

A PROTOTYPE STRUCTURE

by

Ralph Lewis Knowles
B. Arch., N.C. State College, 1954

and

Stanley P. Steinberg
B.S., Georgia Institute of Technology, 1954
B. Arch., Georgia Institute of Technology, 1958

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Handwritten scribbles consisting of several small loops and lines.

Signatures of Authors

Ralph Lewis Knowles

Stanley P. Steinberg

Signature of Head of Department

Lawrence B. Anderson

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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 10, 1959.

ABSTRACT

The Master's Thesis offers an uncommon opportunity to investigate areas which are normally outside the realm of the practicing architect or engineer. The pressures of economy and client need usually limit the amount of serious investigation that the designer may undertake on a project. Even if new ideas develop as he works through a conventional problem, he may never have the time or the opportunity to encourage them to function.

Another opportunity offered by the Master's Thesis is that of pooling effort and common interests to mutual advantage; varied backgrounds and abilities can complement each other and work to the mutual benefit of those concerned.

Finally, there is the opportunity to develop a direction of investigation which can be continued and broadened by others. The most important aspect of research, besides its direction,

is that it may continue indefinitely and that each new attempt may add to a growing store of knowledge.

A prototype structure of limited span and specific architectural condition (relatively high space confined by a peripheral low space) was chosen because it offers structural and architectural problems with broad application and, with the appearance of new materials and methods, consistently fresh area for research.

August 10, 1959

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, we hereby submit
this thesis entitled, "A Prototype Structure".

Respectfully,



Ralph Lewis Knowles

Stanley P. Steinberg

ACKNOWLEDGMENTS

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following for their advice
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I. INTRODUCTION

A. OBJECTIVES

The development of a prototype structure that is systematized through the geometric ordering of surface. The structure shall accomodate spaces of different height and shall provide those facilities essential for useful occupation.

B. EXPOSITION

The development of a prototype or original model may have value beyond that to be gained by attacking a specific site problem. The unique qualities of a site may be forgotten and interest can be concentrated on that solution which offers general answers of broader significance and application. The results may not necessarily be used specifically and totally, but can be extended to apply to the generalized problem of space enclosure with all its involved aspects.

Systematization of such a structure is essential to the advantage which may be taken, by the builder, of today's technology. The builder has a broad palette of means and methods that result from modern systems of mining, preparation, shipping, refinement, manufacture, distribution, procurement, and use. Today's system is fundamentally mass production and the prototype structure should find its roots in this fertile base, then extend its essential

character into the field where costly hand processes and unacceptable workmanship can be eliminated.

An essential basis for systematization is the geometric ordering of surface. Repetition, based on this order, can produce an economically feasible building unit.

The increased need for flexibility and inexpensive construction methods has led to a general disregard for the essential relationship between sheltering structure and the contained activity. Much space built today depends for this relationship upon demarcations in plan alone. However, there is real need for vertical as well as horizontal dimensional recognition of activity. This need arises often today when great areas are being covered with single story structures of modest span requirements. The problem of producing a sheltering surface which has height variation over significant and usable areas with minimum support interference raises many interesting questions of moment distribution at the point of level change and produces problems of depth variation in the structure as the condition of support varies. Then those problems of mechanical equipment and light introduction must be solved as they must for any structure.

C. APPROACH

The problem has been approached in the following way:

1. Determine surface to be developed based on the selection of an architectural condition with span limitations.
2. Geometric breakdown of surface; determination of slopes and angles.
3. Determine building material to be investigated.
4. Approximate structural analysis; determine support system, sizes, and details.
5. Determine construction methods.
6. Record findings in written and graphic form.

II. DESIGN CRITERIA

A. BUILDING TYPE

In order to proceed logically from a specific architectural condition, a building type is chosen in which the desired condition exists. This procedure has the advantage of offering specific points of departure and logical limits for the first cautious steps of the designer who ultimately seeks a building system with broader application. The search for a universal building system is exciting, and has, in certain cases, led to results of great interest and wide application. But more often, those systems which have developed wide usage have originated as expedient solutions to specific problems. (Bar joist and the whole range of pre-cast, pre-stressed sections had such beginnings.)

The specific building type can suggest dimensions as well as requirements for light, services, spatial organization, thermal insulation, and sound control.

A school-room unit requires a large unobstructed central space approximately 30' x 30' surrounded by a continuous low space about 10' deep. (See Fig. 1 on page 13.) These dimensions are in a range where the problem of span is simplified and efforts may be concentrated on difficulties arising out of change of height and the problems of lighting, partitioning, ease of erection, and services.

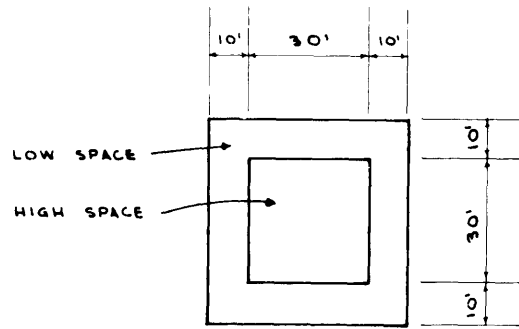


Figure 1

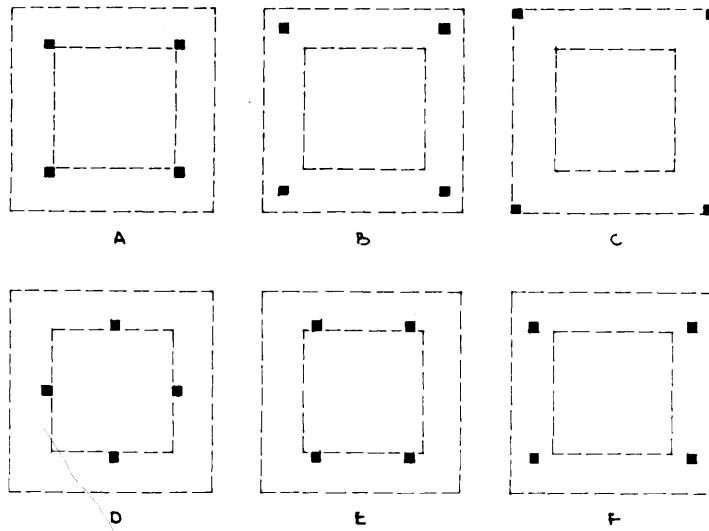


Figure 2

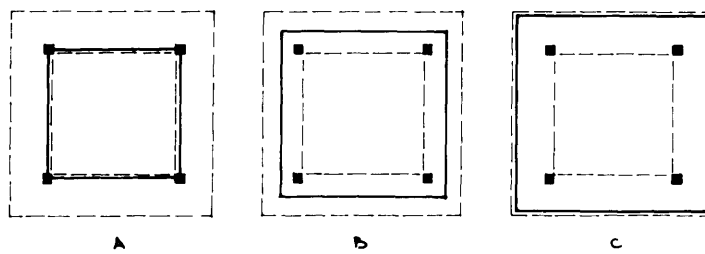


Figure 3

B. QUALITY OF HIGH SPACE

The quality of the high space should be conducive to group activity. The introduction of natural light through skylights can produce that stimulation of intensity variation otherwise lacking in an interior, artificially lighted space. The volume of the room should be sufficient to allow for the psychological and physiological expansion of young people.

C. QUALITY OF LOW SPACE

By contrast, the low space should suggest more intimate activities on an individual or small group basis. In this continuous low space will go the fringe activities of a classroom, such as storage, lavatories, toilets, wet work tables, circulation, all-purpose areas, offices, conference rooms, and unit libraries.

D. STRUCTURES

The systems used to form the surfaces of high and low space should be similar in size, method of installation, and function. One way to accomplish this is by the geometric ordering of all surfaces. In this way, a standard unit of construction may be developed that is usable for the entire structure.

There should be one unified support system to simplify detailing. Two possible systems are:

1. Load-bearing walls which allow only limited flexibility in locating partitions.

2. Columns that offer maximum flexibility when the columns are well located. The modest dimensions of this structure (See Fig. 1, page 13) allow a minimum of four columns to produce practical spans and load conditions. Using four columns, there are six basic column locations. (See Fig. 2, page 13.) Of these possibilities, Scheme A has the greatest structural advantages. The columns are in a position to support both the high and the low surfaces while the overall dimensions are generally proportioned so that the cantilever effect of the lower surface reduces the magnitude of moments in the structure.

In view of these facts, initial studies will be based on a support system of four columns located as indicated in Scheme A, Fig. 2.

E. METHOD OF PARTITIONING

The under surface of the structure should be able to accommodate the greatest flexibility in partition placement. Standard details should be developed for the juncture of partition and structure which operate independently of partition material. This will allow a wide use of wall materials without limiting the effective simplicity of the structure. However, the structure should encourage the development of regular, simple, and economical wall panel systems.

Referring to Fig. 3, page 13, A, B, and C indicate basic

partition locations in the low periferal area of the classroom unit. From these the possibilities multiply as one classroom unit is added to another. Any partition normal to these basic locations should be placed in accordance with an established geometry.

F. INTRODUCTION OF LIGHT

1. Natural Light - Methods of servicing interior spaces have improved to a point where building areas of great dimension are possible without providing exterior wall surfaces to perform the conventional functions of lighting and fresh air intake. However, the stimulation of contact with outdoor light is essential to most activities and for this reason (besides the fact that it offers a high level of free illumination) an effective system of natural light introduction should be considered. This system should be capable of complete integration into the roof structure within the limits of the surface geometry.

2. Artificial Light - Also integrated with the surface geometry should be the artificial lighting which should perform with uniform effectiveness over the entire structure working in conjunction with the natural lighting and the partitioning systems.

G. MECHANICAL EQUIPMENT

1. Heating - The introduction of heating (or cooling) equipment into the structure must be considered with

three important facts in mind: first, heat can more effectively be introduced into a space from below because of the natural movement of warm air; second, in order for complete flexibility of partitioning to exist, the heat must be introduced consistently over the entire structure; and third, since this is a structure to cover single story spaces, there are in existence some excellent systems for through floor heating that can give over-all conditioning as well as peripheral service.

2. Plumbing - This is the most difficult item in which to get flexibility of location. Plumbing service to every part of the structure for flexibility is prohibitively costly. However, there is something to be gained from investigating self-contained prefabricated lavatory, toilet, and service units which can fit into the pre-determined geometry of the structure and become a part of a partition system. In this case, the roof structure should be capable of accommodating vent stacks and room ventilators without special cutting, shaping, or fitting.

3. 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.

H. ACOUSTICS

Although it must be conceded that room use and size should

determine the character of acoustical treatment, there are factors of economy, pre-determined room size, and approximate knowledge of usage that favor integration of acoustic treatment into the structure. In this way, sound conditioning is relatively free of partition placement and the additional process of absorption material application may be avoided.

I. THERMAL INSULATION

The additional process of roof application should be avoided by making thermal insulation an inseparable part of the structure, thus avoiding another costly field operation.

III. STUDIES LEADING TO FINAL PROPOSAL

A. STUDY NO. 1

1. General Description - Study No. 1 is a simple column and beam system consisting of four major beams which intersect at four column supports and cantilever beyond to pick up four peripheral edge beams. The major beams support an upper two-way system of poured-in-place joist (with pre-cast concrete pans used as forms and remaining in place) while a series of pre-cast slabs, supported between the major beams and the peripheral edge beams, form a flat surface for the low portion of the structure. (See Fig. 4, page 23.)

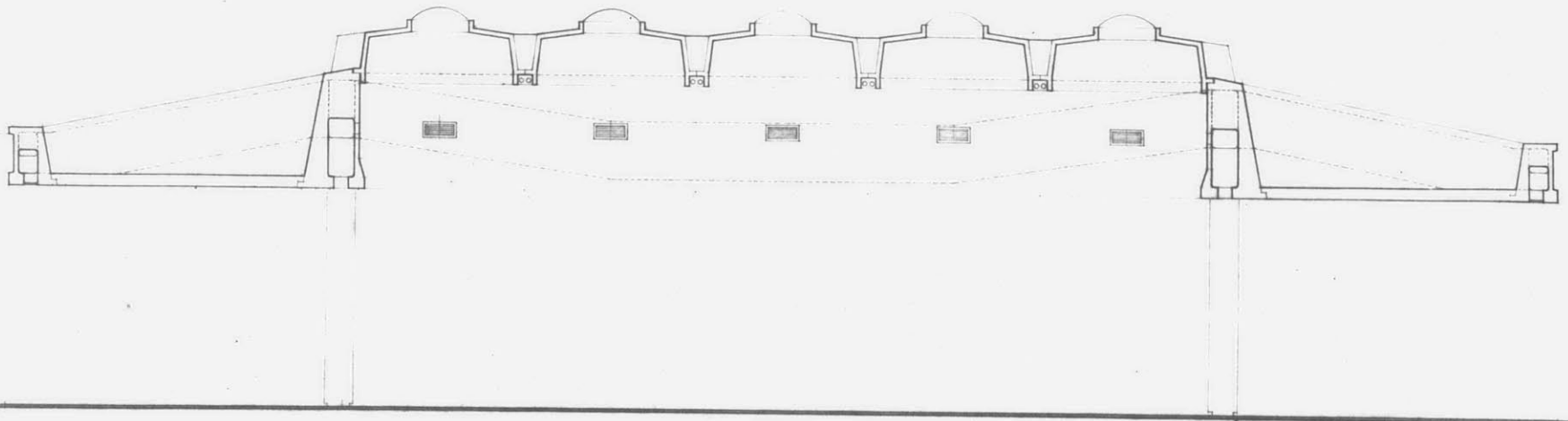
Since the desired difference in height between the upper and lower roof surfaces is five feet, it might be possible to use two beams where the major beam is indicated; however, the depth of these beams would leave little usable space between them and their efficiency could be increased by combining them into one relatively deep beam. Once this decision is made, there arises the possibility of shaping the beam to reduce dead load.

The ideal section for a reinforced concrete beam is one which contains a compression block of concrete and a tensile rod of steel with nothing between them where the concrete is normally in tension and for design purposes is considered

Study #1

Draw. #1

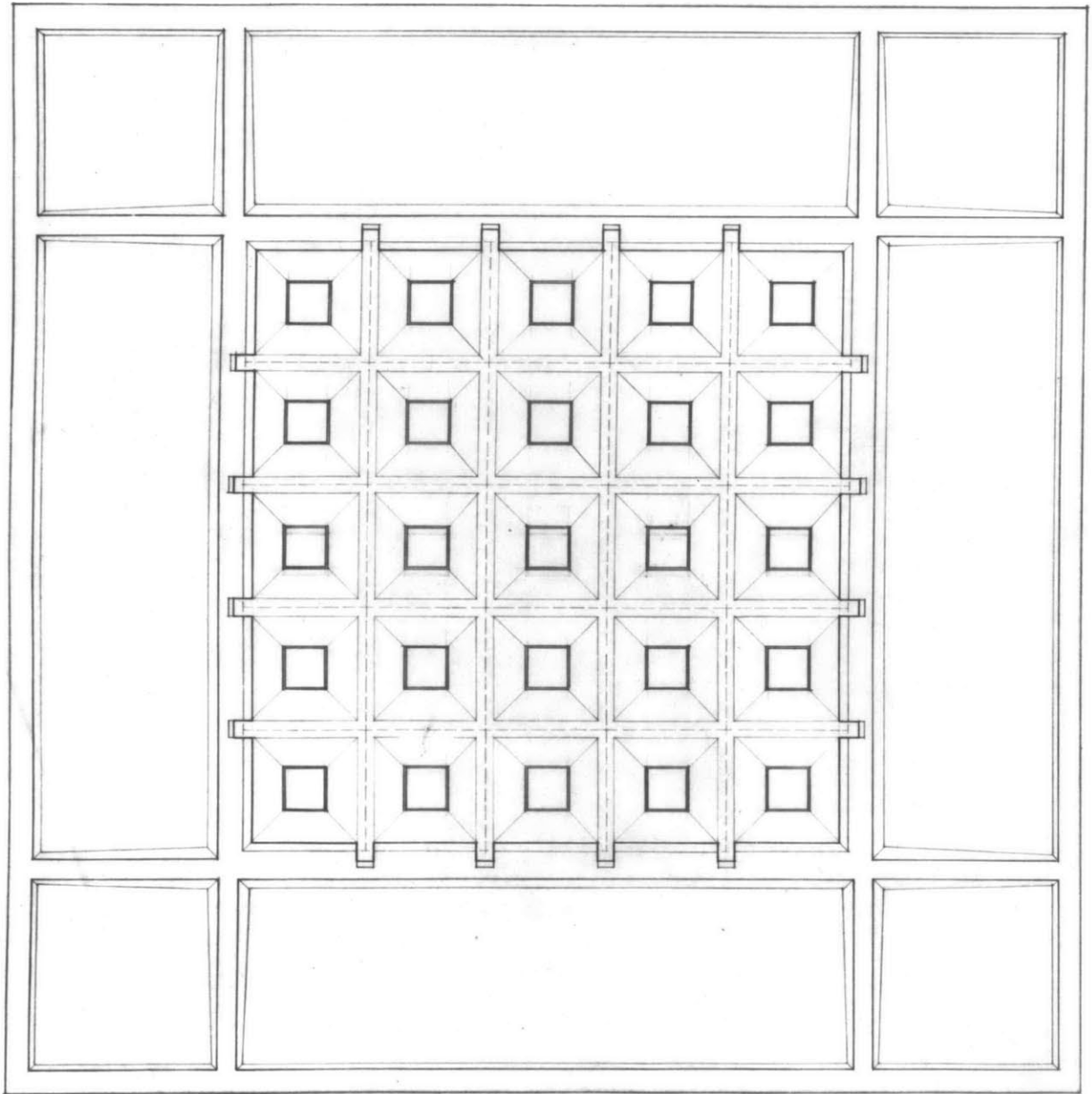
SECTION



Study #1

Draw. #2

ROOF PLAN



cracked. (See Fig. 5-a, page 23.) This section is, of course, impossible to accomplish since there must be some way of holding the steel in place and transferring horizontal shear between the two materials. The conventional solution has been to form a solid rectangular beam, and a further refinement has been the T-beam which is more efficient and still provides a concrete stem to handle transfer of shear and protection of the steel. (See Fig. 5-b, page 23.) However, a beam with two stems could be fabricated and would also be efficient in terms of the reduction of dead weight. (See Fig. 5-c, page 23.) This form offers the advantage of an enclosed space which could be used for the circulation of air, but the disadvantage of being relatively difficult to form. However, the forming of this beam can be accomplished by using inserts around which the concrete is poured as in "AMDEK" (manufactured by American Marietta Co.) or "FLEXICORE" (developed by Price Bros. Co.) units.

The moment diagram of one of the major beams (ABCD) is shown in Fig. 6, page 23, being plotted on the compression side. The compression block should be positioned as shown. However, the location of points of inflection will vary as loading varies and a more gradual transition between the compression blocks is required. The size of the compression block and the depth of the beam can be reduced as moments

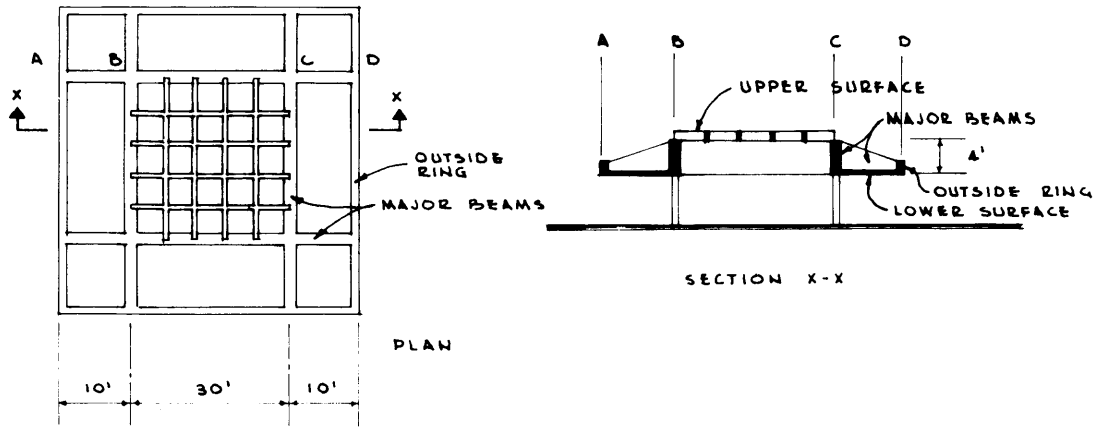


Figure 4

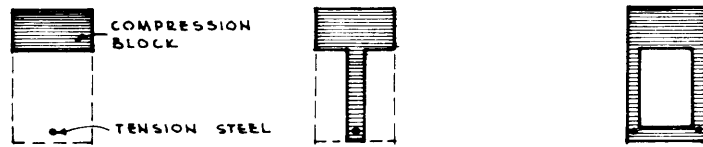


Figure 5

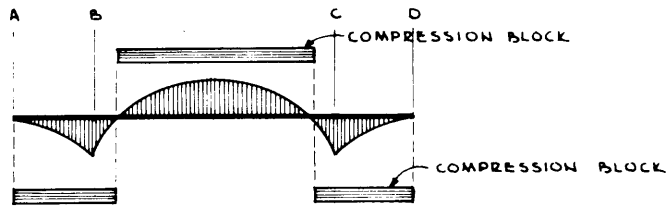


Figure 6

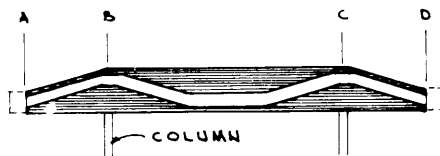


Figure 7

decrease toward the cantilever ends. This may be accomplished with a beam having the section shown in Fig. 7, page 23. (Note that this section provides the necessary shear strength over the supports at B and C.) The outside ring beams can be formed in the same way so that the result is a duct system which is continuous throughout the structure and can be tapped for service where required. (Note that the outside ring beams have a cantilever at each end so their moment diagrams would have the same configuration as that for the major beams so the void would have a similar placement.)

Natural light is introduced into this system through skylights placed in pre-cast concrete pans in the high section.

Artificial light will be placed in troughers formed by the pre-cast pans in the high section, and applied directly to the flat surface of the low section.

Partitioning has complete freedom of placement under the flat portion.

Thermal insulation and acoustical treatment would be post erection applications.

2. Criticism -

a. The two-way beam system of the high section must rest on top of the major beams thus producing a detail more

adapted to timber or steel than to plastic concrete.

b. Roofing becomes extremely difficult because of the beam protrusions above the roof surface.

c. The application of thermal insulation is complicated by the two different structural systems of high and low space.

d. Drainage of the roof surface is complicated by the protruding beams.

B. STUDY NO. 2

1. General Description - Study No. 2 (See Draw. 3 and 4, pages 26 and 27) is an outgrowth of the criticisms of Study No. 1. Structurally, it is similar to the Final Proposal and a detailed explanation can be deferred. However, the method of construction is quite different. A complete concrete grid is poured in place, including a peripheral duct system (hollow tile used as forms) which can feed out the side or bottom depending on partition placement and room organization.

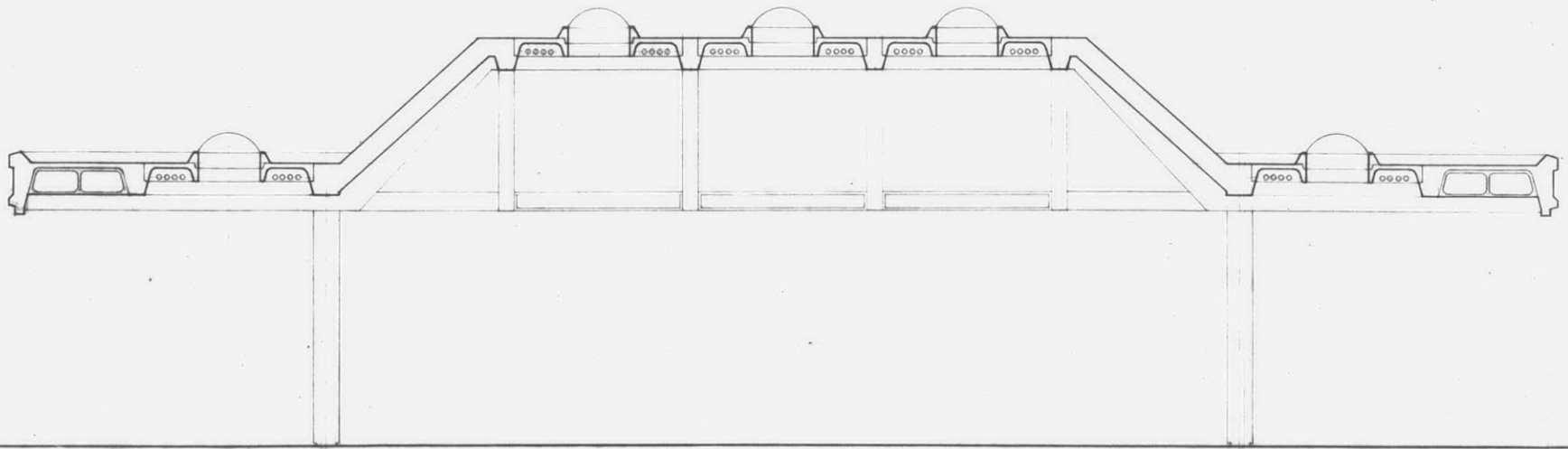
Natural light is introduced through skylights while artificial light is placed in pre-cast panels, equipped with wiring and lighting, and skylights, which would be dropped into place after the grid is completed.

Partitions would be located on the ribs. Acoustical treatment occurs within the pre-cast panels which are formed of

Study #2

Draw. #3

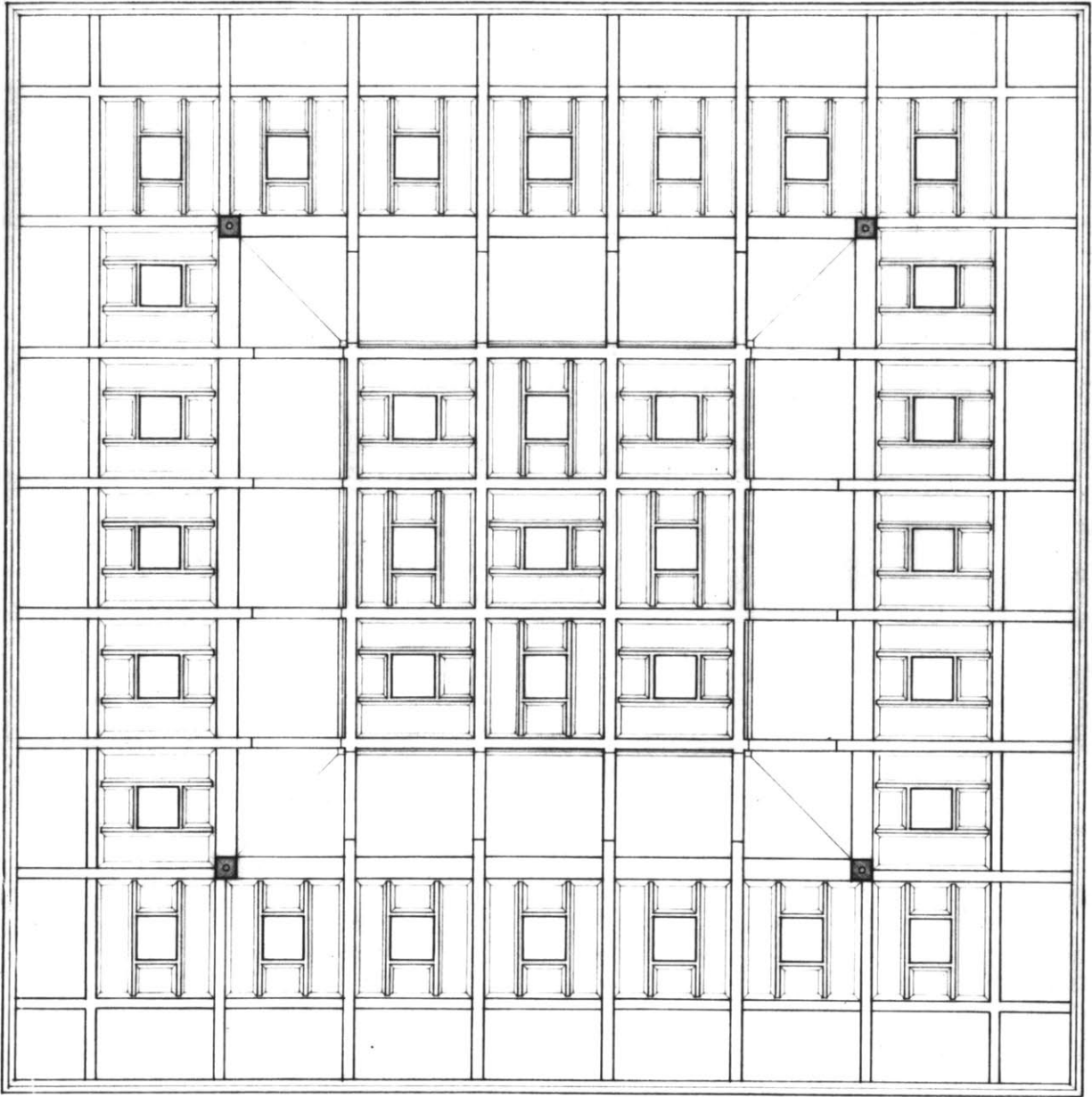
SECTION



Study #2

Draw. #4

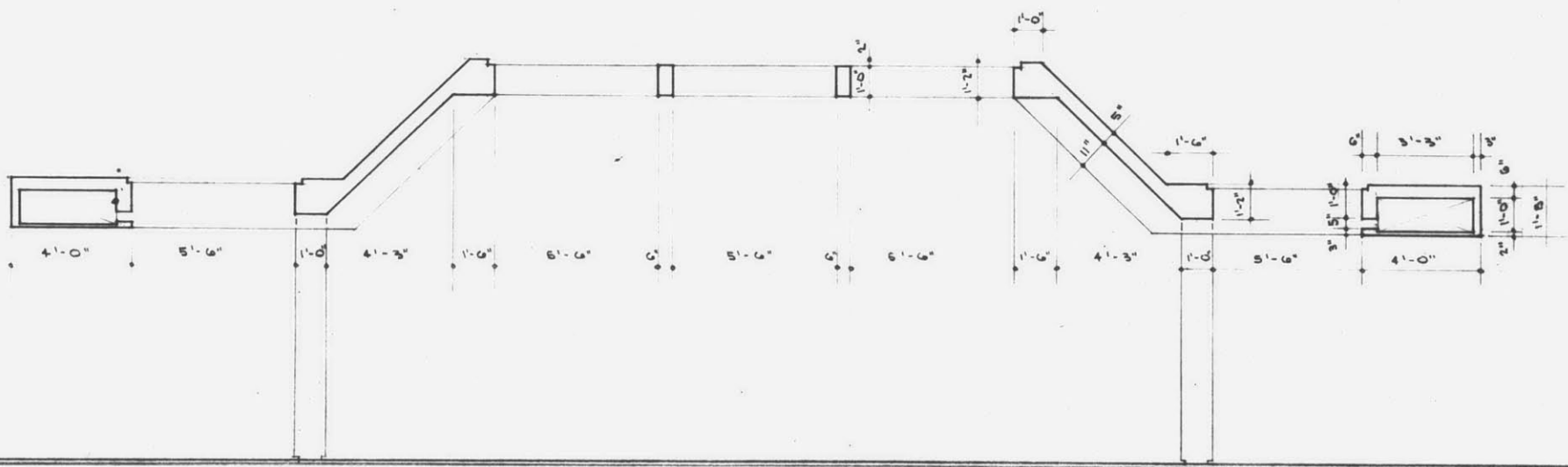
CEILING PLAN



Study #2

Draw. #5

REVISED SECTION



wood or cane fibres and cement.

Thermal insulation would be applied to the outside surface of the structure after completion.

2. Criticism -

a. Site forming would be difficult and costly even if the ribs were simplified as shown in Draw. 5, page 28. Great accuracy would be required to accommodate the panels which would be set in place after the grid was completed.

b. Since the pans are not used consistently over the entire surface of the structure, full advantage cannot be taken of their thermal qualities. (Fibre and cement mixed can have relatively good insulating values, as in "INSULROCK", manufactured by Insulrock Co., or "TECTUM", manufactured by Tectum Corp.) Therefore, additional insulation would be added where the pans are not used.

c. The use of such a duct system leads to inflexibilities in wall placement. In order to get heat both to the periphery and to the large classroom space, either furred ceiling panels must be employed, or partitions must be placed to allow full circulation of air.

C. STUDY NO. 3 (FINAL PROPOSAL)

1. General Description - The use of pre-cast panels as form work for the entire structure sets this proposal apart from the first two. The panels will virtually complete the form-

work with no site forming required. Site work will consist of holding the forms in place and pouring into them. Since the panel-forms are used consistently over the entire surface, other properties may be successfully incorporated into them. The forms are molded of wood or cane fibre and cement. This combination can be easily pre-cast in the shop, is non-combustible, and has good thermal insulating properties,¹ as well as some sound absorption characteristics.²

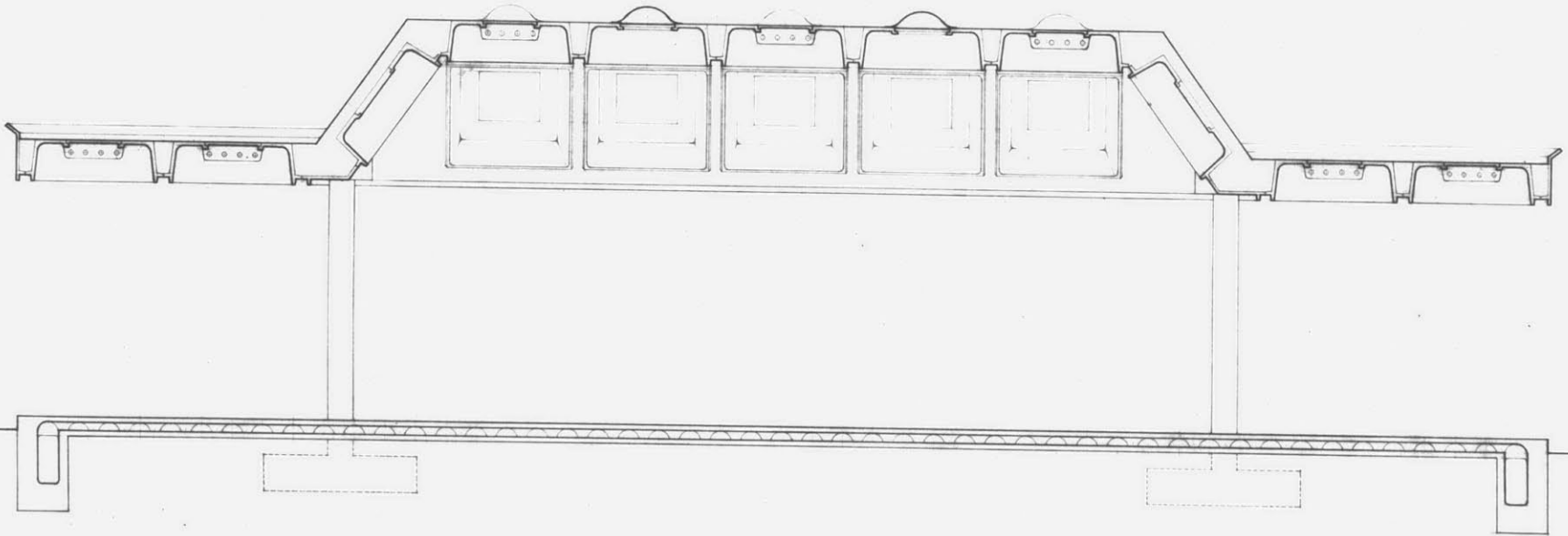
The duct-work has been removed from the structure and heat is introduced through the slab. This change has four advantages: first, heat is most successfully introduced from below for peripheral heating and if the duct-work is run in a grid system like "AIRFLOOR", manufactured by Airfloor Company of California, Inc., there is also radiation gain through the slab; second, the builder is not limited in his choice of heating systems; third, no portion of the

- - - - -
- 1.) 2" of this material would have a U value of .20 BTU/SQ.FT./HR./ F. Compare this with Pittsburg Corning Co.'s "FOAM GLASS", 2" with U value of .16.
 - 2.) This material has a Noise Reduction Coefficient of .5 to .6. Compare this with "CUSHION TONE", a wood fibre product by Armstrong Cork Co. with a Noise Reduction Coefficient of .55 to .80.

Study #3

Draw. #6

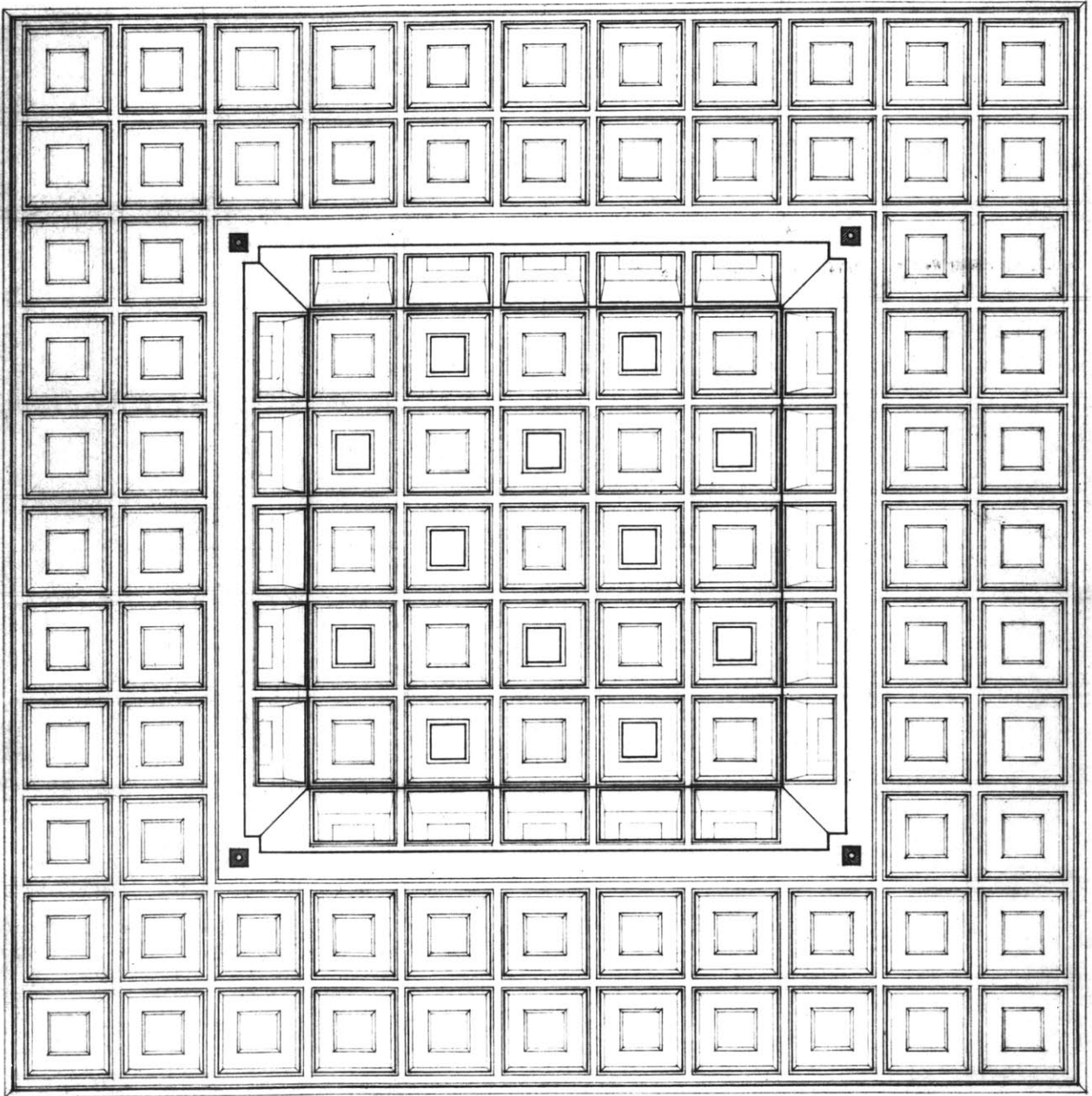
SECTION



Study #3

Draw. #7

CEILING PLAN



structure need perform different functions from any other part so it is possible to use one standard form consistently over the entire structure; and fourth, there is complete freedom of partition placement within the geometric ordering of the surface since the heat-carrying facilities are not localized in the structure.

Partitions may work on a completely modular system since all panel-forms are identical and receive the partition heads in precisely the same way over the entire structure.

2. Structural Explanation - The structural discussion of Study No. 3 (See Fig. 8, page 34) will deal with the major structural elements as follows:

Concrete frames in both directions (A-B-C-D-E-F) with their upper portions (C-D) defining the high surface of the structure and the cantilevered elements (A-B and E-F) defining the low peripheral surface.

Four relatively thin supporting beams (1-2, 2-3, 3-4, and 1-4) formed on the top surface of the sloped portions (B-C and D-E) of the frames.

Four horizontal beams running along the bottom edge of the four supporting beams.

Four columns located at the inside corners of the low surface (1,2,3,4).

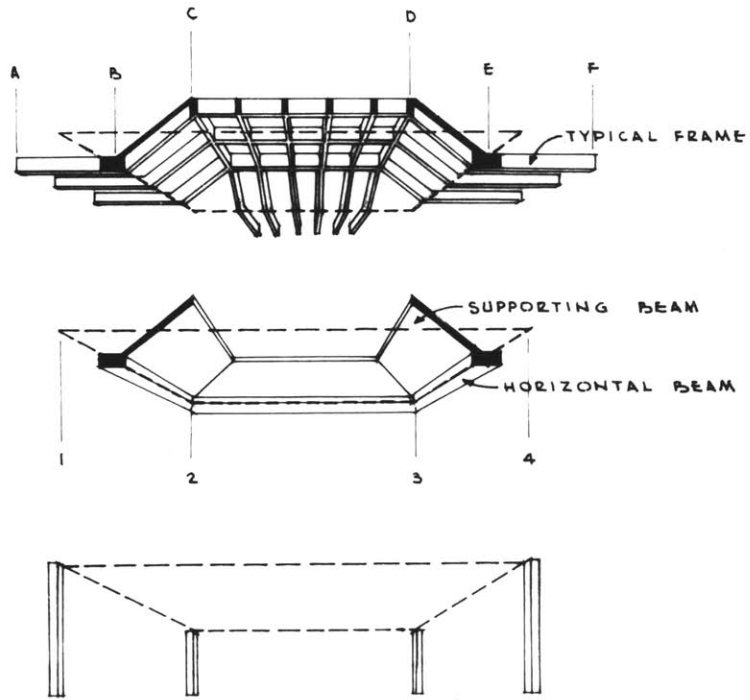


Figure 8

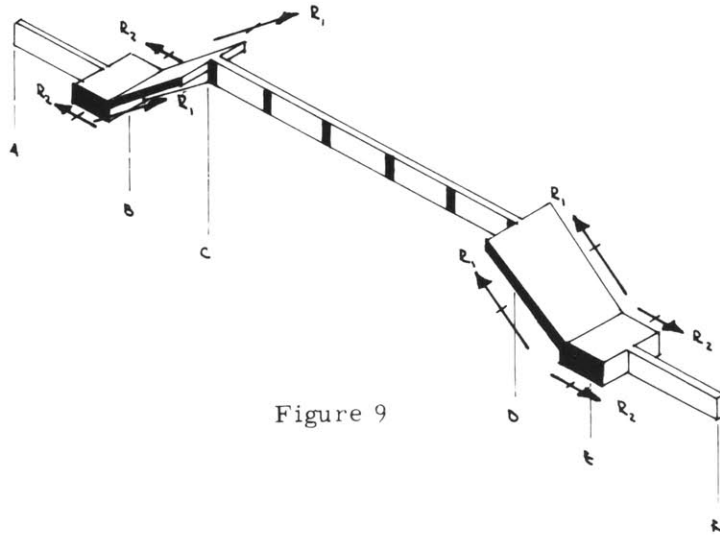


Figure 9

a. Frames - The upper surface of the structure defined by the frames (C-D) is a two-way system. The major reactions on any one frame (A-B-C-D-E-F), discounting the effect of the two-way portion for which compensation may be made by proper proportioning of the loads thereon, will be indicated in Fig. 9, page 34. Note that all reactions are taken either by the supporting or horizontal beams.

In order to understand the effect of the loads on a typical frame, a simple analysis is required. Certain assumptions are made and are valid for this rough analysis; a more exact analysis will be required for the final design.

Assumptions:

- (1) Frames (A-B-C-D-E-F) have a constant section.
- (2) Points B and E are stationary in space due to the action of the supporting and horizontal beams.
- (3) Loading will be assumed symmetrical since this is a low roof, and the unsymmetrical loading conditions are not acute.
- (4) Tortion taken by the supporting beams (1-2, 2-3, 3-4, and 1-4) is negligible.
- (5) The loading on the upper portion of the frame (C-D) is one-half that on the cantilevered portions (A-B and E-F) since the high surface is determined by a two-way system.
- (6) The loading over the sloped portions of the frame

(B-C and D-E) is twice that over the cantilevered portions (A-B and E-F) due to the weight of the supporting beams.

Analysis: (For loading diagram, see Fig. 10, page 37.)

(1) Stiffness factors:

$$K = I/L$$

$$K_{cb} = 3/4 \times I/6 = .125 I \quad (\text{Pinned at B})$$

$$K_{cd} = 1/2 \times I/22.5 = .022 I \quad (\text{Symmetry})$$

(2) Distribution factors:

$$DF_{bc} = 1$$

$$DF_{cb} = .125 I / .147 I = .85$$

$$DF_{cd} = .022 I / .147 I = .15$$

(3) Fixed-end moments:

$$FEM_{ba} = + \frac{wL^2}{2} = + \frac{(w)(9)^2}{2} = + 40.5w$$

$$FEM_{bc} = -FEM_{cb} = - \frac{wL^2}{12} = - \frac{(2w)(4.5/6)(6)^2}{12} = -4.5w$$

$$FEM_{cd} = - \frac{wL^2}{12} = - \frac{(.5w)(22.5)^2}{12} = -21.1w$$

(4) Moment distribution:

DF	B		C	
	0	1	.85	.15
FEM	+40.5w	- 4.5w	+ 4.5w	-21.1w
Dist.		-36.0w	+14.1w	+ 2.5w
C. O.		0	-18.0w	0
Dist.		0	+15.3w	+ 2.7w
Fin. Mom.	+40.5w	-40.5w	+15.9w	-15.9w

$$M @ \dagger C - D = M_c + \frac{wL^2}{8} = -15.9w + \frac{(.5w)(22.5)^2}{8} = +15.8w$$

For final moment diagram, see Fig. 11, page 37.

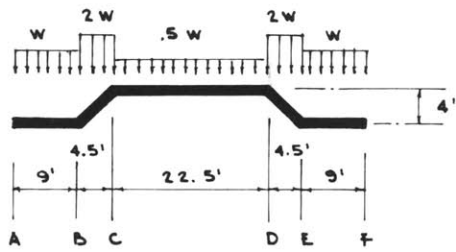


Figure 10

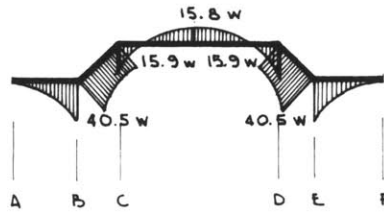


Figure 11

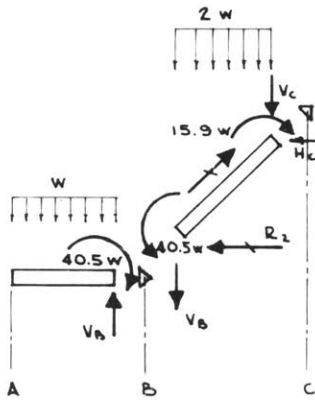


Figure 12

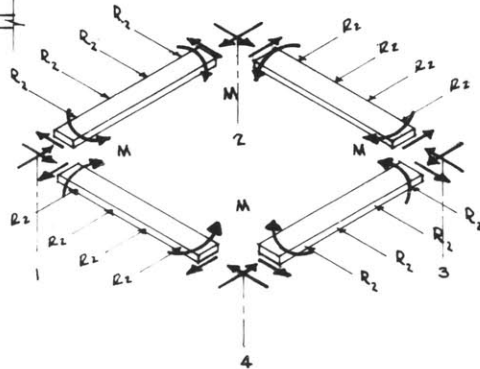


Figure 13

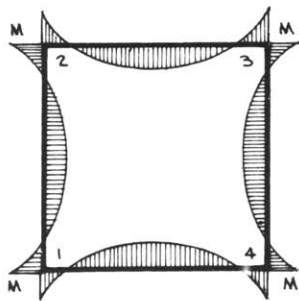


Figure 14

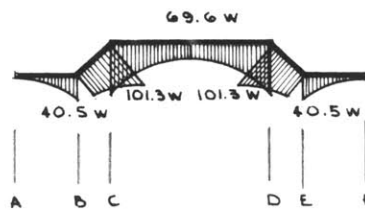


Figure 15

(5) Reactions and axial forces: (See Fig. 12, page 37.)

$$R_1 = 6.0/4 [(w \times 9) + (2w \times 4.5) + (.5w \times \frac{22.5}{2})] =$$

$$6.0/4 [23.6w] = 36.4w$$

$$R_2 = 4.5/4 [23.6w] = 26.6w$$

$$V_b = w \times 9 = 9w$$

$$V_c = .5w \times \frac{22.5}{2} = 5.6w$$

$$\Sigma M_b(B-C) = -40.5w + 15.9w + (5.6w \times 4.5) + (2w \times 4.5 \times \frac{4.5}{2})$$

$$- (H_c \times 4) = 0$$

$$H_c = 5.2w$$

Observations:

- (1) R_1 is the loading for supporting beams.
- (2) R_2 is the loading for the horizontal beams.
- (3) H_c is an axial compressive force in member C-D, desirable in a concrete section. However, if members B-C and D-E are not sloped, this axial load would become tension.
- (4) The moments over the frame would be less efficiently distributed if members B-C and D-E were not sloped.

b. Supporting Beams - The main function of the supporting beams (1-2, 2-3, 3-4, and 1-4) is to transfer the resultant forces (R_1) from the frames to the columns. (Figs. 9 and 12, pages 34 and 37.) They accomplish this by simple beam action. It becomes practical to make these beams relatively thin (five inches) for the following reasons:

(1) The beams are relatively deep (six feet for a thirty feet span).

(2) The frames (B-C and D-E) act as stiffeners four and a half feet on centers so there is little danger of buckling.

(3) Because these beams are thin, their relative torsional stiffness is small when compared to the bending stiffness of the frames (B-C-D-E) and the torsional stresses imposed upon them by the action of the cantilevered portions of the frames (A-B and E-F) are negligible.

c. Horizontal Beams - The primary function of the horizontal beams is to resist the horizontal reactions (R_2) from the frames (Figs. 9 and 12, pages 34 and 37). They do this through beam action and the transfer of reaction moments and reactions between each other as shown in Fig. 13, page 37. The moment diagram for the four beams will be as shown in Fig. 14, page 37, and the reactions from one beam to the two beams perpendicular to it at its ends will be desirable compressive axial forces. (See Fig. 13, page 37.) The weight of these beams will be carried by the supporting beams.

If these horizontal beams were removed from the structure, points B and E would be free to move horizontally in space and portions A-B-C and D-E-F would act as cantilevers from points C and D respectively. An analysis of a typical frame under this condition will be made

for comparison with the results of the previous analysis.

Analysis:

$$M_b = M_e = \frac{wL^2}{2} = \frac{(w)(9)^2}{2} = 40.5w$$

$$M_c = M_d = w(9) \left(\frac{9}{2} + 4.5 \right) + \frac{(2w)(4.5)^2}{2} = 101.3w$$

$$M @ \text{ † C-D} = M_c - \frac{wL^2}{8} = 101.3w - \frac{(.5w)(22.5)^2}{8} = 69.6w$$

For final moment diagram, see Fig. 15, page 37.

Observations:

If the moment diagram of the frame with the horizontal beams (Fig. 11, page 37) is compared to the moment diagram of the frame without the horizontal beams (Fig. 15, page 37), it is obvious that the frame is more efficient (250% - based on the maximum moments in each case) with these elements which add relatively little to the cost of the structure. A tabulation of the respective moments is shown for comparison.

Point	Moments	
	With Hor. Beams	Without Hor. Beams
A, B	40.5w	40.5w
C, D	15.9w	101.3w
† of C-D	15.8w	69.6w

A secondary function of the horizontal beams is to resist the thrust of the supporting beams (1-2, 2-3, 3-4, and 1-4) at the columns by using a tie member.

d. Columns - There are no moments transferred to the columns under the loading conditions as discussed. However, under certain conditions, there will be lateral loads imposed on the structure and it becomes necessary for the columns to resist moments. There are three combinations of connections that could be used between the columns and the structure and the columns and the footings. They are: (1) fixed at top and bottom, (2) fixed at top, pinned at bottom, and (3) pinned at top, fixed at bottom. Each of these conditions has an effect on the size of moments produced in the columns, the size of moments produced in the structure, and the magnitude of the soil pressures produced under the footings. The smaller number in the table below indicates the degree of desirability of the condition for each case.

Column Connections	Moments in Column	Moments in Structure	Soil Pressure
Fixed top and bottom	1	2	2
Fixed top and pinned bottom	2	3	2 1
Pinned top and Fixed bottom	2	1	2 3

Considering the three criteria of equal importance, the most desirable column connections are fixed top and bottom. However, there may arise a time when soil conditions are

such that low soil pressures are desirable. In this case, the columns would be pinned at the bottom.

3. Erection Sequence

a. Site is prepared and four square individual footings are poured.

b. Columns are either poured in place after footings are completed or pre-cast and set in place before footings are poured.

c. Floor slab containing the heating equipment and any plumbing connections necessary is poured. Floor slab details depend on site location.

d. Scaffolding for support of pre-cast panels is erected on floor slab. It may be constructed of either rough lumber or metal tubing, depending on number of planned re-uses. There is no form-work required.

e. Pre-cast panels are set in place on scaffolding. Two men can easily handle each panel.

f. Reinforcing bars are placed between panels and necessary conduits are inserted.

g. Concrete is poured between panels on horizontal surfaces and over panels on sloped surfaces.

h. Scaffolding is removed.

i. Inserts, whether sky-lights, blank panels, or utility panels, are placed in openings in pre-cast panels. Lighting is installed.

j. Roofing is applied.

k. Partitions, utility units, and storage units are located under structure as dictated by proposed use.

l. Exterior walls are glazed (unless pre-glazed panels have been used), finishes and finish materials are applied, furniture is installed.

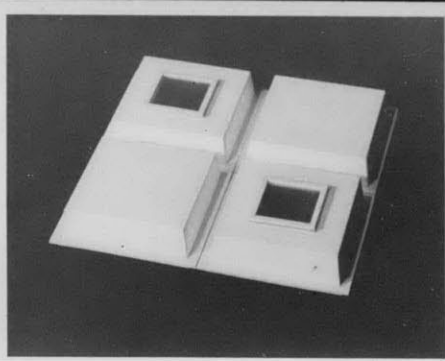
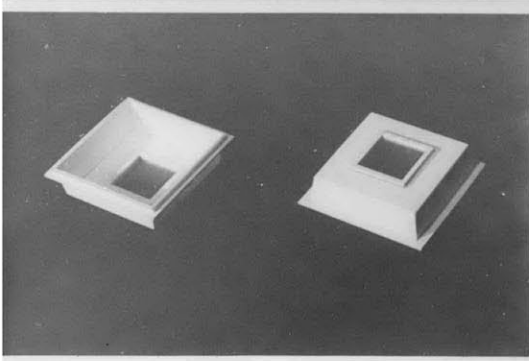
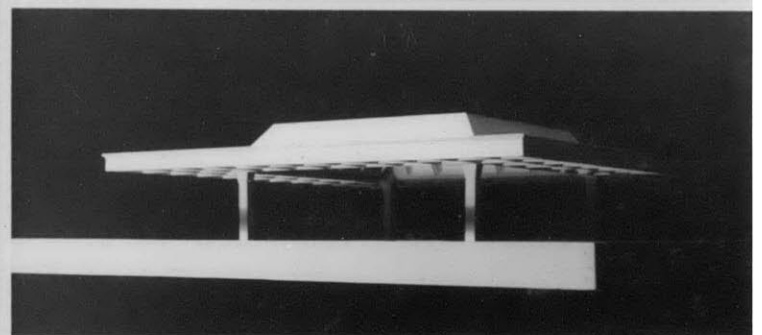
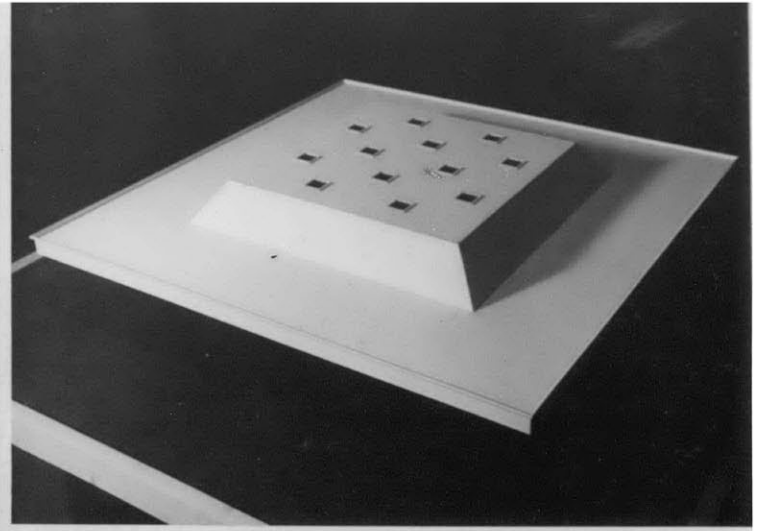
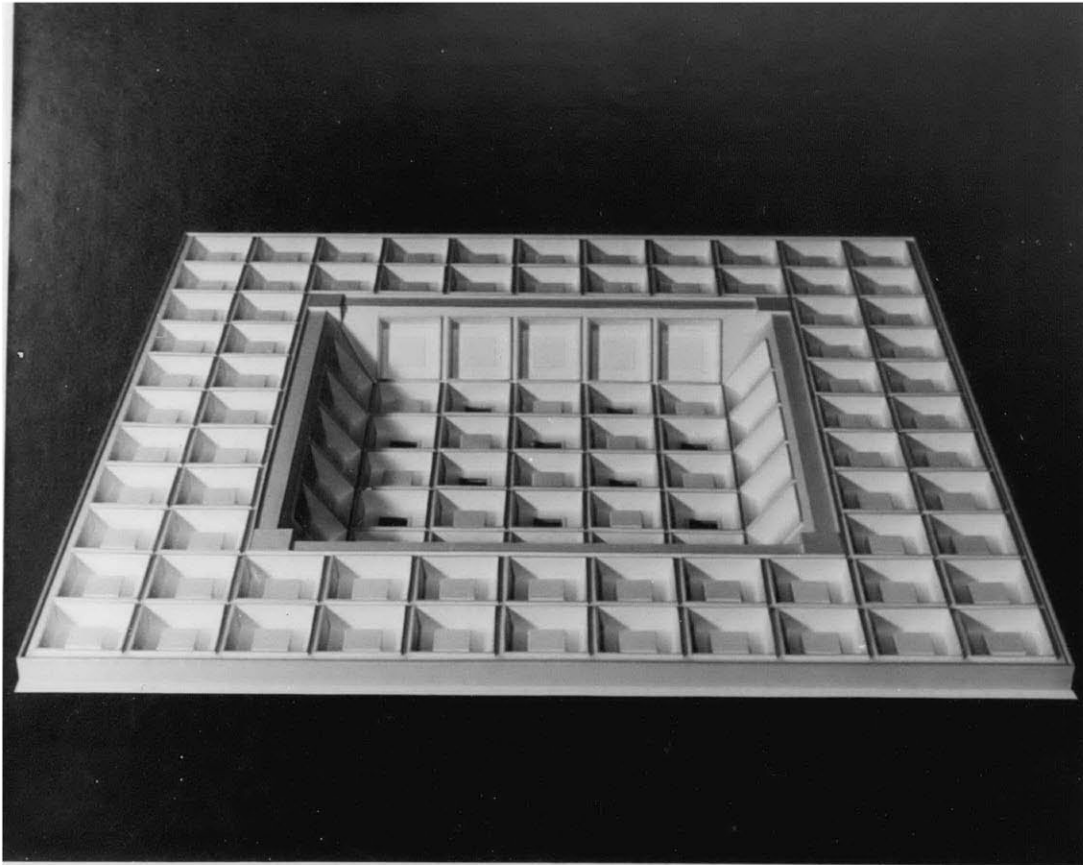
IV. CONCLUSION

A. A systematized structure based on the geometric ordering of surface can be developed to satisfy a specific architectural condition.

B. This structure can be designed to provide the essential services for useful occupation.

C. Based on the stated span condition, this structure can be erected in the field economically, with a minimum amount of skilled labor.

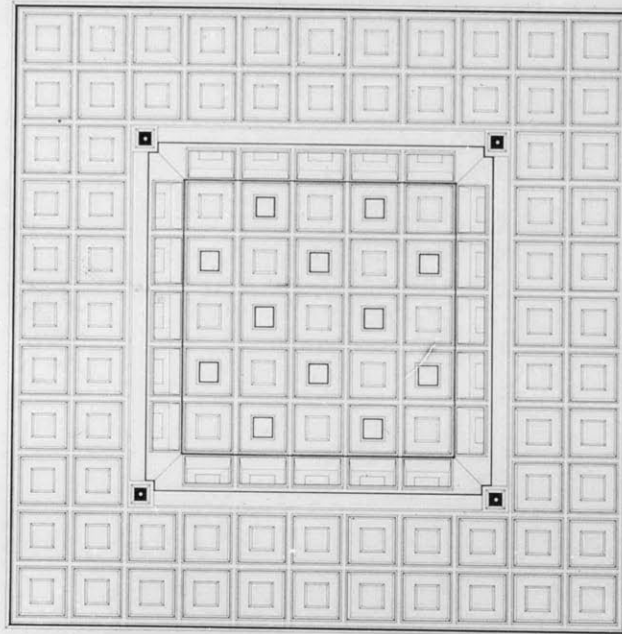
D. This investigation deals with principles that have broad application in the building industry and offer potential for future research into materials, methods, and use.



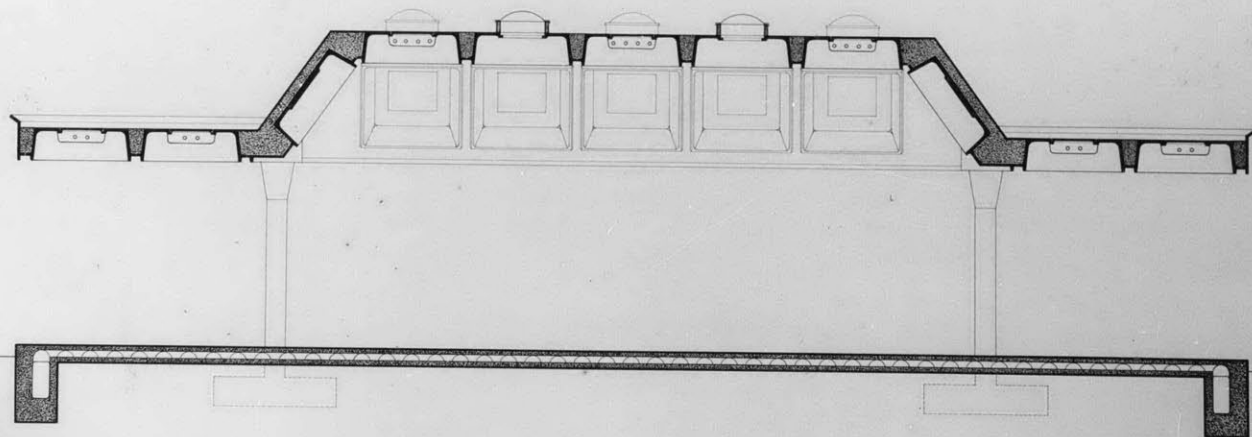
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A PROTOTYPE STRUCTURE

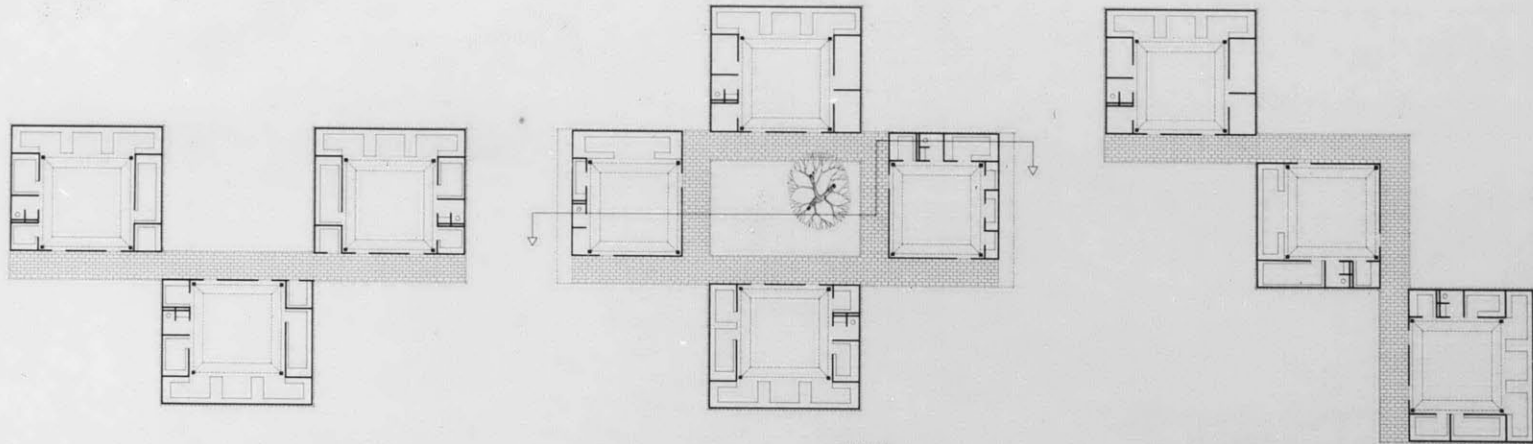
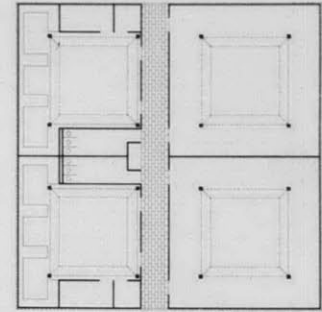
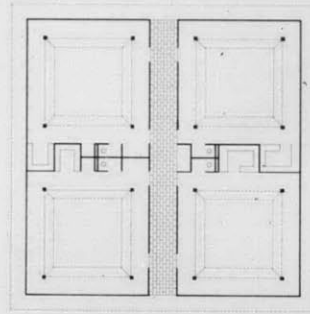
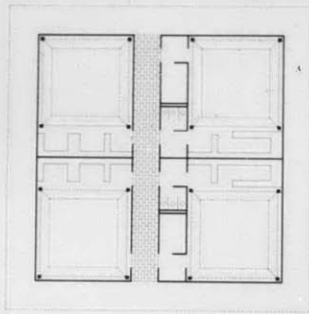
RALPH LEWIS KNOWLES
STANLEY P. STEINBERG



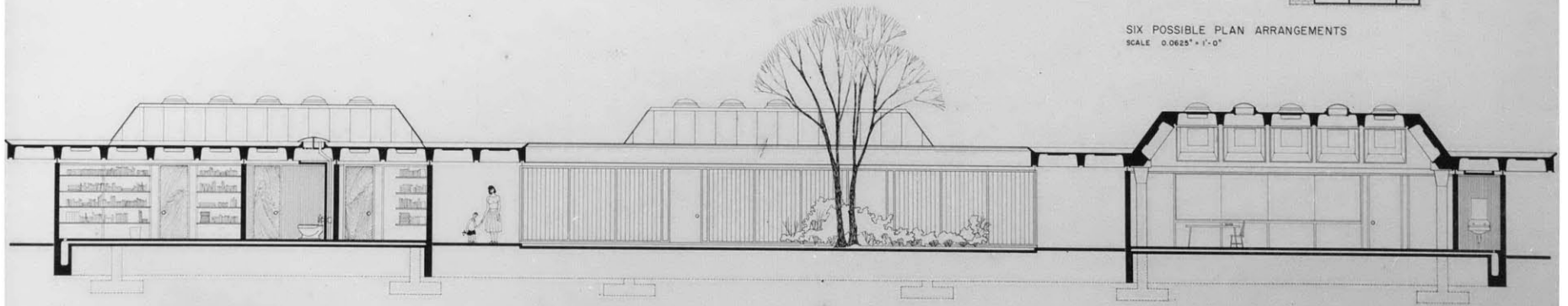
REFLECTED CEILING PLAN
SCALE 0.25" = 1'-0"



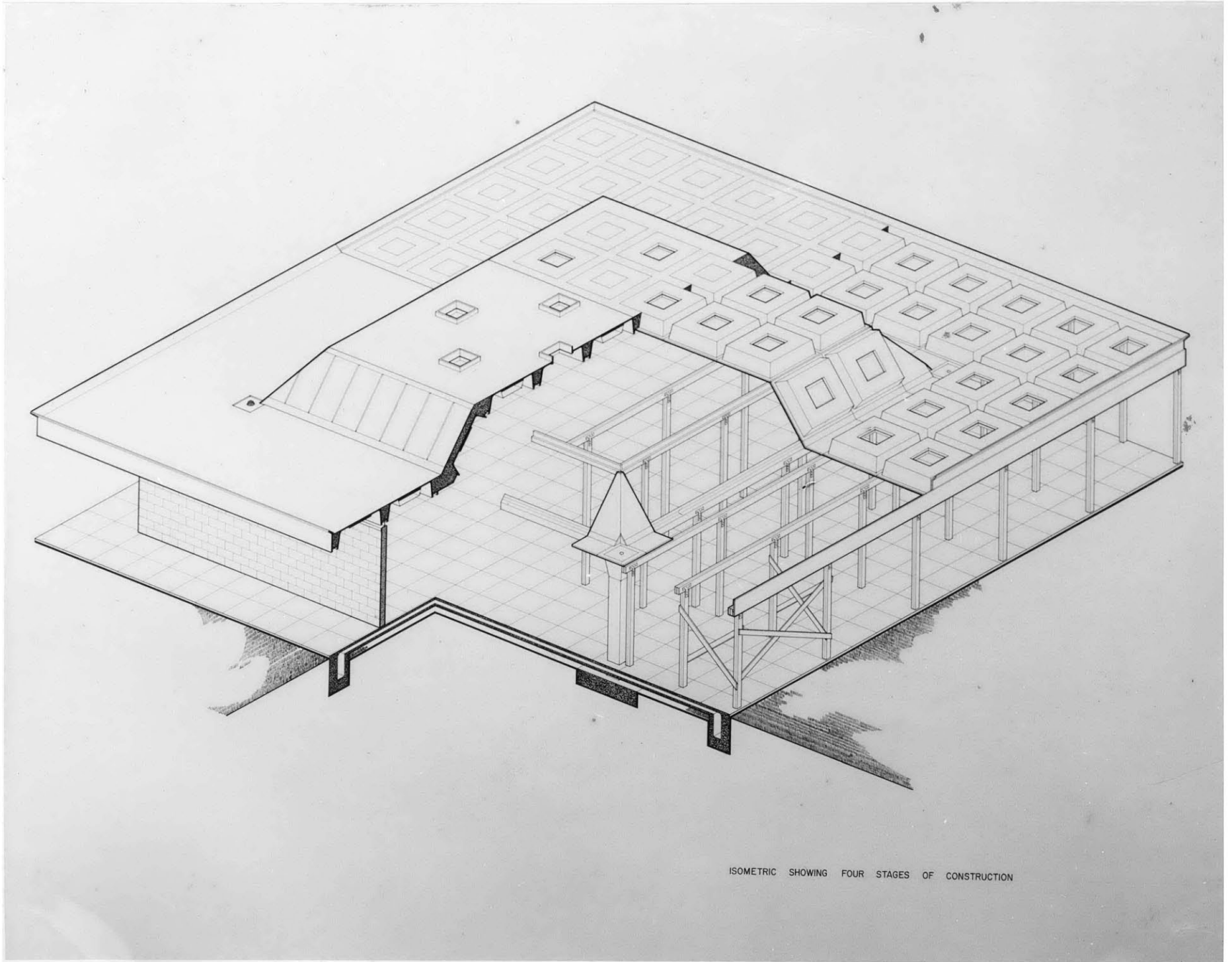
TYPICAL SECTION
SCALE 0.80" = 1'-0"



SIX POSSIBLE PLAN ARRANGEMENTS
SCALE 0.0625" = 1'-0"



SECTION
SCALE 0.25" = 1'-0"



ISOMETRIC SHOWING FOUR STAGES OF CONSTRUCTION

