Concrete City: Chicago's Role in Concrete High-Rise Engineering

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Abstract

Chicago's iconic skyscrapers—the Sears Tower and John Hancock Building, in particular, have given the city a deserved reputation as a center of innovation in steel engineering and construction. However, Chicago has a parallel history as the leading center of concrete high-rise innovation, which also deserves recognition alongside its traditional steel-centric history. This was particularly true during the second half of the 20th century. More than half of the roughly 400 buildings taller than 12 stories built in Chicago from 1950 to 1986 were concrete, not steel. More significantly, six of the ten structures that claimed the title of the world's tallest concrete skyscraper from 1902 to 1989 were built in Chicago.[1] Research done for the Spring 2025 exhibition *The Modern Concrete Skyscraper* at New York City's Skyscraper Museum suggests that Chicago's leadership in concrete high-rise construction was due to three main factors: its geology, the initiatives of curious, innovative designers along with entrepreneurial suppliers and contractors, and Chicago's culture of collaborative efforts among and across disciplines.

Early Concrete in Chicago

Even as the city's earliest iron frames emerged in structures like the Home Insurance and Rookery, Chicago's builders experimented with 19th-century versions of concrete—mainly as a replacement for natural stone. Like the history of terra cotta fireproofing businesses in Chicago, the 1871 fire inspired entrepreneurs and inventors to join the massive rebuilding effort. Portland cement, a mixture of crushed limestone and calcium silicates, was first patented in England in 1824 and gradually improved over the following decades, forming a crucial ingredient in producing strong "artificial stone" that won favor for its resistance to fire and manufacturing processes that limited labor costs. By 1876, there were more than 100 buildings with artificial stone fronts or structural elements in Chicago and five manufacturers, among them Ransome and Smith, an enterprise of concrete pioneer Ernest Ransome.[2] Ransome himself relocated to the city from 1890 to 1895 before settling in New York City in 1896. Ransome and others patented systems for fireproof concrete floors, reinforced with twisted or shaped steel bars, in the late 1890s that became the basis for more comprehensive building systems.[3] Ransome's patented system was used for the first reinforced concrete skyscraper, the Ingalls Building in Cincinnati, in 1903-5. Builders in Chicago and elsewhere quickly saw the advantages of the hybrid material's durability and strength. Montgomery Ward's 2,000,000 square foot Catalogue House, designed by Schmidt, Garden, and Martin, deployed a concrete frame over a winding, six-acre site along the Chicago River in 1908, and Studebaker built a seven-story building at Michigan and 21st Street in 1909 that used paneled slabs to span 24' x 24' column bays.[4] Henry Ericsson, the city's Commissioner of Buildings, was fascinated by the new material's fire resistance but concerned about its structural performance and durability. After commissioning laboratory experiments from Arthur Talbot at the University of Illinois and W.K. Hatt at Purdue University in 1911, he drafted one of the first building codes in the United States to address flat-slab construction, which had vexed engineers because of its hyperstatic performance. "Owing to the complication of methods used in designing reinforced concrete flat slab or girderless floor systems," *Cement Age* noted,

"…there is little agreement among designers of this type of construction in determining the thickness and reinforcement of flat lab floors. Therefore, the ruling drawn up by the Chicago Building Department should prove both rational and simple, since it is the result of nearly four years' study and testing."[5]

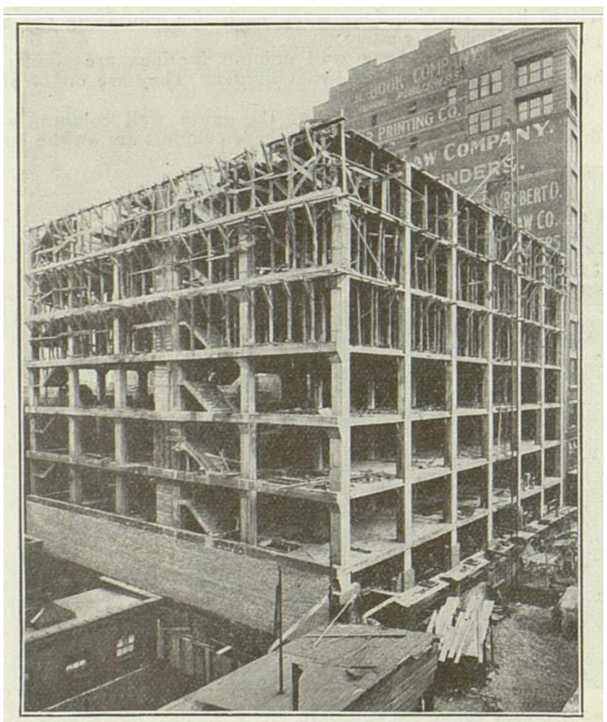

Fig. 1. Typical early-20th-century concrete construction in Chicago: the Moser Paper Co. Bldg., Plymouth Ct. The Construction News*, Nov. 27, 1909.*

While reliant on rules of thumb instead of mathematical analysis, the code gave builders and engineers confidence in the material; 1911-12 saw half a dozen major warehouse, manufacturing, and office structures built concrete in Chicago. "Never before in the city's history," reported the journal *Concrete,* "have cement and crushed stone played so prominent a part in building construction." Among these were the Sharples Cream Separator Building, designed for 225 psf loads, the Rand-McNally Building, which reached a height of ten stories, and the Dwight Paper Co., another ten-story structure that rose at a record rate of one floor per week.[6] Laboratory research at Purdue and Illinois was supplemented by extraordinary static and dynamic testing supervised by Talbot and others on the Western Newspaper Union Building. This 1910 nine-story concrete structure was demolished in 1917 as part of the city's Union Station project, and it served as a test bed for developing theories and rules of thumb for concrete engineering. The structure's floor slabs withstood over 900 psf loads, suggesting that the city's codes and engineering practices were overly conservative.[7]

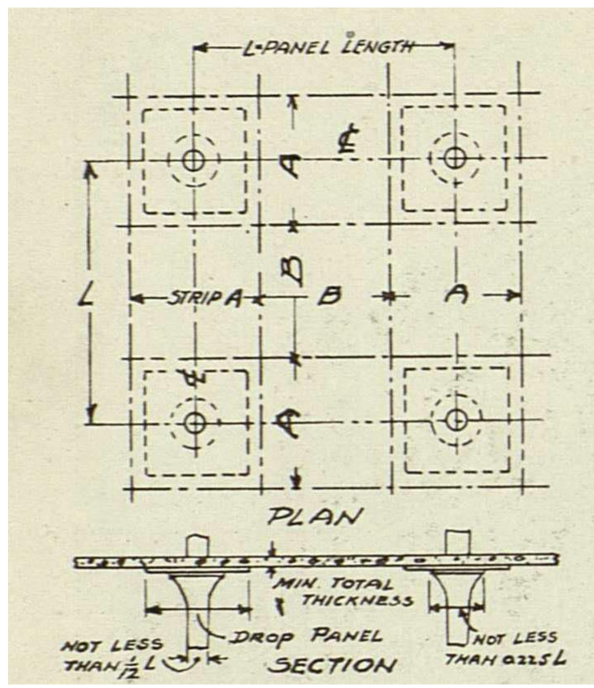

Fig. 2. Chicago's 1911 Code illustrated. Concrete-Cement Age, *Nov. 1, 1914.*

Flat slab construction saw a natural market in residential high rises in the 1910s and 1920s as advances in reinforcement allowed thinner structural depths than steel construction, maximizing the number of floors possible within a given height. The original Edgewater Beach

Hotel, built to designs by Marshall and Fox in 1917, used dense reinforcement mats to resist punching shear, eliminating the mushroom capitals and drop panels of typical industrial construction.[8] Similar reinforcing was used in the all-concrete Bournique Apartments on Goethe St. in 1916.[9] Concrete became standard for Chicago's high-rise residential construction, such as the 22-story Powhatan and Narragansett Apartments (both 1929) as its malleability allowed designers to take advantage of the city's post-1922 setback code while providing reliable fire separation between floors. Its durable, inexpensive construction made it ideal for the city's public housing projects, beginning with the low-rise Ida B. Wells Homes in 1939 and extending upward into the Chicago Housing Authority's early high-rise projects, in particular, the Dearborn Homes (1949-50) and Loomis and Ogden Courts (1951, 1953). Mies van der Rohe's Promontory Apartments (with PACE and Holsman, Holsman, Kleklamp, and Taylor, 1949) featured exposed concrete columns and slabs, suggesting that the material had aesthetic possibilities alongside its affordability and fire resistance.

Marina City

Engineer Henry Miller and architect Milton Schwartz set a record for tall concrete construction with the 40-story Executive House Hotel on Wacker Drive in 1958. Executive House relied on two-foot-thick shear walls of heavily reinforced concrete around its elevator core for stability, but these were hidden behind a slick, stainless steel and glass exterior. More dramatic structural performance and architectural expression came with the 60-story, 588' tall twin towers of Marina City, built across the River from the Executive House beginning in 1959. Designed by visionary Chicago architect Bertrand Goldberg, Marina City catalyzed advanced concrete construction in Chicago even as it set new urban development and architectural design standards. Goldberg's design called for cylindrical shafts of apartments that would open outward toward views of the city and the Chicago River with curving, cantilevered balconies. The structure, based on stiff central cores surrounded by rings of columns, all connected with moment-framed girders, was engineered by a team including Frank Kornacker, Bertold Weinberg, and Fred Severud from New York City. While elegant in concept, the structure relied on rigid connections between balconies, girders, columns, and cores. Goldberg's relentlessly circular geometry expanded into three dimensions and produced doubly-curved forms that would have required extensive skilled carpentry. Further issues arose with scheduling; traditional concrete construction would have pushed the schedule out to three or more years, while financing requirements made it necessary to begin renting in 1962.

Fig. 3. Marina City under construction, showing fiberglass formwork and slip-form core construction. (Chicago History Museum).

McHugh Construction, a local firm founded by bricklayer James McHugh at the turn of the century, had developed concrete expertise through winning bids on Chicago Housing Authority projects throughout the 1950s. By 1960, they had established a reputation for reliable concrete work that supported their successful bid on Marina City. McHugh developed innovative solutions to form Goldberg's complex, curving shapes and meet the aggressive construction schedule, developing fiberglass formwork that could be mass-produced and used up to

60 times apiece.[10] They also proposed using the cores as the bases for self-climbing Linden cranes, which could rotate 360° and hoist up to 8,000 pounds—about two cubic yards of concrete—from ground locations up to 90' distant. McHugh matched the speed of the Linden equipment with an extraordinary coordination of concrete delivery and placement. Ironworkers assembled reinforcement panels on the ground, relying on the Linden's capacity to lift them, fully assembled, into place. The fiberglass forms were staged to allow them to 'jump' three stories above as concrete came to strength. With these advances, McHugh averaged a new floor every two days.[11] Concrete surfaces were left as-struck and painted; the smooth finish imparted by the fiberglass required no additional work, and exposed concrete became a signature element in the building's space-age aesthetic.[12] McHugh would go on to use fiberglass formwork in sculpturally rich concrete apartment towers such as 2020 Lincoln Park West (1971) and in "rib-cage" high-rises including Eugenie Square in Lincoln Park (1972); rigid concrete tubes of closely-spaced concrete mullion-columns formed by steel jump forms that matched Marina City's record for floor construction.

Portland Cement Association and Materials Service Corporation

McHugh's innovations in formwork, reinforcing, and scheduling were matched by advances in Marina City's concrete itself, which relied on a low water/cement ratio, lightweight vermiculite aggregate, careful grading, and slag from nearby steel mills to achieve then-remarkable strength, at 5000 psi in its caissons and lower levels, and lightness, at 100 pounds per cubic foot in 3750 and 3000 psi concrete higher up.[13] These advances relied on research conducted by the Portland Cement Association, an industry organization based in Chicago that began providing advice and data to engineers, architects, and builders in 1916.[14] PCA was founded to compete with the ease of specification and engineering that the American steel industry enjoyed since Carnegie Steel's ubiquitous handbooks were published in the 1890s. PCA advanced concrete engineering and construction practices from a relatively unsophisticated and inefficient knowledge base to a discipline rivaling steel's precision and scope by establishing practices, mixes, and standards. Constant experimentation in their laboratory at 33 West Grand Avenue, just north of the Loop, in the prewar years led to reliable knowledge in areas that had previously frustrated contractors and designers alike, producing gradually stronger mixes based on adjustments to water/cement ratios and more reliable interaction between concrete matrices and reinforcing bars. Research scientist Duff Abrams led much of this work, relying on equipment at PCA and the Lewis Institute, one of the academic entities that would merge to form the Illinois Institute of Technology in 1940.[15] By 1962, PCA had opened a large testing laboratory in Skokie, employing more than 600 engineers and publishing widely on concrete strength, forming, and maintenance.[16] Other academic collaborations, in particular with the Talbot Laboratories at UIUC, were vital contributions to understanding and improving strength and versatility.

PCA's proximity to Chicago engineers and contractors alone would have made the city a natural center for innovation, but the local industry provided tangible research efforts in real-world conditions, too. One supplier, Material Service Corporation, adopted practices that ensured knowledge and experience were shared among practitioners throughout the city's construction and engineering communities. Founded by Henry Crown and two of his brothers in 1919, the company quickly grew to dominate the market for cement and aggregate in Chicago. By mid-century, it owned eight quarries that provided good-quality limestone, four cement factories, and five gravel plants. The stone, sand, and cement from these sources were collected and mixed at 13 distribution yards located strategically throughout the city, ensuring that concrete could be delivered to any construction site in Chicago well within the 90 minutes that was agreed, industry-wide, as the maximum time between initial mixing and placement for concrete.[17] Materials Service developed its own mixing trucks and built a fleet of low-profile barges that could bring gravel from outlying locations via lake and river, saving time by slipping under Chicago's river bridges; competitors, with larger vessels, were slowed by the time it took for bridges to raise and lower. The company's primary mixing plant, "Yard One," was located alongside the River at Chicago Avenue, making it an ideal transfer point for river-borne raw materials and a convenient 15-minute drive for ready-mix trucks to construction sites in the Loop. This proximity gave concrete in Chicago a considerable advantage over cities, where land prices kept ready-mix plants at a much farther distance—across the Hudson River, in New York's case, and only accessible by tunnels and bridges prone to traffic jams.[18]

Fig. 4. Materials Service Corporation's "Yard One" on the Chicago River in the mid-1970s. (Paul James).

Yard One and Materials Service had provided the strong, rapidly delivered concrete for McHugh at Marina City, and that expertise became the basis for hands-on testing and experiments with mixes, aggregate grading, and admixtures, especially under the leadership of two engineers who became key figures in Chicago's high-strength concrete development. Technical Marketing Manager Jaime Moreno and Quality Control Manager John Albinger, in conjunction with another industry specialist, Flood Testing Service, led an outreach program that actively fostered collaboration and communication among the city's contractors, engineers, and architects. Materials Service leveraged their expertise to use job sites as laboratories, often trying to exceed specified strengths in column pours to gradually ratchet up what was achievable.[19]

Moreno's program was one of constant refinement, which he and Albinger described in a 1981 *Concrete Construction* article:

"Selecting the proportions of a high-strength concrete mixture is a combination of art and science. Because of the innumerable types of gradings of aggregates, chemistries of various cements, fly ashes, and admixtures, and the subsequent interaction of any combination of these materials, arriving at the optimum combination is often a matter of trial and error…as in blending blue and yellow to make green, many combinations must be tried to attain the desired mix."[20]

Moreno and Albinger contributed papers and columns in technical and industry literature, and Moreno, in particular, was an active member of the Chicago Committee on High Rise Buildings, an industry organization founded in 1968 that brought together skyscraper engineering, design, and construction experts to share best practices. Albinger summarized his company's ethics in a 2006 reminiscence:

"By design, every job was used to investigate the next higher strength. Either a couple of columns were poured using higher strengths than required, or in situ tests were conducted to measure such attributes as creep or the effect of temperature. By the time the next high-rise was on the drafting table, all interested parties had enough data and confidence to justify using higher strength concrete. The results of all these tests and experiences were shared with the entire concrete community. No single company benefited. Such cooperation is rare in any industry."[21]

Moreno and Albinger championed the use of fly ash and superplasticizers in concrete mixes as ways to reduce the amount of water required while achieving low enough viscosity to handle, and much of Materials Service's research went into fine-tuning proportions of these, along with intensive quality control, to refine and improve strength gradually.[22] The short times required for transporting batches from Yard One were crucial to this program—fresher concrete was more liquid, and the time gained by the proximity of the mixing plant to job sites allowed for precise, careful on-site slump testing.[23] Chicago's naturally occurring limestone provided a sound basis for strong concrete—limestone from Materials Service's quarries at Thornton averaged around 22,000 psi. This was less than granite from eastern sources, but limestone had the advantage of being seamed and, thus, easy to split and crush into useful aggregate.

Flat Slabs and Tubes

Putting theory into practice, however, demanded clients, builders, and engineers willing to see the drafting table and construction site as laboratories. Chicago's high-rise community developed an innovation-friendly mindset early; Fazlur Khan, Hal Iyengar, Bruce Graham, and others at SOM experimented with new forms of structural design that led to that firm's well-known tube structures, beginning with the 1961 Brunswick and DeWitt-Chestnut buildings, both of concrete deployed around those buildings' extreme perimeters. While the concrete tube represented a radical "return to the bearing wall" in structural engineering, Brunswick used regular 5000 psi concrete on its lower floors and lighter-weight, 4000 psi concrete above. The first Chicago building to reach 6000 psi was 1000 Lake Shore Plaza (1962), a 57-story apartment tower designed by Sidney Morris and engineered by William Schmidt. This building's relatively small footprint, at just 85' x 90', put a premium on floor space and efficiency, driving the need for smaller columns.[24] While snaring the concrete height record from Marina City, at 590 feet, the jump in concrete strength was relatively easy, adding fly ash and pozzolith to achieve a higher cement-to-water ratio. For the 645' Lake Point Tower at the foot of Navy Pier, Schmidt's next project relied on further experimentation and tighter quality control procedures to achieve 7500 psi. As the tower rose, its structure was instrumented with seismographs to provide data on its deflection under wind loading and the long-term effects of creep.[25]

Fig. 5. The 645' Lake Point Tower, engineered by William Schmidt, showing flat slab construction. (ALCOA).

Khan and SOM designed One Shell Plaza, a 714-foot tall tower in Houston that relied on high-strength, lightweight concrete to surpass Lake Point Tower. Still, the height record came back to Chicago in 1975 with the completion of Water Tower Place (Loebl, Schlossman, Bennett, and Dart, architects, C.F. Murphy Associates, engineers), a mixed-use complex composed of a 76-story, 859-foot tower housing a hotel and condominiums atop an eight-story shopping mall and a large theater. This mélange of programs required complex transfer structures to bring the tower's columns and shear walls to the foundations.

To save space on the lower floors and to enable the entire structure to sit on shallow, hardpan caissons instead of deep bedrock foundations, concrete was specified in various weights and strengths throughout: 4000-psi, lightweight concrete for all floor slabs, 6000-psi concrete for the podium structure, and 4000-psi up to 9000-psi for the tower columns. Materials Service provided its most sophisticated mix to date for the latter, incorporating 100 pounds of fly ash per cubic yard to reduce the water-to-cement ratio content to just 36%.[26] McHugh, the concrete contractors for the project, adhered to strict requirements that saw cylinders from multiple trucks sent to PCA's Skokie laboratories overnight for testing. Additionally, they developed 'puddling' techniques that blended higher-strength column concrete into floor slabs where punching shear forces were highest.[27] The result was a structure that held the height record for concrete for 14 years, until a pair of Chicago towers—311 S. Wacker Dr., by Kohn Pedersen Fox and Two Prudential Plaza, by Loebl, Schlossman, and Hackl with CBM, structural engineers—surpassed it at 961' and 915', respectively, in 1989-90.[28] 311 S. Wacker was particularly noteworthy; columns on its lower levels achieved 12,000 psi using microsilica admixtures, and its floor slabs were post-tensioned, requiring 9000 psi compressive strength. Its 8' thick mat foundation, designed to spread the tower's load out over 102 caissons below, was the largest single high-strength concrete pour ever, involving 60 trucks coordinated to arrive precisely four minutes apart.[29]

Supertalls and Industry Changes

311 S. Wacker, however, was designed by New York architects and a Dallas engineering firm; the contractor was Charlotte-based. Its structural system, a frame-shear-wall interactive design, "was developed in the 1960s," according to one-time PCA engineer Mark Fintel.[30] High-strength knowledge had diffused well beyond Chicago by the 1980s and plateaued. Changes to the industry saw the Portland Cement Association and Materials Service evolve; PCA spun off its research arm into Construction Technology Laboratories, Inc., and General Dynamics, the conglomerate that had owned Materials Service since the Crown family engineered a financial merger, taking the larger company over in 1959, gradually distanced itself from the construction market, finally selling Materials Service to Hanson, a large aggregate supplier, in 2006, Hanson was acquired, in turn, by the international materials supply corporation Heidelberg the following year.[31] While the McCook quarry remained active under the Heidelberg name, the Thornton pit was taken over as a surface reservoir for Chicago's Deep Tunnel stormwater project.

Fig. 6. Water Tower Place under construction. (Paul James).

Structural design for high rises evolved, as well. Concrete and steel construction economics have always balanced time, cost, and labor. As the speed of curing, strengthening, and formwork placement increased through the 1980s, many traditional hurdles to building tall concrete disappeared. Steel's globalization also made it a more volatile commodity. Hybrid forms that optimized construction schedules, materials costs, and labor emerged in Chicago and elsewhere, particularly so-called "composite" construction that paired the shear resistance and fire protection of concrete cores with the rapidity and light weight of steel framing. Composite structures were not new—Emperger columns and combinations of steel and concrete framing meant that engineers and builders had experience with hybrid performance and forming as early as the 1926 American Furniture Mart in Chicago.

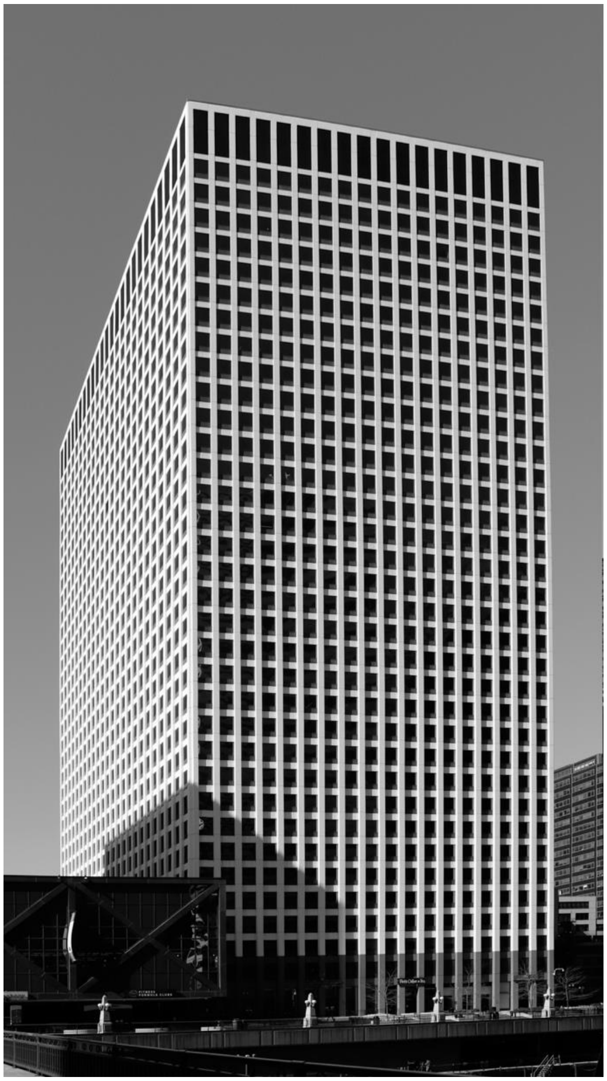

FIg. 7. Gateway Center III (SOM, 1972). (Authors).

Later, hybrids included SOM's Gateway Center III, adjacent to Chicago's Union Station, which paired a rigid concrete tube exterior with a lightweight internal core. This was partly a response to the irregular layout of railroad tracks underneath, but its construction demonstrated that pouring and erecting schedules could be coordinated and that the structural results were promising. Interest in optimizing construction speed, material, labor expenses, and building weight led engineers to new hybrids that took advantage of concrete's improving speed and performance. Developer Miglin-Beitler's Oakbrook Tower (1987), a 34-story office building designed by Helmut Jahn in the western suburbs, was one of the first that was consciously designed with a rigid concrete core and a lighter steel frame; the core was started first, providing stability, and the steel 'caught up' around it. Tacit agreements with steelworkers in New York, where union arrangements stipulated that no work could be done above the topmost steel crew, made this construction impossible there, but it quickly proved itself in Chicago.[32]

As strengths continued to rise, pumping grew more efficient, and curing times were reduced through new admixtures. Concrete became more competitive for commercial towers in Chicago. Miglin-Beitler's 1988 "Skyneedle" proposal was one of several unrealized projects for the city that sought to take fuller advantage of concrete's newly achievable strength and speed. The site at the corner of Madison and Wells was just 40,000 square feet—too small to allow a conventionally-framed tower. But with stronger concrete and advanced calculation techniques, engineers Thornton Tomasetti developed a stiff, solid concrete core with bracing perimeter fin columns to brace and support a 2000-foot tower "by taking advantage of the mass and stiffness of the high-strength concrete that is available in the Chicago area and combining it with the advantages of a structural steel floor system with its inherent strength, speed of construction and flexibility to allow tenant changes."[33] The exterior fins were connected to the core by haunched concrete link beams and three pairs of intersecting, two-story deep cross walls at regular vertical intervals. Further stiffening the slender structure was done with steel Vierendeel trusses that filled in between the fin columns on the building perimeter, making the structure a complex collection of techniques—stiff core, perimeter shear walls, and outrigger columns. The interactions of these various elements in three dimensions were calculable only with the help of new computer technology; engineer Charlie Thornton noted that the software running on the firm's VAX-11/750 mainframe was "like an SST" compared with earlier generation's "Model T" programs. This, he explained, allowed them to calculate the structure's behavior in multiple dimensions instead of "uncoupling" north-south and east-west systems to allow manual, linear calculations.[34]

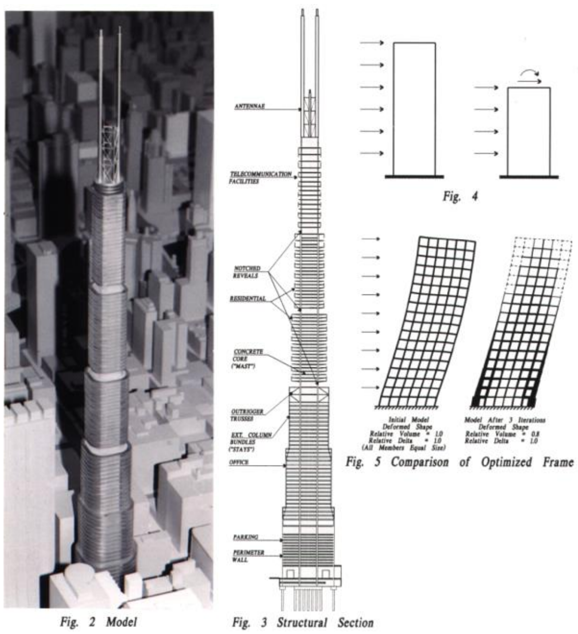

Fig. 8. 7 S. Dearborn (SOM, 2004, unbuilt). SOM.

Thornton Tomasetti were New York-based, and the Skyneedle's architects, Cesar Pelli & Associates, were located in New Haven. Still, expertise in Chicago was also vital to supertall concrete and hybrid structures for the city. SOM's 7 South Dearborn (1999), engineered by a team led by William F. Baker, developed a "stayed mast" system on the 33,000 square foot site for another 2000' tower scheme. This system improved on the Miglin-Beitler tower concept by substituting steel perimeter columns for the earlier project's concrete fins, taking up less space and connecting them to the central core—just 66' square—with outrigger trusses. The design relied on 12,000psi concrete and advanced digital techniques, including aerodynamic analysis and multifactor optimization, which Baker credited with "breaking through several barriers that have limited buildings in the 100+ story range," mainly drift and spatial efficiency on lower floors.[35] While 7 South Dearborn remained unbuilt in the aftermath of 2001, the concept of a stiff core, braced by vertical elements set at the building perimeter—or, at least, a distance far enough to establish a reasonable moment arm—was a key step in the "buttressed core" that Baker and the SOM engineering team developed for Tower Palace III in Seoul, South Korea (2004), and the 2700' Burj Khaliffa in Dubai (2010).[36]

Chicago has continued to build tall concrete—SOM's 1362' 401 N. Wabash, completed in 2009, relies on a core-and-outrigger system with two-story walls of 16,000 psi concrete connecting the core to perimeter columns. McHugh Construction and Materials Service collaborated on the tower's concrete mixes and pours, carefully selecting high-strength limestone, using admixtures to create a particularly dense product, and employing a 680-horsepower concrete pump to move 6000 pounds of concrete per minute to the upper floors. Self-jacking formwork on the core and specially produced formwork enabled a pour rate of one floor every three days. The tallest building constructed in Chicago since 1974, 401 N. Wabash sits just 400 feet from Marina City. The two projects provide a convenient illustration of concrete's evolution as a structural material and of the collaborative engineering and construction communities in Chicago that raised concrete to ever-new heights.

Acknowledgements

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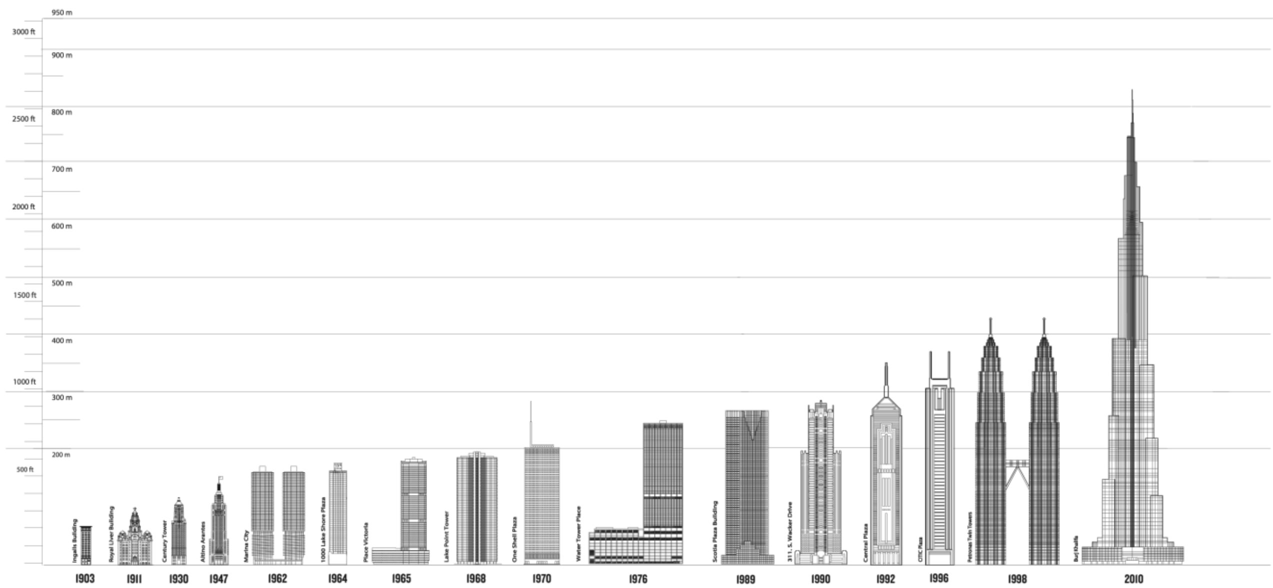

Fig. 9. World's tallest concrete buildings, 1903-2010. Graphic by the Skyscraper Museum.

Notes:

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