A PROTOTYPE FLOOR STRUCTURE

by

Bruce E. Erickson

B. Arch., University of Minnesota, 1958

SUBMITTED IN PARTIAL FULFILLMENT OF
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Submitted in partial fulfillment of the requirements for the degree of Master in Architecture in the Department of Architecture on August 19, 1960.

Abstract

The focus of this investigation is the integration of a floor structure, mechanical services, and all its related aspects with an architectural realization. A prototype floor structure of a given span and specific architectural conditions was chosen because of its broad architectural implications.

In approaching the investigation, three systems are considered as possible solutions. Study No. 1 has a simple concrete joist as the primary structural system supporting a secondary structure made up of concrete tables. Study No. 2 is an outgrowth of the criticisms of Study No. 1. The final proposal, Study No. 3, integrates precast structural core units with mechanical, acoustical, partitioning, and electrical considerations.

A modular breakdown of the floor system is determined to fit certain span and partition requirements, as well as, construction methods. A structural analysis is given providing floor depth, unit sizes, and details. The type of material investigated is reinforced concrete.

August 19, 1960

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 Prototype Floor Structure".

Respectfully,

Bruce E. Erickson

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I should like to thank the
following for their advice and criticism
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and

Members of the Thesis Committee

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Preface

The Master's Thesis offers the opportunity for a shift of emphasis, where the need is not to paraphrase architectural practice directly, but to investigate design areas independent of any specific client. Our present day professional practice, due to various related economic needs, prevents us from any prolonged thorough investigation of the design implications emerging from our rapidly changing technology. Therefore, this investigation will consist of creative work given a definite direction of study. The most important aspect of a detailed investigation is that it continues indefinitely, and increases in significance by future research.

Therefore, the developement of a prototype structure may have a value that is not gained when doing a specific design problem. A concentrated effort can be placed on details or design implications which offer general answers and applications of a broader significance. The results may not be as specific as when dealing with a unique design problem, but can be applied generally to the problem of mechanical flexibility and with the integration of all its involved aspects within a building system.

The increased need for flexibility and the general disregard for specific space relationships within a building system are a constant challege to the architect as building and expansion needs undergo rapid changes. At the present time, the idea of component or systemitized construction is being received with considerable interest by builders and manufacturers of building products. In architectural terminology, a component is merely a larger part of the construction manufactured away from the site. Because the component is a large part and is fabricated usually away from the site, it must be designed and engineered to fit the other components. The use of components therefore, requires a total system of construction. This system in turn must be related to the entire construction process so that the installation time of the components will be reduced and best serve the building function.

Adopting a greater degree of shop fabrication is obviously the most efficient use of labor and materials to provide economic construction. This method of construction is analogous in many respects to the techniques used by manufacturers for the mass production of other finished products. Today' s building technology not only demands a system of mass production, but also needs a control over unacceptable workmanship. These factors increase the need for creating a repetition of building components, based on a structural and modular order, that can be fabricated under shop supervision.

The problem of producing a floor system which will accomodate the flexible requirements of present day buildings as well as the many aspects of mechanical, electrical, and acoustical needs, raises an interesting architectural question.

Design Criteria

I. Building Type

In order to proceed logically with definite points of departure, and with realized design limits, specific architectural conditions can suggest spacial requirements as well as mechanical, lighting, and acoustical requirements. In educational buildings, a large variety of spacial requirements must be fulfilled. Classroom units require approximate areas of from 40' x 40' spaces to one half this size, 20' x 20'. In considering an intermediate 8' corridor for the two small classroom areas, or an 8' adjacent corridor for the 40' spaces, the span range is 28' to 48'. For a greater degree of flexibility, the larger span of 48' would be used. Offices and secretarial areas can also be worked into these span conditions. A typical solution is shown on pages 43 - 48. The problem of a geometrical unit or module must also be considered. Here a 4' module is preferred to create room sizes of the gradient, 8' - 12' - 16' - etc. This module would also solve some lighting considerations as shown in graphic form.

II. Quality of Space

The quality of an educational space should be conducive to good sound control, group activity and participation, plus aesthetically pleasing. Finishing materials of a hard, rugged character will reduce maintenance costs, and preserve the original finish of the walls, floors, and ceilings.

III. Structural System

The system used to form the floor structure should be uniform in size, method of installation, and function. This uniformity could be achieved throughout the entire floor structure by the use of component parts or a systematic ordering of all the structural units. A structural unit with standard components, carefully designed to accomodate the various services, could also provide an order of construction.

IV. Method of Partitioning

The ceiling surface of the floor structure should accomodate the greatest flexibility in partition placement. These partitions would be placed in accordance with an established floor module. A standard detail developed for the juncture of partitions and structure operating independently of partition material would allow a side use of wall materials without limiting the effective simplicity of the structure. The structure should encourage the developement of regular, simple, and economical partitions.

V. Lighting

Integrated into the surface geometry, the artifical lighting would be given the flexibility to perform with uniform effectiveness in various work areas. Standard lighting equipment would be accomodated in the surface geometry of the ceiling.

VI. Mechanical Equipment

A. Heating and Cooling

Several important factors affect the introduction of heating or cooling equipment into a structure. In the first place, the natural movement of warm air makes the introduction of heat more effective into a space from below. Secondly, a uniform distribution of heat throughout the building would have to take into consideration the complete flexibility of partitioning. Thirdly, the return air system should be taken off at higher levels on the opposite wall from the supply inlet.

B. Plumbing

This is the most difficult item in which to maintain flexibility of location. Plumbing service to every part of the structure is prohibitively costly. However, there is much to be gained from the investigation of a core of plumbing within the building design. In this case the floor system will accomodate only minor plumbing facilities.

C. Electrical

Electrical service should be supplied in a consistent system throughout the structure. Wiring, conduit, junction boxes, and switches should be integrated into the structure and not left for surface installation.

VII. Acoustics

Although it must be realized that classroom use and size should determine the character of acoustical treatment, there is approximate knowledge of usuage that favors integration of acoustical treatment within the ceiling surface. In this way, sound conditioning is relatively free of partition placement. There are factors of reverberation time, flutter, and reinforcement of sound and definite room useage that require the possibility of integrating the acoustical treatment to the ceiling surface. This also provides a relatively free use of partition placement and type.

Studies Leading to Final Proposal

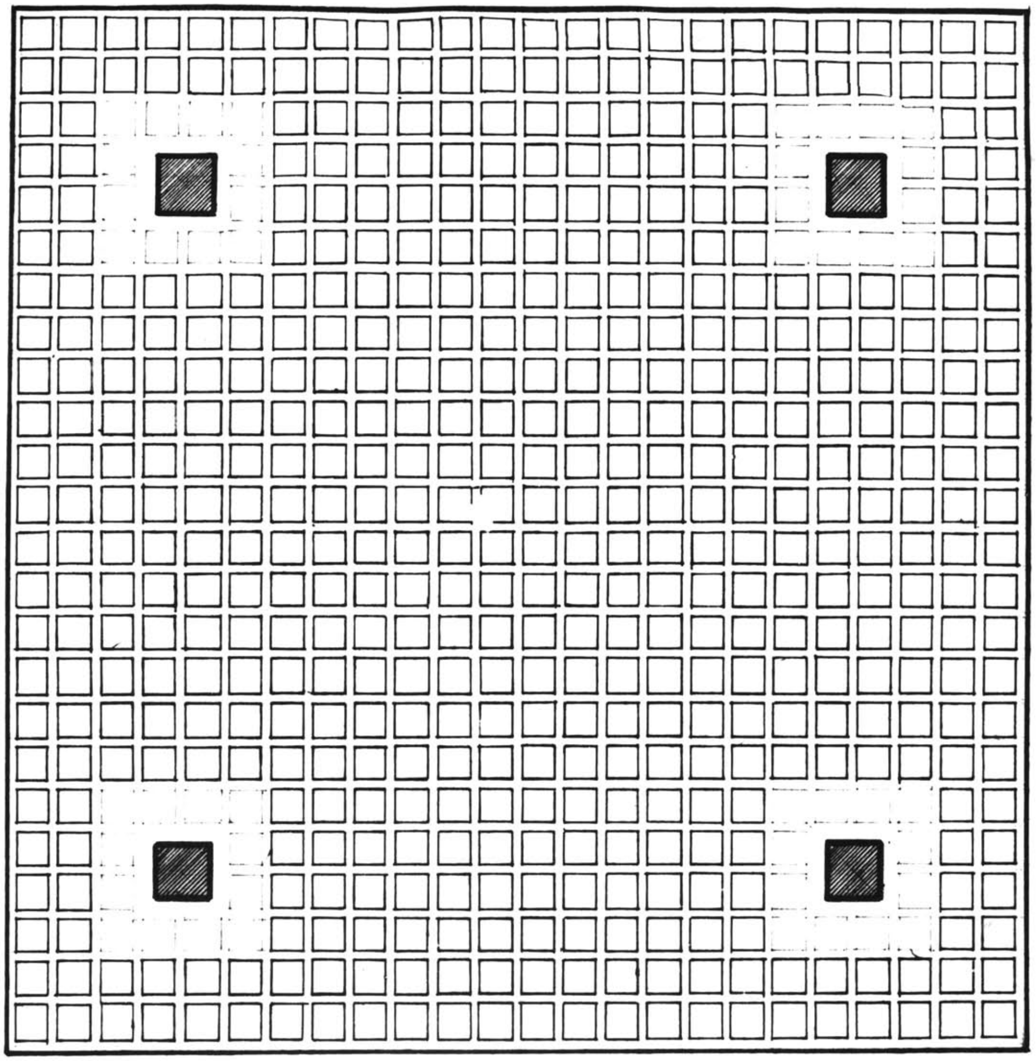
Study No. 1

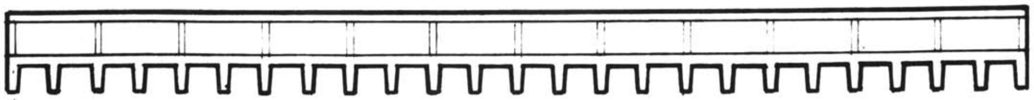
General Description: Study No. 1 is a simple concrete joist with a primary structural system supporting a secondary structure made up of concrete tables. This structural joist system is approximately 2' in depth and the tables are 2' in height giving a 4' total height. The main joist system would be a two way poured in place system (with metal pans as forms) while the secondary system would be a series of 5' x 5' precast concrete tables. This table would form a flat,flare surface and also because of the depth, provide 1'6" mechanical service space. (see drawing) The structure floor would be calculated to take the extra live load of the floor tables. The structural system would be poured with the mechanical system laid on the finished structure floor. This gives the advantage of eliminating scaffolding as the structural floor would provide a good working surface for the mechanical men.

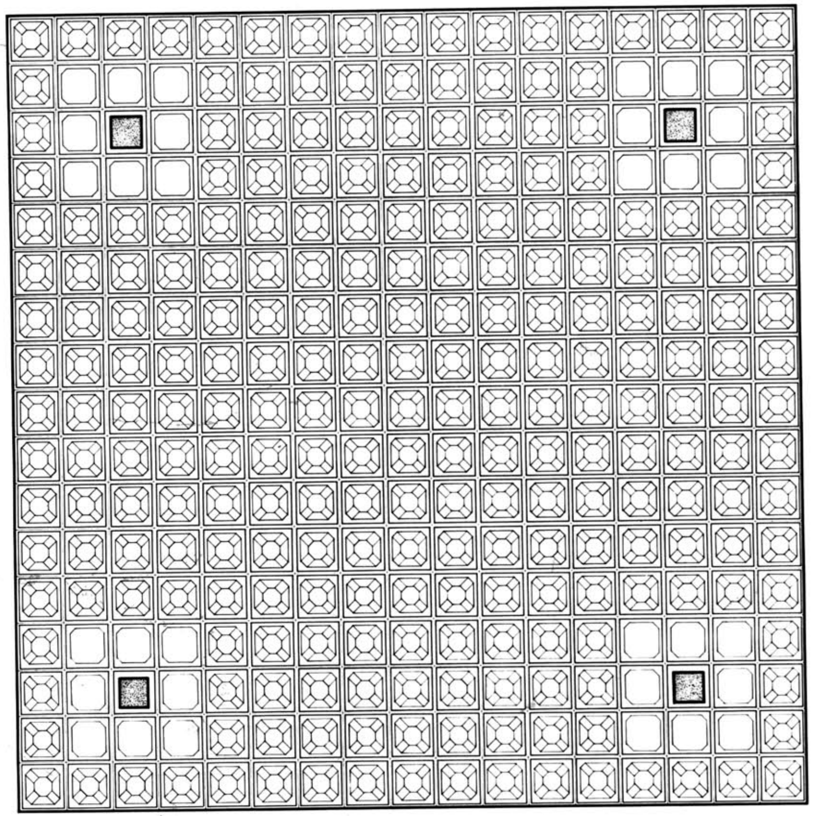
Criticism: The overall depth of the floor is 4' and yet only half of this depth is being utilized, and therefore the full potential of the structural depth is not being realized. The span condition of 48' is going beyond the considered ideal concrete waffle or joist system. The problem of weight of construction is also significant as another smaller modular structure is added on top of the main structural system.

STUDY I.

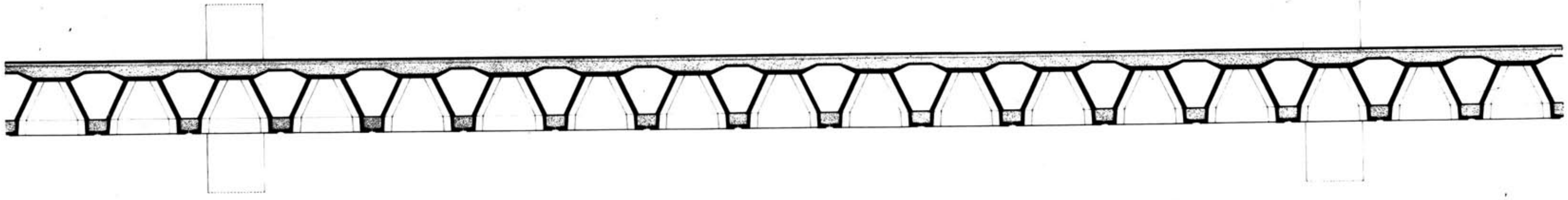
Fig. 1


REFLECTED CEILING PLAN


SECTION



REFLECTED CEILING PLAN
SCALE: 1/4" = 1'-0"



SECTION
SCALE: 1/2" = 1'-0"

Study No. 2

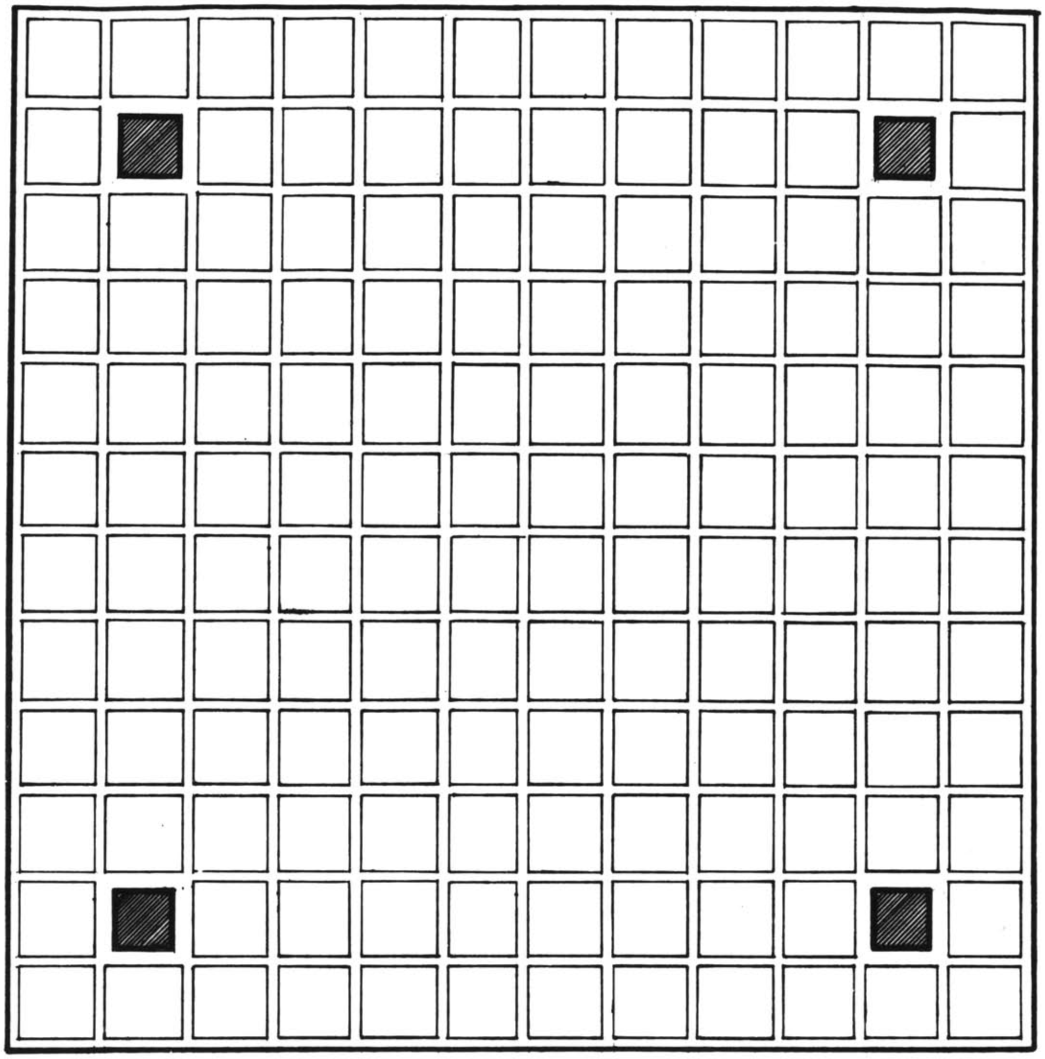
General Description: Study No. 2 (see drawing) is an outgrowth of the criticisms of Study No. 1. Structurally, it is similar to the final proposal and therefore a detailed explanation can be deferred. The method of construction, however, is quite different. A complete concrete grid is poured in place, including short spacer or core columns as in the compression slab. This system brings all the services required for occupation from the ceiling down. The lighting is placed within this structural grid or can be hung below it. Mechanical systems can be run within this open grid system (between concrete slab and tension grid) or within the core. Partitions would be located on the ribs. Acoustical treatment would occur within precast panels formed of wood or cane fibers and placed within this modular grid.

Criticism: Site forming would be difficult and costly, even if the ribs were simplified as shown. Great accuracy would be required to accomodate the acoustical and lighting panels set in place after the grid was completed. The use of a grid system receiving the partition at the structural grid, rejects the system of running services down from the core space within a hollow partition and therefore furred out spaces would be required in partition walls preventing a simple partition system. The open space duct running between ceiling grid and

and compression slab creates a sound control problem. This space has to be plaster-filled when a partition is installed or removed. This factor prevents a clean job of flexible partitioning.

STUDY II.

Fig. 2



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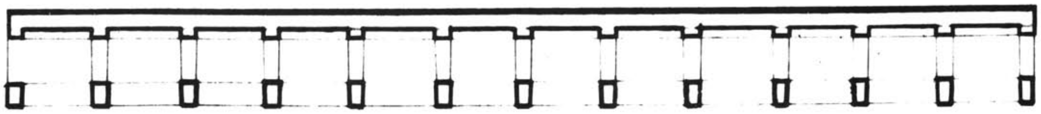
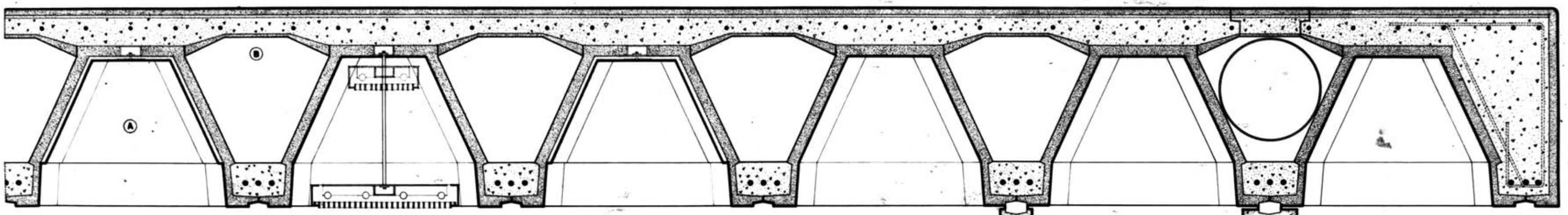
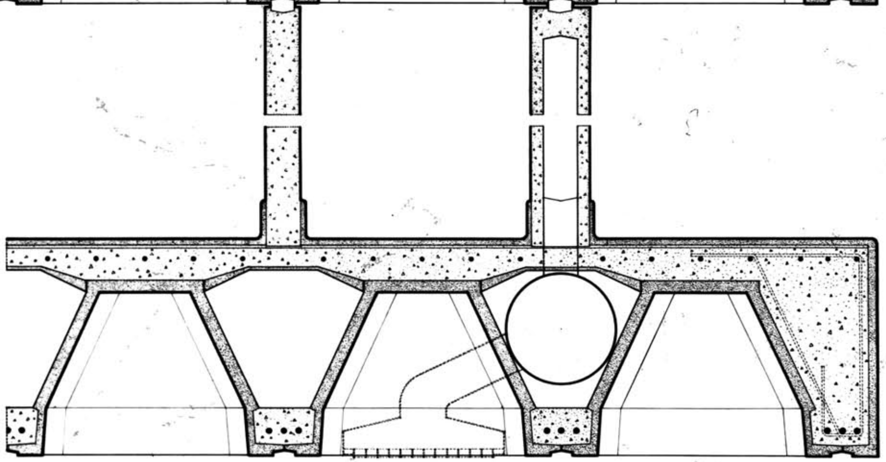
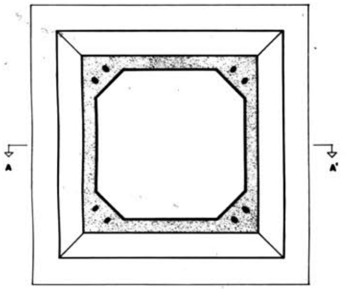


SECTION

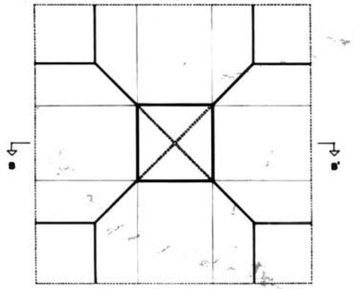




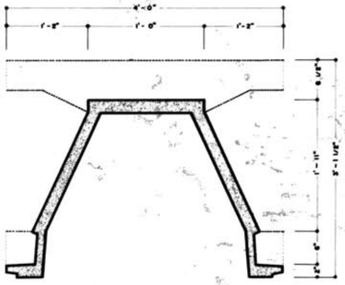
CROSS SECTION
SCALE: 1-1/2" = 1'-0"



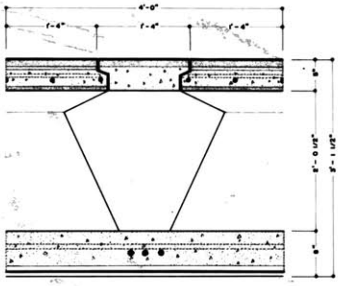
UNIT "A" SECTION DETAIL
SCALE: 1-1/2" = 1'-0"



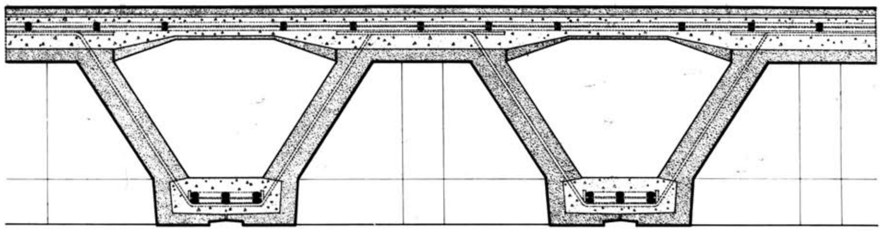
UNIT "B" PLAN DETAIL
SCALE: 1-1/2" = 1'-0"



SECTION A-A'
SCALE: 1-1/2" = 1'-0"



SECTION B-B'
SCALE: 1-1/2" = 1'-0"



DIAGONAL SECTION
SCALE: 1-1/2" = 1'-0"

Study No. 3 - Final Proposal

General Description: The use of a precast component as form work and as a structural core unit, sets this proposal apart from the first two proposals. The core units will complete the form work with no site forming required. Site work will consist of holding the core units in place, placing reinforcement steel, grouting, and pouring compression slab and the finished floor. The precast core units are used consistently over the entire structure with the successful incorporation of all the other services into them. The mechanical duct work is placed before the compression slab is poured. Openings for the duct work or to the duct space for entrance panels are also provided for at this time. The pyramid shape of the core units provide a two way system for mechanical space throughout the structure. The electrical conduit is laid within the compression slab with outlets precast within the core units. Partitions may work on a completely modular system since all core units are identical and receive the partition in the same way over the entire structure.

Structural Explanation: The structural discussion of Study No.3 will deal with the major structural elements: compression, slab, core units, and tension steel. The structural analysis used to define this structural system will consist of two types: the structural sandwich analysis, and the flat slab analysis.

A structural sandwich is a layered construction formed by binding two thin facings to a thick core. It is a stressed-skin construction similar to some prefabricated house constructions in which facings are bonded to spaced stringers or studs. The core of the sandwich is continuous or so nearly continuous that much thiner facing can be used than in stress-skin construction. The basic design concept is to space the strong, thin facings far enough apart with a thick core to assure that the construction will be stiff, to provide a core that is stiff and strong enough to hold the facings flat through a binding medium, and to provide a core of sufficient shearing resistance.

The advantage of spaced facings to provide greater stiffness without much increase in amount of material needed, was investigated in about 1820 by a Frenchman named Duleau. He tested space bolted bars and found the stiffness varied as the difference between the cube of total thickness, and the space between the bolts. This discovery eventually lead to the design of I beams and other stiff structural shapes. The structural sandwich is analogous to an I beam, with the facings carrying direct compression and tension loads as the I beam flanges do, and the core carrying shear loads as the I beam web does.

In order to clarify the term structural sandwich, the American Society of Testing Materials adopted the following

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In order to clarify the term structural sandwich, the American Society of Testing Materials adopted the following tentative definition in 1953: " A lamina construction comprising a combination of dissimilar simple or composite material assembled and intimately fixed in relation to each other so as to use the properties of each to attain specific structural advantages for the whole assembly ".

A flat slab is a concrete slab so reinforced in two or more directions as to bring its load directly to supporting columns, generally without the help of any beams or girders. Beams are used where the slab is interrupted, as around stair walks, and at the discontinuous edges of the slab. The supporting columns may be increased in size near the top to form a column head or column capital. In addition, the slab may be thickened by a drop panel around the column, but many slabs are constructed without the drop panel. The A.C.I. Code also considers " slab with recesses or pockets made by permanent or removable fillers between reinforcing bars " as flat slabs. This includes two way joist systems and the waffle slab.

Flat slabs being thin members are not economical like steel, but they are in their form work. Since form work represents over half the cost of reinforced oncrete, economy of form work aften means over-all economy. For heavy live loads, that is, over 100 psf, flat slabs have been recognized as the most economical construction. In more recent years, flat plate floors have proved economical in apartment house construction in the New York City area. Reduced story height resulting from the thin floor, and the smooth ceiling, all seem to be factors in the over-all economy. Flat slabs, although now widely used throughout the world, are distinctly an American development. Originated by C.A.P. Turner, they were built and sold long before a generally accepted theory of design was developed. Numerous flat slab structures were load tested during the period from 1910 to 1920. These slabs performed well under test loads, in fact so well that there is difficulty in correlating test results with the static moments which were required for equilibrium.

Structural Analysis

Assumptions:

(1) Loading will be assumed as a uniformly distributed load over the entire floor structure.

(2) The edge beam will be employed and designed to take the torsion of the edge condition created when a continuous system is not used.

Design Moments:

The total positive and negative moment required by statics is:

$$M_o = \frac{1}{8} WL \left(1 - \frac{2}{3} \frac{c}{L} \right)^{*}$$

W is the total uniform panel load, L is the span, and c is the diameter of the column capital. This conclusion follows from a static analysis of a half panel. (See Fig. 3, page 33)

For design purposes, the floor panel is divided into two strips in each direction, each strip one half panel in width, as shown in Fig. 4, page 34. Within these strips, average moments are used for design rather than maximum moments. The column strip carries the heavier moments and in design controls the floor depth for moment. The middle strip carries smaller moments, which calls for lighter steel reinforcement. The A.C.I. code sets up a method to establish total negative and total positive moments in each direction, and then to separate these into moments in column and middle strip on the basis of percentages. (See Figures 5,6, pages 35 and 36.) Using the moment given by the code, the total moment is:

$$M_o = 0.09\ WL\ \left(1 - \frac{2}{3}\frac{c}{L} \right)^{*}$$

Shear and Bond Stresses: The horizontal shear within this floor construction is the critical and governing factor of this design study. The shear that occurrs must be provided for by the cross section of the prigmatic units. The shear stress is:

$$u = \frac{V}{.875 \times bd}$$

Where bd represent the cross section areas of the prisms. Diagonal tension around the column capital may determine the depth of the slab required. Hence any opening adjacent to the columns must receive the most careful, and conservative design attention. The bond stresses in this structure are usually not critical if care is taken to extend the straight bars and bent bars beyond the extreme range of three points of inflection and if small enough bars are used to comply with maximum spacing conditions. (See Fig. 7,8, pages 37 - 38)

Steel reinforcement placement sequence:

As in the case of two way slabs, planned sequence for placing the reinforcing steel is necessary to avoid confusion in the field and to insure agreement between actual and assumed effective depth. Fig. 9, 10, pages 39 - 40, give the length of the bar reinforcements for both negative and positive moment conditions.

Calculations

Precast Unit Weight

50 sq. ft. of surface 2" thick

Light weight concrete (fine aggregate)

6 lbs. per sq. ft./inch thickness

600 lbs. per 4' unit

fc = 3000 lbs./in 2

fs = 20,000 lbs./in 2

Floor Loads

Live Load..........	100 lbs. pfs
Structure...........	38 psf - core
	72 psf - compression slab
	36 psf - tension grid
Floor finish........	25 psf
Movable partitions..	15 psf
Total Load.........	286 psf

Column capital diameter

.2L = .2 x 48' - 0" = 9.6' needed

Column capital is 12' diameter

Min. slab thickness = $t = \frac{L}{36} = \frac{4}{3}$

$t = 1.33'$ $t = 1' - 4"$

Floor system is 3' - 2" thick

Deflection

$$t = .028\ L\ (1 - \frac{2\ c}{3\ L} \qquad \frac{w'}{f/c\ /\ 2000} \qquad + 1.5$$

$$t = 1.4\ (\ 1 - \frac{1}{6}\ ) \qquad \frac{2}{3} \cdot 286 \quad + \ 1.5$$

$t = 18.2"$

Structural depth is 3' - 0"

Shear

Vertical section

$W = 644{,}000$ lbs.

$V = 48 \times 48 \times 286 = 644{,}000$ lbs.

$$u = \frac{V}{jbd}$$

Load on column capital = $12 \times 12 \times 286 = 41{,}000$ .bs.

$V = 644{,}000$ lbs. - $41{,}000$ lbs. = $603{,}000$ lbs.

$d = t - 1\ 1/2" = 36" - 1\ 1/2" = 34\ 1/2"$

$b = 17' \times 4 \times 12 = 816"$

$$u = \frac{V}{jbd} \quad \text{or} \quad u = \frac{603{,}000}{.875 \times 816 \times 30"}$$

Capital diameter is 12' therefore perimeter is:

$$4 \times 17 \times 12 = 816"$$

$$u = \frac{603{,}000}{22{,}000} = 28 \text{ psi}$$

Shear

$W \text{ (total)} = 644{,}000$

$\frac{V}{2}$ (two way system) $\qquad \frac{1}{12} \; \frac{V}{2} = \text{unit section load}$

$\frac{1}{24} \times 644{,}000 = 26{,}800 \text{ lbs.} \qquad V_1 = 26{,}800 \text{ lbs.}$

$$u = \frac{V}{.875 \times b''} \times \frac{1}{jd}$$

$$u = \frac{26{,}800}{.875 \times 18''} \times \frac{48}{30}$$

$u = 94 \text{ psi} \times 1.6 = 150$

Allowable for concrete is 90 psi, therefore 60 psi taken by steel.

Bond Stress

$$E_o = \frac{V}{ujd} \qquad E_o = \frac{26{,}800}{120 \times .875 \times 30} \qquad E_o = \frac{26{,}800}{2{,}880} = 9.3''$$

Steel

$$20{,}000 = \frac{26{,}800}{.875 \times A_s}$$

$$(.875)\, A_s = \frac{26{,}800}{20{,}000} \qquad A_s = 1.5 \text{ psf}$$

8 - 1/2" bars give an area of 1.56

Allowable shearing stress is .L25 fc = 75 psi

$$M_o = .09\ WL\ (\ 1 - \frac{2\ c}{3\ L}\ )^{*}$$

$$M_o = 58{,}000 \times 48\ (\ 1 - \frac{1}{6}\ )^{*}$$

M_o = 1,970,000' lbs. or 24,000,000" lbs.

Referring to figure 6, page 36.

1. Column strip, negative moment =

   $.46\ M_o = .46 \times 24{,}000{,}000 = 11{,}000{,}000$

2. Column strip, positive moment =

   $.22\ M_o = .22 \times 24{,}000{,}000 = 5{,}300{,}000$

3. Middle strip negative moment =

   $.16\ M_o = .16 \times 24{,}000{,}000 = 3{,}840{,}000$

4. Middle strip positive moment =

   $.16\ M_o = .16 \times 24{,}000{,}000 = 3{,}840{,}000$

$n = 10$ $\qquad$ $fc = .45\ f'\ c$ = 1,350 lbs. psf

$j = .875$ (actually pertains only to solid slab analysis)

Effective structural depth:

$d = 30''$

$$A_s = \frac{M}{fs\,jd}$$

1. $$A_s = \frac{11{,}000{,}000}{20{,}00 \times .875 \times 30} = \frac{110}{5.2} = 21''^{2}$$

Accept 27 - 1" round bars each direction

2. $$A_s = \frac{5{,}300{,}000}{20{,}000 \times .875 \times 30} = \frac{53}{5.2} = 10.2''^{2}$$

Accept 18 - 7/8" bars each direction

3. and 4.

$$A_s = \frac{3{,}840{,}000}{20{,}000 \times 1875 \times 30} = \frac{38.4}{5.2} = 7.4''^{2}$$

Accept 14 - 7/8 bars each direction

Construction Sequence

I. Site preparation and pouring of the column footings.

II. Columns are either poured in place after the footings are completed, or precast and set in place.

III. Ground or basement slab poured.

IV. Scaffolding for the support of the precast units is erected on the ground floor slab. It may be constructed of either rough lumber or metal, depending on the planned re-uses. There is no form work required.

V. Precast units are set in place on the scaffolding.

VI. Reinforcing bars are placed and grouted between the units as shown in the drawings.

VII. Mechanical ducts, electrical conduits, and plumbing are laid in place between the units.

VIII. The second precast compression slab form is laid in place and the required openings for ducts, and accesses are determined.

IX. The compression slab is poured and the finished floor is laid.

X. The scaffolding is removed.

XI. Lighting and acoustical panels are installed where needed.

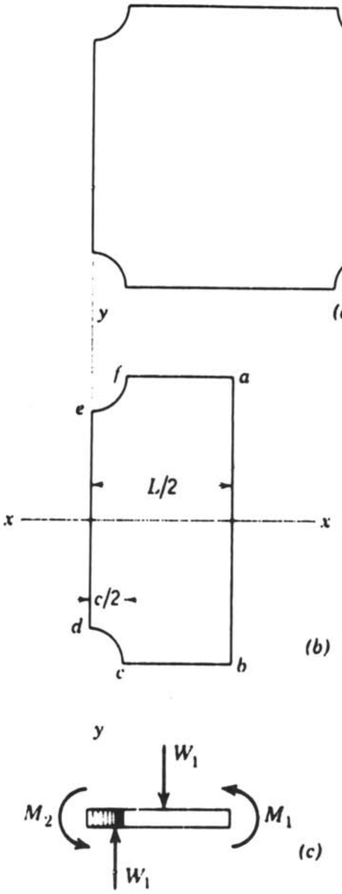


Fig. 3 Equilibrium conditions indicate $M_1 + M_2$ is established by statics.

The moment of this load about axis y-y is:

$$\frac{wL^2}{2} \times \frac{L}{4} - \frac{\pi c^2 w}{8} \times \frac{2c}{3\pi} = \frac{wL^3}{8} - \frac{wc^3}{12}$$

If the upward shear W_1 is considered uniformly distributed around the quadrants cd and ef, the resultant acts at a distance c/π from the y-axis. Equilibrium of moments about the y-axis then gives:

$$-M_1 - M_2 + \frac{wL^3}{8} - \frac{wc^3}{12} - \frac{w}{2}\left(L^2 - \frac{\pi c^2}{4}\right)\frac{c}{\pi} = 0$$

$$M_1 + M_2 = M_0 = \frac{wL^3}{8} - \frac{wc^3}{12} - \frac{wcL^2}{2\pi} + \frac{wc^3}{8} = \frac{wL^3}{8}\left(1 + \frac{c^3}{3L^3} - \frac{4c}{\pi L}\right)$$

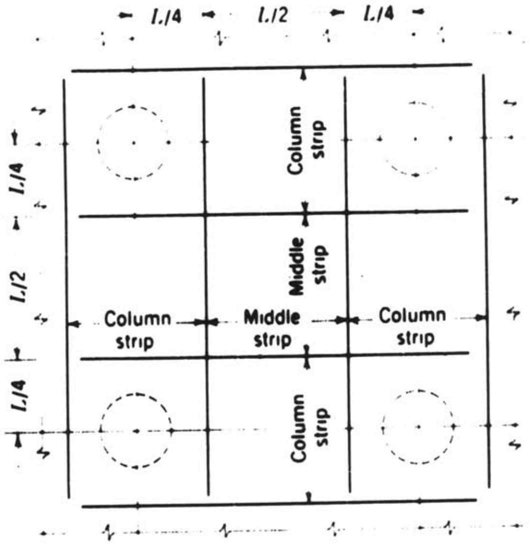


Fig. 4 Flat slab design strips.

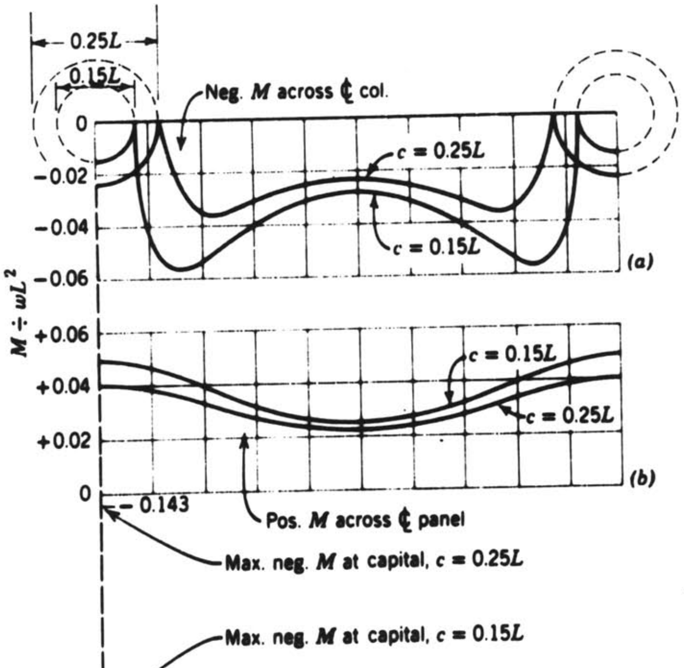


Fig. .5. Theoretical bending moments (Poisson's ratio zero). Adapted from Ref. 2, ACI. (*a*) Negative moments on strips crossing the center line of column and the column capital. (*b*) Positive moments on strips crossing the center line of span.

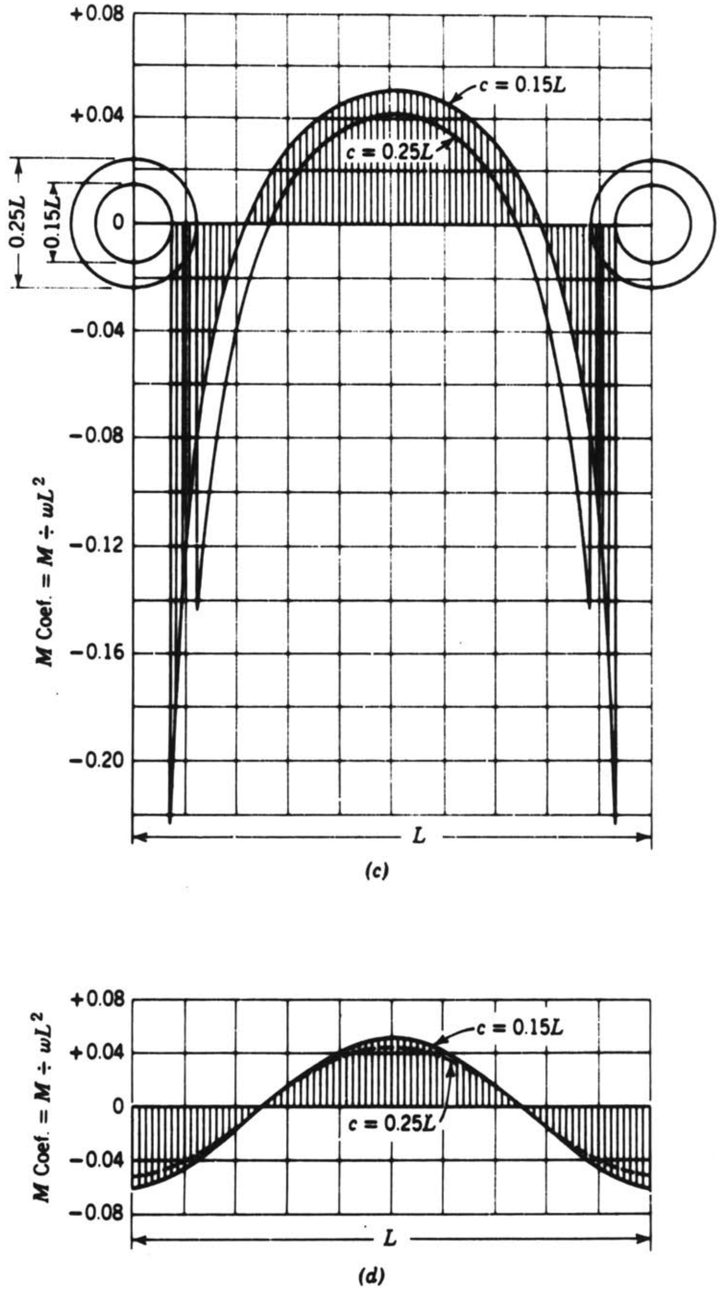


Fig. 5 (continued). Theoretical bending moments (Poisson's ratio zero). Adapted from Ref. 2, ACI. (*c*) Moment diagram for strip along center line of columns. (*d*) Moment diagram for strip along middle of panel.

Fig. 6

Moments in Flat Slab Panels in Percentages of M_0

Strip	Column head	Side support type	End support type	Exterior panel			Interior panel	
				Exterior negative moment	Positive moment	Interior negative moment	Positive moment	Negative moment
Column strip	With drop		A	44				
			B	36	24	56	20	50
			C	6	36	72		
	Without drop		A	40				
			B	32	28	50	22	46
			C	6	40	66		
Middle strip	With drop		A	10				
			B	20	20	17*	15	15*
			C	6	26	22*		
	Without drop		A	10				
			B	20	20	18*	16	16*
			C	6	28	24*		
Half column strip adjacent to marginal beam or wall	With drop	1	A	22				
			B	18	12	28	10	25
			C	3	18	36		
		2	A	17				
			B	14	9	21	8	19
			C	3	14	27		
		3	A	11				
			B	9	6	14	5	13
			C	3	9	18		
	Without drop	1	A	20				
			B	16	14	25	11	23
			C	3	20	33		
		2	A	15				
			B	12	11	19	9	18
			C	3	15	25		
		3	A	10				
			B	8	7	13	6	12
			C	3	10	17		

Percentage of panel load to be carried by marginal beam or wall in addition to loads directly superimposed thereon	Type of support listed in Table 1004(*f*)		
	Side support parallel to strip	Side or end edge condition of slabs of depth t	End support at right angles to strip
0	1	Columns with no beams	
20	2	Columns with beams of total depth $1\frac{1}{4}t$	A
40	3	Columns with beams of total depth $3t$ or more	B
		Reinforced concrete bearing walls integral with slab	
		Masonry or other walls providing negligible restraint	C

* Increase negative moments 30 per cent of tabulated values when middle strip is continuous across support of type B or C. No other values need be increased.

NOTE: For intermediate proportions of total beam depth to slab thickness, values for loads and moments may be obtained by interpolation.

Fig. 7 Minimum Length of Negative Reinforcement

Strip	Percentage of required reinforcing steel area to be extended at least as indicated	Minimum distance beyond centerline of support to end of straight bar or to bend point of bent bar*			
		Flat slabs without drop panels		Flat slabs with drop panels	
		Straight	Bend point where bars bend down and continue as positive reinforcement	Straight	Bend point where bars bend down and continue as positive reinforcement
Column strip reinforcement	Not less than 33 per cent	$0.30L$†		$0.33L$‡	
	Not less than an additional 34 per cent	$0.27L$†		$0.30L$‡	
	Remainder§	$0.25L$ or	$0.20L$	$0.25L$ or	To edge of drop but at least $0.20L$
Middle strip reinforcement	Not less than 50 per cent	$0.25L$		$0.25L$	
	Remainder§	$0.25L$ or	$0.15L$	$0.25L$ or	$0.15L$

* At exterior supports where masonry walls or other construction provide only negligible restraint to the slab, the negative reinforcement need not be carried further than $0.20L$ beyond the centerline of such support.

† Where no bent bars are used, the $0.27L$ bars may be omitted, provided the $0.30L$ bars are at least 50 per cent of total required.

‡ Where no bent bars are used, the $0.30L$ bars may be omitted provided the $0.33L$ bars provide at least 50 per cent of the total required.

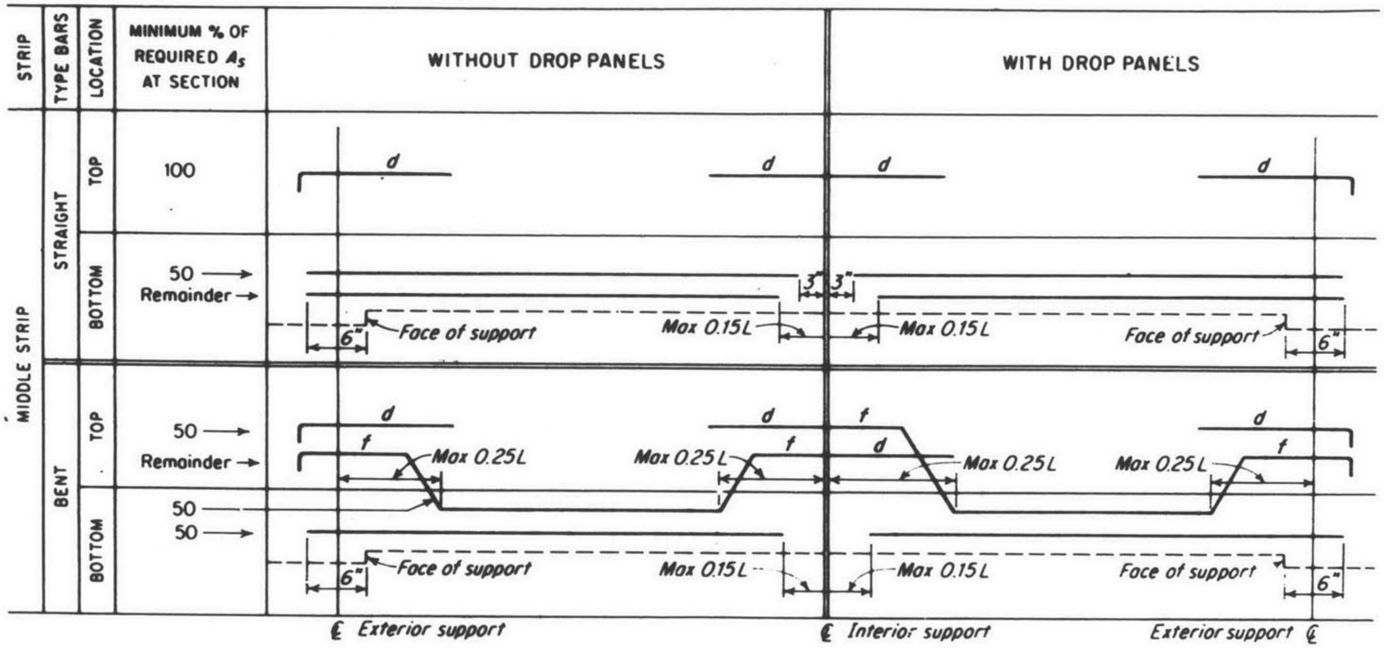
§ Bars may be straight, bent, or any combination of straight and bent bars. All bars are to be considered straight bars for the end under consideration unless bent at that end and continued as positive reinforcement.

Fig. 8 Minimum Length of Positive Reinforcement

Strip	Percentage of required reinforcing steel area to be extended at least as indicated	Maximum distance from centerline of support to end of straight bar or bend point of bent bar			
		Flat slabs without drop panels		Flat slabs with drop panels	
		Straight	Bend point where bars bend up and continue as negative reinforcement	Straight	Bend point where bars bend up and continue as negative reinforcement
Column strip reinforcement	Not less than 33 per cent	$0.125L$		Minimum embedment in drop panel of 16 bar diameters but at least 10 in.	
	Not less than 50 per cent*	3 in. or	$0.25L$		
	Remainder*	$0.125L$ or	$0.25L$	Minimum embedment in drop panel of 16 bar diameters but at least 10 in. or	$0.25L$
Middle strip reinforcement	50 per cent	$0.15L$		$0.15L$	
	50 per cent*	3 in. or	$0.25L$	3 in. or	$0.25L$

* Bars may be straight, bent, or any combination of straight and bent bars. All bars are to be considered straight bars for the end under consideration unless bent at that end and continued as negative reinforcement.

Fig. 9



FLAT SLABS WITH SQUARE OR RECTANGULAR PANELS

MINIMUM LENGTH OF BAR FROM ℄ SUPPORT

MARK	a	b	c	d	e	f
LENGTH	0.33L	0.30L	0.27L	0.25L	0.20L	0.15L

At interior supports, L is longer of adjacent spans.

Fig. 10

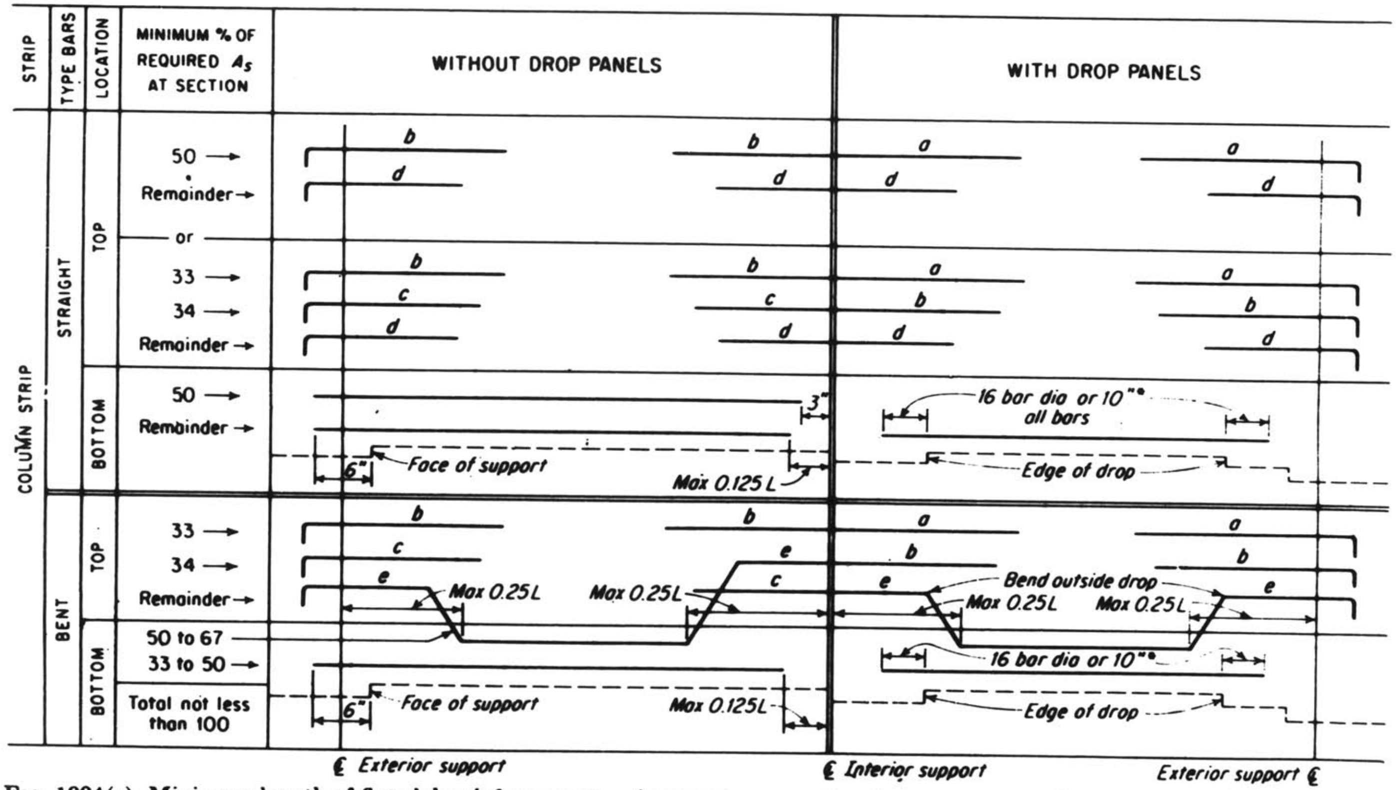


FIG. 1004(*g*). Minimum length of flat-slab reinforcement. At exterior supports, where masonry walls or other construction provide only negligible restraint to the slab, the negative reinforcement need not be carried farther than 0.20*L* beyond the center line of such support. Any combination of straight and bent bars may be used provided minimum requirements are met.

* For bars not terminating in drop panel use lengths shown for panels without drops.

A TYPICAL SOLUTION

Fig. 11

Observations

Structural:

The calculations included are approximate calculations based on the assumption that the floor system behaves structurally as a flat slab.

Before arriving at a final structural design, more detailed consideration should be given to the following:

(1) Behavior of the cellular slab in carrying the vertical shears around the periphery of the solid slab over the columns.

(2) Behavior of the top slab locally between the support areas furnished by the pyramidical cells. Essentially the top slab acts locally as a flat slab supported on top of the pyramidical cells.

(3) More detailed consideration of the pyramidical cells both with regard to carrying the shear between the top slab and lower grid, and with regard to the local bending of the side faces of the pyramids.

(4) More detailed consideration of the local stress in the pyramidical core units. A wire mesh would be used within the unit to take care of many of these stresses.

Mechanical:

The floor structure provides a two way system of trenches in which to place the duct work with access points at intervals of 4, 8, or 12 feet.

A peripheral edge beam is employed where services from a vertical service core penetrate the floor system.

Electrical:

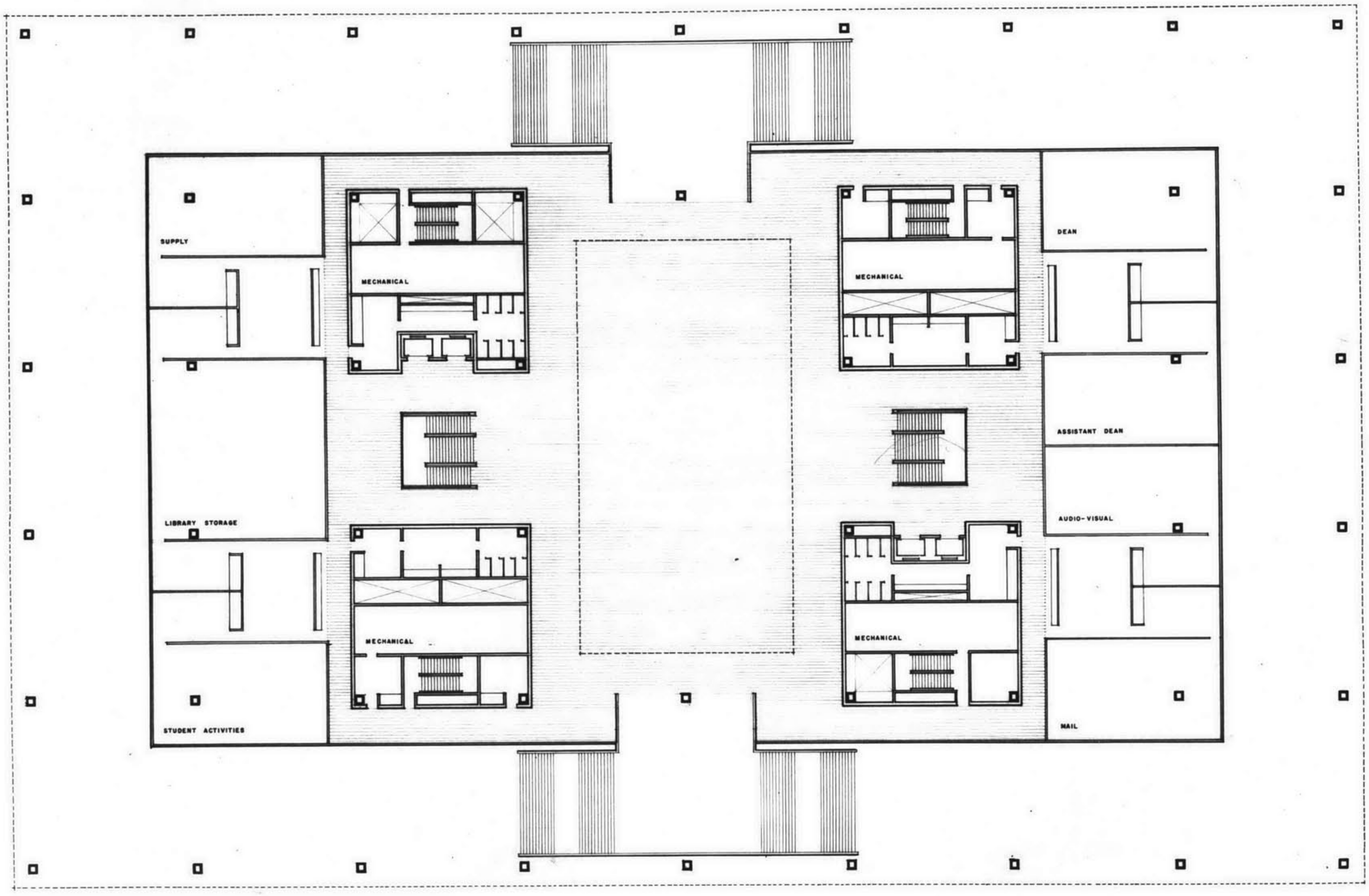
Lighting is suspended on a rod system, where the vertical placement of the fixture can be placed where desired. The outlet box is cast into the precast units to provide a flexible lighting layout.

Acoustical:

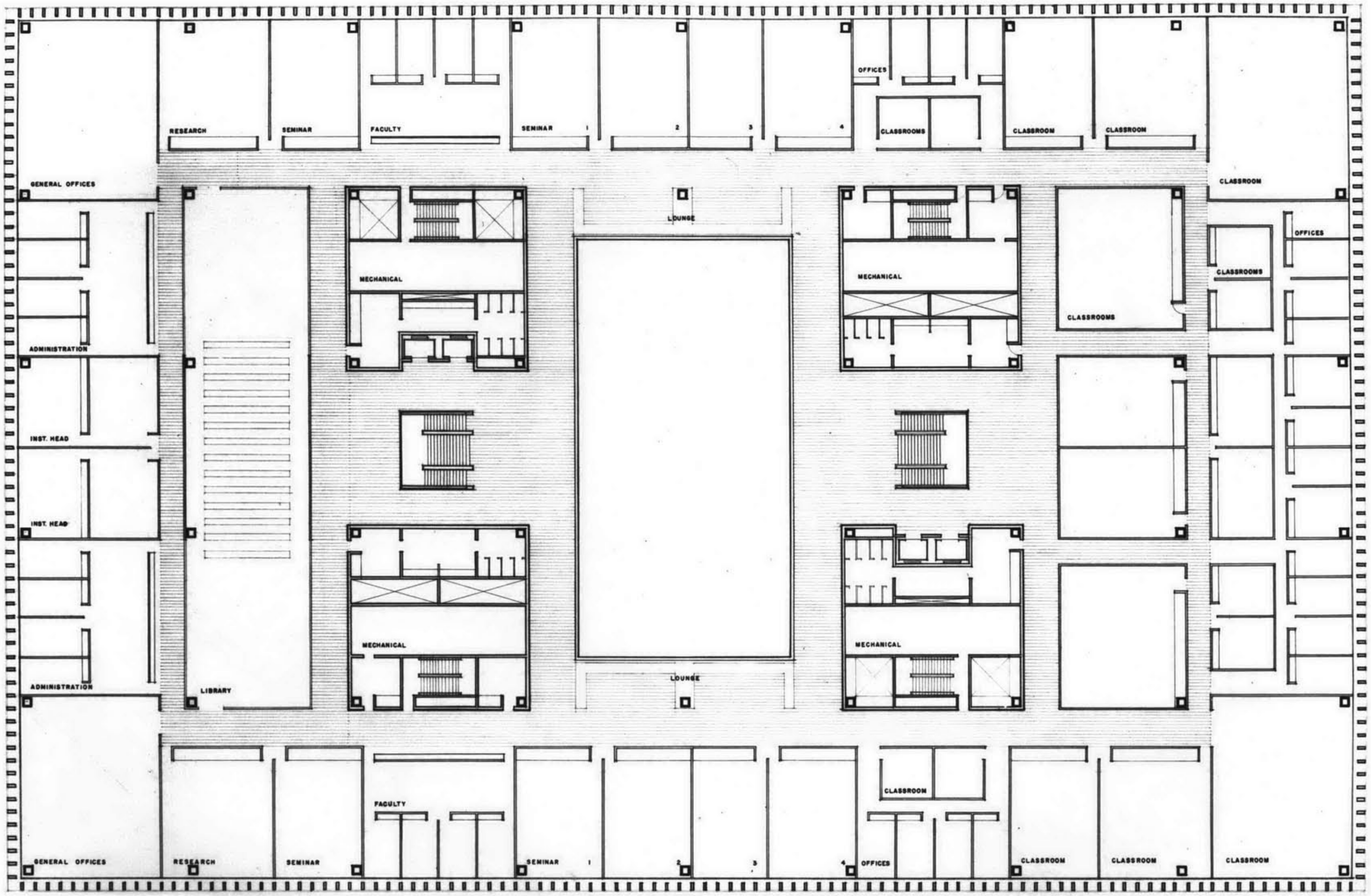
Acoustical precast inserts for the pyramidical coffers, are fastened in the same manner as the lighting. The coffer shape of the ceiling provides good sound distribution for high frequencies, and the closed ceiling employed has all services entering from the floor.

Partitions:

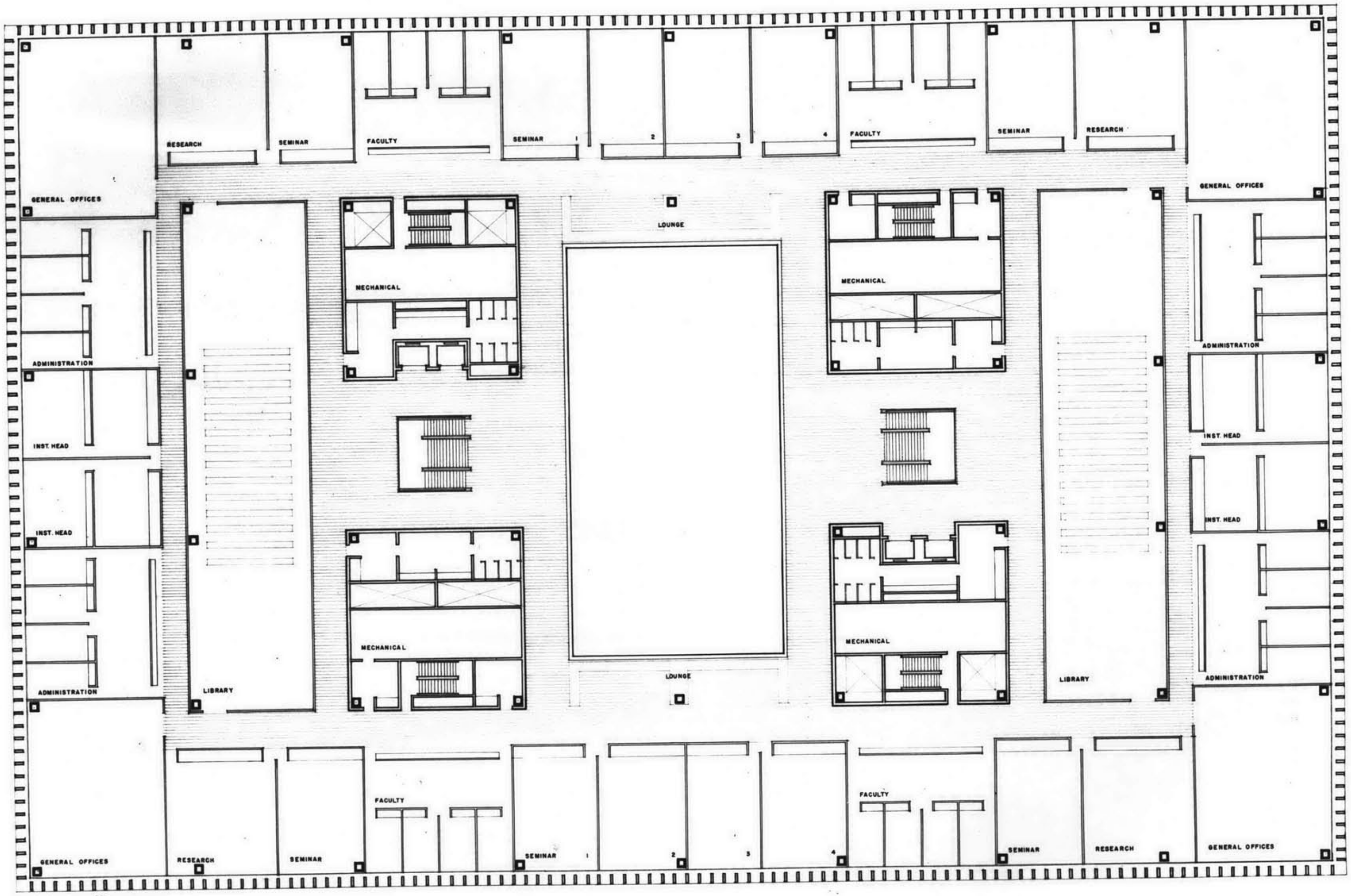
Partition flexibility is achieved as the partitions can be set on a 4' module. Easy access is gained from the mechanical space to a double partition due to the pyramidical core used.



FIRST FLOOR PLAN



SECOND FLOOR PLAN


RESEARCH
SEMINAR
FACULTY
SEMINAR
1
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FACULTY
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GENERAL OFFICES
LOUNGE
MECHANICAL
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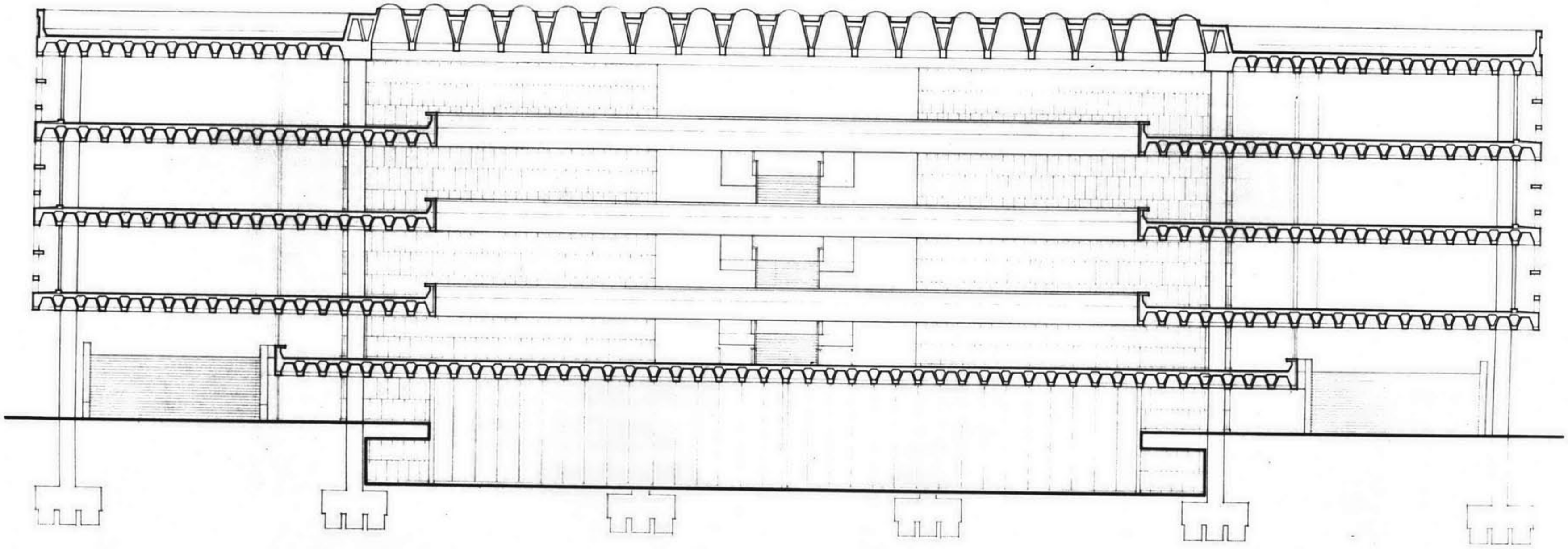
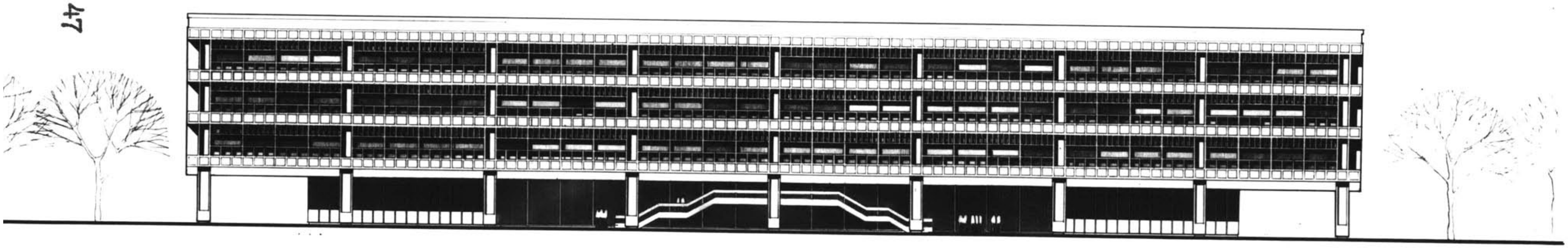
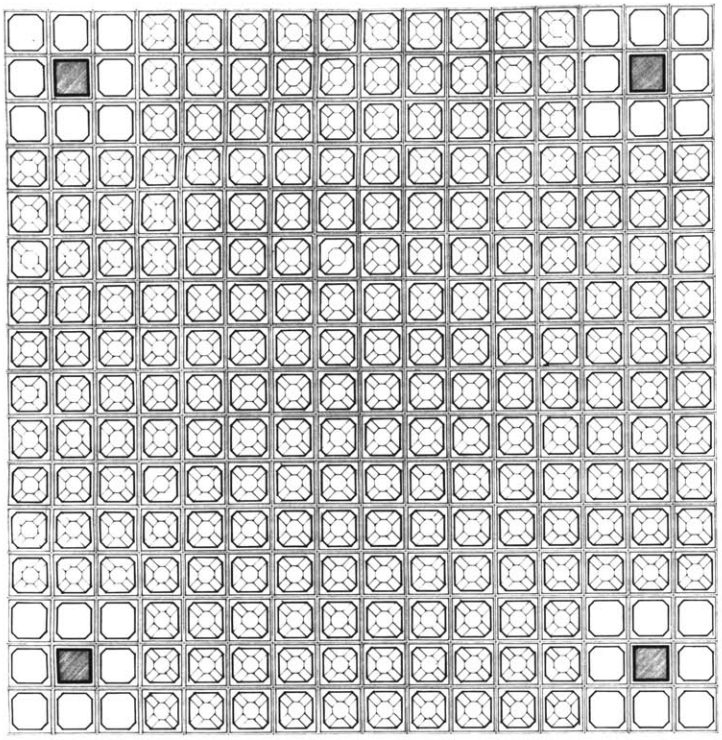


TRANSVERSE SECTION

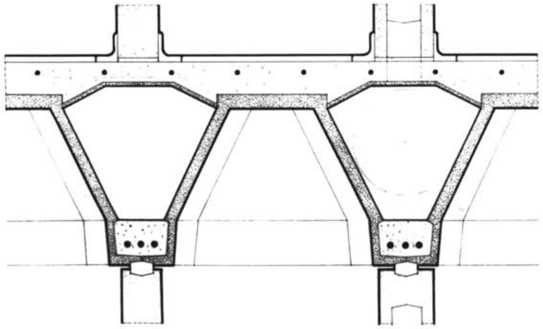


ELEVATION



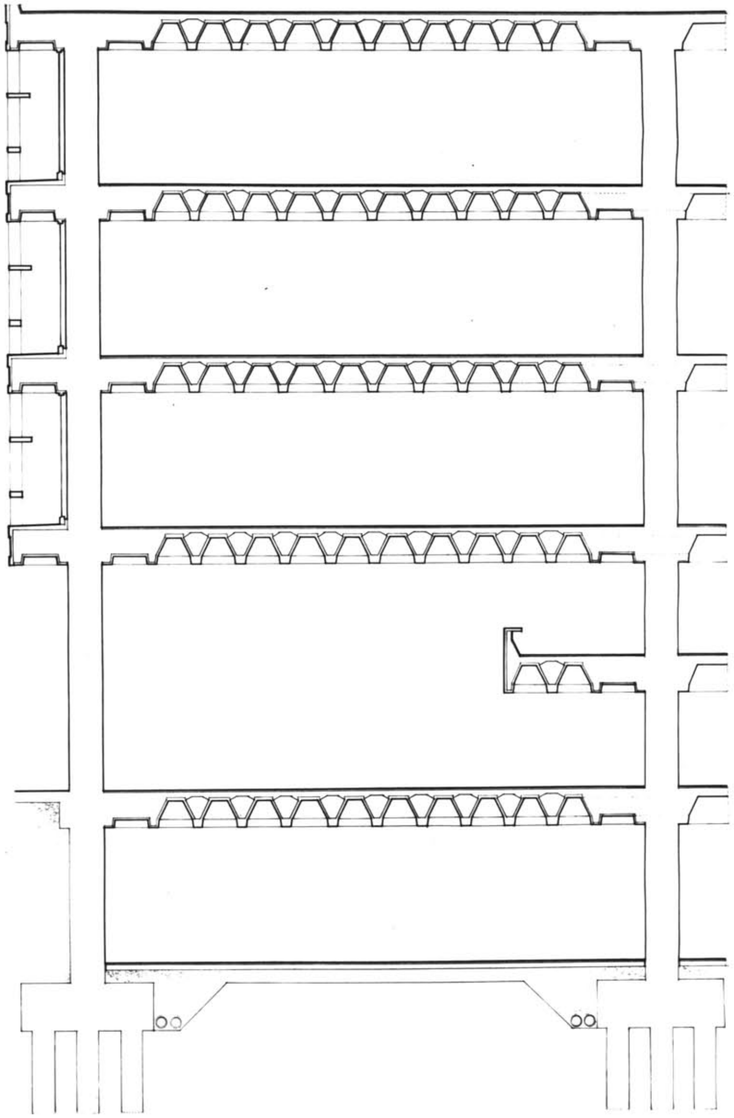
REFLECTED CEILING PLAN

SCALE 1/8" = 1'-0"



STRUCTURAL DETAIL

SCALE : 3" = 1"-0"



TYPICAL STRUCTURAL SECTION

SCALE : 1/4" = 1'-0"

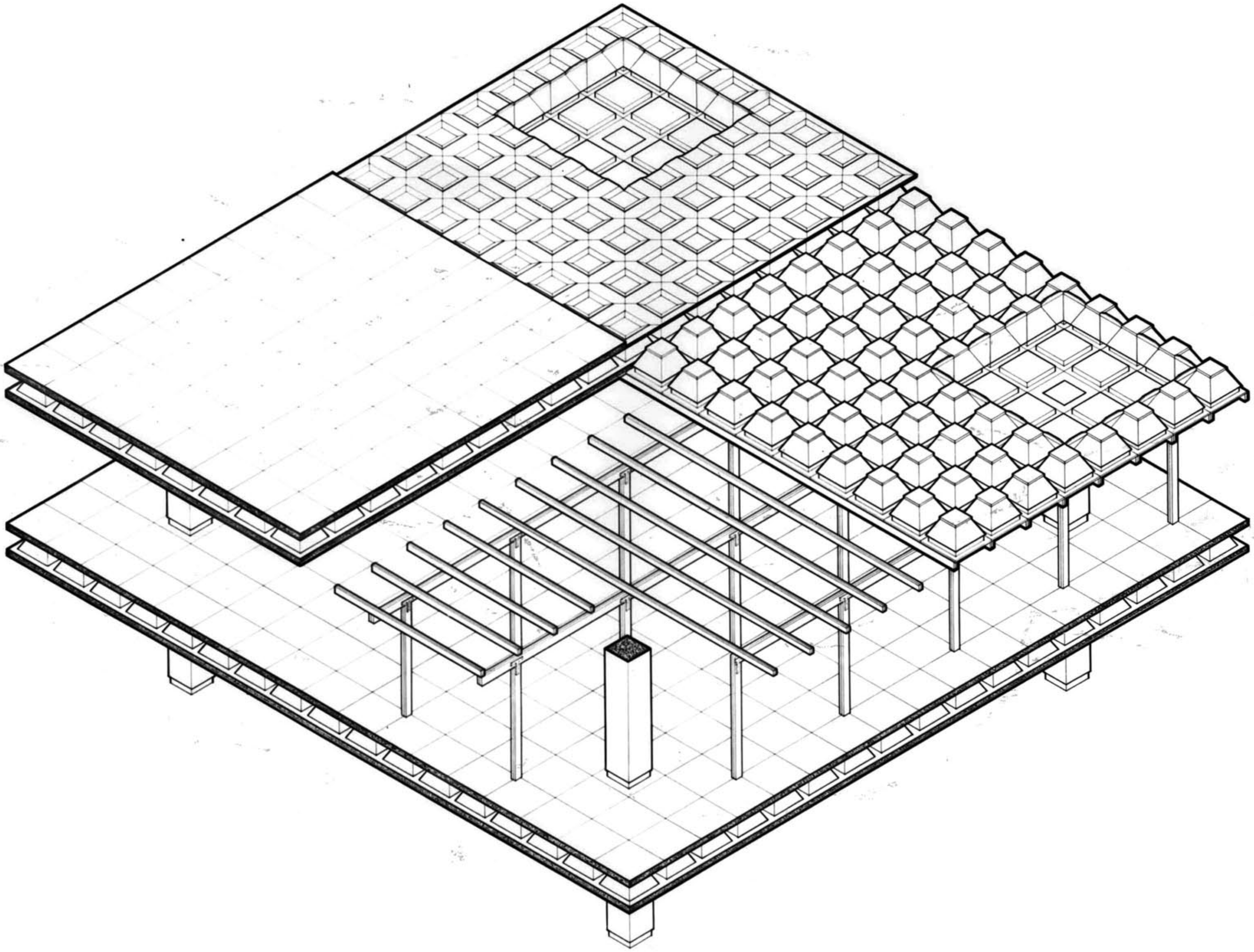


DIAGRAM SHOWING 4 STAGES OF CONSTRUCTION

SCALE: 1/4" = 1'-0"

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Study I and II were proposed by graduate students, Winter Semester, 1960 in the Department of Architecture as structural solutions for an Architectural or Humanities Building in a University Campus Development. Figure 11, a Typical Solution, was submitted by the author of this thesis as a Humanities Building for the same period, under Professor Eduardo Catalano.