

THE DEVELOPMENT OF
A LINEAR STRUCTURAL SYSTEM
FOR TWO DIRECTIONAL GROWTH

by

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Dear Dean Belluschi:

In partial fulfillment for the degree of Master in Architecture I submit this thesis entitled, "The Development of a Linear Structural System for Two Directional Growth".

Yours respectfully,

Joseph Brunon

ACKNOWLEDGEMENTS

I am grateful to all those members of the staff who offered their encouragement and criticism during the development of this thesis, and particularly to Mr. Waclaw Zalewski, Visiting Professor of Structures, Mr. Leon Groisser, Instructor in Structures, and Professor Eduardo F. Catalano, Thesis Supervisor.

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INTRODUCTION

For centuries man has sought an apprehension of the universe both through his intellect and through his senses in an effort to establish order around him. Systems of order are readily recognizable, being a set of things whereby each member of the set is bound to other members in some clear relationship. Each member is a complete entity, yet functions as a part of a system forming a pattern which at every stage of its growth exhibits an orderliness. A simple example of a system studied and explained in the earliest days of modern science is our own solar system and the planetary systems of the universe. The planets move within their own orbits in relation to their sun and each solar system moves as part of a greater system forming organized galaxies in the universe. The introduction of the microscope revealed a whole new world of systems in nature hitherto unknown. Minute cell structures, independent unicellular systems, and crystals all became seen as growing forms obeying laws to produce complete systems.

With the development of mathematics, the system approach became a basis for scientific study whereby laws were discovered, such as a mathematical formula describing a parabola. Solid geometry introduced further systems such as

the hyperbolic paraboloid. In our time, the electronic computer has opened a new field for systems, the organization and complex processing of vast quantities of data.

A. THE NEED FOR ANALYTICAL METHODS IN ARCHITECTURE

Architecture always will remain a spatial art. However, because of new demands made by an enlightened and interested public and because of the complexity of projects the architect faces today, the concept of the architect as an artist is unacceptable. The architect must use logic and clarity to put his emotions on a responsible level. "How convenient for the architect to consider himself an artist!

....emotional attitudes must act with common sense, not in its place."¹

The architect who is governed by emotion and intuition makes decisions more readily, for this is easier than making decisions governed by responsibility. "As his capacity to invent clearly conceived, well-fitting forms is exhausted further, the emphasis on intuition and individuality only grows wider.his intuitive ability to organize physical form is being reduced to nothing by the size of the tasks in front of him, and mocked by the efforts of the 'artists'. What is worse, in an era that badly needs designers with a synthetic grasp of the organization of the physical world,

the real work has to be done by less gifted engineers, because the designers hide their gift in irresponsible pretension of genius."²

In order that the architect may play his role on a responsible level he must turn to the logic and clarity of construction as the tool in fashioning architectural form. The greatest defense the architect has is to base his point of departure on construction. Specifically, the clarity which is necessary in today's construction is obtained with systems. It is in this way that architecture is the link between art and science. Because of this link, the architect must approach his design task analytically. Systems are the path to the analytical approach, "a way of reducing the gap between the designer's small capacity and the great size of his task".³

B. THE APPLICABILITY OF SYSTEMS

To bring a building into existence, the architect must establish a discipline which governs the structure, services, and spatial requirements. Each discipline imposed constitutes a system. The system has flexibility according to pre-determined laws, such as restrictions of structure. The amount of freedom the designer has, to achieve varying spaces and flexibility within the system, signifies the success or lack of success of a system. Furthermore, the

amount of freedom available when all the systems are superimposed into the building gives a further measure of success of the system. It is essential that all systems employed be orderly, flexible, easily combined one with the other and economical.

The frame of reference that systems provide is instantly recognizable and forms a science in itself. The successful system should allow design freedom for the form of the building while preserving many similar conditions, thus providing economy and speed of erection, factors which will always be influential in building.

"But the most necessary and indispensable condition for the correct development of a project is a mental attitude of complete freedom of mind with respect to solutions that have already been studied for similar problems, or to fashions and stylistic trends of the moment."⁴

C. THE NEED FOR CREATIVE ENGINEERING

While the engineer is predominantly occupied with analysis, the architect is occupied with design. The structural system and mechanical systems although prepared in detail by the engineer must be proposed in comprehensive outline by the architect. This means that the architect must have a good technological competence to put forth creative

thinking for these systems to be individually and collectively successful. The ingenuity in the sequence of operations to produce any element used in the building, the way in which these elements are connected, the economy created and imagination all require the creative skills of the architect. The creative engineering has to be part of the architect's vocabulary if he is to make a contribution to a valid architecture. "A complete command of technology is necessary and fundamental as a starting point for all architectural solutions that are to rise above the usual construction banalities."⁵

D. THE PATH OF ARCHITECTURE IN THE FUTURE

Now that the goal has been reached when physically we can build anything we desire, we are faced with greater responsibility than ever before for how we build and what we build. The technological ingenuity of the architect, his comprehension of human needs, his consciousness to prevent obsolescence in the building; all these factors must govern the architecture of the future.

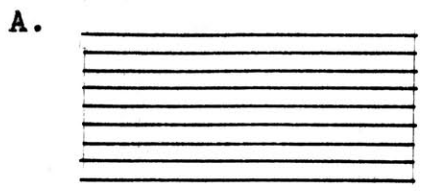
ABSTRACT

This thesis serves to illustrate how a structural system is derived from clear techniques of construction to form a self-sufficient building unit with its own integrated mechanical services. The system is designed to grow in two directions while the integrity of the building to which it is applied is preserved at any stage of growth.

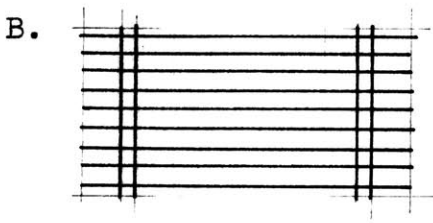
Here it is applied to a building for Research and Development, of approximately 600,000 sq.ft. in the initial stage, for the National Aeronautics and Space Administration.

This type of building changes its needs extremely quickly and the system of construction must provide flexibility and potential for growth to prevent the obsolescence that arises when expansion or alteration is virtually impossible even though the structural shell of the building is still intact.

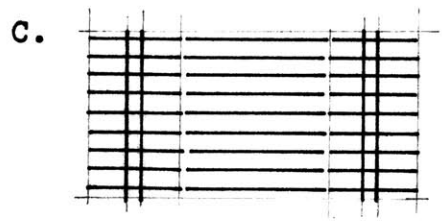
THE DEVELOPMENT OF THE STRUCTURAL SYSTEM



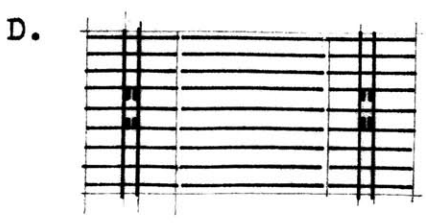
The system is linear. The load carrying members which are T-sections, 5' on centers, are regularly spaced and clearly identify the structural behaviour.



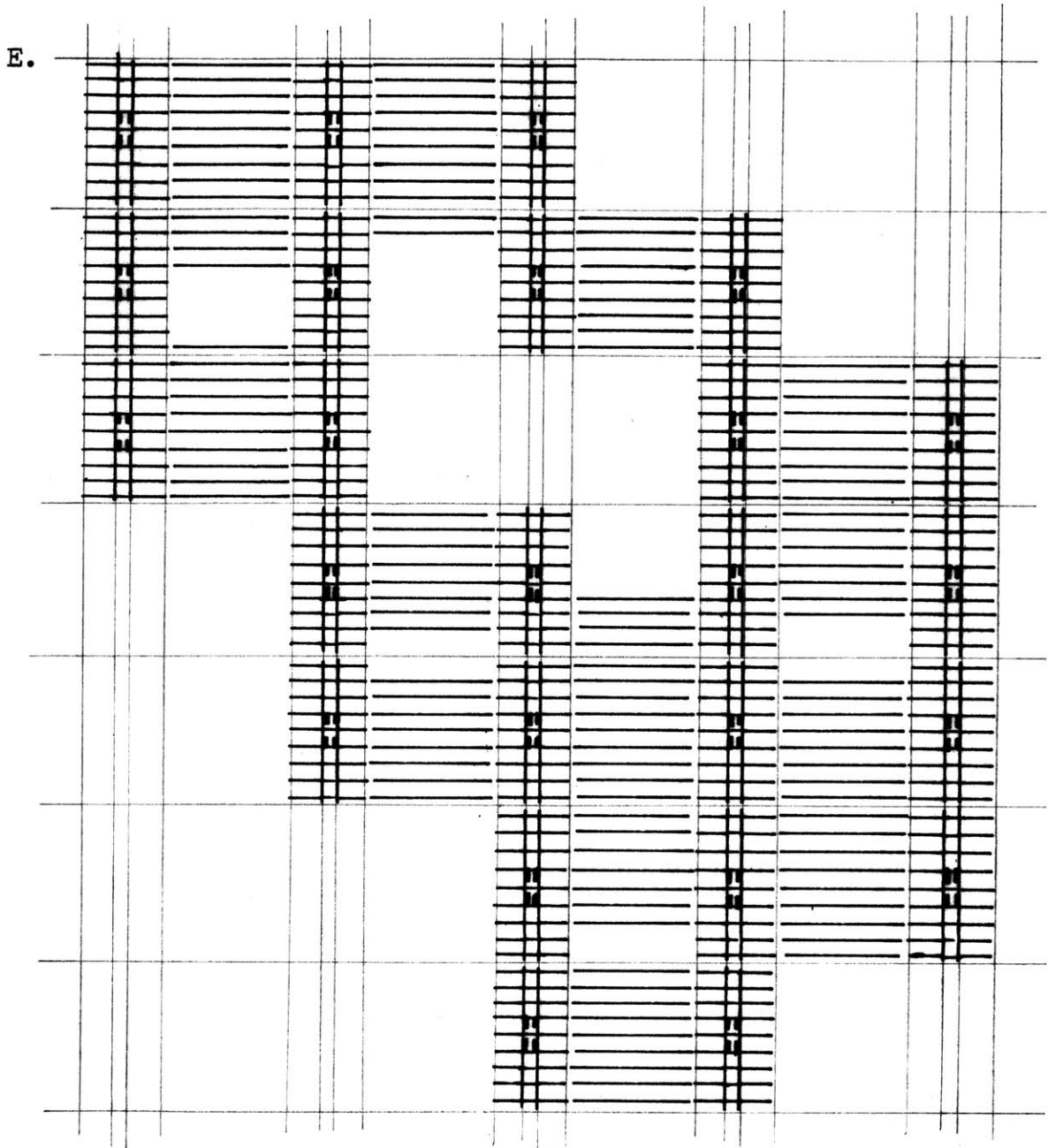
The loads on the T-beams are transferred to twin girders spaced 5' apart with a 60' clear span between faces of girders.



The T-beams are cut in two places and provide a flexible section 40' long which may be removed in portion or totally.



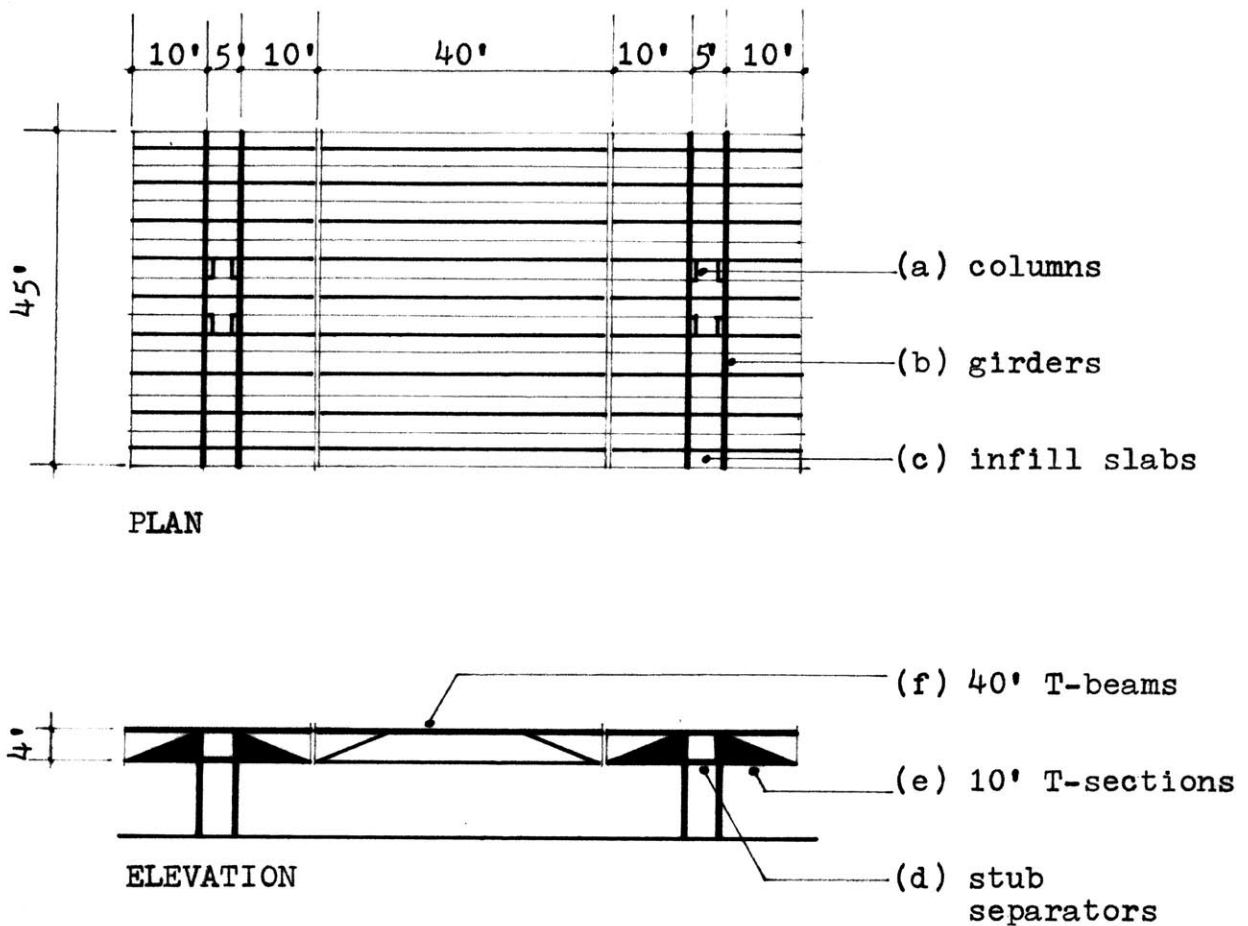
The girders with the remaining 10' T-beams attached to them are placed on column clusters.



The simplicity of organization of the structural unit provides a potential for growth in two directions. The girder assemblies may be joined to each other end to end or they may be repeated on either side while the 40' T-beams bridge the gap between them.

THE FABRICATION OF THE SELF-SUFFICIENT BUILDING UNIT

The unit measures 45' x 90' and is composed of six basic precast concrete elements.



Each unit is composed of:

- (a) Four columns which are H-shaped and cast with the web in a horizontal position, the concrete being placed in each flange.
- (b) Four 45' girders which are cast from the top with

appropriate openings for the passage of mechanical services and indentations to receive the infill slabs and stub separators.

- (c) Eighteen infill slabs, 5' x 4'6", which rest on top of the girders and serve to separate them. These are cast in a conventional horizontal position.
- (d) Eighteen stub separators, 4'4" long, which hold apart the bottoms of the girders. Their reinforcing pierces the girders and is attached to the seats as part of the assembly to support additional elements.
- (e) Thirty-six 10' T-sections which are cast from the top and are provided with a channel and perforations through which run the post-tensioning cables.
- (f) Nine 40' T-beams cast similarly to the 10' T-beams. These are the flexible portions of the system.

The structural depth of 4' is needed for openings to be made in the structure for the passage of mechanical services. Also it allows drain pipes to have sufficient slope in their distance to be housed within the structural depth. Because

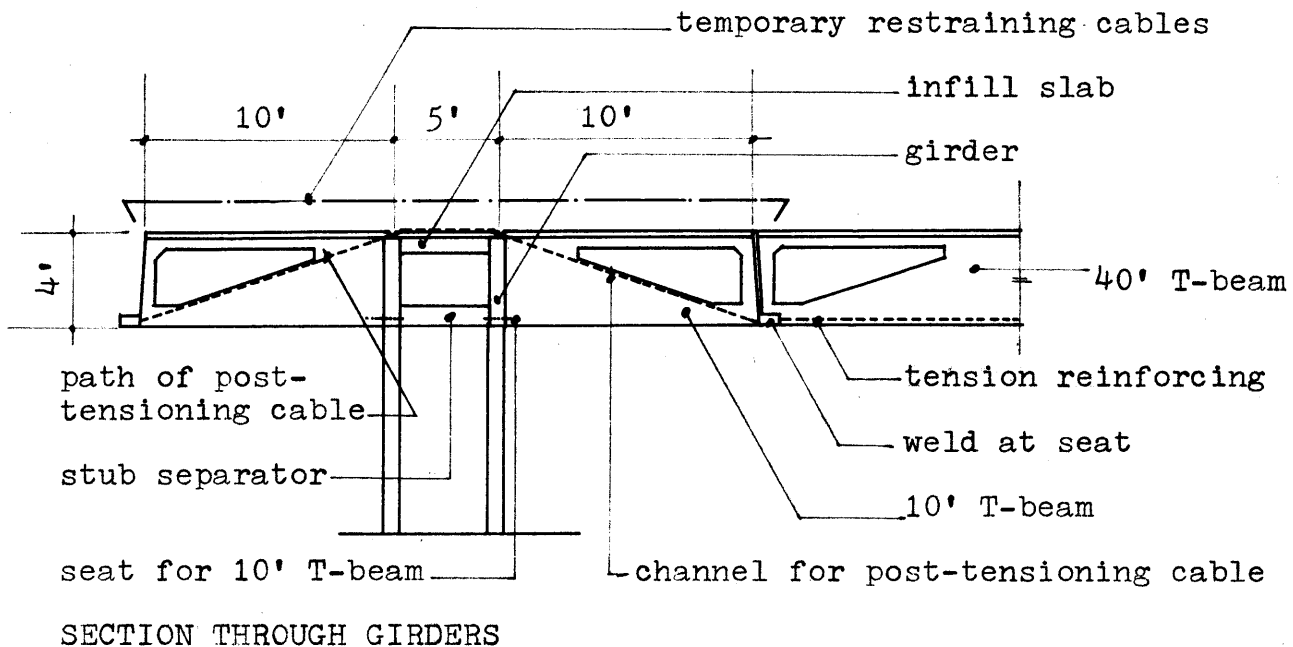
this depth is available it is possible to make all the elements simple reinforced concrete without the need of prestressing. The six fundamental elements are of a convenient dimension for them to be prefabricated in the factory and transported to the site on trucks.

THE ADVANTAGES OF PREFABRICATION

The prefabrication of elements in the factory offers distinct advantages over the on site work.

1. The elements may be produced while preliminary site work is being done.
2. The elements may be manufactured on a 24-hour basis with no restrictions imposed by the weather.
3. Factory control over the raw materials assures uniformity and high quality.
4. Because the majority of the elements formed are of a complex nature, the manufacture of these elements is better controlled in a factory. Site work even by experienced labor may bring poor results.
5. Prefabricated concrete, because of the elimination of curing time on the site, allows a totally dry construction and an inherent speed of erection.

ERECTION



Two girders are joined at the bottom by the stub separators and their reinforcing is welded together. The seats which hold the 10' T-beams are applied and the exposed reinforcing is grouted over. The infill slabs are then placed in position on top of the girders.

This assembly is hoisted by cranes on to the erected pair of columns. The 10' T-beams are positioned, two at a time, on the seats provided for them at the bottoms of the girders. The ends of their slabs rest on the tops of the girders and they are restrained temporarily by cables running lengthwise on top of the slabs until such time as the permanent

post-tensioning cable is threaded and tightened.

When all of the eighteen 10' T-beams are tensioned and a similar assembly is placed on a corresponding pair of columns then the infill 40' T-beams are positioned. The webs of the 40' T-beams rest on seats which are at the ends of the cables that post-tension the 10' T-beams to the girders. The reinforcing of the 40' T-beams is welded to the seats giving continuity to the whole structure.

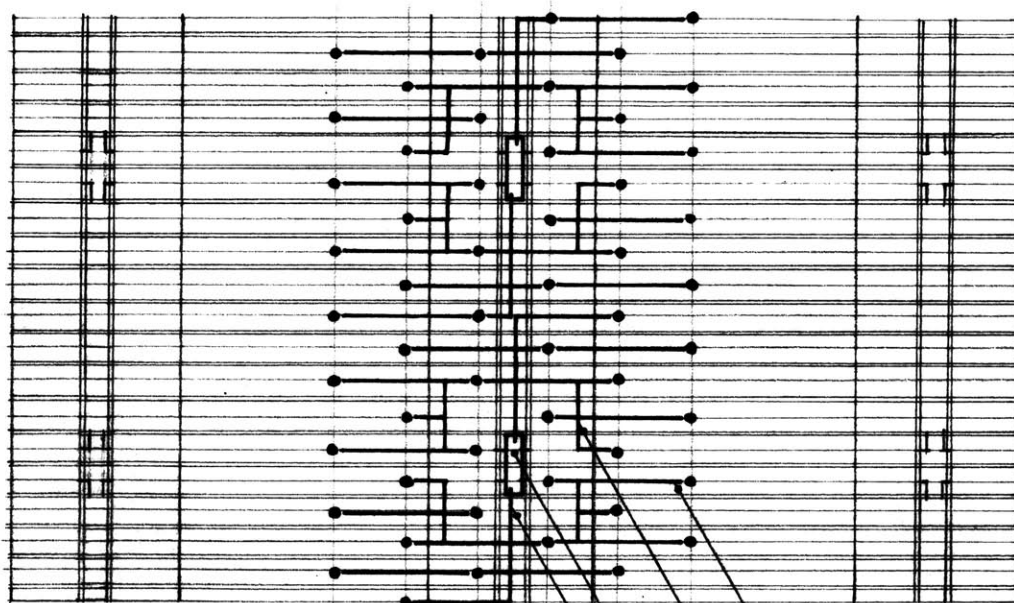
The girders which are supported in their center sections cantilever 17'6" past their columns. Where the girders meet in a continuous situation the reinforcing in them is welded together so that there is a continuity in the structure. When this not the case, as in an end condition, then post-tensioning cables are introduced to the tops of the girders to give adequate support.

An alternative method of prefabrication and erection of this unit would simplify and speed erection. By using more complex molds, it would be possible to manufacture the entire girder assembly consisting of 2 girders, 9 infill slabs and 9 stub separators as one element in the factory and transport this entire element to the site. Also the post-tensioning operation including attaching the 10' T-beams

could be done on the ground and there would be no need to have the temporary cables to support the 10' T-beams during the post-tensioning process. The entire 25' x 45' assembly could then be hoisted into position on the columns by cranes. However, due to the fact that for this method of erection the slab involved presents approximately 20 tons of extra load, it may be difficult to carry out the hoisting operation on the site using conventional cranes without special equipment.

MECHANICAL SERVICES

All the mechanical equipment is in the lowest subterranean service level of the building. The mechanical services, comprised of supply and return air ducts and pipes for water and waste, are run to the appropriate floors in the column clusters. As a result, the building is free to grow as needed and take with it the necessary mechanical services in its structure. The building unit is therefore self-sufficient.



fixed runs between girders

vertical runs in column cluster

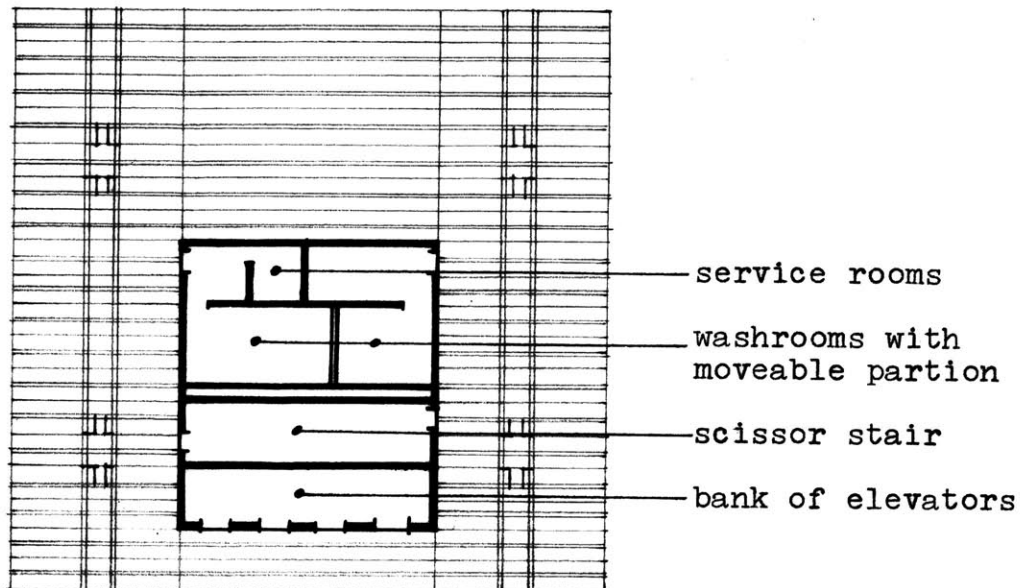
fixed branches penetrate 10' T-sections

flexible branches between T-beams

The air handling system is low velocity calculated as 1 sq.ft. of supply duct for every 1000 sq.ft. of floor area served and similarly for the return duct. So that the column clusters do not become overly large with services, the building is confined to a height of four floors.

Supply and return air utilize the same diffuser. The return duct is placed over the supply duct. Each half column cluster has the supply and return ducts for one quarter of a self-sufficient building unit. The runs between twin girders are kept constant as are the runs within the 10' T-sections. Branches from these are free to be shortened or lengthened as dictated by the partition arrangement. The exterior zone has pipes running within the spandrel which come from the columns either between the twin girders or in the direction of the T-beams.

CORES



All cores are 40' in the direction of the beams by a multiple of 5' in the direction of the girders. They are completely free of the columns and replace a sequence of 40' T-beams. Their design follows the module of the T-beams. For example, a major core as illustrated is 40' x 45'. The space for elevators and scissor stairs is 40' x 10' each. Washrooms have a moveable partition dividing the 40' x 12'6" space to accommodate the men to women ratio. Vestibules and service rooms occupy the remaining 40' x 10' space. The location of the cores between the 10' T-sections provides a constant 10' corridor between columns, permitting an orderly two directional circulation within the building.

CONCLUSION

The objective in adopting systems is to be able to design the freedom to allow a building to do what the architect wants it to do.

The linear structural system presented in this thesis has freedom to grow in two directions. It allows a building to have varying cantilevers in one direction but restricts them to 10' in the other. The three dimensional changes in the building, made possible by the removal of 40' T-beams, are unlimited in the direction of the girders but are confined to the 40' length of the T-beams unless an entire girder assembly is taken out.

Although the cores are restricted to one 40' dimension, they are nevertheless self-contained, are independent of the structure and can occur wherever necessary.

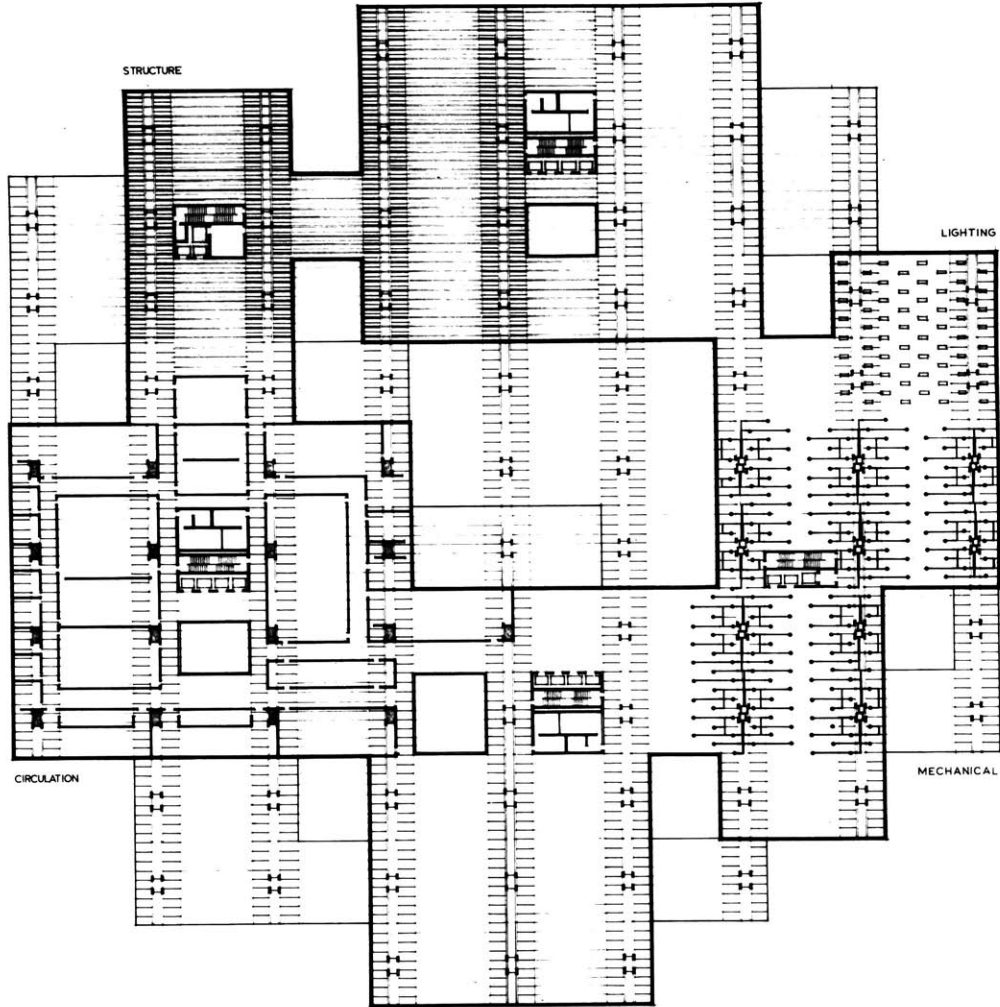
By confining the mechanical services to the columns, the self-sufficient building units may be repeated in any direction but the building is restricted in height by the adoption of a low velocity air handling system. A high velocity system would permit greater height in the building.

The post-tensioning technique for assembling the structure allows transportable elements to be put together simply and welding at the seat connections easily achieves continuity.

The system used has certain advantages but it also imposes certain restrictions. Nevertheless the advantages obtained and the restrictions imposed result from construction techniques. The building gives expression to the system.

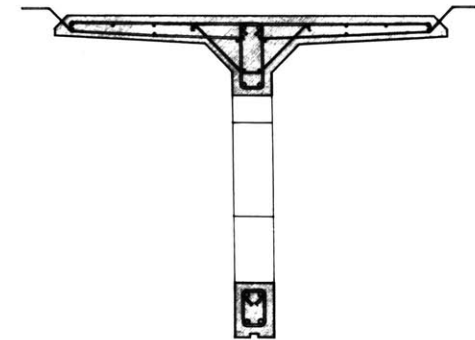
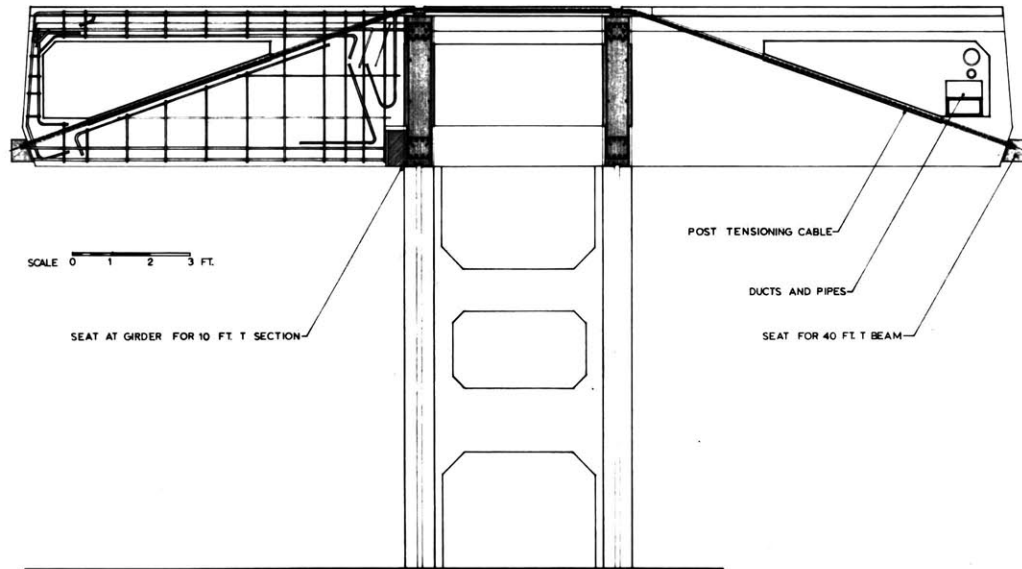
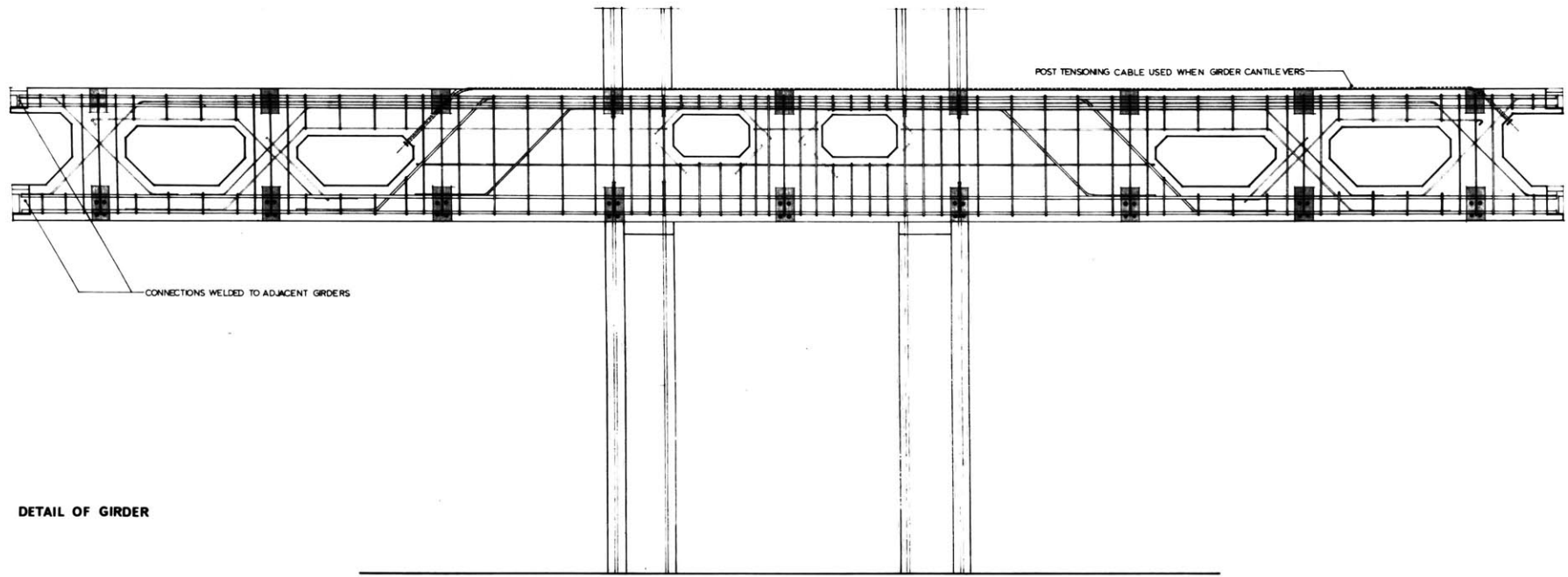
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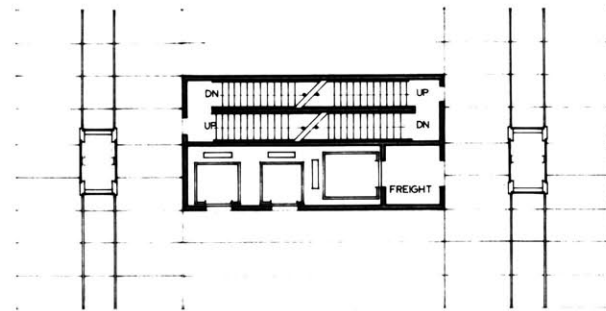
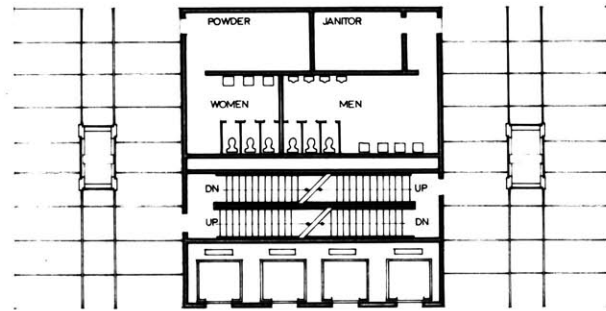
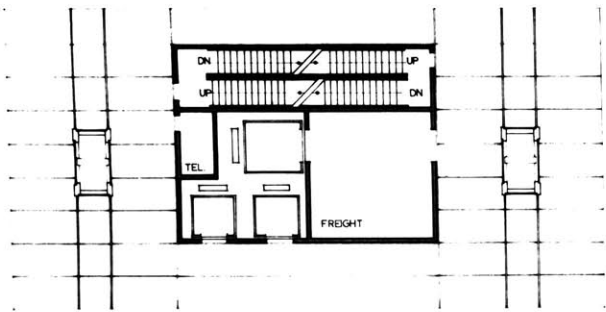


TYPICAL FLOOR PLAN

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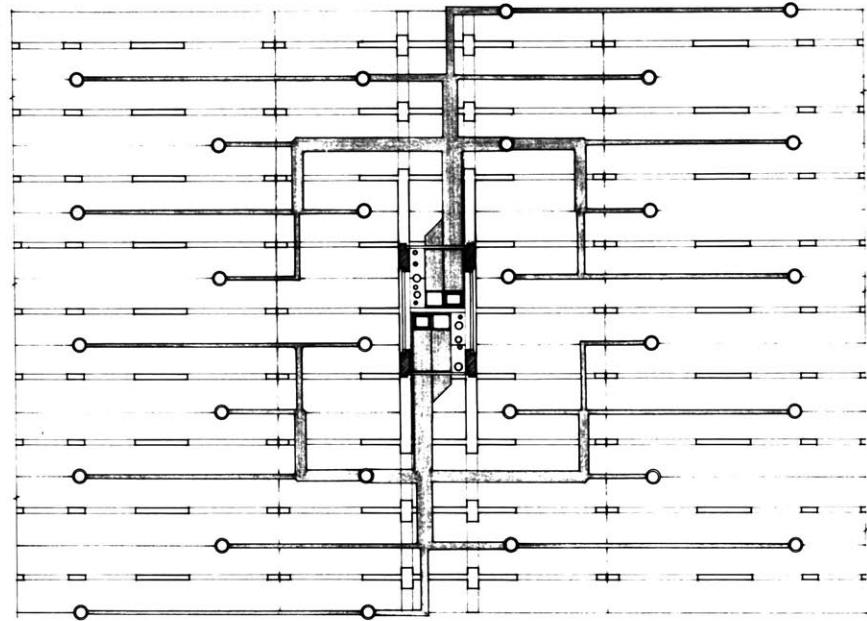


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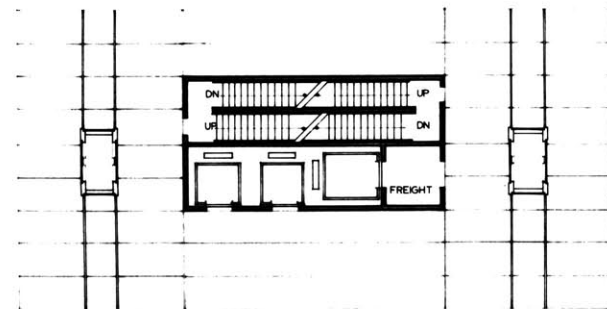
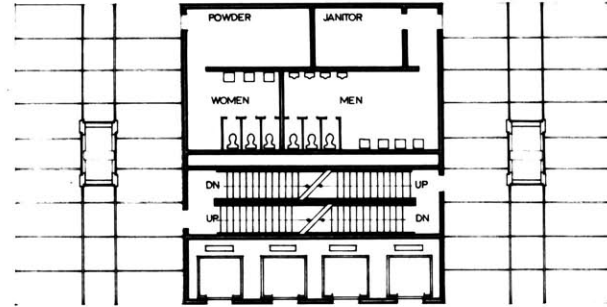
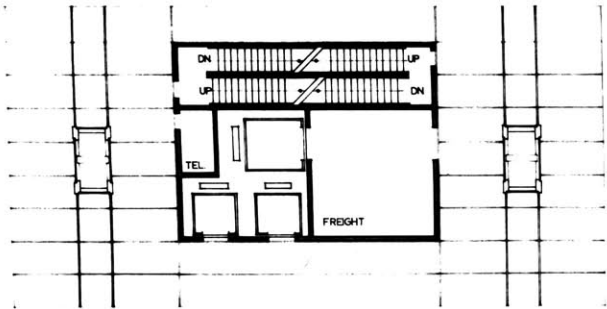
CORE TYPES

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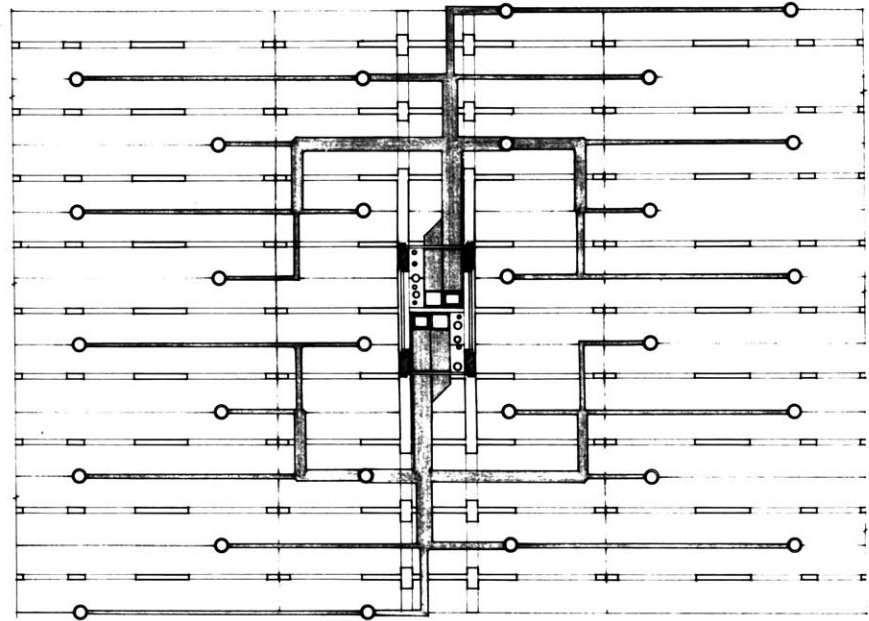
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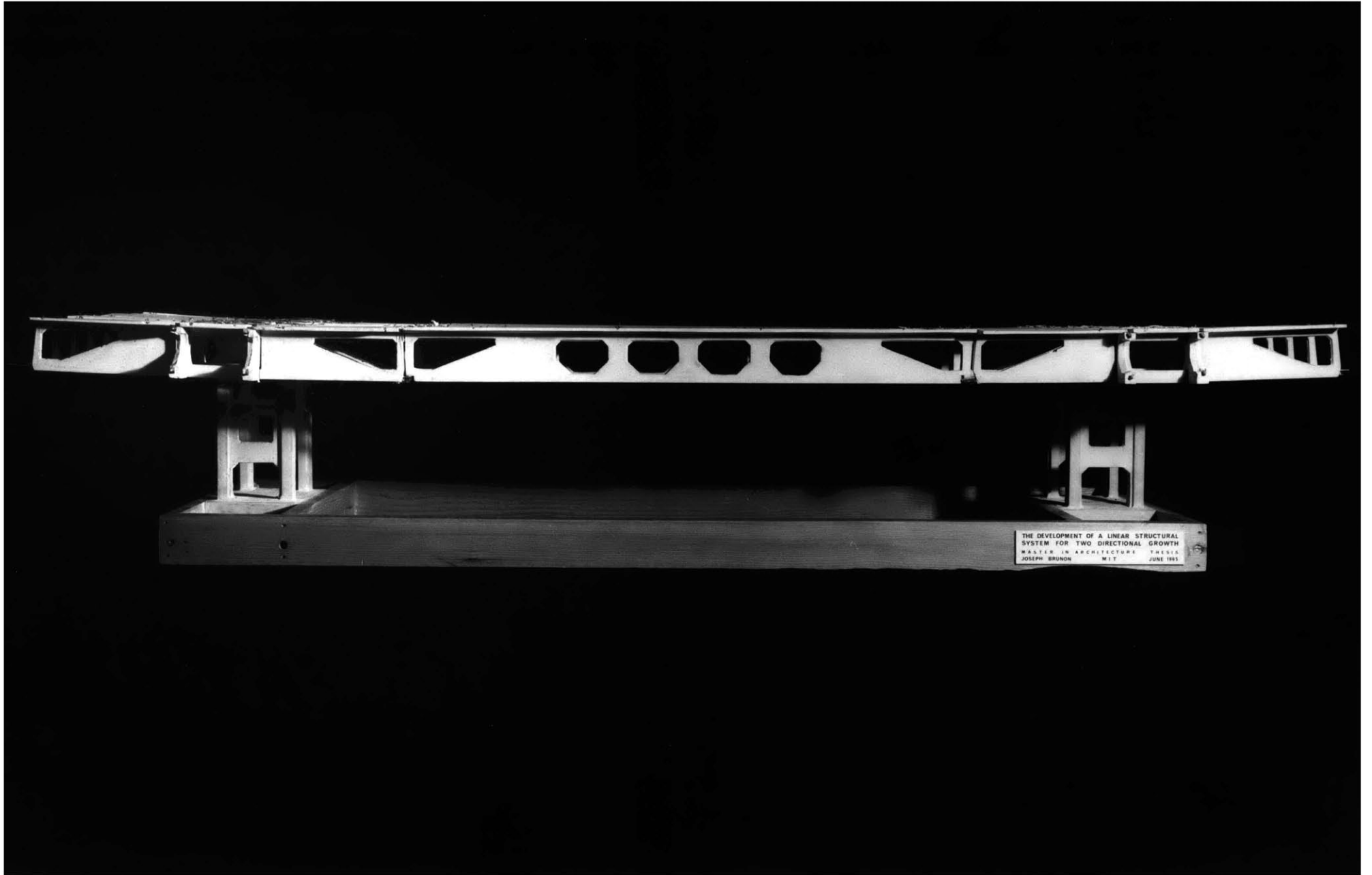
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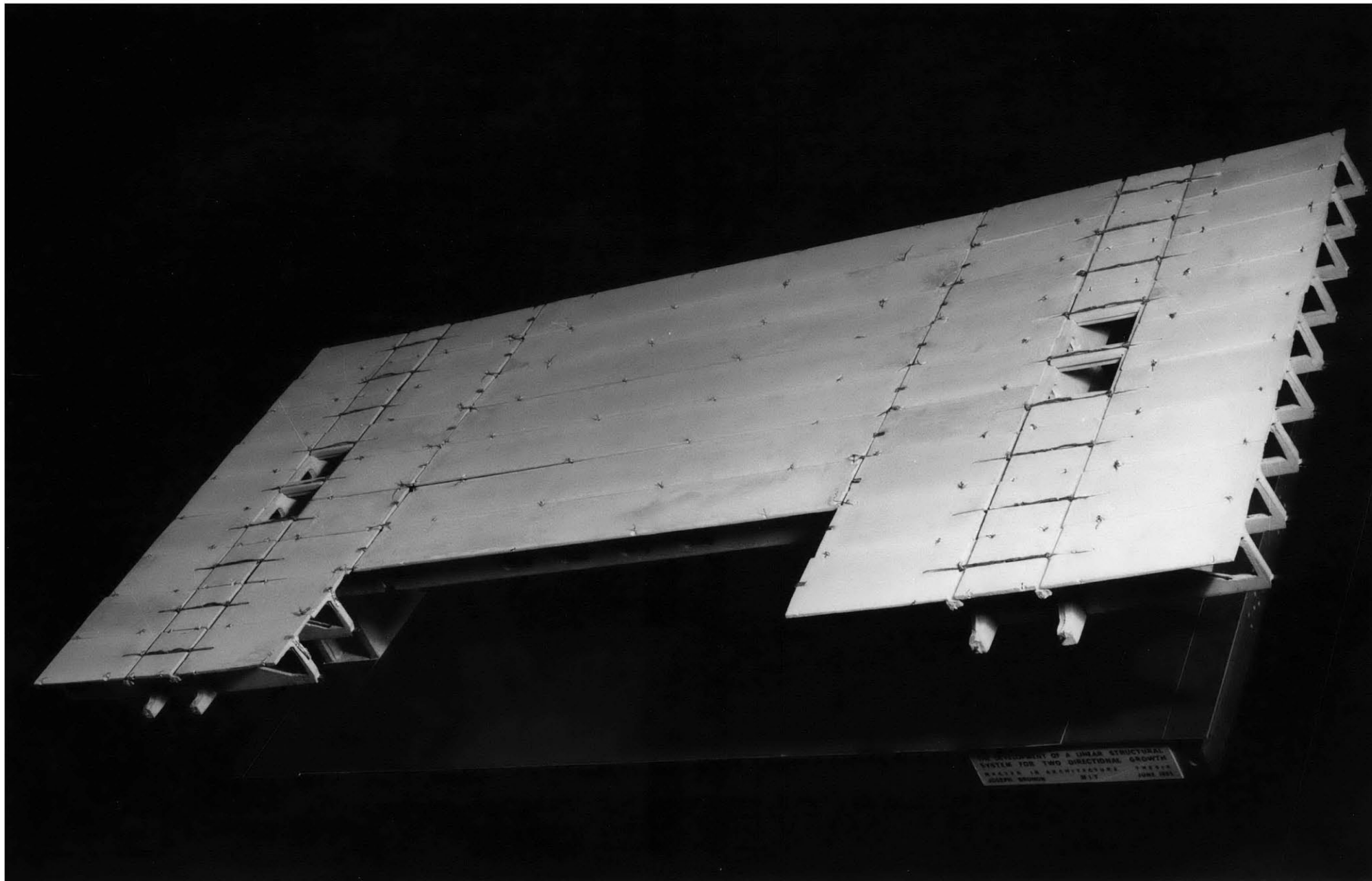


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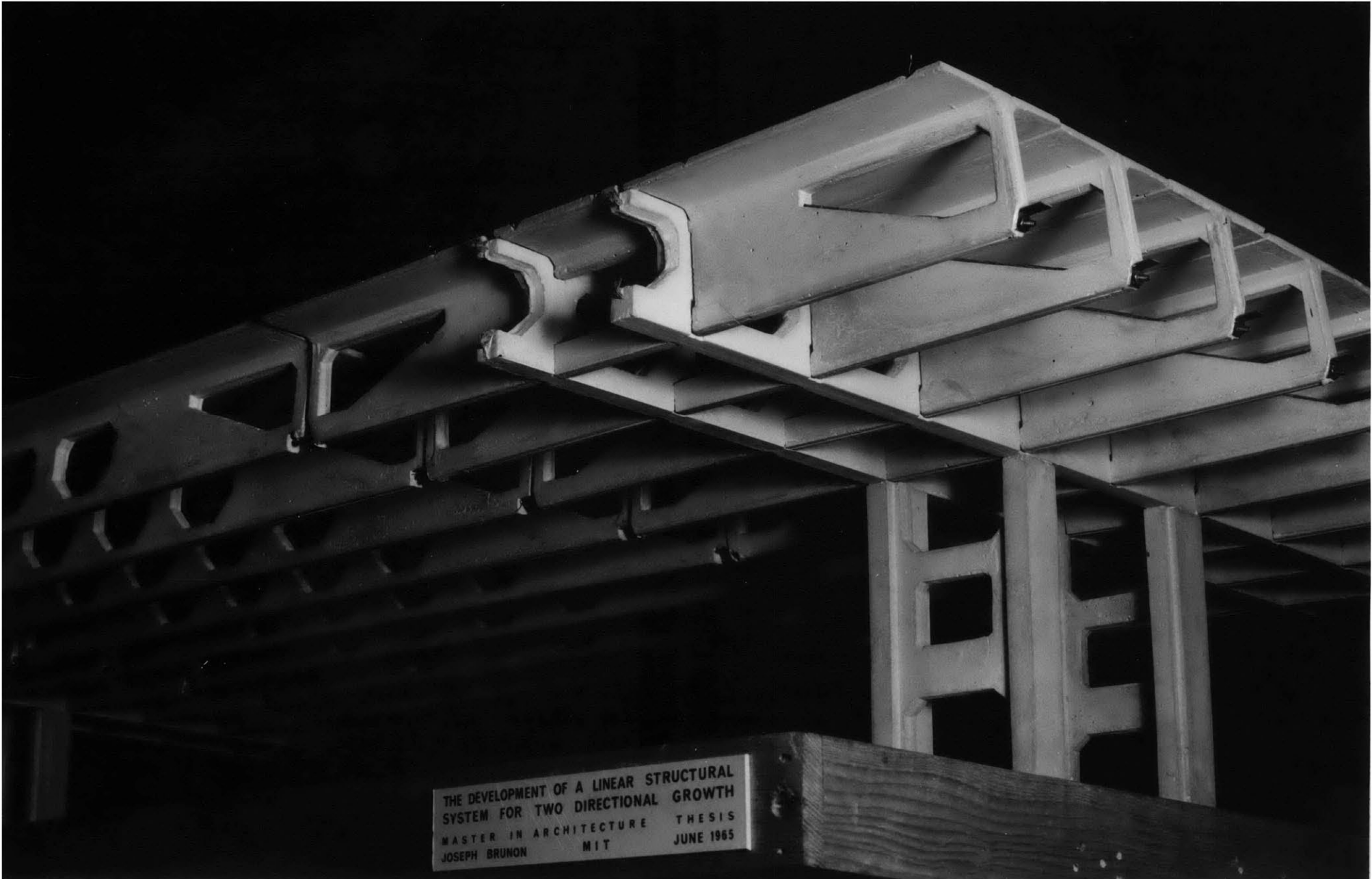
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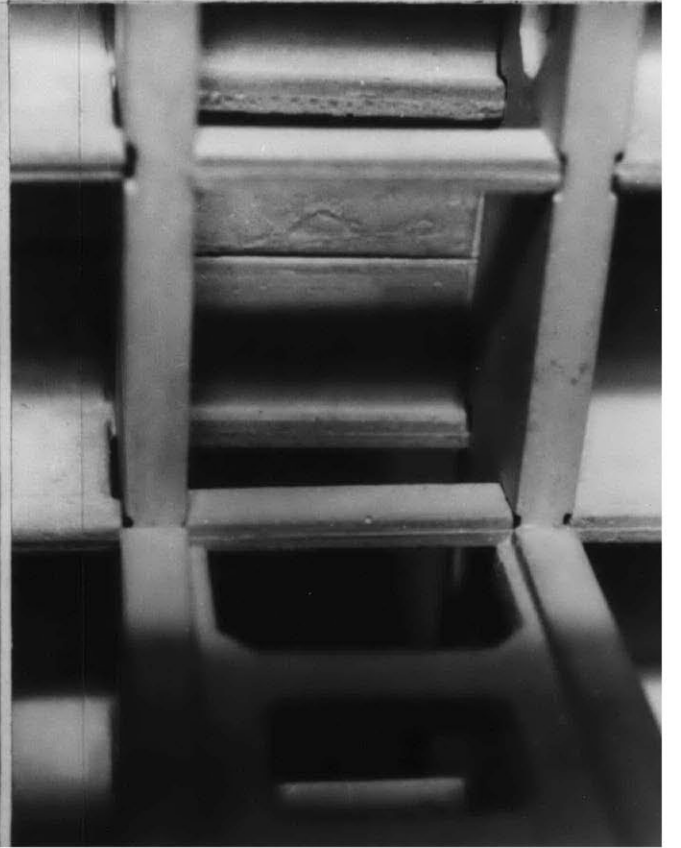
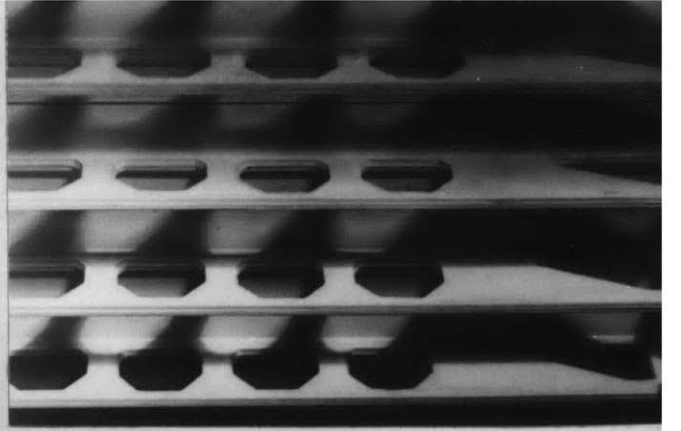
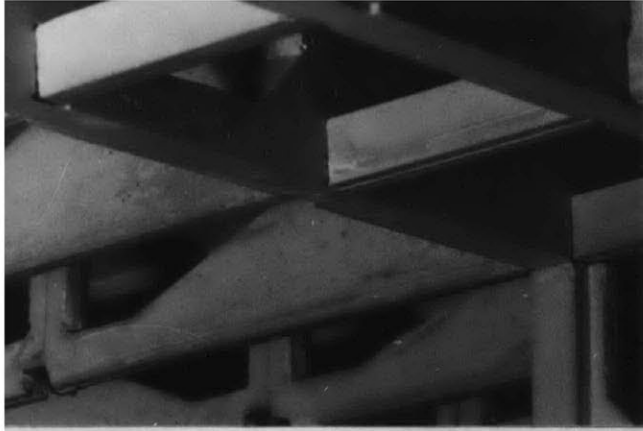
THE DEVELOPMENT OF A LINEAR STRUCTURAL
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MASTER IN ARCHITECTURE THESIS
JOSEPH BRUNON MIT JUNE 1983

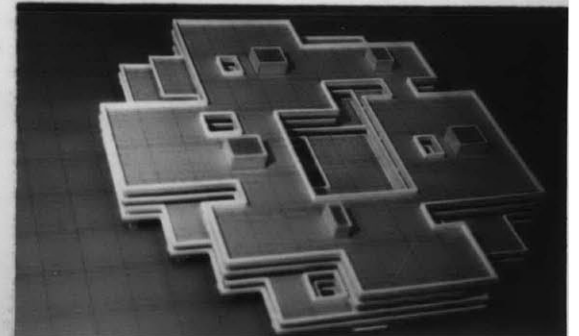
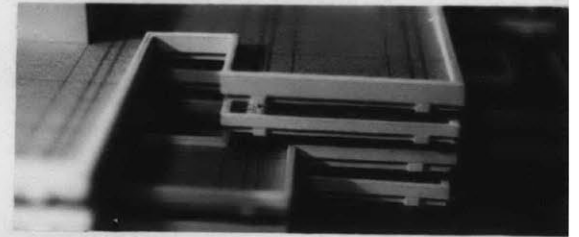
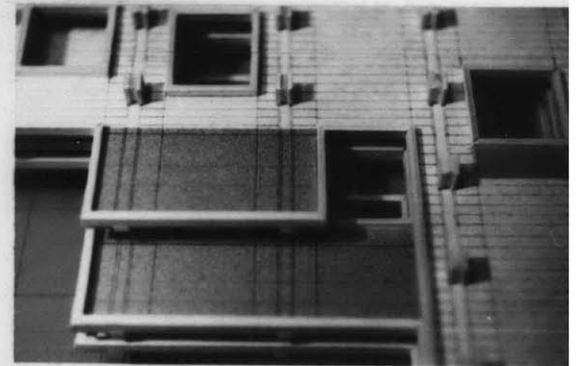
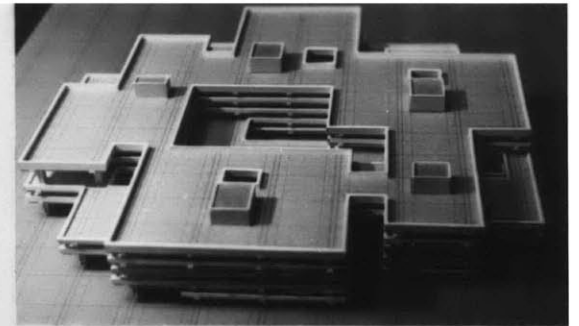
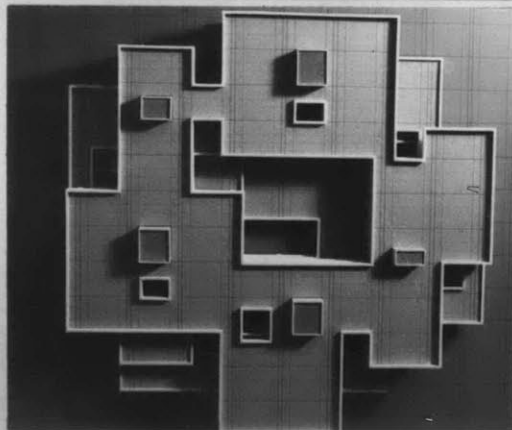
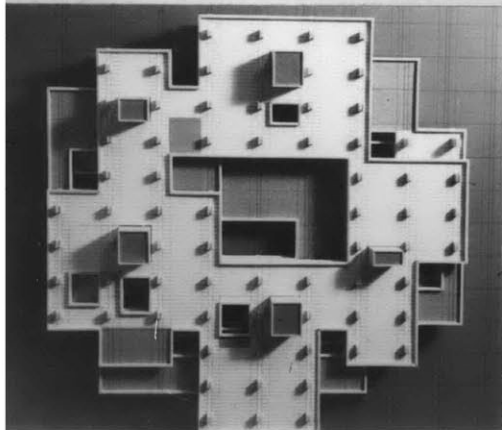
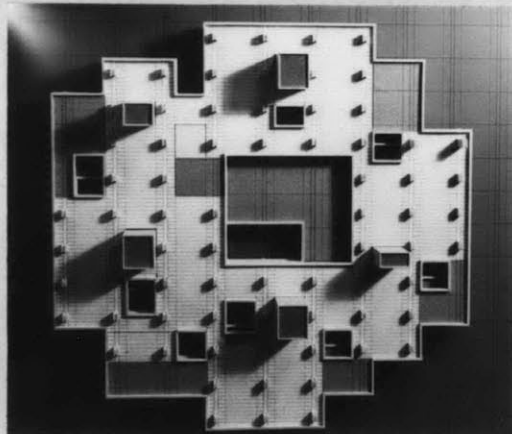
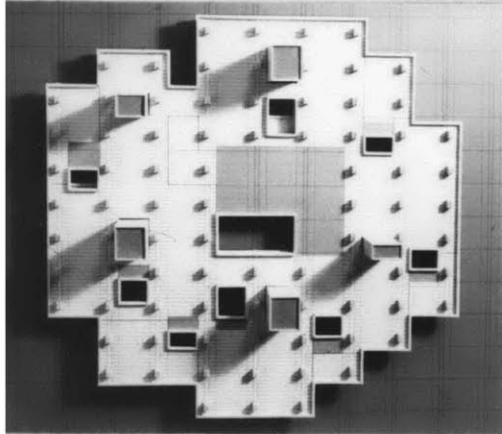
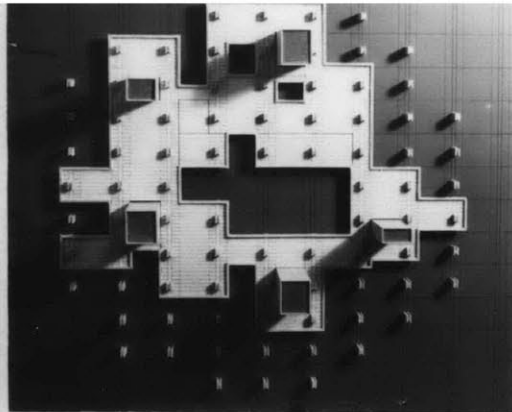
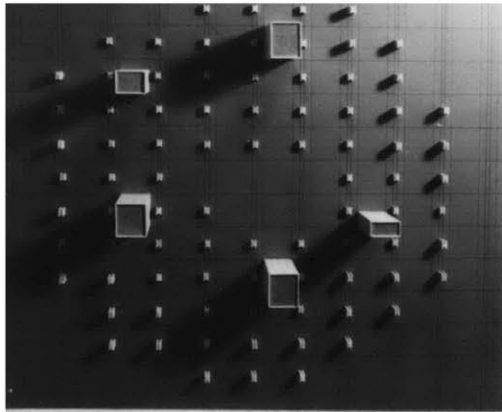


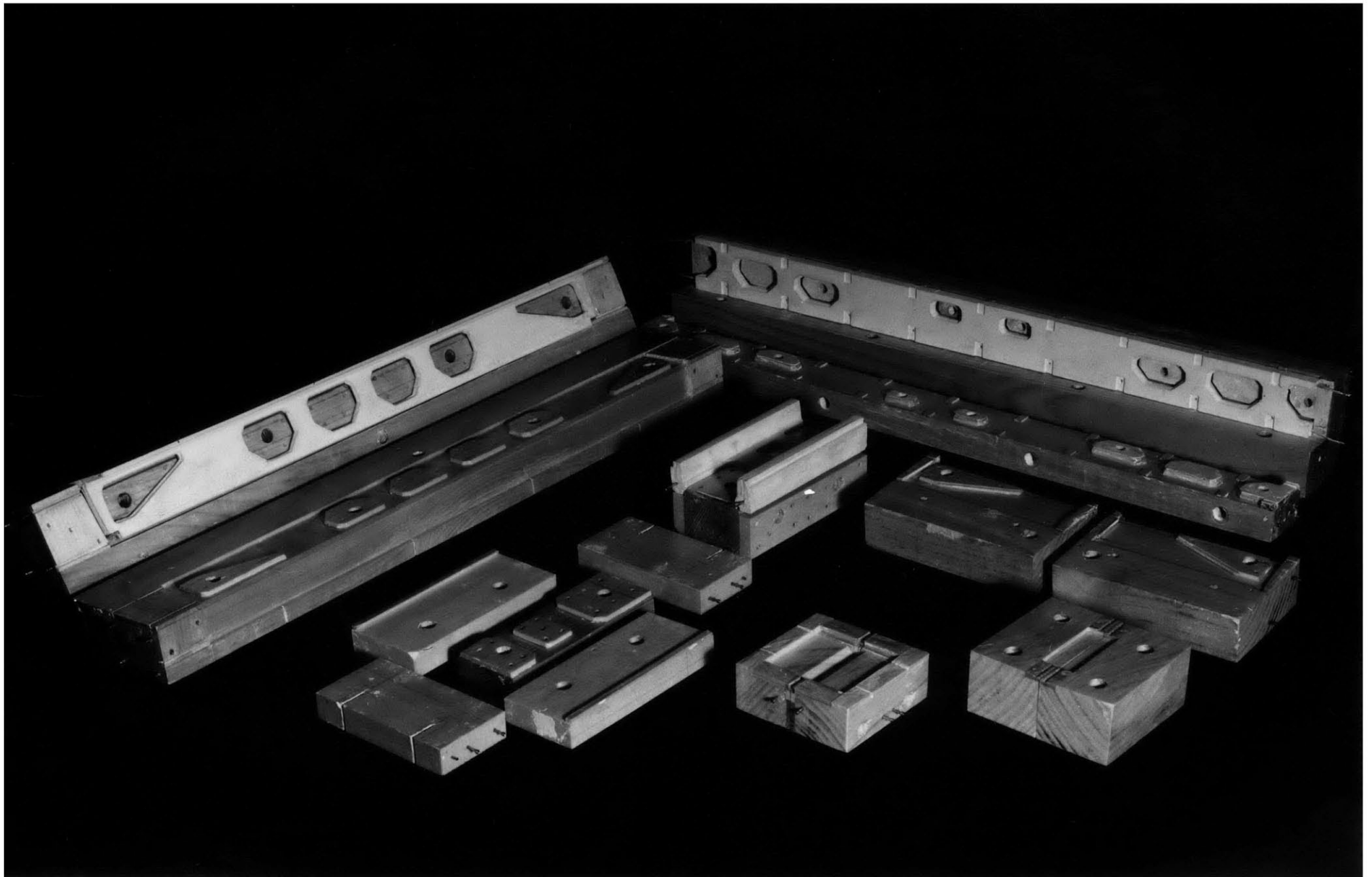
DEVELOPMENT OF A LINEAR STRUCTURAL
SYSTEM FOR TWO DIRECTIONAL GROWTH
SCALE 1/8 INCH TO ONE FOOT 1954
JOHN WOODS



THE DEVELOPMENT OF A LINEAR STRUCTURAL
SYSTEM FOR TWO DIRECTIONAL GROWTH
MASTER IN ARCHITECTURE THESIS
JOSEPH BRUNON MIT JUNE 1965







APPENDIX

THE CASTING PROCESS

All the elements of the demonstration model of the structural system were cast using Hydrocal B-11 Gypsum Cement manufactured by the United States Gypsum Co.

The forms were made from clear pine and finished with two to three coats of wood sealer. The forms were designed for easy release of the cement and long aluminum bolts with wing nuts were used to hold them together during casting.

Two coats of Epoxical PVA Liquid Parting Film manufactured by the United States Gypsum Co. were applied to the forms before casting.

Reinforcing was copper wire, straight or braided, and this was stretched by making fast around nail heads projecting from the forms.

The gypsum cement was mixed with water to a thick consistency and applied. The form was vibrated all through the application with an electric vibrator pressing on the working surface. When the cement was settled, the exposed surface was trowelled smooth.

After twenty to thirty minutes, the forms were struck by cutting the reinforcing from the nail heads, removing the bolts and tapping the forms off gently with a block of wood and hammer. The elements were washed to remove excess parting film and were allowed to dry. Before re-using, the forms were scrubbed to remove parting film and cement stuck in small openings.