

Myron Goldsmith and the development of the diagonally braced tube

M. J. Neveu & E. P. Saliklis

California Polytechnic State University, San Luis Obispo, CA

ABSTRACT: Myron Goldsmith (1918-96) was a unique figure in the development of tall building design. He successfully blended the roles of architect, engineer and teacher throughout his tenure at Skidmore Owings and Merrill (SOM) and in the Department of Architecture at the Illinois Institute of Technology (IIT). Indeed, many of the projects supervised by Goldsmith and his colleagues, to include the pre-eminent structural engineer Dr. Fazlur Khan (1929-82), directly influenced built work. The few published studies of Goldsmith acknowledge, but do not fully explore, the innovations that Goldsmith oversaw as thesis advisor to many graduate students at IIT in the 1960s. An essential link between the student work and the large-scale office projects at SOM were the “Saturday Sessions.” There, architects, engineers and students met for weekly reviews at IIT and then a lengthy and lively lunch at Bertucci’s restaurant in Chicago. Goldsmith encouraged the free exchange of scholarly and practical ideas during these Saturday Sessions and we argue that this was a vital part of Goldsmith’s pedagogy. This paper will focus on a fascinating network of students, architects, and engineers that led to the innovation of the diagonally braced tube tall building.

1 INTRODUCTION

In 1938 Mies van der Rohe became director of the Armour Institute in Chicago. Enrolled students were given the choice of completing their degree in the traditional Beaux-Arts manner or to shift their studies and work with the new director. Myron Goldsmith chose the latter. Goldsmith completed his first degree with Mies (BS, 1939) and then continued his studies towards a Masters degree, something he would not complete until 1953. In the meantime Goldsmith served for the US Corps of Engineers (1944-46) and was employed by Mies (1946-53). While in the office, Goldsmith worked on a variety of projects and contributed greatly to the completion of the Farnsworth House. One important component of the life of the office was the frequent “table talks” between Mies and his office workers/pupils. Goldsmith’s notebooks are full of aphorisms from Mies and this dynamic dialogue, though perhaps slightly different in tone, certainly set a precedent for the Saturday Sessions at IIT. (Comte, 1991) Upon completion of his thesis, Goldsmith was awarded a Fulbright and travelled to Rome where he worked under Pier Luigi Nervi until 1955. Goldsmith returned to the United States to work, not in Chicago, but in the San Francisco office of SOM. Three years later, however, he was back in Chicago working for SOM where he became Design Partner in 1967. In 1961 Goldsmith became a member of the Graduate Teaching Faculty at IIT. He would continue the working at IIT and SOM until his death in 1996.

What little research exists on Myron Goldsmith typically focuses on his contribution to the development of tall building solutions in the 1960s and 1970s. Goldsmith was uniquely positioned to make such contributions through his thirty-plus year relationship with the Chicago office of SOM and specifically with his working relationship with Fazlur Khan. While working at

SOM, Goldsmith and Khan developed pioneering approaches to tube-framed and diagonally braced tower projects. Goldsmith's approach to such problems was begun very early in his career with his own Master's thesis at IIT, "The Tall Building: the Effects of Scale" (Goldsmith, 1953). The thesis explored the relationship between the scale of a building and the structural system employed in the building. Simply put, Goldsmith's thesis posited that if the scale changed, so too must the structural system. Goldsmith's proposal was not radical in concept. Indeed, Galileo and D'Arcy Thompson's work and others are clear and acknowledged precedents for Goldsmith. What was unique, however, was the exploration of the problems of long span and tall building construction within the interstices of academia and practice. In his Master's thesis, Goldsmith analyzed bridge design and made two project proposals: a diagonally braced tower in steel and an eighty-four-story super frame tower in concrete. Both proposals were then developed further by Goldsmith's graduate students and, in many instances, realized as built work by SOM.

2 COLLABORATION

In many ways, Goldsmith's professional and academic pursuits were profoundly influenced by his collaboration with Dr. Fazlur Khan. (Ali, 2001) The two first worked together on an extension to the United Airlines Executive Office Building in 1959. Soon thereafter, Goldsmith brought Khan to the Saturday Sessions at IIT where he continued to work as a graduate advisor for over twenty years without ever drawing a paycheck. Khan's original interest in exploring the optimization of pre-stressed concrete developed in his Ph.D. dissertation led him to the problem of tall building design, something that was being explored both in the graduate work at IIT and also at SOM. For Khan, tall building design presented great engineering opportunities and concomitant challenges. The primary design issue, as perceived by Khan, is resisting the deflections due to lateral loads. The second issue, the so-called "premium of height" problem, related to the weight and cost of materials. In a typical moment frame construction, a building will reach a height in which the materials needed to construct and support the building become irrationally inefficient. In response to these issues, Khan's initial studies involved the exploration of shear walls in conjunction with a variety of structural systems and the economy of construction (Khan, 2004).

Though Khan continued to develop his study of materials and the uses of shear walls in construction, the Brunswick Building (1961-65) and the Chestnut-De Witt Apartments (1964-66), both in Chicago are a marked departure from his earlier thinking. For economic viability and due to site restrictions, both projects were intended to be concrete towers. Both projects, however, are also residential projects. The constraints of this program severely limit the length and number of shear walls to resist lateral loading. Khan's innovation was to propose that the building be structured as a tube frame that would resist the entire lateral loading, allowing for more freedom in the placement of columns to account for vertical loads. Indeed, the Brunswick building is often cited as being the first built project to have been conceived structurally as a tube. (Ali, 2001) What is not often addressed in the literature, however, is the origin of this conception. Yasmina Khan, daughter to Fazlur and author of an important study of Khan mentions that, "[w]hile mulling over possible techniques for implementing cantilever action in building construction for the Chestnut-Dewitt Apartments project, Khan had a casual conversation with a colleague about building design, which he credited with releasing his imagination: What was needed for efficient lateral load resistance was a vertically standing hollow box-shaped building, with all structural material pushed out to the periphery, cantilevering out of the ground." (Khan, 2004) At the same time Khan was having this conversation with an unnamed colleague, Myron Goldsmith (a colleague at SOM and IIT) was developing a tube frame tower for a thesis project in Tokyo. Our research leads us to give credit to Goldsmith for being a critical player in the development of the tube frame, and as we shall point out, in the development of the braced frame.

3 SASAKI THESIS

As mentioned, Khan had been working with Goldsmith and others at IIT on Saturdays as early as 1960. Saturday sessions were held then, as today, to allow professionals to participate in the review of student work. This had the fortuitous result of bringing cutting-edge research to SOM, as well as bringing world-class structural expertise to the graduate design studio at IIT. Indeed, many who participated in the Saturday Sessions—to include Bill Baker, John Zils, Fazlur Khan, Hal Iyengar, and John Vinci—comment on the import of these sessions both for the students as well as for the professionals involved. The format of the theses at IIT was well suited for such an interaction. Almost exclusively, the theses were project-based and involved working through an architectural and structural problem involving a tall building design or a long-span structure. Final documents would include a small narrative, structural hand calculations, drawings and photographs of models. Very often, the models themselves were also used to test structural principals.

Mikio Sasaki's thesis, supervised by Goldsmith and Khan, entitled "A Tall Office Building" (Sasaki, 1964) is an important example of the rich collaboration that was occurring between engineers and architects, and between academia and practice. The thesis proposed a fifty-three story square tower with a central core for circulation and services. Sasaki clearly states the problem he faced when designing a tall building. "In designing the structural frame for a tall building such as this, the most critical consideration becomes the resistance to lateral loads." (Sasaki, 1964) At first, Sasaki proposed a more traditional series of vertical shear trusses around the elevator and service cores. This, however, was rejected for two reasons: first, the trusses were considered too inefficient for resisting the lateral shear load, and second that the planning flexibility of the core would be greatly reduced. As noted earlier, this is the same rationale employed by Khan for the Brunswick Building that was being designed concurrently at SOM. In light of these difficulties, and following the thinking of Goldsmith's thesis eleven years earlier, Sasaki needed to develop a structural system that was specific to the scale proposed in his thesis. Remarkably, Sasaki proposed a square braced tube to surround the building. The steel bracing, which aligns with the spandrels on every third level, resisted all of the lateral load and much of the vertical load of the building. The structural plan of each floor is similar (six bays at 8.5m (28'-0") around a core of four bays also at 8.5m (28'-0")) and allows for a forty-five foot column-free space between the core and the exterior façade. Most notable is the expression of eighteen-story diagonal bracing on the exterior of the building. (See Figure 1)

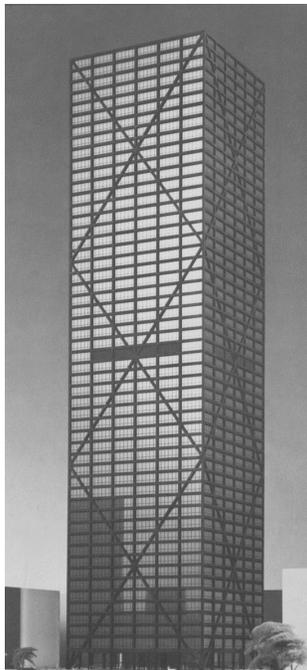


Figure 1. Sasaki Model

Once the team of Goldsmith, Khan and Sasaki proposed the concept of a three-dimensional braced tube, it became necessary to work out the geometry of the bracing to regularize the intersections between columns and girders. To physically test the efficacy of a braced plane, a plexiglass model of a ten story planar frame was laterally loaded. The deflection was recorded using a dial gage. Diagonals were added to the frame and cemented in place to simulate fully welded connections. This frame was then once again loaded and it was found to be at least one hundred times stiffer than the un-braced frame (Sasaki, 1964). Khan and Sasaki performed rudimentary calculations on the equivalent stiffness of a cantilever member that simulated both the un-braced and the braced planar frame subjected to lateral load. Hand calculations confirmed the plexiglass model results. Even more interesting are the calculations that Sasaki created to capture typical beam deflections, reactions, and fundamental building period. To calculate base shear due to earthquake, Sasaki used the Structural Engineers Association of California (SEAOC) recommendations from 1960. Here, the base shear due to earthquake load was calculated to be 32.9 MN (7400 kips). He also estimated the first period of vibration to be 2.7 seconds. He calculated these values from estimates of dead load, which

in turn were based on a detailed proposed floor plan for varying stories. (See Figure 2) We have modeled the Sasaki proposal using ETABS. The model allows us to investigate the building's response to gravity loads and to lateral loads (wind and seismic). We performed analyses due to gravity loads, ASCE 07 wind loads, and IBC2006 earthquake loads. (See Figure 3) Our results show the seismic base shear to be 39.5 MN (8873 kips) and the first period to be 3.9 seconds. Both of these values agree well to Sasaki's simplified hand calculations.

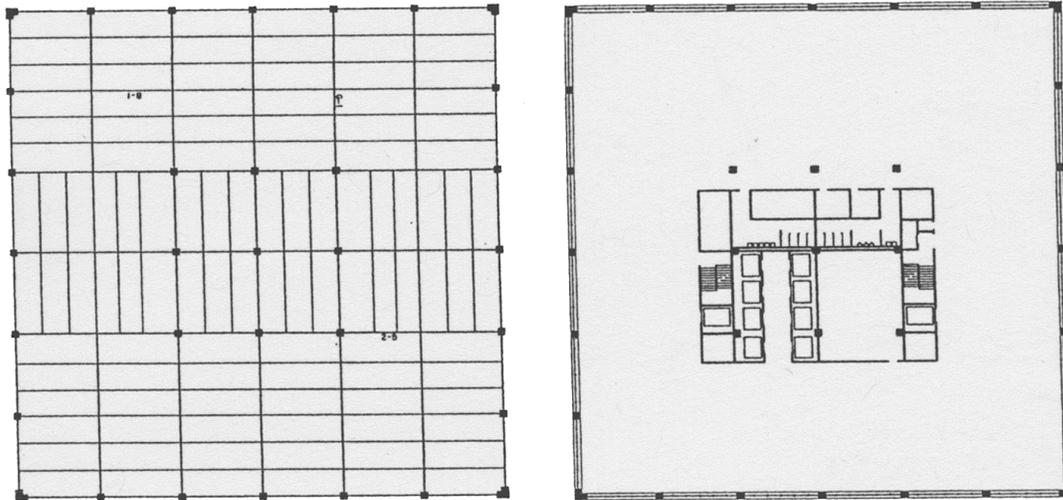


Figure 2. Sasaki Plans

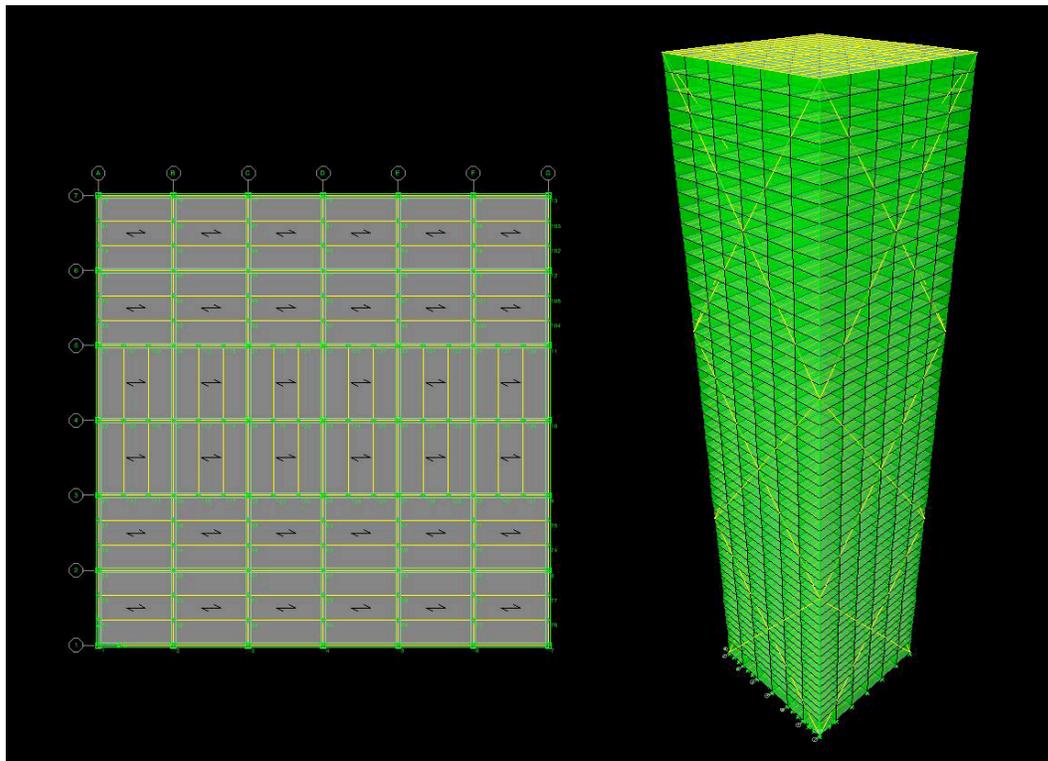


Figure 3. ETABS Model

Sasaki's conceptual solution was truly a breakthrough in tall building design. To put this into context, in 1964 Tokyo buildings were restricted to eight or nine stories because of an unsophisticated building code. Sasaki proposed a fifty-three-story structure that could easily withstand severe wind and seismic loads. His solution emerged from the unique contributions of Goldsmith and Khan, and from the creative freedom afforded to him by the design studio atmosphere. It has been noted in the literature (Ali, 2001) and by Goldsmith himself (Goldsmith, 1986) that Goldsmith was the first to propose an exterior braced tall building system. But an analysis of Goldsmith's 1953 thesis shows that he used bracing in a somewhat traditional two-dimensional manner. Goldsmith surrounded the lower stories of his proposed thesis building with dense exterior bracing, and the upper stories with more widely spaced braces. But significantly, Goldsmith did not conceive of this system as a three-dimensional tube. (See Figure 4) Looking back to his thesis project it is very clear that the braces do not meet on the corner columns to provide 3D continuity, thus precluding true three-dimensional action. Further, the bracing on Goldsmith's thesis project responds to a varying stress levels by variations in the sizes of the braces themselves. Sasaki attempted no such variation because he estimated a fairly uniform state of stress in the bracing elements.

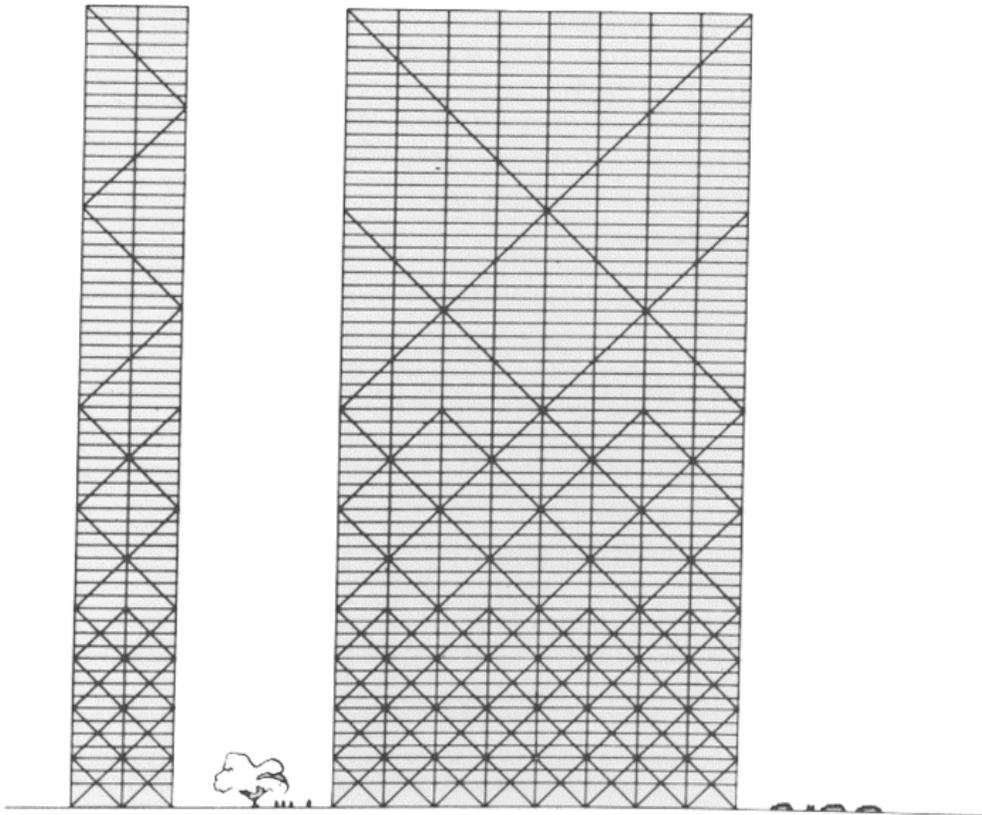


Figure 4. Goldsmith Thesis - note unaligned bracing at corner

In Sasaki's thesis, we see the first true three-dimensional braced tube. One source notes, "this project may have been one of the first proposed diagonally braced tube structures" (Ali, 2001). Others (Khan, 2004) also have made this distinction. Sasaki himself states, "the diagonally braced structure was my own idea." (Sasaki, 2009) Yet without the mentoring of Khan, the idea would not have developed. Khan was brought in to act as structural consultant on the thesis along with Prof. David Sharpe who guided the architectural development of the project. Khan had already developed the tube building and the tube-in-tube format at the Chestnut-Dewitt

Building in 1965 and the Brunswick Building in 1966 with his colleague Goldsmith at SOM (Goldsmith, 1986). Khan deeply understood the difficulty of obtaining true tube action from a moment frame on the exterior of tall buildings. He knew that as the buildings rose above twenty or thirty stories, shear deformation, not cantilever action would begin to dominate the deflection, thus precluding the use of a moment frame for the entire structure. Khan guided Sasaki in both experimental studies and structural calculations predicting the overall stiffness of a braced-tube structure. Whereas Sasaki extended his mentor Goldsmith's idea of a braced tube, it was Khan who realized this revolutionary idea in one of the world's tallest buildings. This efficient and economical bracing scheme manifest itself as a prominent architectural form on the façade that eventually became fully realized in SOM's John Hancock Building in Chicago.

Work for the John Hancock tower was begun around the same time that Sasaki's thesis was being completed. The project, completed by Fazlur Khan and Bruce Graham, shares undeniable similarities to Sasaki's thesis. The expressed diagonal exterior bracing resists both the vertical and lateral loads. Differences do, however, exist. The taper of the Hancock building and the varying floor heights both respond to programmatic issues. Fortuitously, both of these changes also contribute to the structural and architectural performance of the building. The Hancock Tower was also subjected to an enormous amount of analysis. At SOM, Hal Iyengar and Joe Colaco analyzed the building in tiers on the computer, which at the time was an innovation. Several others conducted individual analyses including Paul Weidlinger working in New York, John Goldberg of Purdue, Steven Fenves of the University of Illinois at Urbana-Champaign and Robert Logcher at MIT. Wind tunnel tests were also conducted at the United Aircraft Corporation Research Lab. Khan continued earlier studies from the Chestnut DeWitt on the stresses and manufacture of glass to be used in tall buildings. Khan also developed a "tale of the tub" test to measure relative comfort with the sway that might occur at the top of the building. (Khan, 2004) Certainly there was much more rigorous analysis in the development of the Hancock Tower. What is perhaps most fascinating is that the structural principle developed through Sasaki's thesis in conjunction with his advisor's Myron Goldsmith and Fazlur Khan remained throughout the design process.

4 CONCLUSION

Goldsmith's ability to combine architecture, engineering and aesthetics together into one functional coherent whole is well documented. Our position is that his deeply invested interest in the relationship between architecture, engineering and aesthetics began with his approach and commitment to pedagogy. The many interviews we have conducted with Goldsmith's colleagues and students reveal his mastery of the art of mentoring. Goldsmith was a great listener; he was sincerely interested in students' ideas, yet he was also an insightful leader. Goldsmith was famous for his lecture on the history of structural architecture in which he related his work to a tradition that he believed began with the Gothic. Such architecture, Goldsmith posited, was that "the most sublime emotions can be expressed through the use of structure." (Goldsmith, 1986). During the 20th c., Goldsmith believed projects such as the Monadnock building and the Carson Pirie Scott Building in Chicago also possessed this ability to affect our emotions through an understanding of structure. In both instances, the work of the structure is visibly present and is difficult to categorize as either "structural" or "architectural." It is clear that this same attitude permeated his teaching and it is from this approach that innovations such as the diagonally braced tube frame could develop.

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