International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 11 Nov 2021, pp: 875-885 www.ijaem.net ISSN: 2395-5252

Evaluation of different structural systems for High Rise Construction

1st Smita Sambhaji Patil.
Student of Third Year B.Tech Civil Engineering,
Rajarambapu Institute of Technology, Rajaramnagar Islampur, Tal-Walwa, Dist-Sangli, State-Maharashtra, India.

Submitted: 10-11-2021 Revised: 24-11-2021 Accepted: 27-11-2021

ABSTRACT-
Nowadays, there is a huge increase in the population across the world day by day. This results in a large number of houses and other structures. To save the land area in a congested environment it is good to construct tall buildings and hence, it is becoming more popular and now it is fashionable to construct high rise buildings. To construct any kind of high rise construction there is need of planning and design of its structural system according to parameters like vertical loads as well as lateral loads caused by wind or seismic gravity. There are different types of structural systems that the paper reviews in detail with their suitability.
Keywords-High rise buildings, structural systems, interior structures, exterior structures, braced-frame structures, tube structures, hybrid structures.

I. INTRODUCTION-

There is no specially mentioned demarking line to separate high rise buildings and low rise buildings. However, as per the methods used in the world, the buildings above twenty stories could be considered as high rise buildings [1]. Design of structural frames for high rise buildings is one of the most complex design tasks in structural engineering.

The commonly used structural forms can be classified into different categories, counting on sorts of stresses which will arise in the structural members due to application of loads [2]. The tall buildings shall be designed to withstand the gravitational loads and lateral loads due to actions of wind, earthquake, etc. There is a need to develop a method that would simultaneously reflect the impacts of decision making on the cost and environment. The design making process involves selection of the best alternative from several possible options. The selection is based on evaluation of relevant qualitative and quantitative criteria.

What is a structural system?
In building construction, the particular method of assembling and constructing structural elements of a building so that they support the transmission of applied loads safely to the ground without exceeding the allowable stresses in the members. Correct structural system is to provide stability and durability.

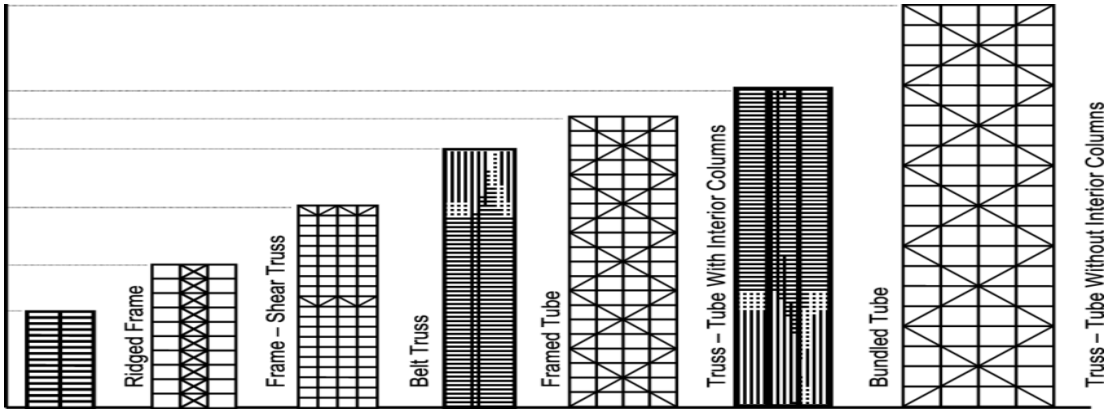

Fig.1) Structural systems for high-rise buildings
Source- www.slideshare.net (accessed on 02-09-2021 21:50:28)

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It is designed to cope with vertical gravity loads as well as lateral loads caused by wind or seismic gravity.

A classification of the structural system of a high-rise building introduced in 1969 by Fazlur Khan and was extended to incorporate interior and exterior structures. Classification of structural systems is as below-

Types of structural systems-

1. Braced frame structural system
2. Rigid frame structural system
3. Wall frame system (dual system)
4. Shear wall system
5. Core and outrigger structural system
6. In filled frame structural system
7. Flat plate and flat slab structural system
8. Tube structural system
9. Coupled wall system
10. Hybrid structural system

1 Braced Frame structural system-

This technique employs steel construction; it is both an efficient and economical way for improving the lateral stiffness and resistance of rigid frame system [2].

The bracing will almost eliminate the bending of columns and beams by resisting lateral loads primarily through axial stress, thus allowing for slenderer elements.

In braced frames the lateral resistance of the structure is provided by diagonal members that together with the girders, form the 'web' of the vertical truss, with the columns acting as the 'chords'.

For ex. Empiring State Building, John Hancock center etc.

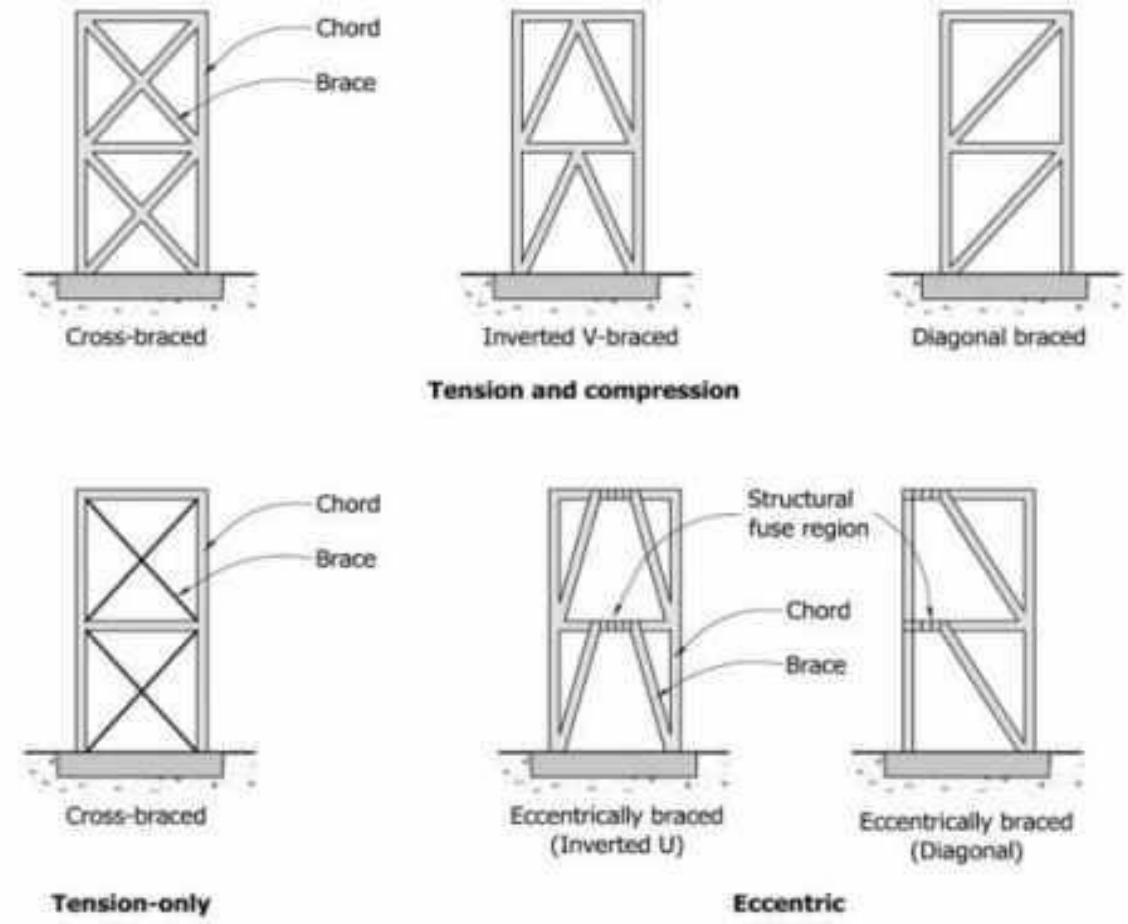

Fig.2) Braced Frame structural system

Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

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Fig.3) Braced Frame structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

2 Rigid Frame structural system-

It is also called as moment frame system that is used in steel and reinforced concrete buildings.It is an un braced frame that can resist both vertical and lateral loads by bending of beams and columns.

Reinforced concrete is an ideal material for this system by its naturally monolithic behaviour resulting with inherent rigidity at connections [2].

The structural stiffness of rigid frames is directly proportional to the cross sectional dimensions and bending rigidity of the beams and columns and inversely proportional to their length and spacing.

For buildings constructed in regions of high seismic activity the details of the connections between structural elements are very important because of the need for ductile behaviour in the rigid frame due to the large lateral drift during severe earthquakes.

For ex. Burj Khalifa

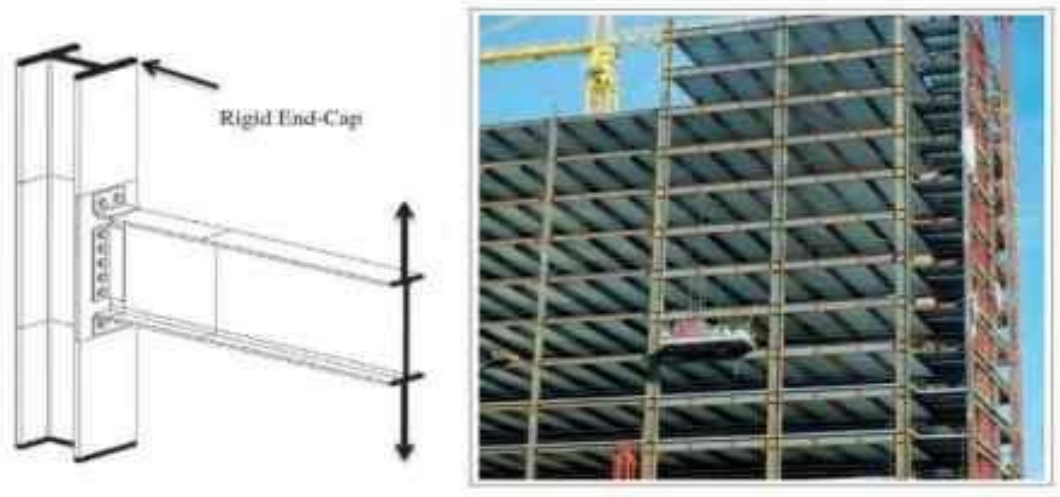

Fig. 4) Rigid Frame structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

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3 Wall Frame structural system (Dual system)-

Wall frame structures are considered as one of the most efficient and economical propositions for tall buildings.

It consists of assembly of shear walls and moment resisting frames.

The system is less weight and earthquake effect than the solid shear wall system, and has a good ductility [5].

At the same time, the system has simple construction, high economic efficiency and good energy-saving emission reduction effect.

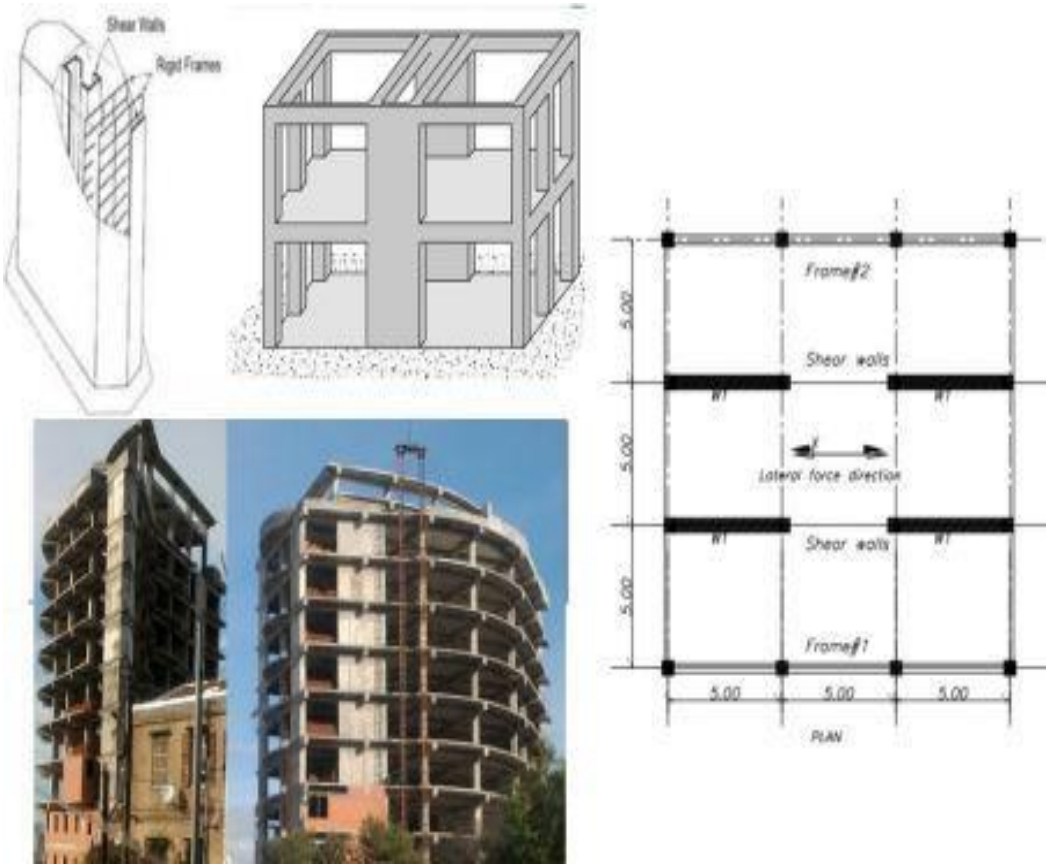

Fig.5) Wall Frame structural system (Dual system)

Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

4 Shear wall structural system-

This system consists of reinforced concrete shear walls which can be perforated (with openings) or solid. Here, as a vertical cantilever frigidly fixed at the base, can resist all vertical and lateral loads on a building without columns.

Owing to the nature of cantilever behaviour, the inter-storey drift between adjacent floors is greater in the upper floors than in the other floors. For this reason, in super tall buildings it is difficult to control the lateral drift at the building top.

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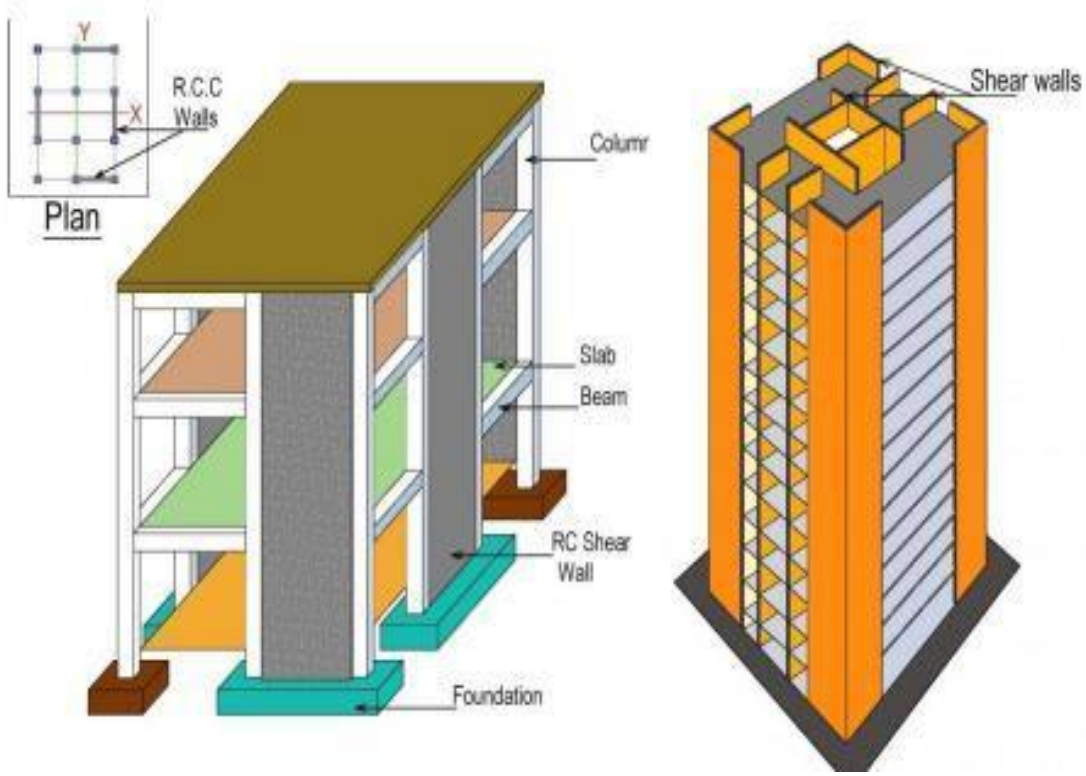

Fig.6) Shear wall structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

5 Core and outrigger structural system-

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

The flexural rigidity of the core in the systems is limited by the flexural depth of the core. The outriggers are structural elements connecting the core to the perimeter columns at one or more levels through the height of the building to stiffen the structure. This structural element is a horizontal extension of the core shear truss/wall to the perimeter columns in the form of a knee.

For ex. Shanghai World Financial Centre, China.

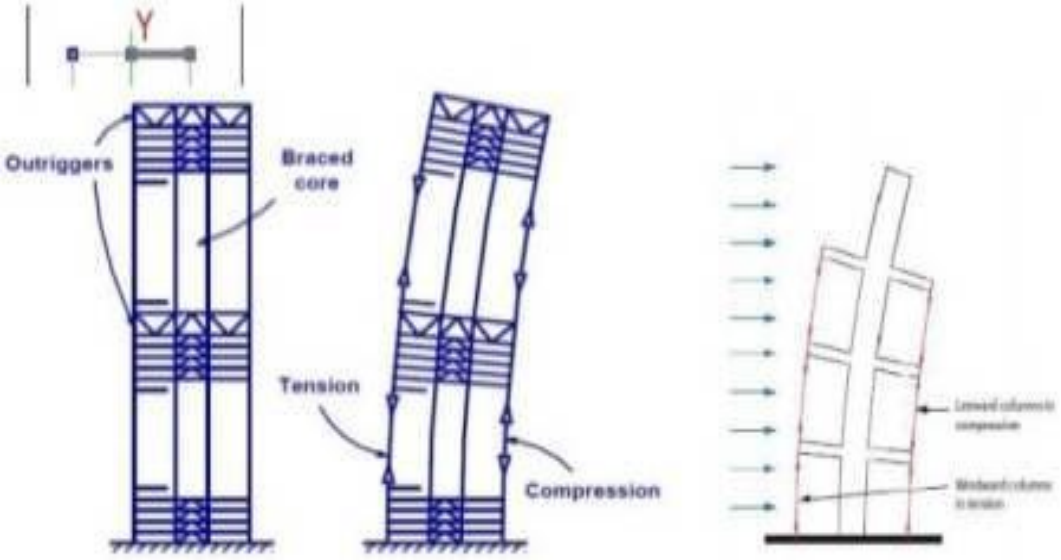

Fig.7) Core and Outrigger structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

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6 In Filled Frame structural system-

Infilled frame structure system consist of a beam and column framework that some of the bays are infilled with masonry, reinforced concrete, or block walls.

Infill walls can be part-height or completely fill the frame.The walls may or may not be connected to the formwork.

Great in plane stiffness and strength of the walls prevent bending of beams and columns under horizontal loads. As a result, frame structural performance will be improved [6].

During an earthquake, diagonal compression struts form in the infills so the structure behaves more like a Braced Frame rather than a Moment Frame. It can build up to 30 storey buildings.

Fig.8) In Filled Frame structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

7 Flat plate and Flat slab structural system-

This system consists of slabs (flat or plate) connected to columns (without the use of beams). Flat plate is a two-way reinforced concrete framing system utilizing a slab of uniform thickness, the simplest of structural shapes.

The flat slab is a two-way reinforced structural system that includes either drop panels or column capitals at columns to resist heavier loads and thus permit longer spans.

Lateral resistance depends on the flexural stiffness of the components and their connections, with the slab corresponding to the girder of the rigid frame. Suitable for building up to 25 stories.

Fig. 9) Flat plate and Flat slab structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

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8 Tube structural system-

This system consists of exterior columns and beams that create a rigid frame, and an interior part of the system which is a simple frame designed to support gravity loads.

The building behaves like an equivalent hollow tube. It is substantially economic and needs half of the material required for the construction of ordinary framed buildings. Lateral loads are resisted by various connections, rigid or semi-rigid, supplemented where necessary by bracing and truss elements. It is used for the construction of buildings up to 60 storeys.

Types of tube structure system include framed tube system, trussed tube system, bundled tube system and tube in tube system. Trussed tube system is formed when external bracing is added to make a structure stiffer. This structure type suitable for building up to 100 storeys.

Bundled tube system consists of connected tubes and it withstands massive loads. A tube-in-tube system (hull core) is obtained, if the core is placed inside the tube frame structure.

For ex. Plaza on DeWitt, Chicago.

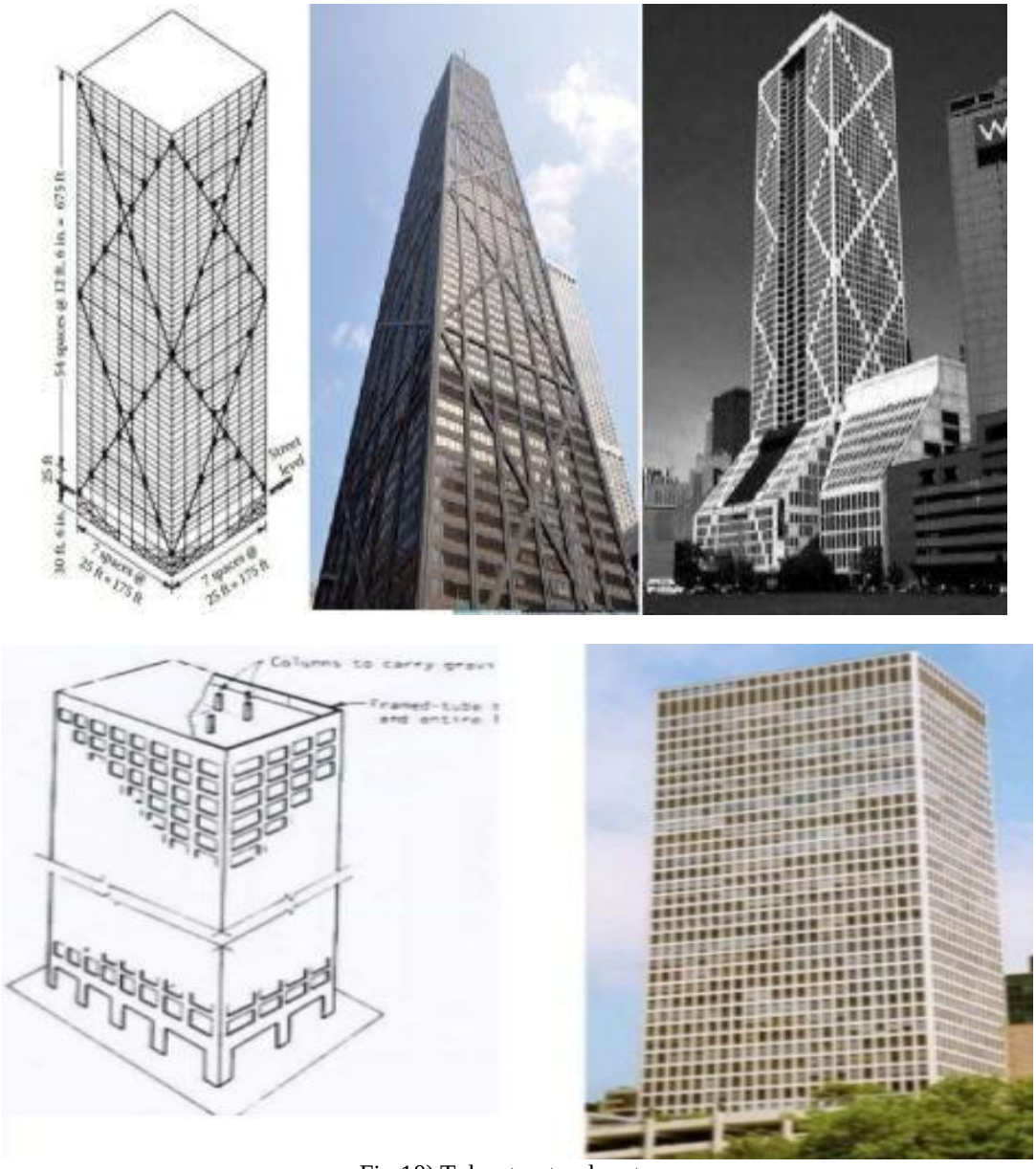

Fig.10) Tube structural system

Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

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9 Coupled wall structural system-

This system composed of two or more interconnected shear walls Shear walls connected at the floor levels by beam or stiff slabs. Stiffness of the whole system is far greater than that of its components.

The effect of the shear-resistant connecting members is to cause the sets of walls to behave partly as a composite cantilever, bending about the common centroidal axis of the walls. The system is suitable for buildings up to 40 storey height.

Since planar shear walls support loads in their plane only, walls in two orthogonal directions need to withstand lateral loads in two directions.

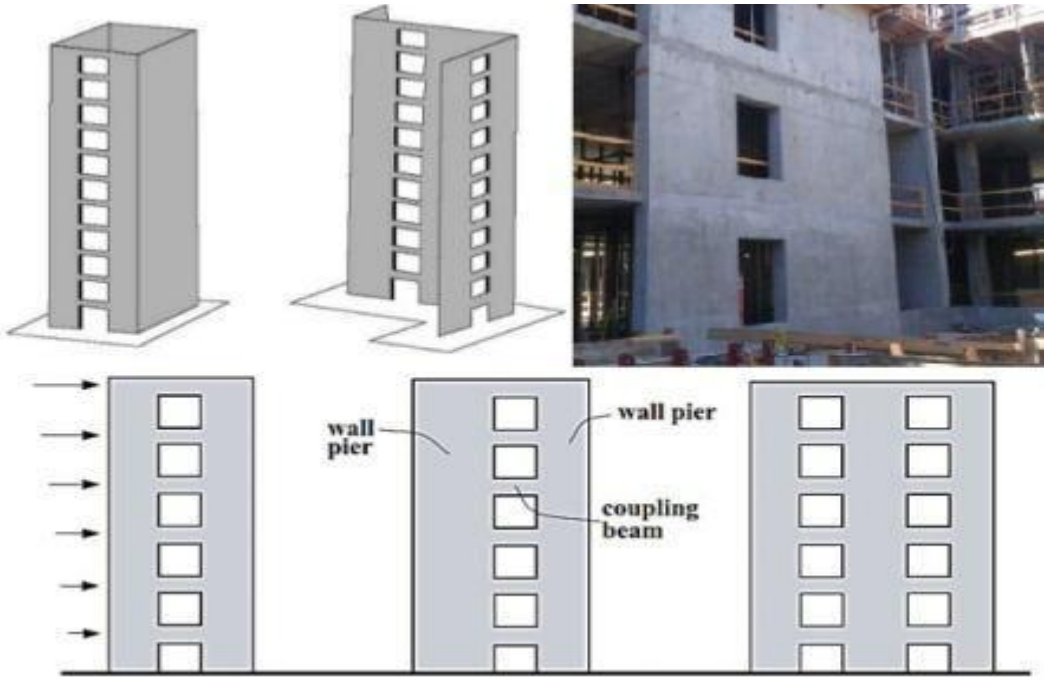

Fig.11) Coupled wall structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

10 Hybrid structural system-

It is the combination of two or more of basic structural forms either by direct combination or by adopting different forms in different parts of the structure.

Its lack of torsional stiffness requires that additional measures be taken, which resulted in one bay vertical exterior bracing and a number of levels of perimeter vierendeel "bandages" It can be used for buildings as high as 300m.

According to chines code (JGJ 3-2002), hybrid system can be used for the construction of buildings with maximum 150m height in seismic regions.

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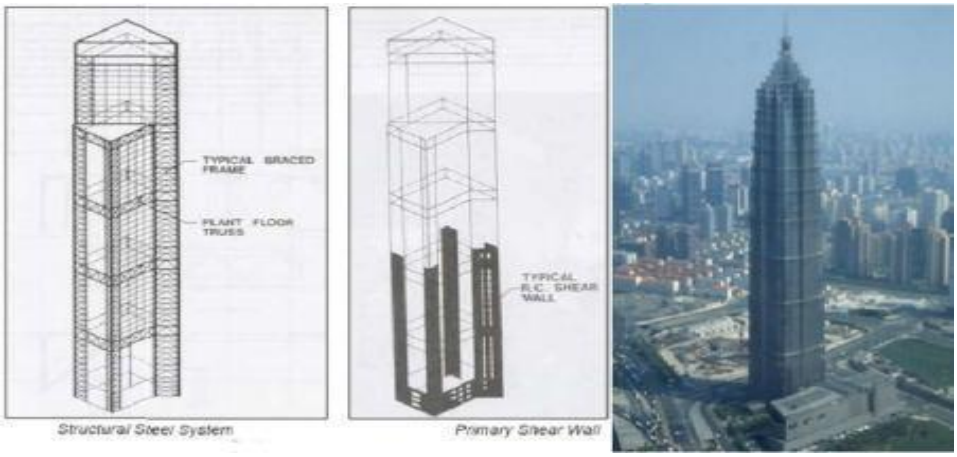


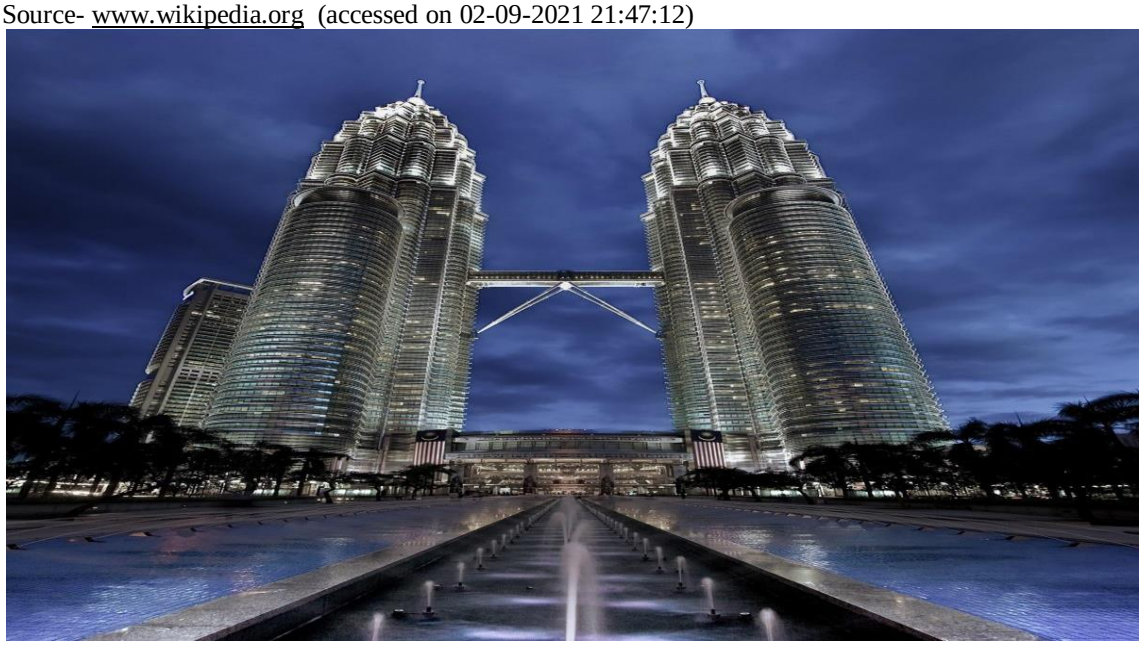
Fig.12) Hybrid structural system
Source- www.theconstructor.org (accessed on 02-09-2021 21:47:12)

II. CASE STUDY-

1 PETRONAS TOWER

Petronas Tower is a symbol of national pride and shows the nation's advancement in the world economy and technologies. Concrete was used for its construction mainly because it was easily available and cheap when compared with steel, which was a new material for the builders. The architect successfully incorporated malaysia and Islamic motifs in design. The skybridge was an important feature of the design using 'tube in tube' structural system [4]. The structural member was made with high strength concrete which was cast on site. The perimeter columns are held together with the help of ring beams. The internal core structure is made of concrete shear walls. The building didn't require extra damping systems because the heavy structural members were made of concrete. Even though no new advancements in technology was made during the project, the available technology was used smartly.

Fig.13) Petronas Tower, Malaysia.
Source- www.wikipedia.org (accessed on 02-09-2021 21:47:12)



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2 BURJ KHALIFA

The Burj Dubai project is designed to be the centrepiece of the large scale Burj Dubai development that rises into the sky to an unprecedented height of 800 meters and that consists of more than 800 floors [4]. The decision to build Burj Khalifa is reportedly based on the government decision to diversify from an oil based economy to one that is service and tourism based. Unlike many super high- rise buildings with deep floor plates, the Y- shape floor plans of Burj Dubai maximize views and provide tenants with plenty of natural lights. The structural system of burj khalifa was a new system developed for the building. The system is called 'buttressed core'. In this system the lateral loads and gravity loads are shared equally between the interior core and perimeter structural systems linked by the link beam which makes the structure super strong.

Fig.14) Burj Khalifa, Dubai.
Source- www.wikipedia.org (accessed on 02-09-2021 21:48:22)

Mistakes during implementation of structural system-

Mistakes at the site happen due to various reasons. Below information addresses most of the errors/mistakes which happen during execution of buildings particularly in reinforced concrete buildings.

1. Lack of information about drawings- Clarification regarding this shall be obtained by raising requests for information.
2. Use of old drawings which has been revised due to various reasons such as services requirements, architectural, clients' requirement, clarity in structural detailing.
3. In several sites we observed the changes in various aspects such as thickness in slab, cut out locations and size of cut out, reinforcement spacing, profile of the bars might have changed.
4. Formwork can be deshuttered 18 to 24 hours is recommended. Most of the time concreting happens till later hours of evening throughout the

day and deshuttering happens the next morning which leaves concrete less time to develop strength.

Suitability of structural systems-

1. In rigid frame structure its members can take bending moment, shear and axial loads. By using this we can build up to 20-25 floors high rise buildings.
2.In shear wall structure concrete or masonry continues vertical walls may serve both architecturally and structurally to carry gravity and lateral loading. By this it is possible to make up to 35 floors of high rise buildings.
3. In outrigger structures core may be centrally located with outriggers extending on both the sides or in some cases it may be located on one side of the building outriggers extending to the building columns on other side. This can make up to 150 floors high rise construction.
4. With the present technology and known materials, it is possible to build higher and faster high rise constructions.

III. CONCLUSION-

Various structural systems within each category of the new classification have been described with emphasis on innovations. Efficient structural systems in seismic zones also need to be further investigated. For the future, it is expected that the building heights will be continuously increasing in conjunction with the improvements in technology in structural systems, materials, energy efficiency, and damping systems.

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