Case Study of John Hancock Center Structural Design

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Introduction and Facts

- Client: Jerry Wolman
  the John Hancock Mutual Life Insurance Company underwrote the project
- Location: Chicago, Illinois
- Project Year: 1969
- Project Area: 2.8-million-square-feet
- Height: 1,127 feet
- Project Cost: $95 million
- Lead Architect: Bruce J. Graham, Skidmore, Owings & Merrill (SOM)
- Structural Engineer: Fazlur R. Khan, SOM
- Primary Contractor: Tishman Construction
Program Requirements

- 100 Story multi-use tower
- 1,000,000 sq. feet of residential space
- 800,000 sq. feet of parking and commercial space
Project Challenges

- **Large** floor areas needed for Parking levels and offices
- **Small** floor areas needed for Residential space
- Designing for wind loads
- Cost
- Sway and vibration
Importance of Building

- The structural design marked an evolution in the design of structural systems for skyscrapers.

- The John Hancock Center was the first “trussed tube” structure utilizing exoskeletal members.
Design Concept

- 100 stories above the ground
- 343.7 meter / 1128 feet tall
- 2,799,973 sq ft Floor area
- 896,980 square feet of office space
- 171,771 square feet of retail space.
- 49 floors are dedicated to 700 residential condominiums.
Design Concept

- A true architectural aesthetic form must express the nature of itself
  - Two separate towers; a 70 story office building and a separate 45 story residential building.
  - One of the few mixed use high rises

- Gently Tapered and inward sloped façade
  - Increased visual verticality of the building; adding perceived height
  - Optimum floor plan size
  - Reduced wind loads
Diagonals & Interior
Innovations and Interesting Facts

- One of the few mixed use high-rises for the time
- Tapered shape the efficiency in:
  - floor plans,
  - floor heights,
  - and steel usage ($15 mil)

- Provision of at least 12” higher interior spaces by avoiding the conventional usage of concrete slab ceilings
- The very first use of the trussed tube system with concern to height premium and shear lag concepts
Structural Height Premium

![Graph showing the relationship between weight of steel and number of storeys.](Image)

- **WEIGHT OF STEEL (lb/ sq. ft)**
- **NUMBER OF STOREYS**

- **PREMIUM FOR HT**

- **65 lb/ sq. ft**
- **WIND**

- **25 lb/ sq. ft**

- **HYPOTHETICAL GLASS DOME**
Plaza at DeWitt
Location: Chicago
Architect: SOM
Engineer: SOM
Start of Construction: 1963
Completion: 1965
Height: 373ft
**Number of Floors: 43**
Material: Concrete
Tall Buildings

“Harmony between structure and architectural form is the key to success of expression” (Ali, 990).

Architecture as Structural art and express their structure with clarity.

“The John Hancock Center design is surely rooted in constructional reality” (Sev, 19)
Innovation of the Tubes

- Creator of the tubed structure 1963. Father of tubular designs for high rises

- Defined as: “a three dimensional space structure composed of three, four or possibly more frames, braced frames, or shear walls, joined at or near their edges to form a vertical tube-like structural system capable of resisting lateral forces in any direction by cantilevering from the foundation” (Evolution of Skyscrapers)

Evolution of Structural Systems

- **Type I**: Shear Frames
- **Type II**: Interacting Systems
- **Type III**: Partial Tubular Systems
- **Type IV**: Tubular Systems

![Graph showing the evolution of structural systems](image)
Tubed Structures

- Advantages of Trussed Tube form:
Advancement
Foundation

- **Composite** Foundation System comprised of
  - Basement **Concrete Slab**
  - **Compacted** Soil
  - Gridded **two way** Concrete Slab
  - 239 **Caissons**
Soil Conditions

- **Clay** soils (former lake-bed) with low bearing capacity
- Bedrock **120 - 190 feet** below grade with much, much greater bearing capacity
Caisson Construction Issues

- Steel tubes used to retain soil and water as caisson holes excavated
- As concrete was poured, the tubes were removed for re-use
- Some concrete was pulled up with the steel, leaving voids that was filled with water or soil
- Settling during construction caused all caissons to be tested and 26 received corrective work
Lateral Loads

Wind load:

- Consulted with meteorologists and researched data from the U.S. Weather Bureau
- Factor of 1.25 above the municipal Chicago building code of that time.
- The building's tapered form helps reduce surface/wind loads

Seismic Load:

- low risk seismic zone
- Khan later concluded system would be too rigid and not sufficiently ductile for use in high seismic zones
Load Resistance

Trussed tube system handles the lateral loads on the exterior of the building.

Efficient because the diagonal bracing redistributes lateral loads evenly to the exterior columns.

Without the cross-bracing, the columns would act more independently and there would be significant difference in the loads that they carry.

Figure shows how forces are redistributed at the column, diagonal and spandrel intersections.
**Load Resistance**

Figure illustrates how a hypothetical load is redistributed as it goes down the structure where ultimately each column ends up carrying a similar load.

Lateral loads and vertical loads are integrated by the diagonal cross-bracing.

Spandrel beams are also helpful in redistributing lateral and gravity loads to the columns.
Load resistance

Vortex shedding frequencies wouldn’t be able to come together to produce an effective amount of dynamic force.
Connection Details

Heavy gusset plates tie the diagonal bracing, columns, and spandrel beams together.

Members are ASTM A36 steel and gusset plates are ASTM A441.
Connection Details

Avoided field welding by **prefabricating** the joint assemblies

Bolted the wide flange members in place

This construction photo reveals the scale of the prefabricated main joints. (Courtesy of Skidmore, Owings & Merrill LLP.)
Axial Stress Diagram
Shear Stress Diagram
Moment Diagram
Deflection Diagram
Design Wind Pressure

- Initially set 20% past the Chicago Building Code recommendation
- Later raised to 25% due to disputes with the independent consultant
- Building members analyzed when wind loads twice the size of the Chicago building code recommendation were applied to the structure
- Checked the Gravity Loads at the same time to make sure the members would not yield or buckle
Movement And Vibration

- **No standards** for movement and vibration criteria in reference to wind load in 1965
- Few studies had been done by 1965 on **movement** or **vibration**
- Khan **tested eight subjects** to see how they were affected by differing levels of motion
- Used 2 **accelerometers** to move the floor and found at which point the subjects could **feel** the **motion**
- Khan’s **research** gave the owner and designers **confidence** in the future performance of the building
Conclusions

“A building’s natural strength should be expressed”

The integration of structure and form made the John Hancock center an efficient and successfully building
Reference

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