A PRE-CAST STRUCTURAL FACADE FOR A LOW OFFICE BUILDING

by

Ronald R. Williams
B. Arch., Illinois Institute of Technology, 1961

SUBMITTED IN PARTIAL FULFILLMENT OF
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JULY 1961

Signature of Author
Ronald R. Williams

Signature of Head of Department
Lawrence E. Anderson
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Abstract

This thesis is primarily concerned with the design of a structural facade which involves the integration of pre-cast and poured-in-place concrete. Obviously, the structural facade is a system which will both support and enclose a building's periphery, and, as such, it will be necessary to restudy the "vertical member to floor" connection and the integration of mechanical equipment.

Other influencing factors in the design which will be discussed include:

1. Building Type
2. Choice of Module
3. Choice of Floor Structure
4. Mechanical System
5. Lighting and Acoustic Treatment
6. Partitioning
July 25, 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, "A Pre-Cast Structural Facade for a Low Office Building".

Respectfully,

Signed

Ronald R. Williams
ACKNOWLEDGMENTS

I should like to extend my gratitude to the following for their advice and criticism during the course of this study:

Professor Eduardo F. Catalano
Doctor Howard Simpson
Professor Giulio Pizzetti
Mr. William Dickson
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I. Preface

Stated simply, a structural facade replaces the peripheral line of supports with a series of closely spaced posts which thus form a load bearing wall with many openings. It is ideally suited for use in buildings where there are many changes in the division of spaces (at both the large and small scales), and where a regular design rhythm in the facade is desirable. Its use can also be justified economically by virtue of the fact that its repetitive nature can take full advantage of the benefits of mass production and erection.

Considering these facts, it becomes obvious that the structural facade is particularly well suited for use in the design of apartment and office buildings. Thus, two basic and arbitrary decisions must be made before the design can proceed - they are: the type and height of building to be designed. I chose to do a low office building.

Early research disclosed that most low office buildings are usually very small and never use concrete extensively since it would be more economical to build with
steel or wood. However, there has been a trend to locate fairly large urban businesses, which in turn would require larger and more elaborate facilities, in suburban areas. (1) Furthermore, the suburban office shares many of the assets of the city office, since the city center is in easy reach and travel to it can be done in off-peak hours. The reduced operating cost and better working environment are other factors which have, in most cases, more than offset the poorer direct communications. Looking to the future, a firm in such a location can count on the population explosion to provide all of its staffing needs, while there is land available for expansion. (2)

Taking these facts into consideration, the proposal of a structural facade for a low office building becomes quite reasonable.


II. Design Criteria

A. Choice of a Module

The planning requirements of a firm can be considered in three parts: Organization, communication, and flexibility. These factors combine to determine the physical changes within a given space and may range from the need to move a few feet of partition to the need to transfer whole departments to other parts of the country. Therefore, the choice of a module is of extreme importance since it will determine whether or not a space can accept the wide range of demands which will probably be placed upon it.

The choice of a module for an office building may be limited by the amount of money available, while in cheaper buildings the standard systems of walling, usually dictate the module chosen. (Fortunately, these systems have been devised with general needs of both planning and economy of materials in mind.) However, it would be a great mistake, in this instance, to let the dictates of economy be the sole guide in the selection of a module.
The structural facade and its modular nature should have a strong influence over the choice of a module. Moreover the module, under these circumstances, should be expected to reach its most thorough degree of integration with windows, partitions, ceilings, lighting, area allocation, and other supporting elements. Thus it will afford maximum flexibility in the arrangement of space and permit simple and economical revision to office layouts as changing operations may require.

The choice of 5' x 5' working module - which would allow standard floor, wall, and ceiling materials to be used - has the inherent flexibility necessary for a changing office layout. The planning grid will consist of a 40'-0" clear span which could accommodate an office depth of 15' to 20', a secretarial depth of 10' to 15', and a corridor 10' in depth.

B. Choice of Floor Structure

Having established the fact that a totally integrated modular system should be part of the basic design criteria considerably narrows the choice of floor structure. Indeed, the most logical choice is a "waffle" slab with its ribs coinciding with the established module grid of 5' x 5'. The slab thus establishes uniform connection conditions for partitioning throughout the entire floor, while creating recessed troughs in which other necessary fixtures can be located.
C. Choice of a Mechanical System

Today there is an increasing concern over the selection of a mechanical system which best fits the particular requirements and design of a given building. If the choice is made early enough, it is conceivable that the system may be integrated with the plan and structure for optimum economy and space utilization. But before the kind of system to be used can be considered a study of the basic heat load patterns of the building must be made.

A more thorough discussion of the mechanical system will be found on page 33.

D. Lighting and Acoustic Treatment

Lighting

Since one of the main objectives in this design is to provide flexibility in the work spaces, a lighting system, related to the module by locating it in the recessed trough created by the ceiling surface of the floor structure, will be provided. However, there are certain inherent features of this kind of lighting system which should be discussed here.

Ideally it is the work and not the work spaces that should be lit, with a flexible plan this objective must be
sacrificed, as it inevitably means a rigid installation. Two further demands that flexibility makes on an installation are for a generous layout of distribution wiring, and for an ample carrying capacity in these wires to allow for a possible increase in the power loads.

Acoustic Treatment

The recessed troughs can also be lined with sound absorbent materials, as required, in order to control the level of high frequency sounds common in offices. In this way sound control is relatively free of partition placement, but it should be noted that other steps may have to be taken depending on the size and use of a space.

E. Partitioning

Partitions will be placed in accordance with the established module, and will have a core area which will accept the necessary wiring for any fixtures that may be attached to their surfaces.
III. The Structural Facade

Background Information

The exterior design of a building requires that the architect consider such practicalities as economy, availability, handling, attachment, insulation, maintenance, and fire resistance of the material used for structure and/or enclosure. The suitability of concrete in all these respects has been proven. Moreover, where there is no limiting factor, such as the importance of vertical continuity in a high structure, the use of pre-cast concrete is justified.

In most cases appreciable cost savings can be effected by in-plant fabrication, compared with on-the-job construction of concrete. Casting in a plant also permits better control and more efficient curing of the concrete resulting in a finish of higher quality than that of poured-in-place concrete. In addition, expediting delivery time of the finished product can cut weeks off the erection time of the structure and thus save even more money for the investor. (1)

The following is a brief description and analysis of three buildings which employ the principle of a pre-cast concrete structural facade.

(1) Roy L. Peck, "Three Dynamic Factors in Concrete's Future", Modern Concrete (May, 1962), 41-47
BUILDING  
Banque Lambert

ARCHITECT  
Skidmore Owings and Merrill

NUMBER OF FLOORS  
9

FLR TO FLR HEIGHT  
11' - 1/4"

BAY SIZE  
30' x 30' (Approx.)

STRUCTURAL FRAMING  
Concrete

STRUCTURAL FACADE  
Pre-Cast Concrete

SPAN TO INTERIOR SUPPORT  
Varies from 15' to 35' (Approx.)

STRUCTURAL MULLION SPACING  
5'

WINDOW  
Set Back from Structural Facade

MECHANICAL SYSTEM  
A combination of natural ventilation with fin tube radiators under peripheral windows, and tempered fresh air from ducts located above corridor ceilings.

REMARK  
See following explanation

- 11 -
Banque Lambert

The exterior pattern is a structural grid which carries all floor loads transmitted to it. The structural unit is a pre-cast reinforced concrete "cross" placed at modular intervals of 1.5 meters around the periphery of each typical floor. The vertical legs of each cross are tapered to a point halfway between floor and ceiling lines. At this point, the crosses are pinned together with a stainless steel connection. The horizontal bar of the cross acts both as spandrel beam and as formwork to receive the floor slabs which were poured against it on the job.

Comments

The most obvious fault of this building is that it has the same expression on all four elevations implying, since it is a structural facade, that the loading conditions at the periphery are the same. This is not so. The structural crosses on the short sides of the building carry less than half the load acting on the crosses of the long sides. (See column location on following drawings.)

One other point, though it is not a fault in the structural concept, should be made concerning the connection
between the vertical legs of the crosses. While the narrow waisted columns do express the flow of structural stresses - the column's bending moment is greatest at the spandral beam, smallest at the waist - the resulting exposed steel connection would present problems in the United States. Code restrictions would not permit the connection because of its possible exposure to fire.
<table>
<thead>
<tr>
<th>BUILDING</th>
<th>College of Education, Wayne State University</th>
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<td>ARCHITECT</td>
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<table>
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<tr>
<th>NUMBER OF FLOORS</th>
<th>FLR TO FLR HEIGHT</th>
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<tr>
<td>5</td>
<td>11' - 5&quot;</td>
<td>52' clear span</td>
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<td>from &quot;core&quot; area</td>
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**STRUCTURAL FRAMING**

Poured-in-place and pre-cast, pre-stressed concrete

**SPAN TO INTERIOR SUPPORT**

52'

**STRUCTURAL FACADE**

Pre-cast concrete

**STRUCTURAL MULLION SPACING**

5'

**WINDOW**

Integrated with structural "trees"

**MECHANICAL SYSTEM**

Fan coil unit at periphery (?)

**REMARK**

See following explanation
This building's perimeter is a multiple of modular units three stories high, with one-story high units at the fourth and fifth floor levels. These modular "trees" are repeated around the perimeter of the building.

The interior structure is a combination of poured in place concrete and pre-cast pre-stressed concrete. Portions of all floors are framed with pre-cast pre-stressed double tees which span fifty two feet. The entire central core area is framed using a conventional poured in place system of beams, columns and slabs. The core extending through the height of the building provides a rigidizing anchor and bracing for the rest of the pre-cast concrete structure.

Comments

This building, considering its structural clarity, is far inferior to the Banque Lambert. The pre-cast trees only carry the load from a strip about 5 ft. wide around the periphery of the building and are merely "frosting on the cake". These "trees" are also weak in concept because the lateral connection is difficult. (Since shearing forces require a certain depth at the point where the "T" is formed
the attempt to minimize its length at the joint between units results in an expression sadly reminiscent of "steamboat Gothic".) However, these "trees" do constitute a structural facade and are included in this report because they show that a pre-cast unit need not be limited to one story in height, but can go as high as three or four using certain construction procedures.

These procedures have been more thoroughly discussed on page 27.
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<td>Integrated with</td>
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<td>structural frame</td>
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<td>MECHANICAL SYSTEM</td>
<td></td>
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<tr>
<td>Single duct high velocity</td>
<td></td>
</tr>
<tr>
<td>system (?)</td>
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<td>REMARK</td>
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- 21 -
The structural system is an integration of cast-in-place, pre-cast, and pre-cast pretensioned concrete components.

Office areas, which are column free loft spaces, have walls of pre-cast concrete structural units which carry the pre-cast pretensioned floor beams, and also serve as window frames. Continuity between the frames was achieved by a poured concrete filler and dowels extending between the upper halves of the 10' x 25' framing units, while the lower halves hold supply air ducts.

These pre-cast structural units have hard smooth surfaces made possible by the use of steel forms and intense vibration of the mix. (To insure proper weathering, flat surfaces were avoided.)

Comments

The structural expression of this building is probably the most honest of the examples given. Its space is created by a one-way span and the exterior expresses exactly that. Here again the use of a multi-story pre-cast unit is made possible by the construction procedure which enables the
unit to be put in position and held securely with a minimum of effort. (See discussion of this technique on Page 27.)

The most disturbing feature of the structural unit is the exposed metal sheet which covers the air supply duct running between the units at the lower level.
1 Air-distribution vertical duct
2 Precast-concrete unit 10' x 25'
3 Air-distribution horizontal duct
4 Air return
5 Air-return shaft
6 Fresh-air intake
7 To air filters
Analysis

While these examples show the feasibility of a pre-cast concrete structural facade for low buildings, they are by no means complete in their representation of the different techniques that have been used or proposed. Therefore, a brief discussion of the remaining techniques will be necessary in order to familiarize the reader with them and to establish some basis for the choice of one system over the others.

Thus far, the "cross", the "T", and a variation of the rectangular frame have been illustrated and described. Two other basic approaches remain: the "H" frame and the simple rectangular frame.

The "H" Frame - This system has some of the same problems associated with the "T" inasmuch as the lateral connection is difficult. It has a further disadvantage in its joint rhythm which is irregular. (They alternate between units.)

The Rectangular Frame - This system, while the most obvious, also seems to be the most logical. However, it does present some difficulty in obtaining vertical continuity.
Generally speaking, all of the techniques described can be done in single or multi-story units. However, with multi-story units the assembly of the building must be able to proceed faster since the frame develops critical forces in the vertical members until the bracing effect of the floor is realized. This eliminates a poured-in-place floor construction and a pre-cast pre-stressed system becomes mandatory. A multi-story frame also requires over designing in a sense, because the stresses introduced by handling are far more critical than the stresses caused by the loads acting on a member completely positioned.

A system in which the units have been vertically staggered has also been used, but it creates problems at the corner and makes the use of other pre-cast elements necessary in order to fill the gap between the actual frames.
and minimize the effects of weathering by reducing the amount of concrete to be seen in one plane.

The glass is set deep within the frame and extends from floor to ceiling in order to take full advantage of natural lighting whenever possible. Although it might have been more economical to reduce the amount of glass and thus lower the heating and cooling loads the mechanical system has to overcome, the additional loads caused by the large glass area are far from critical in this instance because of the building's size - 144,000 sq. ft. vs. 800,000 sq. ft. typical for high rise office building
IV. Structural Concept of the Building

The building will consist of 5 stories (including the basement) and will have a gross area of 28,800 square feet (120' x 240') per floor. The upper three floors are to be supported and enclosed by means of a structural facade where the span between the facade and the next interior support is equal throughout. This, however, creates a critical condition at the corner panel of the floor slab and is inherent with the system when it is properly employed. At this point a "critical rib" is assumed to take one fourth of the live and dead loads from the corner panel of the slab and distribute it to adjacent ribs. The load which this critical rib is assumed to take determines the uniform depth of the floor structure. (See diagram on p.39.) This depth could have been reduced by using pre-stressed concrete, but this was thought to be unnecessary and uneconomical since the floor to floor height is not as critical as it would be in a high rise building.

Another problem of the structural facade arises at the base of the building. Having established a tightly scaled, highly efficient system, how is the ground level opening to be treated? That an interruption of the system is indefensible in purely economic terms should be obvious, but for
both esthetic and practical reasons, an open base may be desirable. In any case, concentrating the effort of spanning a large ground floor bay is distinctly advantageous to spanning that bay in every floor. The open base has therefore been chosen as the method of terminating the facade, and the calculation for its design will be found on page 48.

The structural facade will consist of pre-cast and poured-in-place posts which act integrally. The poured-in-place portion is located in the void provided at the vertical joint of the pre-cast frames, and their integration is achieved by means of lateral ties. These ties are anchored in the legs of the pre-cast frames and are bent around the compressive reinforcement of the poured-in-place concrete. Since the reinforcement of the poured-in-place portion of the post has been designed to take all of the compressive forces to act on it, the vertical reinforcement in the pre-cast frame is thus "extra" and can be counted on to take any bending which might occur.

Vertical continuity of the posts is achieved by continuing the main reinforcement into the post above the distance necessary for proper reinforcement "lapping".

Four interior columns, running through the full height
of the building, occur between and in line with the walls of the structural cores. The columns are thus positioned so as to correspond to the span from the core wall to the exterior supports.
V. Mechanical Concept of the Building

Heating, cooling, and ventilation of the building is to be accomplished by an "indirect system" which calls for the compressors, condensors, and hot water generators to be located in the basement with the cooling towers located on the roof. Air which has been properly conditioned in the basement is then distributed to the mechanical rooms at each floor located at opposite ends of the building.

Each floor has been divided into two zones - exterior and interior - each of which requires a different kind of mechanical system. Calculations of the heating and cooling loads for these zones established that an "airfloor system" could be used. (Another possibility would have been to locate the necessary ductwork between the bottom of the floor slab and a hung ceiling, but this was eliminated since it was desired to expose the "waffle" of the slab.) The airfloor is located on top of the structural floor and consists of 5" void, which can be baffled to provide direct supply or return of air, and a 3" top slab which rests on adjustable vertical supports.

Interior Zone

Conditioned by an all-air low velocity single duct system which is fed through the plenum created by the air-floor and diffused through combination air diffusers and light fixtures.
Exterior Zone

Conditioned by an all-air high velocity single duct system with terminal reheat. (1) The air for this system is also fed through the plenum created by the airfloor and is diffused through the floor at individual units located in a continuous line under the windows. The flexibility necessary for this system to operate effectively is achieved by providing a thermostat for every four units which will control the temperature of the supplied air by limiting the amount of it to be passed over the coil.

Return Air

Air will be returned by means of ceiling diffusers which are located so as not to interfere with the supply diffusers and will be integrated with the lighting also. A portion of this air is to be brought back to the main circulating fans while the rest is exhausted directly from shafts located at roof level.

Electricity

All wiring for power and telephone requirements will be located in the electrical "cells" incorporated in the airfloor.

(1) The terminal reheat in this system will consist of a "coil" which can be fed with hot or cold water.
VI. CONSTRUCTION PROCEDURE

The Pre-cast Frame

A. Number of Forms

The number of forms to be used depends on the amount of time available for pre-casting. The ideal situation is to have the number of forms which will allow them to be "written off" because of the number of times they would be used. A rough estimate of the number of forms required in this particular instance would be about eight, figuring on fifty four castings per form. This would also allow eight frames to be produced every 24 hours.

B. Type of Forms

The type of form used, in most cases, depends on the pre-cast plant. Some plants have their own form shop, while others prefer to have the form fabricated somewhere else. In any case, the form would probably be made of steel or wood.

C. Method of Pouring

The frames would be cast face down using "finished surface" concrete through out, rather than a "composite" pour.
D. Handling

The handling procedure will vary according to plant setup also. It is conceivable that two sets of hooks will be necessary for this purpose - one would be required for handling in the plant and shipping, while the other would be required for erection purposes.

The Floor

The 5' x 5' waffle of the floor will require that special pans be made. The number of pans necessary would be that number which would allow one half of the floor to be poured at once. Each pan would then be used about ten times and would also be within the limits dictated by economy.

Connection of Frames to Floors

At the first floor, the frames will be positioned on the edge beam, (which is to have the same detail at its top as the pre-cast frames) and welded to the vertical reinforcement provided. Forms for the floor above are then put into place and filled with concrete after the required reinforcement has been properly positioned.
VII. CALCULATIONS
Chicago Building Code

Minimum uniformly distributed floor live loads:

Business Units ... Offices - 50 lbs./ft.²
Lobbies - 100
Corridors - 75

Reduction of uniformly distributed floor loads:

Permitted live load reductions:

Columns - 2 floors = 80%
3 = 75
4 = 70

No reductions of roof loads permitted
Permitted reduction for floor of more than 300 sq.ft. = 85%
ANALYSIS OF CRITICAL "WAFFLE" JOIST

DIAGRAM OF CORNER CONDITION LOADING

KEY: ——— = Critical Joist

△ or △△ = Total Loading on Critical Joist

= Joists Assumed to Take Critical Loading
ANALYSIS OF CRITICAL "WAFFLE" JOIST

LIVE AND DEAD LOAD CALCULATIONS

Assume Depth of Slab = 27 in.

Wt. of Stem = 2.0 x .83' x 40' = 66.5 ft.³ x 150 lbs./ft³ = 10,000 lbs.

Wt. of Horiz. Stem = 2.0 x .83' x 28.7' = 47.5 x 150 = 7,120

Wt. of Top Slab = .25' x 5' x 40' = 50 x 150 = 7,500

Wt. of A/E Floor = .25' x 5' x 40' = 50 x 150 = 7,500

Total Dead Load = 32,120

Wt. of L.L. = 60 lbs./Ft.² x 5' x 40' x .85* = 10,200

Total L.L. + D.L. = 42,320 per Joist

Total L.L. + D.L./ft.² = 210

* Allow L.L. Reduction from Building Code
ANALYSIS OF CRITICAL "WAFFLE" JOIST

Equivalent Uniform LD/lin FT. Due to Triangular Loading

\[ \frac{WS}{3} = \frac{210 (40)}{3} = 2,800 \text{ lbs./lin. Ft.} \]

Since: It is assumed that 4 joists will support triangular load, let triangular loading = \( W \), where

\[ W = 2,800 \times 40 = 112,000 \text{ lbs.} \]

Problem: How is \( W \) distributed to 4 joists?

Resolve \( W \) into force \( W \) + Moment \( M \) Thus:

Resolve \( W \) into force \( W \) + Moment \( M \) Thus:

\[ W \]

\[ W + M \]

\[ \frac{W}{4} + \frac{W}{4} \]

\[ +3F + F - F - 3F \]

\[ \text{The force/joist} = \frac{W}{4} + \text{Effect of } M \]

Where the effect of \( M \) = +3F, +F, -F, -3F

Solving for \( F \):

\[ 3F \left( \frac{68}{2} \right) + F \left( \frac{25}{2} \right) = W \left( \frac{28}{2} \right) \]

\[ 10FS = \frac{3WS}{2} \]

\[ F = \frac{3W}{20} \]

- 41 -
ANALYSIS OF CRITICAL "WAFFLE" JOIST

Force on Critical Joist = \( \frac{W}{4} + 3F \)  
(Due to Triangular L.D.)  
\[ = 28,000 + 50,400 \]  
\[ = 78,400 \text{ lbs.} \]

Total force acting on critical joist = \( 78,400 + \frac{\text{Wt. of 1 joist}}{2} \)  
\[ = 78,400 + 21,160 \]  
\[ = 99,560 \text{ lbs.} \]

Since: Shear force will govern design (from previous calculations) determine dimensions of critical joist webb to take shear force.

Shear force = \( \frac{5wl}{8} \)  
(Critical at Core)  
\[ = 62,100 \text{ lbs.} \]

Area of Web = \( \frac{b'd}{240 \times .875} \)  
(Req'd)  
\[ b'd = 295 \text{ in.}^2 \]

Area of Web = \( 27 \times 11 = 297 \text{ in.}^2 \)  
(Actual)  
\[ \therefore \text{O.K.} \]
ANALYSIS OF CRITICAL "WAFFLE" JOIST

Negative Moment at Core Wall = $\frac{WL^2}{8}$

= $\frac{2490 \times 1600 \times 12}{8}$

= 6,000,000 in. lbs.

Moment Safely Taken by Concrete = $Kbd^2$

= $313 \times (11) \times (27)^2$

= 2,500,000 in. lbs.

... Compressive steel necessary.

Moment to be Taken by Compressive Steel = 6,000,000 - 2,500,000

= 3,500,000 in. lbs.

Reg. $A_s = \frac{3,500,000}{810,000}$

= 4.32 in.²

Use 2 #10s and 2 #9s

Moment to be taken by tension steel = 6,000,000 in. lbs.

Reg. $A_s = \frac{6,000,000}{810,000}$

= 7.4 in.²

Use 3 #11s and 3 #9s
ANALYSIS OF CRITICAL "WAFFLE" JOIST

Positive Moment

\[ \frac{9 \frac{WL^2}{128}}{128} \]

\[ = \frac{9 (2490)(1600)}{128} \times 12 \]

\[ = 3,360,000 \text{ in. lbs.} \]

Reg. \( A_s = \frac{3,360,000}{810,000} \)

\[ = 4.15 \text{ in.}^2 \]

Use 4 \#9\(_s\) and 1 \#6

Web Reinforcement for Shear

Amount of Shear taken by concrete of joist web:

\[ 11 \times 27 \times .875 \times 90 = 23,400 \text{ lbs.} \]

Force Stirrups must Resist:

\[ V_1 = V - V \text{ of concrete web} \]

\[ V_1 = 62,100 - 23,400 \]

\[ V_1 = 38,700 \text{ lbs.} \]

Distance over which stirrups must be provided:

\[ \frac{38,700}{62,100} = \frac{X}{20} \]

\[ X = \frac{774,000}{62,100} \]

\[ X = 12.5' \text{ or } 12' - 6'' \]
ANALYSIS OF LATERAL RIB

Force Acting on Lateral Ribs Due to Force on Critical Joist
\[
\frac{W}{4} + 3 \left( \frac{3W}{20} \right) = \frac{14W}{20}
\]

Force Acting on 1 Lateral Rib = \( \frac{14W}{20} \times \frac{1}{7} \)
\[
\frac{14(112,000)}{140} = 11,200 \text{ lbs.}
\]
O.K. since web is sufficient to carry 23,400 lbs. shear force in concrete alone.

Moment Resistance of Lateral Rib:

Force acting on typical lateral rib spanning between critical and its adjacent joist = 11,200 lbs. (at critical joist)

Force acting on typical lateral rib spanning between critical and its adjacent joist
\[
= \frac{W}{4} + \frac{3W}{20} \times \frac{1}{7} = \frac{8W}{140}
\]
\[
= 6,400 \text{ lbs. (at adjacent joist)}
\]

Difference in forces acting on critical lateral ribs:
\[
11,200 - 6,400 = 4,800
\]

\( M_{\text{Max}} \) due to this load:
\[
M_{\text{Max}} = .1283 \frac{WL}{L} \text{ (since uniformly decreasing load)}
\]
\[
= .1283 \times (4800) \text{ 48 in.}^* 
\]
\[
= 29,650 \text{ in. lbs.}
\]
* Clear distance between joists.
ANALYSIS OF LATERAL RIB

Required $A_s$ at this point:

$$M_s = A_s \times (30,000) \times (27)$$

$$A_s = \frac{29,650}{810,000}$$

$$A_s = 0.04 \text{ in.}^2$$

Therefore it is safe.
DESIGN OF CRITICAL POST

Total load acting on critical post \( = 107.4 + 2.32 \)
\[ = 109.7 \text{ or } 110 \text{ K} \]

Determine if Post should be designed as long or short column:
\[ h = 12' - 6" \quad h = \frac{150"}{10.5} = 14.3 \]

\[ . \ . \ \text{Design as long column.} \]

Find corrected P Value:
\[ 110 = P (1.3 - .03 \times 14.3) \]
\[ \frac{110}{.87} = P \]

\[ 126 = P \]

Load acting on Post = 126 K
Load carried by Concrete = 113
Load carried by Steel = 13

Absolute Minimum Load to be Carried by Steel:
\[ .008 (20,000) 66 = 10.6 \text{ Less than } 13 \text{ O.K.} \]

Req'd \( A_s = \frac{13,000}{16,000} \)
\[ = .81 \text{ in.}^2 \]

Use 2 #6s, \( A_s = .88 \)
DESIGN OF EDGE BEAM

Load acting on beam at 5'-0" intervals = 12,050 (Due to D.L./Fl.)
Load acting on beam at 5'-0" intervals = 3,375 (Due to L.L./Fl.)

Roof Load = 16,600
4th Floor Load = 15,500
3rd Floor Load = 15,500
2nd Floor Load = 15,500
D.L. of Posts = 3,500

Total Load = 63,600 lbs. (acting every 5')

Equiv. Unif. LD/LIN FT. = \( \frac{63.6}{5} \) = 12.7 K

Uniform design Load (including Wt. of Beam = 13 K/FT.

Negative Moment = \(-0.096 (13)(38)^2\)
= 21,600,000 in. lbs.

Positive Moment = \(0.057 (13)(38)^2\)
= 12,840,000 in. lbs.
DESIGN OF EDGE BEAM

Determine Dimensions of Beam

\[ M_c = Kbd^2 \]
\[ 21,600,000 = 313 \left( \frac{d^3}{2} \right) \]

52 in. = \( d \quad \Rightarrow \quad b = 26 \)

Try Making Beam 48 x 20

\[ M_c = 313 (20) (2304) \]

14,400,000 in. lbs. .. Compressive Steel Necessary

Force to be Taken by Compressive Steel

\[ 21,600,000 - 14,400,000 = 7,200,000 \]

Req'd \( A_s = \frac{7,200,000}{1,440,000} \]

\[ = 5.0 \text{ in.}^2 \]

Use 5# 8s & 2 #7s, = \( A_s 5.15 \text{ in.}^2 \) Minimum Web Width = 16 in.

Req's \( A_s \) for Negative Moment

\[ 21,600,000 = 30,000 (48) A_s \]

\[ \frac{21,600,000}{1,440,000} = A_s \]

15 in.\(^2\) = \( A_s \)

Use 6 #11s & 6 #9s, \( A_s = 15.36 \)

Req'd \( A_s \) for Positive Moment

\[ \frac{12,840,000}{1,440,000} = A_s \]

8.9 in.\(^2\) = \( A_s \)

Use 4 #10s & 4 #9s, \( A_s = 9.08 \text{ in.}^2 \)

Compressive steel for positive moment is not necessary.
Assume exterior column dimensions = 20 x 20

Total load acting on column = 455 K (Critical)

Load acting on concrete = 360 K

Load to be carried by steel = 95 K . O.K.

Using steel where $f_s = 20,000$ the number of bars required is:

10 #7"
Since a change in the size of an interior column would require a corresponding change in the waffle pan size, the interior columns will maintain the same dimension throughout the building.

**Design of First Floor Column**

Total loads acting on column
- 252,000 Roof
- 252,000 4th Fl.
- 252,000 3rd Fl.
- 168,000 2nd Fl.

Total 924,000

Assume 28 x 28 column

Load acting on column = 924 K

Load acting on concrete = 706 K

Load to be carried by steel = 218 K O.K.

Use 14 #9s
### Design of Basement Column

<table>
<thead>
<tr>
<th>Load Location</th>
<th>Load (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>252,000</td>
</tr>
<tr>
<td>4th Floor</td>
<td>252,000</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>252,000</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>168,000</td>
</tr>
<tr>
<td>1st Floor</td>
<td>252,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,176,000</strong></td>
</tr>
</tbody>
</table>

Assume 28 x 28 column

<table>
<thead>
<tr>
<th>Load Type</th>
<th>Load (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load acting on column</td>
<td>1,176 K</td>
</tr>
<tr>
<td>Load acting on concrete</td>
<td>706 K</td>
</tr>
<tr>
<td>Load to be carried by steel</td>
<td>470 K</td>
</tr>
</tbody>
</table>

.* use 20 #11s
DESIGN OF STRUCTURAL WINDOW FRAME

ELEVATION OF FRAME ON ITS SIDE

PLAN OF TOP OF FRAME

DESIGN FRAME AS A BEAM WHERE:

\[ a = 9'' \text{ and weighs } 560 \text{ lbs.} \]
\[ b = 24'' \quad \text{955} \quad '' \]
\[ b' = 30'' \]
\[ c = 5'' \quad \text{87 lbs./ft} \]
\[ d = 9'-9'' \]
\[ e = 12'-0'' \]
\[ f = 6'' \]
\[ g = 21'' \]

TOTAL WEIGHT OF 1 FRAME = 2320 lbs.

\[ M \text{ at } 6'' = \frac{-560 \times 4.5}{2} = -2530 \text{ in.-lbs.} \]
\[ M \text{ at } 6'-0'' = \frac{-560 \times 4.5 + 950 \times 66 - 87 \times 5.25 \times 31.5}{10,600} = -8595 \text{ in.-lbs.} \quad \text{CRITICAL} \]
\[ M \text{ at } 10'-3'' = \frac{-955 \times 9}{2} = -8595 \text{ in.-lbs.} \]

Determine req'd depth of concrete to handle critical moment.

\[ M_c = k \times b d^2 = 238 \times (13) d^2 \]
\[ 1.86'' = d < 5'' \quad \therefore \text{O.K.} \]

\[ M_s = A_s f_s j d = A_s (30,000)(.896)(9) \]
\[ .079 = A_s \]

* USE K FOR 3750 CONCRETE SINCE THIS FORCE WILL OCCUR BEFORE THE CONCRETE HAS BEEN CURED TO ITS 5000 VALUE.

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