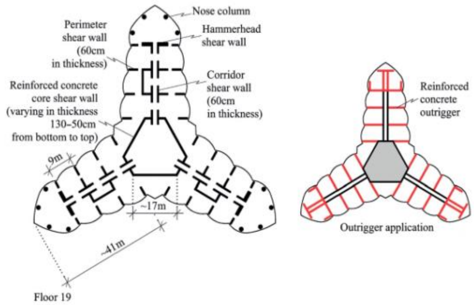


Fig.33: Burj Khalifa plan and structural axonometric

**Thehexagonal central core** consists of reinforced concrete shear walls with thicknesses varying between 130cm at the bottom to 50cm at the top (below the spire) through the height of the building

## 3. Examples and analysis

### 3.1Burj Khalifa

**official name**: Burj Khalifa (formerly Burj Dubai).


Fig.32: Burj Khalifa

**location**: DubaiU.A.E.
**building function**: Mixed-use (hotel, residential, offce).
**architectural height**: 828m
**number of storeys**: 163.
**status**: Completed.
**completion**: 2010.
**architect**: Skidmore, Owings & Merrill – SOM; Hyder Consulting.
**structural engineer**: William F. Baker (SOM).
**structural system**: Outriggered frame system/reinforced concrete.

**Burj Khalifa: Architectural and Structural information**

It is a reinforced concrete building with an outriggered frame system. The system is also classifed as a buttressed core system.

**The Burj Khalifa gained the title of "the world's tallest building" in 2010.**

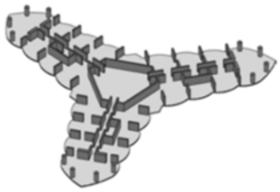


Fig 34:Burj Khalifa plan and structural axonometric.

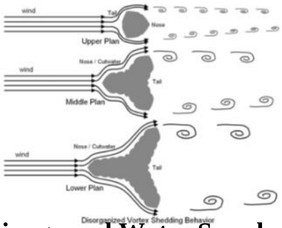
**The structural system of the Burj Khalifa is composed of a hexagonal central core and outriggers.**

The slab system on each storey consists of two-way reinforced concrete flat plates that vary between 20 and 30cm in depth as they pass through spaces of approximately 9m between the nose columns, perimeter shear walls and the hexagonal central core.

**Facing Wind force :**

Wind force was dominant in the lateral loading and it was accepted that the maximum lateral drift at the top of the building would be 1.2m. The setbacks and wings on the building were developed using wind tunnel tests on a 1:500 scale model and at every stage the form of the building was re-shaped after repeating these tests, which resulted in a reduction of the wind load to an absolute minimum

Fig 35:
Wind force




**Water drainage and Water Supply** ;

Drainage of water through tanks in which pipes are collected after each set of floors
In the beginning, a pump is connected to push the water up. The main reservoir in each of the floors is filled until the last reservoir is filled. The floors are fed by pipes that connect the water to each floor.

Fig 36: The reservoir is located between each set of floors and huge pipes

Fig 37: Water flow from the main pump to the last reservoir

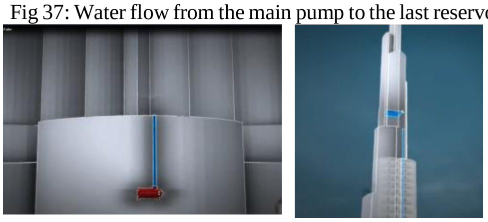
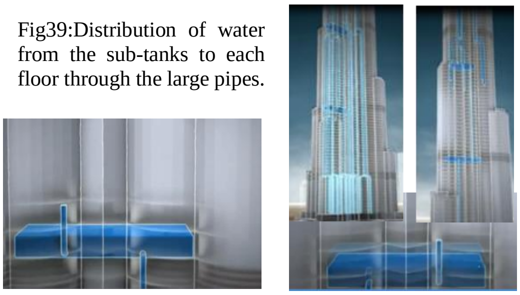


Fig38: Fill the sub-tanks on the floors

Fig39:Distribution of water from the sub-tanks to each floor through the large pipes.



## 3.2 Commerzbank Tower

**official name**: Commerzbank Tower.
**location**: Frankfurt, Germany.
**building function**: Offce.
**architectural height**: 259m.
**number of storeys**: 56.
**status**: Completed.
**completion**: 1997.
**architect**: Foster + Partners.
**structural engineer**: Ove Arup & Partners; Krebs und Kiefer.
**structural system**: Mega column system/ Composite**.**

Fig38:Commerzbank Tower

**Architectural and structural information**

The 56-storey, 259m high Commerzbank Tower in Frankfurt (Germany) was designed by Foster + Partners.
The Commerzbank Tower gained the title of “the tallest buildingin Europe” in 1997.
It won the “Green Building Award of the City of Frankfurt” in 2009 in recognition of the building’s pioneering role in environmentally friendly and energy-saving architecture.
Other prestigious awards include “RIBA Architecture Award”, “Bund Deutscher Architekten–Martin-Elsaesser-Plakette Award” and “British Construction Industry Award”.

Fig39:The exterior elevation of the building

Norman Foster (the architect), indicated that two important factors were central to the design of the Commerzbank Tower: i) the transparency of the building to light and to views and ii) the incorporation of nature. These two unique design features were attained by the innovative structural design of the building. The structural and environmental innovations were the major success factors of the design of the building.

Fig 40:
transparency of the building
to light and incorporation of nature

**The environmentally conscious**

Commerzbank Tower has an equilateral triangular plan with gently rounded corners and slightly curved sides each measuring at about 60m.

As a result of this plan scheme, the building performs better against wind pressure compared to a building having a rectangular plan.

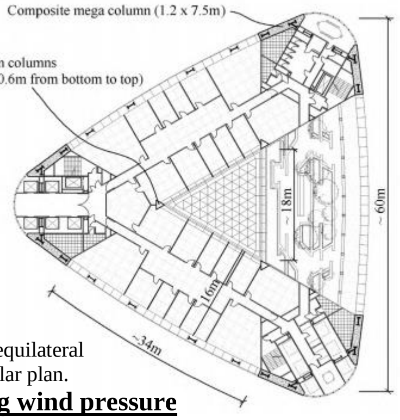


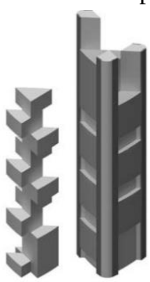

Fig41: equilateral
triangular plan.

**Facing wind pressure**

wind pressure compared to a building having a rectangular plan. The building's main design feature is the central triangular atrium and its relationship with the corner cores.

This full height central atrium is supported by triangular steel columns at the corners which vary 140cm to 60cm from bottom to top.

The central atrium is surrounded by landscaped sky gardens, which spiral up the building to form the visual and social focus of offce floors.



The relationship of the central atrium with the spiralling sky gardens

**The glass curtain wall** enclosed sky gardens also improve the environmental conditions inside the building, bringing daylight and fresh air into the central atrium, which acts as a natural ventilation chimney for the inward facing offces. Hence, all offces can gather direct sunlight and fresh natural air due to the availability of sky.

Fig42:The glass curtain wall

**structural system information**:

The building's unique design had been made possible by a structural system which is

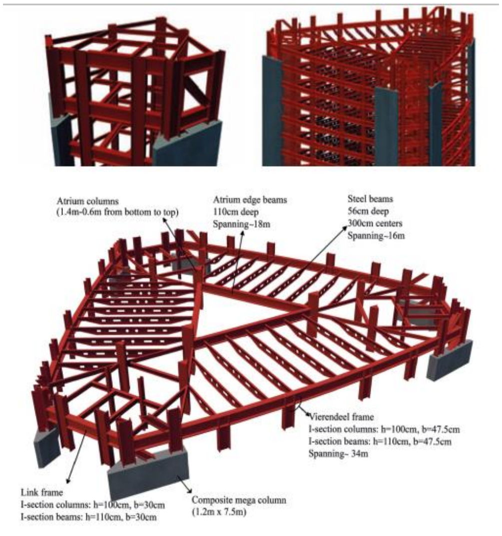



FIGURE 4.39 Commerzbank Tower structural axonometrics

composed of corner cores consisting composite mega columns (shear walls) coupled by steel link frames and steel Vierendeel frames coupling these cores.

The two composite mega columns in corners consist of diagonally braced two vertical steel H-section profles encased in reinforced concrete. Each core, having two mega columns with dimensions 1.2x7.5m, is connected to the other with the 8-storey-deep and 34m spanning Vierendeel frames along the outside of the building. Besides connecting the corner cores, these frames provide the structure to span sky gardens between the cores

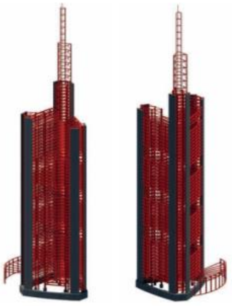


Fig 43 : The two composite mega columns

### 3.3 HsB Turning Torso

**official name**: HSB Turning Torso

**location**: Malmö, Sweden

**building function**: Residential

**architectural height**: 190m

**number of storeys**: 57

**status**: Completed

**completion**: 2005

**architect**: Santiago Calatrava

**structural engineer**: SWECO

**structural system**: Mega core system/reinforced concrete.

**Architectural and structural information:**

The 57-storey, 190m high HSB Turning Torso in Malmö (Sweden) was designed by Santiago Calatrava. It is a reinforced concrete building with a mega core system. The HSB Turning Torso was awarded a prize by the International Concrete Federation as "the world's most technically interesting and spectacular reinforced concrete building constructed in the last 4 years".

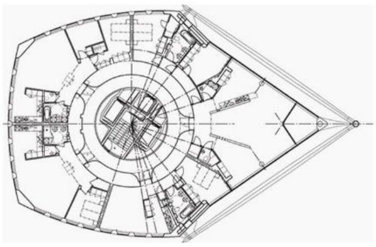
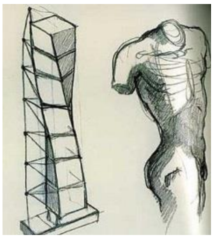


Fig44: HSB Turning Torso plans

**The HSB Turning Torso,** is an important project in the redevelopment plan for the residential zone in the industrial district known as "the Western Harbour".

**The design concept of the building**



Building, which has become an icon for Malmö, was designed as a response to the need for housing. The well-known Spanish architect/engineer Santiago Calatrava, the designer of the building, was inspired in designing the HSB Turning Torso by his own sketch entitled "Twisting Torso". The sketch, which depicts a turning human body (torso), guided the form of the building and consists of 9 modules positioned on top of one another, with a facade twisting through 90˚ from bottom to top.

**Structural information:**

The central mega core supports the entire vertical and lateral loads. It is a reinforced concrete core shear wall having circular cross-section with an internal diameter of 10.6m and wall thickness varying from 2m to 40cm from bottom to top so that its external diameter varies between 14.6 to 11.4m (from bottom to top)

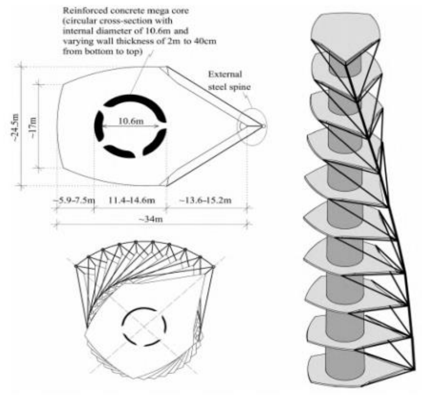



FIGURE 4.11 HSB Turning Torso plans and structural axonometric

Fig45: HSB Turning Torso plans and structural axonometric.

**Three edges of the pentagonal** shaped floor slabs are slightly curved and the other two edges forming the apex of the pentagon are straight. Reinforced concrete floor slabs in the modules are cantilevered from the core and are supported by discontinuous steel perimeter columns

down through the height of the modules. The bottom slab of each module is a strengthened cantilever floor slab which supports the perimeter columns of the upper storeys in the module. While floor slabs are 27cm thick, strengthened cantilever slabs of modules that protrude from the core are 90cm thick at the cantilever root reducing to 40cm at the perimeter.

In addition to the mega core, a reinforced concrete perimeter column and an exoskeleton (an exterior truss), both with the same rotation as the tower, are located at the tip of the triangular part of the floor slabs.

The exoskeleton is attached to the modules by horizontal and diagonal steel members.

Both the perimeter column and the exoskeleton not only help to support the cantilevered floor slabs, but contribute positively to the central core by reducing the lateral drift of the building created by wind loads.

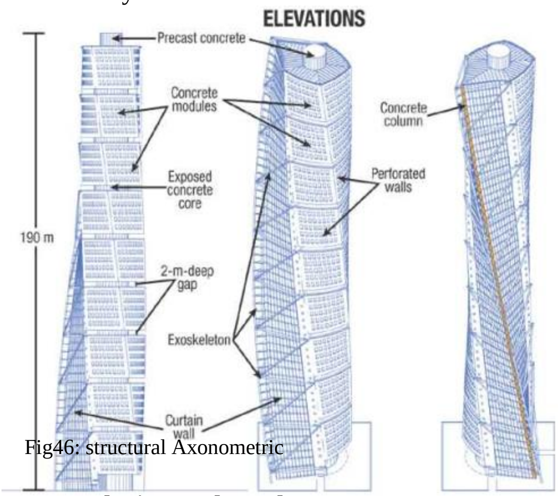



Fig46: structural Axonometric

## 4.Conclusion and results:

1) Tall building", "high-rise building" and "skyscraper" are diffcult to defne and distinguish solely from a dimensional perspective because height is a relative matter that changes according to time and place.

2) Today's skyscrapers are monumental buildings too, and are built as symbols of power, wealth and prestige.

3) These buildings emerged as a response to the rapidly growing urban population, with the aim of meeting the demand for offce units to be positioned as closely as possible to one another.

4) Study the high buildings and study the different irrigation systems suitable for them and study the impact of wind and earthquake loads and feeding systems and drainage in them.

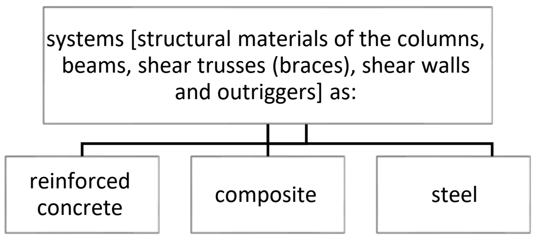
5) Know the definition of high buildings (According to the CTBUH1- According to the Emporis Standards- According to Ali and Armstrong, the authors of Architecture of Tall Buildings).

6) Study The Challenges Facing in the Design of Tall Building(The Effect Of Wind On Tall Building- The Effect of earthquakes- The Structural system of Tall Buildings ) .

7) Study The Structural system of Tall Buildings

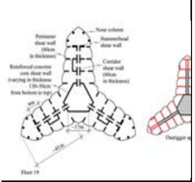
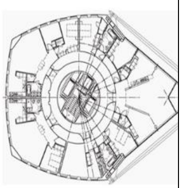
1) rigid frame systems.
2) flat plate/slab systems.
3) core systems.
4) shear wall systems.
5) shear-frame systems .
6) mega column (mega frame, space truss) systems.
7) mega core systems.
8) outriggered frame systems.
9) tube systems .

8)

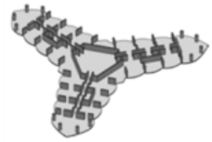
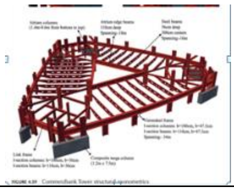
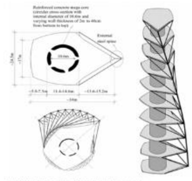



9) Wind-induced building motion can essentially be divided into three types ( along wind motion – across wind motion – torsional motion

**<u>Comparison between three of the most important and tallest buildings in the world in terms of structural system, height, number of floors, building function, date of construction, architect and structural engineer:</u>**

| **Tower Name** | **Tower Pictures** | **Architectural information** | **structural information** |
|---|---|---|---|
| **Burj Khalifa** |   | **official name**: Burj Khalifa (formerly Burj Dubai).<br>**location:** DubaiU.A.E.<br>**building function**: Mixed-use (hotel, residential, offce)<br>**architectural height**: 828m.<br>**number of storeys**: 163.<br>**status**: Completed.<br>**completion**: 2010.<br>**architect**: Skidmore, Owings & Merrill – SOM; Hyder Consulting.<br>**structural engineer**: William F. Baker (SOM). | **structural system:**<br>Outriggered frame system/reinforced concrete.<br>The structural system is composed of a hexagonal central core and outriggers . The slab system on each storey consists of two-way reinforced concrete flat plates that vary between 20 and 30cm in depth as they pass through spaces of approximately 9m between the nose columns, perimeter shear walls and the hexagonal central core. |
| **Commerzbank Tower** |   | **official name**: Commerzbank Tower.<br>**location**: Frankfurt, Germany.<br>**building function**: Offce.<br>**architectural height**: 259m.<br>**number of storeys**: 56.<br>**status**: Completed.<br>**completion**: 1997.<br>**architect**: Foster + Partners.<br>**structural engineer**:<br>Ove Arup & Partners;<br>Krebs und Kiefer. | **structural system:**<br>Mega column system .<br>The 2 mega columns in corners consist of diagonally braced 2 vertical steel H-section profles. Each core, having 2 mega columns with dimensions 1.2x7.5m, is connected to the other with the 8-storey-deep and 34m spanning Vierendeel frames |
| **HsB Turning Torso** |   | **official name**: HSB Turning Torso.<br>**location**: Malmö, Sweden<br>**building function**: Residential<br>**architectural height**: 190m<br>**number of storeys**: 57<br>**status**: Completed<br>**completion**: 2005<br>**architect**: Santiago Calatrava<br>**structural engineer**: SWECO | **structural system**:<br>Mega core system/reinforced concrete.<br>The central mega core supports the entire vertical and lateral loads.<br>It is a reinforced concrete core shear wall having circular cross-section with an internal diameter of 10.6m and wall thickness varying from 2m to 40cm from bottom to top so that its external diameter varies between 14.6 to 11.4m (from bottom to top) |

**<u>Similarity or variation:</u>**

| **Tower Name** | **Tower Pictures** | **variation** |
|---|---|---|
| **Burj Khalifa** |  | 1-Mixed-use (hotel, residential, offce)<br>2- height: 828m.<br>3- storeys: 163.<br>4- structural: Outriggered frame system / reinforced concrete.  |
| **Commerzbank Tower** |  | 1-Offce.<br>2- height: 259m.<br>3- storeys: 56.<br>4- Mega column system .  |
| **HsB Turning Torso** |  | 1-Residential<br>2- height: 190m<br>3- storeys: 57.<br>4- Mega core system/reinforced concrete.  |

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# **<u>مقارنة بين أنظمة الأنشاء المختلفة لبعض المبانى المعاصرة عالية الارتفاع .</u>**


**<u>الملخص :</u>**

على مر التاريخ ، بنى البشر مبانى ضخمة مثل المعابد والأهرام والكاتدرائيات لتكريم آلهتهم.

التى تقابلها اليوم ناطحات السحاب فهى عبارة عن مبانٍ ضخمة ، وهي مبنية كرموز للسلطة والثروة والمكانة, ظهرت هذه المباني كاستجابة لسكان الحضر الذين يتزايدون بسرعة, لجأ المعماريون للتمدد الرأسى وبناء المبانى شاهقة الارتفاع بسبب التزايد المستمر فى الحضر وتقلص الاراضى التى ادت الى ارتفاع تكلفتها , وهو سبب زيادة ارتفاع المبانى

**<u>مشكلة البحث:</u>** الزيادة في ارتفاع المباني تجعلها عرضة لأحمال الرياح والزلازل الناجمة عن الأحمال الجانبية, حيث يمكن أن يؤدي النفاذ الشديد للرياح فى المبانى إلى تلف العناصر غير الإنشائية ، وكسر النوافذ.

ولذلك ، كان من الضروري دراسة أنظمة الانشاء االمختلفة في تصميم الأبراج العالية ودراسة تأثير الرياح والزلازل على المبنى وعلى البناء.

**<u>الغرض من البحث</u>:** دراسة أنظمة الانشاء المناسبة في المباني الشاهقة ومقارنة النظم المختلفة ، وتحديد فرص التصميم لأنظمة بناء الأبراج المختلفة.

دراسة التوسع الرأسي والأفقي للمباني وتطوير المباني ذات البحور الواسعة والارتفاعات العالية.

**<u>مناهج البحث العلمي: استندت منهجية البحث على الجانب النظري والتحليلي:</u>**

**<u>نظريًا</u>** استندت منهجية الدراسة إلى مجموعة من الأنظمة الهيكلية المختلفة المناسبة للتوسع الرأسي.

مقارنة بين أنظمة البناء المختلفة وتصميم المباني عالية الارتفاع .

**<u>تحليلياً</u>**:دراسة تحليلية لبعض الأمثلة على المباني العالية تحديد عناصر المقارنة بين فراغات مختلف أنظمة إنشاء الأبراج مثل: إمكانيات التقسيمات الداخلية وفتح الفراغات على بعض، توجيه البرج للخارج (أو الداخل)، بحور وأرتفاعات فراغات البرج على كافة الأدوار، التشكيل فى كتلة البرج، مواد البناء، الحركة الداخلية، الإحتياجات الفراغية للخدمات مثل الحركة الرأسية والحمامات والأجهزة الكهروميكانيكية.