REINFORCED CONCRETE STRUCTURAL FACADE, ITS APPLICATION FOR HIGH RISE OFFICE BUILDINGS

by

Robert P. Sitzenstock
B. Arch., The Ohio State University 1954

Submitted in partial fulfillment
of the requirement for the degree
of Master in Architecture

at the

Massachusetts Institute of Technology

July 1962

Signature of Author

Robert P. Sitzenstock

Signature of Head of Department

Lawrence B. Anderson

July 16, 1962

Pietro Belluschi, Dean
School of Architecture and Planning
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Dean Belluschi:-

In partial fulfillment of the requirements for the degree of Master in Architecture, I hereby submit this thesis entitled "Reinforced Concrete Structural Facade, Its Application for High Rise Office Buildings."

Respectfully,

Robert P. Sitzenstock

ACKNOWLEDGMENTS

I am grateful to the following people for their invaluable advice and assistance during the thesis.

Professor Giulio Pizzatti	Turiu, Italy
Doctor Howard Simpson	Cambridge, Mass.
Mr. A.J. Harris	London, England

Professor Eduardo F. Catalano ----- Advisor

The members of the M.I.T. Faculty who participated in the preliminary thesis jury, May, 1962.

C O N T E N T S

ABSTRACT

This thesis is concerned with an investigation of reinforced concrete structural facade, its application for high rise office buildings. Special attention is given to the structural mullion and its relationship to the floor and mechanical systems.

Specific areas of study include:

1. Investigate the envelope of building.
2. Design requirements of office buildings.
3. A structural analysis to give choice of structures.
4. Investigate the mechanical and electrical systems.
5. Special Problems.

A. EXPOSITION

The development of a structural facade of reinforced concrete and its application to high rise office buildings offers a great experience in planning, and structural analysis without the consideration of a specific site. The study will give the opportunity to research the possibilities and limitations of concrete. It will endeavor to express the importance of structures to the concept in building design. The proposal may not necessarily be taken as a specific case but as a general approach to a problem and how its application may be used in design.

HIGH RISE OFFICE BUILDING ANALYSIS

To get a fuller understanding of the development of office buildings it is necessary to investigate the concepts and the advancements made through technology of past and present office buildings. These developments have brought about changes in the basic floor plan concept, design, materials, cost, structures and mechanical equipment.

ENVELOPE

Five basic envelopes have evolved in the development of office buildings. .The early buildings form was U-shaped as illustrated in Sullivan's Wainwright building, in St. Louis, 1890, and Guaranty building, in Buffalo, 1895. This allowed maximum use of natural light for each office. The light court walls were a white glazed brick or terra cotta to give maximum brightness to the offices. Another concept which eliminated the light court was Burnham and Root's Reliance building, in Chicago, 1895. These two concepts prevailed until the late twenties when the U-shape form was completely dropped in favor of the square building as illustrated in Hood and Howell's Tribune Tower, Chicago, 1925. The square plan concept was dropped in favor of the long rectangle of slab as illustrated in Harrison, Hood and Fouilhoux, Rockefeller Center, in New York, 1930. The slab appeared earlier in Burnham and Root's Monadnock building in Chicago, 1890, but was not developed until the Rockefeller Center. The Rockefeller Center plan influenced later buildings like;

UN Secretariat, Belluschi's Equitable, Portland, and SOM's Lever House. A plan with the served area separated from the service was designed by SOM for Inland Steel building in Chicago, 1957. This allows maximum flexibility in office layout. In recent buildings the floor plans form a large rectangle as in Mies Van Der Rohe Seagrams building and Saarinen's CBS building, or the square in SOM's L.O.F. building in Toledo and John Hancock, in San Francisco.

DESIGN

Floor plan design of early office buildings consisted of individual offices of approximately 320 square feet. The office had exterior operating windows and a lavatory. The corridors were double loaded and elevators and stairs were located on the inside of the U-shape. There was generally only one stairs which was open, later the stairs were closed in because of fire regulations. Burnham and Root's Rookery building in Chicago, 1885, is one of the best remaining examples of a building with an open stairs. As artificial lighting improved the buildings increased in depth from the corridor to the outside wall thus allowing deeper working areas. With more code restrictions the buildings of the twenties had fireproof stairs and toilets on every floor. The offices had more depth and single loaded corridors were generally used. With the design of the RCA building in New York, the plan gave a variety of rental space per floor which allowed the tenant flexibility in office lay out. Wright's office building designs used three dimensional planning with high and low space for office and working areas. Unfortunately this has been ignored in present day design. Wright used this principle in the Larkin building in Buffalo, 1904, and Johnson Wax Administration building, Racine, Wisconsin. The Un Secretariat building plan was similar to RCA with the circulation around the core with various depths from the core to the outside wall. Lever House was the first serious study of movable partitions which SOM perfected in Inland, Chase Manhattan and Union Carbide. The buildings now had a controlled environment with high quality lighting, air-conditioning, movable partitions and the module to give maximum flexibility.

The use of the module for the standard unit became the rule in office design. The size of the module depends on many factors; high or low rental, large or small tenants, one owner building and special use requirements. The module ranges from 3'-5" in Equitable Life in New York, 4'-10" in Chase Manhattan to 6'-0" in SOM's United Air Lines EXO in Chicago. The average module for buildings is between 4'-7" - 5'-0". Some examples; Seagrams 4'-7", Harris Trust 5'-0", Union Carbide 5'-0", CBS 5'-0" and Brunswick 4'-7". The 6'-0" module is considered one of the best working modules because it provides good working offices and the standard desk layout for secretaries and general office areas is 6'-0" from front to front of desk. Thus the light conditions are much better than most other modules. With 5'-0" and 6'-0" modules standard floor and ceiling tile can be used. Some buildings have used egg crate ceilings with lights and the diffusers above to clean up the ceiling appearance as in SOM's Reynolds, LOF and Connecticut General with a result of very poor sound control between offices. Many new buildings have been designed with columns outside the working areas. This allows for a more efficient use of the floor area. SOM's Inland was the first and later examples are John Hancock, Brunswick Tower and Saarinen's CBS in New York. The relationship of the module to the outside wall is an important factor in building design, should the module be in front of the column, on the column line or behind the column. When the module is in front or on the center line of the column a special partition has to be used. Only when the module is on the back of the convector or on the back of the column can you take full advantage of standard movable partitions.

The facades of early buildings were of masonry as illustrated in Burnham and Roote's Monadnock building in Chicago, 1891 with brick bearing walls - from 2'-5" - 5'-5" in depth. Other buildings used terra cotta and brick but the thickness and weight increased the weight on their steel structure. Through the advances in metal and fabrication the metal curtain wall was designed to enclose buildings. This cut down the weight on the structure and construction time. Examples of material selections for curtain wall installations are: Mies Van Der Rohe's Seagrams, Bronze; SOM's Inland, Stainless Steel; SOM's LOF building, Aluminum; Mies, 860 and 880, Painted Steel. The position of the window wall depends on esthetics, cost and heat loads. The flush window wall takes full advantage of the floor area but the flush window has a large initial cost. The reason for increased initial cost is: installation methods, the wall has to be water tight, and a higher quality of glass has to be used to prevent distortion and heat load. When the glass is set back as in SOM's Hartford in Chicago, the installation cost is down because it is easier to install plus the wall does not need to be as water tight, heat load is less and lower grade of glass can be used because the distortion and heat load is not as important. True the building lost floor area but the initial cost was reduced which is an important consideration to many clients.

The exterior wall may also be structural as illustrated in SOM's John Hancock building in San Francisco, with a 1'-0" thick wall and a window 5'-0" every other module. Saarinen's CBS Tower is similar to John Hancock because the columns are also 5'-0" wide but the spandrel is set back and the 5'-0" column has a triangular exterior shape. Both buildings have granite cladding. Structural mullions is another approach. SOM's Brunswick, in Chicago, and Pei, in his apartment buildings in Chicago, New York, Philadelphia and MIT's Earth Science building. With this approach the color of cement, aggregate, method of forming and the forms used is very important to maintain good results. The use of the structural wall or structural mullions in conjunction with a structural core eliminates many problems in designing of the core and office areas.

STRUCTURE

Masonry:

The early office buildings were built of masonry and until the use of steel the height was limited. The Monadnock building in Chicago was the last of the masonry high rise buildings with brick outside structural walls varying from 2'-5" at the 16th floor to 5'-5" at the foundations and an interior iron frame.

Steel:

Steel gave the architect the opportunity to design buildings higher and lighter with the skeleton frame. The bay was a system of design. The early buildings used cast iron columns. The Wainwright Guaranty and Reliance buildings used built up steel columns with cast iron plates. Rolled steel sections were perfected and soon became standardized for the building industry. The early building bay size was small, approximately 15' x 20'. The early buildings had permanent partitions and there wasn't a need for long spans. The RCA building plan offered a variety in rental spaces and the need for a larger bay became apparent. The use of the module and movable partition required a standard size bay as in Pei's Mile High Center in Denver, SOM's Inland Steel building was the first building with a column free floor of 60' x 170' which allowed maximum flexibility.

SOM made a study of comparative bay sizes to tonnage and found that there was only a forty pound per ton difference between 25 ft. x 25 ft. to a 37ft. x 37 ft. bay: the savings in caissons were also great.

The United of America building in Chicago by Shaw, Metz and Assoc. a steel building used a low carbide steel in the upper floors and as the structure picked up the weight they used high strength steel making a saving in weight and cost of the structure.

Concrete:

Concrete was not used for office building construction until a few years ago. The reason was because of speed of construction and steel was much cheaper. Since that time concrete has become more competitive with steel. Saarinen's last project CBS was designed in steel and concrete and the bids revealed concrete was cheaper.

In 1922 Mies Van Der Rohe proposed an office building in concrete which was never built. Belluschi's Equitable building in Portland, 1948, used poured in place concrete rib system with concrete columns. SOM's Hartford building in Chicago, 1961 used a concrete flat slab. SOM' John Hancock building in San Francisco has structural poured in place exterior walls and core. This building eliminates the bay system principle in building design. When the core walls are structural the planning of the functions inside the core is not as restricted as in bay system planning. This system was used in Saarinen's CBS Tower and SOM's Brunswick building in Chicago.

I.M. Pei project in Chicago, New York, Philadelphia and MIT's Earth Science building indicates a new direction in precast and poured in place concrete by making the mullions structural concrete. The glass is set in place with a neoprene gasket in the concrete or an aluminum frame. SOM used a rubber zipper in Brunswick. Among the advantages offered by this type of construction is economy and an expression of the structure of the building.

Precasting and prestressing in concrete has also made a change in office buildings. The Norton building in Seattle by SOM combined 70' precast prestressed concrete beams with steel girders and columns. SOM's Octavian, which because of Greenwald's death, was never built, used an exposed structure of precast prestressed concrete of five and six sided stars with concrete slab over. This system was later used in SOM's Brussels, Banque Lambert and John Hancock building in Kansas City.

The use of post tension concrete for buildings requiring large spans is becoming more economical than conventional methods. The difference between poured in place and post tensioned concrete under 42 ft. in span is very small and it was recommended by T.Y. Lin that post tension concrete should be used over 42 ft. and up to 72 ft. in span for economy. T.Y. Lin in his article in Architectural Forum, said by using today's prestressing techniques it is possible to increase a typical bay size of a building to 100 ft. x 100 ft. with a prestressed floor slab of 3'-0".

Myron Goldsmith, project for an 86 story concrete office building, 1948, takes into account a new method of construction in prestressed concrete. The building consists of an 86 story, 1 x 3 bay buildingforming a verendel truss with six platforms. Between each platform are 15 intermediate stories, seven of which are suspended from the platform above and seven are supported on the platform below. Among the advantages offered by this system is a reduction in construction time and the reduction and number of internal columns below that are necessary with conventional construction.

Frank L. Wright's concept of tower buildings using a concrete core and a concrete cantilever floor may now with the use of prestressed concrete be more useful in the design of office buildings.

MECHANICAL

Due to clients' requirements for more flexibility and comfort, mechanical equipment has made great strides to make the office environment as ideal as possible.

Mechanical equipment in early buildings was not considered a major cost in the building. Most of the early buildings took advantage of natural ventilation withthe U-shape and one office depth between the outside wall and corridor. Sullivan used vacuum ventilation systems in most of his buildings. The early buildings and up to the late twenties used one or two pipe low pressure systems with cast iron radiators. The heat control and zoning was almost unknown until the late twenties.

Belluschi's Equitable building in Portland, 1948, made a great stride in the use of mechanical equipment and was the proto type for most of the building that followed it. Equitable was the first sealed building with a controlled environment. It used sealed double glazing with the outer sheet of the sandwich of 3/4" heat-absorbing plate glass. The actual distribution of air is handled by ducts in the suspended ceiling which is fed by central fan rooms on each floor in the ceiling over the toilets and elevator lobby. Heat pumps cool and heat the system, the pumps extract heat and cold from well water, electricity being the only "fuel".

The main mechanical room may be located as follows; middle floor, top floors, top and basement floors, basement or separated. SOM's Harris trust in Chicago, the mechanical equipment is either located on the top or bottom floors the distances become too great and the system has to have a secondary room elsewhere in the building. CBS is an example of this condition. Top and bottom mechanical rooms can be used as in SOM's LOF building, it gives even distribution but is expensive. The separated mechanical area runs become very long and the problem of connection of the service to the served area is difficult. SOM's Inland Steel is an example.

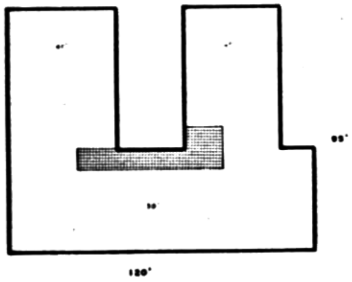
There are three systems of vertical distribution for office buildings. Many buildings have used the exterior wall for vertical risers for perimeter heating and the core for interior spaces as illustrated in Rudolph's Blue Cross building in Boston, and Saarinen's CBS tower. The interior core may be used but the horizontal runs to the perimeter become very large as illustrated in SOM's John Hancock building. SOM in Inland Steel separated the vertical riser from the served area but the problem connection is difficult.

There are three systems of horizontal distribution for office buildings. In most buildings, the supply and return ducts are suspended below the structure to cut construction cost. Yamasaki's Detroit Gas building, uses an air floor on top of a 5'-0" waffle. By employing this method, there is a saving on suspended ceilings and the thickness between ceiling and floor is reduced but the form work has to be of a higher quality and a closer control of the trades has to be maintained during the construction period. Some buildings have run the horizontal ducts through the structure but when the structure is complicated the cost of installation is high. The perimeter window units have been cut in height, for example UN Secretariat, was 2'-6" to Mies Van Der Rohe's Seagrams 1'-0".

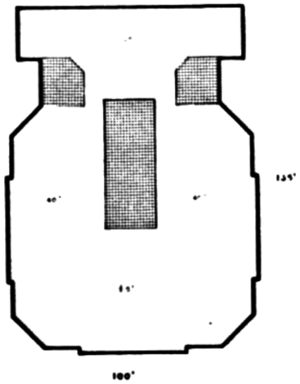
Advances have been made in the supply and return grills in order to clear up the unsightly ceiling appearance. In SOM's Harris Trust Bank, the light fixture was combined with the supply and return, but special care was taken in this design to avoid discoloring of the fixture. Inland used the perforated metal pan ceiling for both supply and return. The ceilings in Chase Manhattan Bank are equipped with flush lighting units and between each pair it is possible to insert a diffuser or return plate when needed. Union Carbide shows a refinement in diffusers. Half of the runners that divide the luminous ceiling are also continuous air conditioning diffusers. Yamasaki in Detroit Gas building and SOM in the LOF building used egg crate ceilings with lights and diffusers above.

A closer integration of structural to mechanical is bringing the architect and mechanical and structural engineer much closer together.

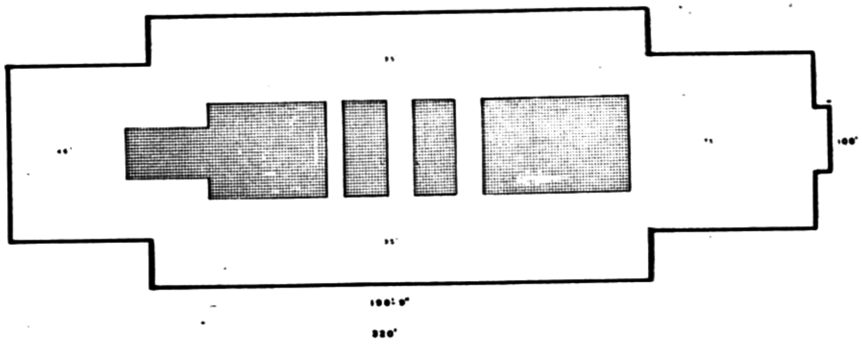
With increasing advances in technology, plan concepts, design, use of materials, structures, mechanical equipment and cost, the buildings of the future are less likely to resemble the past.



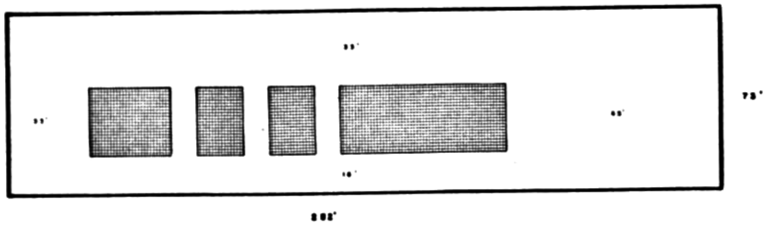
GUARANTY BUILDING, BUFFALO



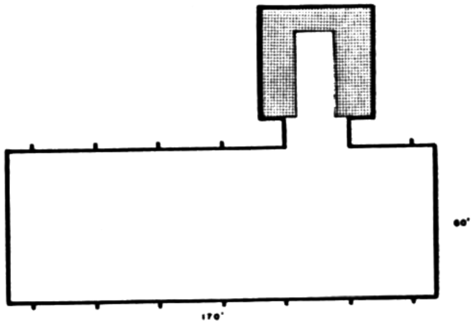
TRIBUNE TOWER, CHICAGO



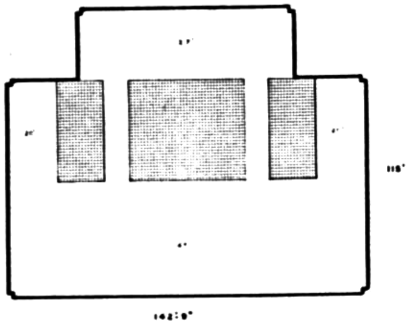
RCA BUILDING, NY



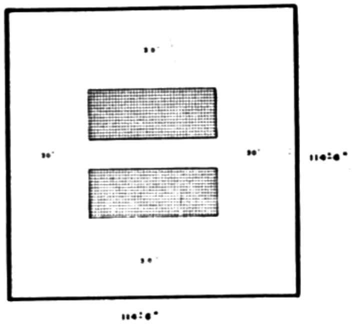
UNITED NATIONS SECRETARIAT, NY



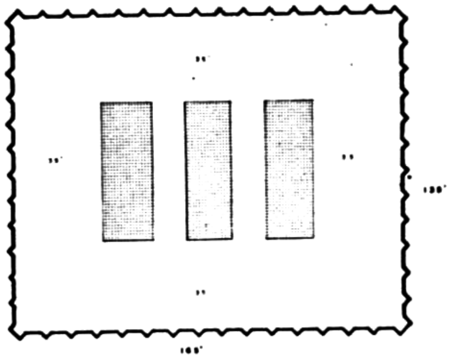
INLAND STEEL, CHICAGO



SEAGRAM'S BUILDING, NY



JOHN HANCOCK, SAN FRANCISCO



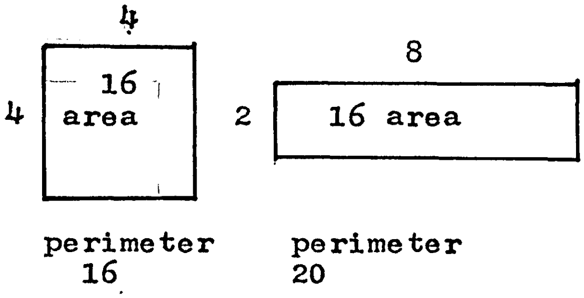
CBS BUILDING, NY

DESIGN CRITERIA

In order to study a building a logical sequence must take place with given architectural requirements. The building concept must take into consideration the envelope of the building, design requirements, structural, mechanical, methods of construction and economy.

ENVELOPE

The envelope of recent office buildings have been either a large rectangle or square. For efficiency the square is more desirable because it has less perimeter for a given square footage. Example: This is important in office building construction because the perimeter wall is considered a large proportion of the total construction cost. Also with a given square footage the mechanical load is reduced. I have selected a square envelope because of efficiency, no site requirements and as an architectural expression.



DESIGN REQUIREMENTS

My investigation has shown that recent buildings under construction or completed have a total gross square footage of 750,000 to 1,000,000 square feet. This is based on a rental ratio of total owner occupancy to rental occupancy. I have selected an approximate gross area of 800,000 square feet.

Each floor will have a total gross square footage of 20,000 to 25,000 square feet with a net rental area excluding the core of approximately 80 per cent. Each floor will give the opportunity for efficient and flexible arrangement of office space. Each floor will contain a large column free open floor with a central service core of elevators, stairs, toilets and service shafts. Each floor will be designed with a 5'-0" working module, fluorescent lighting fixtures, perimeter air conditioning units and under floor duct systems to be related to the module. The 5'-0" module was selected because it gives more flexibility in planning of office layout, and standard floor, wall and ceiling materials may be used.

Careful coordination of architectural design and the engineering of the mechanical and electrical systems and acoustics to allow the maximum flexibility in the arrangement of space to permit simple and economical revisions to office layouts as a client may require.

STRUCTURES

The office building structure will be concrete. The structural facade will have columns or structural mullions every 5'-0" on center. This allows flexibility of the interior space and expresses the module on the exterior of the building. The structural consultants advised that with a building of this height the structural mullions shall be poured in place. The floor system shall be concrete and the ceiling to floor depth shall be kept to a minimum to reduce the overall height and cost of the building.

Special attention shall be given to forming, and methods of construction.

MECHANICAL AND ELECTRICAL

An investigation must be made in order to locate the main mechanical equipment floors and also the vertical and horizontal distribution and the individual supply and return grills. The electrical lighting shall be integrated with the modular system and give proper illumination at desk level. The power and telephone shall also be integrated with the modular system to give more flexibility.

BUILDING CONCEPT

The 32 story office building has a total square footage of 800,000 square feet. Each floor has a total gross square footage of 24,000 square feet with a total net rental space of 19,800 square feet which is 82.5 per cent of the total area. The flexible office area has a 45'-0" or 9 module span from the core in all directions to the structural facade. The module line is on the inside edge of the column to allow for maximum use of movable partitions. To express the floor structure the 5' x 5' structural grid has been exposed which also allows partitioning to be attached to the bottom of the grid. Inside each 5'-0" grid is a combination light fixture and diffuser with acoustic treatment above. The floor will use an air floor system which allows a space above the structural slab for the mechanical, power and telephone services. All inside concrete will be painted. The floor plan was designed for 1,2,3, and 4 tenants per floor with their entrances to their space directly off the core.

The structural core will contain 14 automatic elevators to provide high speed service from the lobby to all floors; a freight elevator to satisfy all service needs; also toilets, janitor closet, stairs and service shafts.

STRUCTURAL CONCEPT

Structural Mullions

The structural facade or structural mullions, core and floor structure are poured in place concrete. The structural mullions are 8" x 12" on the top floors and increase in width and depth as they pick up the loads to 12" x 40" at the base. 5000 pound concrete is used in upper stories and the lower stories use 6000 pound concrete. Also the strength and percentage of steel increases from 60,000 psi and .03 at the top, to 75,000 psi and .04 at the base. This was done in order to keep the weight and size to a minimum. The fiber glass form work for each structural mullion unit will be five foot wide and eleven foot six inches high. There will be an inside and outside form for each unit. The unit will be from column center line to column center line. All the structural mullions for a floor will be poured at one time along with the floor it supports. This is done in order to avoid variation in concrete and to have a better bond between units. Special attention should be taken in order to keep the batches uniform to avoid color variations. The forms have curved corners and beveled surfaces in order to ease the pouring and ease the removal of the forms. This gives the building an expression of the plastic effect of concrete. The selection of the cement color, aggregate size and color and if the concrete is to be bush hammered, sand blasted or left alone are important visual considerations. The glass is set into the concrete with neoprene rope and gasket.

Floor System

Different types of floor systems were investigated and were discarded as follows:

A. Poured in place 15½" slab with diagonal prestressing at each mullion on the exterior wall. This allowed the possibility of vertical risers behind each 5 foot mullion. The weight was excessive and ceiling had to be furred down for mechanical, lighting and acoustics.

B. Poured in place with a 5' x 5' grid. The depth and weight was excessive. Also at the critical corner a special wide beam had to be used which broke up the ceiling pattern.

C. A combination of prestressed precast concrete for the critical section and regular concrete in other areas. The weight and depth was kept to a minimum. The connection of the beam to the core and exterior was a problem. Also visually the joint would be disturbing and the matching of the floor precast units to be poured in place was difficult.

The floor system that was used is a poured in place concrete which employs prestressing in the critical areas, and a regular two way system in other areas. The structural floor is exposed and has a depth of 21" with a 5 foot by 5 foot grid. With this system the weight and depth is kept to a minimum. The floor design employs the use of brackets at all corners in order to cut the corner triangular load and this load is spread over six ribs and these ribs are prestressed. The post tensioning will be done in three stages. The anchorages will be on the exterior wall and the post tensioning will be done on the interior core wall and brackets. Fiberglass forms will be used. The core walls will be poured when the floor is poured. The core also increases in thickness as it picks up the loads of the structure.

The advantages of this structural concept are as follows:

1. The facade expresses the structure and the module used in the building.
2. After the forms have been removed the floor can be immediately finished off. This will be a savings in time and construction cost.
3. The structural mullion forms may be used over as many as 10 times. This is also a savings in construction cost.
4. The office area is free of columns and gives the opportunity for efficient and flexible arrangement of office space.
5. The floor structure is exposed and expresses the structure. It also gives additional height and texture.
6. With a minimum depth it reduces the total cubage and height of the building thus reducing the total cost.
7. The forms used for the floor can be reused.
8. When the core walls are structural it allows for maximum freedom in planning of the core.

CALCULATIONS

Subjects covered in calculations

A. Design of floor system

B. Design of structural mullions and columns

C. Thermal expansion

D. Wind Calculations

E. Bottom beam calculations

A. DESIGN OF FLOOR SYSTEM

CRITICAL BEAM

The corner condition is critical in the design of the floor system. The design employes the use of brackets from the core in order to cut the corner triangle load and this load is spread over six ribs and these ribs are prestressed.

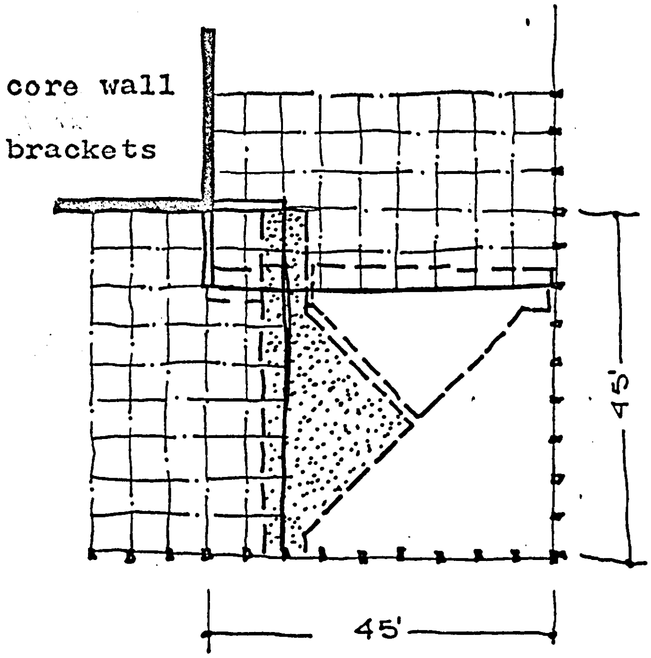
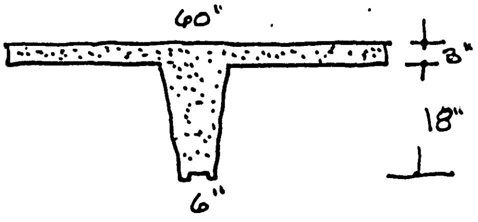


Diagram of corner condition loading

Key

━	Critical beam
▨	Total loading on critial beam
═	Beams assumed to take critical loading

Live and Dead Loads for a typical beam.



Span 45'-0"

Assumed depth 21"

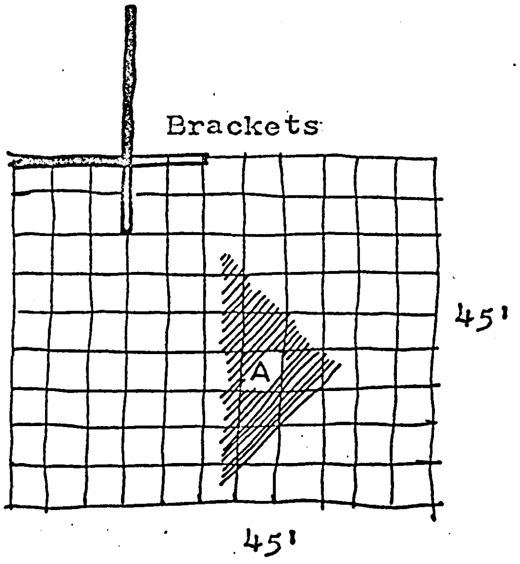
Weight of concrete 150 lbs / sq. ft.

Chicago code for L.L. for offices is 50#/ sq. ft.

Chicago code reduction factor for L.L. is 85% L.L. use 42.5#/ sq.ft.

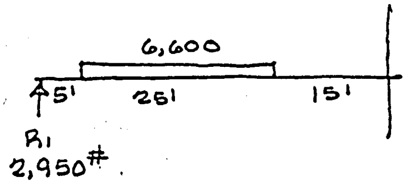
Loads

webs	11,200
3" concrete slab	8,400
9" air floor	7,750
Total Dead Load	27,350#
Live load with reduction factor	9,550#
Total D.L. and L.L.	36,900#



L.L. add D.L. of area A

3" concrete slab	8,450
9" air floor	7,700
Webs	11,800
Total D.L.	27,900#
Say 28,000#	
Total L.L.	9,550
Total DL. and L.L.	37, 550#



The R & M of 'A' L.L. on critical beam after the load is distributed over 6 ribs.

$$\frac{2950}{\left(\frac{6,600}{25}\right)} = \frac{2950}{264} = 11.2$$

$$R_1 = \frac{P b^2}{2 l^3}(a+2l)$$

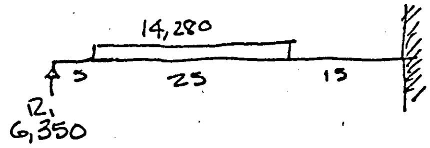
$$R_1 = \frac{6600(27.5)^2}{2 \times (45)^3}(17.7 + 2\times45)$$

$$R_1 = 2,950\#$$

$$M = 2,950(5+11.2) - 264\frac{(11.2)^2}{2}$$

47,800 − 16,500

M = 31.3' Kips



The R & M of 'A' D.L. on critical beam after the load id distributed over 6 ribs.

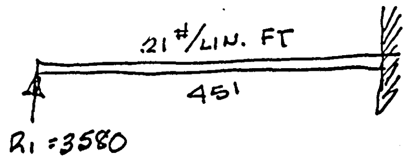
$$\frac{6350}{\frac{14,286}{25}} = \frac{6350}{570} = 11.1$$

$$R_1 = \frac{14280(27.5)^2}{2\times(45)^3}(17.5 + 2\times45)$$

$$R_1 = 6,350\#$$

$$M = 6,350(5+11.1) - 570\frac{(11.1)^2}{2}$$

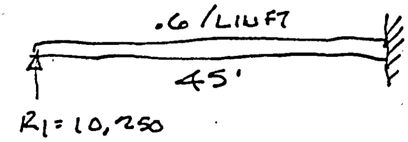
M = 67,000 FT lb



The R & M for L.L. on critical beam without 'A'

$$M = \frac{w l^2}{8} = \frac{.21(45)^3}{8} = 53' \text{ Kips}$$

$$R_1 \ \frac{3wl}{8} = 3,580\#$$



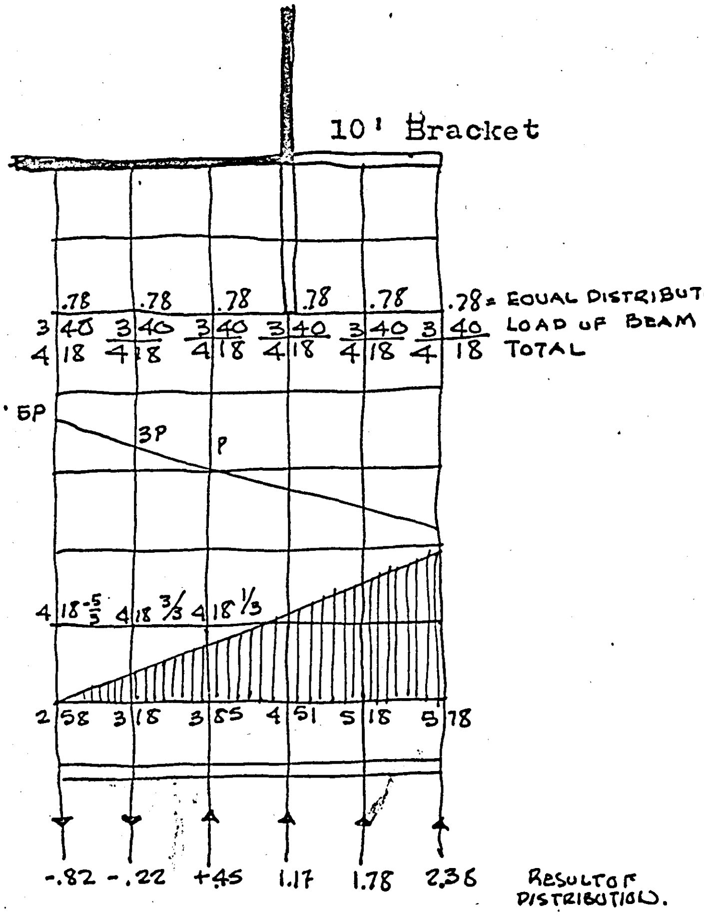
The R & M for D.L. on critical beam without 'A'

$$M = \frac{wl^2}{8} = \frac{.6(45)^2}{8} = 154' \text{ Kips}$$

$$R_1 = 10,250\#$$

M FOR CRITICAL BEAM WITHOUT "A" LD.	154' Kips	R_1	1025	
M OF 'A' ON CRITICAL BEAM	67	R_1	635	
TOTAL D.L. M	221 FT Kips	R_1 =	16.60	FOR DL
M FOR L.L. ON CRITICAL BEAM WITHOUT "A" LOAD	530	R_1	358	
M FOR LL. OF A	31.3	R_1	295	
TOTAL L.L. M =	84.3' Kips		653	LL.

TOTAL D.L & L.L. M = 305.0 FT Kips R_1 = 23.13 For col + spandrel



Method of distributing the the triangle dead load of 'A' over six ribs.

D.L./6 = 28/6 = 4.75

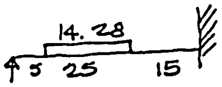
4.75/6 = 0.78

5P x 25 + 3P x 15 + Px 5 = 12.5 x 4.75

P = 60/175 say 1/3

Add 2.38 / rib for the critical beam

2.38 x 6 total load of 'A' = 14,280#

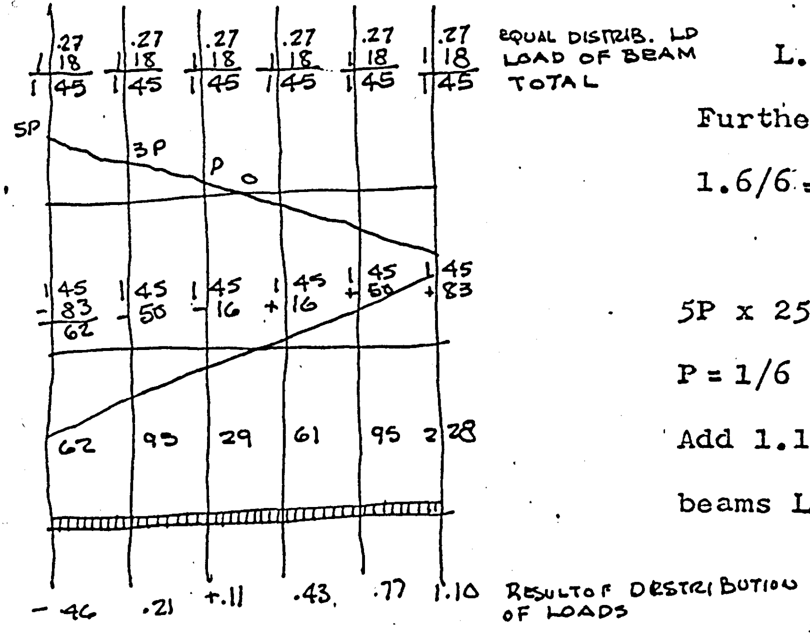


Method of distributing the triangle Live Load of 'A' over six ribs.

L.L./6 = 9.55/6 = 1.6

Further distribution over 6 ribs

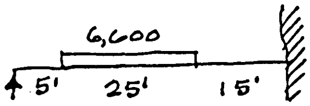
1.6/6 = .27



5P x 25 + 3P x15 + Px5 = 12.5 x 1.6

P = 1/6

Add 1.10/ rib for the critical beams L.L. 1.10 x 6 = 6,600



An approximate method is used in calculations of the preliminary design of the critical beam prestressed concrete section.

1) ELASTIC WORKING

The prestressed - concrete beam to resist a total moment of 305 ' k.

Overall depth 21"

The effective prestress for steel is $f_s = 125{,}000$ psi

Allowable stress for concrete under working load $f_c = 2250$ psi

Ultimate unit stress in steel $f'_s = 240$ ksi

Ultimate unit stress in concrete, generally at 28 days $f'_c = 5{,}000$ psi

$$F = T = \frac{M_T}{0.65h} = \frac{305 \times 12}{0.65 \times 21} = 270^K$$

$$A_S = F/f_s = 270/125 = 2.16 \text{ SQ. IN.}$$

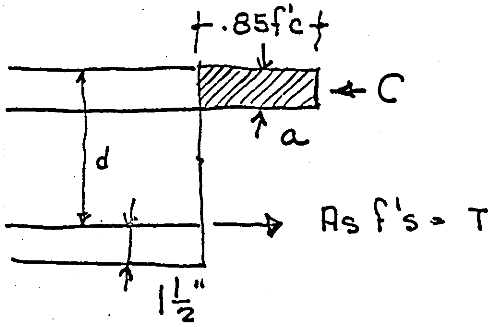
$$f_c = .45 f'c = .45 \times 5{,}000 = 2{,}250$$

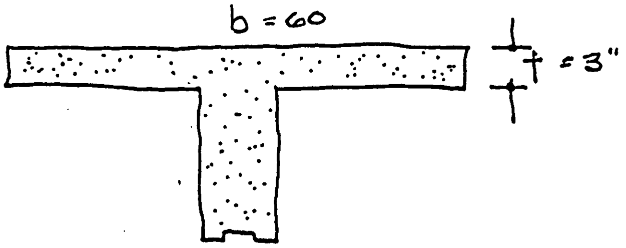
$$A_c = \frac{C}{0.5 f_c} = \frac{270}{0.5 \times 2250} = 240 \text{ SQ. IN.}$$

AREA OF SECTION = 342 □"

240□" < 342□" OK FOR ELASTC WORKING

CHECK FOR ULTIMATE STRENGTH





$T = C$ $\quad a \times .85 f'_c \times b = C = T = A_s f'_s$

$a \times .85 \times 5000 \times 60 = 2.16 \times 240{,}000$

$a = 2.04"$

$a < t$ OK ∴ $2.04" < 3"$ OK FOR ULIMATE STRENGTH

$M_{ULT} = A_s f'_s (d - \frac{a}{2})$

$= 2.16 \times 240 (19.5 - \frac{2.04}{2})$

$= 9{,}000$ $\qquad 9000/12 = 750$

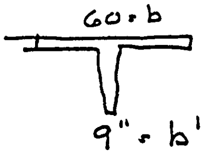
$1.2\ M_{DL} + 2.4\ M_{LL}$

$= 1.2 \times 221 + 2.4 \times 84$ -

$= 452$

$775 > 471$ ∴ BEAM OK

CHECK STRESSES AT WORKING LOADS

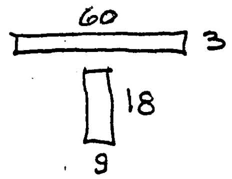


FROM p. 81 CRSI

$I = C\,\frac{b'h^3}{12} = 1.95 \times \frac{9(21)^3}{12} = 13,500 \text{ in}^4$

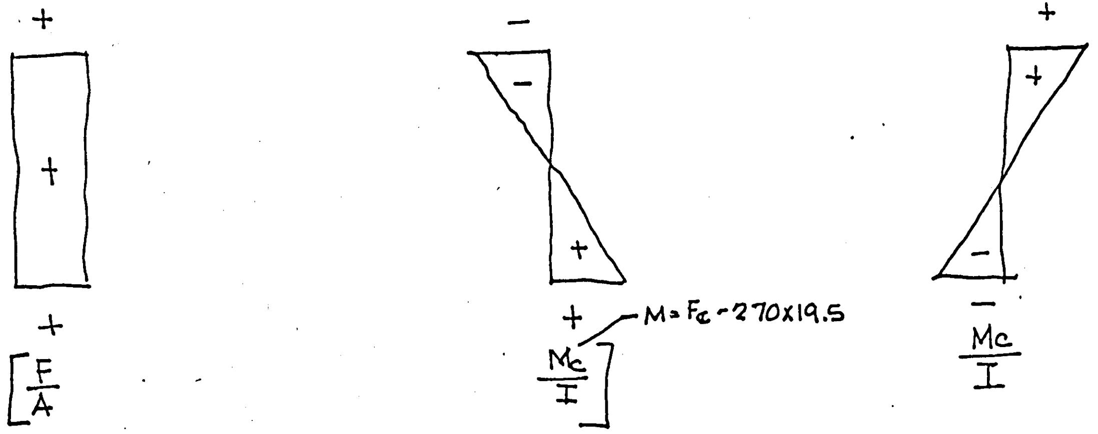
$\frac{b}{b'} = \frac{60}{9} = 6.6$ $\frac{t}{h} = \frac{3}{21} = .144$ $C = 1.95$

c = DISTANCE FROM cgc TO EXTREME FIBER = 6.75"



A	y	Q
180	1.5	270
162	12	1940
342		2310

$\bar{y} = \frac{\Sigma Q}{\Sigma A} = \frac{2310}{342} = \underline{\underline{6.75"}}$



TOP $+ \frac{270,000}{342} - \frac{270 \times 19.5 \times 6.75}{13,5} + \frac{305 \times 19.5 \times 6.75}{13.5}$

$= 790 - 660 + 296$

$= 426 <$ AS ACI ALLOWABLE FOR STRESSESS (2605) IS $3\sqrt{f'_{ci}} = 3\sqrt{5000} = 672$

∴ OK IN TENSION

BOTTOM

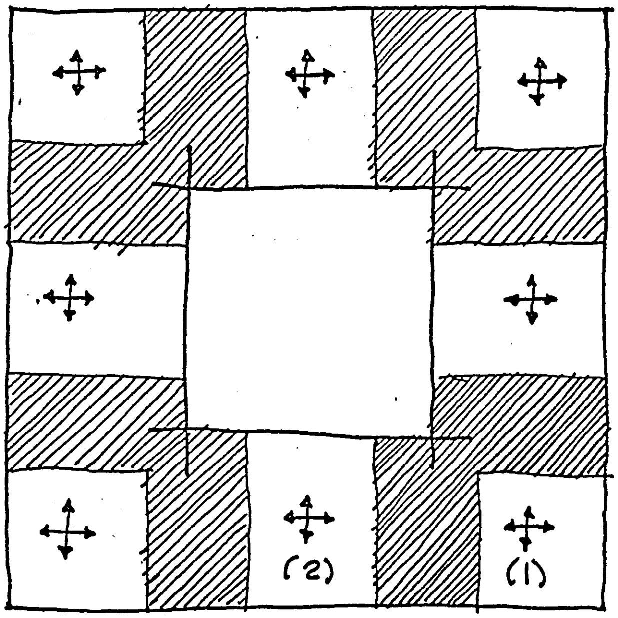
$= \frac{270,000}{342} + \frac{270 \times 19.5 \times 14.25}{13.5} - \frac{305 \times 19.5 \times 14.25}{13.5}$

$= 790 + 5,5,70 - 6250$

$= 110 <$ ACI COMPRESSION ALLOWABLE $6\sqrt{f'_c} = 6\sqrt{5000} = 1344$

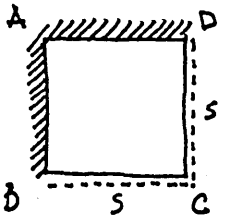
∴ OK IN COMPRESSION

Calculations for two way slabs other than prestressed areas.



SLAB 1 = SQUARE SLAB

$a = 35$



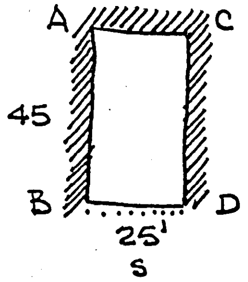
BUILT IN AT AB
AD

MAX NEG. MOMENT
$-0.049\ W s^2$ PER FOOT
$= 49,400$ #/□'

SUPPORTED AT DC
BC

NEG. MOMENT $-0.025\ ws^2$
POST. MAX M $+.037\ ws^2$
$= 37,000$ #/□'

SLAB 2



$\frac{45'}{25} = 1.8$

CONTINUOUS AT
S = 45

AC MAX NEG. M.
AB $-0.085\ ws^2$
CD M $- 43,500$ #/FT.

COL. SUPPORTED @ BD $+ 0.064\ ws^2$
M = 32,600

SLAB 1 & 2 WILL TAKE A DEPTH OF 21" WITHOUT PRESTRESSING.

A. DESIGN OF STRUCTURAL MULLIONS

By ACI building code using formula 1403 for tied columns

$P = A_g (.18 f'_c + .32 f_y p_g)$

Design of critical column

typical floor load D.L.	16,600
L.L. maybe reduced 50% above 8th fl	3,850
weight of spandrel	6,700
weght of glass	200
TOTAL LOAD PER FLOOR OF TYPICAL COLUMN	27,350 say 27.4

Formula's used

4th - 15 fl $P = A_g (1080 + .32 \times 75{,}000 \times .04)$ $f'_c = 6{,}000$ psi

$P = 2040\ A_g$

15 - 27 fl $P = A_g (1080 + .32 \times 60{,}000 \times .03)$ $f'_c = 6{,}000$ psi

$P = 1656\ A_g$

27 - Roof $P = A_g (900 + .32 \times 60{,}000 \times .03)$ $f'_c = 5{,}000$ psi

$P = 1476\ A_g$

COLUMN SCHEDULE

NO OF FLOOR	BEAM LD. AT COL.	COL. WGT.	P/FLOOR KIPS + WIND LD.	P-1476 Ag	P-1656 Ag	P-2040 Ag	COL. SIZE	AREA OF STEEL
ROOF	21.5							
							8x12	
32		.9	22.4				8x12	
31	27.4	.9	40.7					
30	27.4	.9	69.0				10x12	
29	27.4	.9	97.3	66.0				2.0
28	27.4	.9	125.6	85.0				2.5
27	27.4	.9	153.9	104.0	93.0			3.1
26	27.4	1.1	182.0		110.0			3.3
25	27.4	1.1	210.0		128.0			3.9
24	27.4	1.7	242.0		146.0		10x18	4.4
23	27.4	1.7	272.1		164.0			4.9
22	27.4	1.7	302.2		180.0			5.4
21	27.4	2.3	332.9		230.0		10x24	6.9
20	27.4	2.3	363.6		218.0			6.5
19	27.4	2.3	394.3		238.0			7.1
18	27.4	2.8	425.5		260.0		10x30	7.8
17	27.4	2.8	457.7		270.0			8.1
16	27.4	2.8	489.9		298.0			8.9
15	27.4	3.4	524.7		316.0		12x30	9.4
14	27.4	3.4	557.5		336.0			10.0
13	27.4	3.4	590.3		356.0			10.7
12	27.4	3.4	623.1		376.0			11.3
11	27.4	4.0	656.5		396.0		12x36	11.8
10	27.4	4.0	688.8		415.0			12.4
9	27.4	4.0	723.3		430.0			12.8
8	27.4	4.0	756.7			370.0		14.8
7	30.1	4.0	792.8			389.0		15.5
6	32.8	4.0	832.6			407.0		16.3
5	35.5	4.0	875.1			430.0		17.2
4	38.2	4.5	921.8			450.0	12x40	18.0

Roof - 27 Columns will be 8" wide from roof to 27th depth 12"

27 - 15 Columns will be 10" wide depth 12" - 30"

15 - 4 C Columns will be 12" wide depth 30" - 40"

Approximate calculations for bottom columns indicate their size will be approximately 6'-0" x 6'-0".

C. THERMAL EXPANSION

I know that the classic solution to this problem would have been to design slabs with the lowest moment of inertia such as to be able to deflect without cracking even for thermal expansion of the facade of say a couple of inches. But in this building the rigidity of the ribbed slab is to high to allow for such a deflection. There fore horizontal expansion joints have been adopted.

The horizontal expansion joints have not as far as I know been developed in buildings of this kind and there fore little may be said about their effectiveness. Any way the concept was that their pressure will have surely a good effect allowing if not the whole thermal effect of deformation as least a part of it which will give a certain safety against concentric form of stresses which would be other wise not avoidable.

$\alpha = 0.00079$ for a variation of 100° F

Assume a variation of 70° F $\alpha = 0.00055$

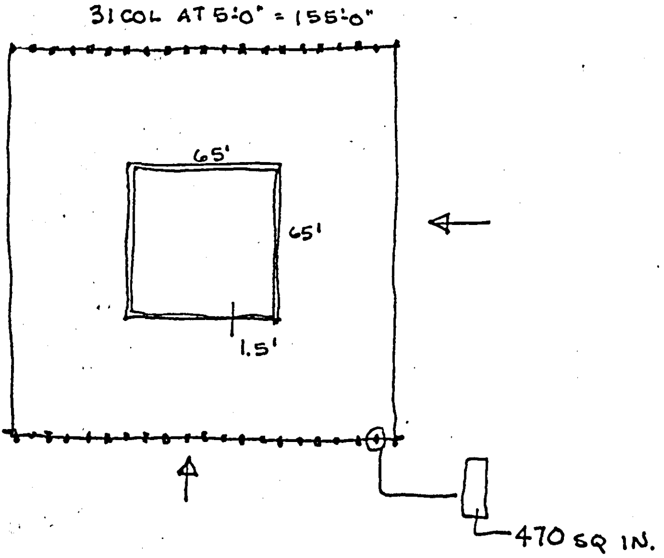
Length of expansion 70 feet = 840" - 6 stories

Δl 0.00055 x 840 = 0.46 of an inch $\frac{1}{2}$ "/ 6 stories

Expansion joint to carry load of building and also to allow for thermal expansion. For $\frac{1}{2}$" of expansion 3" of expansion material must be used.

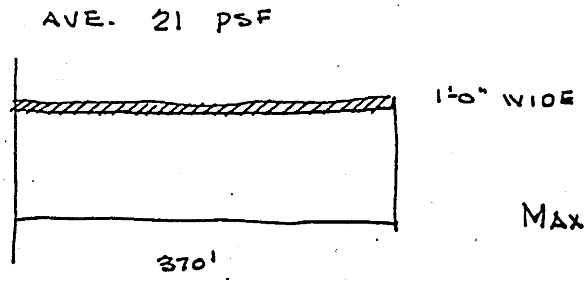
D. WIND CALCULATIONS

The effect of wind has been checked in an approximate way considering that the structural portion of the building that will resist against the wind should be the core and the double row of opposite columns.



The amount of bending effect of wind to be taken by the above mentioned structural elements can be determined by computing their moments of inertia.

From the Chicago building code min. design wind pressure for buildings over 300 feet is a dd 0.25#/□' for each foot above 300 feet.



$$\text{MAX. M.}\ \frac{21 \times 370^2}{2} = 1,440,000\ \text{PSF}$$

J_x COLUMN $= 2 \times 470 \times (77.5 \times 12)^2 \times 31$

$= 25{,}200{,}000{,}000 \text{ in}^4$

J CORE $= 2(65 \times 1.5) \times 32.5^2 + 2\frac{1}{12}\, 1.5 \times 65^3$

$= 6{,}800{,}000{,}000\ ''^4$

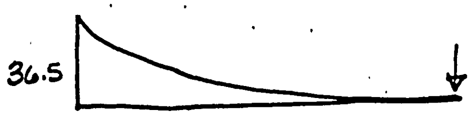
The comparison of the moments of inertia to the central axis of the columns and of the core shows that:

$$\frac{J_{COL}}{J_{CORE}} = \frac{25{,}2}{6.8} = 3.72$$

M TO THE COLUMNS $\quad \frac{M}{J_{COL} + J_{CORE}} J_{COL} = 1{,}446{,}000 \times \frac{25{,}200}{32{,}000} = 1{,}135{,}000$ PXF.

M TO THE CORE $\quad \frac{M}{J_{COL} + J_{CORE}} J_{CORE} = \quad 33{,}000$ PXF

EFFECT ON A COUPLE OF OPPOSITE COLUMNS



$1{,}135{,}000 \times 5 = 5{,}650{,}000$

$\frac{5{,}650{,}000}{155'} = 36.5$ KIPS

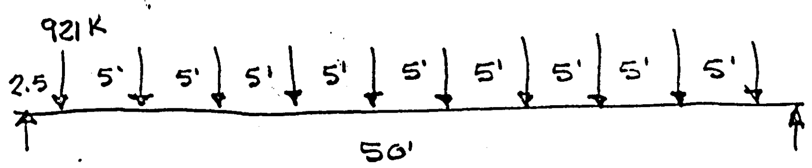
36.5 KIPS MUST BE ADDED TO THE LOAD ON THE 4TH FL & EACH FLOOR EFFECTED.

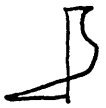
There is also secondary bending effect on each column which has has not been calculated but for this the reinforcing of columns has been concentrated on the two borders.

E. BOTTOM BEAM CALCULATIONS

The bottom beam is a structure which does not belong to the beams of the classical strength of materials, and does not b belong to the family of sheer walls or wall beams because of its big width.

The calculations involves major analytical problems and therefore this beam has been dimensioned by taking in account the classical theory of bending and the analysis of static behavior of wall beams. On this basis the dimensions and reinforcing have been designed as follows:

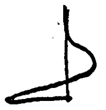




TOTAL LOAD = 921 X 10 = 92,100 + 921 = 93,021 KIPS

$= \frac{93,000}{50} = 186$ KIPS

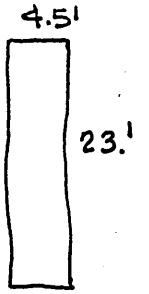
$6 = \frac{921,000}{60 \times 48} = 320$ psi



CHECKING BY CLASSICAL THEORY

MAX. POS. M = $\frac{1}{13}$ 186,000 X 50^2
= 35,800,000 FT P.

MAX. NEG. M. = $\frac{1}{10}$ X 186,000 X 50^2
= 46,400,000 FT P.



$J = \frac{1}{12} \times 4 \; 23^3 = 4,060 \; FT^4$

$S \; \frac{4,060}{11.5} = 364 \; FT^3$

$\sigma_{ox} = \frac{46,400,000}{364}$

$= 890$ psi

THIS TENSION DUE TO THE WALL BEAM EFFECT COULD BE INCREASE UNTIL 1.6 ÷ 1.7. TIMES OR 1600 PSI.

MECHANICAL AND ELECTRICAL SYSTEMS

The main mechanical areas are located on the top floor and third floor. In early designs the mechanical area was located in the mid stories. This was changed because the building employs a large beam at the base which is 23 ft. high with space behind which can be easily used for mechanical equipment.

The concept is to have 4 zones - the 2 lower zones will be supplied by the 3rd floor and the upper 2 zones by the top floor mechanical. All vertical distribution will be inside the shaft in the structural core.

The horizontal distribution for each floor will be as follows:

1) Each outside wall will have a separate zone.
2) Each one of these zones will have a high pressure system on the exterior wall and a low pressure system in the interior space.
3) The distribution of the systems is by an air floor which allows the passage of ducts and services above the structural floor. The duct and service will feed the floor above or the floor below.
4) The plenium of the air floor will be used as the return system.
5) The supply or return grill for the ceiling will be combined with fluorescent lighting fixture. These units will be controlled by a damper.
6) The exterior wall units will be supplied by a high velocity single duct system with terminal reheat units and also served by water under pressure. The units are 8" wide and 2'-6" high. Control dampers are used for individual control.

The heat loads have been reduced by using glare and heat reducing glass, venetian blinds and the sill is 2'-6" above the floor.

Spoilers are placed in the ducts systems to cut sound transmission.

LIGHTING

Each 5'-0" x 5'-0" module will have a fluorescent light fixture providing 60 foot candle at desk level in office spaces; under floor duct for telephone and electrical service will be at each module.

EARTH SCIENCE BUILDING

Structural

Poured in place concrete with a span of 50 feet. Depth of concrete beam is 4'-5" at 9'-0" centers. Columns are 2'-9" by 2'-2" at 9'-0" centers. Column sizes remain the same size throughout the building. Fiberglass forms are used and the concrete is sand-blasted. The sills are precast and the glass is set in the concrete with a neoprene gasket.

Mechanical

The vertical risers are in the core. The perimeters supply is a large 9" pipe along the wall and passes through the columns. The interior zone is fed off the corridor. No suspended ceilings.

THE BRUNSWICK BUILDING

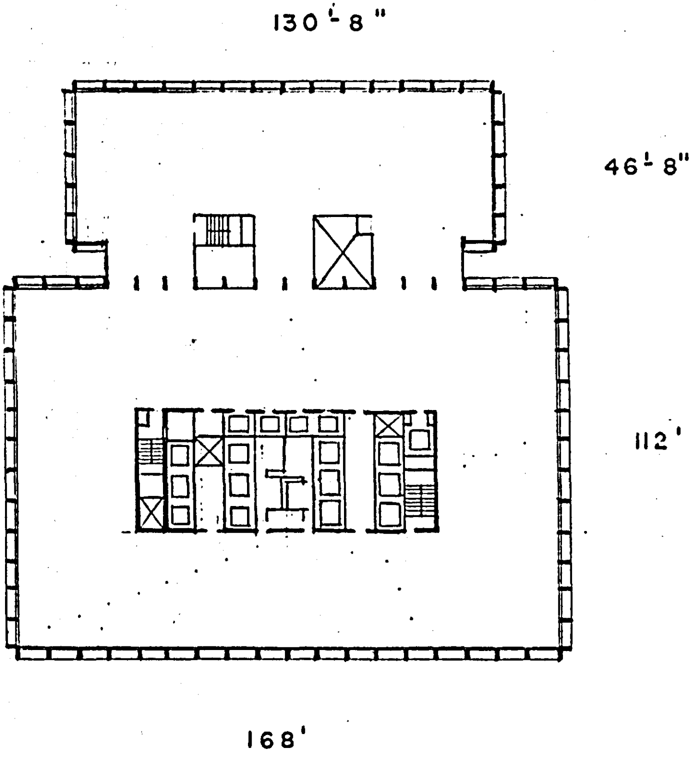
Structural

Poured in place concrete with a 37 foot span from a concrete structure core. The floor system employs a two-way waffle in corners and rib slabs on the long walls. Structural depth 27". The columns or structural mullions are 9'-0" on center and increase in width and depth as it picks up the weight of the structure. Example width 1'-4" top to 1'-10" - depth 2'-0" to 3'-8". Rubber zippers are used for glass.

Mechanical

Mechanical floor located on top and 3rd floors. Vertical perimeter risers are located on the back of columns. Interior zone riser is located in the core.

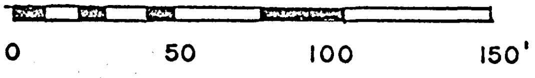
The horizontal distribution is below the structure in a suspended ceiling.



37 STORIES

STRUCTURAL CORE & WALL - 37'-0" SPAN		
MODULE		4'-6"
GROSS AREA/FLOOR	26,600 -	18,800
NET AREA / FLOOR	21,200	15,360

BRUNSWICK BLDG. CHICAGO
SKIDMORE OWINGS & MERRILL



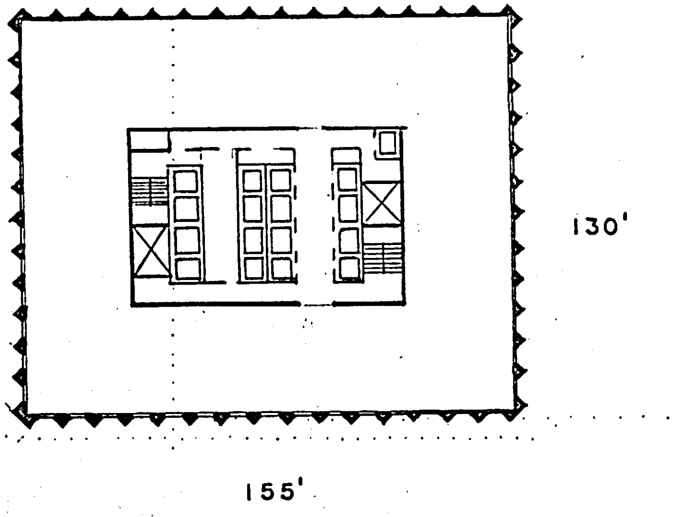
C.B.S. TOWER

Structural

Poured in place concrete with a 35 foot span from a structural core. The floor system employs a 2'-6" waffle in all corners with a depth of 17" x 3". The long side of core employs rib joist with a depth of 17" x 3". The columns are 5'-0" wide and 5'-0" apart and form a triangular shape on the exterior wall. The concrete is insulated and cladded with granite.

Mechanical

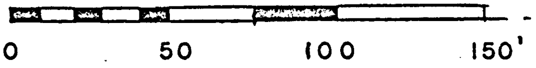
The main mechanical floor is located on the top floor with a secondary mechanical at the base. The vertical perimeter risers are integrated with the structural columns so that when the size of riser is smaller, the column is larger. The interior area is supplied by vertical risers in the core. The horizontal distribution is below the structural floor in a suspended ceiling.

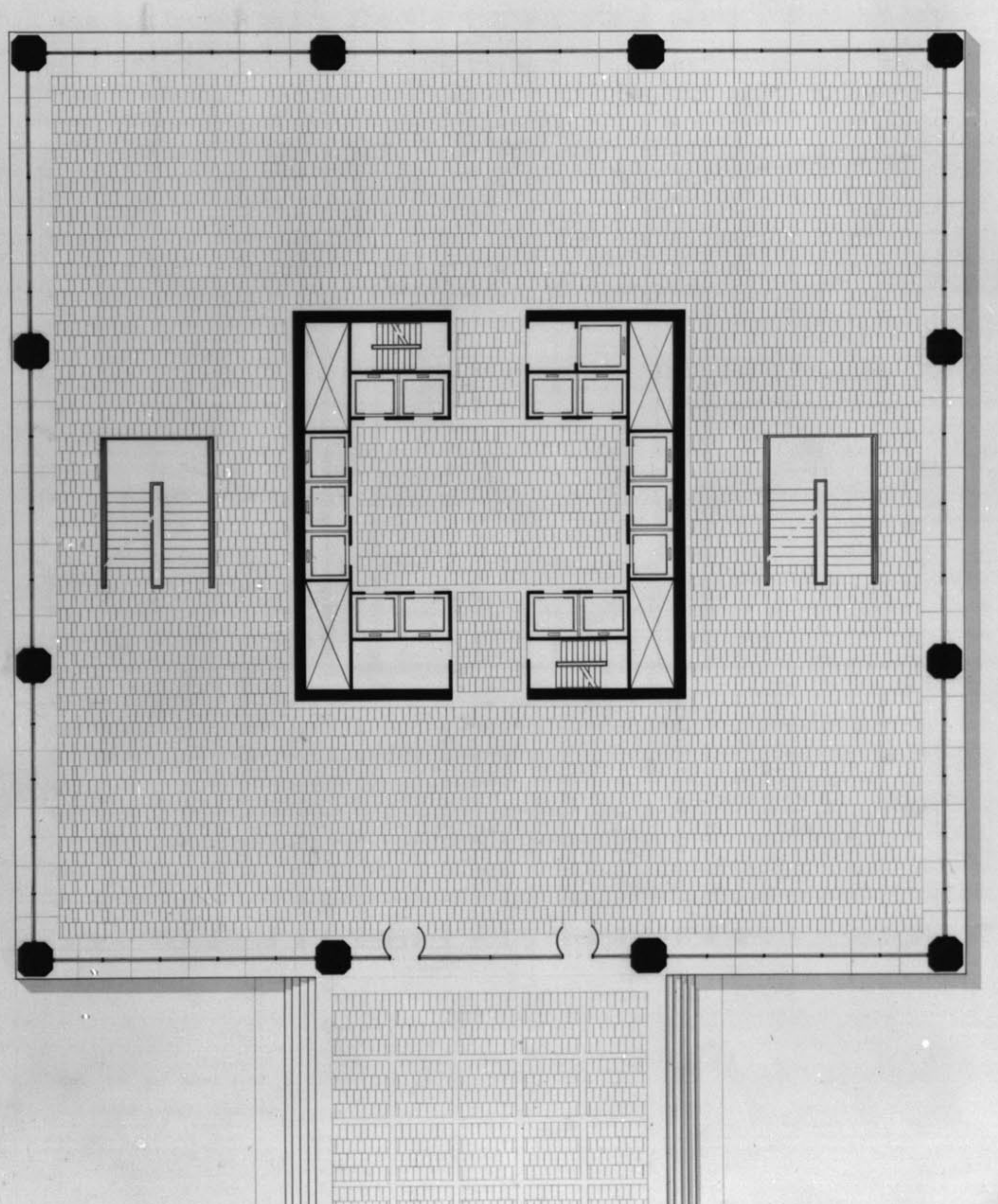


38 STORIES

STRUCTURAL CORE & WALL	35'-0 SPAN
MODULE	5'-0"
GROSS AREA/ FLOOR	20,000
NET AREA / FLOOR	15,300

CBS BLDG. NEW YORK
SAARINEN

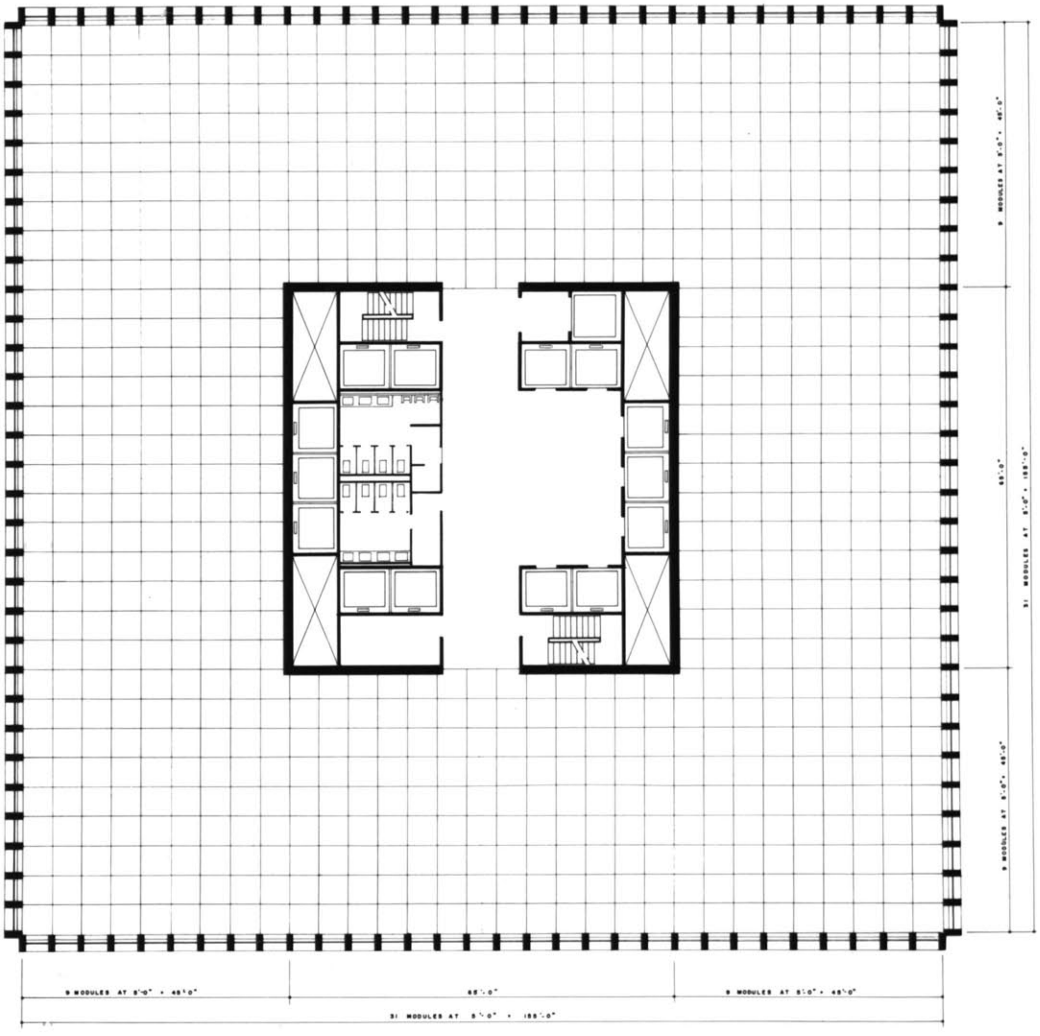




ENTRANCE LEVEL

0 5 10 20 30 40 FEET

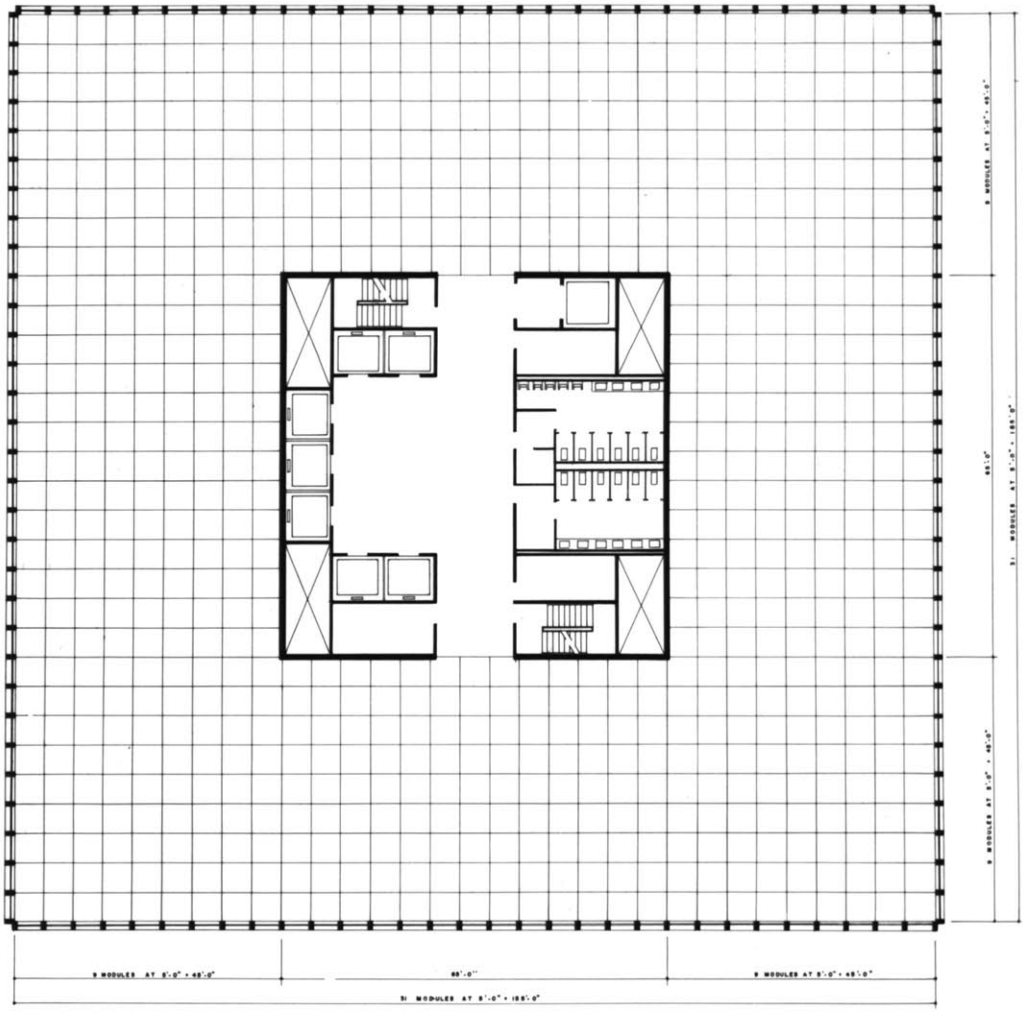
REINFORCED CONCRETE STRUCTURAL FACADE
MASTER IN ARCHITECTURE THESIS
ROBERT F. SITZENSTOCK M.I.T. 1962



TYPICAL LOW RISE FLOOR PLAN

0 5 10 20 30 40 FEET

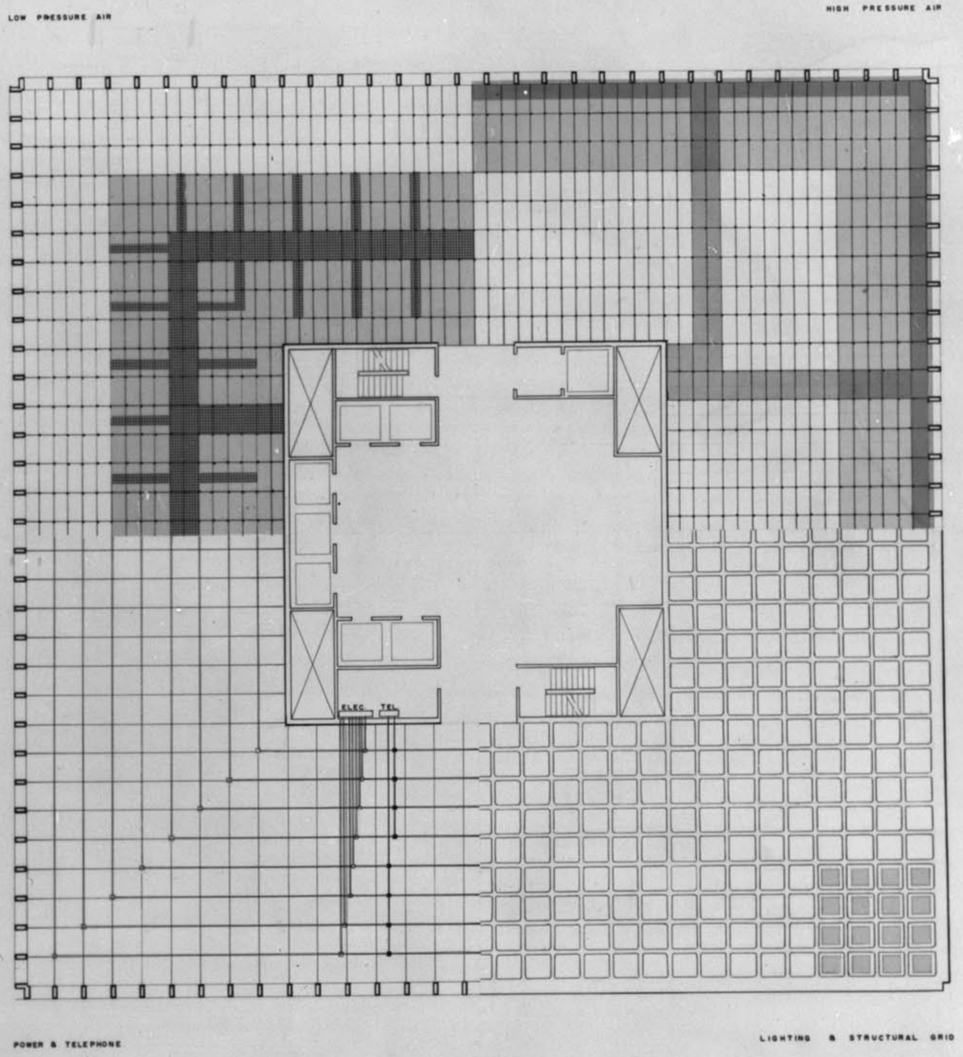
REINFORCED CONCRETE STRUCTURAL FACADE
MASTER IN ARCHITECTURE THESIS
ROBERT P SITZENSTOCK M.I.T. 1962



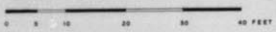
TYPICAL HIGH RISE FLOOR PLAN

0 5 10 20 30 40 FEET

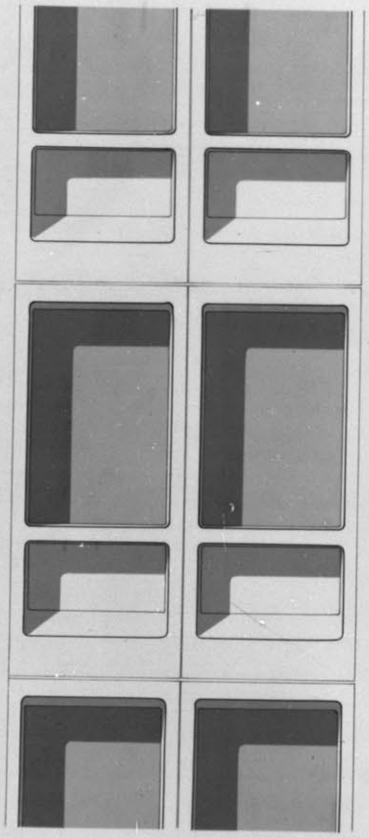
REINFORCED CONCRETE STRUCTURAL FACADE
MASTER IN ARCHITECTURE THESIS
ROBERT F. SITZENSTOCK M.I.T. 1962



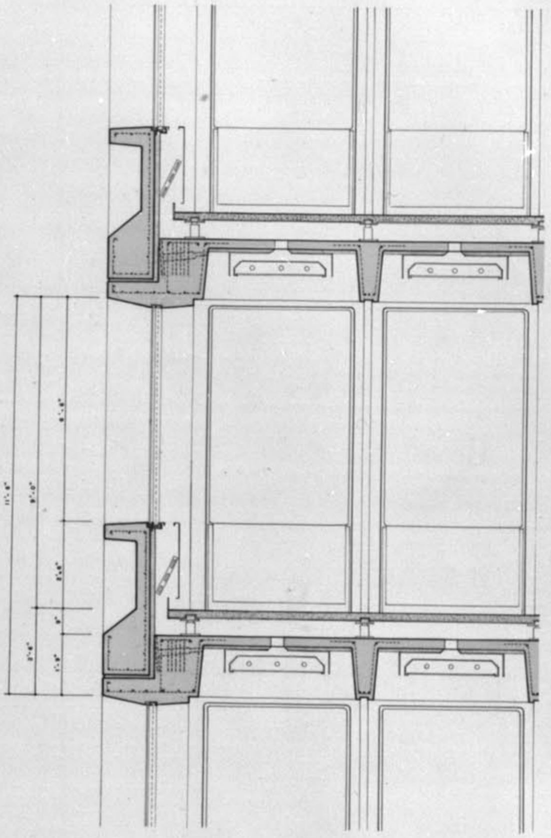
MECHANICAL, ELECTRICAL & STRUCTURAL SYSTEMS



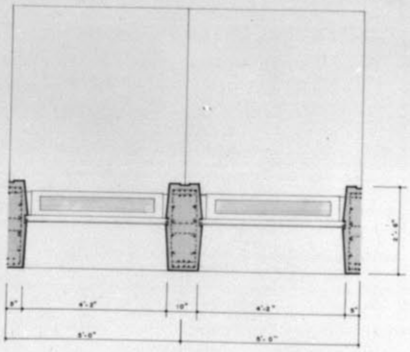
REINFORCED CONCRETE STRUCTURAL FACADE
MASTER IN ARCHITECTURE THESIS



ELEVATION



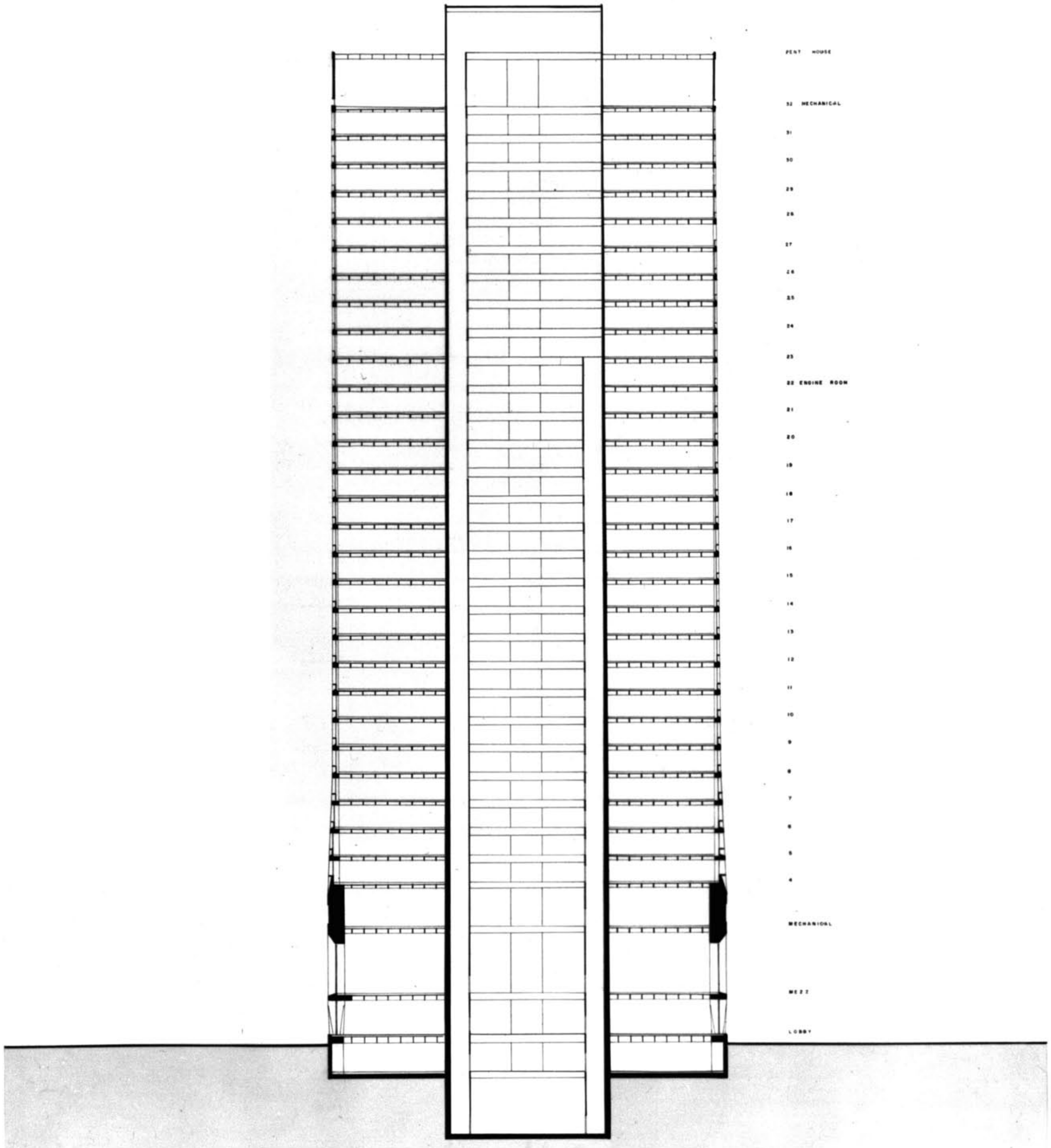
SECTION



PLAN

STRUCTURAL MULLION DETAILS

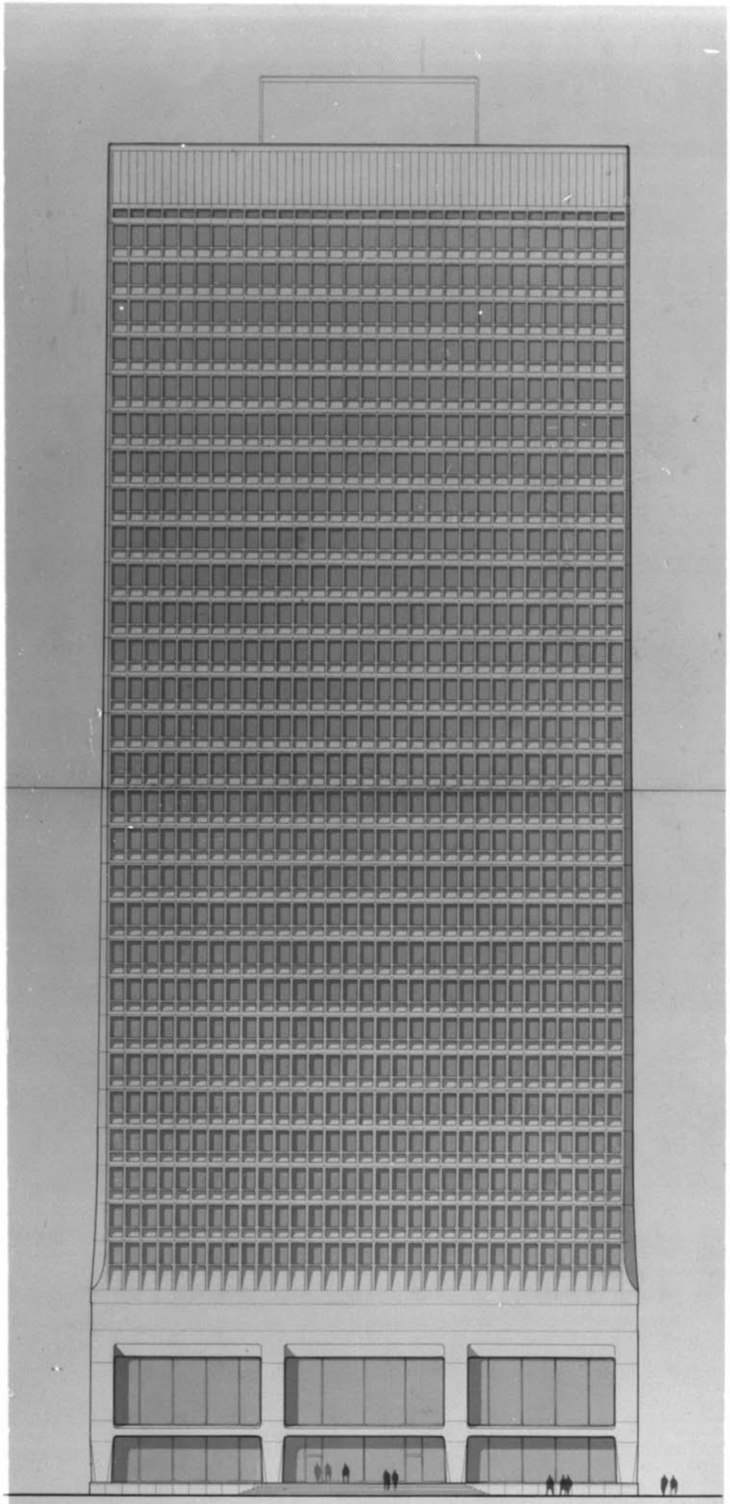
0 1 2 3 4 5 FEET



SECTION

0 5 10 20 30 40 50 FEET

REINFORCED CONCRETE STRUCTURAL FACADE
[illegible] THESIS



ELEVATION

REINFORCED CONCRETE STRUCTURAL FACAD

MASTER IN ARCHITECTURE THESI