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Structural Systems for Tall Apartment Towers

The early development of structural systems for tall buildings concentrated on tall office towers. The favored systems were “tubular” in design which provided for the lateral-load-resisting system in the façade of the tower. Two types, namely “diagonally braced tubes” and “framed tubes,” were the main choices. Examples of these systems are the Bank of China building in Hong Kong and the former World Trade Center Towers in New York. Some dual systems, such as core walls with perimeter frames, were also used in the Petronas Towers in Kuala Lumpur, Malaysia, and Taipei 101 in Taiwan.

In tall apartment towers, it is desirable to have minimum reduction of outside views from the interior of the apartment. Hence “tubular” systems, especially framed tubes, are less desirable. Framed tubes give less than 50% (in some cases 30%) exterior glass. It was therefore necessary to evolve different systems for apartment towers. Moreover, apartment towers favor concrete construction for many reasons such as cost, fireproofing, acoustics, etc.

The systems that are considered are:

- Full width systems
- Core walls with outriggers
- Spine walls with outriggers

Currently two towers under construction in Dubai, including an 88-story tower in the Dubai Marina, illustrate these systems. This presentation will describe in detail the development of the structural system for this tower.
Structural System for Tall Apartment Towers

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I. Introduction:

Since 1965 there has been a systematic development of structural systems for tall Office Buildings. The current trend is the development of tall Apartment or Mixed - Use buildings. There are differences in architectural design of office and apartment buildings with regard to building widths and shapes. Office Buildings generally tend to larger widths in floor plan whereas Apartment buildings tend to be narrower because it is more important for most apartment spaces to be closer to the exterior wall. Moreover, Apartment building design tends to favor fewer exterior columns.

With regard to structural systems for tall Office Buildings the use of diagonally braced or framed “Tube” systems are favored. Examples of these systems are the Bank of China Building in Hong Kong and the former World Trade Center Tower in New York. Some dual systems such as core walls with outrigger or perimeter frames were also used in the Petronas Towers in Kuala Lumpur and 101 Taipei Tower in Taiwan.

For Apartment buildings similar systems have been attempted. An example of a diagonal braced system is the Onterie Tower in Chicago (Fig.1A) and of a framed tube is the Chestnut De-Witt Apartment Towers also in Chicago. (Fig.1B) Framed tubes generally provide less than 50% (and in some cases 30%) exterior glass. In general the new generation of tall apartment buildings favors more transparency in the exterior façades.

II. Criteria for Selection of Structural Systems for Tall Apartment Buildings

Apartment buildings are generally built in reinforced concrete using flat plate concrete floors and core walls.

For apartment buildings in the range up to 30 stories, a concrete shear wall core with the columns and flat plate slab floors (forming an equivalent rigid frame) are adequate to take care of the lateral loads.

For apartment buildings in the range of 30 to 60 stories, the concrete shear walls alone are inadequate. The usual practice is to provide outrigger beams (or walls) at mechanical (“service”) floors connecting the core walls to exterior columns. Analysis (1) has shown that the optimum vertical location of the outrigger is at about 60% of the height of the building from the base. One of the problems with this type of systems is that under gravity load, the exterior columns have high stresses whereas the core walls have low stresses. This results in a differential axial shortening for elastic and long term shrinkage / creep movements. This necessitates special construction techniques (2).

For apartment buildings greater than approximately 60 stories tall, a new approach is required.

III. Structural System Alternates for Tall Apartment Buildings

The following structural system menu is available.
A. Core Walls with Outriggers: In building where there are several mechanical ("service") floors spread through the height of the building, the core walls with Outriggers is possible.

B. Cross Wall Systems: One advantage of tall apartment buildings is the presence of fixed partitions – generally the demising walls between apartment units. This gives rise to the possibility of having long structural walls that essentially go through the width of the Building.

C. Tubular Systems: Both diagonal and framed tube systems should be investigated. The 100 story John Hancock Centre in Chicago shown in Fig. 2 is a diagonal tube system and has apartments in the top half of the tower. The building was completed in 1970 and has been successful.

D. Spine Wall Systems (with and without Outriggers): Walls are placed along corridor walls as a “Spine” running through the length of the floors. A good example of this is in the Burj Dubai Tower (designed by SOM and developed by Emaar) currently under construction in Dubai. When completed it will be the tallest tower in the world. Fig 3 shows the elevation and Fig. 4 shows the spine walls. Care should be taken to improve the torsional resistance of the tower and this has been done by the triangular core wall around the elevators and stairs in the core of the building.

IV. Case Study:

The selected structure is the 90 story Hircon Tower at Dubai Marina in Dubai. (See Fig 5). The tower is octagonal in plan with a maximum dimension of 41.6m. The tower height to the top of spire is 397.3m. Many structural systems were investigated and are described below.

A. Core Wall with Outriggers:
   Fig 6 is a floor plan of the tower. Two outriggers were placed connecting the core to the exterior columns in both directions.

B. Cross Wall System:
   Fig.7 shows a floor plan with cross walls in both directions. The north-south core wall was eventually rejected as being too restrictive.

C. Tubular System:
   Fig.8A shows a diagonal truss system on 4 faces of the octagon. Fig.8B shows a framed tube system. Both these systems were rejected as they reduced the visibility from the floors looking out.

The selected system is a hybrid as shown in Fig. 9. In the North-South direction the system is a shear wall with deep floor height outriggers at two mechanical floors. Since this is the strong axis of the shear wall, this scheme gives sufficient rigidity in that direction. In the East-West direction, the weak axis of the shear walls, a cross wall system is used. It should be noted that this eliminated the need for “link” or “header” beams connecting the flange of the shear walls. This avoids interference with the air-conditioning ducts. Utilizing this system, the fundamental period of the building is 10.6 and 10.3 seconds in the two principal directions. The torsional period is 6.3 seconds.
CONCLUSION:

The height of Apartment buildings is steadily increasing. A new menu of structural systems has been developed for these towers. These systems take into account of one of the drawbacks which is the "slenderness" of apartment towers which makes them have large height / width ratios and thus wind sensitive. On the other hand apartment layouts provide an opportunity to make them compensate for this slenderness. This article gives the designers some options for consideration.

V. References:


FIG. 5

Dubai Marina – Dubai, United Arab Emirates
MILD STEEL POST TENSIONED SCHEME

TYPICAL FLOOR FRAMING PLAN

Fig. 6  CORE WALL WITH OUTRIGGER
MILD STEEL POST TENSIONED SCHEME

TYPICAL FLOOR FRAMING PLAN

Fig. 7 CROSS WALL SCHEME
Diagonally Braced Tube-Hircon Tower

Framed Tube-Hircon Tower
Fig 9. STRUCTURAL SYSTEM FOR HIRCON TOWER