

A LABORATORY BUILDING FOR RESEARCH AND DEVELOPMENT

by

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Dear Dean Belluschi:

In partial fulfillment of the requirements for the degree of Master of Architecture, I hereby submit this thesis, entitled "A Laboratory Building for Research and Development".

Respectfully,

Austris J. Vitols

## ABSTRACT

Title of Thesis: A LABORATORY BUILDING FOR RESEARCH  
AND DEVELOPMENT

Author: Austris J. Vitols

Submitted to the Department of Architecture on  
June 15, 1965 in partial fulfillment of the requirement  
for the degree of Master of Architecture.

The objectives of this thesis are to develop a structural system based on advances in present-day technology, to supplement this structural system with elements needed in a laboratory building for research and development, and to provide an architectural form which anticipates increases in the building mass.

The structural system encompasses advances in the technology of prefabrication and speed of erection. It also allows for changes in the distribution of services and is thereby flexible.

Therefore, the ultimate objective is a building as a system of growth, structure, and services.

Thesis Supervisor: Eduardo Catalano  
Title: Professor of Architecture

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## TABLE OF CONTENTS

	Page
Title Page . . . . .	i
Letter of Submission . . . . .	ii
Abstract . . . . .	iii
Acknowledgements . . . . .	iv
I. Introduction . . . . .	2
II. Building Concept	
A. Design Approach . . . . .	4
B. Components of Building. . . . .	5
III. Structural Concept	
A. Selection of Material . . . . .	10
B. Types of Precast Concrete Systems .	11
C. Proposed Structural System. . . . .	13
D. Calculations of Components. . . . .	18
IV. Mechanical and Electrical Systems. . . . .	23
V. Photographs of Drawings and Models	

## I. INTRODUCTION

Architecture, in order to meet present-day needs, must develop a vocabulary which makes use of advances in technology, provides for orderly growth of structures, and provides flexibility in the internal spaces of buildings. These objectives can be fulfilled by systematic use of elements based on construction procedures.

Buildings conceived as integrated systems of structure and mechanical services can serve a wide variety of uses within the life span of the building. Permanent materials are used in construction today, but the building becomes obsolete long before the life span of its physical shell is realized. Consequently, a hierarchy must be recognized between permanent and non-permanent elements in buildings. Permanent elements of structure and service cores should allow access to distribution of services which will change as the functions of areas in the building change.

Creative engineering is necessary to conceive of systems which can be manipulated in order to achieve

various spatial configurations in structures, provide life in the building, establish a clarity of organization, and develop a hierarchy of elements. Creative engineering is also needed to make greater use of mass produced building components made in factories under controlled conditions. This will serve to reduce the cost of buildings as well as reducing erection time. The building industry currently forms the largest single element of our economy, and yet it lags far behind other industries in the use of mass production of standardized parts. The majority of structures built today use construction techniques which are at the mercy of the climate.

In conclusion, the architect must make greater use of scientific investigation and seek universal standards in architecture which will not limit man's individuality in creation but will stimulate it. This scientific investigation should be applied to construction. Structural logic has universal values which can be recognized. The result will be a greater order to our visual environment; an order which will not be destroyed by growth but one which will gain in richness as a result of growth.

## II. BUILDING CONCEPT

### A. Design Approach

A laboratory building for research and development requires qualities which are common to many building types today. These qualities are flexibility and potential for growth. The function of such a structure for research and development is to provide a framework which allows for changes in the internal spaces as well as changes in the servicing of these spaces. The building must be flexible in the sense that it may readily expand as the needs arise for additional space.

Growth and flexibility can be realized in an architectural statement by creating a self-sufficient unit of structure and services. Such a unit consists of a basic structural bay which is a two-way system with 50 foot spans between columns and 15 to 20 foot cantilevers on all four sides. The structural bay utilizes the negative moments of cantilevers to relieve positive moments at the center of the span. Four such structural bays combine to form a self-



sufficient cell which is served by a mechanical room. The dimensions of each cell are 175 feet by 175 feet. The resulting floor area is 30,000 square feet. This is the basis for generating an architectural form initially, and for eventually completing the statement by adding additional increments of growth of this size.

#### B. Components of Building

Self-sufficient cells are combined to fulfill the requirements of a 600,000 square foot building. This is achieved by combining 20 such cells into a building mass which makes an initial and permanent architectural statement. This is the dominating element in the initial and future organization of self-sufficient cells.

Servicing cores are structurally independent of the basic structural bay and situated at the meeting point of four structural bays. In this position, services (supply and return air ducts, plumbing pipes, and electrical conduits) enter the structural bay at points of minimum stress. These points occur at the junction of two cantilevered sections and, therefore, are

characterized as areas having the minimum bending moment as well as minimum shear force.

The relationship of cores to structural bays, previously described, allows for a choice of core locations which will best serve the functions of producing life in a structure as well as recognizing the construction procedure of this structure.

Cores are located at positions shown in Fig. 1 in order to distribute services equally to all parts of the building, to satisfy code requirements of emergency egress, to support the minimum number of cranes (2), and to place vertical circulations near the heart of the building. Each core contains vertical shafts for supply and return air. Other air shafts are placed at the exterior skin of the building in order to enter the structure at points of minimum stress and reduce the number of obstructions within the building volume. All cores contain fire escape stairs which are within 150 feet of any part of the building.

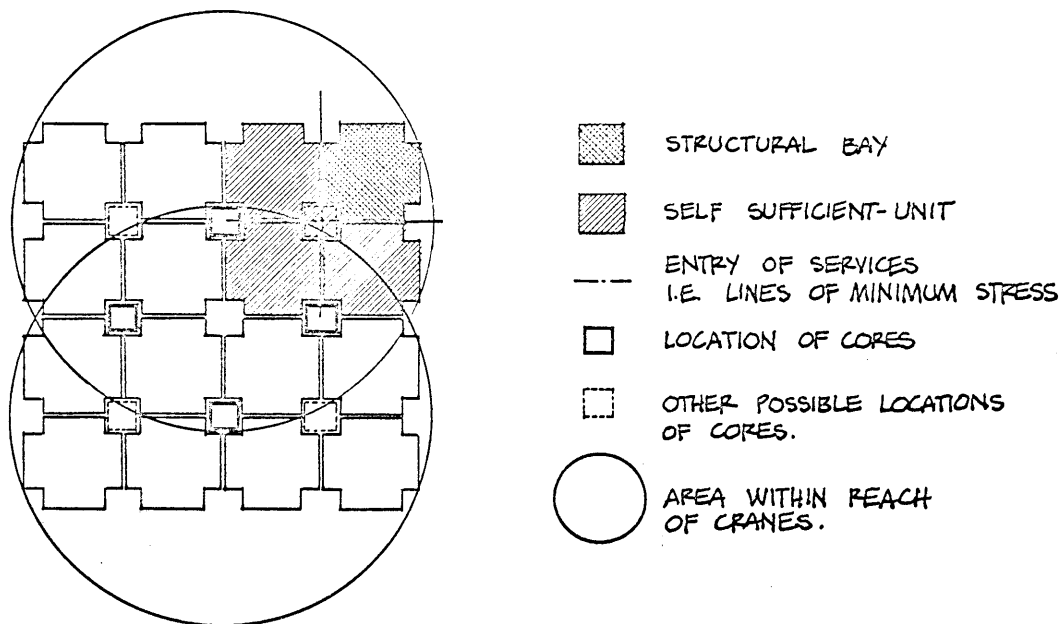


FIG. 1

Areas within the cores are based on the following requirements:

- A. One 5'-0" x 7'-6" elevator in building of five floors serves a net floor area of 50,000 square feet.

Therefore, 
$$\frac{\text{total area of building}}{\text{area served by one elevator}} = \frac{358,400}{50,000} = 8.$$

- B. Return air shafts require 1 sq.ft./1,000 sq.ft. of floor area. Supply (high velocity) air shafts require 1 sq.ft./4,000 sq.ft. of floor area.

- C. One electric closet, 2' x 10', for every 15,000 sq.ft. of gross area.

- D. One telephone closet, 50 sq.ft., for every 15,000 sq. ft. of gross area.
- E. One janitor's closet, 30 sq.ft., for every 30,000 sq. ft. of gross area.
- F. One public telephone for every 15,000 sq.ft. of gross area.
- G. Two 8' x 14' service elevators.
- H. Plumbing selection:
- |                   |            |
|-------------------|------------|
| 450 persons/floor | 28 w.c.    |
|                   | 28 lavs.   |
| Assume 50% women  | 14 w.c.    |
|                   | 14 lavs.   |
| Assume 50% men    | 14 w.c.    |
|                   | 10 urinals |
|                   | 14 lavs.   |

The building system is further manipulated by removing two structural bays, thereby creating an open space near the center of the building. This space becomes the culmination of exterior spaces which will be completed and defined as the system grows.

It also provides an opportunity to perceive the building more fully and serves as a point of orientation within the building. Finally, it exposes spaces within the building to natural light.

Meeting points of the four basic structural bays which are not occupied by service cores form two-story lounge spaces. These spaces contain open stairs for vertical circulation between floors. They are organized around the larger open space providing a hierarchy of spaces from the individual one-story office or laboratory space to the two-story lounge space culminating finally in the large open central space.

The ground floor of the structure serves to house communal functions such as a library and lecture halls.

### III. STRUCTURAL CONCEPT

#### A. Selection of Material

The structure of a building of growth and flexibility must serve to house various arrangements of services and room partitions. It must also provide access to services so that they can be readily altered to serve changing needs. Finally, points of vertical support must be far enough from the building perimeter so that supports may be added as the structure grows without disturbing the existing foundations.

Precast concrete was selected as the structural material because it is fireproof and allows for a complete structural expression which cannot be accomplished in steel because of fireproofing requirements for steel structures. The advantage of being able to continue construction during cold weather, which has been a definite advantage of steel construction in the past, has been eliminated by the use of precast concrete. The precast members may be cast in the plant during freezing weather and assembled on the job site in much the same manner as steel members.

Precast concrete also has many advantages over cast in place concrete. The material offers considerable savings by reducing the use of on the job formwork and scaffolding. As a result, it provides for a faster means of erection. Finally, the material is manufactured under factory controlled conditions ensuring quality control in dimensioning and finishing.

#### B. Types of Precast Concrete Systems

There are three primary types of precast concrete floor systems: the one-way system, the two-way system, and a combination one-way and two-way system.

The one-way framing system is the most direct and has been used extensively in the past. It requires the use of beams and major girders to transfer loads to the column. Only in the most sophisticated applications of the one-way system are both prestressing and post-tensioning performed. The prestressing carries the stressed due to handling and dead loads; the post-tensioning carries the live loads and any topping used as a diaphragm or finished floor. As a result, flexibility of distribution of mechanical services is

hampered because the ceiling which results from exposing the structure is directional and distribution of stresses in the bay is evident in the differentiation of the sizes of members. In addition, the one-way system does not make use of continuity of structure and is therefore less efficient.

The two-way floor system may involve only one typical member post-tensioned in two directions or one or more typical beams pretensioned with filler panels which are post-tensioned, forming a two-way matrix.

In all cases, two-way systems require post-tensioning which involves a more complicated procedure than prestressing. Post-tensioning involves placing of jacks on the structure and tensioning the cables after they have been threaded through the members. The major difficulties in a two-way system arise in the joints between many members. Areas where joints occur must be overdimensioned in order to accommodate compressive forces due to post-tensioning. Secondly, minute deviations in positioning of holes for post-tensioning cables require enlargement



of openings at the surfaces of contact between two precast members. The result is a lessening of the effective bearing area between members. Consequently, the surfaces must be additionally overdimensioned. Finally, assembly of a two-way system composed of small elements usually requires an extensive use of scaffolding.

The advantages of a two-way system are that it makes greater use of continuity of structure and it provides greater flexibility in distribution of services. Girder stresses can be distributed over a large area. Greater areas of the structural slab may be perforated to provide routes for mechanical services because the stresses are distributed more evenly throughout a slab. Finally, the two-way system forms a modular grid in the ceiling plane which will accept partitions in various configurations.

### C. Proposed Structural System

A two-way, precast, post-tensioned, lift slab system based on a five foot module is proposed. The objectives of this system are to solve the problem of

overdimensioning of elements at joints, to simplify the procedure of threading individual members, and to eliminate the use of scaffolding. Elements are cast in 5'-0" x 5'-0" x 4'-0" high sizes in order to eliminate the need for prestressing of members. Such small members are not subjected to excessive loads due to weight of members, nor to excessive stresses which occur during handling and erection.

The system is composed of lower chord members, upper chord members, column clusters, and shear members.

In order to eliminate these problems of the joint, separate precast elements are used in the lower chord. These elements serve as compression members during the post-tensioning process and serve to separate surfaces of members which carry post-tensioning cables. Such an arrangement exposes the post-tensioning cables to view for most of the span and eases the threading of cables throughout the structure. The upper chord, floor slab, and web of the structure are incorporated in one element. This element is table-like with an enlargement of cross-

section at its base to give it stability during assembly. The top slab is notched 5'-0" on center in both directions to receive cables for negative moment post-tensioning. These two elements are repeated over the length of the 50 foot span as well as the extension of 15 foot cantilevers. Major girder forces are distributed laterally over three five foot modules between columns by the use of an additional 4" x 6" x 3'-4" long concrete bar which completes the lower chord in this area. The result is a lower chord of increased area which transfers forces from the slab to the column.

The column cluster, in turn, is composed of four elements angle-like in cross-section, combining to form a cross-shaped void in the interior of the column cluster. Columns are cast in 75 foot sections. Two such vertical sections complete the column length. The angle-like crosssections are given additional stability by a diaphragm member which occurs at each floor level and becomes part of the structural floor slab.

The joint between vertical column sections is accomplished by welding a steel plate around the edge

of the column cross-section to the vertical reinforcing bars. The plate provides a grout pocket for the next column section. A steel dowel is welded to a steel plate placed in the middle of the column cross-section. A steel socket is cast into the top column section. A temporary basket is assembled at the top of the first column section of steel (6'0" long) and wire. This procedure provides a freshly grouted seat for the upper column section which is then hoisted into place. The steel basket is then removed.

The final structural element is a cross-shaped shear piece which fits into the void formed by column clusters. This shear piece is attached to hoisting cables and, using the void in the column cluster as a track, is hoisted into final position and secured there by a wedge penetrating the column cluster.

Erection procedure:

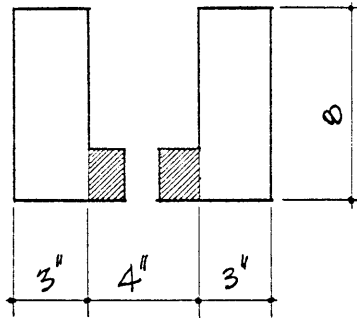
1. Basement floor slab is poured.
2. Walls of cores are poured to an intermediate height and two cranes are positioned (see Fig. 1) and anchored to core walls.
3. Bottom chord elements of first floor slab are

placed into position, shear elements are positioned, and cranes place the table-like elements into cross-shaped slots formed by bottom chord members. The first floor slab is post-tensioned.

4. The same procedure is repeated as three more floor slabs are stacked on the first floor.
5. The bottom sections of column clusters are lowered into place, wedged and secured into column foundations.
6. The top floor slab is hoisted into final position.
7. The remaining floor slabs are stacked above the hoisted floor slab.
8. The upper sections of column clusters are lowered into position and secured.
9. Floor slabs stacked at two levels are now hoisted simultaneously into final positions by hoisting jacks at top of column clusters.
10. Grout is placed in channel of lower chord to fireproof post-tensioning cables.
11. Utilities are placed in the structure, topping is poured and finishing of the building is completed.

## CALCULATIONS

### BOTTOM CHORD OF FLOOR SYSTEM



CROSS SECTION AT  
BOTTOM CHORD

EFFECTIVE AREA =  $48 \text{ in}^2$

TOTAL LIVE LOAD AND  
DEAD LOAD

$$Q = 200 \text{ lbs/ft}^2$$

MOMENT AT MAX. CANTILEVER (20 ft.)

$$M = \frac{QL^2}{2} = \frac{200 \times 20^2}{2} = 40,000 \text{ ft-lbs.}$$

MOMENT ARM OF INTERNAL FORCES =  $3\frac{1}{3} \text{ ft.}$

$$\begin{aligned} \text{MAX. STRESS IN CHORD (1/5)} &= \frac{40,000 \text{ ft-lbs}}{3\frac{1}{3} \text{ ft.}} \\ &= 1,200 \text{ lbs.} \end{aligned}$$

IN EACH UPPER CHORD (WIDTH OF 5 ft.)

$$\text{TENSION} = 1,200 \text{ lbs.} \times 5 = 60,000 \text{ lbs.}$$

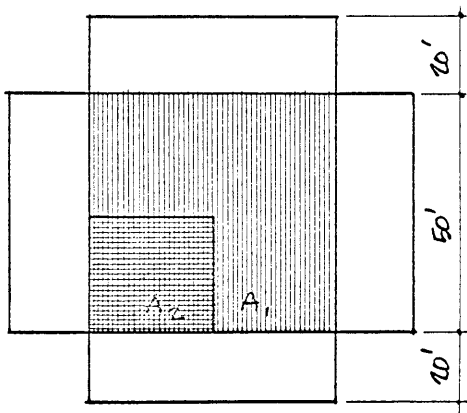
COMPRESSION IN LOWER CHORD = 60,000 lbs.

ALLOWABLE COMPRESSIVE STRESS IN CONCR.  
=  $14,000 \text{ psi.}$

AREA OF CROSS SECTION REQUIRED

$$\frac{60,000}{1,400} = 42.86 \text{ in}^2$$

### TOP CHORD OF FLOOR SYSTEM



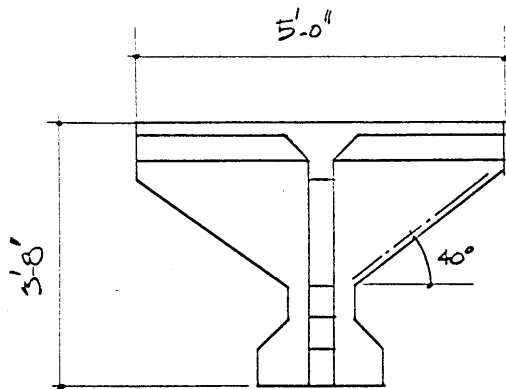
SHEAR AT CONNECTION OF SLAB TO COLUMN

$$A_1 = 50 \times 50 = 2,500 \text{ ft}^2$$

$$\begin{aligned} \text{TOTAL LOAD} &= 2,500 \text{ ft}^2 \times 200 \text{ lbs./ft}^2 \\ &= 500,000 \text{ lbs.} \end{aligned}$$

$$A_2 = A_1/4 = \frac{500,000}{4} = 125,000 \text{ lbs.}$$

TRANSFER OF GIRDER FORCES TO COLUMN  
TAKES PLACE AT FOUR POINTS.

ELEVATION OF UPPER  
CHORD MEMBER

LOAD AT EACH OF FOUR POINTS =

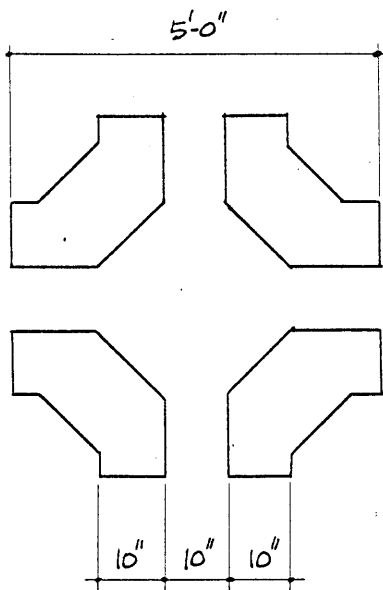
$$\frac{125,000 \text{ lbs.}}{4} \times 1.2 = 37,500 \text{ lbs.}$$

TENSILE FORCES IN MEMBER =

$$19 \text{ TONS} \times 1.4 = 26.6 \text{ TONS}$$

ALLOWABLE TENSILE STRESS IN REINFORCING  
STEEL = 30,000 psi.AREA OF STEEL REQUIRED =  $1 \text{ in}^2$   
USE 2 BARS  $\frac{3}{4}'' \phi$ .

## CALCULATIONS FOR COLUMN CLUSTER

PLAN OF COLUMN  
CLUSTER

TOTAL WEIGHT OF BAY =

$$5,500 \text{ ft}^2 \times 200 \text{ lbs/ft}^2 = 1,100,000 \text{ lbs.}$$

LOAD PER COLUMN CLUSTER =

$$\frac{1,100,000}{4} = 275,000 \text{ lbs.}$$

NUMBER OF FLOORS = 8

TOTAL LOAD PER COLUMN CLUSTER =

$$275,000 \text{ lbs.} \times 8 = 2,220,000 \text{ lbs.}$$

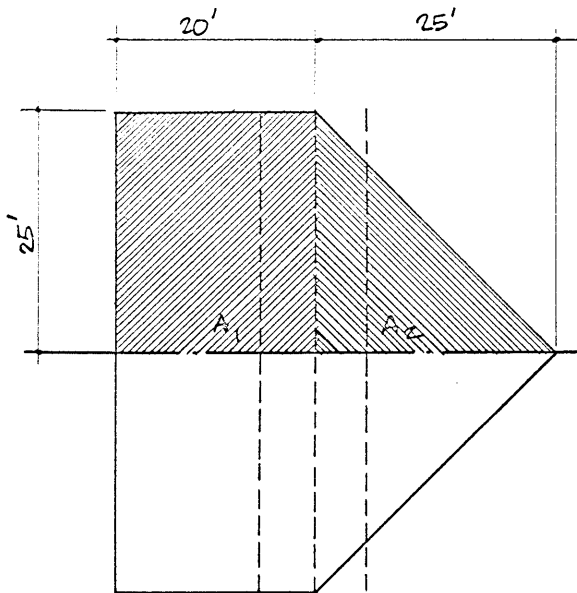
ALLOWABLE COMPRESSIVE STRESS IN  
CONCRETE = 1,400 psi.REQUIRED AREA OF CROSS SECTION AT  
BOTTOM FLOOR =

$$\frac{2,220,000 \text{ lbs.}}{1,400 \text{ psi.}} = 1,590 \text{ in}^2$$

AREA OF EACH MEMBER =

$$\frac{1590}{4} = 400 \text{ in}^2$$

## CALCULATIONS OF GIRDER STRESSES

PARTIAL PLAN  
OF BAY.

$$A_1 = 500 \text{ ft}^2 \quad A_2 = 312.5 \text{ ft}^2$$

$$A_{\text{TOTAL}} = 812.5 \text{ ft}^2$$

$$\text{LOAD ON GIRDER} = 812.5 \text{ ft}^2 \times 200 \text{ lbs./ft}^2$$

$$= 162,500 \text{ lbs.}$$

$$\text{MOMENT} = \frac{312,500 \times 25}{2} = 1,000,000 \text{ ft.-lbs.}$$

$$\text{FORCE} = \frac{1,000,000 \text{ ft.-lbs.}}{3\frac{1}{3} \text{ ft.}} = 300,000 \text{ lbs.}$$

$$\text{REQUIRED CROSS SECTIONAL AREA}$$

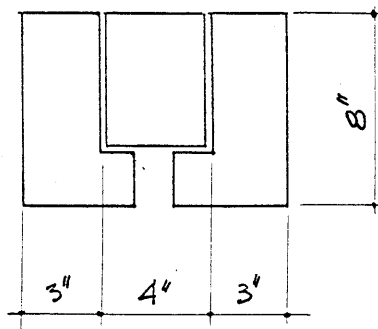
$$= 216 \text{ in}^2$$

GIRDER STRESSES ARE DISTRIBUTED OVER THREE MODULES (5'-0") HORIZONTALLY TO TAKE ADVANTAGE OF CONTINUITY DUE TO NEGATIVE MOMENT POST TENSIONING FOR CANTILEVER.

$$\text{AREA OF RESULTING BOTTOM CHORD} =$$

$$216 \text{ in}^2 \times \frac{1}{3} = 72 \text{ in}^2$$

NOTE! EFFECTIVE AREA OF SECTION INCREASES AT POINT OF CONTACT WITH OTHER MEMBERS.

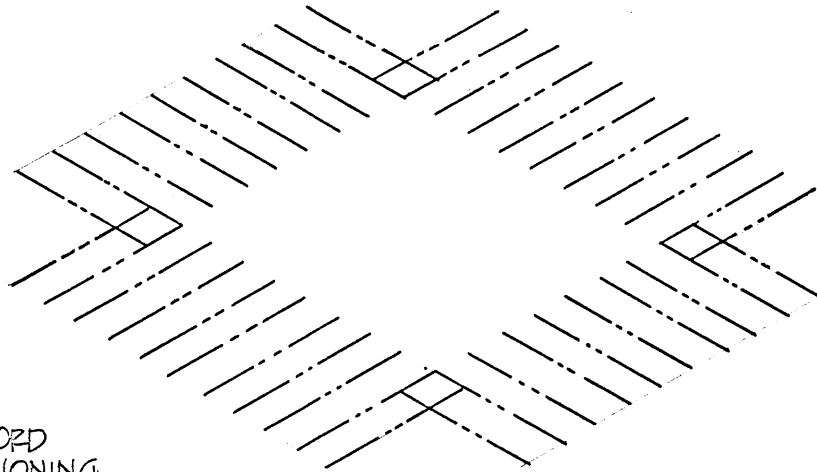
SECTION OF MODIFIED  
LOWER CHORD

LOCATION INDICATED BY  
DASH LINES IN PLAN ABOVE.

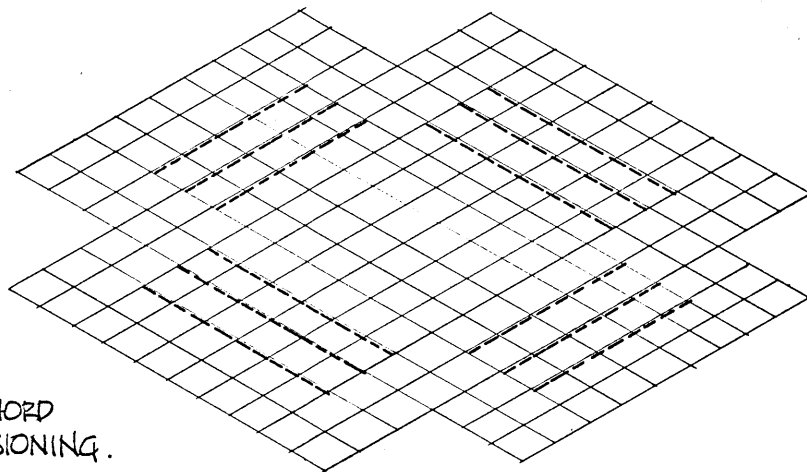
NOTE!! CALCULATIONS ARE APPROXIMATIONS OF STRUCTURAL REQUIREMENTS TO SHOW THE FEASIBILITY OF THIS STRUCTURAL SYSTEM.



ISOMETRIC OF LOCATION OF POST TENSIONING  
CABLES IN TYPICAL BAY.



UPPER CHORD  
POST TENSIONING



LOWER CHORD  
POST TENSIONING.

- |       |                     |                      |            |
|-------|---------------------|----------------------|------------|
| ----- | FOR NEGATIVE MOMENT | - 1 CABLE 1" $\phi$  | 5'-0" O.C. |
| ----- | FOR GIRDER STRESSES | - 2 CABLES 1" $\phi$ | 5'-0" O.C. |
| ----- | FOR BOTTOM CHORD    | - 1 CABLE 1" $\phi$  | 5'-0" O.C. |

The resulting structure forms a monolithic floor slab of constant depth which is perforated in web sections of members in two directions. Utilities can be placed from below. It is a post-tensioned structure made of small pieces but has no visible joints in the lower chord or ceiling plane. Finally, the lower chord members are light enough (450 lbs.) so that they may be shifted and tolerances adjusted during assembly by one or two men with crowbars.

Individual structural elements are cast with metal forms. Four forms are used per member. Reinforcing steel cages are tied in cross-shaped configuration. The forms are placed around the cross, concrete is poured, vibrated and cured. The four sections of the form are then removed and reused in casting other members. No tapering of members toward the extremities is required in this method of casting because the friction forces between cast pieces and forms are at a minimum.

Finally, the problem of joints and tolerances is lessened because no threaded members come in direct contact with each other.

#### IV. MECHANICAL AND ELECTRICAL SYSTEM

A laboratory building for research and development must have a controlled climate. Therefore, windows are fixed and sealed. Air-conditioning takes care of heating, cooling, ventilating and humidity control. With a controlled environment it is possible to arrange partitions in any manner, thereby achieving flexibility.

The mechanical system consists of high velocity supply air shafts and low velocity return air shafts. Air is supplied at a temperature of 60 to 65 degrees to each floor by means of shafts in service cores and on the outer skin of the building. It then passes through boxes which reduce its velocity from 4,000 cu.ft. per minute to 1,000 cu.ft. per minute. Ceiling diffusers are equipped with heating coils so that the temperature of air can be controlled at each point. Lighting fixtures are integrated with the heating coil, supply air outlet and return air grille, and occur 10 feet from center to center in alternating modules. Air in the exterior zone (15 feet deep) is handled by fan coil units placed below the glass to counteract

drafts. Fan coil units are supplied by hot and cold water lines and a return line.

Fans for the mechanical system are situated on the roof in eight mechanical rooms. Four of these are placed on top of cores. Shafts in the service cores conduct plumbing risers as well as supply and return air.

Ducts and plumbing pipes are distributed horizontally in the perforations of the structural system. Openings are cast in the floor slab 10 feet on center, which allows for access to plumbing lines. Fume hood exhausts may be placed in the cavities of the column clusters and exhausted directly at the top of each column.

Telephone and electrical service is situated under floor ducts with access at the center of each module. Electrical conduits and telephone service originate from electrical closets located in the service core on each floor.