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Autor: Thornton, Charles H. / Hungspruke, Udom / Prasad, Jagdish

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The Miglin-Beitler Tower Chicago, IL (USA)

La tour Miglin-Beitler de Chicago, IL (USA)

Der Miglin-Beitler-Turm in Chicago, IL(USA)

Charles H. THORNTON
Chairman and Principal
Thornton-Tomasetti
Engineers
New York, NY, USA

Dr. Thornton is a recognised expert in many structural areas such as long-span structures, brittle fracture, lamellar tearing, creep and shrinkage of concrete and seismic and dynamic analyses. He received a bachelor's degree in Civil Engineering from Manhattan College, a master's degree in Civil Engineering and a doctorate in Philosophy in Structural and Engineering Mechanics from New York University.

Jagdish PRASAD
Senior Vice-Pres. and Princ.
Thornton-Tomasetti
Engineers
New York, NY, USA

Mr. Prasad is in charge of the production of all design jobs in the firm and has been project manager on numerous projects such as Bally's Park Place Casino Hotel, Vanderbilt University Medical Center and Fifth Avenue Place in Pittsburgh. He received a bachelor's degree in Civil Engineering from Howard University and a master's degree in Civil Engineering from Lehigh University.

Udom HUNGSPRUKE
Vice-Pres.
Thornton-Tomasetti
Engineers
New York, NY, USA

Mr. Hungspruke has been project manager for such projects as the Northwestern Atrium Center, United Terminal Complex at O'Hare Airport, and One Liberty Place in Philadelphia, Pa. Mr. Hungspruke received a Bachelor of Science degree in Civil Engineering from Mapua Institute of Technology.

Robert P. DeSCENZA
Associate
Thornton-Tomasetti
Engineers
New York, NY, USA

As Associate, Mr. DeScenza has been responsible for the analysis and structural design of several large projects, including the Northwestern Atrium Center and the United Terminal Complex at O'Hare Airport. Mr. DeScenza holds a Bachelor's degree in Civil Engineering from The Cooper Union.

SUMMARY

A cruciform tube structure provides a safe, elegant, efficient and constructable solution to the challenge of designing the world's tallest building, the Miglin-Beitler Tower in Chicago, Illinois. The proposed structural solution combines the erection speed of concrete construction, the flexibility for future change and the efficiency for horizontal spans of a steel floor system, and the superior dynamic acceleration response of a composite lateral load resisting structural system.

RÉSUMÉ

Une structure tubulaire cruciforme fournit une solution sûre, élégante, efficiente et réalisable pour la conception de l'immeuble le plus haut du monde, à savoir la tour Miglin-Beitler de Chicago, dans l'Illinois. Le modèle structural proposé combine la vitesse de mise en œuvre de la construction en béton, la flexibilité pour des modifications futures, l'efficience des portées horizontales du système de plancher en acier, ainsi que la réponse maximale d'accélération dynamique donnée par un système structural résistant aux forces latérales mixtes.

ZUSAMMENFASSUNG

Für das höchste Gebäude der Welt, den Miglin-Beitler-Turm in Chicago, wurde eine Röhrenstruktur in Kreuzform gewählt, die für dieses ambitiöse Bauwerk eine sichere, elegante, effiziente und ausführungsfreundliche Lösung bietet. Der vorgeschlagene Entwurf kombiniert den schnellen Baufortschritt des Betonbaus mit der Freiheit grosser Spannweiten und späterer Umbaumöglichkeit eines Stahlgeschosssystems. Dieses hybride Aussteifungssystem gegenüber Horizontalkräften gewährleistet ein überlegenes, dynamisches Verhalten.

1. INTRODUCTION

The city of Chicago, Illinois will gain the honor and distinction as the holder of the worlds two tallest buildings with the construction of the Miglin-Beitler Tower. At 610 metres (1,999 feet 11 1/2 inches) to the tip of its spire, the Miglin-Beitler Tower will provide a regal landmark for the Chicago skyline and establish new records as the world's tallest building and the world's tallest non-guyed structure. Its 176,500 square metres of total floor area are to be split up into small plates that will enable smaller sized firms to rent entire floors (see figure 1). At the present time, the owner has applied for foundation permits that will allow a start of construction of the building in mid 1992.

The tower is to have 12 levels of above grade parking with commercial office floors above. At the top of the tower will be a multistory observation deck. From the upper observation level at 462 metres, observers will see the 443 metre Sears Tower below. The steel framed spire will surpass the 555 metre CN Tower in Toronto.

A simple and elegant integration of building form and function has emerged from close cooperation of architectural, structural and development team members. The resulting cruciform tube scheme offers structural efficiency, superior dynamic behavior, ease of construction and minimal intrusion at leased office floors for this 125 story office building.

2. STRUCTURAL SYSTEM

The structural system for the Miglin-Beitler Tower is a composite system that exploits the advantages of both steel and concrete to solve the challenges of a 610 metre tall building. The challenge put to the design team was to come up with an economical and buildable structural frame capable of resisting vertical and lateral loads for this supertall building. The Chicago area is subject to wind forces based upon a 120 kilometre per hour basic wind speed and seismic forces based upon seismic Zone 1. The challenge was met 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 (see figure 2). The building has a density in the range of 2.5 to 3 kN/m^3. 68,000 $Metre^3$ of concrete, reinforced with 9,100 metric tons of steel, will be used to build the Miglin-Beitler Tower. The steel spire will require approximately 9,000 metric tons of rolled structural steel framing.

The cruciform tube structural system consists of six major components, as listed below:

1. A 19 metre by 19 metre concrete core has walls of varying thickness. The interior cross walls of the core are generally not penetrated with openings. This contributes significantly to the lateral stiffness.

2. Eight cast-in-place concrete fin columns are located on the faces of the building and extend up to 6 metre beyond the 43 x 43 metre tower footprint. They vary in dimension from 2 metre by 11 metre at the base to 1.7 metre by 5 metre at the middle and 1.4 metre by 4.5 metre near the top.

3. Eight link beams connect the four corners of the core to the eight fin columns at every floor. These reinforced concrete beams are haunched at both ends for increased stiffness

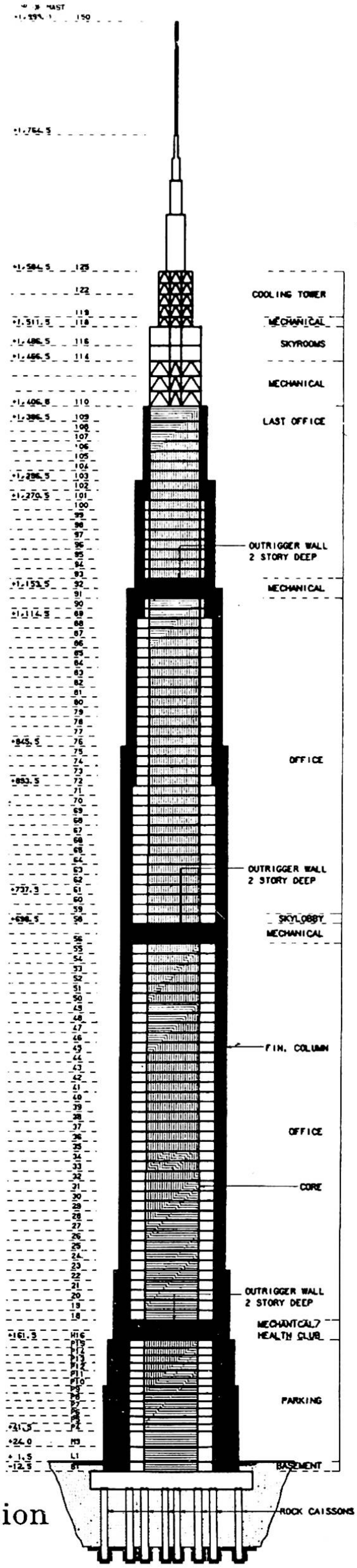


FIGURE 1

Building Elevation

and reduced in depth at mid-span to allow for passage of mechanical ducts. By linking the fin columns and core they enable the full width of the building to act in resisting lateral forces. In addition to link beams at each floor, sets of two-story-deep outrigger walls are located at levels 17, 57 and 89. These outrigger walls enhance the interaction between exterior fin columns and the core.

4. The conventional structural steel composite floor system has 457 mm deep rolled steel beams spaced at approximately 3 metre on center. A slab of 8 cm deep 20 gage corrugated metal deck and 9 cm of stone concrete topping spans between the beams. The steel floor system is supported by the cast-in-place concrete elements.

5. Exterior steel vierendeel trusses frame the entire perimeter of the building. At each of the four faces between fin columns the vierendeels consist of the horizontal spandrels and two vertical columns. At the corners, steel vierendeel trusses are used to pick up each of the four cantilevered corners of the building.The vierendeel trusses provide additional resistance to lateral forces as well as improving the resistance of the entire structural system to torsion. In addition, the trusses transfer dead load to the fin columns to eliminate tensile and uplift forces in the fin columns. All corner columns are eliminated providing for corner offices with undisturbed views. Connections between the steel vierendeel trusses and the concrete fin columns are typically simple shear connections which minimize costs and expedite erection.

6. A 137 metre tall steel framed tower tops the building. This braced frame is to house observation levels, window washing, mechanical equipment rooms and an assortment of broadcasting equipment.

Concrete strengths for the concrete core and fin columns vary from 69 MPa to 96.5 MPa. Because of the mass required to minimize overturning and perception of motion, stresses in concrete are low. High concrete strength is required, however, to give high modulus of elasticity (up to 4.83×10^7 kPa) for increased stiffness (see figure 3).

3. LATERAL FORCES

The proposed building and structural system have undergone extensive wind tunnel testing at RWDI in Guelph, Ontario. Pressure tap models, pedestrian level studies, high frequency force balance and aeroelastic models have been used to determine the static and dynamic behavior of the project under wind loadings. The high frequency force balance results were in very close agreement to the results from the aeroelastic model.

Working in parallel with Thornton-Tomasetti's three dimensional static and dynamic computer analyses, RWDI has accounted for the structural properties, mass and damping of the building in their wind studies and confirmed that the proposed structural system provides ample resistance to all expected wind loads.

The design has also received a superior performance rating in its ability to virtually eliminate occupant perception of wind movements and accelerations. Results from the force balance model indicate that the upper floors of the building will experience accelerations in the range of 26 millig's, while the more refined aeroelastic model indicates accelerations below 23 millig's. Both results fall within acceptable ISO acceleration criteria.

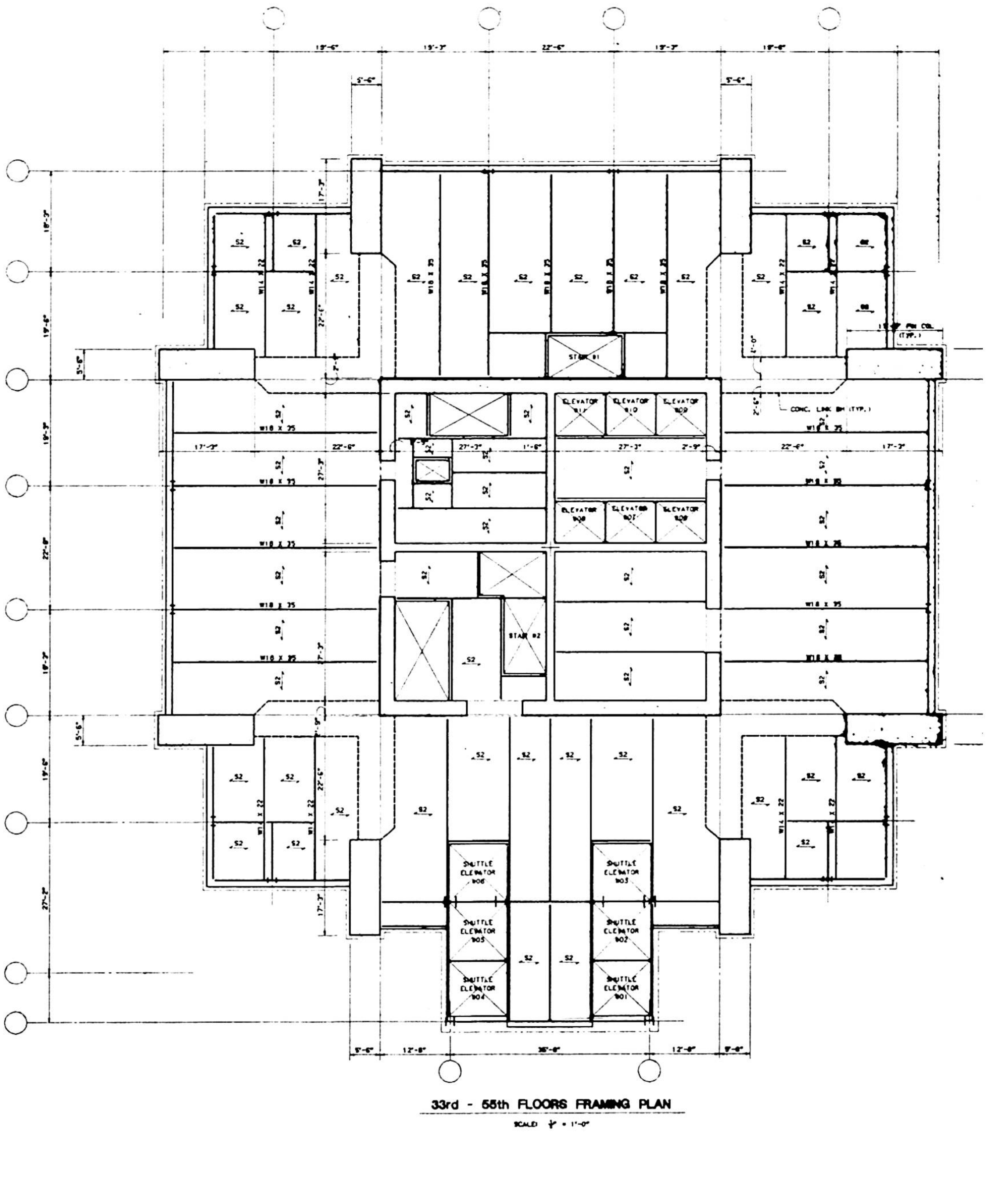
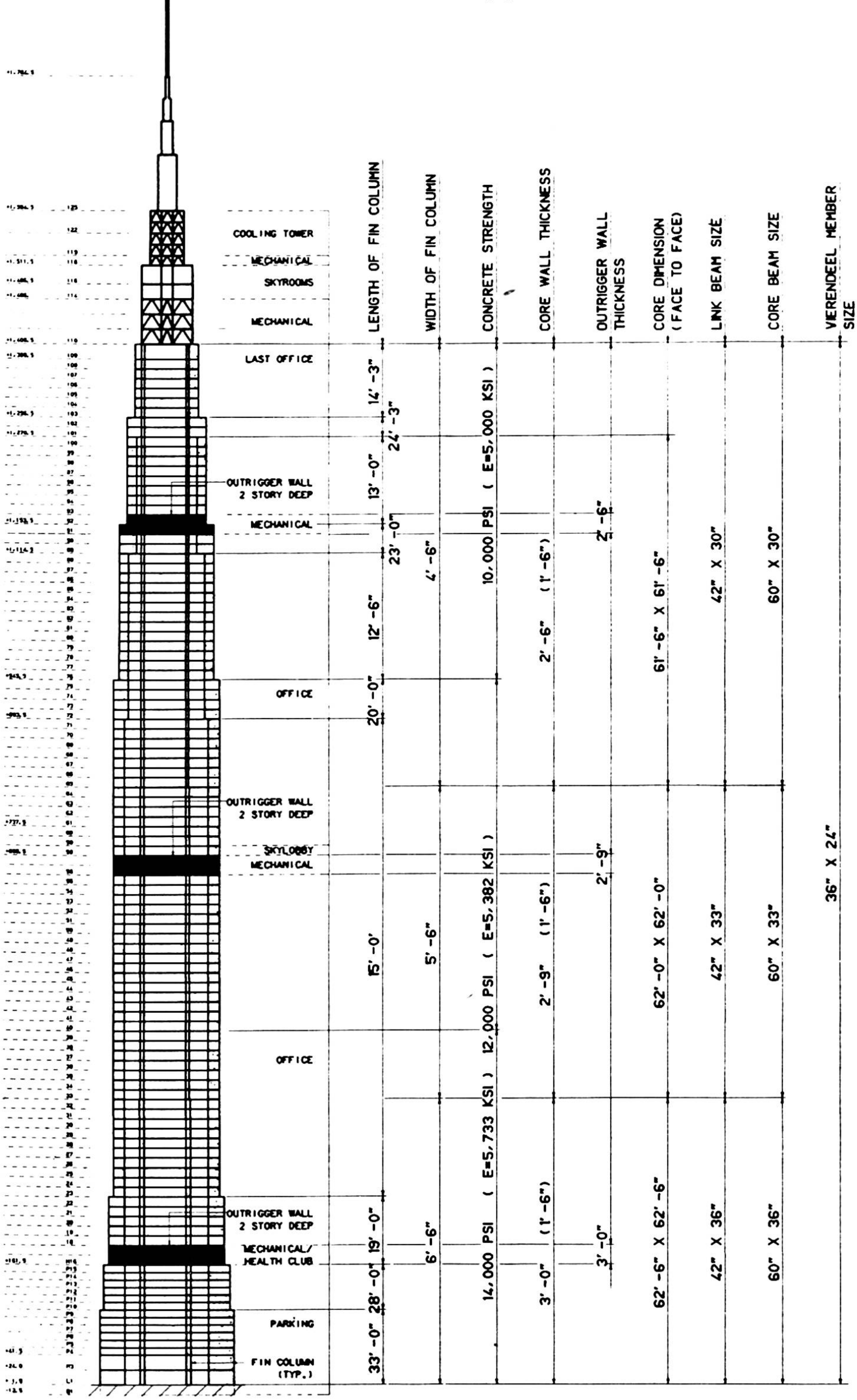
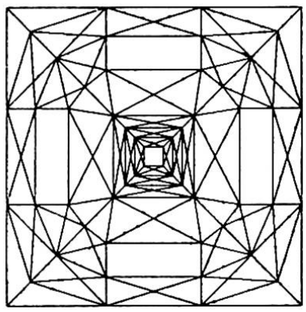


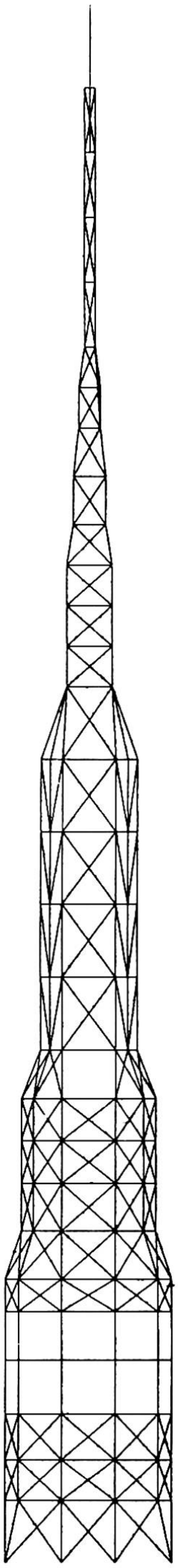
FIGURE 2 – Typical Floor Plan

FIGURE 3 – Typical Properties





3D SPIRE MODEL - TOP VIEW
MIGLIN - BEITLER TOWER



3D SPIRE MODEL - SIDE VIEW
MIGLIN - BEITLER TOWER

FIGURE 4 – Spire Model

Sixteen independent two-dimensional and three-dimensional static and dynamic computer analyses have been used by Thornton-Tomasetti in determining the viability and acceptability of the proposed structural system. Three separate computer programs, EASE-II, SAP90 and ETABS, have provided parallel checks of the accuracy and adequacy of the computer simulations. The EASE-II models were run on a super minicomputer while the ETABS and SAP90 analyses were run on 486-based microcomputers.

The parallel sets of models were compared to validate computer approaches. Static displacements and dynamic mode shapes from the two sets of analyses were in very close agreement. Overall displacements, modal shapes and natural frequencies differed by less than ten percent. The primary periods for the first lateral modes are in the range of 9 seconds. The first torsional mode has a period around 2.4 seconds. Displacements at the uppermost office floor of the building are in the range of 630 mm, which result in a drift index of 1/650.

Although only UBC Zone 1 is applicable, the structural system was investigated for the effects of a UBC Zone 2 earthquake and has been found satisfactory. This is not surprising because seismic building response drops quickly for long-period structures while wind effects increase with increased height.

4. FOUNDATIONS

The foundation system proposed for this project uses caissons varying from 2.6 metre to 3.2 metre in diameter. Each 29 metre long caisson has a straight shaft and a rock socket a minimum of 2 metre into competent rock. Caisson concrete is to have an ultimate compressive strength of 93 MPa to take into advantage the quality rock that was encountered at the site, with an allowable bearing pressure of 23 MPa.

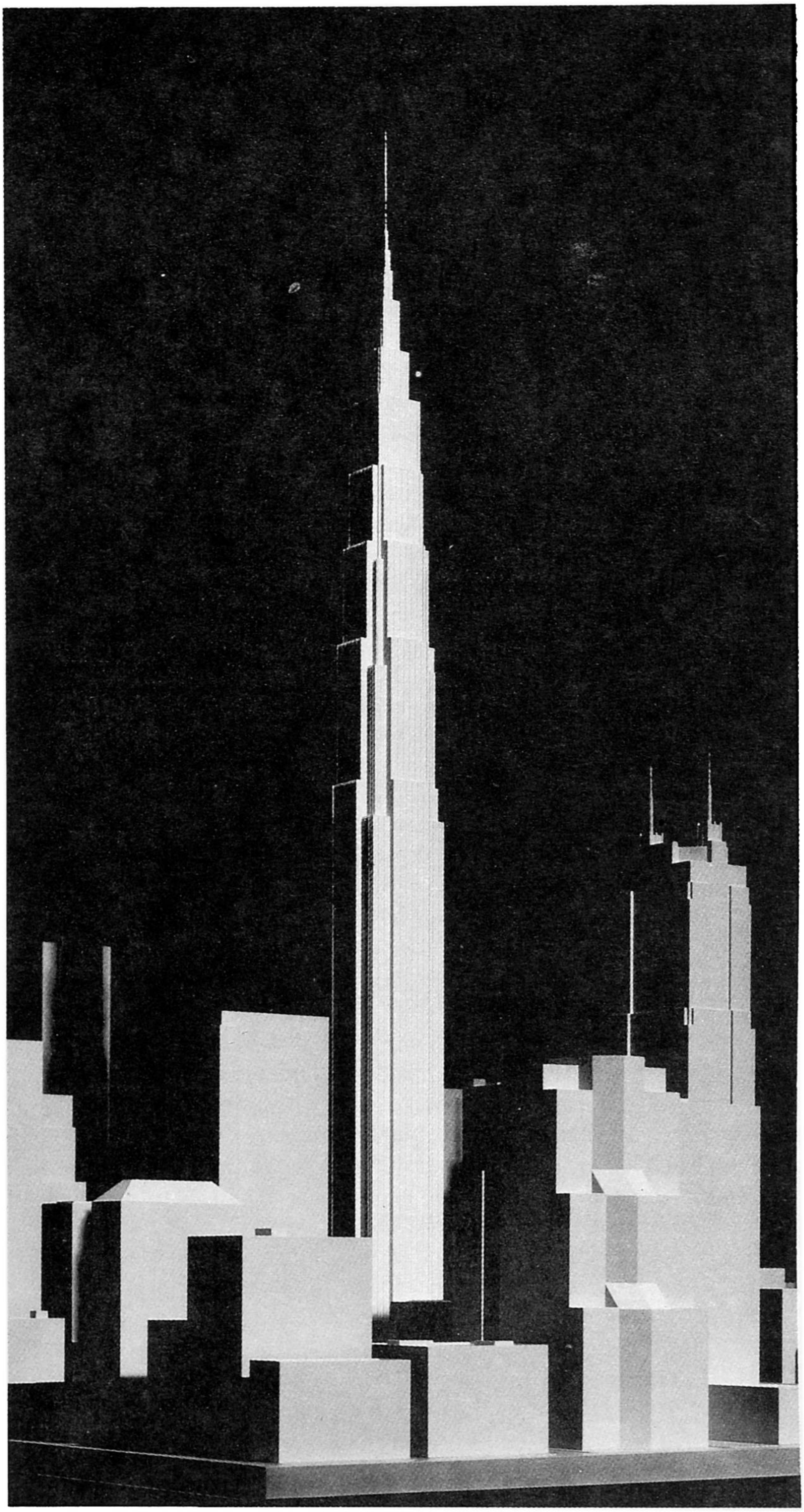
The caissons are tied together with a series of grade beams. Passive pressure on the edge of these lugs and on the projected side surfaces of the caissons provides the lateral base shear resistance for the Miglin-Beitler Tower.

Columns outside of the footprint of the main tower, supporting the parking levels in the bustle of the building, will be in turn supported on belled caissons. The belled caissons with maximum bell diameters of 3.7 metre will bear on a strata of hard pan material approximately 20 metre below grade level. The hard pan has an allowable presumptive bearing pressure of 2 MPa.

5. DIFFERENTIAL SHORTENING

Due to elastic strains, creep and shrinkage, the core strain rate is significantly greater than that of the perimeter fins. A computer program has been developed to analyze the need for vertical camber in the fins and core due to the differential shortening that will occur, primarily, during construction. A system of daily measurements during construction will provide input to constantly update the analysis results and provide information to the contractor.

The program will consider the bending stresses imposed on the link beams due to differential shortening between the core and fins, as well as the subsequent effect of relaxation in the link beams due to creep attributed to flexural compressive stresses.



6. DIFFERENTIAL TEMPERATURE

Portions of the exterior concrete fin columns are outside of the building window line and the controlled environment. To minimize differential temperatures, which can cause significant thermal stresses in the fin columns, the fins will be clad with an insulated exterior facade wall system. This system was designed to minimize thermal differences between fin columns and the core. Stack effect considerations in the cavity have been included.

7. STEEL VIERENDEEL TRUSSES

On each of the four faces of the building, steel vierendeels are employed to frame the 18.6 metre clear opening between the fin columns. The vierendeels consist of a 914 mm deep horizontal beam at each level with two 914 mm deep verticals. To eliminate stresses produced by creep and shrinkage strains in the concrete fin columns, the verticals in each vierendeel are provided with vertical slip connections. This has an added benefit of channeling all of the gravity loads on each of the building faces out to the fin columns to help eliminate uplift forces on the foundations. The steel face vierendeels are to be shop fabricated as horizontal trees 3.8 metre tall by 18.3 metre long. Field connections are simple bolted connections. This system allows for all of the welded connections to be shop fabricated resulting in an economical and elegant solution.

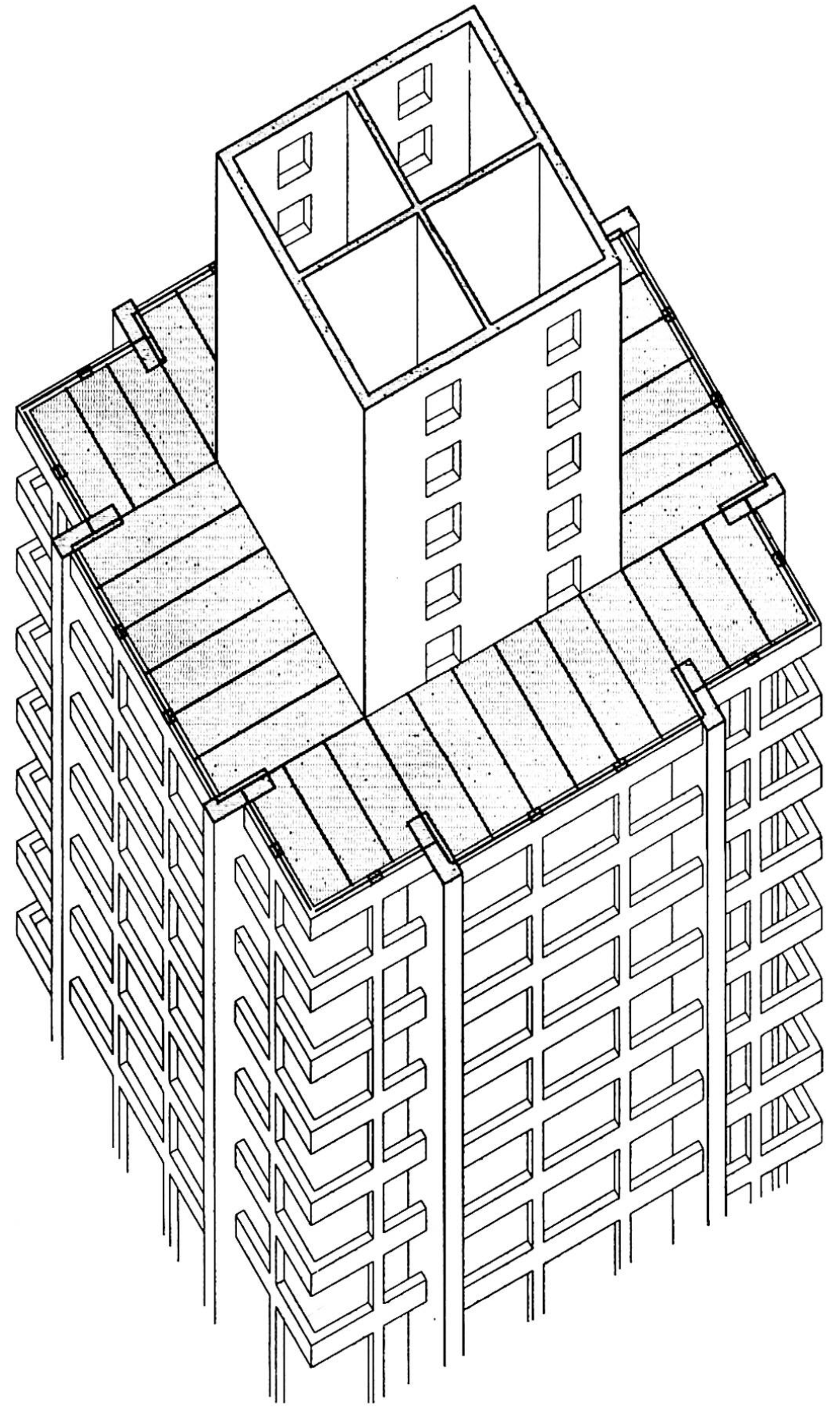
At each of the corners of the Miglin-Beitler Tower, the floor slabs protrude beyond the fin columns by up to 8 metres. Again, it was desirable to channel the gravity loads from these areas to the fin columns to help eliminate uplift in the foundations due to lateral loads. An added challenge was to frame the corners without having a vertical element at the corner, thus allowing the corner offices unobstructed views. The solution to this problem was a vierendeel truss, similar to the face vierendeels. The corner vierendeels are to consist of a horizontal steel beam at each level with a vertical steel beam at the center of each face, thus allowing the corners of the building to be column free. Unlike the face vierendeels, all of the vertical connections are not slip connections. This is to allow the corner vierendeels to resist unbalanced floor loads.

8. STEEL SPIRE

The Miglin-Beitler Tower is to be topped with a 137 metre tall steel framed spire (see figure 4). The spire contains mechanical equipment, window washing equipment, antennas and communication systems. The main structural framing consists of 12 exterior columns that cascade out at each of the setback levels. Each level of the spire contains horizontal bracing that stabilizes the structure. In addition each of the elevations is typically x-braced. Topping off the spire is a section of 2.4 metre diameter steel tube. The tube is to be perforated with openings that allow for the installation of a wide range of broadcast equipment. The entire broadcast support structure is to be clad with a material that is transparent to the broadcast equipment.

9. CONSTRUCTION

The reinforced concrete core, fin columns and link beams will be simultaneously cast at each floor level using a specially developed gang form system. This procedure will eliminate the need for any steel erection columns and provide a three-day floor cycle.



MIGLIN-BEITLER TOWER

FIGURE 5 – Isometric View

Underslung cranes below the gang form will erect floor beams and exterior Vierendeel trusses approximately 3 floors below the level of completed concrete construction (see figure 5). This is made possible by the simple shear connections mentioned above between all steel and concrete elements.
The transfer walls at the three intermediate mechanical levels will be built later-on in the sequence. This not only facilitates erection speed but minimizes resistance to differential shortening between the core and fin columns.

Construction of the building will take approximately three years from start to finish. To increase the economic viability and profitability of the structure, a four part phased occupancy will be used. The first phase includes all of the parking in the lower levels of the structure. These levels will generate a significant income for the owners while construction of the tower is ongoing. The second phase of occupancy includes the lower office levels up to the sky lobby transfer level. This will allow the owner early rental of commercial space in the lower floors. The third phase of occupancy includes the remainder of the office levels up to the base of the spire. This phase will also include observation levels. The final phase of construction will include the steel framed spire housing the upper mechanical level, window washing and broadcast equipment. The phased occupancy approach to the construction of the Miglin-Beitler Tower was developed to enhance the economic feasibility of the project.

10. CONCLUSION

A cruciform tube structure provides a safe, elegant, efficient and constructible solution to the challenge of designing the world's tallest building, the Miglin-Beitler Tower. The proposed structural solution combines the erection speed of concrete construction, the flexibility for future change and the efficiency for horizontal spans of a steel floor system, and the superior dynamic acceleration response of a composite lateral load resisting structural system. The project team is listed in figure 6.

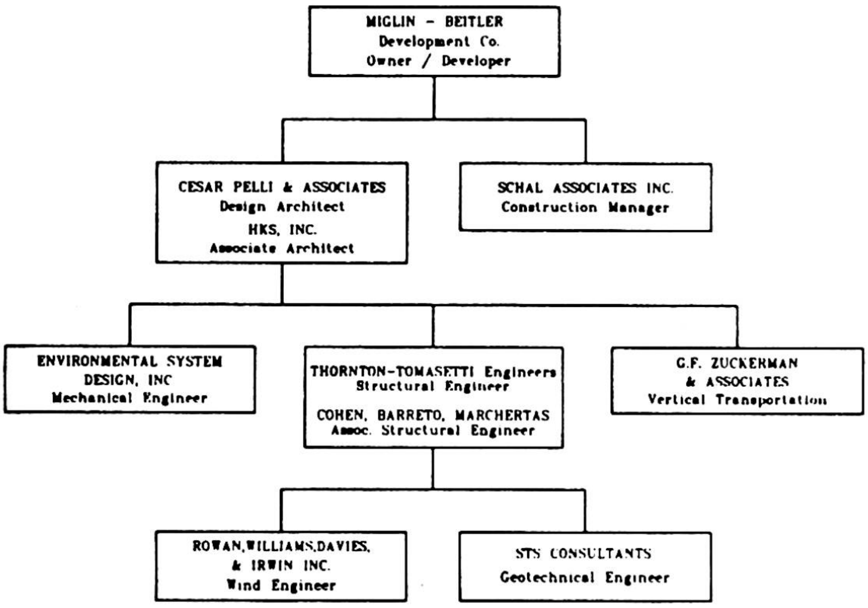


FIGURE 6 - Project team