together on Hell Gate commenced a rivalry between the two that would last a lifetime.

The guns of war—World War I—started thundering across Europe shortly after David met his bride-to-be, Irene Hoffmann, on a trolley car ride on Long Island. Her father Dr. E. Franz Hoffmann, formerly on the faculty at the School of Medicine in Vienna, approved of Steinman, believing he had good prospects. Plus, he could intelligently discuss Kantian philosophy and world events with him.

Married on June 9, 1915, the young couple would have two sons and a daughter: John, Alberta, and David, Jr. John and David would become physicians specializing in psychiatry, and Alberta would become a renowned psychologist.

After his stint with Lindenthal, which, in addition to Hell Gate, included work on the important Sciotoville Bridge, another well-known U.S. bridge builder, John Waddell, employed Steinman. Waddell's main engineering office was located in Kansas City at the time; David was put in charge of his newly established New York office. While there, Steinman helped design the Marine Parkway Bridge.

From 1917 to 1920, Steinman was a part-time professor of civil and mechanical engineering at the newly formed engineering school at City College. In 1920, he opened his own consulting engineering office. His practice began slowly, and prospects looked quite bleak at the start. Recalled Steinman, "My first fee was $5, and for several months it was a difficult and discouraging struggle. Then Holton Robinson (1863–1945), who built the Manhattan and Williamsburg bridges, asked me to join him in a competition to build the Florianapolis Bridge in Brazil" (Ratigan 1959).

Their design proposal won and they were selected as the project's designers. Thus began a partnership—the firm of Robinson and Steinman—that would, over a 25-year period, design hundreds of impressive bridges around the world before Robinson's death in 1945. The Florianapolis, the largest-span bridge in South America when completed in 1926, was the largest eyebar-cable suspension bridge ever built and the first in the Americas to use rocker towers.

Next for Robinson and Steinman came the Carquinez Strait Bridge northeast of San Francisco, the fourth largest cantilever bridge in the world, and the Mount Hope Bridge over Narragansett Bay, Rhode Island. Commissions for the company quickly started flowing in from everywhere, several from overseas. Neither the 1929 stock market crash nor the Great Depression itself seemed to slow down the newly formed firm.

In late 1929, Steinman and Robinson designed the Grand Mere over the St. Maurice River in Quebec. The project introduced prestressed twisted wire rope-strand cables, a Steinman innovation that later debuted in the United States in 1931, with the simultaneous completion of the pair's St. John Bridge across the Willamette River in Portland, Oregon, and the Waldo-Hancock Bridge across the Penobscot near Bucksport, Maine. The Waldo-Hancock Bridge also featured the first-time use of Vierendeel trusses in bridge towers.

Mackinac Bridge

Stretching 17,913 feet across the Mackinac Straits in Michigan, the Mackinac Bridge was a 70-year dream come true when it was completed in 1957. The $100-million structure's two 24.5-inch-diameter main cables totaling 20,600 miles were spun in 78 days. The "Big Mack" held the title as the longest suspension bridge in the world until 1998.

Photo credit: Franklin Meyers and Gar Hoplamazian

Following those came many other noteworthy bridges such as the Henry Hudson (New York), Deer Isle (Maine), and Thousand Islands (linking Canada and the United States across the St. Lawrence River)—plus a wide assortment of significant structures outside the Western Hemisphere.

In 1947, Steinman was selected to do the reconstruction of the Brooklyn Bridge, the project that had first inspired him to become an engineer. He often said he considered it his supreme accolade to be chosen to modernize the Brooklyn Bridge.

In the late 1950s, Steinman was involved in designing the Messina Bridge, crossing the two-mile-wide Strait of Messina between Sicily and the Italian mainland. It would have been the world's longest suspension bridge by a huge margin. It still remained on the drawing board, however, when, on August 21, 1960, Steinman passed away in his beloved New York City at the age of 73.

A true believer in giving back to one's profession and helping advance it, Steinman served as president of a number of engineering groups, including the New York State Society of Professional Engineers, Society for the History of Technology, and American Association of Engineers (AAE).

As president of AAE, he began a national campaign for more professionalism and stringent educational and ethical standards within the engineering profession—and to get PE registration laws in every state in the union, as well as U.S. territories. He vigorously pushed the concept that engineering was a profession on a par with medicine, law, and science.

In 1934, he invited engineering leaders from four state professional engineering societies—Connecticut, New Jersey, New York, and Pennsylvania—to discuss forming a nationwide society of professional engineers. The result was the formation of the National Society of Professional Engineers (NSPE), for which he worked tirelessly to ensure its success (Robbins 1984).

Specifically, he was its first president (1934–1937, serving two terms), and, in his inaugural or keynote address, he emphasized a need to protect legitimate engineers against competition from the unqualified, from unethical practices, and from inadequate compensation. He sought to build public appreciation and recognition of the engineer.

An inspiring figure on the platform, Steinman made countless speeches on behalf of NSPE and the profession, giving depression-stricken engineers—many without jobs—renewed hope and faith in themselves and their profession. Every engineer could make the profession better than he or she found it by getting involved, he believed. What he promised the nation's engineers was pride in self, pride in profession, and pride in public service (AME 1960).

In addition to being a much-sought-after speaker, David was a prolific and accomplished author, writing both prose and poetry. He was the author of more than 600 professional papers and 20 books, among them *Bridges and Their Builders* (1941) with coauthor Sarah Watson; *The Builders of the Bridge* (1945), a best-selling biography of the Roeblings; and *I Built a Bridge and Other Poems* (1955). His 150-plus published poems included titles such as, "Brooklyn Bridge: Nightfall," "Blueprint," "The Harp," "The Song of the Bridge," and "The Challenge," in which he stated, "Nature said: 'You cannot,' Man replied: 'I can.'"

Over his illustrious career, Steinman received an unbelievable number of prestigious honors and tributes. In the period from 1952 to 1956 alone, he received more than 50 international awards, plaques, citations, and decorations, including the William Procter Prize (American Association for the Advancement of Science) and the 1954 Grand Croix de l'Etoile du Bien (French government). The only other recipient of this award in 1954 was Dr. Albert Schweitzer (Ratigan 1959).

In 1957, he was awarded five major medals:

1. The Kimbrough Gold Medal (American Institute of Steel Construction),
2. The George Goethals Medal (Society of American Military Engineers),
3. The Gzowski Medal (Engineering Institute of Canada),
4. The Louis Levy Medal (Franklin Institute), and
5. The Gold Medal of the Americas (Chamber of Commerce of Latin America).

The first of Steinman's 19 honorary degrees was a doctor of science from his alma mater, the City College, New York, in 1947. His doctor of engineering degree from Manhattan College in 1953 was conferred on him by the most eminent Cardinal Spellman on the occasion of the school's hundredth birthday. In 1957, he received a doctor of law degree from the University of Tampa; at the institution's graduation ceremony, he gave a commencement address titled "Moral Armor for the Atomic Age."

In his later years, Steinman became extremely philanthropic, especially in assisting needy and deserving students by establishing the David Steinman Foundation, the Irene Steinman Scholarship, and the Holton Robinson Scholarship. At City College, the school of engineering building—Steinman Hall—is named in his honor, as are numerous engineering awards programs around the world.

A man with many passions, Steinman was, for one, a skilled horseman, regularly riding his white stallion, Bill, at the head of the University of Idaho's Campus Day parades while a professor there. He shared a stamp-collecting hobby with his youngest son, David; he excelled at photography and loved classical music.

Said Steinman, "When I listen to a composition by Bach, Beethoven, Mozart or Schubert, I would gladly give up all my professional accomplishments to be able to create a single composition of exalting music. If I had my life to live over again, I would correct one omission—I would learn to play a musical instrument" (Raitgan 1959).

In its "turn of the millennium" special issue, *Engineering News-Record* honored Steinman as one of the greatest bridge engineers of all time. And his many outstanding bridges continue to be living monuments to that.

CHAPTER FIVE

Structural Trailblazers

The first fundamental idea of 'structure as art,' the discipline of efficiency, is a desire for minimum materials, resulting in less weight, less cost and less visual mass.

—David Billington

Of the major branches of the civil engineering profession, structural engineering, over the years, has remained one of the most visible. The majority of its products—buildings, stadiums, parking garages, towers, dams, power plants, bridges, and so on—are usually above ground and/or readily observable by engineers and nonengineers alike.

Along with the wide array of structures civil engineers design, there is often a tendency to break structural engineering into various subdivisions when practitioners concentrate on a single type of structure. For instance, the designers of certain types of structures such as tunnels, dams, or bridges often prefer the title of tunnel, dam, or bridge engineer. Illustrative of this are the four engineering luminaries spotlighted in Chapter Four, who were identified as bridge engineers. This chapter, in contrast, focuses on four civil engineers who designed all types of structures, predominantly people-use types of buildings.

Although the media often shortchange structural engineers in favor of architects when reporting on people-use building projects, the work of such civil engineers is nonetheless highly visible. At will, these types ofengineers can regularly go to (or drive by) construction sites and admire the fruits of their labor—and point out noteworthy structural features to all who will listen. It is one of the extremely satisfying benefits of being a structural engineer.

Next to spectacular bridges, the structures most reported on by the media are record-setting skyscrapers, sports facilities, space age–looking buildings, and national monuments—and anything that is the biggest, tallest, longest, or first.

Of the structural-civil engineering giants presented in this chapter, Fazlur Khan and Fred Severud concentrated on building structures and monuments, while Willard Simpson and T. Y. Lin divided their attention between buildings and bridges. All four, though, were (and remain) internationally renowned trailblazers in the overall field of structural engineering and in the design and building of trendsetting structures globally, many of them industry firsts and world record–holders. They not only overcame difficult challenges professionally, but also took on consequential leadership roles in their communities, making them better places to work and live.

Through the ages, structural engineering has always been highly regarded as a noble profession. It is the reason communities have all the awe-inspiring structures that they do—soaring stadiums, towering high-rises, spaceage–looking coliseums and arenas, and state-of-the-art public and private facilities.

Virtually all of the historic seven wonders of the world—from ancient times through the Middle Ages to modern days, from the Egyptian pyramids to the Sears Tower, and beyond—were (and are) structural engineering feats. Without the expertise and talents of structural engineers, the structural performance of those facilities would never have reached their maximum potential.

From two decades after the Civil War—and inspired by structural engineering icons such as Chicago's William Jenney and his first skyscraper in 1885—U.S. structural engineers have been at the forefront of creative, cost-effective, and industry-altering structural designs. Many of the world's leading structural engineers over the years, however, did reside in other countries, and many had a significant influence on U.S. engineers and the development of America's structural industry.

Among the most famous was the French engineer Alexandre Gustave Eiffel (1832–1923), designer of the tower bearing his name and the structural framework that holds up the Statue of Liberty. He was one of the most influential forerunners for using structural iron and then steel in multistory structures in lieu of masonry-bearing walls. He was also a proponent of the merits of theoretical structural analysis. In the early 1870s, Eiffel alleged, "The English engineers have almost entirely bypassed calculations. They fix dimensions of their members by trial and error, and by experiments and using small-scale models. They are ahead of us in this practice, but we have the honor, in France, to surpass them by far in theory and to create methods opening up a sure path to progress, disengaged from all empiricism" (Billington 1983).

Two of the most respected world-class pioneers in the structural design of reinforced concrete structures were Eduardo Torroja (1899–1961) from Spain and Pier Luigi Nervi (1891–1979) from Italy. They were possibly the most aesthetically conscious "structural artist" engineers of their day. Ove Arup (1895–1988), who was born in the United Kingdom to Danish parents, sparked considerable interest everywhere with his structural design solutions for the sail-shaped Sydney Opera House, a complex project that took 16 years to complete (from 1957 to 1973).

In the same time frame, "Mr. Thin Shell Concrete Master-Builder" himself, Spanish-born Felix Candela (1910–1997), excited Western structural engineers with the electrifying concrete shells he was designing and building throughout Mexico in the mid to later half of the twentieth century.

These innovative non-U.S. structural engineers sparked the imaginations of engineers everywhere—but especially in the Americas—inspiring them to regard structural design as an art and to push the engineering design envelope higher and higher.

In addition to the designers of buildings, top U.S. engineers were also greatly influenced by Swiss bridge engineers, in particular, Robert Maillart (1872–1940). Maillart epitomized "structural art"—as defined by Princeton's David Billington in *The Tower and the Bridge*—with the endless new and elegant forms he introduced in reinforced concrete. Among the notable American structural engineering giants whose work was greatly influenced by Maillart was Fazlur Khan. According to Billington, Khan perceived much "similarity between Maillart's ideas and his own" (Billington 1983).

In reviewing the stories of the four American-based structural greats featured here, it is obvious that structural engineering thought and creativity currently have no boundaries. Today's generation of U.S.-based structural engineers have picked up where the non-U.S. engineering community of yesterday left off and pushed the structural engineering envelope forward in great strides. In the future, Americans will increasingly impact structural engineering practices around the world, just as European engineering icons did in the past.

Fazlur Rahman Khan

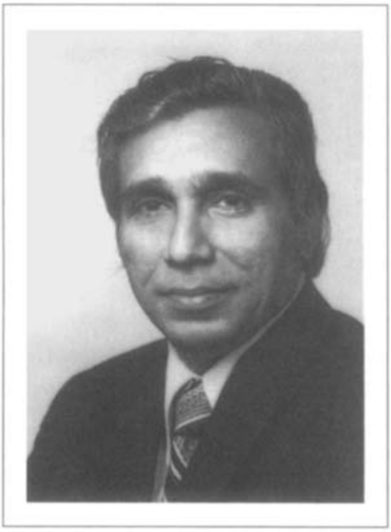
Considered the father of tubular design for high-rises, Fazlur Khan has become an icon in both architecture and structural engineering. Known best for engineering the Sears Tower in Chicago, he created a legacy of innovative structural designs that is without peer. According to senior engineer John Zils of Skidmore, Owings & Merrill (SOM), "It was his unique ability to bridge the gap between architectural design and structural engineering that truly set Dr. Khan apart from other structural engineers."

Born on April 3, 1929, near Dhaka, Bangladesh (then British India), Fazlur's early resolve to become an engineer was influenced by two people—his father and an older cousin who preceded him into college to study engineering.

Khan's father, a well-known and respected mathematician in British India, taught mathematics and wrote textbooks for high school students. The elder Khan eventually became the director of public instruction in the region of Bengal.

Young Khan received his first engineering diploma from Dhaka Engineering College in 1950. A Fulbright scholarship combined with a Pakistan government scholarship brought him to the United States and the University of Illinois at Urbana. There, he earned two master's degrees followed by a doctorate in structural engineering in 1955.

Khan immediately joined the internationally known architectural and engineering firm of SOM in Chicago. By 1960, he was well into establishing his trademark of creating innovative concepts for tall buildings framed with structural steel, concrete, and/or composite systems.



Fazlur Khan

Photo credit: SOM

His "tube concept," using all the exterior wall perimeter structure of a building to simulate a thin-walled tube, revolutionized tall building design. In 1962, while designing the 38-story, reinforced concrete Brunswick Building in Chicago, he developed methods for interacting shear walls and frames to resist lateral forces. Later, he refined the shear wall–frame interaction system to come up with the "tube-in-tube concept," initially used for the 52-story One Shell Plaza Building in Houston.

Khan's diagonal-framed tube system, first used for the John Hancock Center in Chicago, connected widely spaced exterior columns with diagonals on all four sides of the building. The concept allowed the 1965 Hancock building to reach the then-staggering height of 100 stories. The Hancock Center and Khan's Chicago masterpiece—the 110-story Sears Tower with its bundled tube structure (the world's tallest building for many years)—drew worldwide attention to America's innovations in structural engineering for skyscrapers.

Adding to his reputation are Khan's notable international structures, including the Haj Terminal Building at the Jeddah International Airport in Saudi Arabia—a massive tentlike structure covering nearly one square kilometer of area.

Known for his professional leadership in the field of structural engineering, Fazlur was also active in his local community. For many years, he served on the board of trustees for the condominium development in Chicago, where he lived. And he never forgot his roots.

Khan's homeland came to be called Pakistan in 1947. During 1971, the country was divided into East Pakistan (now Bangladesh) and West Pakistan, with its government and military centralized in West Pakistan. Because of this, the economic condition of East Pakistan (Khan's homeland) deteriorated so much that its people boldly protested the unequal distribution of the country's income and wealth. To discourage unrest, the Pakistani government sent its military into East Pakistan to terrorize the people. Ten million Bangladesh refugees eventually made their way to India while Western countries, including the United States, refused to interfere in "internal politics" (Zils 2000).

As a result, Khan founded a Chicago-based organization, the Bangladesh Emergency Welfare Appeal, to help the people of his homeland. The group, which met on weekends in Khan's home, raised money for aid and circulated brochures to influence the public and Washington officials. Many of the Bengalis involved (including Khan) had family and friends in Bangladesh in obvious danger; Khan's group did what they could to make it safer for them. India's aggressive intervention finally put an end to the killing.

This experience, according to Zils, caused Khan "to become reflective: that all people are citizens of the world and while there are intriguing differences between cultures, people should not be categorized or judged according to these groupings." Khan also believed engineers needed a broader perspective on life, saying, "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" (Ali 2001).

For enjoyment, Fazlur loved singing Rabindranath Tagore's poetic songs in Bengali. He and his wife, Liselotte, who immigrated from Austria, had one daughter, who was born in 1960. A structural engineer like her father, Yasmin Sabina Khan said of her father, "He was always concerned with people and how engineering affected them" (Bey 1998). To keep his memory alive, she wrote a comprehensive book about him and the impact of his work, *Engineering Architecture: The Vision of Fazlur R. Khan*. It was published in 2004, 20-plus years after his death.

Khan died of a heart attack while on a business trip in Jeddah, Saudi Arabia, on March 27, 1982. Only 53, he was a general partner in SOM at the time. He was returned to the United States and buried in his adopted home of Chicago.

Sears Tower, Chicago

At 1454 feet, Sears grabbed the global tall building record from New York City's World Trade Center (1368 feet) in 1974. The 110-story 4.4-million-square-foot building featured a unique bundled-tube structural system to resist both vertical and lateral forces.

Photo credit: SOM-Timothy Hursley

In 1998, the leaders of the city of Chicago, because of their high regard for Khan's accomplishments as an engineer, named a street after him—Fazlur R. Khan Way, a stretch of Franklin between Jackson and Randolph.

It was but one of many recognitions he received during his life and posthumously. For example, in 1999, *Engineering News-Record* honored him as one of the world's top 20 structural engineers of the last 125 years. Three decades earlier, when Khan was 41 years old, the Chicago Junior Chamber of Commerce had named him Chicagoan of the Year in Architecture and Engineering.

> *"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."*
>
> FAZLUR KHAN

Among Khan's other honors were the Wason Medal (1971) and Alfred Lindau Award (1973) from the American Concrete Institute (ACI); the Thomas Middlebrooks Award (1972) and the Ernest Howard Award (1977) from ASCE; the Kimbrough Medal (1973) from the American Institute of Steel Construction; the Oscar Faber Medal (1973) from the Institution of Structural Engineers, London; the AIA Institute Honor for Distinguished Achievement (1983) from the American Institute of Architects; and the John Parmer Award (1987) from Structural Engineers Association of Illinois.

Khan was elected to the National Academy of Engineering in 1973 and received honorary doctorate degrees from Northwestern University in 1973 and Lehigh University in 1980.

Apparent from all of Khan's citations are that his main legacy will be that he, more than any other individual, ushered in a renaissance in skyscraper construction during the second half of the twentieth century. He epitomized both structural engineering achievement and the need for creative collaborative between architect and engineer. To him, for architectural design to reach its highest levels it had to be grounded in structural realities.

Fred N. Severud

One of America's greatest monuments, the towering Gateway Arch in St. Louis, Missouri, stands majestic because of a structural engineer's genius—the same engineer who was responsible for creating the awe-inspiring cable-supported roofs for Madison Square Garden in New York City; Yale Hockey Rink in New Haven, Connecticut; and Raleigh Livestock Arena in Raleigh, North Carolina. This engineer was Fred N. Severud, an intense and brilliant Norwegian-born U.S. immigrant with bold ideas.

Born in Bergen, Norway, into a large family consisting of two brothers and nine sisters on June 8, 1899, Fred was educated at the Institute of Technology in Trondheim, Norway. He moved to the United States shortly after marrying his college sweetheart, Signe Hansen, in 1923. It was in this adopted country that Fred aspired to "fulfill my ambition to become the great-