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Building Tall: A Primer on the Essential Technologies for Vertical Construction

Introduction

In this article, I will share my limited knowledge about high rise buildings of 400m or above focusing on the aspects below. Distinguished local and overseas projects are quoted to illustrate the theories. The content is written from a building technology perspective rather than an engineering one.

Structure

In high rise buildings, a robust central core and a buttress system are often used to provide the required strength and stability. The central core often contains staircases, lifts and services accommodation. The buttress system may be in the form of thick structural walls or outriggers connecting to columns at the perimeter. One example is the International Commerce Centre (484m high) located above the Kowloon Station (Fig. 1).

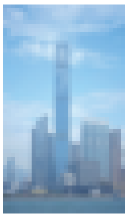

Fig. 1 International Commerce Centre

Fig. 2 Typical office floor Plan from Yahoo images www.architecturalrecord.com

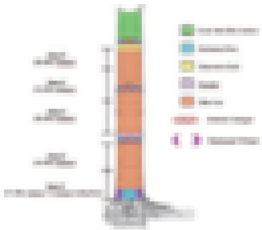

Fig. 3 Diagram extracted from a presentation titled "A Construction Highlight for the International Commerce Centre at Kowloon Station, West Kowloon" by Raymond Wong of City University of Hong Kong in June 2008.

The plan of this building is basically a square shape with slightly curvilinear perimeters (Fig. 2). It has a central core which accommodates staircases, toilets, lifts and services. There are two mega columns near the perimeter on each side, i.e. 8 columns in total. Outriggers at 4 floor levels are extended from the central core to each column (Fig. 3). The lowest set of outriggers is made of steel and prestressed concrete. The others are made of structural steel[1]. This form of construction resembles a person standing on the ground, stretching out two arms and resting on two walking sticks. The central core represents the body, while the outriggers serve as the arms, and the mega columns act as the walking sticks. The Burj Khalifa in Dubai, United Arab Emirates (828 m high) (Fig. 4 & 5) is the tallest building in the world (Its status will be replaced by a forthcoming 1000m high building in Saudi Arabia when completed). It has a construction similar in principle to the International Commerce Centre. It has got a high performance hexagonal concrete core wall plus wing buttress perimeter columns and outrigger walls[7] (Fig. 6).

Fig. 4 Burj Khalifa

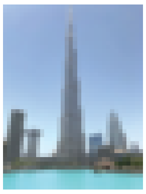

Fig. 5 Burj Khalifa

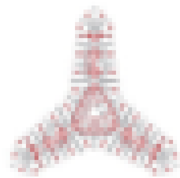

Fig. 6 Picture from Yahoo images media.architecturaldigest.com

Wind load

It is always necessary to reduce wind load on high rise buildings. Not only is it necessary to reduce stress on the structure of the buildings, but also necessary to consider human comfort when the buildings sway in high winds. A circular design is the most effective in reducing wind load but occupiers tend to prefer a square plan[2]. An alternative is to adopt a curvilinear perimeter. Other measures, such as rounded or chamfered corners, can be adopted. Some high-rise buildings taper upward or incorporate setbacks to reduce wind load, for example, the Burj Khalifa. Additionally, it has a Y-shaped plan, which also helps to reduce wind load. Another option is to incorporate a large opening in the building, like the Shanghai World Financial Centre (492 m high) (Fig. 7).

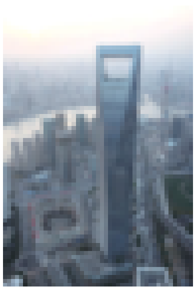

Fig. 7 Shanghai World Financial Centre

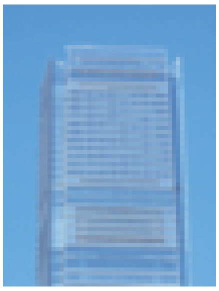

Fig. 8 International Commerce Centre

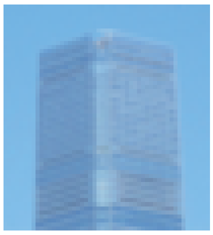

Fig. 9 International Commerce Centre

I would like to introduce an unordinary way to reduce wind load. The International Commerce Centre at Kowloon Station has got notched corners in the form of re-entrants, varying in size on different floors (Fig. 8 & 9). As verified in wind tunnel research, the modified square plan can function similarly to the original circular design[2].

Damper

Pursuant to local requirements and circumstances, some high rise buildings use damper to counteract the effect due to high winds and earthquake. Mass tuned damper is the most common form. One example of this is the golden ball in

Fig. 10 Mass tuned damper in Taipei 101

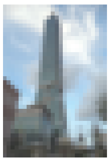

Fig. 11
Taipei 101

Taipei 101, which stands at a height of 508 meters (Fig. 10 & 11).

Here I would lke to introduce an unordinary form of damper. This is the Skybridge in Patronas Twin Towers (451.9 m high), Kuala Lumper Malaysia (Fig. 12 & 13). The two-storey Skybridge is supported by the two towers. However the bridge can slide in and out of the two towers when the latter sway. The main structure of the Skybridge is a pair of parallel girders. A two-hinge arch springing from supports at Level 29 and rising at 63 degrees to support the Skybridge at Level 41. The arch is actually a centering device, equalising joint movement at both Towers. The shape of the arch can change to accommodate movement of the bridge[4,5]. These special features enable the bridge to act technically as a damper for the towers in high winds. Although there is no mass damper for the towers[3], the pinnacles have simple chain impact dampers (Fig. 14) which are sometimes found in mast structures.

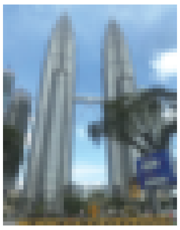

Fig. 12 Petronas Twin Towers with a Skybridge

Fig. 13 A two-hinge arch supporting the Skybridge[6]

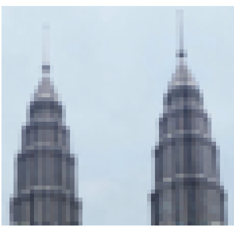

Fig. 14 Pinnacles at top of twin towers

The Burj Khalifa does not have a damper. The building situates in a desert and is therefore free of typhoon problems.

Concrete

High rise buildings invariably use high strength concrete (strength C60, i.e. 60 MegaPascal, but not exceeding C100, as defined in Buildings Department's Code of Practice for Structural Use of Concrete) in the main structure. To reduce the amplitude of swaying in high winds, concrete performs better than steel as the former is more rigid (a higher Young's modulus, stress/strain) than the latter. The use of high strength concrete can further reduce the size of structural members. This not only reduces the weight of the building, but also increases the usable floor area, making the building more commercially efficient and more marketable.

In Burj Khalifa of Dubai, concrete of C60 to 80 is used. As the temperature of Dubai is very high, concrete will likely crack due to shrinkage. The placing of concrete took place at night and ice was used to lower the temperature[7].

In International Commerce Centre of Hong Kong, concrete of C90 is used in lower storeys up to 60/F[1]. Steam was used in the curing process. It should be noted that the higher the concrete strength, the more care has to be employed throughout the process of batching, mixing, transporting (horizontal and vertical), placing, compacting and curing. Of course the pre-requisite is that the right concrete must be used. If the wrong concrete is placed, it may end up in mishap similar to the one taken place in a development project atop Tai Wai MTR Station in July 2021. In that case, concrete of C45 instead of C80 (figures to be verified) was placed. By the time when the fault was discovered, more than 10 storeys had been cast. It resulted in total demolition of the faulty portions.

By the way the skinniest building in the world, the Steinway Tower in New York (435 m high) (Fig. 15), uses concrete of strength 14000 lb/in^2 (equivalent to C97, very high strength). This building was completed in November 2022 and has a slenderness ratio (width to height) of 1:24. A damper is installed at the top of the tower to provide stability against high winds or earthquake.

Fig. 15 Steinway Tower in New York (Photo obtained from Wikipedia[8])

Conclusion

High rise building is an interesting topic which can be approached from various perspectives. I only select a few which are related to construction. With advancements in technology, buildings can now be constructed to greater heights. However the initial construction cost tends to be high. The subsequent running, operation and maintenance costs are significant especially when the works have to be carried out at great height, not to mention the hazard and difficulties involved. The problem of means of escape in case of fire and/or earthquake becomes more challenging as the height of building increases. Despite the precautionary, preventive and firefighting measures are becoming increasingly sophisticated, it is widely recognised that the fire safety hazards increase with building height.

Reference

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