A New Rubric for SEI: Eminent Structural Engineers

The SEI Editorial Board is working continually to improve our Journal. In recent issues we have focussed on preparing well-balanced issues treating a single common theme that combine a range of Structures, Reports, and Science and Technology papers. We believe that this has been well received by you, our readers, and we hope to continue this in the future. The Editorial Board has also discussed the introduction of new rubrics for SEI, in addition to those mentioned above, as a way of increasing the attractiveness of the Journal. We have tried, for example, to encourage readers to submit discussions of published papers. We hope, with your help, to be able to publish such papers in the near future.

This issue marks the beginning of a new rubric; Eminent Structural Engineers. This rubric has been created with the aims of increasing awareness of our structural engineering heritage through a better understanding of the work of eminent structural engineers and promoting good engineering examples that inspire all engineers. The idea is that papers will present a personal interpretation or discussion of how the work of the featured individual influenced structural engineering developments or other engineers. Furthermore, it is our hope that the authors of these papers will be able to draw on a personal relationship with, and be in a position to include personal anecdotes that illustrate the professional facets of, the featured individual.

We are very pleased that the first paper to be published in the new rubric more than satisfies the aims, ideas and hopes presented above. It presents the life and work of Dr. Fazlur R. Khan, one of the most eminent structural engineers of recent times, and it is written by his daughter, Yasmin Sabina Khan. We hope that you enjoy it.

Simon F. Bailey
Chair, SEI Editorial Board

Dr Fazlur R. Khan (1929–1982)

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Introduction

The structural systems for high rise design that Fazlur R. Khan (*Fig. 1*) initiated in the 1960s and 1970s provide a basis for design still today. Responsible for some of the world's tallest structures – notably, Chicago's 110-story Sears Tower, the tallest building in the United States since its completion in 1974 (*Fig. 2*) – Khan established a series of efficient structural systems that significantly expanded the range of alternatives for building construction and secured a new standard for design. These structural types, which include the trussed tube, the bundled tube, and the composite system, also offered logical frameworks as core ideas for architectural design and enabled Khan, through his ideas for structures, to shape building architecture.

Personal Background

Fazlur Khan was born in Dhaka, Bangladesh (then Dacca, British India) on 3 April, 1929. The son of a mathematician and educator, he acquired a thorough grounding in mathematics and analytical thought in his youth; he also discovered a joy for learning that would endure throughout his life. Following undergraduate studies in engineering, he received Fulbright and Pakistan government scholarships, which together supported three years of postgraduate studies at the University of Illinois in the United States. Working at an unusual pace, he earned two master's degrees and a doctorate in this period. He considered the experience essential to his career; his professors reinforced his attitude toward inquiry and strengthened his confidence in innovative thinking. In addition to gaining a firm understanding of materials and principles, he fostered an intuitive comprehension of structural behavior. "I put myself in the place of the whole building," he would later explain, and "visualize the stresses and twisting a building undergoes" [1].

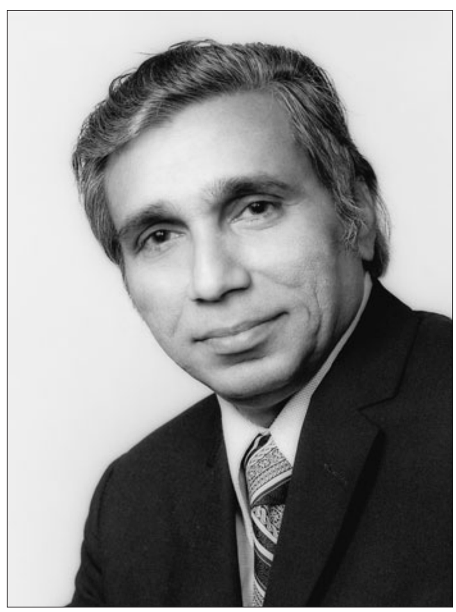

Fig. 1: Fazlur Khan, c. 1980
(Stuart Rodgers Photographers)

Fig. 2: 442 m Sears Tower introduced the bundled tube system (Ezra Stoller© Esto)

Innovative Approach to Design

High Rise Buildings

In 1961, when Khan began to work on tall buildings as a young engineer at Skidmore, Owings & Merrill (SOM), the main structural systems known to designers were the beam-column frame and the shear wall or shear truss. These systems were effective for buildings up to 20 to 30 stories, but their application in taller structures resulted in disproportionate cost increases for increasing height. Contemplating how to reduce unit area costs, he perceived that a tall building tends toward vertical cantilever behavior and that the geometry of the structural frame can contribute to lateral resistance. By designing the structure to minimize shear racking at each floor level, thereby causing cantilever action to be predominant, efficient use of structural material could be achieved.

Over the course of the decade he developed a series of structural systems based on this understanding of cantilever action. He was convinced that different building scales required different structural systems and he took pleasure in crafting structures to meet the needs of his projects. Khan first implemented his concept for a perimeter cantilever tube structure in the framed tube, which he developed in 1962 for the 43-story Chestnut-DeWitt Apartments in Chicago; combining an interior tube with a perimeter tube he created the tube-in-tube system for a 50-story concrete office building, One Shell Plaza in Houston – while working on this project he also formulated an influential load history method for analysis of inelastic deformation, consequent of his study of creep and shrinkage movement. When confronted with the problem of a 100-story structure for the John Hancock Center in Chicago, he refined the tube system to develop a stiff trussed tube, which is clearly expressed in the building architecture (*Fig. 3*), and for the 442 m Sears Tower he stiffened an exterior tube with interior cross-diaphragms, forming the bundled tube. In 1968, reflecting a remarkable openness of mind for the time, he employed a composite structural system in a 50-story office tower, One Shell Square in New Orleans, eliminating the barrier to mixed material use in future high rise design.

When developers raised their sights to the 600–700 m range in the early 1980s, he again searched for a structural system appropriate to the building scale. The solution he arrived at was a telescoping superframe (*Fig. 4*) with one or more wind portals incorporated into the structure. He aimed to avoid reliance on supplemental damping devices, which required regular maintenance and incurred additional construction cost, and intuitively perceived the beneficial effect of portals or façade reliefs on cross-wind response.

Fig. 3: Chicago's John Hancock Center, completed in 1970 (Ezra Stoller© Esto)

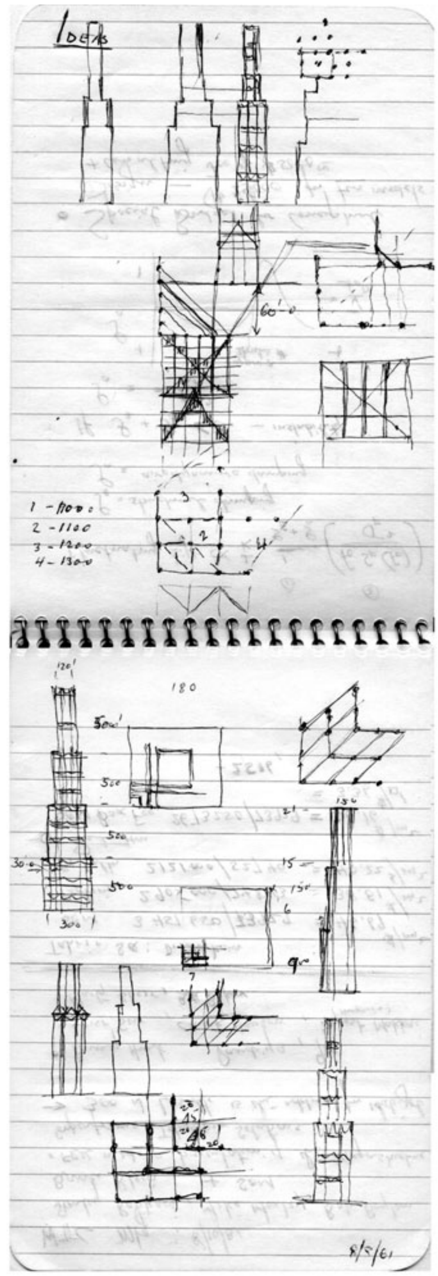

Fig. 4: Ideas for a superframe, Khan's pocket notebook, 1981

Light Weight Structures

Fazlur Khan's influence extends as well to light weight roof structures. In the mid-1970s he utilized a cable-stayed system to create a large unencumbered space at Baxter International headquarters outside of Chicago, thus validating this structural type for buildings. When the design team on an airport project for Jeddah, Saudi Arabia, sought a light weight solution for the immense, 430 000 m^2 Hajj Terminal, he resolved to design a tensile structure unhampered by the level of labor-intensive field construction associated with cable net structures and developed the cable-membrane tensile structure, in which the fabric membrane serves as both enclosure and structural element.

Ability for Critical Judgment

His enthusiasm for structural concepts and efficient systems, which inspired colleagues to share in his excitement for innovation, was complemented by a judicious temperament and the ability to assume responsibility for implementing new techniques. Khan's decision to use lightweight aggregate concrete for the entire structure of One Shell Plaza, for example, preceded the American Concrete Institute's publication of guidelines for its use as a structural material. Despite the problems encountered in earlier applications of lightweight concrete, he was certain that, with strict quality control during mixing and placement, a high quality structural material could be obtained. His confidence and integrity convinced the developer, Gerald D. Hines, to approve the progressive design approach.

His eagerness for progress in engineering did not distract him from concerns of structural performance and critical structural issues. During construction of the John Hancock Center a difficult situation arose that forced him to assess the nature of an inexplicable column movement measurement. Fully aware that costly construction delays might threaten the viability of the project, he discounted consensus in the field that the measurement was erroneous and halted erection of the steel frame to commence a caisson investigation. His judgment proved wise when a dismaying 4,2 m long void was found in one concrete shaft.

Practical Commitment to Progress

Khan was an active participant in professional associations and worked to organize new ones, such as the Chicago Committee on High Rise Buildings and the Council on Tall Buildings and Urban Habitat. He was known for his generosity in terms of time and talent. He was also open with his thoughts for structural systems: as early as 1966 he shared his idea for stiffening a large perimeter tube with cross-diaphragms to lessen the effect of shear lag – this system was not initiated until 1969, however, when he developed the modular, or bundled, tube for the Sears Tower. Likewise, he offered a scheme for a trussed tube in concrete several years before he had the opportunity to realize it in the Onterie Center design for Chicago.

While researching SOM projects for a book on my father [2], I came across numerous examples of his application of load tests and other practical, though sometimes unconventional, methods to verify progressive design. Supplementing theory with experiment allowed him to venture into nascent structural materials and systems, such as prestressed concrete in the 1950s and composite floor framing in the 1960s. When he needed to evaluate building sway for the John Hancock Center, but could not commission extensive motion-simulator tests, he made use of the rotating floor of an exhibit at Chicago's Museum of Science and Industry. He had recognized the potential testing apparatus during a family visit one weekend; holding my hand as we viewed the exhibit he felt a jerk that drew his attention to the rotating mechanism. By putting together a simple study with a few volunteer subjects he evaluated people's perceptions to motion, obtaining results that were surprisingly close to those of subsequent experiments. He continued to devise practical studies in this manner throughout his career.

Collaboration in Design

Committed to interdisciplinary collaboration, he established a level of communication with colleagues that at once provided an important depth to his work and enabled him to participate as an equal partner in design. He was convinced that intellectual exchange stimulates creativity and enlarges the scope of design ideas; he was also determined that a "building's natural strength should be expressed" [1]. During the 1960s he worked closely with Bruce J. Graham, the chief design architect in SOM's Chicago office, who shared with him an interest in structural clarity and logic and provided vital support for the realization of his ideas. Together they created the bold skyscraper designs that celebrate the vanguard structural systems (*Fig. 5*).

The benefit of communication to creative activity has gained wide accept-

Fig. 5: Fazlur Khan and Bruce Graham, 1965
(K & S Photographics – courtesy of Skidmore, Owings & Merrill LLP)

ance in the years since Khan's practice, but in the 1970s he was considered "perhaps the number-one illustration" of a teamwork doctrine [3]. Through example of his work, along with his manner of working with others, he promoted the partnership of engineers and architects in conceiving building schemes.

Conclusion

Fazlur Khan's endeavors were marked by a passionate ambition for progress in engineering. At the same time, Khan greatly appreciated the larger setting of design, notably its functional, aesthetic, and social aspects. It was indeed a broad perspective of design objectives that directed his development of new structural systems.

Vigorously pursuing advances in material use and structural technique, he invigorated the engineering profession and established many of the conventional methods available to designers today. He expressed his ideas for structural action in systems that were not only efficient but also visually coherent, and thereby gained a leading role for engineering in architectural design.

References

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[2] KHAN, Y. S. *Engineering Architecture: The Vision of Fazlur R. Khan.* New York, W. W. Norton & Company, 2004.

[3] *Structures, Professional Matters Are Focus.* Civil Engineering–ASCE, Vol. 44, June 1974, p. 80.