The Greatest Structural Engineer of the 20th Century – Dr. Fazlur Rahman Khan 

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Dr. Fazlur Rahman Khan (1929 – 1982) was a Bangladeshi-American structural engineer, who initiated innovative structural systems that form the basis of tall building design today.

Introduction

Dr. Khan is considered the Father of tubular designs for high-rise buildings. Khan became an icon in both structural engineering and architecture. His most famous buildings are the John Hancock Center and the Willis Tower (formerly Sears Tower) which was the world's tallest building for several decades (from 1974 to 1996). Khan also helped in initiating the widespread usage of computers in structural engineering.

His "tube" structural system concept (using all the exterior wall perimeter structure of a building to simulate a thin-walled tube) revolutionized tall building design. Most buildings over 40-story constructed since the 1960s now use a tube design derived from Khan's structural engineering principles.

Before the 1960s, the structural systems could not efficiently provide lateral support to buildings over 40 stories. Skyscrapers were simply too costly by modern development standards. A tower reaching as high as the Empire State Building could no longer be justified in economic terms.

He was a general partner in Skidmore Owings & Merrill (SOM), the only engineer holding that high position at the time. He died of a heart attack on March 27, 982 while on a trip in Jeddah, Saudi Arabia, at age 52.

Khan was an aficionado of classical music, especially Bach and Brahms. For enjoyment, he loved singing Tagore's poetic songs in Bengali with family and friends. Khan was also a philosopher, visionary, educator and humanist.

Structural Systems

Before Khan introduced his new types of structural systems, most buildings were designed utilizing the Rigid Frame concept (Figure 1).

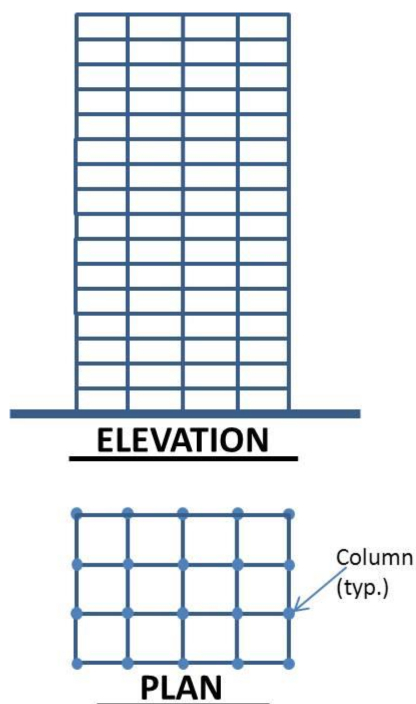

Figure 1. Rigid frame

His innovations led to considerable improvement in structural efficiency, thereby making the construction of tall buildings economically feasible. Below are the six structural systems that Khan introduced and implemented in various buildings.

1. Framed-Tube Structural System

The framed tube structures is one of the most significant modern developments in high-rise structural form. The framed-tube structure has its columns closely spaced (7 to 13 ft.) around the perimeter of the building (rather than spaced throughout the floor plan) and stiff spandrel beams connect these perimeter columns at every floor. This structural system was initiated in 1964 in the construction of the Chestnut-DeWitt Apartments in Chicago (Figure 2), a 43-story reinforced concrete tower. Because of its great relative strength and stiffness, the tubular form immediately became a standard in high-rise design.

Figure 2. The "framed-tube" structural system was first used for Chestnut-DeWitt Building.

The idea is to create a tube that will act like a continuous perforated chimney or stack (Figure 3). The gravity loading is shared between the tube and interior columns. The Tube structures are very stiff and have numerous significant advantages over other framing systems. They not only make the buildings structurally stronger and more efficient, they significantly reduce the usage of materials while simultaneously allowing buildings to reach even greater heights.

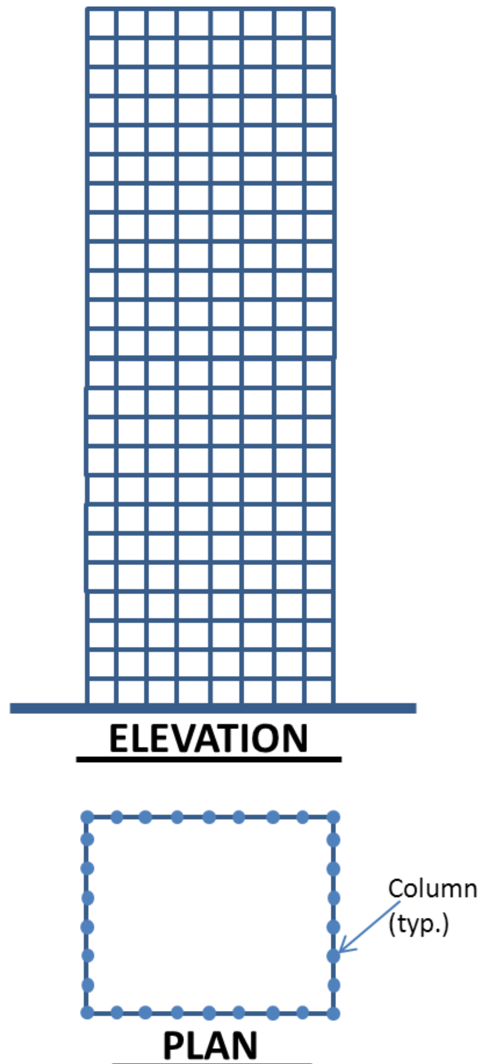

Figure 3. Framed-tube

The World Trade Center's Twin Towers used a framed tube design. The many columns of the framed tube can be seen around the exterior of this horizontal cross section. The towers had a core for services in the center. The design was not tube-in-tube since the core had 47 columns spaced relatively evenly, rather than around the edge of the core.

2. Shear Wall-Frame Interaction Structural System

The shear wall-frame interaction is another innovative system developed by Khan in 1962 (Figure 4)

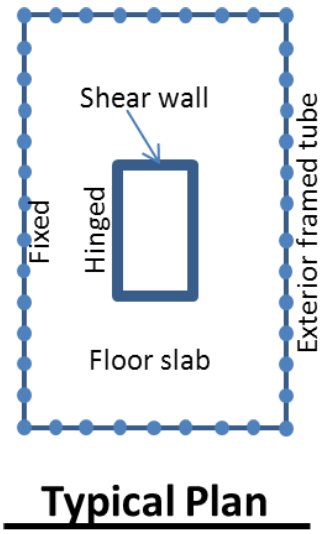

Figure 4. Shear wall-frame interaction

The system is used to design the 38-story, reinforced concrete Brunswick Building in Chicago (Figure 5). Khan used shear wall- frame interaction to resist lateral forces. The loads in the closely spaced perimeter columns are transferred through the transfer beam to the widely spaced columns at ground level.

Figure 5. Brunswick Building, Chicago

3. Braced Frame Tube (Trussed Tube) Structural System

Further improvements of the tubular system was made by cross bracing the frame with X-bracing over many stories (Figure 6).

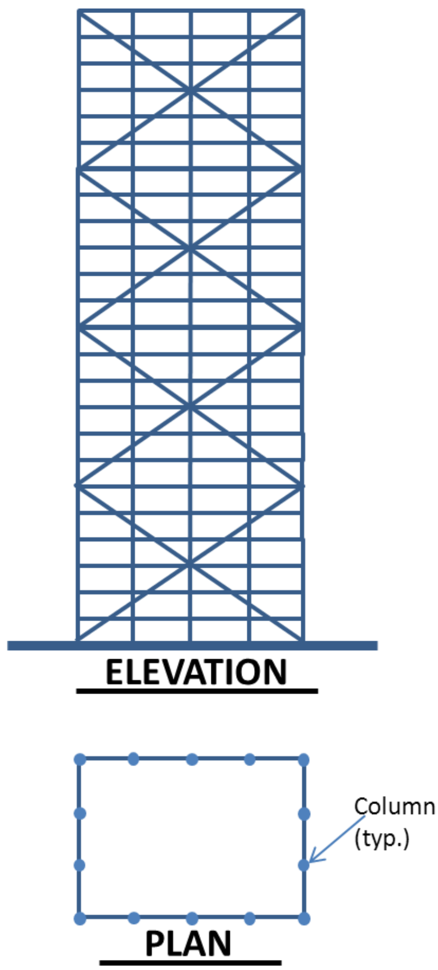

Figure 6. Trussed tube

The concept of installing X-bracing on all sides of the building was developed by Mikio Sasaki, as part of a Master of Architecture thesis at the Illinois Institute of Chicago (IIT) in Chicago. Khan was one of the advisor's to Sasaki. Sasaki states "the diagonally braced structure was my own idea, yet without the mentoring of Khan; the idea would not have developed."

This arrangement was first used in Chicago's John Hancock Building in 1969 (Figure 7), which has trussed diagonals on all sides.

Figure 7. The John Hancock Center, Chicago

The trussed tube is similar to the simple tube but with comparatively fewer and farther-spaced exterior columns. The bracings are introduced along the exterior walls to compensate for the fewer columns by tying them together. Other notable examples incorporating steel bracing is the Bank of China (Figure 8).

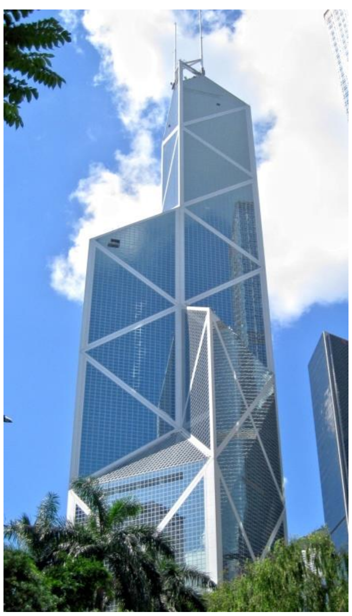

Figure 8. The Bank of China, Hong Kong

4. Tube-in-Tube Structural System

This type of framed tube consist of an outer-framed tube and an inner tube used for elevators and stairs (Figure 9). The inner tube may consist of braced frames. The outer and inner tubes act jointly in resisting both gravity and lateral loading. However, the outer tube usually plays a dominant role because of its much greater structural depth.

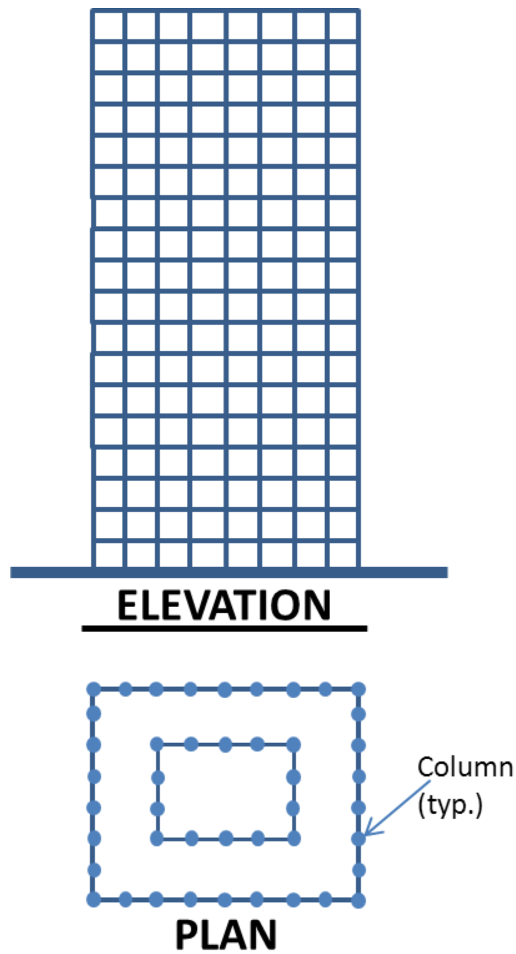

Figure 9. Tube-in-tube

One Shell Plaza building was the first instance of tube-in-tube structure (Figure 10). The inner tube and outer tube work together to resist gravity loads and lateral loads and to provide additional rigidity to the structure to prevent significant

Figure 10. One Shell Plaza, Houston

deflections at the top. With this form, the 50-story One Shell Plaza is able to be taller and lighter than a traditionally designed framed tube building, while still maintaining the stiffness of a much shorter building.

5. Bundled Tube Structural System

The bundled tube system is an assemblage of individual tubes resulting in multiple cells. The increase in stiffness is apparent. The system allows for the greatest height and the most floor area. This structural form was used in the Sears Tower which was completed in 1973 (Figure 11) in Chicago.


Figure 11. Sears/Willis Tower, Chicago

Instead of one tube, a building consists of several tubes tied together to resist the lateral forces. The bundled tube structure meant that buildings no longer need be boxlike in appearance: they could become a sculpture (Figure 12).

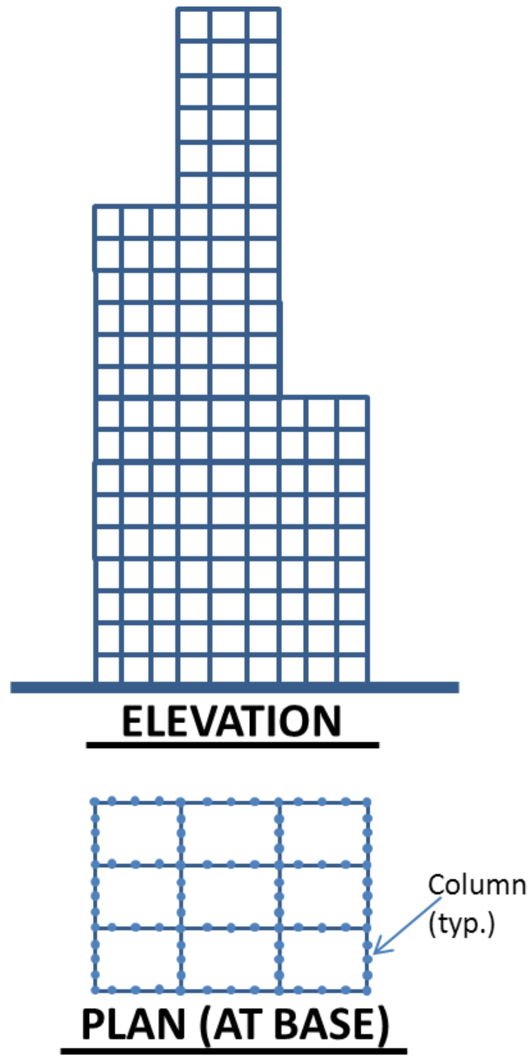

Figure 12. Bundled tube

The Sears Tower plan consists of 9 squares, placed in a three-by-three grid arrangement. Each square has 5 columns per side spaced 15 feet on centers, with adjacent squares sharing columns. As the columns rise up the building, each square in the plan forms a tube, which can be seen on the exterior of the building. These tubes are independently strong but are further strengthened by the interactions between each other through truss connections. Several large trussed levels act as the main horizontal connectors in the buildings. These trussed levels, which also contain the mechanical systems for the building, appear as black horizontal bands on the façade (Figure 13).

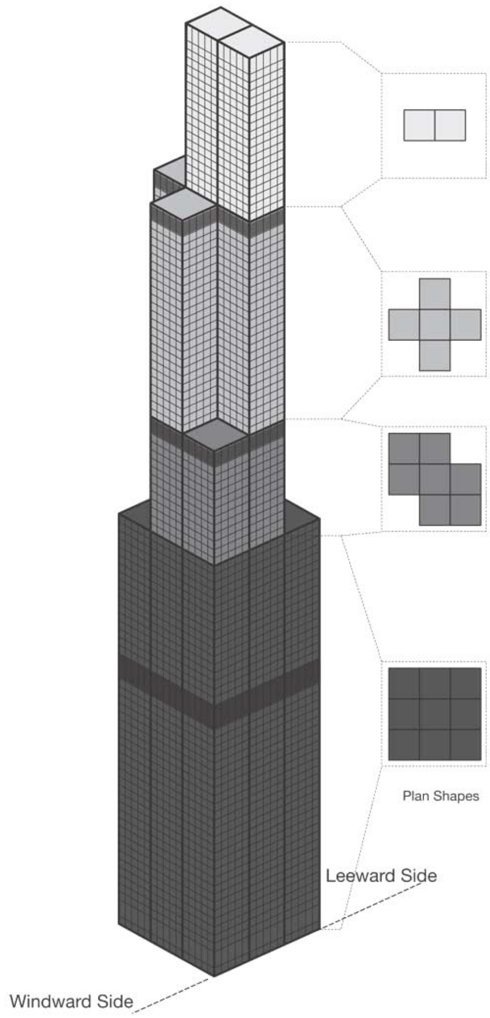

Figure 13. Sears/Willis Tower, Chicago

The closely spaced interior and exterior columns are tied at each floor with deep spandrel beams. At the truss levels, these tubes are tied together. These ties resulted in a stiffer structure, as the building acts as a unified system of stiffened tubes. The interaction between the individual tubes and the belt trusses at mechanical levels allows the building to attain its extreme height.

These trusses serve an additional purpose beyond stiffening the tube structure against winds. Due to the drop offs, the gravity loading on the system is not evenly distributed along the height of the building. These trusses take the gravity loads from above and redistribute them evenly onto the tubes below. This is particularly important for the uppermost section of the tower, due to its asymmetry about the central axis of the building. Because the section is offset, its weight causes columns on one side of the building to experience a greater load than those on the other side. The presence of the belt trusses help to mitigate these effects of differential settlement, which cause the building to tilt.

6. Other Structural Systems - Tensile Structural Materials

For the immense roof of the Hajj Terminal of the new airport in Jeddah, Saudi Arabia (intended to shelter 80,000 pilgrims at a time, waiting up to 36 hours), Khan searched for a coherent scheme that both was efficient and honored the spirit of the Hajj pilgrimage (Figure 14)

Figure 14. The Hajj Terminal, Saudi Arabia

The fabric roof structure that developed melds a traditional concept (the tent) with sophisticated technology. The design for the Hajj Terminal advanced the state-of-the-art of tensile structures and facilitated the use of fabric as a structural material in a range of projects. Construction of the terminal was completed in 1981.

What They Say About Khan

"He was the consummate team leader. You never worked for Khan, you always worked with him as an equal."

"His enthusiasm for whatever the task at hand or the project was contagious. His philosophy was that there was always something new and interesting about any task or project, and that it was up to us to find and pursue the issue."

"I believe his ability to see the opportunities that each situation presents was a major factor in Khan's ability to think beyond the norm, and create and innovate as he did."

"He was concerned, foremost, with people and how engineering affected them. He wanted his structures to be part of a culture and society that strove to benefit its people."

"He was always probing and challenging the norm. He always did this in a collaborative way, incorporating the entire team in the process. As a result, you always felt a part of the process, and when the task or project was complete, all who participated felt some sense of ownership in the result."

Khan's Most Memorable Sayings

"Only when architectural design is grounded in structural realities, thus celebrating architecture's nature as a constructive art, rooted in the earth, can the resulting aesthetics have a transcendental value and quality."

“Think logically and find the relationships which exist in every system, because it will help you understand nature itself, making living more meaningful and exciting."

"The technical man must not be lost in his own technology; he must be able to appreciate life, and life is art, drama, music, and most importantly, people."

"For architectural design to reach its highest levels, it had to be solidly grounded in structural realities."

"When thinking design, I put myself in the place of a whole building, feeling every part. In my mind I visualize the stresses and twisting a building undergoes."

Summary

Khan introduced significant changes in building design, which ushered a renaissance in skyscraper construction. He encouraged implementation of computer technology in structural engineering. He changed the way Architects and Structural Engineers interact in the design of a project. He introduced pioneering and creative structural systems which include: framed tube, shear wall-frame interaction, trussed tube, tube-in-tube, and bundled tube.

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