

A PRECAST CONCRETE BUILDING SYSTEM  
FOR SMALL- AND MIDDLE-SIZED CELLULAR BUILDINGS

by

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ABSTRACT

This thesis is a preliminary study of various form, manufacturing, handling, assembling, and weatherproofing problems of a family of one-way ribbed precast concrete panels as used in the construction of small- and middle-sized cellular buildings. The principal objectives have been to achieve flexibility in the design of vertical as well as horizontal relationships and to achieve a range of enclosure from very open (column and beam) to very closed (bearing and non-bearing walls). An additional objective has been to integrate the mechanical distribution networks with the structural system.

Thesis Supervisor:

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ABSTRACT	page	2
ACKNOWLEDGEMENTS		3
CHAPTER 1 Introduction		8
1.1 Background		8
1.2 Objective		13
1.3 Scope		14
1.4 Methodology		16
CHAPTER 2 The Architectural Program	page	20
2.1 Organization of the School		20
2.2 Use-Form		25
CHAPTER 3 The Proposed Methods of Production/Construction	page	31
3.1 Geometry of the Precast Elements		31
3.2 Casting in Formwork		35

3.3 Production by Extrusion 38

3.4 Types of Connection 39

3.5 Use with Other Building  
Materials/Methods 47

CHAPTER 4 A System of Assemblage page 50

4.1 Geometric Relationships  
Between the Elements 55

4.2 Examples of Assemblages 66

4.3 Structural Connections 71

4.4 Exterior Walls 82

4.5 A Place in the School 86

CHAPTER 5 Evaluation of the System and of  
the Process of Development page 97

5.1 The Perpendicular Connection 98

5.2 Directional Characteristics 100

5.3 Columns and Beams 102

5.4 Size of Use-Forms

103

6

5.5 Comments on the Method of Study

105

BIBLIOGRAPHY

page 109



## INTRODUCTION

## 1.1

## BACKGROUND

A review of the many prefabricated building systems which have been designed or manufactured in the past hundred years reveals a lack of systems with a broad range of form capability. In fact, the more production is moved from the site to the factory, the more difficult it becomes to achieve a significant range of design options. Unfortunately, in the resulting conflict between the desire for higher degrees of industrialization and the desire to maintain traditional degrees of flexibility, the first objective has in most cases been the predominant one.

Current interest in industrialized production focuses particularly on the use of factory finished

box-like components for buildings; with such systems site labor can be reduced to a minimum. Various attempts have been made to retain a degree of flexibility in such designs by variations in the internal design of the boxes, by a variety of relationships between boxes, or by the use of two-dimensional, panelized systems or of more conventional construction techniques for spaces adjacent to and associated with the boxes. Meanwhile, little attention seems to have been paid to achieving the potential design flexibility of other industrialized techniques.

In particular, precast concrete building systems are generally characterized by limited form capabilities. They are based on a horizontal layering of spaces, very often with only one floor to floor dimension. Some systems explicitly permit leaving out sections of floor, making possible multilevel spaces, but even they fail to address the question of substantial vertical design flexibility.

Of course, architects seldom make use of the vertical flexibility of traditional building methods; the fact that the design of systems tends to ignore this variable is not surprising. Nevertheless, many building designers are interested in the design flexibility of vertical sections; their concerns ought not to be ignored by the systems designers.

Precast building systems are normally designed as bearing wall structures or as post and beam structures (aside from the few examples of systems based on concrete boxes and some other three-dimensional shapes). The problem of providing a range of possibilities from solid bearing walls to minimal linear elements has generally been ignored. Designers seem to have reasoned that either bearing walls are acceptable, in which case they use them wherever support is necessary, or that walls are not acceptable, in which case columns are used. With columns the usual attempt is to use as few as possible;

in order to achieve "flexible space". The notion that a variety of spaces ought to be provided and that the concrete components ought to help define the spaces is not generally recognized or accepted.

In addition to the ubiquitous concrete block, one precast concrete product stands out as being widely used in the construction of small- and middle-sized cellular buildings such as residences, schools, and some office structures. The precast floor plank or panel produced by extrusion in lengths of hundreds of feet is used in all sorts of construction. It is inexpensive, it can be ordered in whatever length is required, and it provides the flexibility designers require for floors. Although the producers point out that the same product can be used for walls, the planks are seldom put to such use. This failure may be traced to the fact that they do not incorporate the means for connecting to each other.

In a design studio last spring, a proposal

was made for a precast concrete panel geometry which would facilitate production while it would also provide for considerable design flexibility.\* The panel would be a thin, steel-mesh-reinforced concrete slab stiffened longitudinally by regularly spaced ribs. As proposed, the slab would be one and one-half to two inches thick; the ribs would add six inches to the thickness, would be three inches wide, and would be spaced twelve inches on center. Having a constant cross-section, these panels could be produced in long steel forms or by an extrusion process. With blocking to subtract parts of the full-sized panel, a variety of shapes and sizes could be produced with the same equipment.

It was suggested that the products of this process could be used in many different ways. At one extreme, small, single-ribbed planks of lightweight concrete which could be lifted by two men could be used in self-help

\*  
This proposal was made by  
Professor Waclaw Zalewski.

housing. On the other hand, large channels and multiple-ribbed panels could be assembled with heavy equipment to make schools, housing, and offices. The elements could be assembled in a variety of ways to form walls of different thicknesses, short and medium span floors, beams and columns, air plenums, and mechanical service chases.

## 1.2

### OBJECTIVE

The objective of the present study has been to take the ribbed panel configuration described above as a starting point and to begin the design of a system of assemblage, using primarily the larger panels, that would have the capacity to build a range of spaces of varying size, varying heights, and varying degrees of enclosure.

It has been intended that the system, consisting of a limited family of components and standardized methods of joining them, should incorporate within the structure

spaces for mechanical networks and equipment, particularly for air distribution. The design of the components should retain the capability of easy fabrication. The joints must be designed for structural integrity and for weather-tightness as well as ease of erection. They must respond to the need for construction tolerances, for fireproofing, and for non-interference with the mechanical distribution networks. At the same time it was deemed necessary to limit the variety of component sizes as much as possible, consistent with a reasonable range of built form, for purposes of economic management.

### 1.3

#### SCOPE

Time has not permitted many other design criteria to be considered. No precise structural calculations have been made to determine optimum dimensions for the parts or the structural characteristics of the proposed system of assemblage. The dimensions and geometry used are

assumed to be reasonable; obviously, further development of the system would depend upon careful calculations.

No attention has been given to materials technology or to acoustic design. There has been no study of production and construction economics beyond the acceptance of present practices. The concrete panels are of sizes currently used in construction. Their means of production are similar to techniques commonly employed today. With no other basis than this vague comparison, no evaluation of the costs of the proposed system relative to other concrete systems or other types of prefabricated systems has been possible. It is hypothesized, however, that the flexibility inherent in this system could be achieved without substantially greater cost than that of present techniques.

The methods of production and handling, of construction, and especially of joining of the ribbed panels, while similar to present methods, would have to

be tested and refined before practical use could be made of the panels. Following further design studies and a program of testing, steel forms could be used for on-site production of components for a full-scale trial of the system in a complete building. Should such a trial prove the feasibility of the system, continued development could lead to mechanized mass production of the precast elements. Clearly, the present study is only the very beginning of such a development process.

#### 1.4

#### METHODOLOGY

The studies which culminated in this thesis approached a number of issues more or less simultaneously. Based on a written program of user requirements, studies of spaces and their interrelationships were made, leading to the design of a building. The overall arrangement of the building was also designed in relation to an existing

site. At the same time, various ways of assembling the precast ribbed elements were explored. Along with the issues of use and form at each of these levels are technical problems which were investigated. Some of these problems are how to manufacture the elements, how to connect them, how to duct air through the assemblage, and how to weatherproof the exterior walls.

These various issues were not studied comprehensively; each could be a thesis by itself. Nor were they studied in an orderly framework of investigation. The procedure was to identify a significant problem, such as how to fasten together two precast panels, and to attempt a solution in a context of possible uses, means of manufacture, and relation to the mechanical systems. If an apparently satisfactory solution was achieved, a new problem would be identified and solved. When a problem resisted solution, attention would be focused on changing the problem by rethinking the previous solutions which

led to the problem in question. Thus the design of the system evolved, simultaneously with the design of a building, from an iterative problem-solving method which was wholistic in the sense that issues of architectural design and of technology were not separated but were explored simultaneously in relation to each problem.

The diagrams and designs were developed at a variety of scales in two and three dimensions. Site planning was done at one-thirtieth inch representing one foot. Other studies used scales of one-eighth, one-quarter, one and one-half, and three inches representing one foot. A three dimensional diagram of the building was scaled one-sixteenth inch to the foot. A model at one-half inch to one foot was built of a small part of the building. The variety of scales and of media aided in the identification of an extensive range of problems and in the simultaneous concern with a variety of issues.



## THE ARCHITECTURAL PROGRAM

The development of the building process and the design of the connections between precast elements was carried on simultaneously with, and influenced by, the design of a lower school based on a very detailed program of space requirements, as described in Section 1.4.

## 2.1

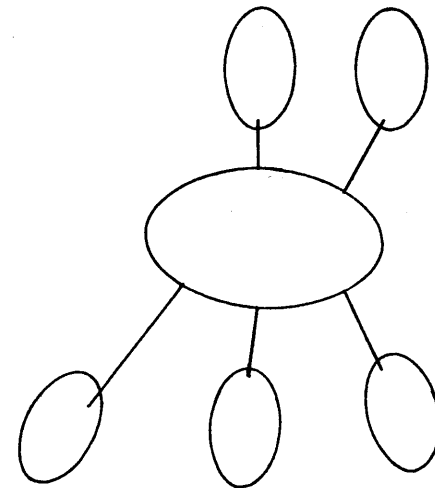
## ORGANIZATION OF THE SCHOOL

The program, developed by Mark Mitchell\*, calls for an enrollment of 875 to 1000 children between the ages of four years and eleven years. The school is ungraded. In order to attain more nearly manageable unit sizes, both for the teachers and the students, the instructional areas are divided into five "houses." Each house provides a variety of spaces for teaching and learning,

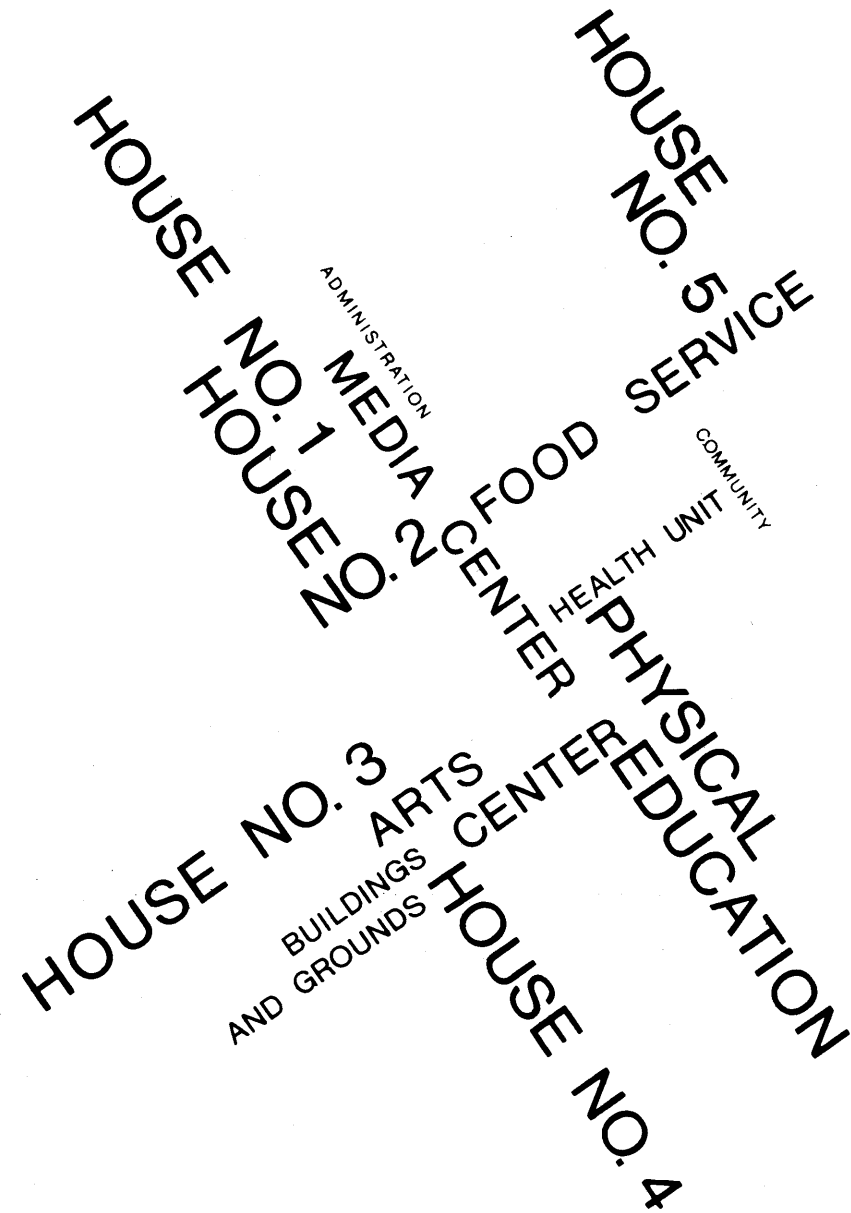
\*  
Mark Mitchell, Design Requirements for the East Boston School, (unpublished Program, 1972).

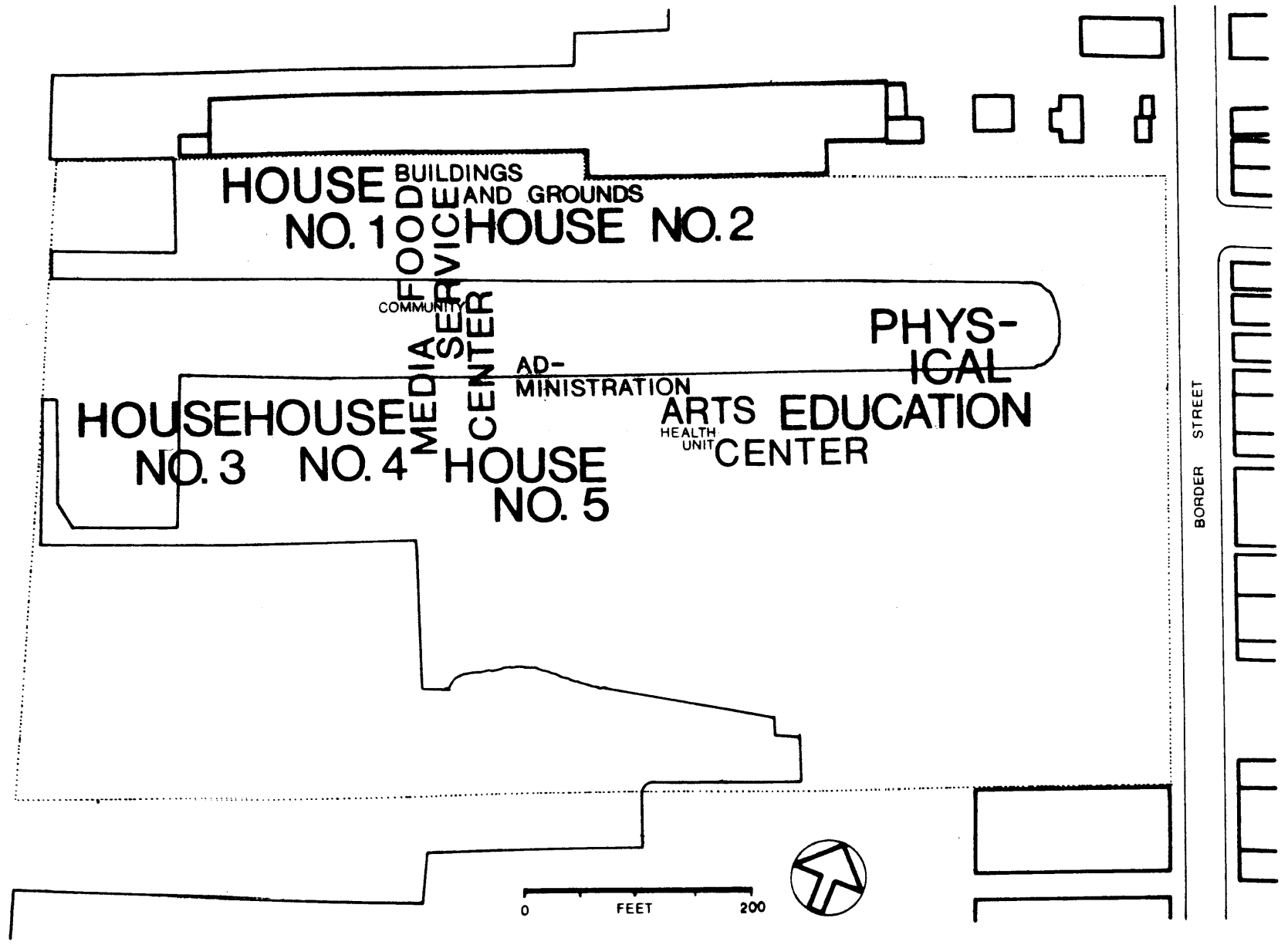
including special areas for language and reading and for art and science projects. Additional facilities which cannot be supported by one house alone are placed in such a way as to serve all five houses. These facilities include administration, arts center, buildings and grounds department, food service, library/media center, athletic facilities and health facilities. The athletic facilities, the theater, the health rooms, and perhaps the library/media center are to be shared with users from the community during non-school hours. A small suite of rooms are to be provided for meetings and organizing community programs.

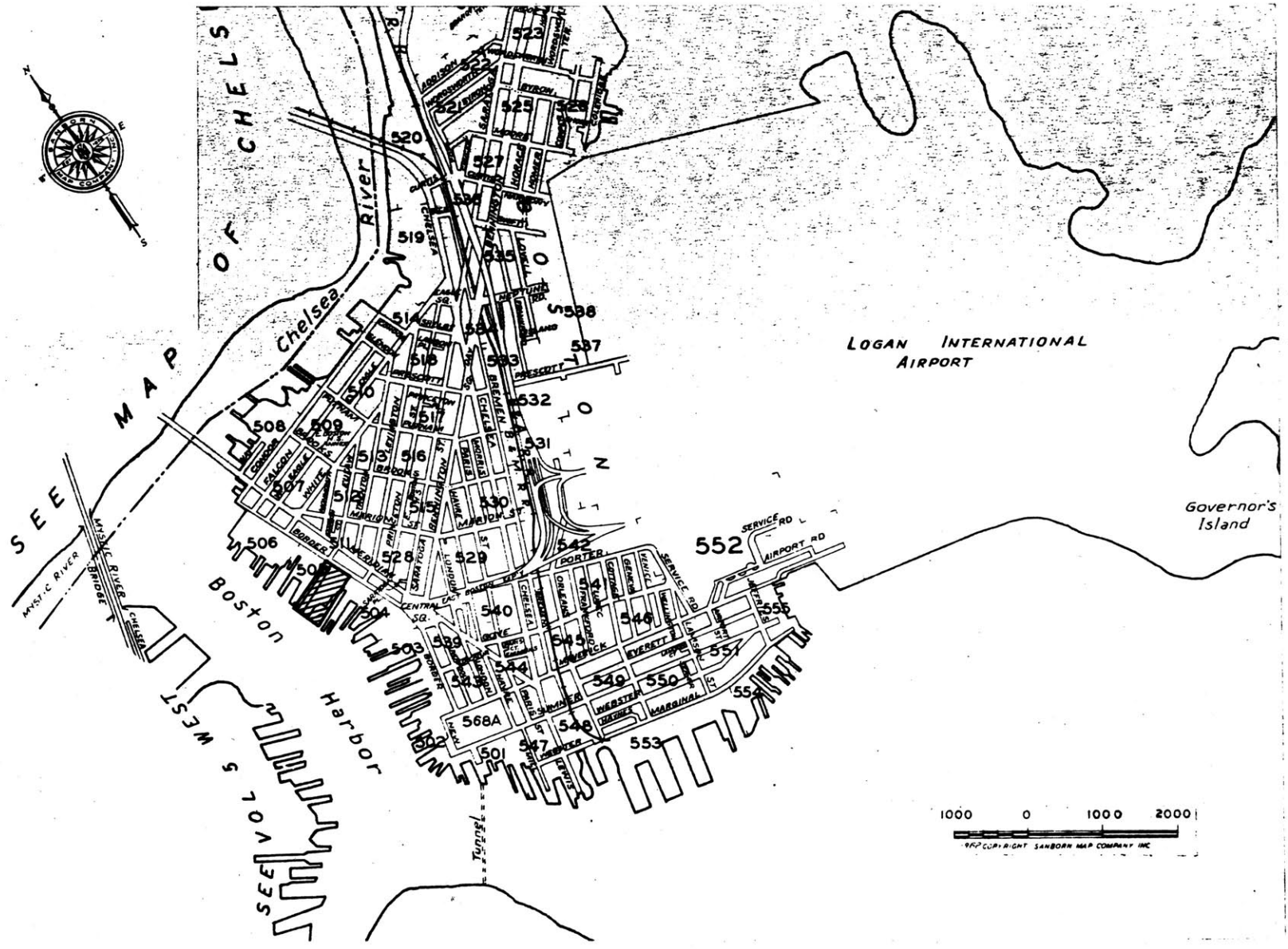
At first, it may appear that the diagram for the school should be a hub of support facilities surrounded by and connected to the separate houses (diagram at right). A closer look at the program must convince the designer that it is not so simple, as the support facilities are a collection of a variety of different



specialized groups (diagram on this page). Furthermore, while a separate identity should be established for each house, there is no need to isolate them. When the directions implicit in the site, as well as the design of the playing fields, are taken into consideration, the diagram may begin to look more like the diagram on page 23. Page 24 is a map locating the site.







## USE-FORM

Use-form is a term which is used to denote objects or spaces the forms of which are related to a range of possible uses. The term distinguishes forms which are generated from concepts of use (as well as formal concepts) from those which are generated more directly from formal concepts such as proportion, rhythm, perspective, symmetry and so forth. One of the best discussions of the relationships of form and use is Stanford Anderson's essay for the exhibition Form and Use in Architecture.<sup>\*</sup> In this essay he presents examples of what is and what is not use-form and describes one-one, many-one, and many-many correspondences between use and form.

It is often claimed that generating form from considerations of use will result in places which will

\* Stanford Anderson, "The Exhibition Form and Use in Architecture," (essay in gallery program, Hayden Gallery, M.I.T.) January 28-March 2, 1969.

become obsolete when no longer needed for those particular uses. Anderson points out that activities such as operating a school, providing information, and teaching are organizations of simpler actions such as being alone, being with a few or with many people, talking, eating, and so forth. Forms generated by these uses, while oriented to one or a few specific uses, will probably be useable for others as well. Furthermore, the ways in which sets of local use-forms may be used will be even more variable.

In the present case, each house of the school must provide places for many different sized groups of people from one person to one hundred seventy-five people. The people in these groups may be engaged in many different sorts of activities. Obviously, the spaces must be designed to support multiple patterns of use. By partially defining specific spaces, smaller spaces can be made for one or two people. These same spaces can also be used as extensions of a bigger space when a

sitting  
walking  
jumping  
climbing  
talking  
eating  
hiding  
discussing  
lecturing  
playing  
observing  
writing  
drawing  
painting  
storing  
...

large group of people does something together. The school program hints at this kind of place in the description of the classroom requirements.

Primary and elementary students will be encouraged to use their classroom as a base from which to pursue their education in the specialized house facilities. The Primary and Elementary houses should therefore be designed as a series of open and interrelated spaces. The use of an individual classroom will depend on the particular group of students and the strengths of the teacher. Within the span of an academic year, it is conceivable that one 25 student group could change from a relatively "closed classroom" to a relatively "open structure" situation. Neither a completely open plan nor a contained classroom plan is appropriate.

Mitchell, description 101-1.

The foregoing considerations make certain specific requirements on the form of each house and, hence, on the capabilities of the building system. Several of these relate to the vertical dimension of the building. In order to increase interaction among the students of each house, and particularly to encourage observation by students of others engaged in a range of activities, a high degree of compactness and interconnectedness was desired for each house. To achieve this consolidation, each house is high enough for two or three use-levels one above another. These levels are not continuous throughout the building, but step up and down with large openings helping to connect the various spaces together. The small level changes, in addition to their role of increasing the continuity of the space (as opposed to that of the surface), act as partial definition. They differentiate areas from each other without establishing a barrier between them (for most people). They also

provide edges on which to work or sit.

29

Other partial definitions will be formed by the permanent supporting structure of columns and walls. Since these definitions cannot be changed, they must be sufficiently incomplete to be used in various ways. More specific use-forms can be made by the addition of demountable infill elements and of furniture. Thus, there are various ways of changing one's surroundings within the permanent structure. Most easily, one can move to a different sort of place. Other changes can be made by moving furniture. Alteration of the infill can produce more substantial and more nearly permanent changes.



THE PROPOSED METHODS OF  
PRODUCTION/CONSTRUCTION

The basis for the building system developed in this thesis, in addition to the use-form requirements discussed in Chapter 2, is a particular geometry of precast concrete building elements. The form of these elements was proposed as a reasonable response to manufacturing technology; this project is an attempt to develop one of the possible uses for the elements.

## 3.1

GEOMETRY OF THE PRECAST  
ELEMENTS

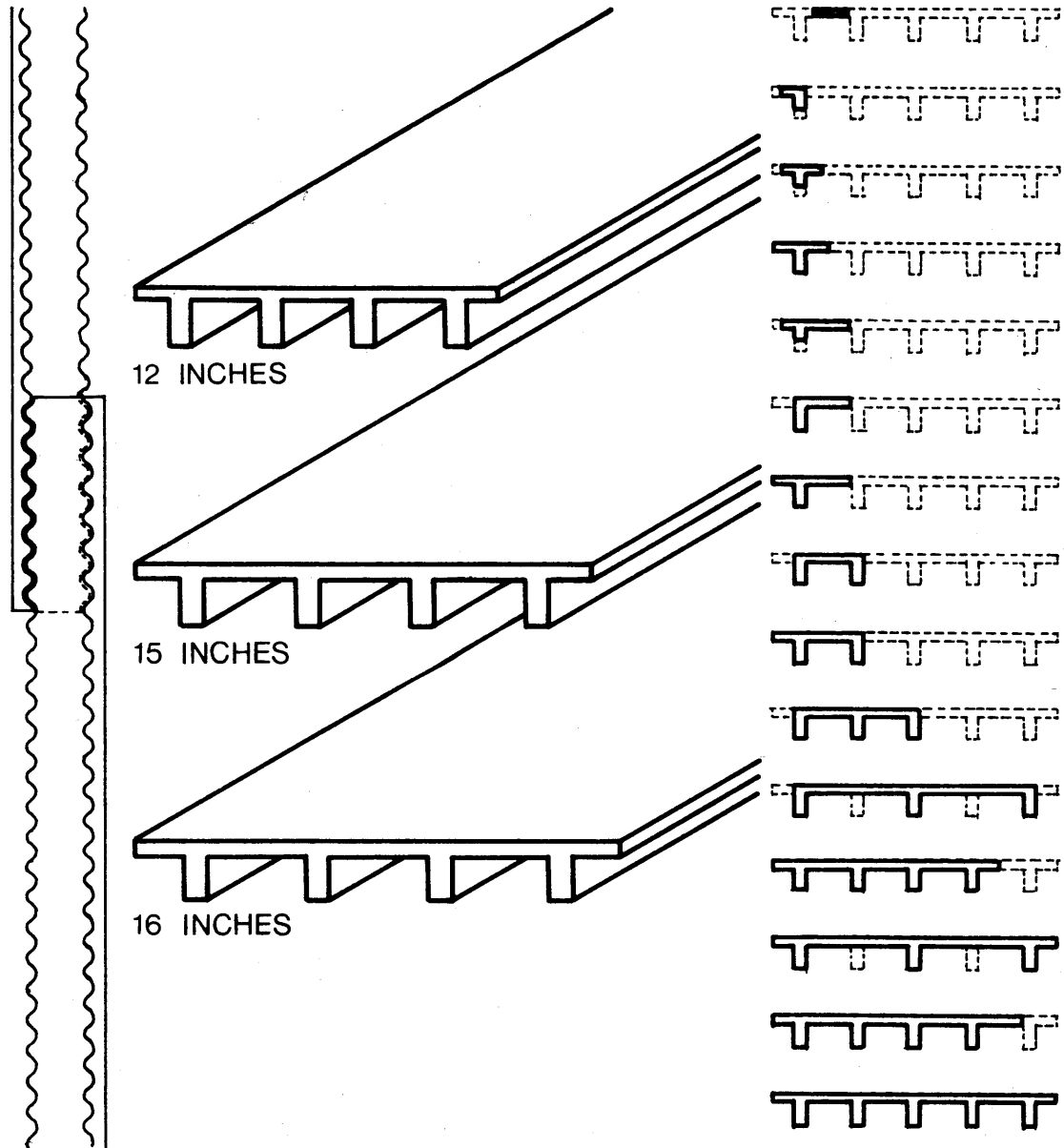
The shape of the elements which has been investigated is a very thin slab reinforced in one direction by ribs, all cast integrally. The largest elements might have five ribs about 15" or 16" on center and be about 6 feet wide by about 30 feet long. Other shapes would be gen-

erated by a subtractive process producing elements with various lengths and widths. The thin slab or web part of the element would be steel mesh reinforced with a minimum thickness of concrete, assumed here to be two inches or less. For additional strength this thickness could be increased. The bulk of the reinforcing would be in the ribs. Where appropriate, the element could, perhaps, be prestressed. The major strength of the element will be in the direction of the ribs; transverse stiffening must be achieved by connection to other elements in an assemblage.

As originally proposed, the ribs would have been three inches wide by six inches deep, spaced twelve inches on center. The slab would have had one surface corrugated and would have been one and one-half to two inches thick. The purpose of the corrugations was to increase the shear strength of a connection by interlocking the surfaces of the two elements. It was

thought that the space between ribs might be used for mechanical services, including air handling. In order to provide more space for air ducts and to improve the geometry of the corner joints, the rib spacing was increased in the course of development to fifteen inches on center. Later, the spacing was changed to sixteen inches to conform with the standard four inch building module.

Optimization of the dimensions of the elements is not part of this investi-



gation. It is assumed that the dimensions used are reasonable and that small changes in the dimensions will not seriously affect ways in which the elements can be assembled. Large changes in dimensions might, of course, be proposed for the purpose of changing the assembly geometry. An investigation of such changes is not within the scope of this study; the limits here are that the elements are approximately planar with a thickness (including the ribs) about equal to the thickness of a wall. The spaces between the ribs are of a size which may be useful for mechanical service distribution or for insulation, but not as a human use dimension.

The basic shape plus the subtractive process allows for an infinite number of different elements. Some of these elements would be small enough to be lifted by two men. Perhaps a method of assembly for self-help construction could be devised. On the contrary, the assembly geometry developed here relies primarily on large panels,

but the implications of the production process cover a much wider range of elements than has been investigated.

### 3.2

#### CASTING IN FORMWORK

Casting the concrete elements in steel or fiberglass forms would require little capital investment. The formwork might be mass produced similarly to existing domes for coffered slabs; in which case, a builder might buy or rent from the manufacturer enough forms for his particular job and cast the elements on the building site. By using precast elements, he avoids the need to build complicated and expensive formwork and shoring. The relatively simple formwork would allow an individual contractor to try the system on an individual building. Whether or not the cost of making connections between precast elements is less than the cost of building formwork for in-situ concrete, thus economically justi-

fyng the precast system, is an unanswered question.

Using this process, maximum advantage could be taken of the generation of shapes by subtraction. At the extreme, each element could be cast in a different shape by the use of a variety of blocking in the standard form. In other words, the system might not involve the use of standard components, but only standardized formwork, procedures, and connections. The issue is not a technical problem. From a management point of view this extreme variation would require special instructions for each element. Presumably, the workers would take longer setting up the form, would require more supervision, and would be more likely to make mistakes. A compromise between such a varied set of elements and a strictly limited set could be the use predominantly of certain standard shapes with occasional special shapes added. The possibilities which this solution would offer have not been explored, although they now appear

attractive.

Casting in forms could also be done on a mass production basis in a factory. In this case improved quality control and better tolerances could be achieved, which improvement, however, would call for more investment in machinery. Transportation and handling might become a bigger problem, while labor and management problems might be significantly different from a small on-site casting facility. These are all issues which have not been studied in this project.

A significant advantage which casting has over the extrusion process is the ability to form non-extruded end conditions. With the proper end blocking, the ends of the cast elements could include exposed steel and off-sets in the concrete which could simplify the joining.

## PRODUCTION BY EXTRUSION

The elements could be formed in long pieces by extrusion machines similar to those used for hollow-core concrete planks.\* Whereas the concrete planks contain only prestressing steel, the ribbed slabs could include steel mesh as well as various inserts or weld plates, because the extrusion head does not have to penetrate the ribbed shape. At any rate, this possibility is assumed. There are existing machines for extruding road curbs and median barriers which operate over steel inserts.\*\* The extension of this method to the more complicated product envisioned here would, naturally, require additional testing and development.

Because of the expensive machinery, this production process presupposes a rather large, steady demand for the products. The fact that shapes from the same family

\*  
for a discription, see Gyula Sebestyén, Large-Panel Buildings, Budapest, Akadémiai Kiadó, 1965, pp. 288-292.

\*\*  
Easi Corporation, Easi-Pour tP880, (manufacturer's catalog), Huron, South Dakota.

might be used in many ways besides those shown in the next chapter could be a definite advantage to the producer. In addition, the elements and the methods of joining them could be thoroughly tested using the casting-in-forms process before any investment were made in sophisticated machinery.

Mass production could bring down the cost of the elements, but it would probably require standardization of a set of components. These components could be stockpiled, thereby simplifying coordination with the assembly process. If production were very large, a wide range of shapes could be produced economically; less production generally implies less variety. In any case, the range of shapes would tend to be limited to a pre-selected set. Alternatively, the management of production, distribution, site organization, and erection might be coordinated and standardized in such a way as to permit greater variation of elements.

The suggestion that the ribbed slab could be a viable mass product, based upon the example of the hollow-core planks, neglects a major factor in the success of the concrete planks. By using prestressing the load-carrying capacity of the materials can be increased. Prestressing a few very long cables yields significant economies over using many short cables, thus contributing to the efficacy of the long-line or extrusion process. In the production of wall panels, no prestressing is required in any case, so it cannot contribute to making the extrusion process economical.

The most significant difficulty with extruded elements is the problem of making firm, weather-tight joints at their ends. A good joint usually steps up from the outside to the inside to reduce water penetration. If a structural connection is to be made at the end, some special condition will also be required for that. The ends of the extruded panels could be cut several times

to form a step, but as the complexity of the operation goes up, the possible economies of the process go down.

### 3.4

#### TYPES OF CONNECTION

Three types of connection between elements, wet, bolted, and welded, were investigated in this study.

Wet joints are made by packing wet concrete around steel exposed at the ends of the panels. The panels to be connected are positioned so that their steel interlocks while the precast concrete leaves sufficient space for the in-situ concrete joint. Some of the advantages of this method are that the joint can accommodate extreme variations from the design dimensions or can even be designed to be a variety of sizes. At the same time that the wet joint eases tolerance problems it allows penetration of the joint by pipes and ducts. This capability seems to be particularly important for a building method

based on concrete panels, which cannot, themselves, be easily penetrated. This joint provides the greatest degree of structural continuity. It is also inherently fireproofed.

The wet joint has various disadvantages including the problems of handling the wet material, the need to provide formwork around the joint, the time the concrete takes to cure, the difficulty of positioning and bracing the panels while the concrete sets, and difficulties with mixing different types of labor and different labor unions. Precast concrete is normally erected by steel workers, whereas the concrete joints would have to be formed by concrete workers. Perhaps, if the concrete panels were made by concrete workers on the site, the same workers would be allowed to place and join the panels.

The panels would have to have steel exposed at the ends; panels formed by the extrusion process could not

be connected with wet joints. Hollow floor decks may be connected by placing steel in the cores and packing with grout or concrete; such a method, of course, cannot be used with ribbed slabs, which include no cavities.

In any case, wet joints would be made only at the ends of panels where the steel of the ribs could be exposed. This limitation rules out the use of passing connections such as could be used with the other joining methods. The wet joint, both structurally and formally, is half way between an assembled joint and a continuous part of the structure. Formally, using the ribbed slab with wet joints ought to require the designer to deal with subtractive geometry in the forming of the parts, plus additivity and continuity in the method of assembly.

Welded connections of steel plates set in the pre-cast elements are commonly used in current precast construction. The metal plates are usually welded to the reinforcing steel before the concrete is cast. A similar

technique could probably be used with the extrusion process. Welding can be used whether the panels butt each other or pass each other, forming a shear connection. The passing connection is likely to require less critical tolerances.

There are two important difficulties with welded connections. The panels have to be held in position while the steel is welded. Some sort of clamping device might be used except in those cases where the elements actually rest one on another and the welding is required only to keep them from pulling apart. The second problem is fireproofing the joint. Welds are often made in recesses which can be grouted for protection. With the ribbed panels such recesses might not always be possible. Another solution in some cases is intumescent paint, a chemical which foams when heated, creating a fire protective insulation around the metal connections.

A more experimental type of connection is made by

using high-strength bolts to press two elements together, the load being transmitted by the friction between the concrete surfaces. The bolts are placed through over-size holes in the concrete and the compression is transmitted from the bolt head to the concrete by a steel plate large enough to distribute the load and avoid crushing the concrete. Erection is simplified because the bolts can be used to help align the elements. Passing or interlocking connections are required to provide the bearing surfaces.

The bolt holes could be cast in the slab, using sleeves or foam inserts, or they could be drilled after casting. To simplify the process, the positions of the holes could be standardized. The formwork could include markers to indicate the standard positions on the panel, then the required holes could be drilled without measuring. It has been suggested that if the bearing surfaces of the concrete elements were corrugated the

joint might be stronger. This hypothesis has not been tested. When casting in formwork the surfaces on the ribbed side could be corrugated by placing corrugated metal in the bottom of the mold. The ribbed side of extruded panels could not be corrugated as it would be the top side, leveled by the extrusion head. The other side, perhaps, could be shaped by a corrugated metal casting bed. The desired location of the corrugations naturally depends on the geometry of the connections to be made.

Bolts could be used to connect other types of elements to the ribbed slabs. Thus the same techniques could be put to greater use, presumably improving the efficiency of the construction process. A major problem with bolted connections, as with welded connections, is fire protection. To protect the bolted connection the steel bearing plates could be cast in concrete which leaves a pocket for the bolt head or nut. After the

panels are secured, the pocket could be grouted.

47

### 3.5

#### USE WITH OTHER BUILDING MATERIALS/METHODS

The concrete panels could be used in an assemblage for structure (supporting, spanning, bracing) and for acoustical and fire-zone separations. They could provide solid support for tackboards, chalkboards, shelves, small platforms and so forth. In addition, they could supply a psychologically desirable sense of solidity and permanence.

Other materials would also be important to the assemblage. In order to retain flexibility of use arrangements, the concrete definitions must be very incomplete, with lightweight, demountable infill elements adding substantially to the use-form. The infill materials might be wood or steel as well as plastic and glass in linear and planar elements. Besides providing

closure or partial closure either inside the building or on the exterior, these elements might build up use-surfaces for sitting, working, or storing things. Similar materials would be used for insulating the exterior walls and for covering the insulation.

Also used with the precast elements would be in-situ concrete, used for foundations, ground-form and ground-related walls which could extend into the building.

The specific nature of these other materials or systems is beyond the scope of this study.



Most of the design development has assumed that the concrete panels would be cast in steel or fiberglass forms with blocking. The actual design and production of the framework was not studied, nor was the question of on-site versus off-site production addressed. The options considered were further limited to facilitate later development for extrusion production. In particular, the only variations from an extruded shape were special conditions at the ends.

An attempt was made to limit the number of different-sized elements to as small a set as possible, consistent with the desired range of use-form. Ten different cross sections were used to build the model shown in Section 4.5. Multiplying by the number of different lengths, about one hundred different elements were required. The idea of a

very limited set of standard elements plus some non-standard elements was not employed.

Various combinations of wet, bolted, and welded connections were studied. The geometry of the assemblage retains options in most cases for the method of connection. All the connections could be dry, or wet connections could be used along with welded and bolted ones.

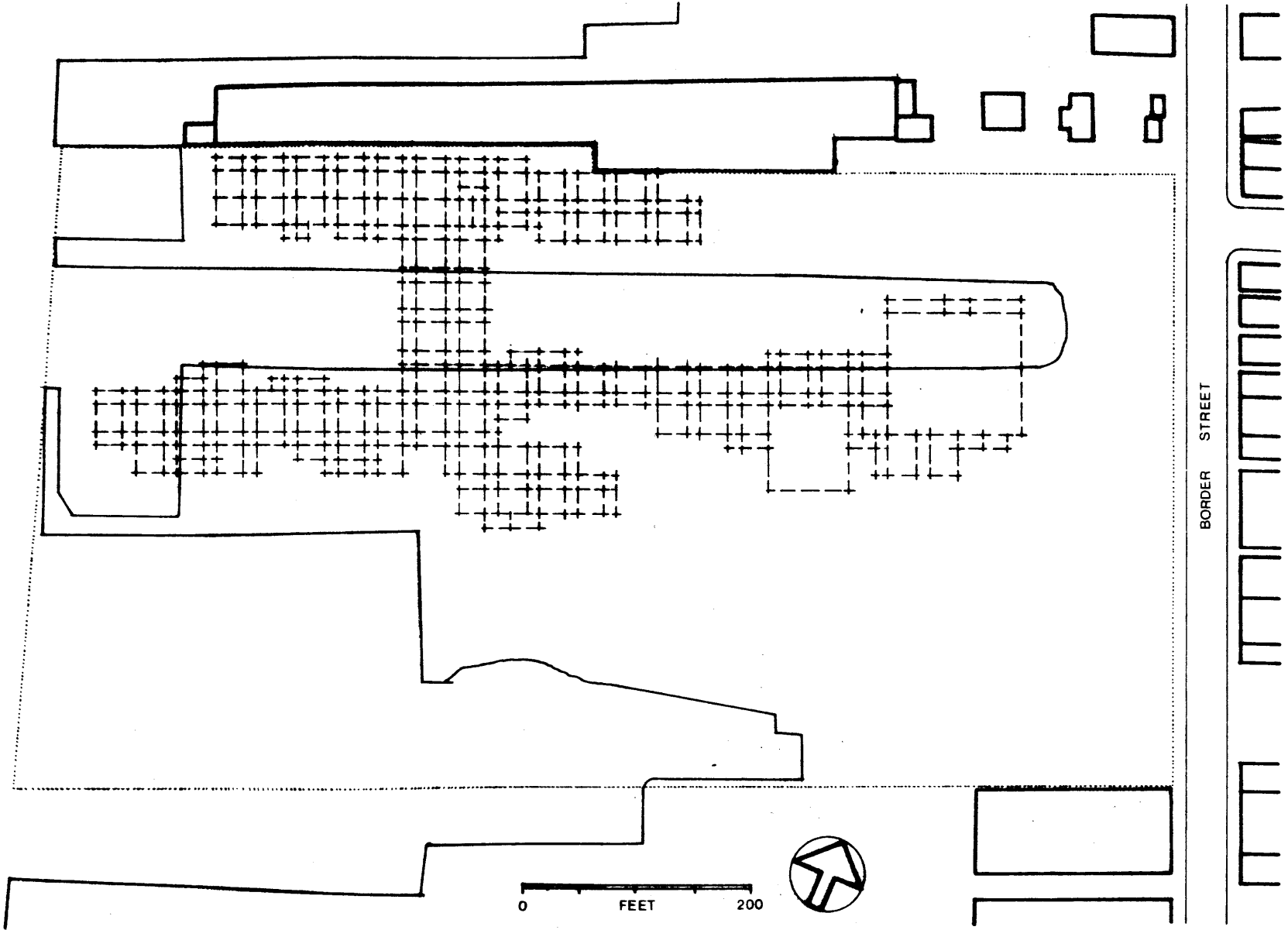
The design of the method of assembly proceeded from a conception of the building or assemblage as a two-way grid of walls. The walls would be mutually supporting and would give substantial stiffness to the assemblage. Providing resistance to wind and earthquake loading throughout the structure, the wall grid solves the structural difficulties of asymmetric buildings at the same time that it reduces the reliance on floor planes to distribute horizontal loads. The floor, then, can be designed to step up or down. Large spaces can

extend vertically through the building establishing greater continuity among the various levels.

The walls could be continuous solid surfaces or could be more or less open with beams substituting for wall panels. At the extreme, the wall could degenerate to a post and beam type structure. All the walls are orthogonal, thus avoiding dimensional problems arising from non-orthogonal geometries. The grid design and construction of the model illustrated in Section 4.5 was formed from 10 and 20 foot dimensions between wall centers. The size and regularity of the grid establishes an organizational structure for the assemblage, while the inflexibility of the grid at small dimensions emphasizes the role of furniture infill in forming habitable spaces. Page 54 shows this structural grid overlaid on the school site.

Major horizontal air ducts would be hung from the ribbed floor panels between the beams or walls of the

ten-foot bay. Small ducts would be made by fastening a panel over two ribs to enclose the channel between them. The connections between floor panels and beam or wall elements permit these small ducts to continue through to the large ducts. Two of the drawings in Section 4.2 show ducts used in this way.



## GEOMETRIC RELATIONSHIPS

## BETWEEN THE ELEMENTS

The precast panels which make up the wall grid may be connected to each other either in parallel or in perpendicular connections as shown in the drawings on the following pages. The norm for connections between parallel wall panels is the overlapping and interlocking arrangement in the drawings on pages 61 and 62. This configuration permits walls of one component thickness or two component thickness with a minimum alteration of the neutral axis. The significance of the point is that a wall can be double thickness to support floors on both sides and then revert to single thickness below without generating large eccentric loads. The overlapping joint also allows adjustment for inaccuracies in casting and placement. Other connections between parallel elements could be used, such as the back-to-back arrangement

shown for insulated exterior wall panels in Section 4.4. These configurations will not maintain the modular relationship to cross walls as described below; therefore, they would not be appropriate at intersections with cross walls. The main use of these relationships will probably be in stiffening very high walls, in making exterior walls, or in making larger mechanical spaces within the wall structure.

The use of a grid of walls requires a four-way joint for wall components in plan. The modular relationships between ribs of parallel components must be maintained across the joint. The joint design shown on pages 63, 64 and 65 achieve these goals plus the ability to fasten two or three components together as well as four. Unfortunately, the edge condition of this joint must be different from that required for a parallel joint, in order to maintain the modularity. If it is desired that the wall be two components thick, the same edge

condition can be used for all the panels at the connection.

Horizontal connections between components have been designed to support floor elements, provide vertical stiffness in walls, and to allow penetration by utility ducts. The connections do all of these when there is a floor on only one side of the wall at that particular level. The stiffness is attained by placing the wall components which are on the side opposite the floor in such a way that they are continuous across the joint. This staggered arrangement of horizontal joints also permits panels which are in place to support panels which are being erected, thus reducing the required bracing. The panels on the same side as the floor support the floor components. Where no panel is continuous across the joint, penetration can be made along the extension of the floor channels.

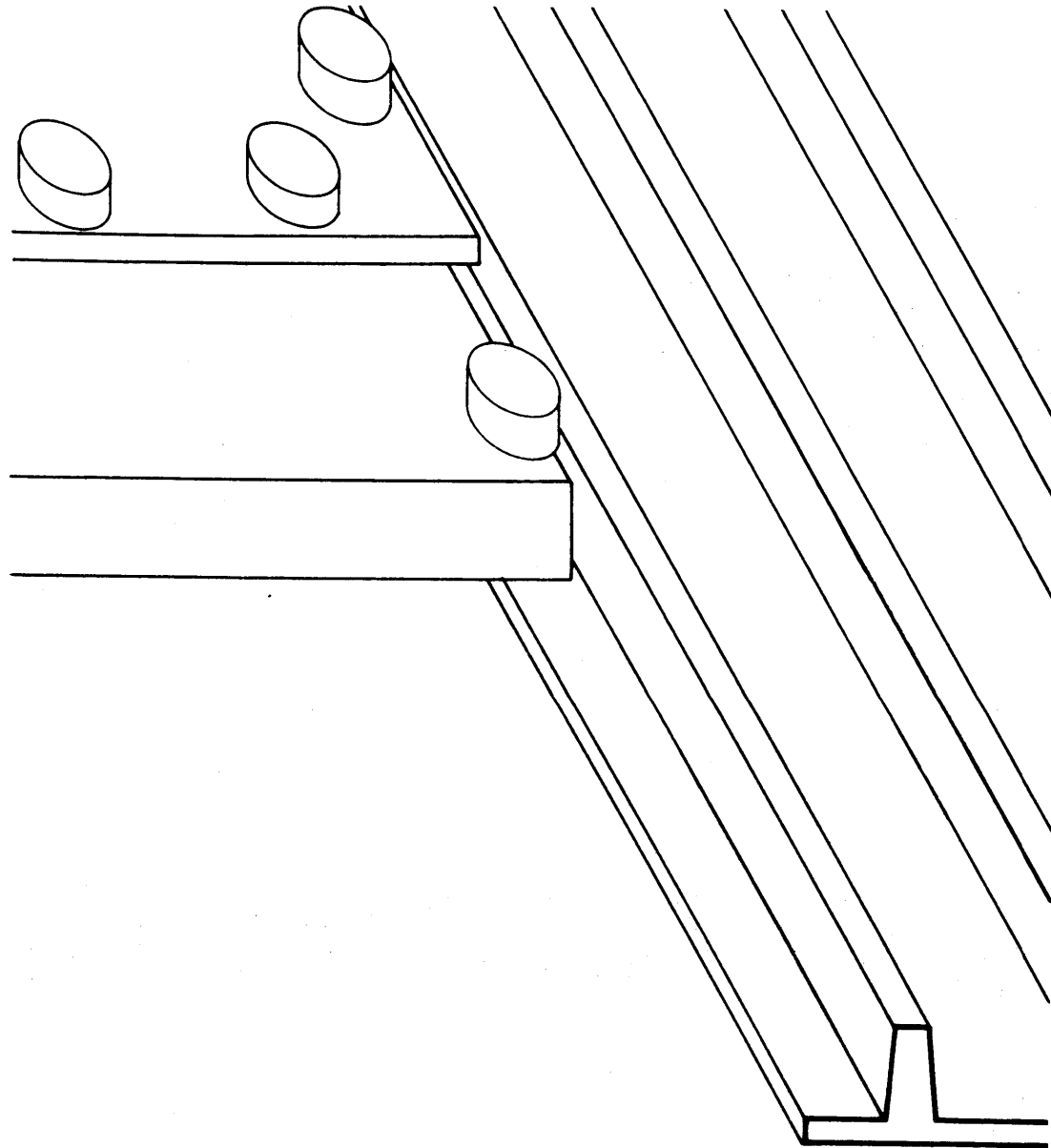
To establish vertical continuity between the

components supporting the floor and those above when there is no continuous panel on the opposite side, precast blocks must be used. If the labor difficulties could be solved, cast-in-place concrete could substitute for the precast blocks, making a superior connection.

When there are floors at the same level on both sides, or when the floor is supported on a beam, the same precast blocks or cast-in-place concrete can be used to make the joint.

SCALE: 1" represents 1'  
TYPE: horizontal section  
and oblique projection,  
looking up.

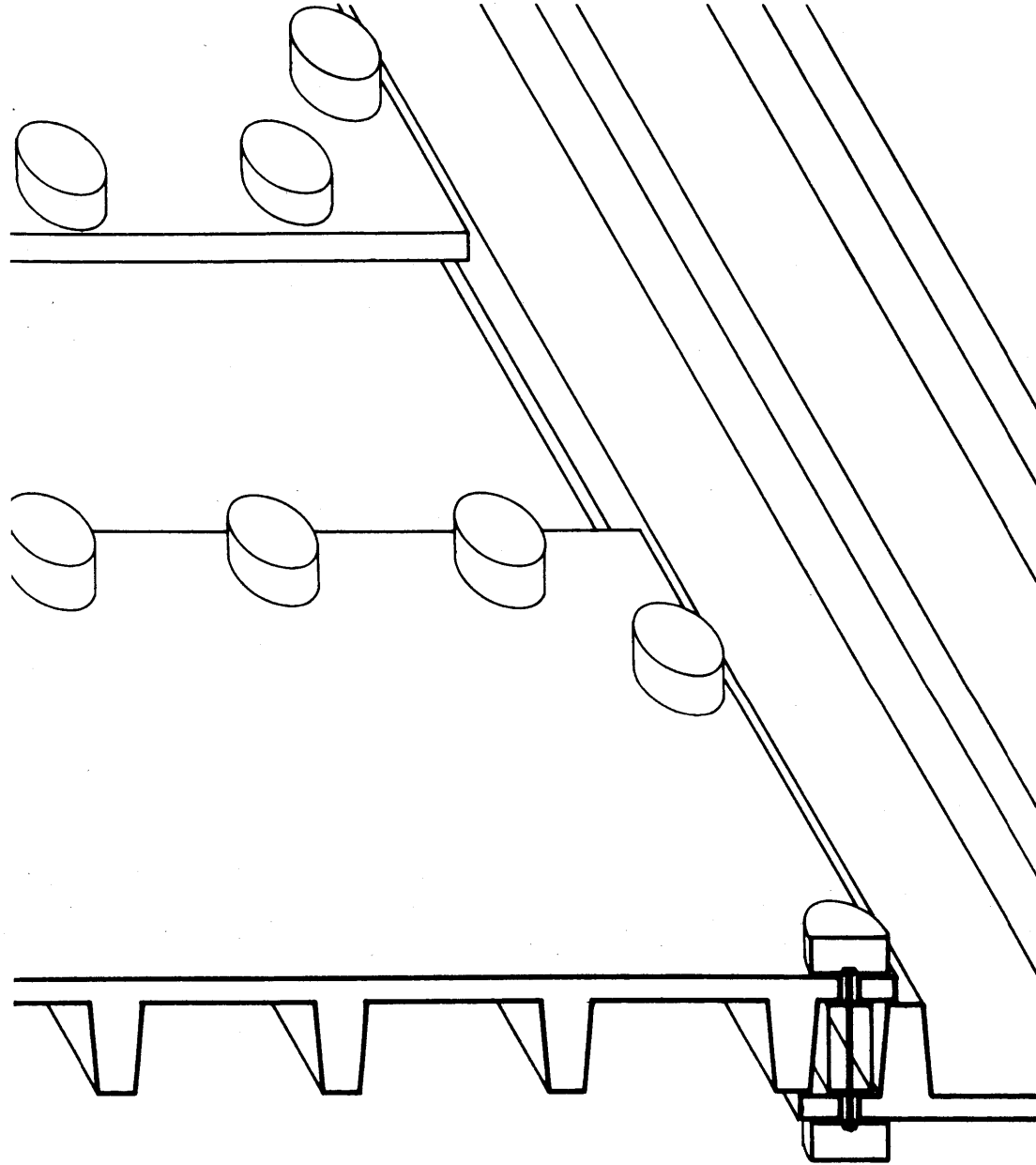
COMMENTS: a precast block  
used as a lintel to stiffen  
a panel over an opening;  
bolted connections.



SCALE: 1" represents 1'

TYPE: horizontal section  
and oblique projection  
looking up.

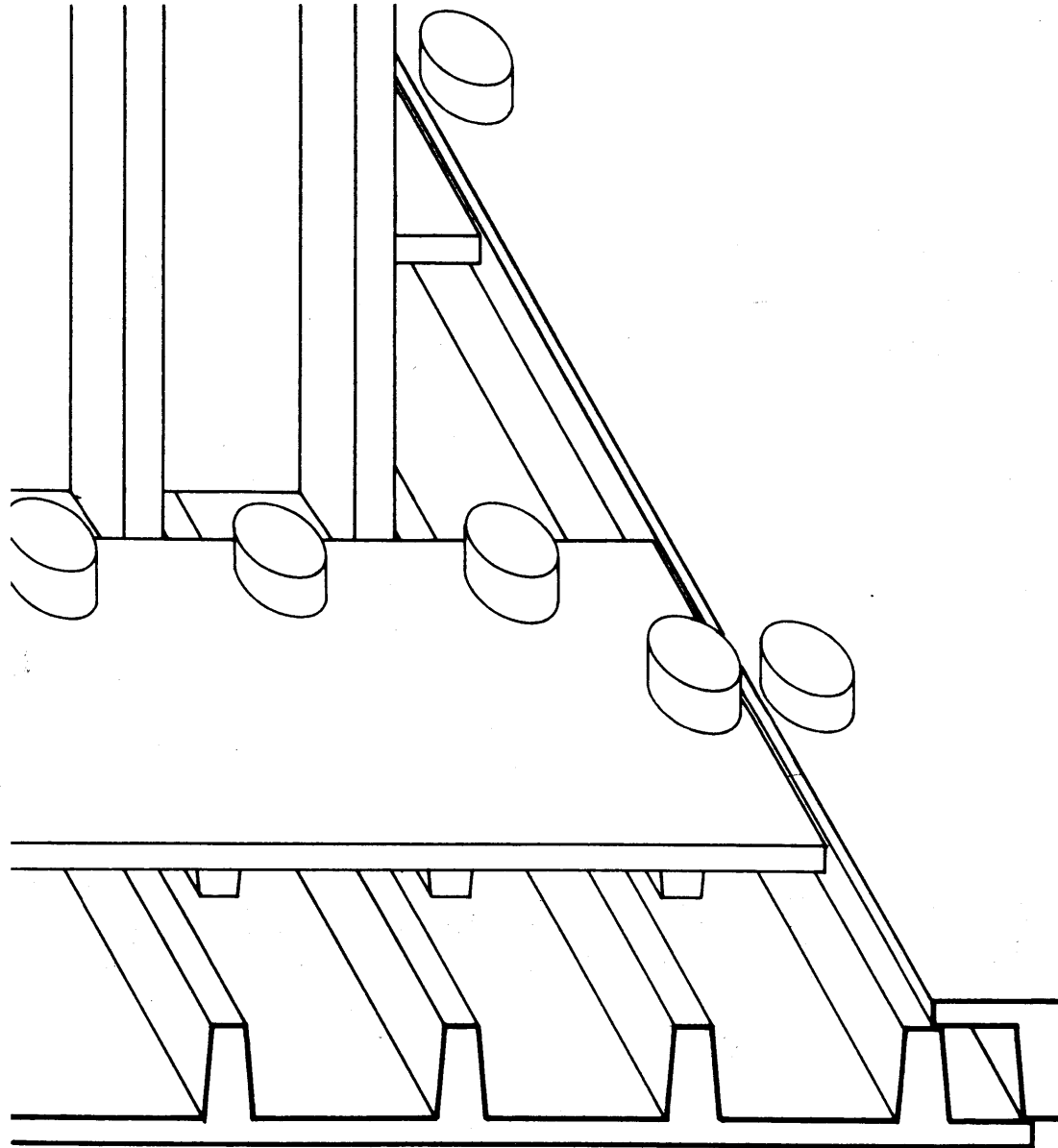
COMMENTS: a horizontal  
joint between two panels  
using a precast block and  
bolts in concrete casing;  
an adjacent panel, continu-  
ous across the joint,  
bolted with steel tube  
spacers.



SCALE: 1" represents 1'

TYPE: horizontal section  
and oblique projection,  
looking up.

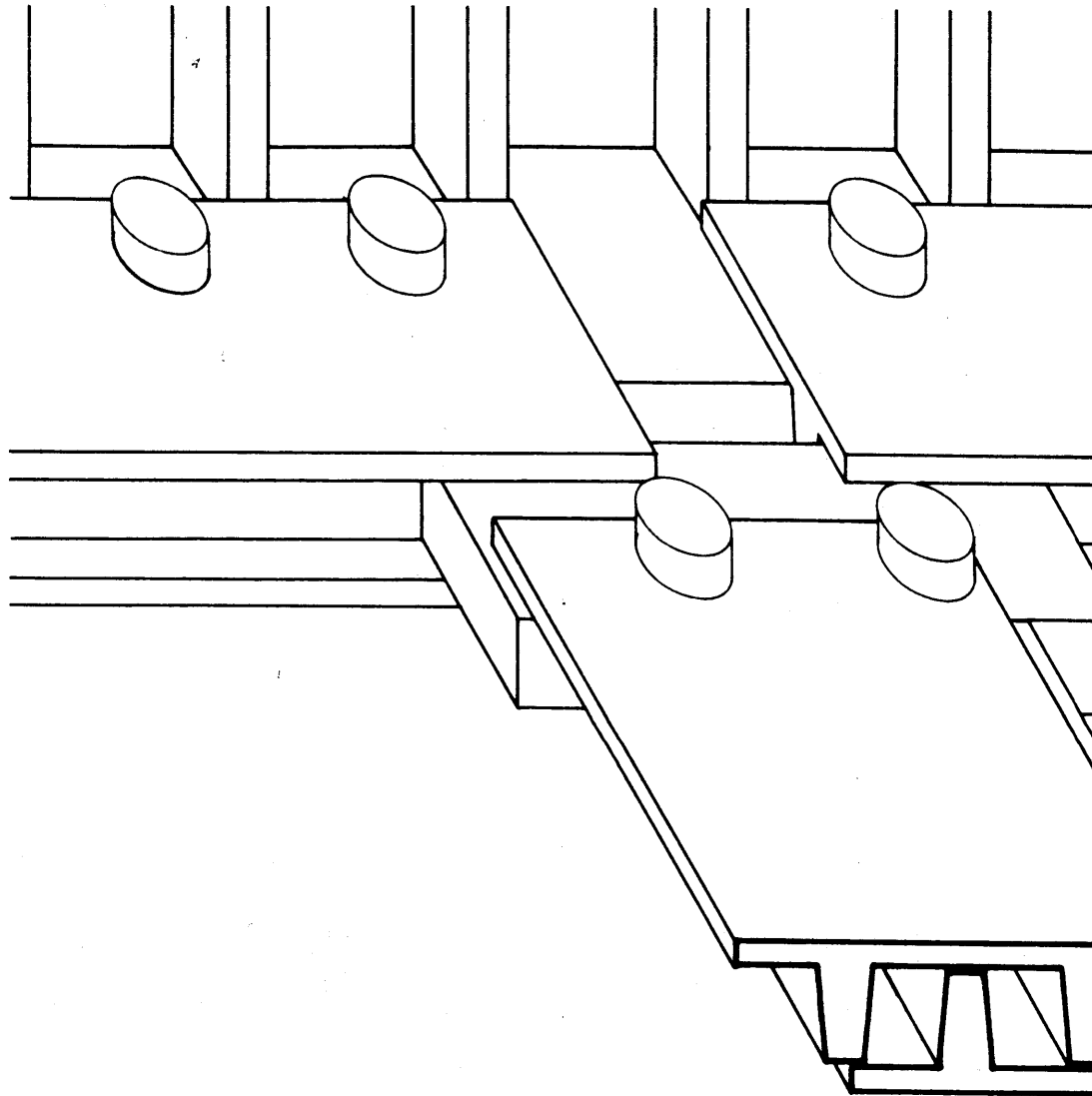
COMMENTS: an assemblage of  
panels in parallel support-  
ing one end of a floor  
panel; bolted connections  
except floor panel welded  
to short wall panel.



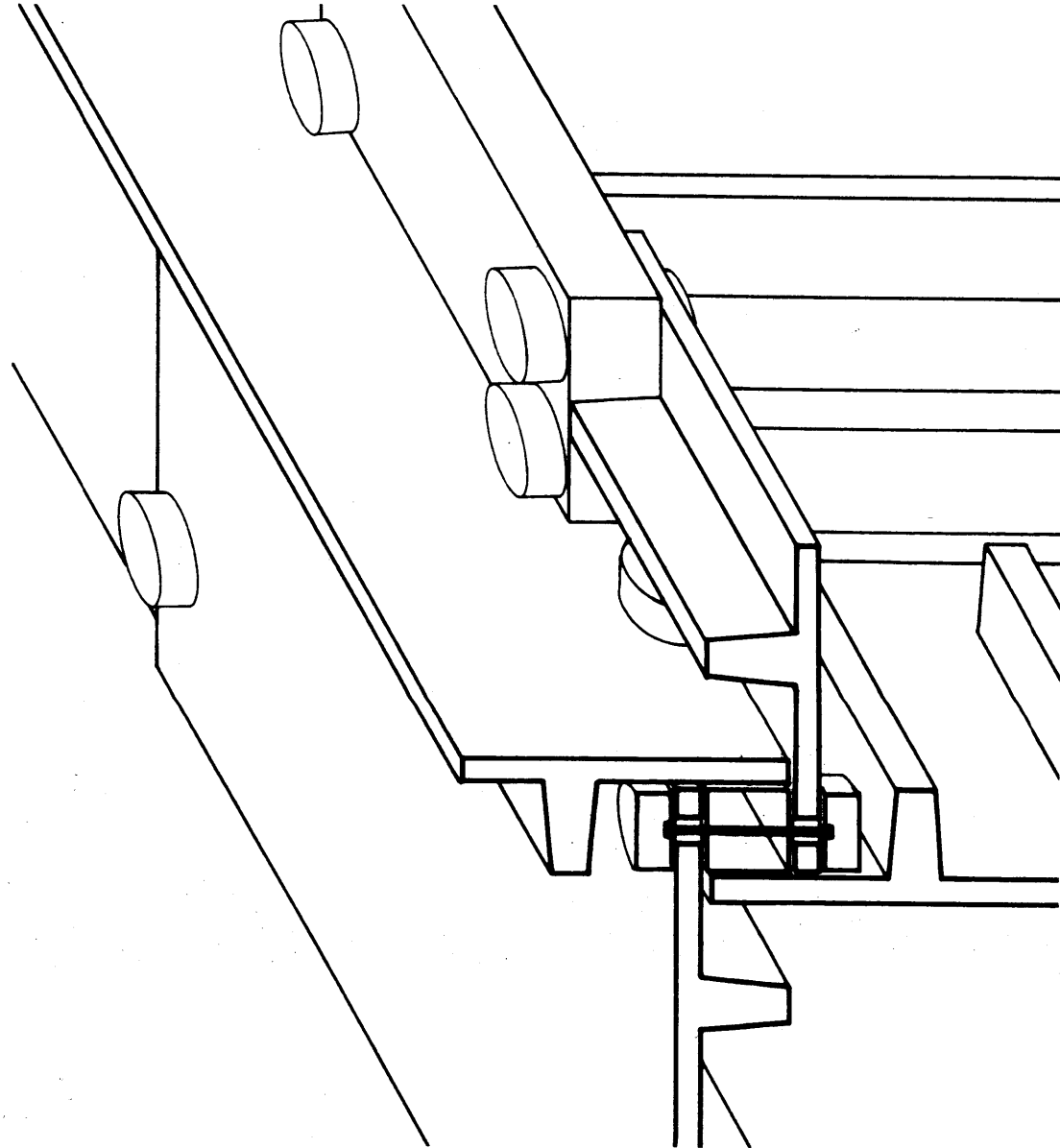
SCALE: 1" represents 1'

TYPE: horizontal section  
and oblique projection,  
looking up.

COMMENT: two panels as  
column; precast block  
supporting beams; precast  
blocks set in the beams to  
add strength and/or support  
panels above floor; floor  
panels supported on beams;  
floor panels welded, others  
bolted.



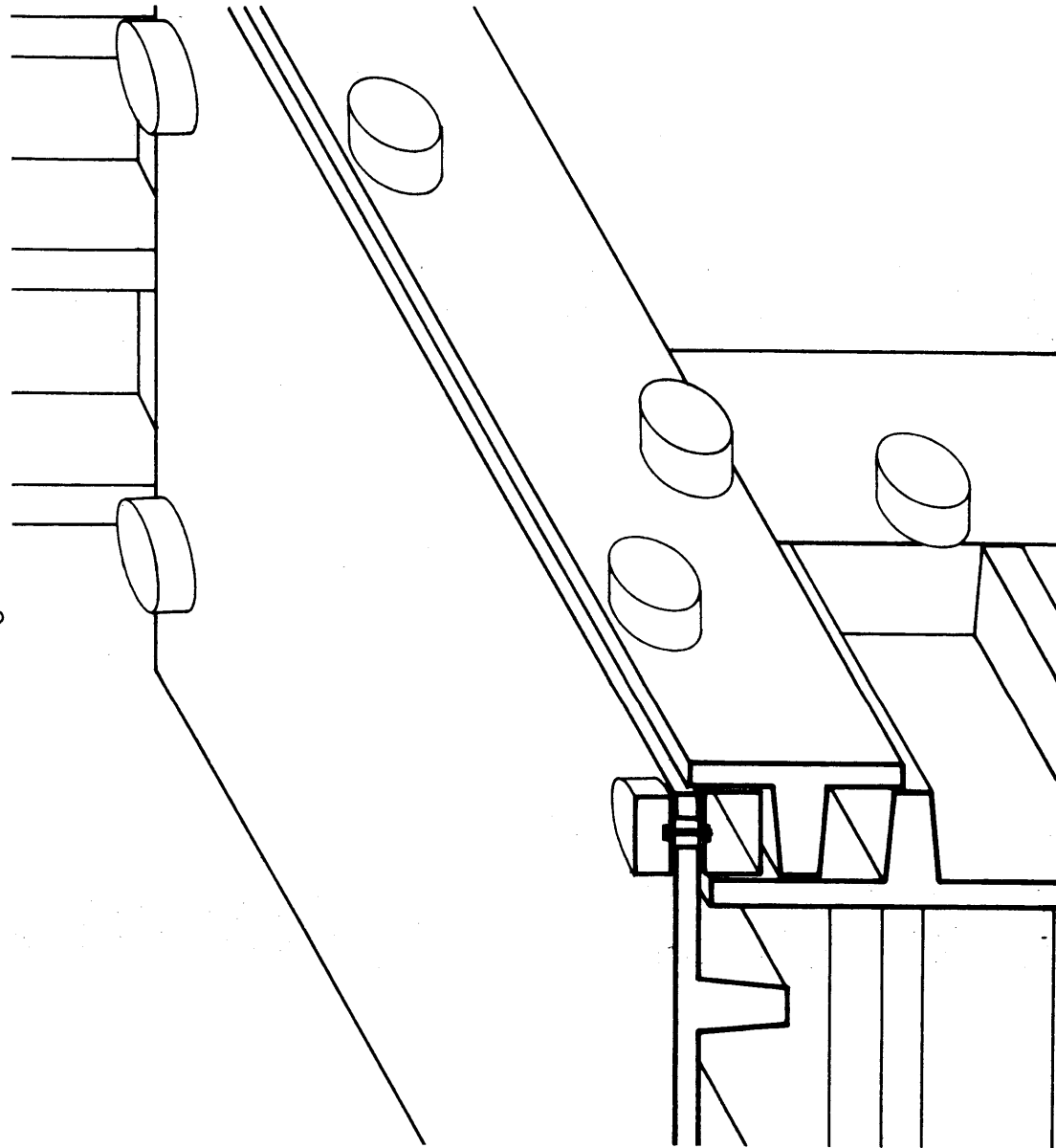
SCALE: 1" represents 1'  
TYPE: horizontal section  
and oblique projection,  
looking up.  
COMMENTS: typical  
perpendicular joint using  
bolts and steel tube  
spacers; staggered  
horizontal joints; floor  
panel in upper right  
supported by wall panel.



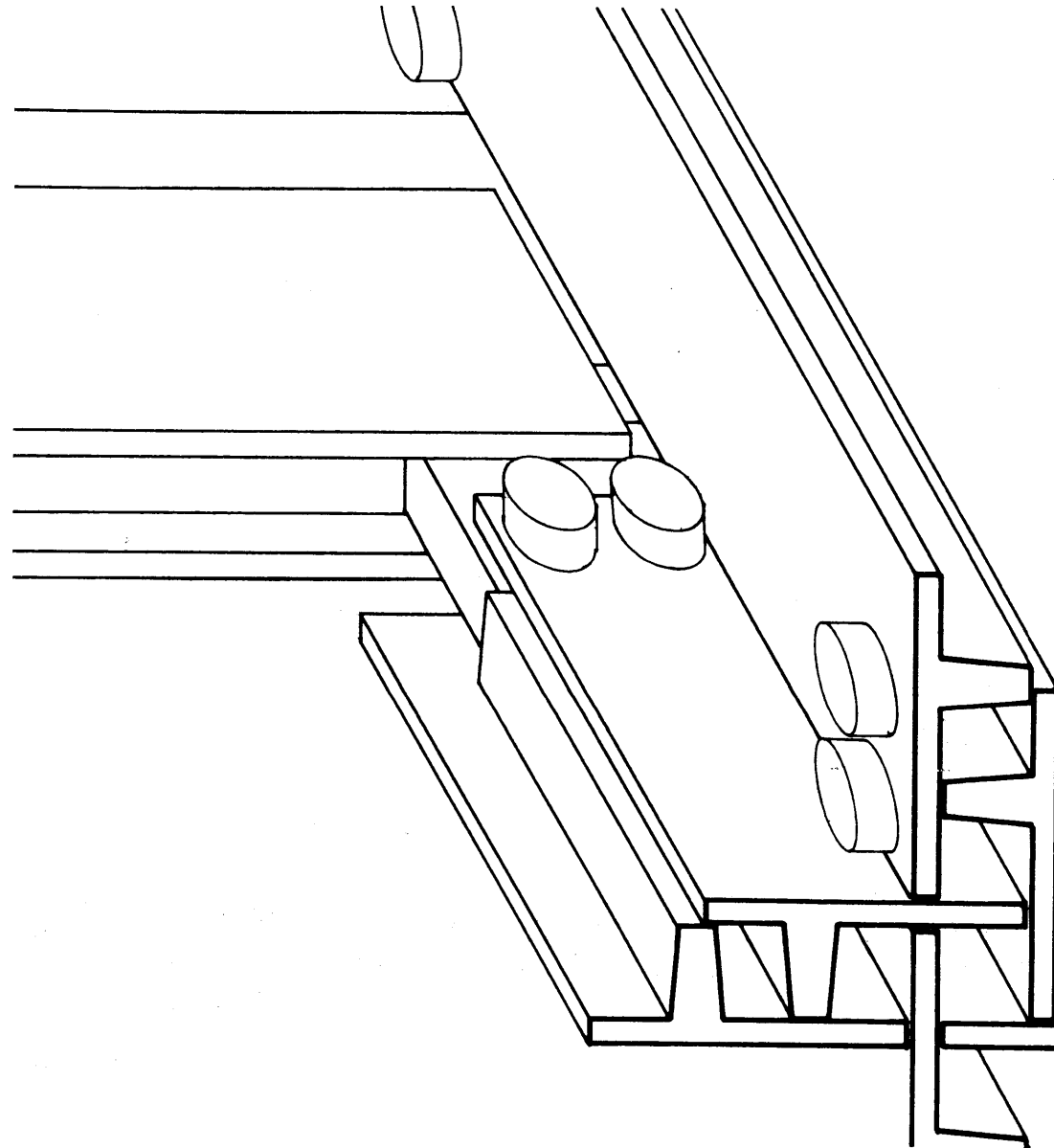
SCALE: 1" represents 1'

TYPE: horizontal section  
and oblique projection,  
looking up.

COMMENTS: a minimal  
perpendicular connection  
using bolts and steel tube  
spacers; wall panels  
supporting floor panels;  
precast block to stiffen top  
edge of wall panel.



SCALE: 1" represents 1'  
TYPE: horizontal section  
and oblique projection,  
looking up.  
COMMENTS: doubled wall  
panels at perpendicular  
connection for stronger  
support of beam; bolted  
connections.



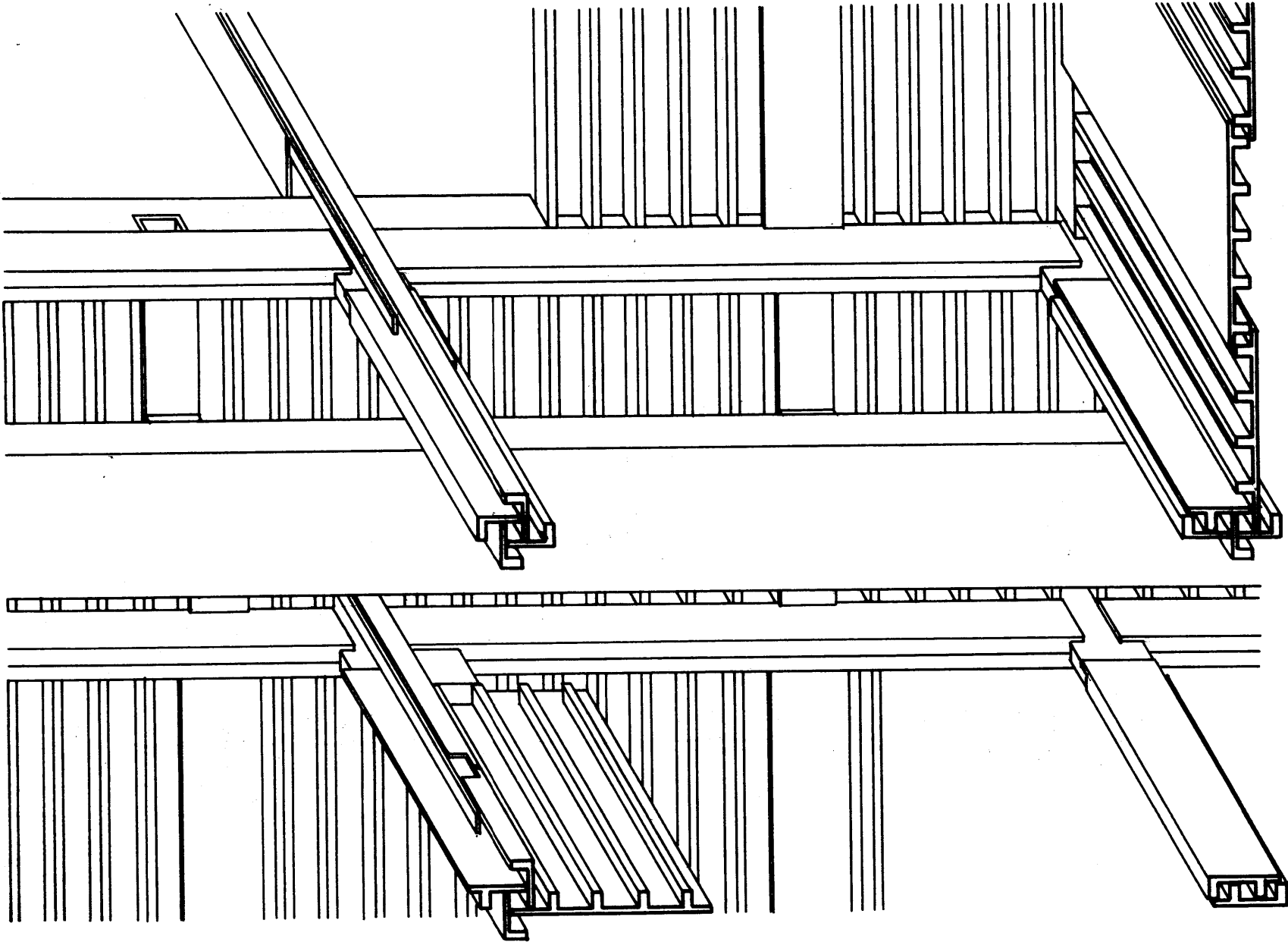
## EXAMPLES OF ASSEMBLAGES

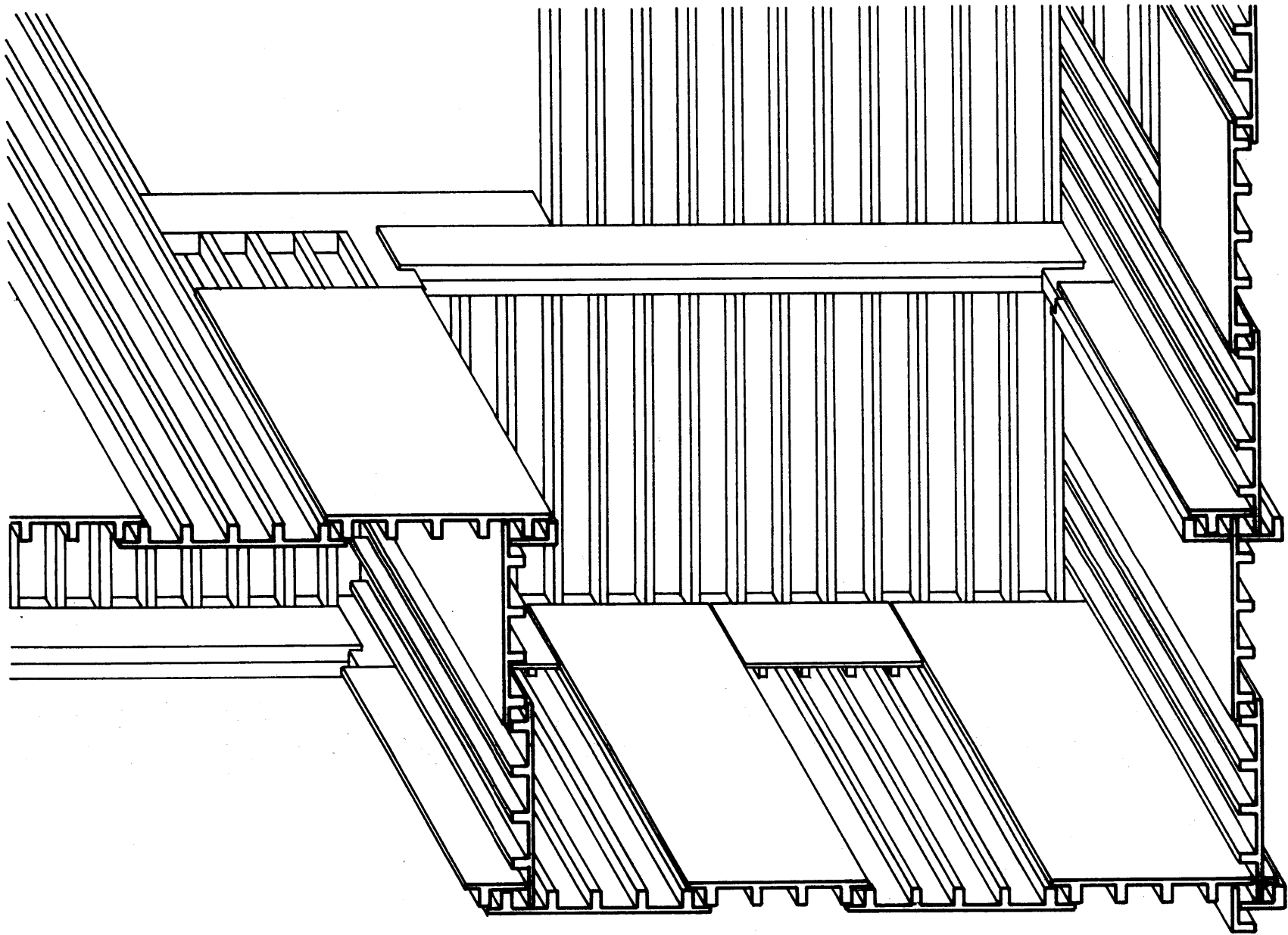
The drawings on the next four pages show some of the conditions which could exist in an assemblage, including the overlapping panel with staggered horizontal joints, fairly minimal column and beam framework, and continuous wall areas. Also illustrated are air ducts, the large ones located in a ten-foot bay with small ducts formed by attaching panels to two ribs. The drawing on page 67 shows some panels which extend beyond the two ribs, forming coves for lights.

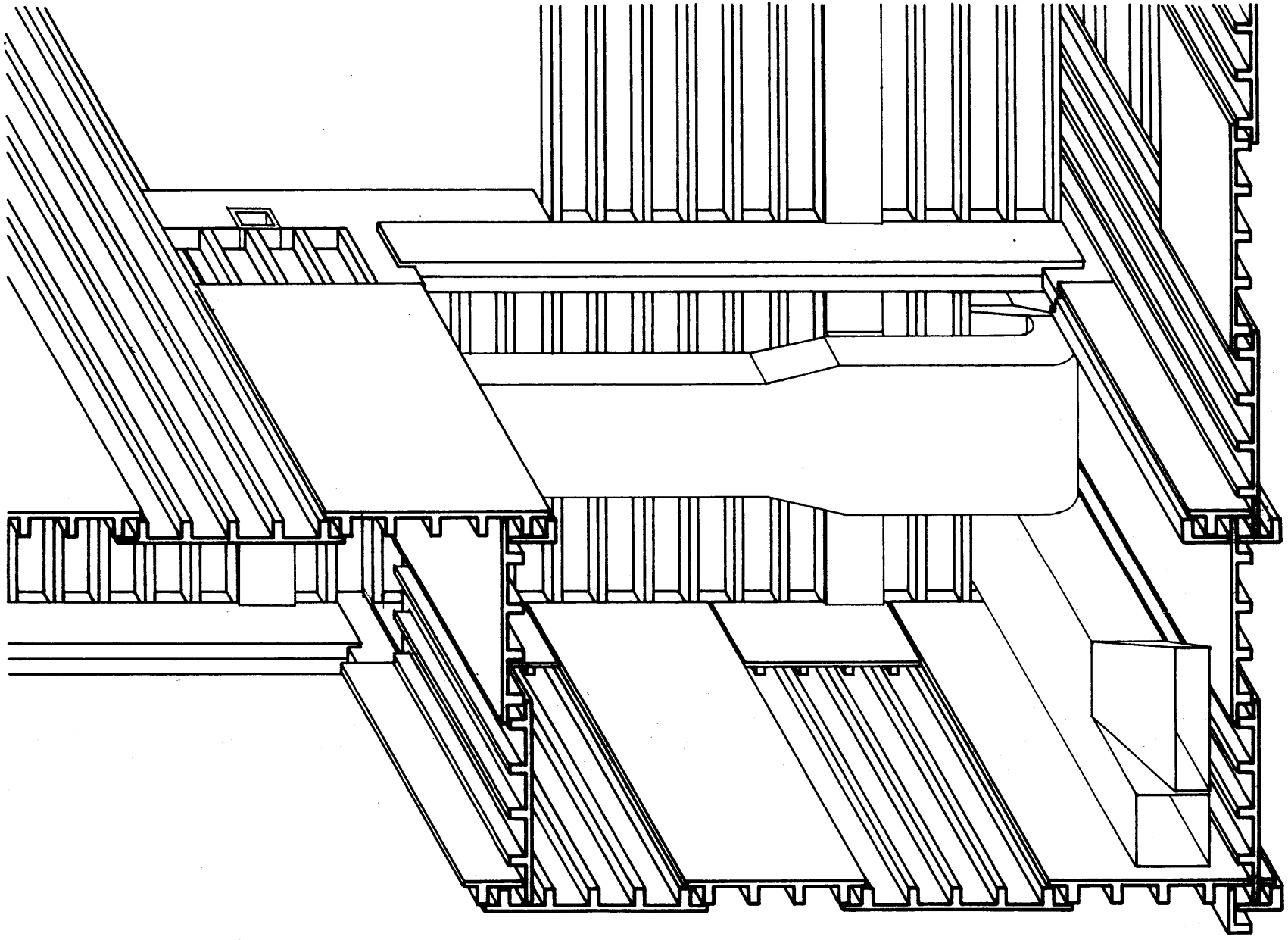
DRAWINGS, pages 67-70

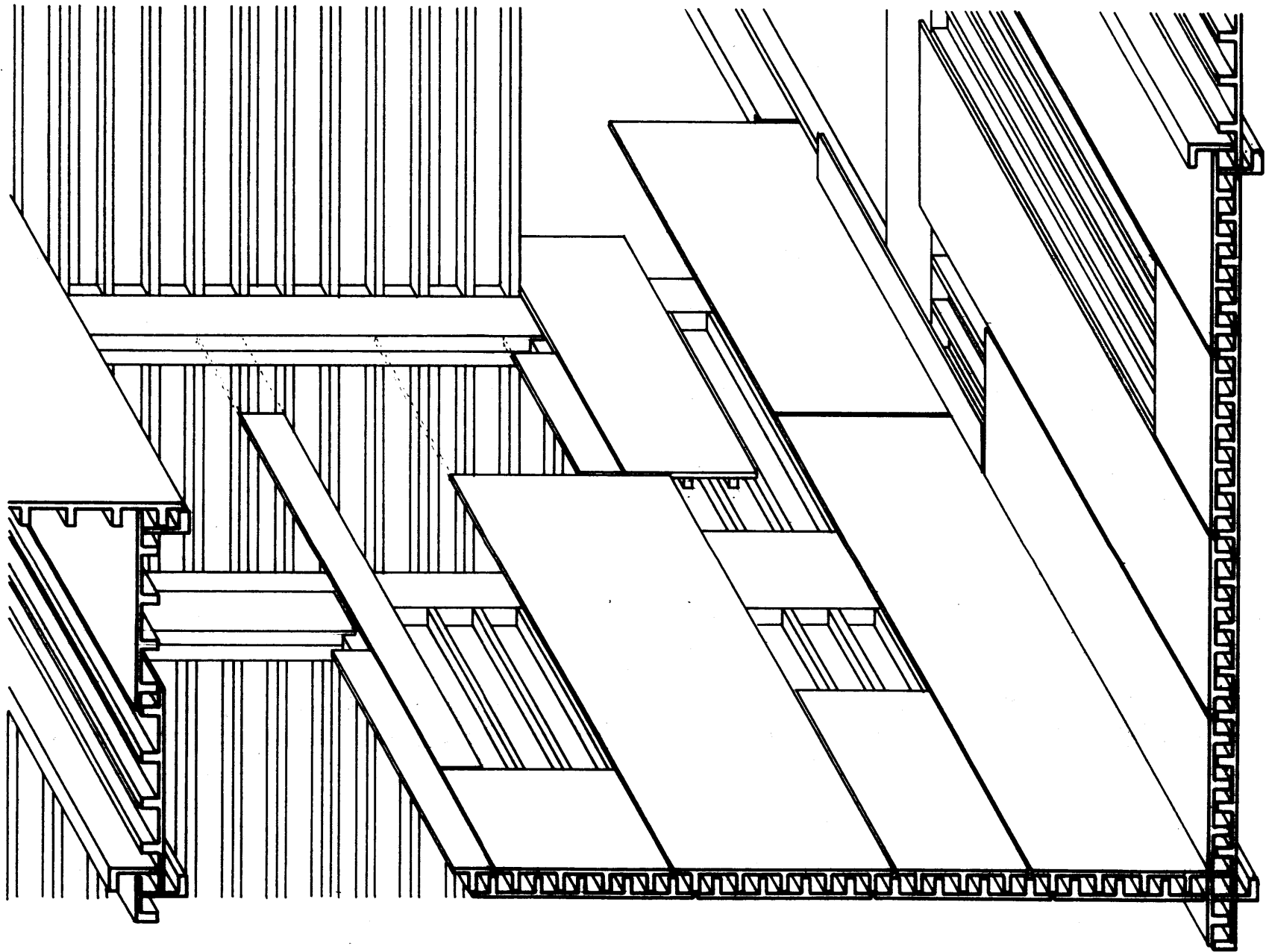
SCALE: 1/4" represents 1'

TYPE: horizontal section  
and oblique projection,  
looking up.









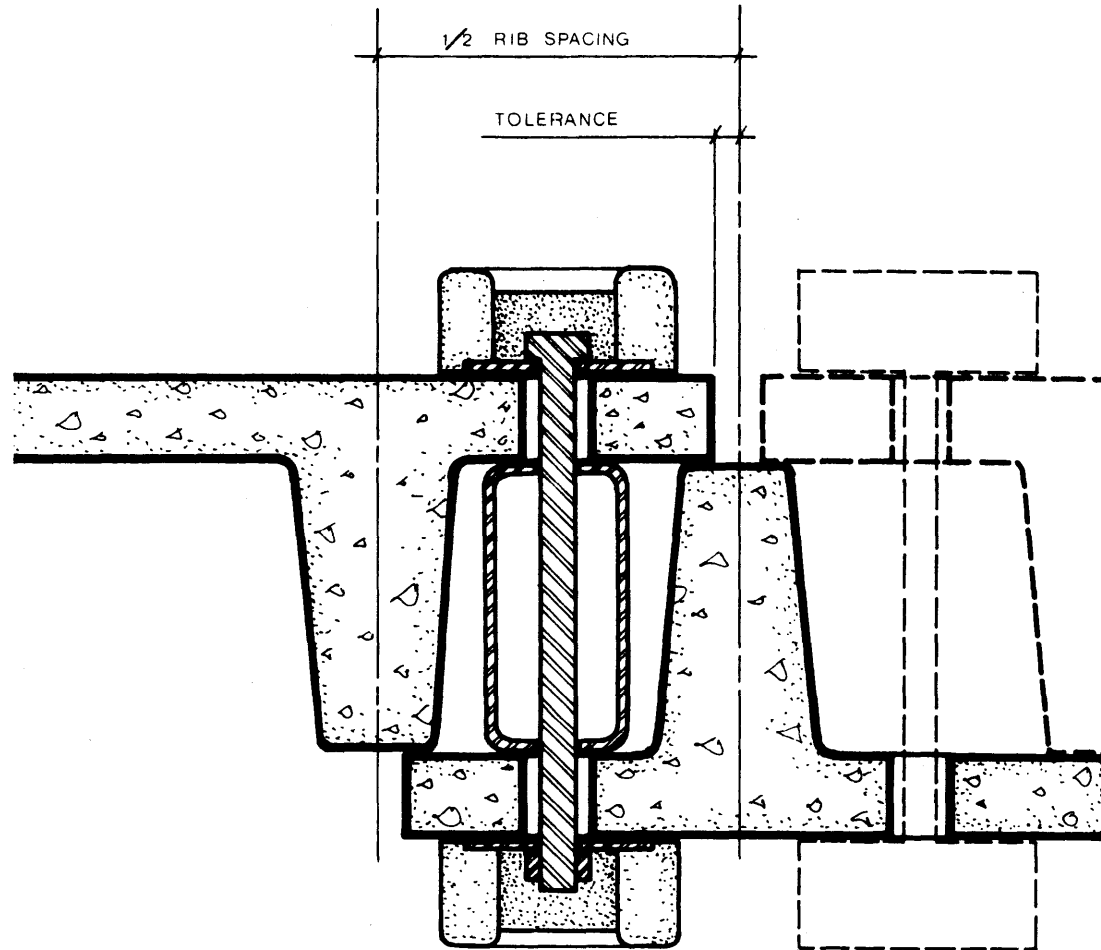
## STRUCTURAL CONNECTIONS

Some typical connection details are illustrated in this section. Details for bolting or welding the vertical connections are shown, while the horizontal connections are detailed as bolted or cast-in-place concrete.

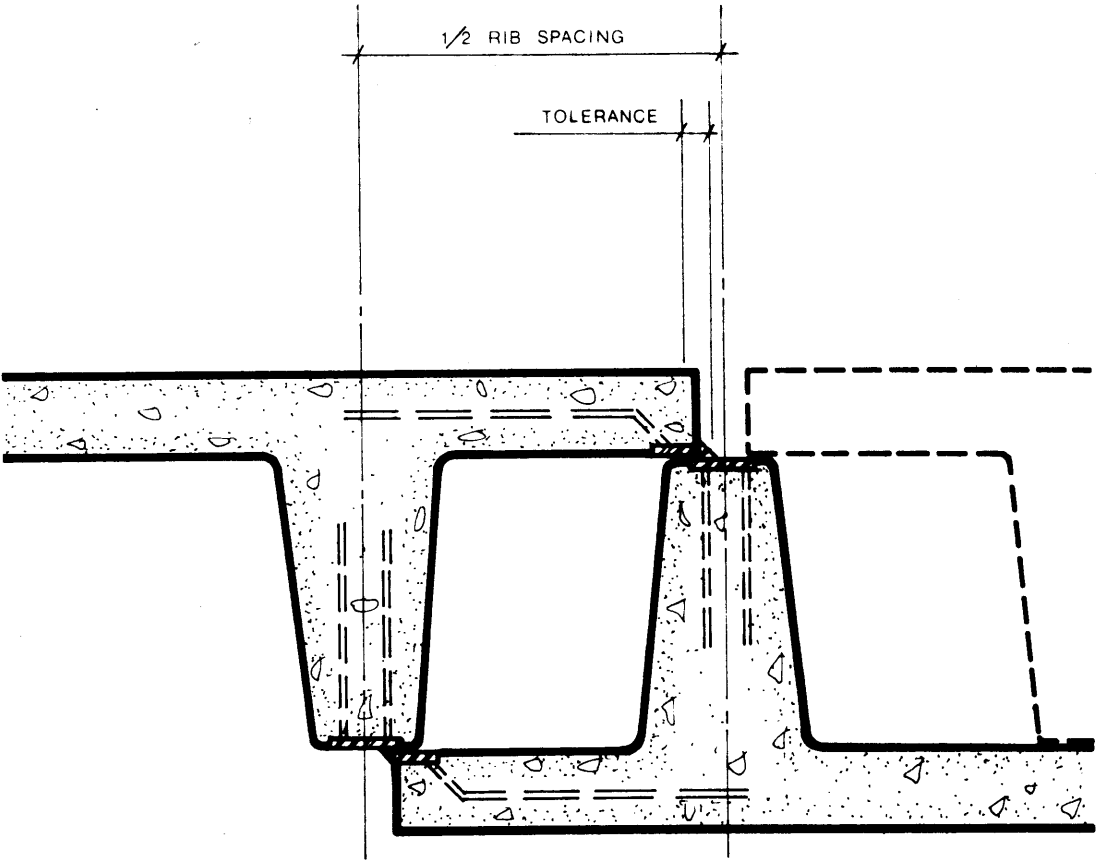
SCALE: 3" represents 1'

TYPE: horizontal section

COMMENTS: a vertical joint  
between parallel panels,  
showing bolt, steel bearing  
plate, steel tube spacer,  
concrete "washer" attached  
to bearing plate, and grout  
covering bolt ends for fire  
protection.



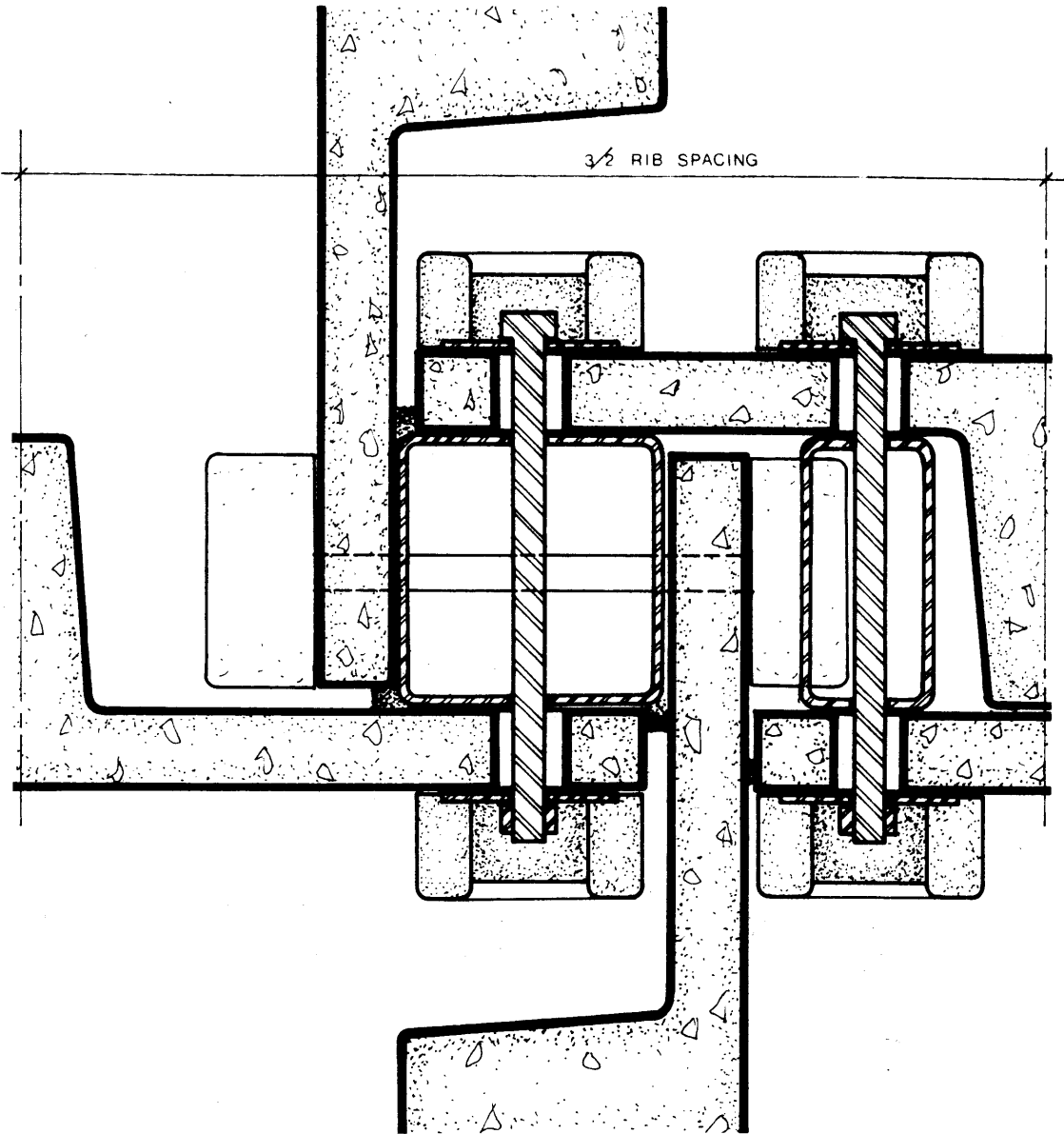
SCALE: 3" represents 1'  
TYPE: horizontal section  
COMMENTS: a vertical joint  
between parallel panels,  
showing weld plates attached  
to steel reinforcing in the  
concrete.



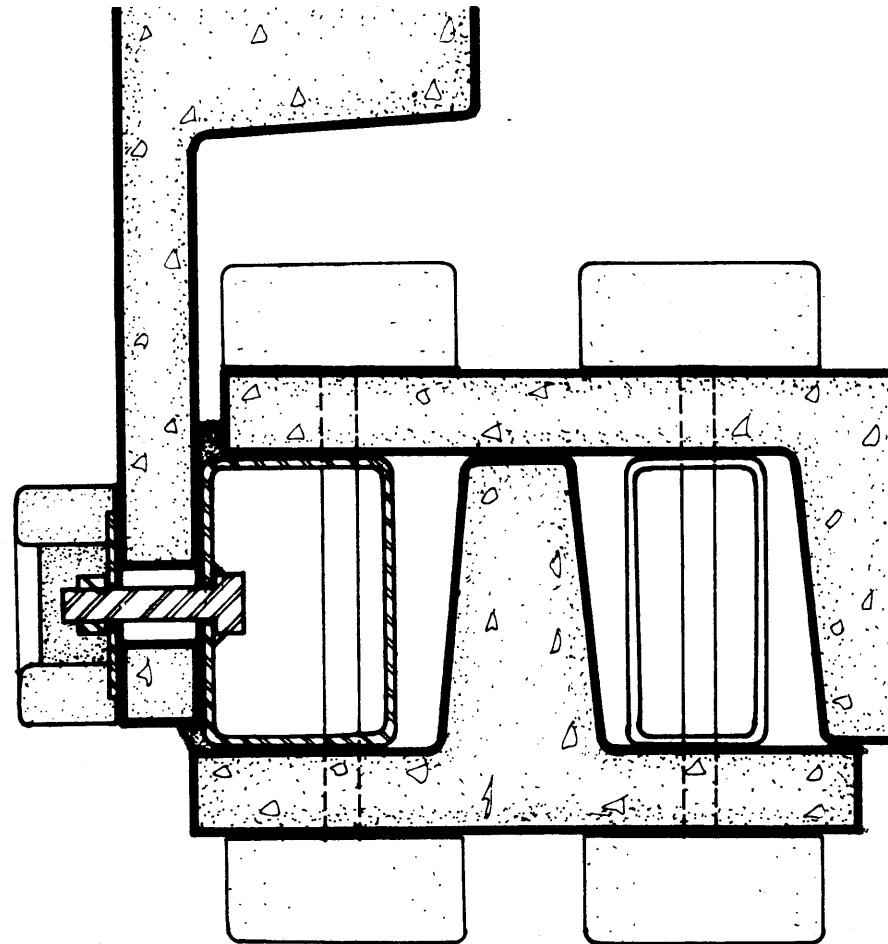
SCALE: 3" represents 1'

TYPE: horizontal section

COMMENTS: vertical joints  
between perpendicular  
panels showing, in one  
case, doubled wall panels;  
also showing bolts, bearing  
plates, concrete "washers,"  
grout, steel spacers, and  
caulked or grouted gaps.



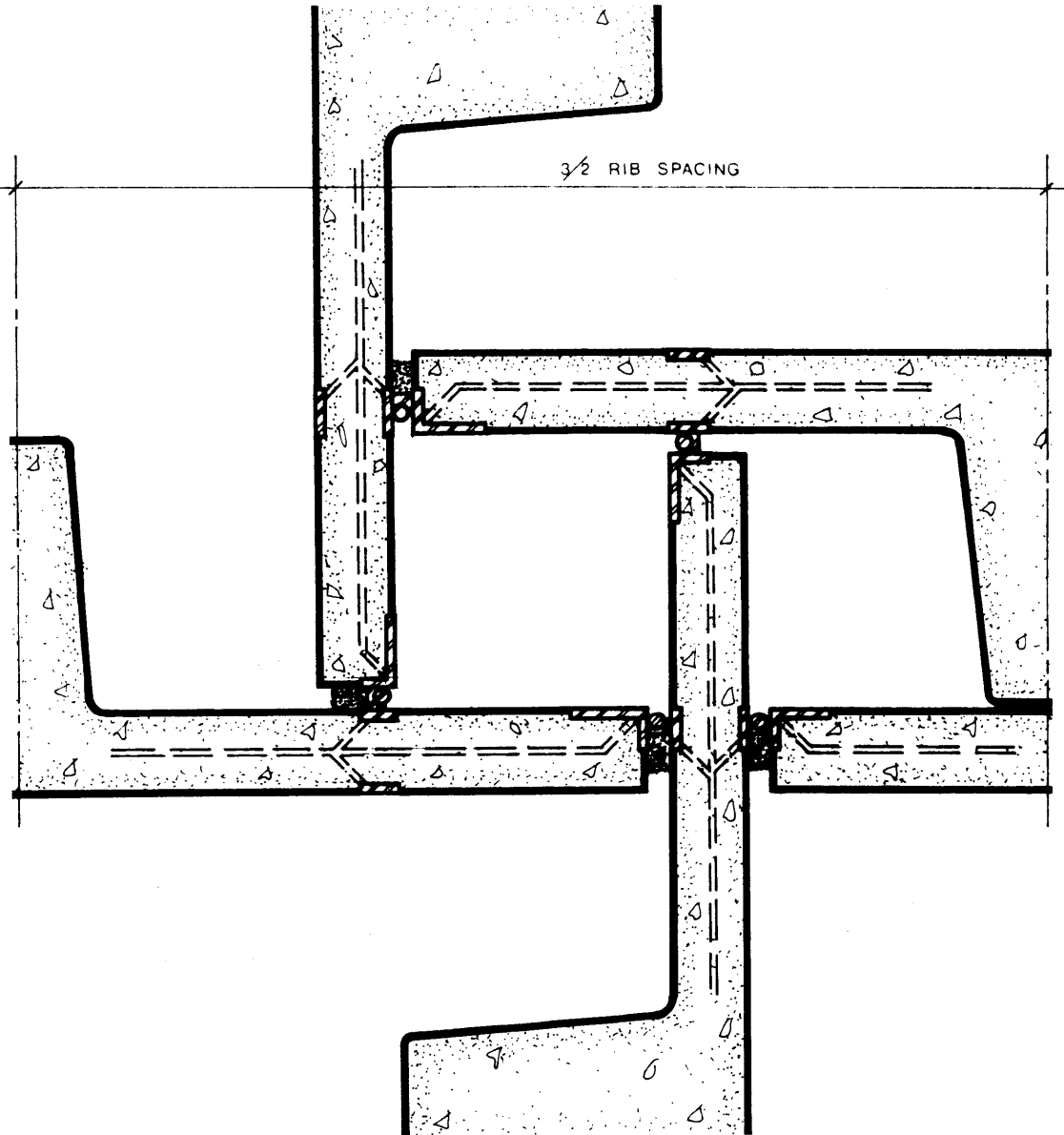
SCALE: 3" represents 1'  
TYPE: horizontal section  
COMMENTS: a perpendicular,  
bolted connection between  
two wall panels, using a  
third narrow panel to  
complete the connection.



SCALE: 3" represents 1'

TYPE: horizontal section

COMMENTS: vertical joints  
between perpendicular  
panels showing, in one case,  
doubled wall panels; also  
showing weld plates tied to  
reinforcing steel, welds  
using additional rod, grout  
over welds.



SCALE: 3" represents 1'

TYPE: vertical section

COMMENTS: horizontal

joint between wall panels

and precast block showing

bolt assembly, grout where

block bears on panels,

corrugated panel surfaces

for shear strength; floor

panels welded to wall

panels and topped with in

situ concrete; opening in

precast block (dotted) for

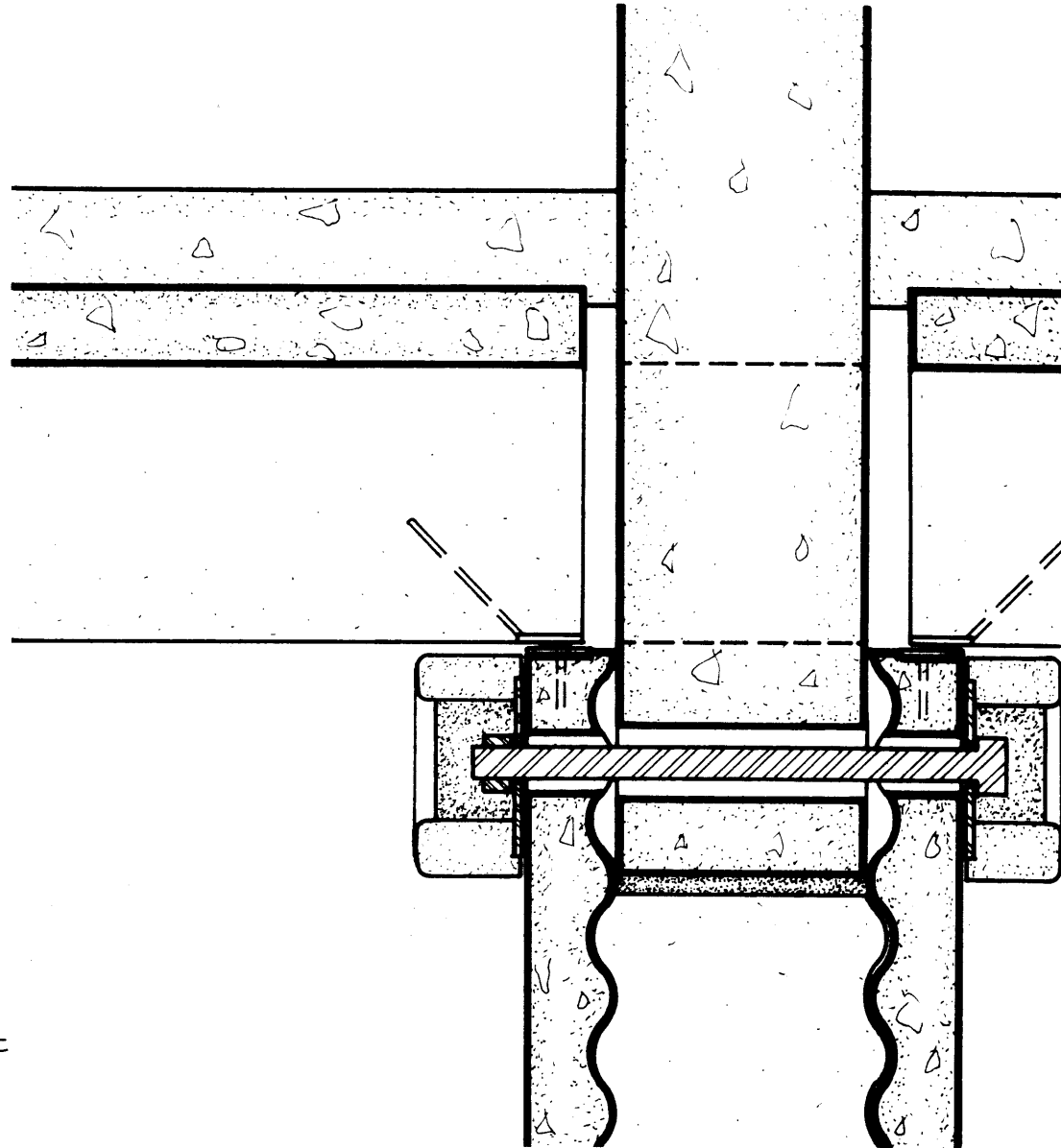
air duct. Precast block

could support additional

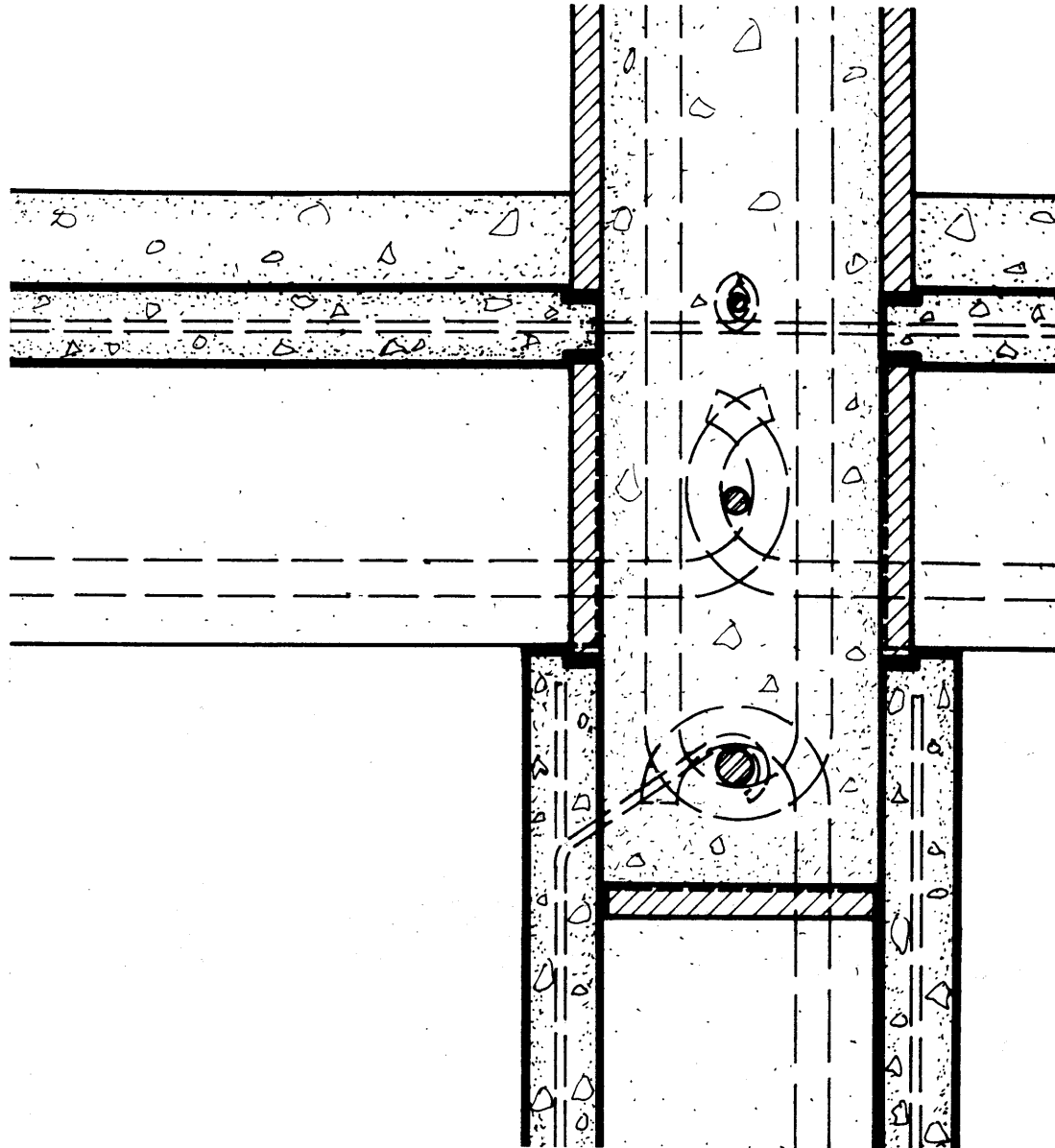
wall panels above, using

the connection detail invert

ed.



SCALE: 3" represents 1'  
TYPE: vertical section  
COMMENTS: horizontal joint showing doubled wall panels supporting floor panels, permanent particle board form-boards, steel extending from precast elements, additional steel reinforcing bars, in situ concrete joint, and concrete topping on floor panels.



DRAWING, page 80

SCALE: 3" represents 1'

TYPE: vertical section  
in two directions.

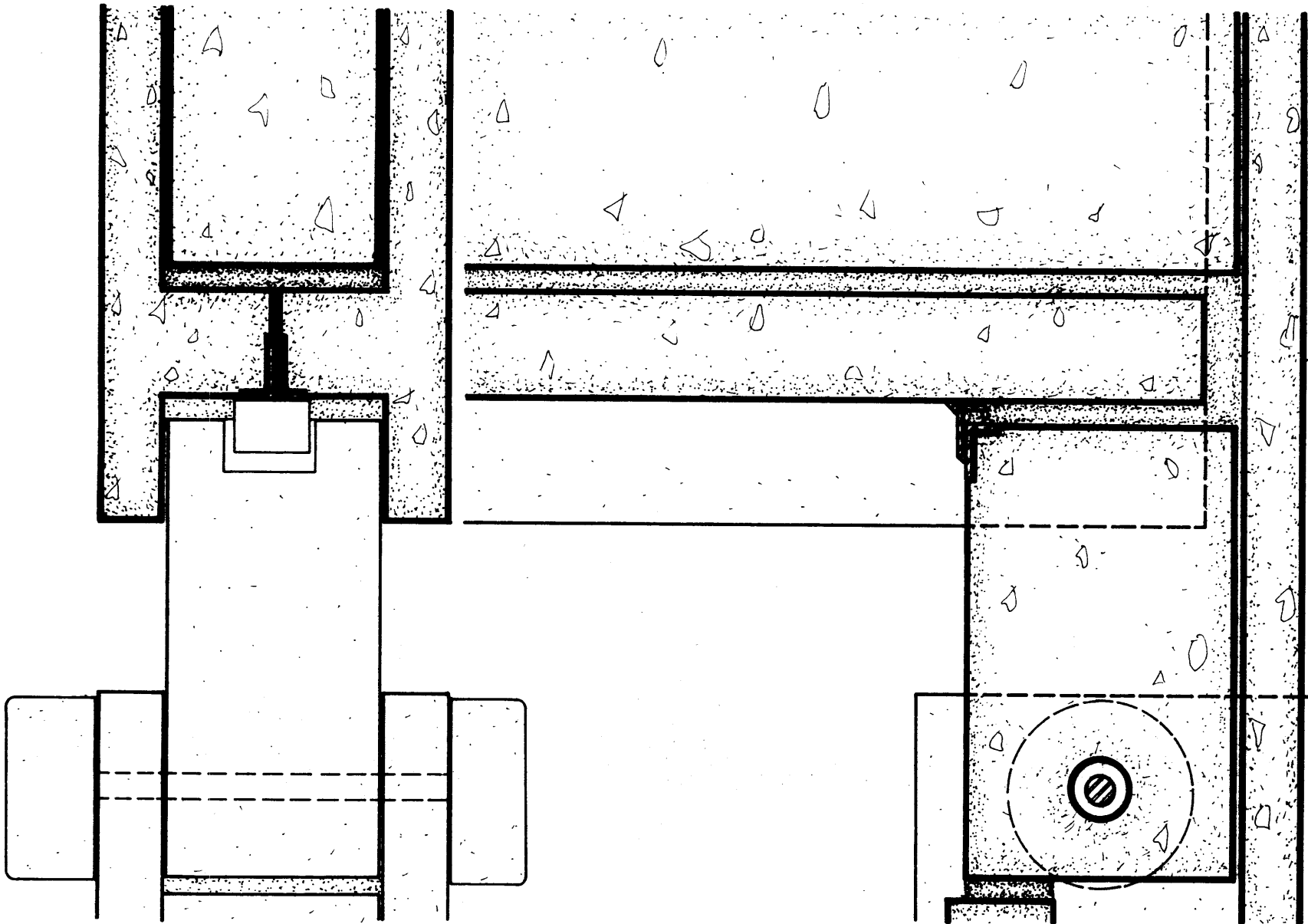
COMMENTS: connection  
between wall panels and  
beam using precast block  
with bolted and welded  
connections; precast  
block set in beam, if  
required; perpendicular  
wall panel in section at  
right.

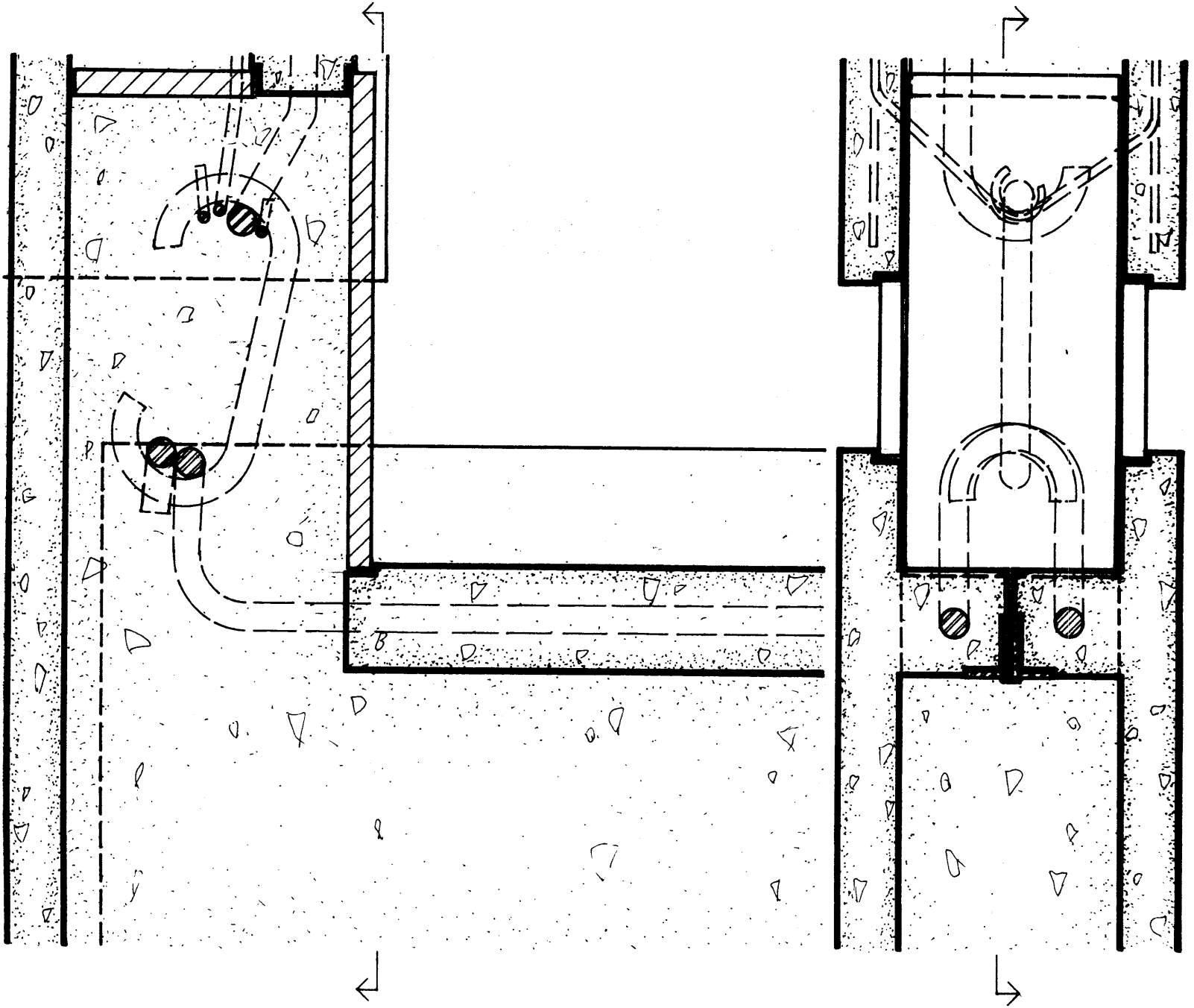
DRAWING, page 81

SCALE: 3" represents 1'

TYPE: vertical section  
in two directions.

COMMENTS: connection  
between wall panels and beam  
showing permanent form-  
boards, reinforcing steel,  
and in situ concrete making  
joint and stiffening beam.





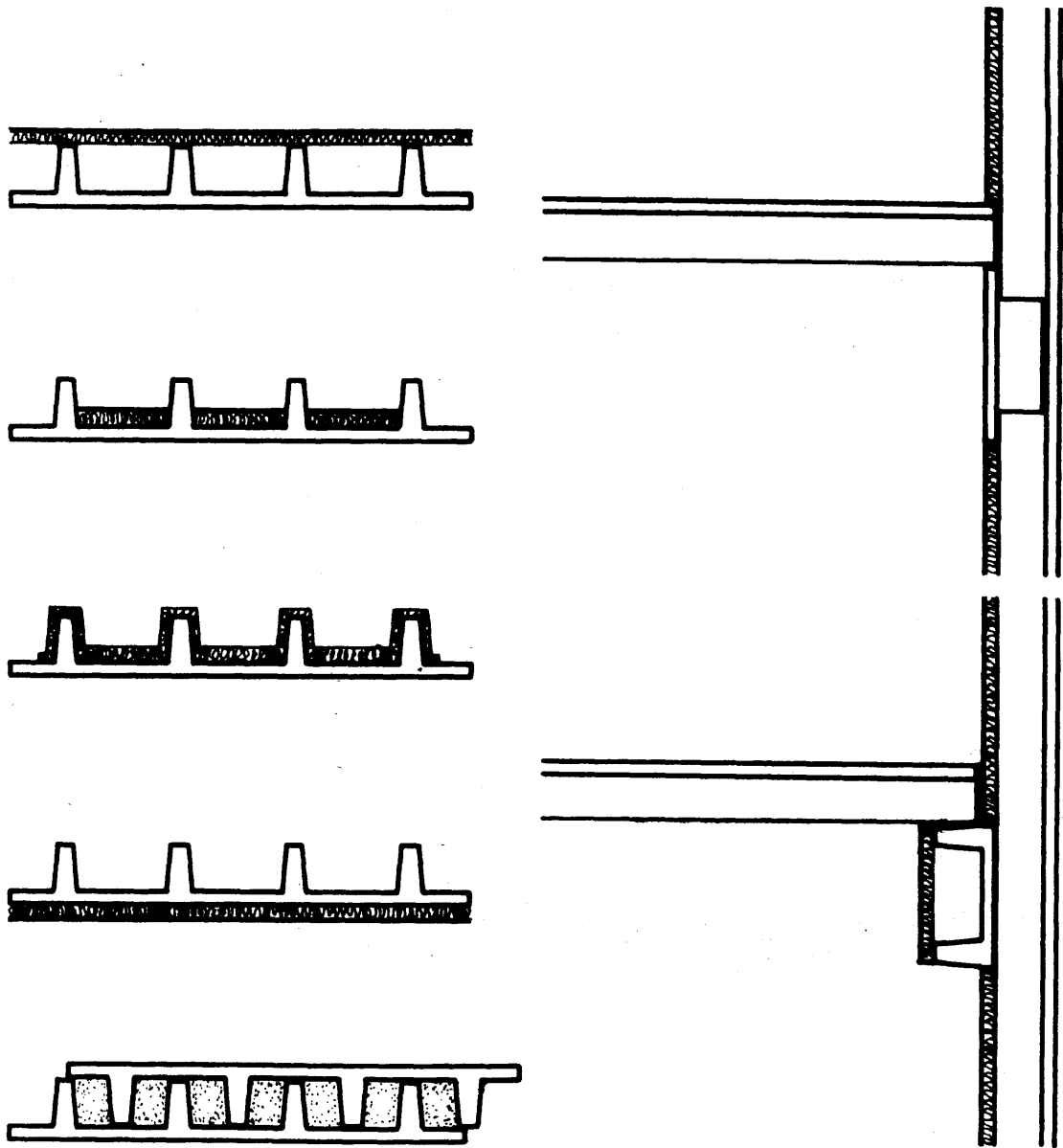
## EXTERIOR WALLS

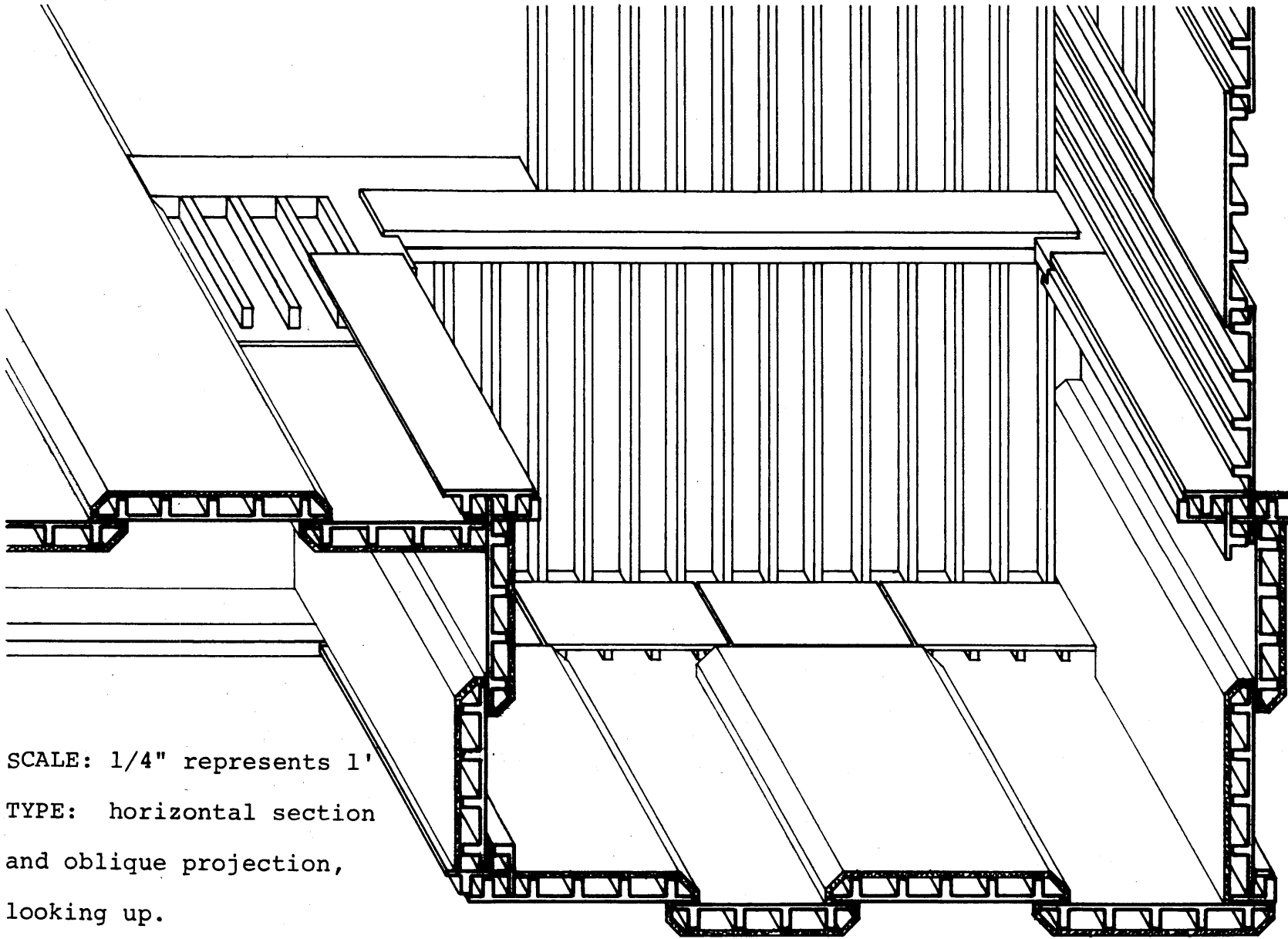
The problem of making a water and thermal barrier between inside and outside has not been resolved in the work to date. The major conflict has been between the idea of a continuous skin covering the concrete walls and the idea of exposing the elements and materials of the assemblage. Page 84 shows some of the possible relationships between concrete panels and insulation. Page 85 shows how the first, and thermally most efficient, of these might be used. The insulation, with a hard protective surface, would be prefabricated in modular widths with separate corner pieces. These would be glued to the concrete panels after they have been assembled. By shifting some of the panels to a back-to-back arrangement, the separate elements can be expressed while the thermal barrier remains virtually

unbroken; the insulation even covers the connections between precast panels, preventing thermal bridges. On the other hand, insulation is discontinuous at points where a floor is supported, as in the top section on page 84. The lower section on that page shows how a different supporting element could be used to improve the thermal barrier.

SCALE: 1/2" represents 1'

TYPE: horizontal and  
vertical sections.





SCALE: 1/4" represents 1'  
TYPE: horizontal section  
and oblique projection,  
looking up.

## A PLACE IN THE SCHOOL

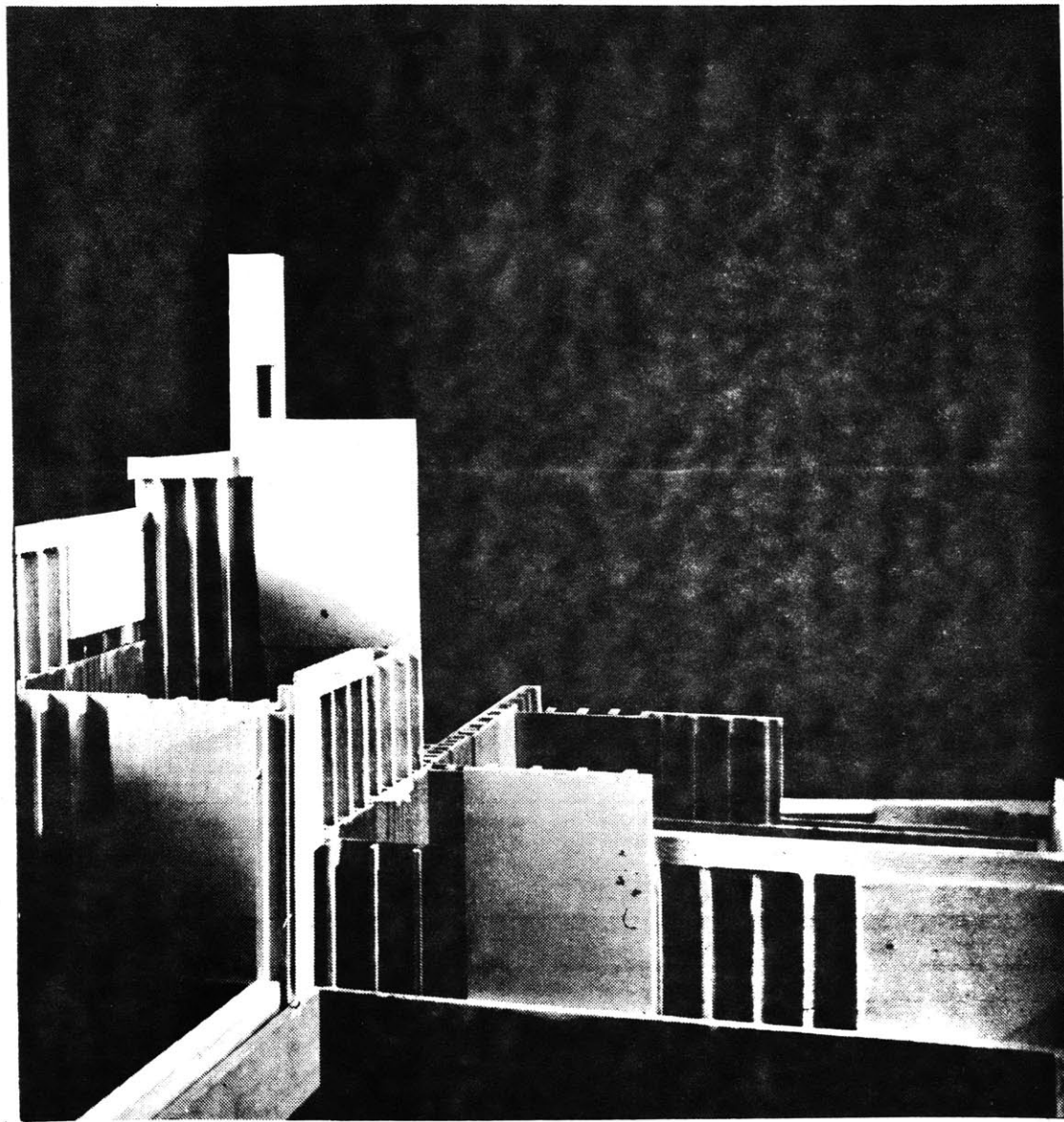
The photographic prints on the following pages show a model which was constructed to show the central space and entry of one of the houses in the school. The outside door is the very dark rectangle behind the girl in the lower-middle area of the pictures on pages 93 and 94. The details of the assemblage are not exactly those presented in this thesis; the model represents an earlier stage of development.

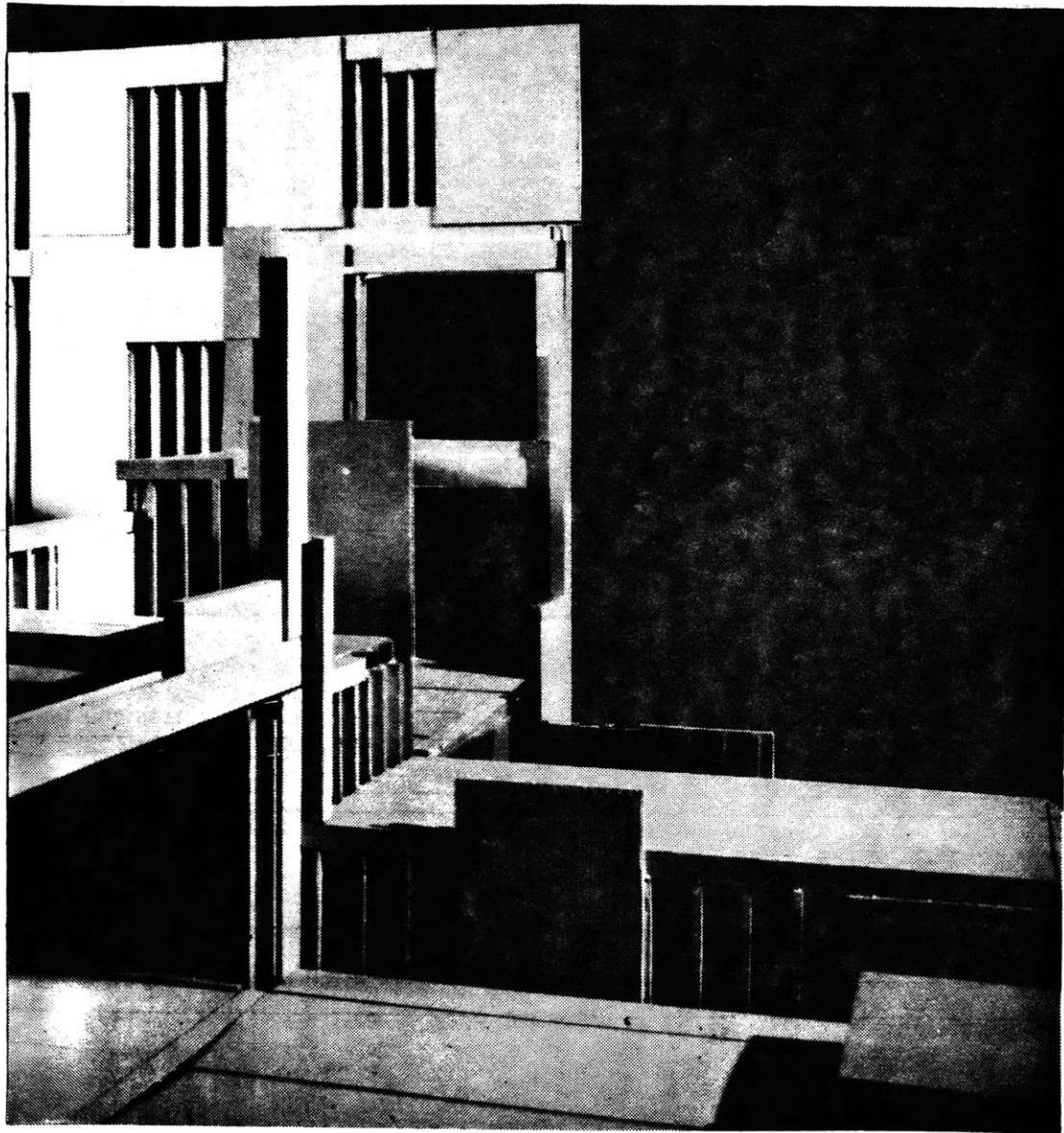
The first five pictures show the model in construction, approximating the actual construction sequence. Panels would be assembled first at corners, where they can support each other. The intermediate wall panels would be assembled next, with the parallel connections accomodating production and assembly tolerances. Once the assembly is started, the staggered horizontal joints

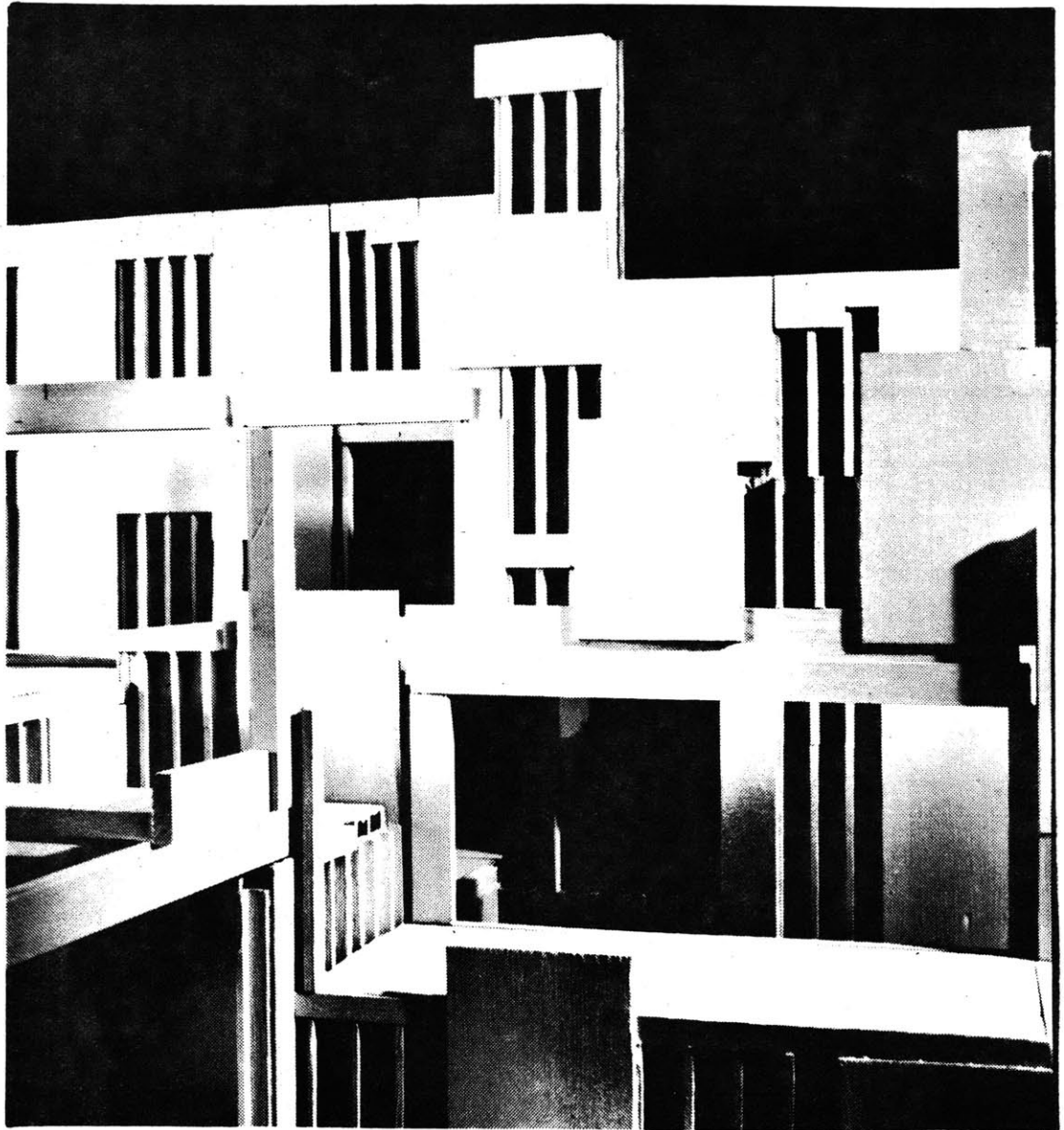
permit panels being attached to be supported almost entirely by panels already assembled.

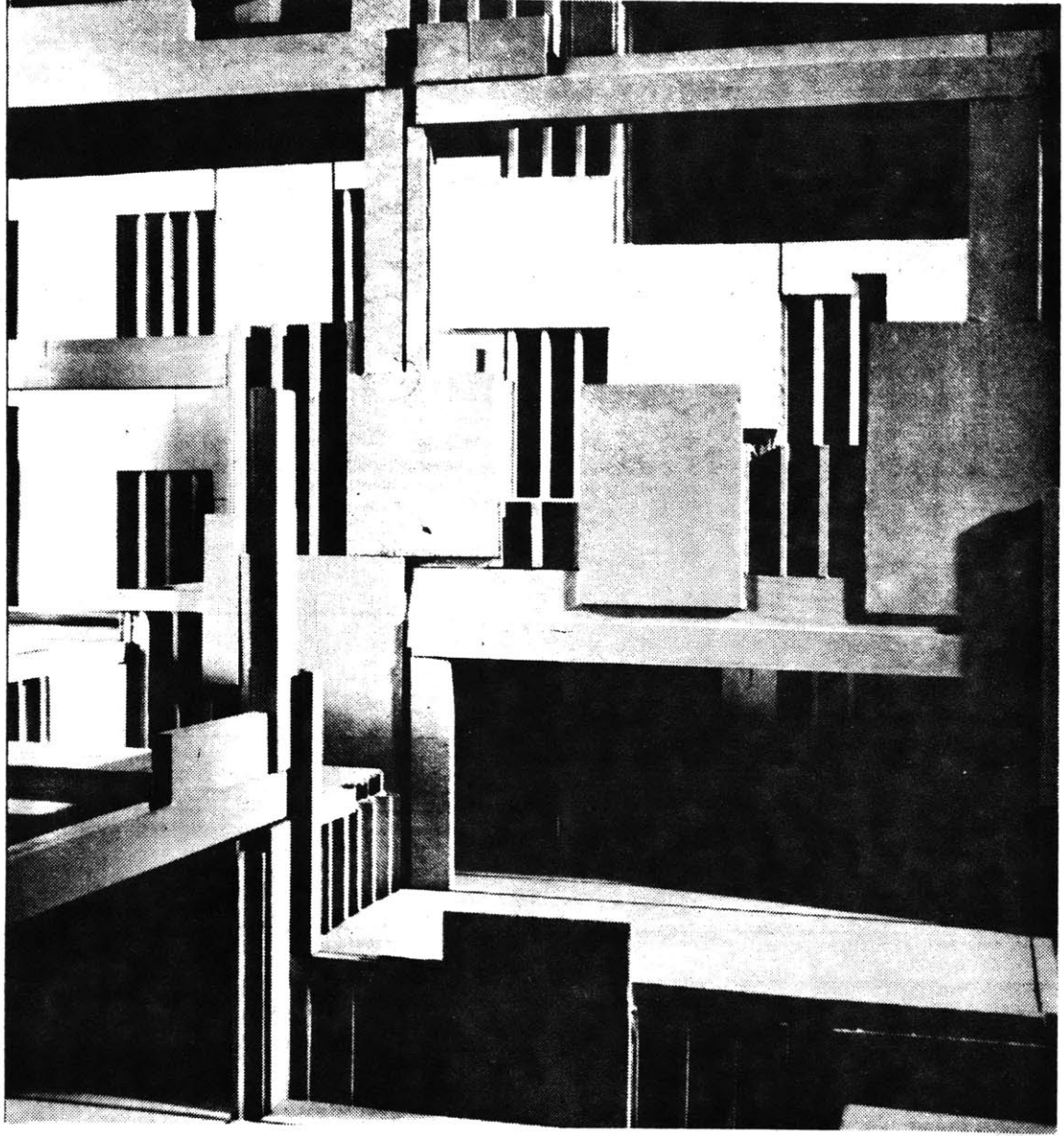
As each floor level is reached, the floor panels would be placed and connected. Infill, mechanical equipment, and insulation or other wall coverings would be added after the precast elements are assembled.

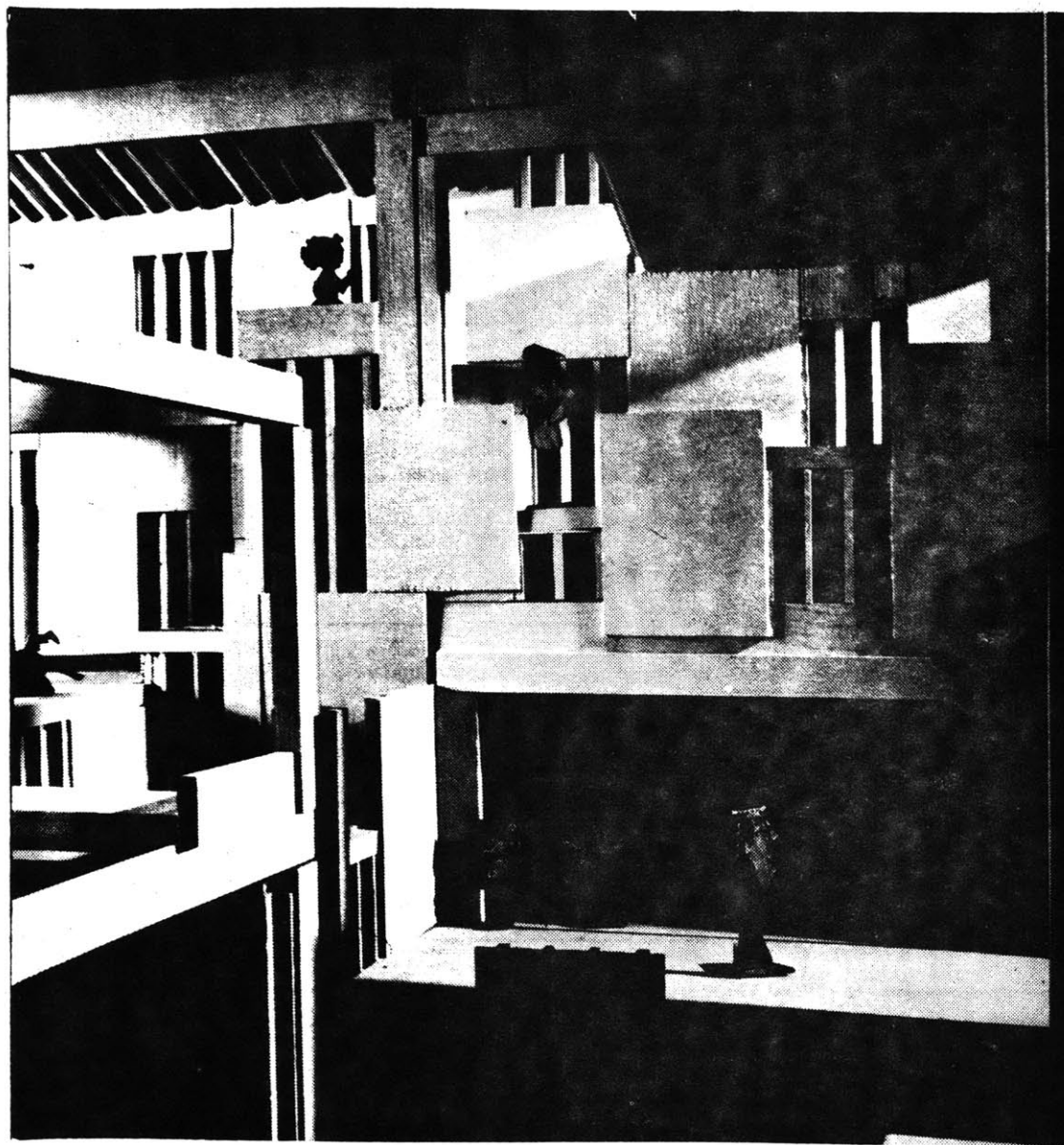
The images on pages 93 and 94 show the completed model with some infill and furniture. (In most places in the school there would be less precast concrete and more infill.) Also shown are the ventilation ducts in the roof and fluorescent lighting associated with two of the branch ducts. The first of the two pictures simulates daylighting; the second, artificial lighting. The final picture, page 95, shows the set-up for the lighting simulations.





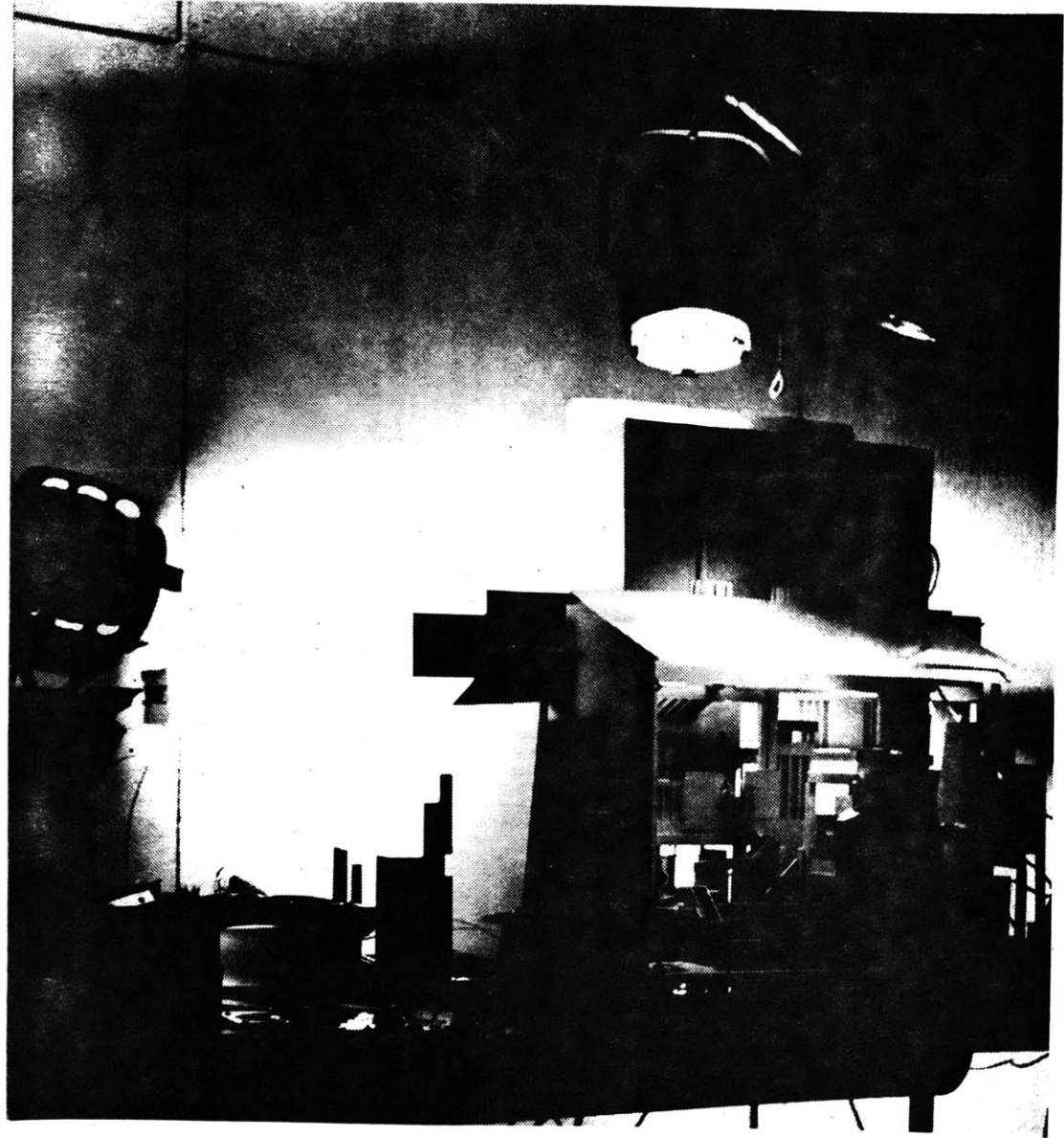














EVALUATION OF THE SYSTEM  
AND OF THE PROCESS OF  
DEVELOPMENT

In its present state of development the precast panel-with-ribs system suffers from a lack of clearly specified production criteria. As noted in chapter 3, the various methods of casting and of joining the elements determine different ways of assembling the elements. The work so far has tried not to exclude any of the production possibilities. Further research should probably focus on particular production and assembly methods.

This study does not deal fully with many of the aspects of a building system. The use of small concrete panels requiring many difficult on-site joints runs counter to the prevailing trend toward larger and larger factory built components. The problems of mixing different processes and consequently different labor

unions was not investigated. Engineering studies of the strength of the panels and of the joints would be most interesting, as would the study of coordination with infill systems, the methods of weatherproofing and insulating and the air distribution and other mechanical systems.

The built-form explorations, which were central to this project, have produced interesting results, although the use of the panels still appears rather clumsy and rigid. Some suggested changes and additions to the geometry of the system are briefly discussed below.

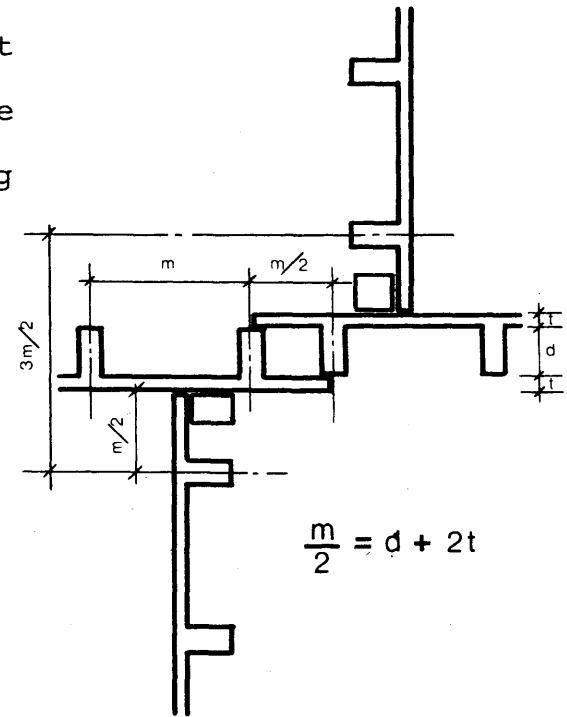
## 5.1

### THE PERPENDICULAR CONNECTION

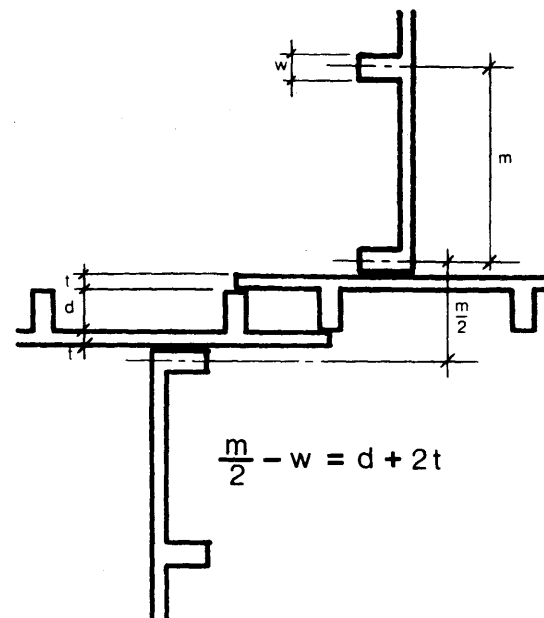
The perpendicular connection between panels not only requires panels with special edge conditions, but also appears formally and perhaps structurally weak. This design resulted from several assumptions, one of which

was that the panels would be assembled in continuous planes which cross each other at right angles and which are equally important. This conception led to the radially symmetric connection of four panels at one place. Another assumption was the necessity of maintaining modular relationships between ribs of the various panels. This restriction eliminates many otherwise reasonable geometries in which the rib of one panel might be attached to the slab of another, thus taking advantage of the right angles in the elements themselves and making a strong connection.

Several different approaches to further development of this connection have become apparent. The four panel connection could be abandoned in favor of an assembly geometry employing only T-connections. These T's could be made with either two or three panels. If the assemblage were based on wall zones as suggested in Section 5.4, the modular coordination of elements might



be altered to accommodate other connection geometries. While such an alteration might be worked out within the system, it would probably cause difficulties in the coordination with infill or other systems. A third possibility would be to design non-symmetric connections, which might be associated with walls of different importance. If the rib spacing could be increased and the rib depth decreased, and if the rib sides could be at right angles to the panel face, the rib of one panel could, in fact, be attached to the slab of another, without destroying the modular relationship.



## 5.2

## DIRECTIONAL CHARACTERISTICS

A number of difficulties with the present geometry of assembly might be better resolved if the two directions of walls were treated differently. The attitude has been that all the walls could be treated in the same way. The

equality of directions is also evident in the use of square bays. However, the floor panels span in one direction. Some walls support floors and some do not. The major horizontal air ducts extend in one direction between beams or walls; they can turn only with difficulty. The secondary ducts are formed by the floor ribs at right angles to the major ducts; they cannot turn. Furthermore, the building itself has major and minor directions in response to the various site conditions and user requirements.

With the system as described in the previous sections it is possible to recognize these differences and to treat them differently in the assemblage. The non-load-bearing walls can be assembled differently from those which carry floors. The bays can be rectangular. The structure can be clarified along with its relationship to the mechanical systems and the site conditions. At the same time, these efforts could be aided by redesigning

the perpendicular connections without the restriction of being radially symmetric.

## 5.3

## COLUMNS AND BEAMS

The columns of this system of assembly are really degenerate walls, assembled from the same elements using the same connections, but forming linear rather than planar assemblages. In fact, the drawing of page 70 shows a column which is just the top level of an assemblage of panels forming a substantial area of wall at the lower levels. This range of form is certainly one of the most attractive aspects of the system.

Some parts of an assemblage may have to be so open that a minimal column and beam framework would be desirable. In such a case these degenerate-wall columns become very inefficient because they must be assembled from many pieces when all that is needed is a single

linear element. Additional precast elements could be included in the system for building column and beam frameworks; these elements could be designed for larger bays and could be used to identify within the structure a larger order than that of the wall panels.

#### 5.4

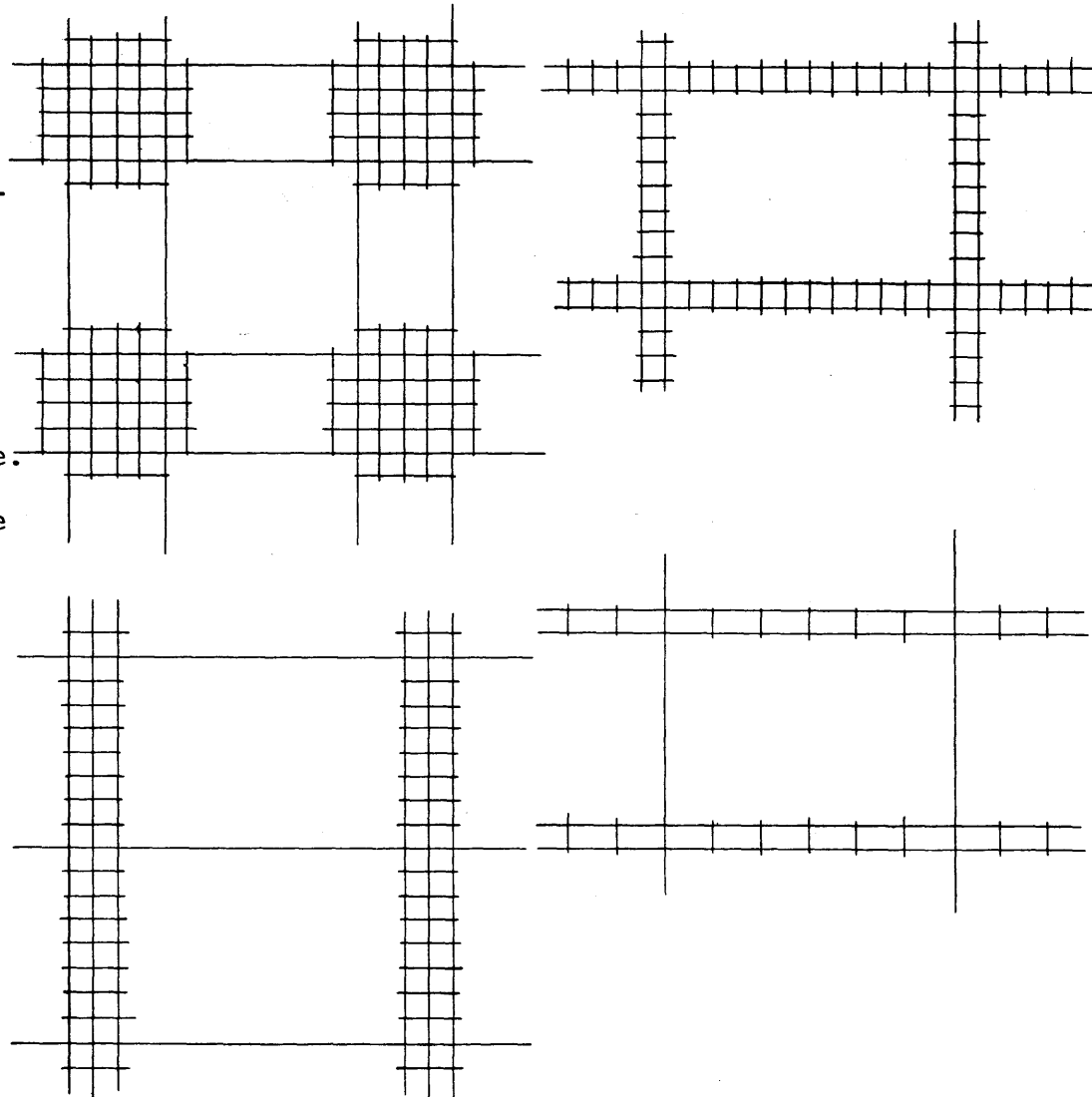
#### SIZE OF USE-FORMS

With a rib spacing, and thus a module of about 15 or 16 inches, the concrete panels could be used to make vary small use-forms. On the other hand, the processes of production and joining become more efficient with larger panels. The assumption in this project has always been that the concrete use-forms should be large and very incomplete, with a system of small panels and frameworks adding furniture-sized forms and making enclosures where they are necessary.

Most of the design studies for the school building used a 15 inch rib spacing with a 10 foot module for the

location of precast walls. This restriction produced a fairly clear but rigid organization of the walls. Some later studies using 16 inch rib spacing were designed to a 16 inch or a 48 inch module. In these studies the concrete assemblage became less of a framework for smaller forms as it tended to incorporate these smaller forms. The result seemed to be too much concrete and too many precast elements.

A direction for further studies which might help resolve this conflict



SOME ZONED GRIDS

between large and small would be to establish zones rather than lines for the precast elements.

## 5.5

### COMMENTS ON THE METHOD OF STUDY

As described in Section 1.4, and as practised, the work leading to this thesis was explorative in character. The ad hoc problem identification and solution technique touched on many aspects of production and assembly of the precast elements. On the other hand, none of these aspects was studied comprehensively. The work to date could, perhaps, be seen as an initial investigation to identify some of the issues involved in the development of the system; it could provide a base from which to proceed with a more rigorous and directed study.

The project has suffered from a lack of clarity and consistency in the reasons for various choices. This lack has been compounded by a failure to document fully

the decisions previously made; thus, when a problem and its solution were reexamined the reasons for the original solution were sometimes not known. Good records of the issues involved in a decision may be particularly important in a study such as this one which attempts to deal with numerous interrelated concerns.

To some readers, the system proposed here will not appear to be very projective; that is, many more things could have been done with the technology in question than have been proposed. This limitation exists. The course of the study has intentionally been to start from what is known, from what can be done, and to expand the options as development proceeds. A contrary approach would have been to suppose a very rich, unrestrained, and ungrounded use of the technology and geometry of the ribbed panels and afterward to determine the restraints required to make use of the panels possible or practical. A third approach to the development of a precast system

would have ignored the technology altogether, concentrating first on the desired results and then on the technical problems, a method which was rejected in the belief that the problem and the solution cannot be separated. The method which was used keeps the problem and solution together at the same time that they remain grounded in the possible. The fact that the study is not very projective means only that the process of expanding options has not proceeded sufficiently far.



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